S. HRG. 100-159

SPACE SHUTTLE OVERSIGHT

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

FIRST SESSION

ON

OVERSIGHT OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION'S SPACE SHUTTLE REDESIGN ACTIVITIES

JANUARY 22, 1987

Printed for the use of the
Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PRINTING OFFICE

72-663 O WASHINGTON : 1987

For sale by the Superintendent of Documents, Congressional Sales Office
U.S. Government Printing Office, Washington, DC 20402

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SPACE SHUTTLE OVERSIGHT

THURSDAY, JANUARY 22, 1987

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
Washington, DC.

The subcommittee met, pursuant to notice, at 10 a.m., in room SR-253, Russell Senate Office Building, Hon. Donald W. Riegle, Jr., (chairman of the subcommittee) presiding.

Staff members assigned to this hearing: Marty Kress, professional staff member, and Pete Perkins, minority professional staff member.

OPENING STATEMENT BY SENATOR RIEGLE

Senator RIEGLE. The committee will come to order. This is the first hearing in the 100th Congress of the Subcommittee on Science, Technology, and Space, and we start on a day with adverse weather conditions here in Washington, and other committees meeting at the same time, so members will be arriving as we go along, but I thought we ought to start on time.

I particularly want to welcome to our subcommittee the new members who will be serving. The subcommittee has been expanded because of the interest of members in the work of this subcommittee, and I want to particularly welcome this morning also the chairman of the full committee, Senator Hollings.

This morning's hearing begins a new chapter in the relationship between NASA and the Senate with new teams in place on both sides of the table. I hope and intend that this will be an era in which the Congress and NASA work together to reactivate the space shuttle and help restore the civilian space program to its former stature.

This subcommittee will be properly independent and active in its oversight of NASA. We expect to be kept fully and promptly informed of all major issues and problems within NASA, as you and I have previously discussed, Dr. Fletcher.

You in turn will find this committee to be dedicated as you are to making NASA the finest agency in our government. That is our common goal, and working together we will meet it.

It was nearly one year ago that we experienced the tragedy of the *Challenger* explosion. A million tears have been shed over the loss of that mission and its crew. Our hearts are heavy whenever we think about it.

With that sacrifice clearly in mind, we have renewed our efforts with painful new wisdom and with absolute American determination to return to space as soon as we are ready, and we are getting ready.

Other astronauts have already been named for the next shuttle flight, and Commander Rick Hauck is here with us now, and I would just ask him, if he would, to please stand. We are delighted to have you, and we wish you and your crew the best, and we intend to give you the best.

I know I express the commitment of our nation, Commander Hauck, in saying to you and your crew that we are determined to make that next launch the safest ever. We have the greatest confidence in you and in your crew and in the entire NASA community as you carry our flag and our hopes back into space.

It is also NASA's role to help restore and advance our technological leadership, and that requires the best human talent and facilities that can let us meet our future goals.

This hearing will be the first in a series of oversight hearings that will examine the progress that NASA is making toward restoring the shuttle program to flight status.

Seated before us today is NASA's new management team. A year ago another team was in charge. Personnel changes were needed, and they have been made. It is important for America to see and to hear its new team.

Today we will focus on the solid rocket boosters, which were the primary cause of the *Challenger* disaster. We will also hear later from the contracting community. We will take testimony from the National Research Council within the National Academy of Science, which has formed an advisory panel to monitor the solution of the solid rocket booster problems.

We want to know where we are in the rebuilding process nearly one year after the accident. We want you to tell us where things stand in NASA today and what your time table looks like for fixing all known problems and resuming safe flight.

I believe that I speak for the entire subcommittee when I say that we expect you to resist any pressures to launch until we have taken every necessary step to ensure the safety of the next launch. If the time table has to be stretched to accommodate further refinements or adjustments, we expect you to say so and to do so.

Let me turn to the distinguished chairman of our full committee for his thoughts this morning, Senator Hollings.

OPENING STATEMENT BY THE CHAIRMAN

The CHAIRMAN. Thank you, Mr. Chairman, and I want to thank Dr. Fletcher and the NASA administration for what they have been doing.

I commend you, Dr. Fletcher, in getting reorganized and I want to hear a little about it. I understand you have got a whole new team. I like what I see at the witness table here this morning, but I think it was a good opportunity for us to get some fresh new young blood. I would like to know about the reorganization.

I am interested, of course, in the solid rocket booster, the Morton Thiokol redesign proposal and the observations or criticisms of the competitive contractors.

I am still a little nonplused when you try to correct the situation. It has been studied and studied and then you come in with heaters and everything else of that kind— It still has joints. I never have been able to understand why we never did go to the monolithic booster.

And I am intrigued by the fact that United Technologies, who is making the Titan, has made the segmented kind of rocket booster, now suggests perhaps we ought to go to that monolith.

I want to be absolutely safe. I don't want to make the same mistake and say, well, we took care of the mastic by getting a different one, we took care of the heat by buying a heater, we took care of the O-ring by getting three O-rings instead of two O-rings.

That doesn't particularly appeal, and I want to see the testing of whatever changes have been done. I want to know that you have enough money, to do all of that testing. I also rather agree with the emergency launch systems—we have to play catchup ball in many areas.

From the budget end, which I am as familiar with as anyone, there is no rhyme nor reason why we can't pay for it. I don't buy that at all. I want to make sure that the Congress supports the NASA and its reorganization and its rededication and its drive to catch up with the Soviets in space.

And on that basis I also want to make sure that you have got some kind of plan. It has come to my attention over the last years that we never did have any plans and goals. We are hearing a lot of testimony here in other areas about the transfer of technology and how it has developed and where we can lead the world and where we should lead. If we do have a plan before the committee, then the Congress itself will be in lock step with NASA as to where they are headed, particularly from a financial basis and other support.

So I appreciate it, Mr. Chairman.

Senator RIEGLE. Thank you, Senator Hollings. In the order of arrival next, Senator Rockefeller.

OPENING STATEMENT BY SENATOR ROCKEFELLER

Senator ROCKEFELLER. Thank you, Mr. Chairman. It has been a year now since the disaster, as you indicated. I think we have seen this nation pull together first in a sense of common shock, but then also in a sense of common purpose and a rededication to make this a can-do effort to make our program the very best.

I feel the report that was prepared by former Secretary of State Rogers was a good one, an excellent one, and his commission members provided us with a comprehensive and I feel fully credible account of the causes of the *Challenger* accident, as well as the set of nine recommendations for rectifying the causes of the disaster.

Among the Rogers Commission recommendations was a revamping of the management structure at NASA. With Dr. Fletcher back at the helm at NASA and with the new team before us, we see that recommendation fully implemented.

The openness with which NASA has addressed the problems posed by the *Challenger* disaster have helped I feel rebuild national confidence. We have got a long ways to go, but I think the new team has done a good job.

Dr. Fletcher indicated at his confirmation hearing in this room some time ago, he felt the shuttle would be back in operation in July of this year. Now that date was changed last summer to February of 1988.

New questions have been raised by the National Research Council concerning the testing schedule that NASA has proposed to assess the adequacy of the redesigned solid rocket booster joint. I hope to hear more about this from Dr. Fletcher and his team in their testimony.

We all want to see the shuttle back in service as soon as possible, but, as the Chairman indicated, not so soon that we risk any further trouble.

In addition to the redesign of the flawed solid rocket booster joint, NASA has indicated its interest in evaluating a completely new design for the boosters, the so-called Block II design.

The four major rocket contractors other than Morton Thiokol have all expressed interest in competing on this Block II booster, although some have expressed doubts as to whether a new booster will be procured if the redesigned booster proves to be adequate.

I, too, have some questions as to this rationale for complete redesign of the booster, but I will reserve that until after I have heard some testimony from you folks.

The final issue, Mr. Chairman, which I would like to touch on briefly has to do with the competition in NASA's procurement of solid rocket boosters. Just before, I believe just, in fact, a week before the *Challenger* disaster last year, NASA announced its intent to accept bids for second source production of the solid rocket booster now produced solely by Morton Thiokol.

Serious questions have been raised in the House by Congressman Jack Brooks's government operations committee, by the General Accounting Office, and others, concerning NASA's reluctance to invite true competition in the shuttle booster program.

Given the cost and the safety advantages which a second source procurement might offer, I see no reason why NASA should not introduce competition now in the booster procurement and not wait around for the Block II issue to be resolved.

Finally, Mr. Chairman, I think we also as a committee, an authorizing committee, have a vital responsibility to address the broader policy issues which we face in the space arena as a whole. With the immediate issues of the shuttle fixed behind us or at least before us, we must examine the policy and the budgetary choices that we have to participate in.

That has to do with our civilian space program, our sense of national purpose, our morale at NASA, the pursuit of scientific understanding and scientific achievement on a civilian as well as a defense basis, all require that we get the shuttle back in service and get on with the job that we need to do.

I thank the Chairman.

Senator RIEGLE. Thank you, Senator Rockefeller.

Senator Gore?

OPENING STATEMENT BY SENATOR GORE

Senator GORE. Thank you, Mr. Chairman. I want to commend you and your staff on the prompt and thorough scheduling and preparation for this significant hearing so soon after assuming the chairmanship of this subcommittee.

As the anniversary of the shuttle disaster approaches, I know that you agree that the American people are eager to learn exactly what is being done to put the shuttle program safely on track.

Further, I believe there is increasing interest in America's future in space along with increasing concern about our ability to set space policy and define the mission of NASA in implementing that policy.

These and the hearings to follow represent an important part of a much needed process to ensure that the shuttle program will continue with proper emphasis on safety and reliability and, moreover, to begin to develop a consensus about the future of America in space.

In these hearings, which deal with how NASA is resolving problems with the solid rocket booster, I intend to focus my questions on two areas of concern, which as we should have learned from the *Challenger* disaster are crucial to the redesign of a safe shuttle.

Number 1, quality assurance, or SRQA, safety, reliability and quality assurance, and, second, NASA's management structure.

While many issues regarding the technical aspects of fixes to the solid rocket booster will be explored in depth by this committee, I agree with others that it is crucial for us as policymakers to also focus on the processes within NASA that should promote careful technical evaluation by the best minds within the agency.

I look forward to working with you, Mr. Chairman, and join you in welcoming Dr. Fletcher and our other witnesses this morning.

Senator RIEGLE. Thank you, Senator Gore.

Dr. Fletcher, it is very good to have you with us today with your new management team and the new structure. And we look forward to having you shortly introduce to us this team and to give us an overview of the proposed shuttle solid rocket motor redesign program, which is the centerpiece of the mechanical work that is being done and the long term procurement issues that relate to that.

So, if you would, let me ask you now to introduce the distinguished members of your new team.

STATEMENT OF HON. JAMES C. FLETCHER, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, ACCOMPANIED BY DALE D. MYERS, DEPUTY ADMINISTRATOR; RICHARD H. TRULY, ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE FLIGHT; AND ARNIE ALDRICH, DIRECTOR, NATIONAL SPACE TRANSPORTATION SYSTEM

Dr. FLETCHER. Mr. Chairman, we don't have all of the members of our new team, but we have at the table this morning several members, particularly of the shuttle organization.

We have on my right Dale Myers, who is the Deputy Administrator, glad to have him aboard. On my left you already remember Admiral Truly, who is Associate Administrator for STS, the shuttle and other transportation. And on my far right is Arnie Aldrich, who is the Program Director, who is now at Headquarters running the shuttle program.

We also have other members here, Mr. Chairman. As we move into it, I will introduce them as we go along.

Senator RIEGLE. Fine. If you would, I think it is important that anyone who has assumed a major managerial responsibility within the last year be so identified so that we have a sense as to who has come into the team and new capacities and so we really understand the scope of the new management structure.

Dr. FLETCHER. I will do that, Mr. Chairman. I should add that at the table this morning with me is an old-timer at NASA, and that is Tommy Newman, who is our controller, because there may be questions about budget. You were asking about is there enough money for this for fixing the anomaly and ELV's and things of that sort, and Tommy is the expert at that, so he is also with us this morning.

Mr. Chairman, if it is all right with you, I would like to submit my statement for the record and sort of summarize the highlights?

Senator RIEGLE. Please do. I want to acknowledge as we pause here for a moment that Senator Heflin, who is a distinguished former member of this committee, is with us this morning. We are delighted to have him.

Is there any comment that you wish to make at the outset here just before we hear from Dr. Fletcher?

OPENING STATEMENT BY SENATOR HEFLIN

Senator HEFLIN. I am delighted to see that we are moving forward in regards to the space shuttle. I have been long an advocate of space. I think I was the first senator that called for the building of the space station and I think there are many aspects of this that need to be thoroughly explored, and we need to move forward and move forward safely and as expeditiously as we can. With your permission I would like to make a brief statement.

Mr. Chairman, let me begin by expressing my appreciation to you and the other members of the subcommittee for giving me the opportunity to participate in today's oversight hearing to review the progress made toward the shuttle recovery and the redesign of the solid rocket booster joint. Although no longer a member of the subcommittee I nonetheless maintain a strong interest in the programs within its jurisdiction, particularly as they relate to NASA. I understand that this is the first of several oversight hearings on NASA's space shuttle program since the *Challenger* accident. I congratulate the Subcommittee Chairman, Senator Riegle, on taking this initiative.

I am particularly delighted to see Mr. J.R. Thompson, the new Director of Marshall Space Flight Center located in Huntsville, Alabama, here today. I have had the opportunity to meet and talk with Mr. Thompson and have been very impressed. I look forward to working closely with him in the future.

On January 28, approximately a year ago, I and my colleagues in the Senate watched in total shock and deep sadness as the space shuttle *Challenger* exploded in mid-air, grounding the shuttle fleet until the cause of the accident was found and a solution reached to get the system back to flight status. At that time, I and many others said that, in the aftermath of the tragedy, we must look to the future with new resolve that our efforts in space go forward. It is my hope that the U.S. space program moves forward quickly and, above all, safely.

NASA has made our country the world leader in space and has helped increase the quality of life of all Americans. In fact, so successful had the agency been, we had all come to expect near perfection. With the *Challenger* disaster, we were hit with the cruel reality that, like all human beings, NASA is far from being infallible. I am happy to see that NASA is going forward with the changes necessary to insure that we will never have a repeat of the shuttle accident and I look forward to hearing today about the progress of this effort.

Thank you, Mr. Chairman.

Senator RIEGLE. Thank you, Senator Heflin.

Dr. FLETCHER. To begin with, I am glad to be back visiting with you in your new capacity, Mr. Chairman, as chairman of this Subcommittee, and also Senator Hollings, as chairman of the full Commerce Committee.

We have made a lot of progress since we were here last, and I am not able to indicate all of it, but we certainly are well along towards fixing the anomaly and towards putting the organization in place that will carry on the activities of NASA for years to come, but we are not there yet. We have got a ways to go and you will notice that as we go along.

First, I would like to focus on three areas of my statement, the first having to do with the organizational management changes, as you indicated, the status of the shuttle recovery activities, and then the status of the solid rocket motor redesign activities, but I don't plan to go into much detail on that because, as I understand it, the next panel will address that in as much detail as you like, although I would be glad to answer any questions that you have on that.

First let me talk about the organization and management changes. We have done a lot partially in response to the Rogers Commission recommendations and partially as a result of a task force that I set up when I first came back to NASA under General Sam Phillips.

And the goal is not just to fix the shuttle, but to fix the entire NASA organization, I don't mean fix, but strengthen it so that we have accountability and we have responsibility where it belongs.

I think we have made a start in that. In fact, before you, I am sure you can't read it, we have a kind of a, we call it a wiring diagram. It is an organization chart which indicates the boxes, and I will indicate some of the people that are already filling those boxes.

In Headquarters we already mentioned Dale Myers who is here today, and we mentioned Admiral Truly. We also have here today George Rodney, who is Associate Administrator for SR&QA. George.

We have the Associate Administrator for Space Station, Andy Stofan, who is probably not here today because this is primarily on the shuttle but, nevertheless, he has come back to Headquarters to run the space station.

We have an Associate Administrator for External Relations, Rick Hauck, who has not yet gone back to being commander of his crew. He will go back around February 1 and he has been introduced to you already.

We have a new Associate Administrator for Management, June Brown, and I suspect she is not here today.

We have new Center Directors at the Johnson Space Center. We have Aaron Cohen as the Center Director and P.J. Weitz from the astronaut group agreed to leave that group and become Deputy.

At the Marshall Space Flight Center we have J.R. Thompson, and he is here today. J.R.

And we also have at the Kennedy Space Center a new Director, Forest McCartney. Forest is not here today.

We have a new Acting Center Director at the Lewis Research Center and, generally speaking, we have filled most of the boxes on that chart, but we are still working on the remainder, and we expect to pretty well follow the Phillips recommendation with regard to our overall organization.

The emphasis has been and was strongly urged by both the Rogers Commission and the Phillips Committee to bring back to Headquarters management of large programs like the space shuttle and like the space station and, also, in addition to that, to try to, as much as possible, with the smaller programs, to have a single center only involved in the programs because a lot of our difficulties had to do with intercenter communications and procedures.

We think we have the beginnings of that strong Headquarters management in the people that I have mentioned, but we are continually adding people. For example, in the Shuttle Program Management Office we have moved Arnie Aldrich from Houston to Headquarters. We have a Deputy Program Director, Dick Kohrs, and I don't know whether Dick is here this morning. Deputy Program Director for Operations, Bob Crippen, whom you have met before; and a Manager of the STS Projects Office, Bob Marshall.

We have done similar things with the space station, but I won't go into the detail except to mention that we have a Program Director, Tom Moser, in Headquarters, and he has a very able staff, and we have a Deputy Associate Administrator, Frank Martin, and a Deputy Program Director, Jim Sissen, who we brought up from the Marshall Space Flight Center.

So we have strengthened both of those program offices and additional changes will be made in Headquarters as we go along.

Senator RIEGLE. Let me just ask you one thing here, and I don't want to interrupt your sequence to any length, but are you finding that you are able to get the talents that you want most, and are there open positions for which you are having difficulty finding or being able to persuade the people to come in and take these jobs that need doing?

Dr. FLETCHER. Mr. Chairman, we have been very lucky to be able to bring in the people that we need in Headquarters at the top levels, and I am optimistic that we will be able to bring them in at the other levels, but I think your question is a very pertinent one because this is an unusual time.

Because of the accident there are a lot of people that are willing to make sacrifices to get the shuttle flying safely again, and we have got to look at the long range picture. We don't want another accidentlike we had.

So the long range picture is going to require some special efforts. When I say long range, over the next four or five years. So part of the recommendation of the Phillips Committee is that we set up a strong institutional manager, and that means somebody that worries about people, worries about the facilities that they have to work in, and the equipment, particularly at the centers, that they will have to work with and really push that hard.

In addition, it is recommended that we bring in a strong person that worries about human resources. We have a good human resources program, but we want to strengthen that so that in the future, and I don't know what inventions we will come up with, but we have got to make sure that we don't have to have an accident every time we want to bring strong people into Headquarters, but the answer to your question is, yes, we have been able to get good people into Headquarters this year and last year.

Two other boxes that the Phillips Committee recommended was two Associate Deputy Administrators, one for policy and one for institutions. Willis Shapley has come back in a consulting capacity to be the ADA, Associate Deputy Administrator for Policy, and he is supported by a policy and planning staff headed by Phil Culbertson, whom you have met before.

We have not yet filled the box called ADA for institutions, but that is a key job and we plan to bring somebody in that can do that well.

In addition to that, we have looked downstream because the space station is closely tied to the space transportation system. It is going to be hard to separate them when we start assembling the space station. They are both operations oriented. And we debated back and forth as to whether we should merge those two.

We decided no, this is not the right time to merge those because it might jeopardize our ability to get the space shuttle flying again safely, but that was left as an open question. When I feel that we can merge those, we will do so, but in preparation for that it was recommended by the Phillips Committee that we set up an Office of Space Operations so that the operations of the shuttle and of the space station can be integrated. And that box is filled also, and Bob Aller is occupying that box.

So we still have some ways to go, Mr. Chairman, but so far we have, and I don't say we have done this without difficulty. There has been a lot of arm twisting going on and people being reminded of their patriotic duty and their commitment to NASA but, nevertheless, we are strengthening Headquarters and strengthening overall the program, not just of the space shuttle, but across the board in NASA.

As far as the recovery program is concerned, we, as you know, have announced a flight manifest. This means that we have made a first guess at what mission should be on what shuttle flights, and we have also made a first guess, a second guess I should say, on when we are going to start flying, and that is February 1988.

Senator Rockefeller reminded me that we thought we could make the July date. That was really a broad guess, Senator, and the February 1988 is a tight schedule and we are still on that schedule, and we have been for several months, using that as a baseline and building up slowly, nothing like the 16 per year or the 25 that we sometimes talked about, but maybe three or four or five the first year and then, as we get more experience, building up to something between 11 and 16 flights per year.

The 11 is the low number suggested by one of our advisory committees. The 16 is the high number, which is something we thought we might be able to someday achieve, but whatever is the case, we are not going to decide on the flight rate until we have had more experience with the shuttle.

Having said that, though, in the outyears, in the 1990's, we have got to have some sort of a backup to the shuttle flights because we can't launch all of our missions on the shuttle even with the 16 flights per year, but certainly if we are down around the 13 or so that some of us at NASA feel might be more realistic, we are going to need a mixed fleet.

And a study is in the process to be finished sometime this month that will advise us on what kind of vehicles we should purchase as an ELV backup, not only in the out years, but in the immediate future because we have missions that have to be launched soon.

In addition to the shuttle recovery, we have a list of what we call critical items that we have always kind of worried about but really didn't have time to thoroughly scrub. We are doing that now.

We have an external review of that critical items list, and that is going on, and we have quite a large number of changes that we plan to make to the first, to the Orbiter and to the SRB before the first flight, one of which, of course, as you remember, was an escape system which blew off the hatch, which I presume Admiral Truly will discuss sometime later.

So we are looking at all of the potential failures of the shuttle. We are doing everything we can, as was suggested, to make the first flight and the follow-on flights as safe as we could possibly make them.

We are also making progress on redesigning the solid rocket motor, and we have several review committees there. We have an internal review committee, and then Guy Stever is here, who is going to testify later, who chairs the NRC, National Research Council committee on the redesign of the solid rocket motor.

He has an outstanding panel, and some of them I know to be outstanding engineers from my previous life, and we pay attention when they talk.

So by and large we have accepted nearly all of their recommendations and are dealing with all of those that we haven't yet accepted.

We have lots of external and internal reviews of all aspects of the shuttle. We have people looking in the crack, so to speak, looking at areas that nobody has looked at before to make sure there aren't additional changes that are necessary that ought to be implemented before resumption of flights.

That is a lot of things that have been happening since we were here last, Mr. Chairman, but I think we are on the road to recovery from the accident, but needless to say, we have a lot of work ahead of us. We have got to not only have people in place, but we have got to make sure they work together as a team, got to make sure that they communicate well, that we have the appropriate procedures and that we follow those procedures, that they are properly documented.

I don't mean that paperwork solves the safety but, nevertheless, you can't just leave a message with somebody. You have got to make sure that it is in writing so there is a paper trail behind what you have decided to do. And, also, when you have anomalies, you want to make sure that actions are started to deal with those anomalies.

All of those procedures and communications we will just have to tighten up as we go along. A lot of it remains ahead of us, although we have been doing that for some weeks.

I guess one of our biggest problems is downstream and, that is, how we are going to accommodate all of the missions that were scheduled for the shuttle, particularly the science missions, and many of those were delayed anywhere from two to five years, the five years being much longer than the shuttle delay, and we hope to come up with a plan for dealing with that, but we are not quite there yet.

Whatever it takes in the way of expendable vehicles we will go ahead and purchase those with whatever money is available, and we don't anticipate difficulties in doing that in the out years. We may have to do some rejuggling in the near term.

By and large that is a summary of my statement, Mr. Chairman, and I will be pleased to answer any questions you or other members of the committee might have.

[The statement and questions follow:]

Statement of

Dr. James C. Fletcher
Administrator

National Aeronautics and Space Administration

Mr. Chairman and Distinguished Members of the Subcommittee:

It has been a number of months since I last appeared before this Subcommittee to discuss the activities of the National Aeronautics and Space Administration (NASA). At that time we were still putting together plans and estimating the costs necessary to restore the Space Shuttle to safe reliable flight. Much has been accomplished in this last year and although the schedule is still quite tight, we still are holding to a planned February 1988 launch of the Shuttle.

Today, I would like to discuss three specific areas with you. First, the status of NASA's recovery efforts including the results and recommendations of the Phillips study; secondly, the specific efforts of the Office of Space Flight (OSF) in this recovery; and thirdly, a more detailed description of the solid rocket motor redesign and alternative sourcing plans and status.

General Sam Phillips has just completed a very comprehensive study on actions that are needed to improve the management of our programs, including relationships between various field centers and NASA headquarters, and a review of the Space Shuttle management structure. The recommendations from that study and the actions NASA is implementing resulting from the study were released on January 9, 1987. The thrust of General Phillip's recommendations is to strengthen NASA's program management through clear organizational responsibilities and to establish a process to identify, enunciate and achieve institutional goals. The major organizational changes being implemented are to set up two Assistant Deputy Administrators, one for Policy and one for Institutions; establish a new policy and planning staff; and form a new Office of Space Operations. Two major reorganizations which preceded this announcement, but which are consistent with the recommendations of the Phillips Committee, are the reorganization of the Office of Space Station and the strengthening of the headquarters management of the National Space Transportation System (NSTS).

We have announced a manifest based on realistic flight-rate goals, beginning with the targeted resumption of Shuttle flights in February 1988 and gradually building up to a safe sustainable flight rate. Based on NASA and NRC studies, this rate will over the years build up to 11 to 16 flights per year with a four orbiter fleet. These flight-rate goals will be continually re-examined as we gain additional experience with Shuttle operations following the many changes which are being made. In addition to reviewing the Shuttle manifest, we have conducted an agency-wide mixed launch fleet study on the use of the mixed fleet concept and are examining priorities and options for incorporating this concept within the funding envelope proposed in our FY 1988 budget.

Although much of our focus has been on fixing the solid rocket motor seals which caused the Challenger accident, we are reviewing all of the critical elements of the Shuttle program to ensure that safety is enforced and that the STS will be an operationally viable Space Transportation System. This approach is consistent with one of the Presidential Commission on the Space Shuttle Challenger Accident recommendations that NASA and the primary Shuttle contractors review all Criticality 1, 1R, 2 and 2R items and hazard analyses to reassess program risks. It was also recommended that an independent audit of the review be performed by the National Research Council (NRC).

On March 13, 1986, NASA initiated a complete review of all Space Shuttle Program potential failures (Failure Modes Effects Analysis - FMEA's) and other critical items Critical Items List - CIL's). Each Space Shuttle project element and associated prime contractor as well as independent contractors are conducting comprehensive reviews. This review is extensive and is being conducted in a meticulous and in-depth manner. Because the formal process is lengthy and will not be complete until later this summer, we conducted a systems design review to assist in prioritizing the items for the formal FMEA/CIL process and to insure that all necessary modifications could be completed before the first flight. We are well into this process and I believe we have identified the major program requirements necessary to resume Shuttle flights and have initiated fixes where they are necessary.

An NSTS Crew Egress and Escape System study has been underway for several months and a preliminary report has been presented to the Office of Space Flight. The total mission profile, which includes pad activities, launch to orbit, and descent to landing, is being reviewed.

The Presidential Commission specifically concluded that a leaking solid rocket motor (SRM) case joint caused the Challenger failure. As a result, the Marshall Space Flight Center (MSFC) established a redesign team, which included participation from NASA centers, as well as individuals from outside NASA, to evaluate alternatives to improve the SRM. An advisory panel consisting of experts from within and from outside of NASA was appointed to insure that the final designs are as safe as possible. In accordance with the Presidential Commission's recommendation, the National Research Council established an independent oversight group.

The National Research Council Panel has a thorough understanding of the redesign activity. They are working conscientiously and actively in critically reviewing the design activity. The NRC Panel has submitted three formal letter reports, the most recent of which was received on January 15, 1987. Members have participated in the Program Requirements Review (PRR), Preliminary Design Review (PDR), and mandatory first flight changes review. The Panel's next meeting is scheduled for January 28-29, 1987, at MSFC.

The MSFC SRB redesign team has evaluated design alternatives, and analysis and testing are in process to determine preferred approaches. Major emphasis is on the case field joints, case factory joints, nozzle to case joints, case insulation, and seals. Our redesign program includes extensive testing of both sub-scale test articles and the new transient pressure test articles.

After an intensive study by the MSFC redesign team and independent studies by Morton-Thiokol, Inc., and USBI Booster Production Company, Inc., it has been determined that the full scale test and certification of the redesigned SRM will be conducted in the horizontal attitude. We are in the process of building a second horizontal test stand, with the capability of simulating launch and flight loads on the motor during static test firings. This second stand will insure that the program test requirements can be fully satisfied while providing increased confidence in our return-to-flight schedule.

I believe that this combination of testing will allow us to fully satisfy the Presidential Commission recommendations to conduct tests which duplicate the actual launch loads as closely as feasible and test over the full range of operating conditions, including temperature. The program requirements review and the preliminary design review have been completed. To better understand the dynamics of the case joints during the ignition transient, several tests have been conducted utilizing older case segments (STS 51-L configuration). On a test which was conditioned to 20 degrees Fahrenheit and had known leak paths the O-rings did not seal and leaked upon ignition as happened during the STS 51-L accident. On a subsequent test, which used an insulation configuration similar to the new baseline design where insulation of the segment joints is bonded, there was no leakage whatsoever. Tests on the nozzle-to-case joint utilizing existing hardware are also planned. Both the case and nozzle-to-case joints will be tested utilizing redesigned hardware as it becomes available. The first of several static test firings is planned to be completed in the first quarter of 1987.

During the first filament wound case (FWC) 140 percent compressive structural load test, to simulate loads at SSME ignition, the aft skirt, which is the same skirt used on the steel case SRB, failed at approximately 130 percent. Inspection revealed a weld crack between a hold down post forging and the adjacent skin section of the skirt. The cause of the failure turned out to be a design weakness and had nothing to do with the fabrication or the fact that it was a filament wound case. A series of failure evaluation tasks are underway by NASA and contractors and an anomaly investigation team has been established.

FWC production has been "mothballed" at this time because the Air Force decided that the first Shuttle launch from Vandenberg will not be before 1992. The FWC development program will be completed this year, however. The program will include compressive loading of a composite segment to failure, ultimate pressure test, damage tolerance tests, material aging tests, and complete documentation. Any mandatory changes to the steel cases, such as seals, insulation, etc., will be incorporated in a re-qualified FWC. A minimum of two years lead time are required for re-qualification and production of FWC flight sets.

On September 2, 1986, five "Block II" SRM study contracts for about $500,000 each were awarded for independent design analyses to support the SRM redesign team decisions and to support NASA's long term SRM procurement planning. The studies by the five solid rocket production companies (Aerojet Strategic Propulsion Company, Atlantic Research Corporation, Chemical Systems Division of United Technologies Corporation, Hercules Incorporated and Morton-Thiokol Incorporated) were completed by December 31, 1986. The ground rules for the studies allowed the contractors to utilize new concepts and approaches for the joint seals, elimination of asbestos in the insulation, and design for improved performance to accomplish a "heads-up" mission profile with greater payload. The contractors were constrained to maintaining current SRM envelope and interfaces.

The five contractors have completed their studies on schedule and the reports have all been received by NASA. Results of these studies have been submitted to the Congress. NASA is conducting an assessment of the design, facilities, costs, and schedule estimates from each contractor. Specific joint and nozzle designs that are considered to have merit for incorporation as backup by the Redesign Team in support of their work will be utilized where feasible. The overall assessment of design performance, costs and schedules will provide the basis for the preparation of an SRM Acquisition Strategy and Plan. We plan to provide our SRM acquisition strategy and a recommendation on an upgraded SRM or a second source initiative by March 31, 1987 as requested by Congress.

Internal and external reviews of all of the components of the Shuttle system are continuing and are expected to be completed soon. These reviews could identify additional changes which need to be implemented prior to resumption of flights.

In summary, we are well on the road to recovery from the Challenger accident but much work lies ahead before we can fly again. When we are further along the road to recovery, we still have the problem of determining how we accommodate all the missions originally planned for the Space Shuttle. Hopefully, in the next month or two we will have a plan for doing this, probably using both the Shuttle and expendable launch vehicles.

Mr. Chairman, that completes my prepared statement. I would be pleased to answer any questions.

QUESTIONS OF SENATOR PRESSLER AND THE ANSWERS
Solid Rocket Motor Redesign

Question 1: What does NASA's FY 1988 budget request provide for the continuation of the SRM redesign effort, and do you believe that this, coupled with the resources in the FY 1987 Operating Plan, are sufficient to thoroughly address the SRM redesign? Are these resources sufficient to pursue a parallel, contingency design?

Answer 1: The FY 1987 Operating Plan and the FY 1988 Budget Submit to Congress for the solid rocket motor redesign effort requested funding to support SRM redesign and analysis, full-scale development and certification tests, redesign of tooling and ground support equipment, additional testing facility/test structures, failure mode and effects analysis, and launch commit criteria and procedures evaluation. As with all major development efforts as the redesign has progressed there have been changes to the original plan. For example, since the formulation of the operating plan, we have increased the redesign scope to include numerous nozzle changes (metal parts, ablatives and internal seals). Two additional static test firings have been added in addition to nozzle testing during burnout and reclamation of existing motors. The FY 1988 Budget request includes all the funds we requested. It appears at this time that sufficient funding is available to complete the redesign activities. Within our budget, we have included cost to conduct preliminary studies of an alternate SRM and limited engineering analyses. In no case, however, will the planned resources allow implementation of any major parallel contingency design beyond the alternates currently in the program.

Question 2: Do you believe that the baseline SRM redesign selected in October represents the best design possible? What limitations or constraints did NASA face in selecting this particular design?

Answer 2: There are always lessons learned regarding the design, producibility, maintenance, or operation as the manufacturing and test phases progress that could be corrected. The consideration deals with flight safety and in this case, nothing has been found to date that compromises safety to any detectable degree. The test program laid out for SRM certification will drive out safety of flight issues, if any, that may not have been considered in the development phase.

The limitations and constraints considered in selecting the October 1986, design focused primarily on the Roger's Commission Recommendation No. 1 and strict adherence to Level I and II safety requirements. Secondarily, it was considered desirable to capitalize on the substantial investment in existing hardware and facilities, so long as flight safety was not compromised.

Question 3: I recognize that in all programs and activities, there are trade-offs that must be made and that very rarely, if ever, are we able to reach a "perfect" solution.

In the case of the SRM redesign, however, what assurances are there that the trade-offs are within an acceptable "margin of safety"?

Answer 3: The trade-offs made in the SRM redesign were based on the substantial understanding of SRM functional performance--particularly the field joint--gained during the CHALLENGER accident investigation, reassessment of motor difficulties, comprehensive analyses and tests conducted in the preliminary design phase, and expert consultation. The latter included not only the solid propulsion industry, but also others in the oil and gas industry that face similar sealing obstacles. In every trade-off decision, analytically derived positive margins above and beyond normal safety factors were mandatory and requisite to design selection. In order to verify these analytical conclusions, a thorough test program is in place to demonstrate the prescribed safety factors and margins where practical over the SRM full environmental operating range. Where it is not practical or possible to demonstrate the full extent of margins, adequate tests will be conducted to verify the analytical models used to predict such margins. Specifically, full size, hot gas, and maximum pressure test articles like the Joint Environment Simulators (JES) and Transient Pressure Test Articles (TPTA) for testing and field and case-to-nozzle joint; the structural test article that applies 140 percent of the design loads to the SRM; and five full scale static hot fire tests that all combined will subject the SRM to the limits of its environmental ranges. It is considered that successful accomplishment of this test series will demonstrate the SRM safe for flight.

Question 4: I understand that one of the "ground rules" for the redesign of the solid rocket motor was to choose a redesign that would take advantage of the current booster casings, 72 of which NASA ordered in 1985.

Do you have any reservations about any constraints to that these steel casings may have imposed on the redesign--are you convinced that safety and reliability have not been compromised by any constraint these casings may impose?

Answer 4: Admiral Truly, in his direction to the program elements for implementing the Roger's Commission recommendation, was very explicit in placing the use of existing inventory as secondary to flight safety. The SRM Design Team and Morton-Thiokol, Inc. specifically addressed each deficiency in the STS 51-L configuration field joints and evaluated various alternate designs prior to selecting the one that utilizes existing case segments. These alternate designs were either inferior to the selected design or did not substantially improve performance. Based on full size redesigned segment pressure tests already conducted, the selected design continued to be the proper choice. These segments were pressurized to full maximum expected motor operating pressure and they proved five to six times better than the STS 51-L design, essentially eliminating joint movement. From these results, we are encouraged with the new design joint safety and reliability and upon successful completion of the test program, will be fully convinced that this design is safe for flight.

The Design Team would not have hesitated to recommend to Program Management that the existing case segment inventory be discarded if safety were an issue. This is supported by the fact that two major components were redesigned to meet stringent safety requirements and design margins to the extent that a substantial inventory of each was rendered unusable.

Question 5: How would you characterize the reliability of this redesign, and prior to the CHALLENGER accident, what was the generally-perceived reliability of the solid rocket motor design in use?

Answer 5: In the case field and nozzle joints, the gap opening, a measure of joint stability, has been improved by a factor of five to six. The O-rings, even the STS 51-L type, now have a 100 percent sealing margin, without the necessity to be pressure actuated as was the case for the old design. The presence of pressure can only enhance sealing performance. The variable performing putty has been eliminated and insulation with an adhesive bond at the segment interface covers the metal joints similar in principal to the highly reliable factory joints. The temperature effects have been eliminated by the addition of heaters at the field joint and a warm purge at the nozzle joint to maintain the seals at a 75^{o}F minimum temperature. Integral to the heater is a weather seal to remove any potential of water entering the joint area.

Every other area in the SRM has been assessed relative to performance margin and past abnormal behavior. From this assessment has come changes in the igniter and case insulation to improve margins; modification of the nozzle to add redundant seals and improve strength, dimensional stability, and ablative insulation erosion tolerance; and additional ground support equipment to minimize the potential for assembly damage.

The redesigned SRM represents a substantially more reliable Shuttle system than before. This will be verified by a much more comprehensive test program than had been in place in the past.

Question 6: "The NRC panel overseeing NASA's criticality review and hazard analysis has recommended that NASA devise some mechanism for and assign priorities to the Shuttle components and systems that are of the most critical nature -- Criticality 1 and

1R items. How will NASA respond to this recommendation?"

Answer 6: Admiral Truly assured the NRC Committee on Shuttle Criticality Review and Hazard Analysis Audit at their November 10, 1986 meeting, that NASA would take action to develop a process to prioritize Space shuttle criticality items. Subsequently, the NSTS Program Office formed a team to solicit, develop, and propose candidate prioritization schemes. The team is presently examining five techniques and plans to recommend one of them or a combination of several for evaluation in actual practice. From early indications, it is expected that the approach eventually chosen by the program will lend itself to being overlaid on the existing process with minimum perturbation to ongoing activities, yet provide an effective measure of relative risk to focus review emphasis and resources allocation. We believe this plan is responsive to the suggestion and that the NRC Committee will be satisfied with the resultant methodology. We are keeping them apprised of our progress.

Question 7: In NASA's Failure Mode and Effects Analysis and the Critical Items List Review, what are the two or three most difficult items that NASA is now addressing that are requiring the most attention and resources?

To date, in this analysis and review, has NASA confronted any item whose correction or improvement may delay the scheduled launch of February 1988? If so, what are they?

Answer 7: Excluding the SRM redesign, the most difficult and costly items we are now addressing for first flight include the 17-inch Orbiter/ET disconnect, RCS primary thruster and SSME blade crack modifications. While the decision to modify these items did not arise out of the ongoing FMEA/CIL reviews per se, they are Criticality 1 items requiring redesign for first flight.

The 17-inch Orbiter/ET disconnects are being modified to include a positive stop mechanism to preclude the propellant valves from closing prematurely. The Orbiter RCS primary thrusters are being modified to provide an automatic detection and shutoff capability in the event of thruster burnthrough.

The most significant Criticality 1 item on the engine is the turbine blade cracking problem. There are three crack problems that are being worked on:

1) HPOTP 1st stage blade surface crack
2) HPFTP 1st stage fir tree crack
3) HPFTP 2nd stage surface crack

The HPOTP 1st stage blade redesign is the incorporation of two-piece damper. The first development sample successfully completed 5000 sec. of testing and no cracks were observed. The HPFTP 1st stage blade redesign consists mainly of the redistribution of loads on the fir tree and shot peening. Testing has been initiated on this redesign. The HPFTP 2nd stage blade redesign addresses the hydrogen sensitivity of blade cracking with gold plating. Testing had also been initiated on this redesign.

No delay from the scheduled launch of February 1988, is anticipated due to these changes.

Shuttle Crew Escape

Question 8: NASA has announced its decision to implement a crew escape system that would utilize an escape hatch and parachutes. The announcement also indicated that the system would be useful only when the Shuttle is in a glide.

What would it cost to implement this system, and how soon after flight is resumed would this system be ready for use?

Could you be more specific as to what phases of a mission this system would be useful, and does this system enable a truly survivable escape?

Answer 8: The escape system is estimated to cost approximately 50 million dollars to implement. The development effort for the crew hatch escape system is underway; however, the schedule for incorporation of the system into the Orbiter fleet is under review. The goal is to provide the system as early as possible in the flight schedule consistent with system development and qualification schedules.

The crew escape system will be useful and survivable for those mission phases which will allow the Orbiter to reach controlled gliding flight following a contingency abort. For contingency abort cases following SRB separation including two and three SSME's out, the percentage of time the escape system will be useful varies from, at a reasonable height without need for breathing equipment, 33 to 75 percent depending on the specific type of abort (TAL or RTLS). These percentages are based on preliminary assessments conducted to date.

Question 9: I understand that NASA is considering a "tractor rocket" system, which would utilize "rockets" to pull the crew from the Shuttle.

Why was this system not selected? What risks did this "tractor rocket" system itself introduce, and over what phases would it provide a survivable means of escape? Are other systems still under consideration, and, if so, what are they?

Answer 9: Development of the rocket personnel extraction system, which would provide velocity to enhance clearance from the orbiter during side hatch bailout, is continuing pending a decision as to its implementation. The risk versus added safety factor for incorporation of this feature into the Orbiter is being assessed. The tractor rockets are being evaluated against other bailout aids to insure the safest and most reliable overall system is utilized. Potential tractor rocket risks include the introduction of propellants and premature pyrotechnic ignition in the crew cabin environment. If approved, the rocket system would be an adjunct to the crew hatch escape system and be utilized during the same mission phases; i.e., contingency aborts following SRB separation.

Conceptual tradeoff studies on more complex first stage (SRB) escape capabilities are underway. These include crew extraction, crew ejection and crew module separation. These systems are under study for possible implementation in the longer term (four - five years).

In addition to development of a crew escape capability, an effort has been initiated to improve the chances of emergency landing of the Orbiter for multiple engine failures in the first 20 seconds of ascent. This concept is referred to as the split-S maneuver. The software for this maneuver has been developed, and further analysis is underway to determine the structural acceptability of multiple engine out cases.

Second Source of Solid Rocket Motors

Question 10: I recognize that NASA's acquisition strategy for procurement of solid rocket motors will not be delivered to Congress until the end of March, but could you tell us your present thinking on the desirability of establishing a second source for solid rocket motors?

What are the most current and valid economic considerations in deciding to initiate a second source competition? What other considerations will be factored into this decision? How does the future development of a Block II solid rocket motor affect any decision to establish a second source for the redesigned solid rocket motor?

Answer 10: The answer to this question will be included in the SRM Acquisition Plan to be submitted by the end of March 1987.

Question 11: A year ago, prior to the CHALLENGER accident, NASA had established as a ground rule for the consideration of a second source that the Agency could not provide funding for the necessary production qualification nor a firm guarantee of recovery of any costs incurred for qualification. Is such a ground rule likely to exist if NASA initiates a second source competition, and does the FY 1988 budget request provide funds for such a competiton?

Answer 11: The FY 1988 budget only includes funding to provide for alternate procurement studies. Further discussions of a second source competition will be included in the SRM acquisition plan to be submitted by the end of March 1987.

Phillips Study

Question 12: One of the recommendations in the Phillips study was to place the Shuttle and Space Station programs under a single Associate Administrator when the Administrator is satisfied that the recovery will not thereby be compromised.

Under what conditions would such an action be appropriate and advisable?

What efficiencies and other gains would be realized from placing these two programs under one Associate Administrator?

What conflicts or inefficiencies could arise from such an action?

Answer 12: The Administrator has this recommendation under advisement. When we are satisfied that recovery of the Shuttle program will not be compromised, the proposal is to combine both the Shuttle and the Space Station programs under a single Associate Administrator.

The potential gains and benefits to be obtained from combining the Shuttle and Space Station programs include:

o Efficiencies in the effective utilization of people and clearer lines of communication both at Headquarters and at the Field Centers which are involved in both projects;

o More effective resolution of complex interface and manifesting issues between station and shuttle;

o Optimization of the use of STS/ELV elements in support of Space Station buildup and routine support;

o Efficient use of the scarce resources that are available to NASA for these two critical, high priority and closely related programs;

o Commonality in key areas of the programs through the use of common components where possible, minimizing the number of software languages and the use of common nomenclature and instructions.

As time goes on, the STS and Space Station programs will become more and more interdependent, resulting in clear advantages to combining the programs under one manager. We will address these as we develop the comprehensive plan and integrate the program and operations activities.

Question 13: The January 15, NRC report expresses concern that valuable time could be lost if it became necessary to run to one of the alternative design as a consequence of something learned from the test program. The NRC goes on to recommend that NASA should strengthen its contingency plans for incorporating alternatives into the redesign program.

Do you agree with this assessment and recommendation, and how will you respond to this recommendation?

Answer 13: Although, NASA has high confidence in the redesigned SRM successfully meeting all requirements and being certified, we also consider it prudent to take specific contingency steps in case of a problem during the test/verification phase. The NSTS Program Director has taken steps to formulate a contingency plan for specific features of the baseline SRM redesign. The plan will emphasize those areas of the redesign where there is the most concern for the success of the current baseline. Decision on implementation of specific contingency alternatives will be made following review of the plan and within the constraints of available resources.

Question 14: The October 10, NRC report expresses concern about the fact that, at that time, the Shuttle Projects Office at Marshall was not only developing requirements, and reviewing and approving design, but also was deeply involved in the detailed design process. This situation, according to the NRC, created the potential for the design team to be able to waive certain requirements. How and to what extent has this NRC concern been resolved?

Answer 14: This concern expressed by the NRC was addressed in detail at the November 21, 1986, panel session held in Washington, D.C. Mr. John Thomas, SRM Design Team Manager, presented the waiver and configuration control discipline process whereby he showed that even though the SRM Project Manager has authority to approve proposed requirement changes to the SRM Contract End Item (CEI) Specification, he can impose requirements. Those proposed changes which do not violate Level II requirements are themselves reviewed by the Level III Configuration Control Board composed, in part, of members who are not full time SRM staff. These type changes are also distributed widely for information. Should this process fail to screen inappropriate specification changes, the CEI Specification is reviewed at both the Critical Design Review (CDR) and the Design Certification Review (DCR), both of which have team and board members from senior management at JSC, KSC, MSFC, Level II Program Office, and Level I Program Directors Staff. Additionally, each CEI Specification requirement must be addressed with evidence cited where such requirement has been verified by test, analysis, etc.

The process described above applies equally to waivers and deviations; but in addition, each waiver/deviation must be specifically addressed at the above referenced reviews.

Inasmuch as the succeeding report from the Panel did not address this topic, it is presumed that the NASA response was sufficient.

Question 15: The October 10, NRC report recommends the establishment of a second Joint Environment Simulator test stand, yet the January 15, NRC report infers that NASA has decided not to do so. Have you satisfactorily resolved this issue with the NRC committee? If so, how. If not, how do you intend to address the concerns of the NRC?

Answer 15: The October 10, 1986, NRC report recommendation for a second Joint Environment Simulator (JES) test stand stemmed from excessive turnaround time between tests, i.e., five to six weeks were required to refurbish, reinstrument, and reassemble the simulator before another test could be accomplished. To alleviate this excess down time, and thus increase the number of tests before return to flight, it was determined to be more expedient to add a second set of simulator hardware. With this approach, one set of hardware is in test while the other set is being refurbished and thus the test frequency is substantially improved. To add another test stand without also adding a third or fourth simulator would not be materially superior to the adopted approach; and, there are not sufficient manufacturing facilities available to fabricate a third or fourth simulator while producing the development (DM-8, 9), Qualification (QM-6, 7, 8), and flight motors in the next 10-12 months.

The January 15, 1987, report suggests that the decision not to add another JES test stand be reconsidered. This topic will be readdressed with the Panel, particularly as it may be influenced by the approach finally agreed upon for the various contingency plans.

Question 16: The October 10, report states that in order to support an appropriate contingency action, NASA should test a case field joint that closes under pressurization. The report goes on to state that as of January 15, NASA had not ordered the appropriate steel case forgings to conduct these tests. Does NASA intend to order these forgings to conduct these case field joint tests? If so, when? If not, how will NASA adequately test a case field joint that closes under pressurization?

Answer 16: The overall contingency strategy is addressed in response to question 13; however, some discussion is warranted on this particular contingency dealing with a case field joint that closes under pressure. The SRM Design Team and MTI are carrying a backup design for a joint that closes under pressure and will be tested on the full scale hot static test of the Engineering Test Motor in March 1987. This design uses the newly designed joint in combination with a carbon epoxy composite band on either side of the joint. This has been demonstrated to close the joint sealing gap in a full size segment pressurized to full motor operating conditions. Although this concept adequately achieves the closure objectives there are some undesirable systems implications such as increased weight and additional installation task complications for the stacking (assembly) process at KSC.

Beside the composite bands, there were only two other practical concepts presented by the Design Team, MTI, or the solid rocket propulsion industry. One was proposed by MTI, called the Grayloc seal, but tests showed severe assembly complications and it has been set aside. The other, presented in one of the SRM Block II study reports, incorporates the two O-ring seals in a capture feature similar to that contained in the new joint design. It was evaluated in the Block II design assessment and was found to fall short of specification requirements and presents safety concerns during assembly.

In the absence of a clearly superior joint that closes, the nearest competitor is a bolted flanged joint that is characterized as the Langley concept. It is considered practical to produce a forging from which the bolted joint can be machined within current processes and machinery bounds; and that the current new design joint can be machined from the larger forging if so desired. In order to comply with NRC desires for contingency plans, MTI has been instructed to prepare orders for a limited number of forgings for the eventual production of test hardware if the overall contingency strategy so dictates.

Question 17: It is my understanding that a decision to procure additional solid rocket boosters must be made by March, if NASA is to avoid any "gap" in future booster availability. This decision would come soon after only the first full-scale static firing test.

If this is true, does this remove from the program the flexibility to make changes, should the redesign prove to be inadequate or require change?

What would be the consequences if significant changes were deemed necessary after these cases had been ordered?

What other procurement options are there?

Answer 17: The current contract with MTI provides for the future delivery of 13 flight sets of SRM's. This will provide the hardware for the flights through FY 1989 per the current mission model (87-1). Backing up from the last delivery in the current contract to provide the lead time required for the first follow-on delivery and the procurement time required to provide a follow-on contract indicates need to release a RFP in September 1987 and award a contract by June 1988 for follow-on deliveries. While it is true that the static test program will not be completed prior to release of the RFP, the confidence level in the redesign should be very high at this point in time. Additionally, changes could be incorporated, if required, during the procurement cycle prior to follow-on contract award in June

1988. In fact, if the condition postulated in your question of significant change being deemed necessary the current planning schedule would slip down stream and it would not be necessary to award a follow-on contract in June 1988 to avoid a gap. In any case postulated, we do not see the need for a contract award prior to complete confirmation of the redesign, therefore, no loss of procurment flexibility due to need for follow-on deliveries.

Question 18: The August 1, NRC report states that some of the details concerning the dynamics of the performance of the Challenger's right solid rocket motor were uncertain and that his uncertainty was very important for the redesign.

How closely have you been able to duplicate the dynamics of the performance of the Challenger's right SRM? What have you been unable to duplicate and how has this affected the redesign effort? What test have been conducted to assess alternate modes of failure?

Answer 18: The uncertainties stated in the August 1, 1986, NRC report concerned the ensuing events following the initial blow-by of the SRM aft field joint seals which ultimately resulted in the loss of the Shuttle. It is recognized that most likely the precise accident scenario will never be fully understood, particularly in the latter stages (40 to 60 seconds timeframe); however, NASA believes that the primary factors causing the accident are well understood. Specific design solutions to these deficiencies are being implemented and tested. The Referee and Joint Environmental Simulator tests (full scale SRM segments) have demonstrated the STS 51-L failure mode of joint rotation and blow-by for low temperatures with artifically-induced blow holes through the putty. NASA has continued to support NRC toward achieving a mutual understanding of the STS 51-L in-flight structural and dynamic loads through presentations and responses to specific action items. Additional analyses have been conducted for both the joint dynamics and external tank attachment strut loads which reconfirms the original STS 51-L investigation results.

To assure that the lift-off and flight loads can be accommodated, all shuttle element loads are being reverified and will be applied to three different test articles during the tests prior to return to flight. These test articles will be dynamically and/or statically loaded to as much as 140 percent of design loads at the predicted temperature extremes and at the appropriate simulated flight phase.

Question 19: The January 15, NRC report expresses concern that the new Solid Rocket Motor test stand to be built at the Morton-Thiokol facility in Utah, may be limited in its capability to simulate launch loads, which could thereby limit NASA's understanding of these loads.

Will, in fact, this test stand be equipped to adequately address the issue of launch loads, as recommended by the NRC?

Answer 19: This topic was readdressed with the Panel at the meeting held at MSFC on January 22, 1987. The updated shuttle system load requirements were explained by JSC/RI, followed by a MSFC presentation on External Tank strut loads and new test stand requirements. MTI responded with the new test stand design and capabilities which were completely compatible with design load requirements. Based on recent comments by various Panel members, it is believed that the Panel will agree with the Design Team's and MTI's conclusions that the new test facility can adequately simulate lift-off and maximum dynamic pressure, flight phase loads, and predominate frequency. This will continue to be the subject of future briefings and reviews with the NRC Panel as the specific test plans for QM-7 and 8 are prepared.

Question 20: Although the case field joint was the joint implicated in the Challenger accident, interim reports of the NRC state that the problems associated with the case-to-nozzle joint may be the most technologically demanding aspect of the redesign. What are your respective assessments of the relative difficulty of addressing the case-to-nozzle joint problems--are there any "show-stoppers" in the redesign of this joint?

Answer 20: There were several design concepts pursued for the case-to-nozzle joint before arriving at the current so-called radial bolt design. This joint exhibited the same undesirable characteristics as the field joint, i.e., gap opening, putty variability, lack of O-ring resiliency at low temperatures, and rapid movement referred to as skip. The majority of these parameter values were more severe in the case-to-nozzle joint than in the field joint. This made the nozzle joint a more difficult task to acomplish.

The redesigned joint now contains 100 radial bolts to control the seal gap opening and which also totally eliminate the skip factor. The gap opening has been reduced by a factor of five to six. The variable putty has been eliminated in lieu of adhesively bonded insulation over the joint. The temperature environment surrounding the joint in the aft skirt will be controlled to a minimum of 75°F.

With the new design, all factors affecting joint performance have been accounted for and tests and analyses to date have not indicated any show stoppers.

Question 21: The October 15, NRC report raises the question of whether the baseline design satisfies all design requirements. Does, in fact, the baseline design satisfy all design requirements, and, if not, could you explain any discrepancies?

Answer 21: The October 15, NRC report was issued around the time of the SRM PDR and some design features had not been finally identified at that juncture. The lack of a firm singular design for every area being assessed could have led to the Panel's apprehension about satisfying all requirements. Since the report issuance date, the Panel has been frequently appraised of the development progress and at this time all areas being redesigned meet the specified requirements. There are, however, two areas not being redesigned that do not fully adhere to generic requirements.

The first area is the factory joint where insulation covers the joint completely throughout motor operation, thus rendering the O-ring seals non-essential. It has been proposed that the internal insulation suffice as the single pressure seal and that the O-ring seals be excluded from the stringent requirements levied on those sealing a true leak path such as the field joint. There are discussions still underway regarding the necessity for redundant seals at this location where over 400 joints have been tested or flown without the slightest evidence of problems. Additionally, all composite motor cases, such as the SRM filament wound case, rely on insulation to seal the entire case surface.

The other area relates to internal nozzle ablative insulation. At certain isolated areas, the virgin material remaining at the end of motor burn time does not quite meet the 2.0 erosion safety factor requirement. This too is under way to confirm that enough material remains based on measure parameters derived from nozzles hot fired to date.

The tests and analyses to date on redesign hardware have shown good margins and planned future tests should identify any deficiencies.

Senator RIEGLE. We will move to that in just a moment. Let me acknowledge the other two members that have joined us since we began. And let me say again that we have a raging blizzard outside here in Washington today, so I am pleased that our panelists are here and that we have such a fine attendence here within the committee.

Let me acknowledge Senator Pressler, who will be serving as the ranking member of this subcommittee. Senator Pressler and I have had a long personal association that predates our service here in the Congress together, and so I am delighted that he will be serving as the ranking member.

Let me welcome you to the subcommittee today. I don't know if there is any opening comment that you want to make before we move on to the other members of the panel here or not.

OPENING STATEMENT BY SENATOR PRESSLER

Senator PRESSLER. Mr. Chairman, I thank you very much, and I do have a statement for the record.

I had a chance to have a very fruitful meeting yesterday with Admiral Truly.

As the new ranking member of this subcommittee on science, technology and space, at this first hearing I certainly want to say that I look forward with working with you and the other members of the committee, and I congratulate you on your post. On this side of the aisle it is a little lonesome here this morning, and we have got to get used to serving as ranking members again instead of chairmen, so you can help me in my adjustment.

Let me say that it has been encouraging to hear and read NASA's public statements, particularly those of Dr. Fletcher and Admiral Truly, that NASA will not resume shuttle flights until it is unquestionably safe to do so. I think the worst thing we could do is to force ourselves to rush into a launch.

Both this subcommittee and NASA are much more sensitive to the requirement that safety, reliability and quality assurance must and shall be integral elements of any program and must be given top priority.

I am confident that this increased sensitivity will yield overwhelming positive results for our space program. I think that is true of us here in Congress, too. We should not be pushing unless we have all of the facts and unless it is a safe time to launch.

The focus of the shuttle recovery effort has been appropriately the redesign of the solid rocket motor. Establishing a National Research Council Committee to oversee this activity was a significant action and should increase immeasurably public confidence in the results of the redesigned program.

By all accounts the role of the National Research Council committee is proving to be constructive and valuable. Similarly, the five proposals submitted for the Block II solid rocket motor design have contributed significantly to this overall effort.

I am hopeful and confident that this overall effort will yield a solid rocket motor that satisfies all safety and reliability concerns and supports effectively and efficiently our shuttle program.

In conclusion, Mr. Chairman, let me say that this solid rocket motor redesign program should also help crystallize and resolve an issue that has been dangling for some time, the desirability of establishing a second source for solid rocket motors and the timing of doing so.

Both economic considerations and the strength of our nation's industrial base for solid rocket motors should and will weigh heavily in the resolution of this issue.

NASA's review of the other critical shuttle components and systems has yielded and will continue to yield valuable information that will enhance and strengthen all elements of our shuttle program. We look forward to Dr. Fletcher's continued efforts in this area. Similarly, the implementation of the recommendation of the Phillips study will prove invaluable and strengthen the NASA organization and institution. Today's hearing will provide the subcommittee insight into NASA's implementation of these recommendations.

Senator RIEGLE. Let me now turn and acknowledge a new member of our subcommittee, and in our opening session we are delighted to have him joining both the committee and the subcommittee, and that is Senator Kerry of Massachusetts, and I am wondering if you have a comment you would like to make?

Senator KERRY. I am delighted to be here and anxious to hear the testimony.

Thank you.

Senator RIEGLE. We are delighted to have you. We look forward to a major contribution from you as we go along here.

Dr. Fletcher, are there others at the table who would want to make any comments at this point or would you rather that we direct our questions to you right now?

Dr. FLETCHER. I think the best thing to do, Mr. Chairman, is to go ahead and direct them at me. If I can't answer them, well, somebody else will.

Senator RIEGLE. Very good. I am going to start by asking Senator Hollings if there are some matters that he would like to raise here with you at the outset?

The CHAIRMAN. What is the one single thing you would ask of the Congress, Dr. Fletcher, right now? What do you really need?

Dr. FLETCHER. Senator Hollings, that takes a lot of thought. We need moral support, and you are giving us that, and I appreciate that.

We may need additional funds, but we are not asking for it yet, when we go to purchase the expendable launch vehicles.

The CHAIRMAN. You do need the funds, though? You can't eat $600 million bucks.

Dr. FLETCHER. We are going to need the expendable launch vehicles, no question about that. How much they are going to cost and so forth, we are not ready to state yet.

The CHAIRMAN. I like the answers that Mr. Dale Myers is giving. He is nodding his head, going up and down. I understand that. I mean, he answers the questions more clearly.

You need $600 million, and that is one of the problems that you have that we can help with at this particular level.

You have got a lot of bureaucracy. What about the people within the system itself? I have always had the view that the process wasn't flowing. I never did agree with the Rogers Commission on that. I thought the process was violated. In fact, I think later on we will hear from a gentleman from Morton Thiokol who wouldn't sign off on the launch.

They tell me I have got an impediment in my speech and I can't listen. Have you got some folks down there that can listen to the Alan McDonalds now and everybody else and not just have that kind of pressure wherever it came from to override common sense?

In other words, in your process you had never launched over the objection of a contractor, this time it was two contractors' objections, and we still launched. And that is the important point to this Senator, that we need some folks down the line in a system where you have some public checks and, thereby, some responsibility.

Dr. FLETCHER. Senator Hollings, what you just described is not going to happen again on my watch, and I suspect not for years to come.

J.R. Thompson has come back. The first thing he did was look into that and said, hey, that is not going to happen when I am here either. I think we have got people working together a lot better, not only the relationship between the contractor and Marshall

Space Flight Center, but between Marshall Space Flight Center and the other centers as well as Headquarters.

This new team that we have got together are bound and determined not to let that kind of thing get in our way. It is not going to happen again.

The CHAIRMAN. And you have got a way to fix the responsibilities?

Dr. FLETCHER. You bet.

The CHAIRMAN. I mean, we got Mr. Aldrich here because he never was informed. I think he is thoroughly competent, and I go along with having him because he never did hear.

Dr. FLETCHER. You are quite right, Senator Hollings, and that is not going to happen again. Not only Mr. Aldrich is going to make sure that doesn't happen again and, also, the two center directors that we have just appointed at Johnson and at Marshall, I haven't asked them to swear on a stack of bibles, but they have told me in no uncertain terms that that will not happen again.

The CHAIRMAN. Well, we have got to have fixed responsibilities. If we all can understand these responsibilities, we will know, if it does go wrong, where it went wrong.

Dr. FLETCHER. That's correct.

The CHAIRMAN. With respect to the talent and the astronauts themselves, we have covered all of the other checks and balances in different offices.

Are you getting the outstanding astronauts that we need now that will stick with the system? I notice a lot of them quiting because of delays and otherwise. They didn't see too much of a future as they personally were concerned.

Have we got a good feed-in now of young astronauts themselves?

Dr. FLETCHER. I will ask Admiral Truly the answer to that, but let me just give you my observation. We took some of the best astronauts and ran them back to Headquarters. One of them is sitting at my left here. Bob Crippen is also back at Headquarters. And for a while we had Rick Hauck. I can just say those are absolutely outstanding astronauts.

Now, for the younger ones, I will have to turn to Admiral Truly.

Admiral TRULY. Thank you, sir. I think that the astronauts in NASA are one of our finest and most dependable group of people anywhere in the organization.

There have been a number that have left in the last year but, frankly, if you will look at those that have left one by one, you will find that some of them have been there for a long time and it was a good career move for them.

There have been one or two who were asked to come back to the military and they saluted and did that. I cancelled last year's astronaut selection because of the delay. It was underway at the time of the accident. There were just so many unknowns and the delay was not precise that we scrubbed that one.

We have, however, with our new schedule and our new requirements started a new call for astronauts, and we will be making a small selection this year. I am confident with the number of people who apply and the quality of those individuals, that the people that we get in on the young end of the program will be just as capable as those that we are used to.

The CHAIRMAN. With respect to the plans for the future, the missions and goals now, we are trying our best to get back up sometime next year, hopefully in February, but once we are into space and we catch up on the defense demands, the communications demands, the health funds and everything else that we are testing in space, do we have an order, a mission, for NASA that we can look out over a period of five to ten years to know where we are headed?

Dr. FLETCHER. Senator Hollings, that is an awfully good question. I will respond the best I can. In the first place, we have the space station, as you know, that is going to be assembled out in the 1993–94 time period. That will last us for some years because that is a permanent base in space.

We also have set internal goals for ourselves, broad general goals, not programs, but things that we think NASA ought to be doing in the long term. We ought to be involved in international cooperations. We ought to be the center of excellence of the whole world in aeronautics.

We ought to be sure that we continue to have the best space science program in the world, which we do now, but it is in trouble because of the slip in the mission in the shuttle.

We also plan to have a human presence in space permanently. And that space station is the first step in that, but we have extended that. We say we ought to move out beyond earth orbit with humans. And what that next stop for a base should be, we are still studying, but with these goals in mind we have put together a rather intensive effort internal to NASA and external and a number of groups are studying what we ought to be doing in 1995 in addition to the space station, what comes next? What is our longer term goal?

Not that we want to start spending money or anything of that sort, but what ought it be? And we have pulled together the various elements of NASA, and another outstanding astronaut is heading up that effort, Dr. Sally Ride, and she has got several committees going inside NASA studying the problem.

We have also our National Advisory Council that is dealing with the problem, and we have also brought in an outfit called Jason, which is a group of academic thinkers, mostly they have been doing work for the Defense Department, but we have asked them to take a look at what do we need to be to be leaders in space? What does this country need to be to be leaders in space?

That means you have to look at what other countries are doing. And that will all come together in the spring of this year. We haven't set an exact date, but sometime in the spring.

We are not going to set those goals without extensive discussions with this committee and, of course, with the White House or other committees in Congress. It is going to be a consensus, whatever we decide to do.

The CHAIRMAN. Thank you, Mr. Chairman.

Senator RIEGLE. Let me just say before moving ahead here, that we will be having hearings on precisely that issue, that is, what is our future in space and what are our goal choices, because I also feel strongly, that we need that national consensus, and that can only come after we have examined our alternatives and discussed them openly and then made our selections.

I want to acknowledge the presence of another new member of the full committee and of our subcommittee, Senator Adams, from the State of Washington.

We are delighted to have you with us. I don't know if you have any brief comments you would like to make at this point before we move along with the questioning.

OPENING STATEMENT BY SENATOR ADAMS

Senator ADAMS. Thank you, Mr. Chairman. I do have just three brief comments.

One, it is a pleasure to be on the committee with you. I was on the Manned Space Committee in the middle of the 1960s when we started both the original orbital flights and, of course, the manned flight to the moon.

So it is a pleasure to be back involved with it.

The second thing is, gentlemen, I share the Chairman's concern that our goals be realistic as we move back into space. I am concerned with the emphasis on the shuttle program at the expense of unmanned vehicles, particularly clustered vehicles that have put us into space prior to the time of the shuttle program. I think we have placed all of our eggs in one basket and that was a mistake.

I hope that we will have a chance to examine the merits of additional shuttles as opposed to unmanned vehicles that will put us in space far sooner and not require us to rely on the Chinese or other sources.

The third thing is I am very much in support of the space station. I am hopeful that unmanned vehicles along with those that are manned can be used in conjunction with one another in order to create the station, and that we are not waiting for a shuttle program to be reinstituted before moving ahead with the space station.

Thank you, Mr. Chairman. I appreciate it and I am glad to be here.

Senator RIEGLE. I want to just say one other thing. Having served with the Senator from Washington years ago in the House of Representatives, I am particularly delighted that he is joining us on our subcommittee.

I think our subcommittee has the potential to be one of the strongest subcommittees in the Senate on any subject, just given the makeup of the group that we have here, and I am determined that if we approach our work properly, we can have that kind of effect and result as a subcommittee.

I will proceed with the five minute time periods, and we will come right down through the list here based on order of arrival after the starting time of the meeting this morning.

So having heard from Senator Hollings, I want to just raise two issues with you now myself, Dr. Fletcher.

I want to raise with you rocket redesign. I am wondering if the proposed solid rocket motor that we have redesigned is really the best possible fix recognizing that what we are doing here is making what I would think you could call a technical change or series of technical changes to what has been called a flawed design.

The conclusion of the committee or rather the Rogers commission was that the design itself was fundamentally flawed.

And I am wondering if making technical changes, however well done they are, is sufficient to make the field joint as structurally sound as a factory joint would be?

I know shortly we will get into the mechanics of how you are doing this, but my basic question to you is—and I know there is debate about this in the scientific community—whether we ought to be working on a fundamentally different design even if it takes us longer to do it, or whether we take the design that we have been using with modifications and feel that that is sufficient?

So I would like you to address that issue head on, if you would.

Dr. FLETCHER. Yes. As you mentioned, Mr. Chairman, that discussion might be better held later on. I can give you my own opinion of it.

I think we have to go with at least a baseline design, one that we are pretty sure will work, and have sufficient testing and analysis so that we know it will work.

On the other hand, it is also important to have backup programs, as you know. Dr. Stever's committee has suggested several ways of doing that. Some of them are long range programs, like a complete new case which would take some years to complete.

Others are different fixes that could be implemented if the current baseline configuration doesn't work.

Having said all that, though, we are pretty optimistic that the baseline configuration will work. We have got a JES, joint environmental simulator, I think that stands for, and that gives a pretty good indication already that the design that is called baseline is going to work.

I don't pretend to be an expert on the seal fix, but those are things that seem, I have been briefed a number of times, and seem like a good way to proceed. You ought to go with the baseline program.

If you start looking at too many things all at once, you don't get any of them done, but have sufficient backup so that, if that doesn't work, you can go to the next possibility.

Senator RIEGLE. For the record, how many successful launches were there with the original design, both the field joint and the O-ring arrangements, that did not work in the last launch, how many had worked successfully prior to that time?

Dr. FLETCHER. There were 24 flights, Mr. Chairman, that were flown, and there is two solid rocket motors on each flight, and how many field joints are there in each motor? Anyway, six times 24.

Senator RIEGLE. So we had an unbroken record of those joints working properly in previous launch conditions prior to the one where it did not work properly, and, of course, we had other factors at work, the cold temperatures and so forth at that time.

Dr. FLETCHER. Mr. Chairman, can I interrupt? If I may, I don't think it is proper to say that those seals worked properly in the previous 24 flights. They did work, but we found a lot of anomalies.

Senator RIEGLE. That is a very important point. They worked sufficiently to allow the flights to occur, but there were dangers that were appearing, and you should have told us at the time that corrections were needed. In fact, certain corrective actions were underway, but they were not completed.

And then we got into the situation of the launch period about a year ago with the low temperatures and we had this terrible accident that we are all too familiar with.

What I am wondering is this now, so essentially the approach that you were taking is to say that that basic design was a pretty good one and it didn't work properly, and you were finding that you were having some inadequate performance of those, and under some conditions just a failure to perform properly, so that you have taken essentially that same design and you have reworked it, but we are still intending, as things stand today, to go with a rocket system with joints, albeit redesigned, pretty much the way we had them before, with these technical changes and modifications, is that correct, or how would you state it?

Dr. FLETCHER. Mr. Chairman, I would say it is a completely different design.

Senator RIEGLE. That is what I want to understand.

Dr. FLETCHER. It is brand new cases that allowed for a thickening to produce several different possible designs, and with a feature which does not allow the expansion that caused the seals not to, or the O-rings, not to function.

The O-rings are new. I would say there is very little resemblance of the new design to the old design. The only thing that is similar, I would guess, is that there are probably still three field joints, and that is about it.

Do you want to add to that, Arnie?

Mr. ALDRICH. I would describe it that way. My description of that would be that the joint was flawed and, in fact, the testing during the past year and still ongoing is determining what the specific flaws were of the joint, and changes have been made that are strong technically in each area.

So in that regard it really is a new joint. It is similar in that it is still a joint that is made in the field, therefore, it is called a field joint, but there are significant differences.

Senator RIEGLE. We will pursue this. My time is up, but I gather you are saying that fundamentally it is different. You feel you have changed it enough that you now have something that is fundamentally different than what you had before, and I think we will need to probe that.

We will also need to probe carefully the issue of the degree to which the new design, if it is that new, is sufficiently tested before it is actually used. And I am very concerned myself about that issue because I know there is great pressure to get going again.

I want to make sure that all of the testing is done short of live conditions where you have got lives at stake, so that we are certain that we have got a design that works.

With that, let me now turn to Senator Rockefeller.

Senator ROCKEFELLER. Dr. Fletcher, when you were here for a confirmation I raised my concern about the need even under these extraordinary circumstances to keep up the pressure on commercial scientific research.

You laid out several months ago a shuttle payload plan for the next several years. And in that the Pentagon will claim 11 of the 26 flights scheduled for the first three years when all of this resumes.

Now, that is the way it works around here. There is a line of prioritization, and military payloads get the first shot, as they should, and then you have this business of critical, as they say, scientific and communications payloads, and then commercial and foreign.

The University of Alabama, represented by Senator Heflin, has been conducting research that could lead to the cure of cancer. The excitement of that and other prospects in science are enormous.

In the aftermath of the tragedy, and also the general problem of putting up into the sky those things which we need for national security, I remain concerned about the importance of medical science, of science which will be put to commercial use which will help us in terms of our competitive position in this world. That is, new technologies, new ideas, that can be brought back down to earth, things that can be done on space but cannot be done on earth.

So that is important to me. Now, prior to the accident last January NASA had planned 50 scientific payloads between 1986 and 1992. Now we are talking about 17.

What I want to get a sense of from you is the priority within constraints that are on you for scientific research that is going to help mankind in terms of disease and help industry and help this country compete in this enormous problem we have with our trade deficit?

Dr. FLETCHER. Senator Rockefeller, I think your concern is justified. It is not proper to say that the defense took over more of the payloads. What happened was that we were asked to not fly any more communications satellites on the shuttle.

So when they were moved off, both the scientific payloads and the military payloads increased, but there are actually fewer numbers of military payloads than there are scientific payloads in the period from 1988 to 1993 or 1995.

Having said that, though, what you are focusing on is what we call space processing, which involves processing of biological materials and metals and things of that sort, and those were cut back severely in the manifest.

And we are trying to deal with that problem the best we can. By the way, I think we are making progress and we are going to have to spend some more money in that area, but we do plan to offload some of those experiments that were planned on to the space station, which can do it a lot better because of the longer duration.

Some of the earliest experiments in space processing for a long duration will be on the space station. I think about the seventh flight or something like that in the process of assembling the space station will be microgravity experiments.

We think you are absolutely right. These are important commercial potential experiments. So does the rest of the world. So we are fighting for space on the shuttle and, of course, we have the priority.

We do think it is an important program. We do plan to put more money into it. We have got a study going on as to how we can put some of those payloads on the shuttle as secondary payloads.

The primary payloads are in the payload bay. The secondary payloads go into what we call GAS cans—what does GAS stand for—Get Away Special cans, that we can tuck in here and there, and conceivably some of them can even go in the cabin. These are all called secondary payloads.

We have a study underway as to what secondary payloads ought to be established and how do we establish priorities on those. Ultimately, of course, when we have our ELV program sorted out, expendable launch vehicle program sorted out, we will know better how much they can be used for similar things.

You are quite right. We have the same concern that you do.

Senator ROCKEFELLER. I notice that the Pentagon is going to be spending over $4 and a half billion getting 48 ELVs.

You feel secure now, I mentioned cancer, there are those who think that the cure for cancer is going to be found up there. Are there certain areas, cancer being one that I would focus on, that we can count on that you will be working on?

Dr. FLETCHER. I wish I could answer you, Senator Rockefeller, more specifically. I can say that life science is one that you can count on. And I will go back and make sure that cancer, among the life sciences, is given a high priority.

If there is somebody else that can answer that question better than I, but I think we would have to supply that for the record. Whatever is the case, now that you have raised the issue, we will make sure that that is given a high priority.

[The following information was subsequently received for the record:]

Under the auspices of the NASA Microgravity Science and Applications Program, we are conducting space experiments in the growth of protein crystals. Protein crystals are a critical element in the determination of the molecular structure and functional relationships of enzymes, nucleic acids, and other macromolecules. Understanding of the molecular structure allows the design of more efficient drugs. Protein crystals are, by their nature, very fragile, and difficult to grow; in some proteins, crystallization can take years. Dr. Charles Bugg, University of Alabama-Birmingham, is leading a large team of academic and industrial investigators in a series of experiments aimed at exploring the feasibility of protein crystal growth in space. It is our belief that elimination or reduction of gravity-driven phenomena, such as sedimentation and convection, will enable better quality, larger protein crystals to be grown in space, in much less time than methods currently used in ground laboratories. Dr. Bugg and his team feel that this area has enormous potential in the science or drug design and subsequent treatment of diseases/illnesses such as cancer, diabetes, and arthritis. Interferon, which shows much promise in cancer treatment, is one such substance we hope to produce in crystal form in space. We are currently supporting a very active program in protein crystal growth, including preparation of advanced hardware to fly soon after the resumption of STS flights.

Senator ROCKEFELLER. Thank you, Mr. Chairman.

Senator RIEGLE. Thank you, Senator Rockefeller. Before calling on Senator Gore, who is next in order, I want to acknowledge also the presence of Senator Bentsen, who has been chairing the Senate Finance Committee this morning, where I also serve.

I want to say, Senator Bentsen, how pleased we are to have you both on the Commerce Committee and on this subcommittee, and we very much look forward to your thoughts and contributions on these issues as they relate to NASA; especially since you represent a state that has such an important concentration of NASA activity and capability.

So we are delighted to have you, and I don't know if you have any comment that you, perhaps, would like to make at this point?

Senator BENTSEN. Only to say, Mr. Chairman, that I am very pleased to be a member of this very important committee and subcommittee, and my home City of Houston has not only a great economic interest, but a great emotional interest in the success of NASA.

And hopefully we are about halfway between the tragedy of the past and the successes that we anticipate in the future.

And I regret that chairing that other committee will limit my time here, but I appreciate your courtesy.

Thank you very much.

Senator RIEGLE. We are pleased to have you.

Senator Gore?

Senator GORE. Thank you very much, Mr. Chairman.

Dr. Fletcher, I want to move to the two areas that I mentioned in my opening statement, but before doing so I want to touch briefly on a matter of old business from last month. I do not intend to pursue it in depth on this occasion, but, as you are aware, I requested a GAO review of matters that were the subject of an extensive public investigation by a newspaper, you were quoted at the time last month as saying that you would seriously consider disqualifying yourself from any new contract decisions on the shuttle booster.

I am awaiting the results of the GAO review, which I am told will be available next month. I want to give you an opportunity to make any comment you wish to make at this time, and then I will move on to other subjects.

Dr. FLETCHER. Well, with regard to your first point, I did have a long discussion with members of our staff on the business of should I recuse myself from future deliberations on a second source or anything having to do with the solid rocket motors, and also discussed this issue with several members of this committee, and it seemed quite clear to me that I could not do that. I couldn't function as an administrator by recusing myself from such an important activity.

On the matter of the GAO report, I am anxiously awaiting their results just as you are.

Senator GORE. I was concerned by the disclosures, and it was for that reason I requested the review. I will return to this at some future time depending upon what that review indicates, but I would like to turn now to the subject of quality assurance.

One of the management changes implemented by you since the accident has been the appointment of Associate Administrator George Rodney, a man with an excellent reputation in the quality assurance field, and from all appearances he seems to be off to an excellent start.

I note in Dr. Thompson's testimony that will be delivered on the next panel that considerable attention is paid to the enhanced role of what you call SR&QA at the Marshall Space Flight Center.

However, there is no indication in your statement, Dr. Fletcher, as to the role of the new Associate Administrator for SR&QA in the proposed baseline redesign program.

Could you tell us about the role of SR&QA and Mr. Rodney in establishing and reviewing the proposed baseline redesign?

Dr. FLETCHER. Yes, Senator Gore. George Rodney and his staff have been intimately involved in that, in fact, have signed off on all of the proposed redesigns.

There are many details involved in that, and if you would like, we could ask George Rodney to respond to how many meetings he has been involved in and how many things he has signed off on.

Senator GORE. Not at this time, if that is all right. Perhaps we can get to that later.

Does he have the right to override any approved redesign?

Dr. FLETCHER. Certainly he does. And if there is an argument about it, it comes to me because, as you know, Senator Gore, the Associate Administrator for SR&QA reports directly to me. So it is an independent route, if you like, to me. So if there is a difficulty, it is up to him to call it to my attention.

We also have a statutory committee, which hasn't been discussed very much but, nevertheless, we have invigorated that committee with a new chairman. We call it the Safety Advisory Panel, I think. Anyway, it was set up by Congress, and they also have an independent channel into me, and they are working closely with George Rodney to make sure that whatever is being done in the line management, where the primary responsibility is, is correct.

And, if it is not correct, it comes to my attention through George Rodney.

Senator GORE. How many people have been added to quality control since the new office was created and what are your future staffing plans for this office?

Dr. FLETCHER. Senator Gore, it is more than just bodies.

Senator GORE. I will accept your statement on that, but I want to know about the bodies. I want to know how many people have been added and how many people you plan to add because there was a 71 percent cut in the bodies in the period of time leading up to the *Challenger* disaster, and how many people have been added?

Dr. FLETCHER. An enormous number of people have been added, some civil servants and some what we call support contractors.

As I recall, just off the top of my head, and George Rodney can help me if it is not right, but as I recall he has been able to recruit almost double the size of staff in Headquarters and a similar number of support contractors. I think the number of support contractors is up by about 150 by now, but that is still in the process, Senator Gore.

Senator GORE. My time is up. I wonder if we could get Mr. Rodney to supply that number, Mr. Chairman, how many people have been added to that office?

Senator RIEGLE. We will not only get that number, I think we can get it today because Mr. Rodney is here. I think whenever we can get information from people who are in the room rather than for the record, I think that is useful because I think if colleagues then want to take and pursue a line of questioning based on that information we can do it then rather than to lose the opportunity.

So, Mr. Rodney, do you have that information?

Mr. RODNEY. I will provide it to the Senator.

Senator RIEGLE. Today?

Mr. RODNEY. Yes, sir.

Senator RIEGLE. Thank you.

Senator Pressler?

Senator PRESSLER. One thing I want to get some analysis on is how you are hiring engineers and your staff bureaucracy, so to speak, at the salary levels available.

As I understand, about $70,000 is about as much as you can pay an engineer. And I noted with great interest these comparisons of the new field joints, and this has already been talked about, the field joint comparison, where we have the third O-ring added and the new interference fit capture latch added which, presumably, would have made the first rocket safe.

Were the engineers who designed this new SRM joint from NASA or were they from Morton Thiokol or did they work together? Also, how much do you pay your engineers who work on a project of this nature and how much does Morton Thiokol pay its engineers who would have worked on this project?

I ask these questions because I know there is a certain amount of dedication involved in government work. I know a lot of people work for that reason.

I know in Sioux Falls, South Dakota at the Arrows Data Center we have Al Watkins, who is a very dedicated guy, and he works at the salary that the government pays, although he could probably double it tomorrow by going out.

There is some point that with all of the dedication in the world, if you have five kids in college, one wonders why a government engineer continues to work for $70,000 a year if he can make three times as much elsewhere?

The basis of my question is, are you getting the right people, not just engineers; are you able to retain the right people, aside from the top management?

Dr. FLETCHER. I think, Senator Pressler, I ought to ask J.R. Thompson to respond to that, but let me give you my support for your concern. We do have a problem of compensating engineers, and that is the purpose of the human resources activity that Sam Phillips' Committee recommended. We have got to figure out better ways of compensating our people all up and down the line.

We are not competitive in some regimes, but we need to fix that. That is a long-range plan.

In response to the specific question you asked about who designed that particular joint, I will have to ask J.R. Thompson to respond.

Senator PRESSLER. I don't know if it is so important who designed this, but how much do your engineers make compared to the engineers at Morton Thiokol? I suspect they designed it together.

If an engineer worked for you and was working side by side with one who was working for Morton Thiokol, how much would they probably make?

Senator RIEGLE. Is there someone here that can answer that question for Senator Pressler?

Dr. FLETCHER. We will have to provide that for the record.

Senator PRESSLER. What do you think the answer is?

Dr. FLETCHER. I imagine, I think it is pretty clear, that on the average the Morton Thiokol engineers are paid more than our engineers, but on that particular joint question we would have to look it up.

Senator PRESSLER. Twice as much maybe?

Dr. FLETCHER. At that level probably not.

Senator RIEGLE. We will ask that question, however, when Mr. Thompson comes, as he will, as a witness here just a little bit later in the morning, so we will be able to get that answer.

Senator PRESSLER. Following up some more on this new joint now, would this third O-ring and the interference fit capture latch have prevented the failure of the SRM on the *Challenger*?

Dr. FLETCHER. That's correct, Senator Pressler, but we have got to have quite a few tests before we can answer with absolute certainty that that is the case, but as far as the early tests are concerned, there is no question in my mind but that would have prevented the accident.

Senator PRESSLER. The NRC panel also recommended that NASA establish and maintain a directed program for continued evaluation improvement in reliability after flights are resumed.

What are NASA's plans in regard to such a program in addition to what you have already said?

Dr. FLETCHER. I think Admiral Truly ought to answer that question.

Admiral TRULY. I think that this could be expanded on also in a later session by J.R. Thompson and the people from Marshall, but I have already discussed this specifically with him.

We do intend to ask for the money in our budget for continued test program even after we start flying. Ground testing is the place to find your problems, and so both in the main engines and in the solid rocket motors, as the program progresses into the future, we intend to have a test program that continues and allows us to have the data, the test data available, should we choose to go to improvements to add safety margin or performance margin in the design.

Senator PRESSLER. The NRC panel further recommended that NASA formally approve the firings of qualification motors seven and eight which, as I understand, would bring the number of full scale static test firings to six.

What is NASA's position on these two firings and, if you do conduct them, will they both take place before the next scheduled shuttle launch as the NRC recommended?

Admiral TRULY. We have approved each of those two qual. motor firings. We planned for the first of those last two to be accomplished before the flight. It will be a chilled to a cold condition, the first, and then the second firing, which is our proposal and which we are going to discuss in detail with Dr. Stever's NRC committee, I believe later this month, we are going to qualify the flight by bracketing a large margin, large temperature margin, and then that last qual. motor firing is intended to be at the hot case.

In other words, it will be a high propellent bulk temperature. This is an issue that we want to discuss more with Dr. Stever's committee. We do have his recommendation. We are going to take it on head on.

I might also add that the ability for us to add in those firings is because we are building a second test stand. And this test stand will also have an added test capability to put dynamic loading into the motor rather than just a plain full duration full scale firing.

And this is another, the design and requirements of this dynamic simulation, is another issue that Dr. Stever's committee commented on, and we will also be discussing that with them.

Senator RIEGLE. Thank you, Admiral Truly. We will have a chance to pursue some of this in our next panel, too, and I think we should.

Senator Kerry?

Senator KERRY. Thank you, Mr. Chairman.

Dr. Fletcher, on a broader sort of policy question initially, as the Department of Defense moves towards the expanded expendable launch vehicle program, how do you intend to adjust the manifest of the shuttle flights to reflect, I hope, a greater number of both commercial and scientific payloads?

Dr. FLETCHER. Senator Kerry, as you know, we already were aware of the DOD's proposed expendable launch program when we decided on the manifest. The only thing that wasn't decided by DOD at that time was the so-called medium launch vehicle, but the Titan IV, which is most useful for us, had already been programmed and we designed the manifest with that in mind.

We don't plan to carry very many of the so-called GPS, Global Positioning Satellites, on the shuttle. They will be primary launched on the MLV's, except maybe in the early days, because it will take some years before the MLV production line is going.

Having said that, however, we are going to modify the shuttle manifest from time to time and, as they find ways of offloading from the shuttle, we will find plenty of opportunities to put our own missions on.

And we will have to continue to do that as the years go by.

Senator KERRY. So there will be the conscious effort to try to expand on those other areas?

Dr. FLETCHER. No question about that, Senator Kerry, but in addition to that, we may even use some of their ELV's for our own mission. In fact, we are seriously looking at one of their expendable launch vehicles that might be available for an early planetary launch and, if it is possible to do, we will purchase that ELV.

Senator KERRY. Thank you. Also, I ask this, I suppose, for the record purposes and partly in following up on the Chairman's question about accountability in the long run.

Last year the Rogers Commission and I think additionally the House Committee on Science and Space specifically found and issued reports concluding that the cause of the *Challenger* tragedy was the failure in the aft right hand solid rocket motor joint, but recent reports are surfacing or have surfaced over a period of time which have received a certain amount of circulation suggesting possibly other considerations may also have contributed to it, such as struts due to excessive pressure strain, et cetera.

So I would like to ask you if, according to the mandate of the Rogers Commission to fully understand the strut, the joint, that you would say at this point in time that you do fully understand it, and would you state for the record what the current assessment of the real cause is, is it the same as was stated then or are there now additional things that you might say were part of it, and is there a full understanding of the nature of that joint at this point in time?

Dr. FLETCHER. Senator Kerry, I think I can say without equivocation that we do understand what caused the accident. It was the field joint.

Having said that, though, we have interviewed and spent a considerable length of time with some of the folks that feel that it might have been a structural failure.

Admiral Truly has been interviewing, he and his staff have been interviewing those folks and have had extensive discussions. Maybe you would like to comment on that.

Admiral TRULY. I would echo Dr. Fletcher's basic answer. In the broadest sense of the word we are absolutely confident that the cause of the accident was what was indicated then, and that was a failure in the field joint.

We simply had a design that we did not understand. We have done, during the investigation and during this year, we have done many tests on that joint. We have duplicated the failure. And some of the later people can tell you more about that. And the proof of the pudding in the redesigned joint will be also testing.

The other comment that I would make, though, is that during the investigation and even today we continually do get inputs from sources, citizens, who have made observations, technical people who believe that they have come up on something that we have missed, and we have treated every one of them seriously.

I get some of them myself and I pass them all directly to the Marshall Space Flight Center redesign teams. And even during the accident we did not treat any of these inputs lightly, but I am absolutely confident that we know the cause of the accident.

Senator KERRY. And you would dismiss any of those other assertions at this point in time?

Admiral TRULY. Well, I treat them seriously. As a matter of fact, we are dealing with one now, that we met with the individual, and we didn't dismiss it. We are going back and doing some analysis to explain to him what we think the facts were in the matter, and we are communicating with that individual.

Senator KERRY. But notwithstanding, I see my time is up, but notwithstanding the ongoing conversations and dialogue with him, you are prepared to say that you do fully understand that there is no question then. Why do you still have the continuing dialogue? Has that been put to rest or is there still an issue as to whether or not there is some credibility to those assertions of that individual?

Admiral TRULY. You said an important word, credibility. I think for us to be credible, we have to continue to treat seriously technical opinions and advice that we get, and we do so.

Senator KERRY. Mr. Chairman, my time is up and I will stop now, but I do have some deep concerns about the testing schedule and the nature of the way in which it has been established, but for this moment thank you.

Senator RIEGLE. Let me just say, Senator Kerry, that I do as well, and I think the subcommittee generally has the view that the testing procedure is vital here because we have got to succeed the next time we launch.

And so we will pursue that very carefully. And I think there will be other questions that people are going to want to submit for the record here as well. I would hope that in this area, that you have just been discussing, if there are other things that you would like to have responded to in detail, that you will provide us some questions, and we will see that the answers are gotten.

Let me make an announcement before calling on Senator Adams, who is next in the order here, and that is we are making good progress in the room. Outside the room the storm is continuing, the blizzard that is taking place in Washington has worsened.

The Federal Government has officially shut down for the day in other locales, but I think those of us in this room can take some small measure of pride of the fact that we are here, we are at work, we are making some progress, and we will stay here and continue to work until we finish with our panels today.

Senator KERRY. We can't get anywhere if we wanted to.

Senator RIEGLE. That's right, we can't escape if we wanted to. What we will do, we are going to change the order of things slightly, and I just want to tell everybody now, so that everybody can plan accordingly.

When we finish this round, as we will do shortly after Senator Adams and Senator Heflin have been given an opportunity, I will suggest that, unless there is some totally compelling point that has to be raised, that we go to our next panel, which is the next level of technical know-how within NASA on these issues, hear from that panel, ask them to be brief in their summary comments at the outset, and then we will probe that, and then we are going to change the order.

We are then going to call up the contractor group next. And I am anxious to get to that group because I want to be able to juxtapose what they may have to say to what the NASA people are presenting this morning.

And so they should be ready to come to the table after we have heard from Panel II and then, finally, Dr. Stever, I know that you are here in town. I don't mean to put you last in any sense other than the fact that I think that is probably the better order to go with today. So then we will call on you at that time.

So with an eye on the need to move as rapidly as we can so that we can cover all of the ground today, let me now call on you, Senator Adams.

Senator ADAMS. Thank you, Mr. Chairman. I will be very brief.

I am concerned about pressure being placed on you and on the remaining shuttles to carry the entire load of the space program as I indicated in my opening statement.

What do you have left in inventory of Delta, Atlas Centaur and the Titan?

Dr. FLETCHER. I don't have a precise picture, but I can give you a rough cut. We have parts of several Delta vehicles.

Senator ADAMS. Less than ten?

Dr. FLETCHER. Less than ten.

Senator ADAMS. Atlas Centaur?

Dr. FLETCHER. Atlas Centaur is a very small number.

Senator ADAMS. Less than ten?
Dr. FLETCHER. They are all less than ten, Senator Adams.
Senator ADAMS. So you have a total of less than probably 25 alternative vehicles?
Dr. FLETCHER. Much less at the present time. We have not ordered any new ones.
Senator ADAMS. In your testing procedure you were using a reusable rocket, correct, in terms of the solid motor vehicle?
Dr. FLETCHER. The solid rocket motor will be recoverable, yes.
Senator ADAMS. Are you in your testing taking into account that this is being retrieved and constantly reused with the problem of the weak joints, in other words, are you actually retrieving the vehicles and then testing or are you just doing lab testing?
Dr. FLETCHER. Senator Adams, that is a good question. My answer is yes, but I think I ought to turn to Admiral Truly.
Senator ADAMS. Admiral?
Admiral TRULY. Yes, sir. We have not totally defined the test program that I mentioned a few minutes ago. They will be continuing after the flights start, but that is precisely one of the things that we will be addressing. We do recover the motors.
Senator ADAMS. And the casing and the O-rings, so that you are using a vehicle that has had basic flaw designs and a real problem with expansion, contraction of what is basically a rubberized-type O-ring, or whatever you want to call the new ring you are going to design, and you are placing that in the ocean, out of the ocean, and then under various temperatures, and then firing it with the vehicle, is that correct?
Dr. FLETCHER. I just wanted to make sure. The O-ring would be a new O-ring. We don't try to recover the O-ring itself.
Senator ADAMS. You then replace the entire casing?
Mr. MYERS. The experimental case is used again.
Senator ADAMS. Well, the O-ring is in the external casing, isn't it?
Dr. FLETCHER. No, the O-ring is a big piece of spaghetti that goes in the groove in the casing. So the O-ring itself will probably not be used again, but the casing itself will be.
Senator ADAMS. That is what I want to know, is each time that you are using your reusable boosters you are retrieving the casing, you are firing it again. Are you replacing all of the O-rings at that time?
Dr. FLETCHER. Yes.
Senator ADAMS. Did you replace the O-rings with the new design?
Admiral TRULY. We have always replaced the O-rings and all other parts of the recovered motor hardware with the exception of the steel case itself.
Senator ADAMS. All right, then you had a new joint design, which I understand you were placing on the vehicles in a seriatim procedure, which was the one with the notch in it and the believed-to-be-safer item.
Why wasn't that being replaced as you brought these boosters back in.
Admiral TRULY. At the time of the accident there was a design being discussed.

Senator ADAMS. You had put it on some, hadn't you, Admiral? Had you not put any of these new features on any of your reusable rockets?

Dr. FLETCHER. Arnie Aldrich is the institutional memory in this, Senator Adams.

Senator ADAMS. Mr. Aldrich?

Mr. ALDRICH. I think that the name for the feature you are discussing is the capture feature.

Senator ADAMS. Precisely, the notch, whatever you wish to call it.

Mr. ALDRICH. And that design, in fact, was in place on the units that were being tested for the filament wound case motor.

Senator ADAMS. It was a 1982 design basically or in that neighborhood? I just know that that was being flowed into the system, as I understand it, from about 1982 on.

Mr. ALDRICH. It was being tested as a baseline component of the filament wound case.

Senator RIEGLE. Can you pull that a little closer? I want to make sure that the stenographer gets this. This is an important question and an important answer.

Mr. ALDRICH. The capture feature was being tested as part of the development of the filament wound case solid rocket motor, which was to be used on the West Coast.

There were designs being discussed for incorporating that into the steel cases for East Coast launches, but, in fact, we had not moved to that point.

Senator ADAMS. You had not moved any or flowed any into the system?

Mr. ALDRICH. Nor had we built any for the steel cases at that time.

Senator ADAMS. You had not built any of the capture features at the time of these launches?

Mr. ALDRICH. Yes, sir.

Senator ADAMS. A final question, Dr. Fletcher, are all people going on these shuttle missions in the future to be professional astronauts?

Dr. FLETCHER. In the near term future that certainly will be the case. We are still discussing among ourselves if and when we should fly with civilians.

Senator ADAMS. But everyone going up from now on in these original launches that are going to take place will be professionals?

Dr. FLETCHER. The first five, probably the first 20 and maybe forever, but we really haven't faced the issue of whether we fly some day so-called non-professional astronauts.

That issue is not before us. We are not going to do it until we feel it is absolutely safe to do so, if we ever do it.

Senator ADAMS. Thank you, doctor. Thank you, Mr. Chairman.

Senator RIEGLE. Thank you, Senator Adams. Several of us have that same concern, and so you will not be alone in expressing that view.

Senator Heflin, did you have anything you wanted to raise at this point?

Senator HEFLIN. I would like just briefly ask a few questions, but first let me say that I appreciate the fact that I, as an alumnus of this committee, can return. I went off about two years ago, and I haven't overused the privilege that has been granted to me, and I come back only occasionally.

Secondly, let me say that, Dr. Fletcher, I want to congratulate you on doing an outstanding job, taking over NASA at the time. In my judgment you have restored confidence in the space program and you have restored the team spirit that I think is so important.

I see a much more enhanced spirit among the people who work with NASA, and I think you should be complimented for your work.

I also am considering, looking down the road, and in earlier testimony you indicated that there would be launch requirements for the space station, the shuttle system would certainly have plenty to do, and that there probably would be a need for a complementary launch vehicle in the future.

We are faced with a number of problems. I see Senator Hollings here. Senator Hollings is a great supporter of the space program, but he is also one of the authors of Gramm-Rudman-Hollings, and we have to look long range for reducing deficits.

Space has been taken care of in the budget this last year real well, and I hope in the future will be. There are other programs that are going to be somewhat in competition that may well call for some long-range planning where they can dove-tail together.

And there can be competition that can arise. We already know in regards to heavy lift vehicles that there can be a problem. The Air Force, for example, wants to take over.

There is no expertise in the Air Force relative to the matter of propulsion, heavy lift, that sort of thing, so I think these things have to be planned. There will certainly be requirements for heavy lift relative to the Star Wars or the Strategic Defense Initiative, and I am a supporter. Senator Hollings is a supporter of the Strategic Defense Initiative.

I can't say that about everybody here, but if I had to say that the space station and its needs to the future were to be on a gambling ratio, I would say that there is 95 percent surety that the space station and the space program will go on.

I can't give that high a percentage, and it would probably be much less than that, for maybe SDI in the long run. I intend to support it as long as the research shows that it is available. And the same is true in other matters.

So I hope that as we move forward in planning in the long range that NASA and the nation as a whole look at it, and my hope is that we won't get off into something that will cost a lot more money, that will have to require the development of expertise and other matters that could arise.

So I realize at this stage it is early, but I did want to make that statement, and I think that we ought to be very much alerted to that.

And I would say that the Hollings influence in the Gramm-Rudman is just as strong as the Hollings influence in regards to space. That is all I have.

The CHAIRMAN. Could I make just one comment?

Senator RIEGLE. Yes, Senator Hollings.

The CHAIRMAN. Gramm-Rudman-Hollings provides for revenue, Senator. President Ronald Reagan signed that into law. It never would have been Gramm-Rudman-Hollings save for that and several other provisions that I inserted in there.

As an old time governor, some of us here believe, we always must pay our bills. In fact, everybody is running around talking about competitiveness and getting new industry and more jobs, but the first requirement is to pay the bills.

Industry is not going to come to a deficit-type state. The national government is no different. What we are really saying is we need this in space. We need SDI and certain things in defense. We need other things in education.

And we have to show a willingness to pay for them. That is all it is. Gramm-Rudman-Hollings doesn't say eliminate the government. It just says pay the bills.

Thank you.

Senator RIEGLE. We are always happy to get new insight on Gramm-Rudman-Hollings, and most particularly from Senator Hollings.

Senator HEFLIN. My remarks were largely just to show that he was a fiscal conservative.

Senator RIEGLE. We all are.

We have come through this round, and I think it is very important that we go to the next panel just as quickly as we can, which is the next level of technical know-how and application within NASA.

Senator Pressler has asked to raise one more question which he feels he can do briefly. So I will call on him to do that.

Is everybody else of a mind to, once that is completed, to move on to the next panel? Very good.

Senator Pressler?

Senator PRESSLER. I just wanted to ask Dr. Fletcher one final question about the February 1988 launch date. Is that a realistic date for the next launch?

I know the NRC panel overseeing NASA's critical review and hazard analysis report said there may not be enough time to incorporate any substantial design changes in time, that may be indicated by the outcome of the critical items review and hazard analysis, if NASA expects to meet its schedule of a February 1988 launch.

Do you agree with this assessment and are you already aware of any critical design changes that could not be incorporated in time for a February 1988 launch?

Dr. FLETCHER. Senator Pressler, I am very glad you asked that question because it gives Admiral Truly a chance to say something he wanted to make clear at the close of this session, but let me just answer for myself.

That February date is a target date. We have to have internal guidelines. We have no reason to believe that that date will slip.

However, it will slip and we will fly when we are ready to fly, regardless of when that is. When it is safe, we will go. When it is not safe, we will delay, but, Admiral, you have your chance now.

Admiral TRULY. I did want to, before the technical people come on after me, I wanted to have the opportunity to assure you publicly, and in doing so to say one more time out loud that February 18, 1988 is not a magic date.

We will not fly this system until we are safe and ready, but we do have thousands of people that are working on this problem nationally at contractors and at centers and in our oversight committees and in Washington.

And these people need a target. And so we set a schedule. And when we have a disconnect in that schedule, a piece of hardware that needs to be at the Cape at the certain time, and the Cape needs it a month earlier, the way we work these problems is, is we identify those disconnects and we put money and people on those problems, and that is how we eventually get to the schedule.

There are threats to it. We may not make it. However, we have had February 1988 as a target date now since last June. We have used this approach during this time. We have discussed it openly with all of the people that are looking at what we are doing.

And today within the program, from Arnie throughout the other parts of the program, and also with the center directors whose responsibility it is for the technical excellence of the projects that are at their centers, as long as we can continue working these disconnects and keep to that schedule, it is good for the system to have it, but we are not going to fly this system until we are ready and until it is safe.

Senator RIEGLE. We thank you for that response.

Senator Danforth has come in. As I mentioned earlier, the Senate Finance Committee has been meeting at the same time. So several of us have had to be in two places at once. Senator Bentsen had that problem and Senator Danforth does as well.

We are delighted to have you here. Do you have a comment that you would like to make at this time?

Senator DANFORTH. Mr. Chairman, I don't have a comment. I appreciate your holding the hearings. I think that you have shown your characteristic diligence in this issue where you have taken such a keen interest in for some time by scheduling this hearing early in the Congress, and I commend you for it.

I am sorry I am late.

Senator RIEGLE. Thank you very much. We are delighted to have you. If there are any questions that you want to have us have answered for the record, please let us know.

Senator Gore has asked to raise one other issue and then we will conclude and go to the next panel.

Senator Gore?

Senator GORE. One brief question, a follow-on to Senator Adams' questions.

You were talking about the reusable components of the shuttle system. I am wondering about your reaction to the National Research Council's finding that the baseline redesign of the case joint does not allow for reworking or for inspection of the hidden surfaces of the case joint and that, as a result, this problem may prohibit the reuse of the casings which, of course, would dramatically change the economics of the shuttle.

This is what the National Research Council has said in its January 15 report. And I am interested in your reaction.

Dr. FLETCHER. That is a new one on me. Arnie?

Mr. ALDRICH. That is a concern with that particular feature of the redesign that the NASA team has addressed in the baselining of the design and, as Admiral Truly points out, we will be continuing to work each of these questions with the National Research Council in detail.

We think we have plans in place that will allow us to understand the cleanliness and goodness for reflight of that area, but it is a complex area and does require additional study.

Senator GORE. Thank you, Mr. Chairman.

Senator RIEGLE. Well, let's just pursue that for a second. Is that a new problem or was that a problem that we had previously in terms of the difficulty of the inspections in those areas?

Mr. ALDRICH. It is a characteristic of the new design that will be described. It is shown on this sketch in front of you.

Senator RIEGLE. I think it is very important that Mr. Thompson, who is about to come to the table, address that issue in detail as he goes through this design change.

Let me thank all of you for coming. Let me ask now that this panel leave us, and we thank you for your testimony, and let us now have the next panel come forward, Mr. Thompson, Mr. Marshall, Mr. Thomas, Mr. Garrison, Mr. Dorsey, and Mr. McDonald.

Senator RIEGLE. Can I ask that the people find seats and that we get whatever materials we need to have up front here for display purposes?

Mr. McDonald, if you can't find a seat up there we will give you one up here.

Let me welcome this panel. Mr. Thompson, will you be the person who speaks for this panel?

STATEMENT OF J.R. THOMPSON, DIRECTOR, MARSHALL SPACE FLIGHT CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, ACCOMPANIED BY ARNIE ALDRICH, DIRECTOR, NATIONAL SPACE TRANSPORTATION SYSTEM; BOB MARSHALL, SHUTTLE PROJECTS DIRECTOR, MARSHALL SPACE FLIGHT CENTER; JOHN THOMAS, MANAGER, SOLID ROCKET MOTOR DESIGN TEAM; U.E. GARRISON, PRESIDENT, MORTON THIOKOL AEROSPACE GROUP, MORTON THIOKOL; EDWARD G. DORSEY, VICE PRESIDENT AND GENERAL MANAGER, WASATCH DIVISION; AND ALAN J. McDONALD, DIRECTOR, SOLID ROCKET MOTOR VERIFICATION TASK FORCE

Mr. THOMPSON. Yes, sir.

Senator RIEGLE. Would you take a moment and introduce the members of this part of the team? Just go across the table and indicate who they are.

If I am not mistaken, almost everybody on this list is new to the assignments that they hold, am I correct in that?

Mr. THOMPSON. On my right is Arnie Aldrich, who was here just a few moments ago as the Director of the shuttle program and reporting directly to Dick Truly.

To my extreme right is John Thomas, who heads the redesign team at the Marshall Space Flight Center.

On my immediate left is Bob Marshall, who heads up the shuttle propulsion work at Marshall, but reports to Level II, Dick Kohrs, within the shuttle program.

Ed Garrison, the President of Morton Thiokol, of the Aerospace Group, is to Bob's left. And then Ed Dorsey the Vice President and General Manager out at Thiokol, and then Alan McDonald, down at the end of the table, heads up the Engineering and Verification Task Force at Thiokol as we get back into the redesign.

Senator RIEGLE. I will have you go ahead and make whatever summary comment that you wish to make on behalf of the group that you were speaking for, and then we will move on into questions.

Mr. THOMPSON. Very good. Mr. Chairman and distinguished members of the subcommittee, I and my colleagues welcome the opportunity to appear before you today to discuss actions that are being taken by the Marshall Space Flight Center and our contractors to return the shuttle to flight and do it in a safe way.

I have submitted a prepared statement, and I would like to summarize several of the key points at this time and give you also a brief status on where we stand as we prepare our propulsion systems for flight.

Next week marks one year since our tragic accident. I can assure you that all of the men and women of the Marshall Space Flight Center and our total contractor work force are rededicating themselves and have made a commitment to getting the space program back on the right track and, also, to keep it there once we become flying again.

We are following the leadership here at NASA Headquarters, and we are aggressively implementing the recommendations of the Rogers Commission. And, I might add, that we totally support their report.

At Marshall we have made several significant organizational changes that I think I have highlighted in my statement. I would like to touch on a few of the key.

Our SR&QA organization is now headed by Alex McCool, and he reports directly to me.

We have consolidated our propulsion work in one laboratory under very strong and effective leadership, and that is under John McCarty.

We have assigned a chief engineer for all of our propulsion activity at the Marshall Space Flight Center, and that individual is Judd Lovingood.

The manager of our Shuttle Projects Office, Bob Marshall, now reports directly to Dick Kohrs at Level II located at JSC.

We have also had a number of personnel changes. I believe that we have got the right people in the right jobs. They are very experienced and very dedicated.

I would mention one, Jim Odom, who heads up our science and engineering directorate. He is an excellent engineer and has a track record as being one of the best managers throughout all of NASA.

And I am personally committed to addressing the communication issues that were brought up in the Rogers Commission report, not only within the Marshall Space Flight Center, but as we look outward.

To me that is my number 1 priority. When I fix that, I think other good things will follow.

Let me make a few comments now about our overall recovery status in the shuttle and specifically in propulsion.

In general I think it is going quite well. The propulsion systems are our most critical systems. We are making a large number of changes. They are all mandatory before we return to flight.

That primarily is focused in two areas, our solid rocket motor, of course, where we had the failure on 51-L, and our space shuttle main engine.

I would like to make a few general comments on the progress in our main engine, and then more detailed comments on our solid rocket motor, and then we can certainly entertain any questions that you have in even more detail.

In the space shuttle main engine our primary thrust is improving our margins of safety and specifically knowing where these margins are and are not. We certainly have a very rigorous analysis and always have had, but now we are embarking on a very aggressive ground test program which will be the proof of the pudding.

Certain areas we are interested in are turbine blades, our turbo pump bearings, and where we have life-limited components that are caused by fatigue stresses, both mechanical and thermal.

Our progress has been excellent. I can only report to you that over the last six weeks we have conducted the equivalent of some six plus missions' worth of main engine firings. We have done this with no new safety issues, no old safety issues. Our data looks excellent, and the inspections of the hardware are coming along quite well.

We have got a long way to go, and over the next several quarters we are going to be pushing the engines in these propulsion systems to the limit, to the point of failure.

I only mention this because I believe it sets the pace for the same kind of testing that we are going to conduct and be embarking on in our solid rocket motor program.

Let me turn now to that. The redesign activity, I believe, is progressing about as I expected. We are making good progress. It is taking longer than I would like to see in getting to our first all up flight motor, which is DM-8.

That is being paced by tooling for our internal motor insulation. I conducted a very extensive review at Thiokol over this past weekend with senior managers and engineers from the Marshall Space Flight Center as well as our management of our SR&QA organization, and Thiokol was equally well represented.

Our primary focus was on DM-8, our first all up flight motor. That will drive the design, the tooling, the manufacturing, all of the processes we used as well as our quality control and inspections.

The reason I want to focus there, and we are driving that schedule, we won't make the back end of the schedule, meaning the flight end, unless we can show progress on the front end, and I am very interested in getting away from the charts and the design drawings, and the design drawings, and getting into the test area.

Testing again will be very extensive. It started not now, but back during the middle of the summer in the investigation. We have conducted a large number of laboratory tests. We are now to the point, as Dr. Fletcher mentioned, of testing our joint environmental simulator of the redesigned joint.

We will be doing that very extensively over the next several months. Before we get to our redesigned motor, the all up firings, we will test the field joint that failed individually some 20 times in the redesigned configuration.

We will be testing the case-to-nozzle joint, which is very similar, over and above the all up flight motor some 11 times. Again, the real proof of the pudding is going to start at mid-summer, toward the tail-end of July, with DM-8. That will be followed by DM-9, QM-6 and QM-7 and QM-8.

Those are all all up motors to the redesign configuration. We have as a requirement that we successfully conduct DM-8, DM-9, QM-6 and QM-7 before we fly again. That means no hitches in four all up motors. We will follow that, as Dick Truly indicated earlier, with the hot motor case test condition, which is QM-8.

We feel that if the prior four motors are successful across the board in all respects, then we can fire QM-8 after the first launch. That is our current opinion.

A lot is going to depend on our test program. I believe it has got to be very aggressive. It is going to be very aggressive and we have a lot of eyes looking at it.

I personally believe the launch date is going to fall out, and it is going to be dictated as a result of the progress we make in our test program, and that is why I am putting a lot of priority——

Senator RIEGLE. Excuse me. When say fall out, do you mean get pushed further out in time?

Mr. THOMPSON. No, sir. I believe right now we are on a track to make it, but it is going to fall out of the results of our test program.

If our test program is as successful as I believe it will be, because of all of the eyes we have got inside of Marshall, within NASA and outside of NASA looking at this joint, and other areas, I can think we have got a good shot at making it.

Senator RIEGLE. You said four firings without any hitches?

Mr. THOMPSON. That's correct.

Senator RIEGLE. If there are any hitches, or if you have any unsettled questions in your own mind about this thing, and anybody pushes you to go ahead, how would you respond to that?

Mr. THOMPSON. We will stop and fix it. Any problem, that is going to be our reaction, we will stop and fix it.

Senator RIEGLE. And if somebody tries to push you past that point?

Mr. THOMPSON. We will stop.

Senator RIEGLE. You will just stop?

Mr. THOMPSON. Yes, sir, we will stop.

Senator RIEGLE. I would hope as well that you would let us know if that happens because we can't have that situation arise.

Mr. THOMPSON. I certainly agree with your point, and we will proceed in a way I think that is consistent with the thrust of the committee.

I know very deeply within NASA we feel that way now.

Senator RIEGLE. Please continue.

Mr. THOMPSON. I would like to make a few other points. Our project managers at Marshall will be making recommendations to Dick Kohrs and to Arnie, on up to Dick Truly, and I will be making them into Dick Truly, that we add to our program about two ground test motors per year to parallel our flight program to continue to push these motors to the limit so we know where the margins are and are not, as well as through ground test resolve any anomalies we see that come up in the flight program.

We have a number of key people now at Thiokol from our redesign team headed by John Thomas, numbers about 25, and over the next several weeks I believe we will be adding to that, specifically John personally, to again put more attention on DM-8, which I think is going to be the proof of all of the work that we have done now over the last half year in this redesign activity.

Let me just make two other points. These aren't the only problems we have got in the solid rocket booster. We had an aft skirt failure as we were testing the filament wound case.

We are going to be redesigning that. We are in the process of reanalyzing it now, but that is a mandatory fix before the next launch.

We also are relooking at some fasteners that have failed on our ET attach ring. In no way did these contribute to the 51-L accident. We are absolutely convinced of that, but it is a weakness now that we see in our analysis and through test, and we will be addressing those issues before we return to flight.

That concludes my comments, except I would like to add one thing, sir, and that deals with people. I primarily addressed hardware and schedules.

I see throughout NASA since my return they are highly motivated, not only within NASA, not only at Marshall, but throughout our contractor work force. I believe that they are totally dedicated to returning to flight getting back on a track and doing it in a safe way and, once we get there, keeping it on that track.

With that, sir, I would like to stop and entertain with my colleagues your questions.

[The statements follow:]

Statement

of

Mr. James R. Thompson, Jr.
Director, Marshall Space Flight Center

National Aeronautics and Space Administration

Mr. Chairman and distinguished Members of the Subcommittee:

I am pleased to appear before you today to discuss the actions being taken by the Marshall Space Flight Center (MSFC) in support of the NASA program to return the Shuttle safely to flight. I want to assure the Subcommittee that each and every person in the work force of the Marshall Center is deeply committed to the success of that effort.

Next Wednesday, January 28, marks the first anniversary of the tragic Challenger accident. We shall always remember the sacrifice made by the Challenger Crew and their families, and upon that memory have rededicated our efforts to minimize the risks that are inherent in space exploration.

I want to thank the Subcommittee for its confidence in, and support of, the Nation's space program, and I want you to know that we at the Marshall Space Flight Center are pledged to do our very best to be deserving of that support and confidence.

During the brief time I have served as Director of the Marshall Center, it has been evident to me that the team spirit, which has always been characteristic of the Marshall Center, is alive and well. That spirit has been manifested in the diligent efforts of our people as the Center has responded to the leadership of Dr. Fletcher, Mr. Myers and Admiral Truly in implementing the recommendations outlined in the report of the Presidential Commission on the Space Shuttle Challenger Accident. It is our plan, in following the Administration's lead, to implement not only the substance of that report, but also the spirit, in all the actions we are taking in support of the Shuttle Program recovery efforts.

The specific actions that I will discuss with you today include organizational changes and management policy changes implemented at the Marshall Center; the activities underway to redesign the Solid Rocket Motor (SRM); and a brief update on the actions being taken to assess alternate SRM designs and the actions being taken relative to the other propulsion elements of the Shuttle under the management responsibility of MSFC.

ORGANIZATION AND MANAGEMENT POLICY CHANGES

A number of organizational changes have been implemented at the Marshall Center to improve our operational effectiveness and strengthen our ability to meet the challenge of safely returning the Shuttle to flight status. All MSFC safety, reliability and quality assurance (SR&QA) activities have been consolidated, strengthened, and placed under a single organization. This new organization, the Safety, Reliability and Quality Assurance Office, reports directly to the Center Director. The office represents a consolidation of the MSFC Safety Office, and two SR&QA elements of the Science and Engineering Directorate--the Reliability and Quality Assurance Office, and an organizational element of the Systems Analysis and Integration Laboratory. The capability of the new SR&QA Office has also been strengthened by the addition of more civil service personnel, some with experienced leadership in SR&QA functions and others with significant journeyman experience in various elements of SR&QA. In addition Col. Charles Bolden has been assigned by the Astronaut Office to the MSFC SR&QA Office to assist with flight safety and serve as a liaison for the two organizations. This increased staffing level will provide for enhanced leadership, management and performance of all SR&QA functions, including the acquisition, processing, and analysis of performance, anomaly and trend data.

In addition to increasing the number of civil service personnel, an experienced SR&QA contractor is being utilized to provide additional SR&QA support to the Center. As an interim measure, this support is being provided through the existing Johnson Space Center (JSC) SR&QA contract. This effort is being applied in the areas of Failure Modes and Effects Analysis (FMEA), Critical Items Lists (CIL's), and Hazard Analyses for the Space Shuttle. The Marshall Center has also initiated procurement action which will result in the competitive selection of an SR&QA contractor for all MSFC projects in Calendar Year 1988.

Significant organizational changes have been made in the Science and Engineering Directorate which is the technical backbone of the Marshall Space Flight Center. These changes were implemented to place greater focus and emphasis on our propulsion system efforts. The previous Office of the Associate Director for Engineering has been divided into two separate elements, the Associate Director for Space Systems and the Associate Director for Propulsion Systems. Also, propulsion systems functions which were previously assigned within several of the Science and Engineering Laboratories have been consolidated under the newly established Propulsion Laboratory.

In order to place special emphasis on the SRM redesign activity, a dedicated SRM Design Team was established in March 1986. This team, headed by a highly respected senior manager, Mr. John Thomas, is staffed by experienced design, analytical, manufacturing, and test personnel, not only from Marshall but from several other NASA Centers. Other key team staff members include systems safety personnel and flight crew members. The team also is being supported by contractor engineers and scientists drawn from a wide spectrum of recognized industrial firms, ranging from large aerospace organizations to oil field sealing experts to small specialized analytical groups. This team has utilized the full resources of the Center to conceive designs, manufacture hardware, and test the features of many design concepts and materials. They have conducted literally hundreds of tests in support of the evaluation of design alternatives. The design team has worked independently, but in concert with Morton Thiokol, Inc. (MTI), to redesign the SRM field joint and certain other assemblies deemed appropriate to correct difficulties encountered in Shuttle flights and to enhance reliability. The design team and MTI have planned a thorough and comprehensive test program, and substantial testing has already been accomplished. John Thomas' team, accompanied by MTI, interacts directly and frequently with the National Research Council (NRC) Panel which is overviewing the SRM design activity.

Some adjustments have also been made in the MSFC Shuttle Projects Office to place increased emphasis on the reassessment activity, analysis, test, production, and operational aspects of the Shuttle Program. The Flight Engine and the Development Engine Project Offices were consolidated into the Space Shuttle Main Engine Projects Office. Additional responsibility was assigned to this office for the alternate turbopump development and main propulsion testing. The Solid Rocket Booster Project Office was expanded to include a sub-element for the management of the Solid Rocket Motor alternate source study. The business management, project control, and integration functions were consolidated into the Systems Management and Integration Office.

The Marshall Center has also participated in the development of and is fully supporting the restructure of the agency Shuttle Program management structure. This recent change in the agency's Shuttle management retained the Shuttle Projects Manager's Office at the Marshall Space Flight Center with MSFC responsible for the External Tank, Space Shuttle Main Engine, and the Solid Rocket Booster. This office has a clear line of responsibility to the Level II Manager who is the Deputy Director of the NSTS Program. The Manager's responsibilities are to manage the three MSFC Shuttle elements for the Shuttle Program and make the decisions/recommendations that are necessary for hardware and operational flight, and to provide the appropriate MSFC interface with the Level II Manager.

The budget function at the Center continues to report directly to the NSTS Program Director in the Office of Space Flight at NASA Headquarters. The MSFC Shuttle Projects Manager will, for the Center, define the project requirements and the Center will include these in the Center budget submission to Headquarters. These budget requirements will also be addressed in parallel with the center management through the Level II and Level I Shuttle management structure. I believe this line of management for the program and path for submission of the program budget is acceptable and will help to improve the execution of the program decisions.

In addition to the organizational changes which I have mentioned, a number of changes in management policy and practices have been put in place based on a review of the Presidential Commission Report and as a part of an overall effort to provide the best possible management to the Marshall Space Flight Center and the agency as a whole. In many cases, specific steps have been taken to improve communications both within and external to the Center.

Management policy and practice changes include: initiation of more frequent meetings with major project managers; expanded attendance at staff meetings; increased impromptu visits to Center elements by the Director; encouragement of more open communications at all levels; initiation of more employee-oriented events; facilitating improved access to Center representatives by the press; increased acceptance by the Center Director of press requests for interviews and speaking engagements; increased interchange with universities; encouraging the assignment of MSFC employees to NASA Headquarters for extended TDY; participation in routine intercenter coordination meetings with other center directors; initiating exchange visits with other centers; involvement of MSFC support contractor personnel in functions in which they had not previously been involved; initiating a Marshall "Management Council" composed of Center managers to provide for discussion of and resolution of key issues facing the Center; and enhanced communications with employee unions.

SOLID ROCKET MOTOR REDESIGN

The Presidential Commission's first recommendation concerned the design of the SRM. The Commission recommended that the SRM joint and seal be redesigned to eliminate the inadequacies of the original design, or that a new design be developed to eliminate the joints. In keeping with that recommendation and the agency's objectives, changes are being made in the design of the case joints, the nozzle joints, nozzle parts, the igniter, the propellant configuration, and the ground support equipment. Various NASA Centers (LaRC, LeRC, JPL, JSC and KSC) along with the USAF Rocket Propulsion Laboratory and the U.S. Army Missile Command are participating with MSFC in the redesign effort. The progress made to date in these areas is very encouraging. The requirements, design changes, and recertification plans have been thoroughly reviewed within the agency by the SRM Design Review Committee and by the NRC Panel for the Technical Evaluation of the Redesign of the Space Shuttle Solid Rocket Booster.

The criteria for redesigning the SRM was solidified by a formal Project Requirements Review in August 1986. The primary redesigned configuration was confirmed by a formal Preliminary Design Review in October 1986. Seven review sessions have been held with the NRC panel. Four review sessions were held with the SRM Design Review Committee. After very thorough consideration and study of vertical static test, the determination has been made that testing in a horizontal mode is the superior test orientation. A second test stand has been initiated to assure schedule accomplishment for the program and to introduce external loads dynamically to the motor during static test. The comprehensive test program includes use of these and other new subscale and full size test stands located at both MTI and Marshall. At MTI, a new test stand, the Joint Environment Simulator (JES), has been constructed and is in operation. Three full size case segments, which include two field joints, are placed in the JES for extensive short duration hot fire environmental and functional testing. The JES can accurately simulate actual motor pressure conditions during ignition. Another new test stand, the Nozzle Joint Environmental Simulator, is operating to perform similar type testing on the case-to-nozzle joint. Construction is just beginning at Marshall on the Transient Pressure Test Article test stand for first use in the late spring. This stand will test the motor joints under environmental and dynamic load conditions. The total test plan calls for these major tests along with five full-scale static tests and a thorough full scale static load test to 140 percent of the design limit loads. The static load test will be conducted in an existing test stand at Marshall. Many other smaller tests are planned and underway along with extensive analyses--all of which go toward overall motor certification.

Other significant activities and accomplishments include the continued monitoring of the Titan Failure Analyses Program progress for implications into the SRM design--special attention being devoted to process verification and nondestructive test methods for which the Associate Administrator for SR&QA has formed a special panel to assure that technological advancement is considered; involving the solid rocket propulsion industry in the redesign program through soliciting critiques of the primary joint design, development of backup joint design proposals, and development of new and original joint proposals; and fabricating test hardware of the newly designed joint configuration.

Figure 1 is an illustration depicting both the old and new configurations of the field joint. The new design eliminates all the factors contributing to the Challenger accident. A capture feature is added to essentially remove seal gapping. A heater is incorporated to eliminate environmental influence. O-rings and their grooves are larger to more closely adhere to industry standards. A third O-ring is included in the capture feature to permit proper O-ring positioning. The variable putty has been discarded in favor of a fully sealed insulation that is principally like the factory joint. Also, we are working diligently to obtain a more resilient O-ring material. Substantial subscale and full size tests on this joint configuration are very encouraging. These tests have shown that assembly can be repeatedly accomplished without any deterioration, that the insulation does not leak hot gas even if not bonded, and that gapping is so small that any candidate O-ring material, even the old fluorocarbon material, can remain sealed with a 200 percent factor even with two of the three O-rings missing.

We are confident that the new joint will resolve the Challenger problem, and a comprehensive test and analysis program is underway that will fully reinforce or dispel our confidence.

STATUS OF SOLID ROCKET MOTOR ALTERNATE DESIGNS

The Center is assessing alternate designs for the Solid Rocket Motor. Activity is underway to evaluate the five solid rocket motor conceptual design proposals for Block II to support the Administrator's commitment to assess the merits of an alternate design by March 31, 1987.

The objective, which is to identify an SRM design concept that may offer performance and/or reliability and safety margin improvements over the Redesign Team baseline configuration, also involves the definition of corresponding development and verification testing, cost and schedule requirements for implementation.

A formal plan is in effect for the evaluations which will encompass conceptual SRM design evaluations, contractor capability assessments, and cost and schedule projections. A full review of concepts for compliance with the Contract End Item Specification and assessment of potential performance and/or reliability and safety margin improvements will be accomplished.

Design concepts to be evaluated were submitted by Aerojet Strategic Propulsion Company; Morton Thiokol, Incorporated; Atlantic Research Corporation; United Technology Corporation; and Hercules, Incorporated.

REVIEW OF PROPULSION SYSTEM ELEMENTS

During the down time for the redesign of the SRM, the Center is undertaking an extensive review of the design and verification of all Shuttle elements for which it is responsible, and is accomplishing substantial testing of the Space Shuttle Main Engine (SSME). This testing is addressing certification of changes incorporated for the resumption of flight. In addition, tests are exploring the life limits of hardware and operational limits of defined redlines. It is the intent of the margin tests to explore the failure point of the "weak link" in the engine system. The reviews are addressing the measured flight environment and comparing this environment to the design requirements for each Shuttle element. A Design Certification Review (DCR) will be accomplished for all items to assure that the design complies with the requirements and that an adequate qualification test program has verified the hardware for flight.

Failure Mode and Effects Analyses for each element is being redone utilizing in-house resources, prime contractors, and independent contractors to assure that all failure modes and critical items are identified and that retention rationale is developed. Parallel to the FMEA/CIL activities, the Center and the prime contractors are re-evaluating the hazard analysis for each of the flight elements. The MSFC Safety, Reliability and Quality Assurance Office, supported by its SR&QA contractor, is participating in the hazard analysis assessment.

With the reviews mentioned, new criticality items and requirements will be identified and are required to be incorporated in the Kennedy Space Center (KSC) launch processing documentation. This documentation, the Operations Maintenance Requirements Specification Documents (OMRSD) and Operation Maintenance Instructions (OMI), are being reviewed with KSC to assure that these new requirements are incorporated. These review activities are substantial for all the Shuttle elements and I believe they will add to the assurance that requirements are clearly defined and understood for the systems.

One additional area to be addressed is a concern that has been expressed by some that existing contract incentives used by NASA do not adequately address or promote safety and quality concerns -- with most emphasis being placed on meeting cost and schedule requirements. All of our contracts are being re-examined to ensure that we have the correct form of contract and that proper emphasis is being placed on the SR&QA functions. Membership of the Performance Evaluation Board is being amended to evaluate a representative from the SR&QA organization.

In summary, our efforts to date in strengthening our management structure, improving our management practices, redesigning the SRM, investigating new designs, and reviewing other propulsion system components for safety and design adequacy are progressing satisfactorily. Our schedule is tight, but with continued hard work by our NASA and contractor team, we believe that it is achievable.

That completes my prepared statement, I would be pleased to answer any questions you may have.

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FIELD JOINT METAL AND INSULATION

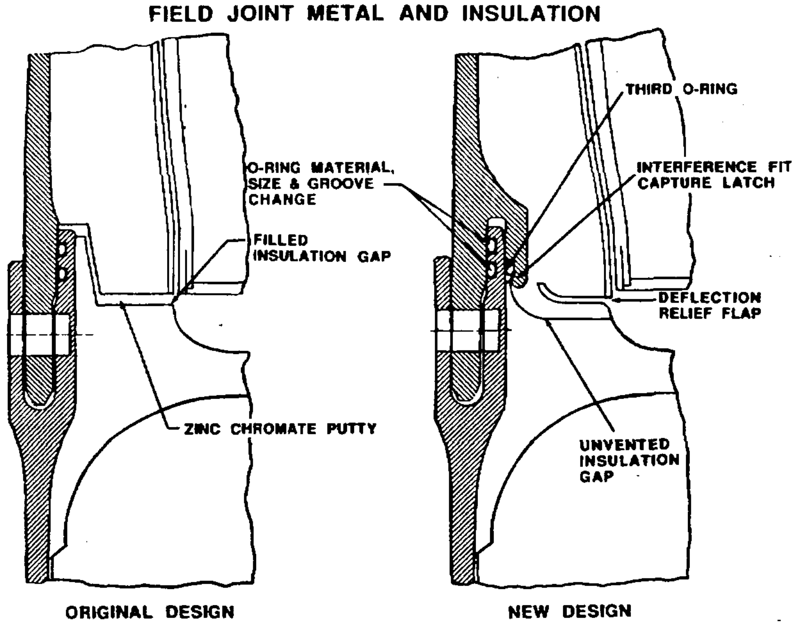


Figure 1

STATEMENT OF U. EDWIN GARRISON, PRESIDENT, AEROSPACE GROUP, MORTON THIOKOL, INC.

Mr. Chairman and distinguished members of the Committee, I am Ed Garrison, President of the Aerospace Group of Morton Thiokol, Inc. located in Ogden, Utah. I am pleased to appear before this Committee to offer testimony regarding the solid rocket motor redesign, development and test program to return the Space Shuttle safely to flight. With me today are Mr. Edward G. Dorsey, Vice President and General Manager of our Space Division, and Mr. Allan J. McDonald, Director, Redesigned Solid Rocket Motor Development.

Speaking personally, for our Space Division—indeed, for all Morton Thiokol employees—I want to assure this Committee that we are totally committed to those efforts required for a safe resumption of Space Shuttle flights. We are keenly aware of the tragic events of approximately one year ago. We are determined to accomplish successfully a redesign and test program which fully supports the objectives and requirements of this distinguished committee and of NASA, and one which fulfills the national interests of an active and productive space flight program.

Mr. Chairman, with your permission, today I will discuss organizational and management changes which I have directed within the Morton Thiokol Aerospace Group. Also, I would like to summarize the detailed report which we have submitted to the Committee for the record, which discusses the solid rocket motor redesign and test work now underway; the parallel and alternate design activities; and program accomplishments.

ORGANIZATION AND MANAGEMENT

Shortly after the *Challenger* accident I completed a thorough review of our Space Shuttle organization and management structure. In March 1986, I directed a series of organizational changes. The objective of this reorganization was to bring together all necessary resources under Mr. Dorsey to accomplish the important work ahead. The Space Division now has these resources, which include a full range of technical, management, and manufacturing capabilities. It also consolidates all Space Division safety, reliability and quality assurance functions to assure a strong role for these disciplines in the redesign effort. Mr. Dorsey reports directly to me, and we are in daily communication on the program status.

THE REDESIGNED SOLID ROCKET MOTOR

Al McDonald is the Program Manager for the redesign. Under his direction the SRM field joint and its seals have been thoroughly analyzed and redesigned. The work has received numerous reviews by the Marshall Design Review Committee and by the National Research Council Panel. In the redesign, a capture feature has been added to the metal case joint to negate joint opening. A sealed insulation design has been introduced as well as a third O-ring which is followed by a metal-to-metal fit of the capture feature.

The redesign has a high degree of redundancy. Hot gas cannot reach the final seal unless it penetrates four separate barriers. The joint is designed to be safe even if it opened several times as much as we could anticipate under a worst case scenario. The joint redesign also includes heaters and a water barrier. I am confident that the on-going test program will prove this field joint redesign to be completely satisfactory.

In accordance with NASA's redesign objectives, we also completed a thorough assessment of all other aspects of the SRM design. This assessment has caused significant design changes in the nozzle and minor changes to the igniter and propellant configuration.

TEST PROGRAM

A comprehensive test program, including work from laboratory benches to full scale, full duration rocket motor static firings has been defined, coordinated with NASA, reviewed by the NRC, and it is well underway. Laboratory tests, material tests, and subscale motor firings are being used to verify that our design is sound. The major efforts now in progress will continue into six full scale, full duration static firings to test and verify the SRM redesign. Specialized new test stands are complete and in use at our facility for full scale, short duration static firings to test the field and nozzle joints.

Full scale, short duration tests and structural tests are being conducted at Marshall to supplement the program. We are also constructing a second test bay to assure schedule integrity and to provide capability for applying external dynamic loads on qualification motor firing.

PARALLEL AND CONTINGENCY DESIGNS

Parallel designs for the critical case joint areas are being carried along in development with the primary design so that the backup can be incorporated in the motor program if desired. There are also contingency designs which are pursued through concept definition in parallel with the primary and backup designs. Parallel and contingency designs are active for the most significant design areas—the field joint and case-to-nozzle joint.

PROGRAM ACCOMPLISHMENTS

Mr. Chairman, I can report that significant progress is being made on the Space Shuttle solid rocket motor redesign and test program. The preliminary Design Review for the baseline design was completed with NASA on October 10, 1986 and the information communicated to the NRC panel. Substantial testing has been conducted ranging from laboratory to subscale to full scale. To date, test results are verifying our design approach. Our efforts are being conducted to support a Space Shuttle flight in February 1988, but it is a tight schedule. Our basic and overriding goal is the safe return of the Shuttle to flight.

Thank you for the opportunity to make this statement, Mr. Chairman. We would be pleased to answer any questions you or the other members the Committee may have.

Senator RIEGLE. Thank you very much. We all have some questions.

Before I pose the first one, and I will tell you what that is so you can start thinking about it, I want you to walk us through this technical change so that we can understand how the new system is designed to work.

I gather that that is what is before us on this table. So I want to go to that in my first question.

Before I do, in terms of the team that you have introduced to us across the table here, and this will have a meaning to Senator Hollings as it does to me, I am particularly pleased to see Alan McDonald in this group.

I say that because those of us, and it includes most of us in the room that went through the events of a year ago, and unraveling that situation and finding out what the truth was, and looking at it squarely and deciding what we needed to do as a result of that, his help was critical in that effort, and his efforts to try to stop that launch for all of the reasons we now know were a very key part of what happened at that time.

And sometimes there is a tendency to kill the messenger when the messenger brings news that isn't happy, and that might even have happened, but it didn't happen here, and so Mr. McDonald is still part of this operation as he properly should be.

And I for one am very pleased that he is, and I know Senator Hollings feels the same way. So we are happy to see all of you at this table and have that particular feeling with respect to Mr. McDonald.

So, if I may now, let me ask you, Mr. Thompson, would you walk us through this new design approach and how and why you feel that this will solve this problem that we have had before?

Mr. THOMPSON. Yes, sir. What I would like to do is ask John Thomas, who heads up our redesign team, to do that for us, and then I will add to that.

Senator RIEGLE. Fine. Mr. Thomas?

Mr. THOMAS. Mr. Chairman, as you may recall, there were five potential problems or five potential factors contributing to the 51–L accident in the defective joint, defectively-designed joint.

This represents the new design joint, and I have a small model laying right here—this is the old one—that I can use, I think, to switch from one to the other to explain not only the problem, but what has been done to alleviate the problem.

The first condition or first factor contributing to the accident was the amount of gap opening that was caused by the so-called joint rotation, and that was the gap at this location between the two O-rings opening to such an extent that the cold O-rings could not track the gap and, therefore, opened the seal.

The second one of those contributing factors was then temperature. And the temperature affected the O-ring as I just described and, secondly, the temperature was a factor with respect to the potential of having ice in the joint, the ice having froze as a result of the lower temperature, and possibly, possibly I say, affecting the function of the O-ring to seal and do its job.

The third item was the squeeze that was put into these O-rings during the initial assembly and, that is, if this joint was very tight, that is, almost metal to metal, the O-rings were squeezed into the grooves, and by virtue of being cold they could not pop out as the joint rotated, nor, because they were pressed into the joint, could pressure get beneath them and actuate them in order to seal.

The remaining factor dealing with the accident was the so-called putty. And the putty was, it is not shown here, but the insulation, as you recall, is in this side of the joint. It must be separated at this point to allow the assembly and disassembly of the field joint, and that opening in the putty was filled with putty which performed in a variable manner.

And that variability was that we could not always tell if the putty was completely consistent or if there were holes caused by assembly blowing pressure back through that, which we refer to as back blowholes, or the leak check procedure.

Now, taking those in the order that I just listed them, I would like to tell you what we have done to the joint that leads us to believe that we have resolved those critical deficiencies.

The first is the gap rotation. In order to remove that gap rotation we have added the capture feature that is on the upper part of the cylinder. It has a slight interference fit in the assembly process that sets the distance between the tang and the O-rings at this point assuring that that opening is always known and that, with the application of pressure, it does not significantly change.

And in the new design the change is minute with respect to what it was during 51–L based on testing of actual hardware at a thousand PSI.

The next factor was the temperature. We have taken two courses to resolve the temperature conditions. The one is to add a heater, which will keep the O-rings at a comfortable 75 to 120 degree temperature, and we also set about in parallel to understand and define a new O-ring material that would be not so affected by low temperature.

Now, we have found three O-rings that are better than the O-rings that we flew on 51–L from a resiliency standpoint, but, as is typical, not all of that comes free. There is some detrimental effects of, for example, grease, on a couple of those different O-rings.

We think we know how to overcome that, but we have not reached that point yet. We have not reached the point that we must make a decision on the O-ring material to be put into DM-8.

However, we are confident that with the heaters even the old O-ring material will meet the stringent design requirements that we have on the joint and, that is, it must track this joint if the opening is twice as much as we think it is.

The next factor, subfactor, within the temperature, was the ice. And by adding the heater we have incorporated in that subassembly a weather seal that will prevent the possibility of rain water entering the joint from the outside in this location as long as the joints are assembled and exposed to the environment.

Lastly, the variability of the putty was questioned and, therefore, the putty has been eliminated. And instead the two insulation halves have been moved to be adjacent, and there is a seal, an adhesive, located at this point in order that O-rings will not be exposed to the hot gases of the motor unless there is a leak through this particular joint in the insulation.

Now, what we have set as a goal for ourself, and we think it is quite obtainable, is that we must demonstrate that even if the insulation seal leaks and leaks hot gas down to this point, that there will be no detrimental effects to the joint.

Now, we have tested a version of this under hot fire conditions in the joint environment simulator, which is full scale, full diameter, and it did not leak. And we have many more tests in the program that are going to verify that and, in fact, we will introduce known defects in not only this, but the O-rings, and test to be sure that we understand their performance.

Senator RIEGLE. When you say it didn't leak, you mean it didn't leak at all?

Mr. THOMAS. Did not leak at all. It did not allow pressure to reach the O-rings.

So those are fundamentally the design changes that we have added to the joint.

Senator RIEGLE. Let me just pause right there and ask you to remain there, and I will ask my colleagues if they have any specific questions that they would like to raise at this point with respect to this design or any aspect of it?

Mr. THOMAS. Mr. Chairman, could I add one thing?

Senator RIEGLE. Please.

Mr. THOMAS. I forgot to mention the third O-ring in the capture feature, which was added in order to allow us to apply pressure through this port, seal this cavity, and put this primary O-ring in its proper sealing position.

And that is the extent of the changes.

Senator RIEGLE. Senator Gore?

Senator GORE. Yes. Thank you very much, Mr. Chairman. I wanted to pursue the last question I asked Dr. Fletcher, and get you to point out on your diagram there the area of concern identified by the National Research Council that could lead to a prohibition on reuse of the casing.

Mr. THOMAS. Certainly.

Senator GORE. It is that bottom lip there?

Mr. THOMAS. You see this third O-ring groove right here? The apprehension is that with this moved, of course, in a disassembled fashion, that one can get the proper inspection equipment into this area to detect small corrosive pits or potential cracks that might reside here.

Now, I would like to add to that. You will notice that there is a slight shallowing of the O-ring groove in the front. We did that for a purpose, and that was to provide better visibility and better access back into this joint.

We believe that we need to further discuss this with the panel and show them precisely what we have in mind in terms of procedures and equipment, and see if then they still think that there might be some possibility that we will lose a case or two later on.

This is not, I would like to point out, is not a flight safety issue, but a reuse issue.

Senator GORE. Well, in other words, you believe that the National Research Council is wrong on that point, but you wish to engage them in discussions in order to resolve the difference of opinion about the point, is that what you are saying?

Mr. THOMAS. I think the Research Council, based on the information that we have presented to them thus far, has reason to be concerned with that.

I think with further dialogue that we can allay that concern.

Senator RIEGLE. We will have the chance to ask that question.

Senator Hollings?

The CHAIRMAN. Mr. Thomas, I am worried about being locked in by a contract with Morton Thiokol to a continuation of a faulty design.

I am only posing that question. We do this politically when we lost in 1984. Democrats all got together and said we had too many special interests and caucuses. So we immediately instituted another caucus and called ourselves a leadership caucus.

So we have some O-ring problems, and I know how you have been frustrated and even had gone to the automobile engineering show in November of 1985 to see whether automotive engineers had any ideas how to solve it.

So instead of two O-rings we get three, and then we put a heater on it and it sounds like the M–1, that we have got a good tank, but it can only go three miles to one gallon and then we have to chase it through the desert looking for a filling station.

My question, is, and maybe, Mr. Thompson, you can answer this question of contract renewal because our friend Mr. McDonald was there at Huntsville Wednesday and Thursday before this tragedy, and necessarily there was some interest no doubt that the contract be renewed, and maybe that is why they overturned Mr. McDonald at the Cape.

Now, are we just locked into this thing, because we have had good witnesses testify that it ought to be a monolith? You can put on another O-ring. Instead of having two, have three. Instead of calling it plastic or mastic, now you call it adhesive and, more particularly, now they say with the heater that the adhesive becomes detached as a result of the heater. So the heater, while it may solve one problem, creates another.

Let me begin at the beginning, Mr. Thompson. Are we locked in by a contract? Is Morton Thiokol going to make this thing regardless of the next three or four years or do you have alternative sources or not?

Mr. THOMPSON. What we are doing, we are carrying this as our baseline for the next flight. We do have several variations of that, but they are really quite minor in concept that we are carrying along as contingency.

We are in the process, as you are aware, of evaluating inputs for additional contractors as well as Thiokol as to what we really want to do over the longer haul. That is a very aggressive look within Marshall. We will be reporting back to Dr. Fletcher here within the month and then on up to the Congress shortly after that.

The CHAIRMAN. Well, in brief, is this design—you know we have been talking about the process flaw—is this design also fundamentally flawed? I am not an engineer, but I understand you run the best tests in the whole business and we are delighted to get you back in NASA. We appreciate your sacrifice because you do come at a sacrifice.

Am I to honor them because contractually I am locked in, you have to work with the contractors, so you go ahead and work with the contractor's design?

Mr. THOMPSON. Let me tell you how I feel about it. Obviously, the joint that we were flying and had designed has shortcomings. Clearly, looking back, we see that now in spades.

Having all of that data and going to school on that, I am quite confident that the design modifications in this joint are going to end up quite reliable. And I believe that we have got a test program structured to demonstrate that in spade. And if it is not, if that doesn't end up being the case, we will just have to stop and take further corrective action.

Now, the NRC has encouraged us to start thinking ahead now and develop even more contingencies to what what we are talking about. And I support that and I think we are going to be looking at that quite hard.

They are also very supportive of us taking a much broader look for the country and seeing where we want to go with these so-called Block II designs. We at Marshall are very much into that right now. And we have just got to develop our own thinking so we can go up and report it to Dr. Fletcher.

I am confident from what I see now on paper, on the design and from the simulator tests that we have run, I believe that we can lick this problem. It is a mechanical problem. I know we have got to address the cold. The heaters do sound like a kludge, I don't disagree with that, but I believe they are going to make it work if we can come up with the material that gives us the performance we want at the colder conditions and don't need the heaters.

I want to do that. I just want to make sure that we don't back into another problem associated with the grease, but I am confident in the path we are on but with everything we have got on the table, we need to be looking even further. I certainly support that. I think that is the general thrust of the NRC report. We will be working with them on that.

The CHAIRMAN. Where and when did you make that test when they had no leakage?

Mr. THOMAS. This was made, I believe it was back in November. It was made at Morton Thiokol on the so-called joint environment simulator.

The CHAIRMAN. Up in Utah?

Mr. THOMAS. Yes, sir.

The CHAIRMAN. Under what temperature condition?

Mr. THOMAS. 20 degrees.

The CHAIRMAN. Very good.

Senator RIEGLE. Could you describe that test to us? That was a stationary test?

Mr. THOMAS. The test is on a test facility that has the real flight motor aft dome. It has a segment, three segments in fact, that produces two field joints. And then it has a forward dome.

And in this dome is mounted an igniter and a small amount of propellent is spread throughout the motor. The joints are cooled down. The igniter is initiated. And the propellent produces the same pressure profile that one gets within the real solid rocket motor.

And it was, in fact, then a simulation of the first second of flight environment for that joint from an internal motor pressure viewpoint.

Senator RIEGLE. I think Senator Hollings has asked the key issue here in terms of whether or not we are just trying to fix something that, while we keep making repairs to it, the basic design is wrong. And there are people who argue that it is.

What I hear you saying, Mr. Thompson, is that you are just as interested in looking at whole new options and that that is going down a parallel track here and that your mind is open to a completely different design at some point. If our exploration of that option proves that that is what we ought to do, at some point we would bridge over into a brand new design; is that correct?

Mr. THOMPSON. That is correct, sir.

Senator RIEGLE. Now I want to understand the question that Senator Hollings raised with respect to the contractual relationship with Morton Thiokol. Are we locked in with the contract side of this thing and the money commitments in such a way that even if at some point we wanted to bridge over, there would be such a financial barrier to doing that that we might be dissuaded from doing it just for financial reasons.

Mr. THOMPSON. No, sir, we are not. As a part of the ongoing discussions we have got with Thiokol right now associated with the restructuring of the contract, it takes us out no longer than the early 1990s, which would be consistent with when we could bring, if indeed we chose to do that, some other design or some other contractor, phase them into the program.

So we are not locked in with our current contractor, nor with that design.

Senator RIEGLE. You used one other word, maybe you can recall what he said, but when he was describing in response to your question about reliability, will this work, the word you chose to use was not the fact that you are absolutely convinced or it will have to be that it is going to work, period. You used a somewhat more conditional word than that.

But in terms of taking the test results from this approach and deciding whether or not we are ready to go and put lives at risk on the strength of this thing working, what kind of safety parameter, what kind of degree of confidence do you feel that you have to have as the person in the end that is ready to say this is sufficient and we are ready to go?

Mr. THOMPSON. If in conducting these four all up motor tests, the last one of which will be under inflight load conditions that we are building into our new test stand, and that test will be conducted at the cold conditions, and all of that has been preceded by a simulator test where we build in flaws in our bonded joint, and basically those motor firings and the scale motor firings come out highly successful, then I will have great confidence in that joint, but I have been in engineering long enough to know that you have got to send these designs through a solid test program and I might be wrong.

Right now I have a lot of confidence in that joint from everything I have seen on paper, but now it has to go through the test wicket.

Senator RIEGLE. Senator Hollings, did you finish?

Senator GORE. Could I follow on the contract questions briefly? Is that appropriate?

Senator RIEGLE. Yes, and then we will go to Senator Kerry.

Senator GORE. If that is all right. The company made, the way I see it, the company made some mistakes in building this booster. Under the terms of the contract, is NASA going to pay them extra money to correct the mistakes they made?

Mr. THOMPSON. Let me answer that, but let me preface it by saying I am in the middle of discussions on this very issue now with some of the gentlemen seated at this table. Just in general, to correct the problem, Thiokol will receive no fee from my standpoint, no profit.

Senator GORE. I do not want to get into any area that will compromise contract negotiations, but I do want to express the concern that I think others share, because I have information that looks like they could be paid as much as $350 million for anomaly resolution and actions in response to the Rogers Commission identifying serious problems with the work, as it was originally done.

Is the work that the company is now performing for anomaly resolution being done under the existing contract and, thus, treated as old work or is the anomaly resolution new work and, hence, under a new contract?

Mr. THOMPSON. I think the basic difference there is under the terms of the contract, the costs we pay, profit and fee is a totally separate issue.

Senator GORE. Is it a new contract or an old contract?

Mr. THOMPSON. We are in the process now of restructuring that contract. We have no new contract in force now since the accident.

Senator GORE. But it is on a cost plus basis?

Mr. THOMPSON. It is a cost plus basis, that is correct.

Senator GORE. Any costs that they incur to correct mistakes that they made on the original work, you are obligated to pay?

Mr. THOMPSON. Yes, sir. Now, there are penalty provisions associated with the accident that I am sure you are aware of. And we are discussing these conditions with the contractor.

Senator GORE. Well, that is the kind of contract, I mean the nature of that contract should itself be an issue as you consider whether or not to compete, whether or not to open it up to others who would like a chance to offer better terms.

I am concerned, if they are going to end up making a great deal of money out of this entire thing by having a cost plus arrangement to do 300—well, I have here $290 million worth of anomaly resolution and corrective actions going to the company, out of a total of $798 million in the account, and $50 to $75 million for actions in response to the Rogers Commission out of $580 million in that account, so $350 to $365 million, under this contract, the way it is structured, for correcting what many believe were mistakes that never should have been made. So I hope you will take that into account.

Mr. THOMPSON. Certainly we will. As we go forward, we will certainly be mindful of your points.

Senator GORE. Thank you.

Senator RIEGLE. Senator Kerry.

Senator KERRY. The Rogers Commission specifically directed that the faulty motor rocket seal be changed, had to be changed. And they specifically set out two options for you.

Option Number 1, you can eliminate the joint, develop a design that is new. Option Number 2 is redesign the current joint. You have proceeded with Option Number 2. I would like to ask you, I sit here and I hear Senator Hollings, and I am just a lay person with this stuff too and not as versed as he is and some of the others on the committee, but I see us going from two rings to three and a little new putty here, redesign, whatever you want to call it.

What was the decision process that put you on the track of redesign rather than the alternative?

Mr. THOMPSON. I believe that we have taken both paths. We have embarked on this redesign. John has described that. That is the near term.

We have also solicited and now have received the input from five contractors, Thiokol plus four, that are quite innovative. And we are committed to exploring that.

Senator KERRY. I realize that. And that is precisely what concerns me. What you are basically saying to me is that you are willing to go along with this for the moment and place some astronauts on top of a rocket with something that may be less than what you are looking at that is out there that you haven't yet decided on.

Mr. THOMPSON. Only if the redesign—with our flight experience and looking backward—if that redesign passes the very rigorous test program, I believe we will be in a very safe position to fly. I contrast that with almost any new redesign. It hasn't failed yet because it hasn't been in the test stand. I worry about that. I don't want to jump from what we have got to something else.

I am very interested in some of the alternate proposals that have come forward. I am not in love with this redesign. It has got to pass a very rigorous test program before we fly it or we will just wait.

Senator KERRY. The one that went before it passed a very rigorous test program, did it not?

Mr. THOMPSON. Obviously not vigorous enough. That is looking back, and you are right. That got away from us. I believe there were signals during the flight program that, to be perfectly honest, we just missed.

We are very much attuned throughout NASA, certainly at the Marshall Space Flight Center, to that. And we know the criticality and the sensitivity of these propulsion systems.

Senator KERRY. Should we be thinking about and are you thinking about whether or not the standard here is to fly with something that is deemed to be safe according to the standards that you set up by which you make that judgment or should we be thinking about flying what is the safest possible design?

Mr. THOMPSON. The safest.

Senator KERRY. Are you convinced then that this is the safest design measured against the alternatives?

Mr. THOMPSON. Measured against what I know of the alternatives to date. I don't have a design on the alternative. I have got some ideas. They have got to go through a design. If, indeed, we embark on that track, a very vigorous test program.

We are well along on that with this design, here with this redesign, but we are not there yet. We still have got a lot to do. If we come up short, we are going to stop. If it goes through all of the wickets, with all of the eyes that we have got and others that are going to be looking at this thing, then I believe collectively we will be very confident in having a very safe flight program.

Whether that is the best rocket motor over the long haul from an economic standpoint or having too many eggs in one basket, is something we will be discussing with Dick Truly and Dr. Fletcher.

Senator KERRY. You haven't done the horizontal test of this yet; is that correct?

Mr. THOMPSON. Not of the new design. The all up motor will be DM-8, occurring in July of this year, to be followed by, on about two month centers, with these other all up certification motors.

Senator KERRY. How many of those tests under the current plan will there be?

Mr. THOMPSON. Five planned, all of the same configuration and design, four before the first flight. And we have got to have outstanding results. As I mentioned, over and above that we plan to introduce into the program two flight-configured ground test motors per year to parallel our flight program.

That would address one of the earlier comments that was brought up; that is, are we going to be testing on the ground motors that have been reused to make sure that we are appropriately addressing the reuse issue?

And on this concurrent parallel ground test program, we will be doing just that.

Senator KERRY. Will those tests be tested to a specific percentage or will they be tested until point of failure?

Mr. THOMPSON. They will be tested, it will be a nominal burn, but I suspect, and we have not designed these tests yet, but consistent with the kind of thing we are doing in our space shuttle main engine program, we will induce limiting loads to thermal extremes, probably with the most reused hardware to try to flush out any weaknesses that we have got either in the design or in our reuse program. That would be the intent of that parallel ground test program.

Senator KERRY. Thank you, Mr. Chairman.

Senator RIEGLE. Senator Pressler.

Senator PRESSLER. I guess I would address this to Mr. Garrison of the Morton Thiokol Company. As I questioned earlier, wasn't the new SRM joint designed by engineers from Morton Thiokol?

Mr. GARRISON. I think it was designed—it was a combination of effort between Morton Thiokol and NASA.

Senator PRESSLER. I am trying to get to some facts relating to the retention of engineers within NASA. What do you pay your engineers who worked on this, roughly speaking?

Mr. GARRISON. Senator, I don't have the exact data with me. I am not prepared to answer specifically, but I would say that the technical people working in the area would range from recent college graduates to people that are paid up to probably $50,000 or $60,000 a year.

Senator PRESSLER. $50,000 or $60,000 a year?

Mr. GARRISON. That is the top end. And they would have supervisory responsibilities and they would have longterm service or experience.

Senator PRESSLER. So you are paying about the same level of salaries to engineers as the government is paying?

Mr. GARRISON. I cannot answer that question. I do not know what the government is paying.

Mr. THOMPSON. Sir, let me take a shot at trying to put it on an apples-to-apples basis and then we can give you some detailed facts. It would be my judgment that at the nonsupervisory level but very senior design engineers working the details of that joint, that O-ring and that kind of thing, you are probably looking at a differential between any contractor, not just Morton Thiokol, aerospace and NASA of about 25 percent. That would be my guess, NASA being on the low end.

As you get up in management and supervision, then I think perhaps that starts to take it further apart. That would be my guess.

Senator PRESSLER. You people are very senior experienced businessmen, and one is the head of the company. As one approaches the upper management positions, how much is the difference?

Mr. THOMPSON. You know what I make. It is about $70,000.

Senator PRESSLER. What does your counterpart at Morton Thiokol make?

Mr. THOMPSON. I don't know.

Senator PRESSLER. I am trying to get a feel for what engineers make in the private sector, compared to their government counterparts.

Mr. GARRISON. I think you should not address that to Morton Thiokol, sir. I think you need to look at the aerospace industry as a whole. And that is what we do. We pay in accordance with what the competition pays and the going rates. We have to do that.

Senator PRESSLER. I am not criticizing you. You are the head of the company. How much do you pay your top engineers?

Mr. GARRISON. I gave you a range.

Senator PRESSLER. $50,000 to $60,000 a year?

Mr. GARRISON. I think that I would say engineering people are paid that much, yes.

Senator PRESSLER. So the people that design this, the very top people are paid $50,000 to $60,000 a year?

Mr. GARRISON. No, I said some of the top engineering people who are working on it are paid that. It depends on the other responsibilities. You have to take a composite.

We also have people, engineers on the drafting board running analyses, running computer programs that are very low paid. So it is not an easy question to answer, sir.

Senator PRESSLER. I am just trying to get a feel for a range of salaries.

Mr. GARRISON. I really do not know what the difference is. I don't have the advantage of knowing what NASA pays. And I have never looked at a composite in our company in that manner. We will try to supply that to you.

Senator PRESSLER. I am not criticizing. I am trying to get a feel for what our people are paid in government as opposed to in the private sector. Would you please submit the best information you have available. I am not interested in individuals' salaries by name, but categories.

I would like both of you to submit that for the record side by side.

Mr. GARRISON. We would be happy to do that.

[The following information was subsequently received for the record:]

Upon examination of the information provided by Morton-Thiokol, Inc., we find that only limited comparisons can be made between NASA Marshall Space Flight Center (MSFC) and Morton-Thiokol engineering positions. There are such significant differences in the organizational structure, scope of mission, and size of the two organizations that it is virtually impossible to make reliable comparisons.

This is especially true for supervisory and managerial levels. For example, we have compared the job responsibilities of the Director of the MSFC Science and Engineering Directorate, Mr. Jim Odom, to the Vice President, Space Engineering at Morton-Thiokol. Mr. Odom manages the work of 1,600 engineers involved in 20 to 25 projects including the solid rocket motor. The Morton-Thiokol Vice President manages less than 300 engineers on a smaller number of projects. Mr. Odom's job is shown in Table 1 with salary of $75,500. The Morton-Thiokol Vice President's job is shown on Table 2 with a salary of $82,014.

Tables 1 and 2 show the types and average salaries of engineering positions at Marshall Space Flight Center and Morton-Thiokol, respectively. Table 3 is a side-by side comparison of some nonsupervisory positions which appear reasonably comparable in terms of level of responsibility, complexity and experience.

TABLE 1.—NASA MARSHALL SPACE FLIGHT CENTER: ENGINEERING POSITIONS

Title	Grade	Average salary
Enineer trainee I	7	$23,866
Engineer trainee II	9	28,518
Engineer junior	11	31,370
Engineer	12	35,727
Engineer expert	13	44,407
Engineer team leader	14	50,338

TABLE 1.—NASA MARSHALL SPACE FLIGHT CENTER: ENGINEERING POSITIONS—Continued

Title	Grade	Average salary
Branch chief	14	56,125
Division chief	15	65,971
Laboratory director	SES-4	73,400
Director, science & engineering	SES-5	75,500
Solid rocket motor joint design:		
B. Powers (MSFC) 48,876		
R. Boisjoly (MTI) 61,506		

TABLE 2.—MORTON-THIOKOL ENGINEERING POSITIONS

Title	Grade	Average salary
Engineer associate	10	$29,732
Engineer associate senior	11	32,931
Engineer	12	34,528
Engineer senior	14	38,792
Project engineer	15	44,325
Project engineer senior	16	52,624
Section supervisor	16	51,501
Section supervisor/manager	17	57,805
Engineering manager	18	65,487
Engineering manager	19	78,437
Engineering design manager	20	78,000
Vice president engineering	21	82,014

TABLE 3.—MSFC—MTI COMPARISON

Title	MSFC (grade)	Average salary
Engineer trainee (I)	7	$23,866
Engineer trainee (II)	9	28,518
Engineer (junior)	11	31,370
Engineer	12	35,727
Engineer (expert)	13	44,407
Engineer associate	10	29,732
Engineer associate senior	11	32,931
Engineer	12	34,528
Engineer senior	14	38,792
Project engineer	15	44,325

In response to Senator Pressler's initial questioning about the salaries of the engineers working on the design of the solid rocket motor joints, we are providing specific salaries for two people, Roger Biosjoly of Morton-Thiokol and Ben Powers of Marshall, who were counterparts for the joint design.

The wide pay disparity at the entry level is compatible with the findings of current nationwide pay comparability studies, and NASA's own experience. In recent years, it has become increasingly difficult to hire and retain the best personnel because of the heightened marketplace competition for top talent. The Challenger accident has escalated these pressures. As a whole, the aerospace industry has much more flexibility to attract and retain top talent. NASA needs similar flexibilities to maintain the quality of leadership that is expected and required.

Senator PRESSLER. The January 15th NRC report expressed concern that valuable time could be lost if it became necessary to turn to one of the alternative designs as a consequence of something learned from the test program.

The NRC panel goes on to recommend that NASA should strengthen its contingency plans for incorporating alternatives into the redesign program. Do you agree with this assessement and recommendation and how will you respond to this recommendation? I address that to Mr. Garrison and Mr. Thompson. Mr. Garrison probably should go first.

Mr. GARRISON. Yes, I do agree with it. I think we are complying within the activities that we are authorized to proceed with to respond to that. We have a number of both parallel and contingency designs and a major effort on them underway.

I believe we have something like three or four for both the case joint and the nozzle-to-case joint. I think we are complying and we do agree with that, sir.

Mr. THOMPSON. Yes, sir, I believe we will be doing more of it. I think the point or the issue that we have with the NRC, and it is not a basic issue, its one of priorities, is they want us to do even more.

My only concern is I want to know how many balls we get in the air. I want to be able to do what we do and do it well.

Senator RIEGLE. I do want each member to have the chance to pursue it, but I want to make sure we hit everybody. I am concerned about the safety of people leaving later in the day and getting out of here. I am talking about our witnesses particularly.

Senator Hollings, I know you have one thing you wanted to raise.

The CHAIRMAN. I do thank you very much, Mr. Chairman. Quickly, Mr. Thompson, I tried to approach it from the standpoint of contract restriction or of pressure. Let's do it from the standpoint of common sense and then you correct me, maybe I am oversimplifying.

In other words, I never have merged a rocket motor with a booster rocket itself. I have always found that the rocket motor worked, propellent and everything else, never a defect there, but since this was designed and manufactured 2,000 miles away, it had to be brought in segments down to Florida and all joined together.

So we asked over a year ago almost, we said: Why not get the monolithic or single motor so that would forgo any kind of field joints and another O-ring and bringing heaters and doing all of that stuff? It just couldn't leak. And we had responsible contractors saying that is the way it should go. I think that is what we are going to hear again.

I want to hear one more time before we hear from them, is there some drawback or defect, in the monolithic booster itself—at that time we heard you didn't have barges to get them and bring them around to the Cape. I have barges coming out of my ears down in Charleston, South Carolina. The Navy has them backed up in creeks and I can get you all the barges to move the thing.

I am not worried about that, but that is the excuse. They said it was a good idea, Senator, but we didn't have barges. That is why I come back to a test engineer and a design engineer, your expert judgment on the fundamental design of this thing. Is there a drawback to having a monolithic one?

Mr. THOMPSON. Certainly it is not the transportation of any significance. I am intrigued by the idea. You are pouring a lot of propellent and curing it in one shot. The people that do that have a lot of confidence in it.

If we embark on that road, we have also got to develop that confidence. And that is kind of the process we are going through now. You always have to end up with at least one joint. However we go, we have got to have a reliable joint design, but the monolithic concept is attractive to some of us in NASA. We are looking at it very hard.

I personally want to hear more about it. That is what I have got the people doing now.

The CHAIRMAN. Thank you, Mr. Chairman.

Senator GORE. Mr. Chairman, I don't have another question, but before the witness leaves, I just want to say that listening to him, I feel a good deal of confidence in the way you have taken charge at Marshall in this aspect of the program.

I am very impressed and look forward to visiting at Marshall.

The CHAIRMAN. I think we ought to get him a job at the National Security Council so the President can hear what is going on. I can hear you.

Senator RIEGLE. Let me say that we appreciate the testimony today. And the more we see of the new team, speaking for myself, the more I see of the new team, the better I feel.

And we are here to work with you. So the intensity of interest that you see today to have this many Senators here and as involved as we are, we are not trying to do anybody else's job. We are trying to do our job, and that is to understand what is happening here and to be sure that what is being done is right and conforms with the Rogers Commission recommendations and that we are getting the job done.

So we will have the closest kind of working relationship but it will be a constructive one and a positive one and an independent one, as it properly should be.

So let me thank you now. Let me now invite the contractor group to come to the table, if they would.

Let me ask, if I can, if we can have others in the room be seated so that we can proceed. Let me say to the contractor group which is at the table that we are pleased to have you with us today. We thank you for braving the elements and the blizzard to come here.

Those of us that come from more northern climates are used to snowstorms and blizzards of this kind, but they are relatively uncommon here. So to get through the traffic and to get here is a major achievement. And I thank all of you for doing so.

I will start with asking a couple of things, posing a couple of questions and then I will call on you, Mr. Brown, to kick this off. I think we will go in the order of Mr. Brown, Mr. Crosby, Mr. Mettenet, Mr. Sides and Mr. Dorsey, in that order. I want to get your opinions on what we have just been discussing; namely, your professional judgment about this solid rocket motor redesign program that has just been described.

I want to hear your thoughts on both your feeling about the way that seems to be proceeding and also the question of an upgrade to a solid rocket motor of a different kind.

I think it is very important that you all be involved actively in searching for these answers. I think out of the competition and the alternatives that can be developed by different engineering teams, can lead us to the best possible result. And it may very well be a different design for the future.

I think we have just heard from Mr. Thompson that he is very interested in looking at other designs as are others in NASA, as we are, because we want to make sure we are using the best approach that we can find. So you folks are really vital to the process of helping us determine whether or not there is an alternative out there that would be better and that we ought to move towards.

So, Mr. Brown, let me start with you and then we will go down through this group. I will ask, in the interest of time, including your own time, that you condense your thoughts as best you can. And if you have a lengthy prepared statement, we will put it in the record and review it carefully, but if you can summarize it, that would be helpful to us.

STATEMENTS OF GEORGE G. BROWN, VICE PRESIDENT FOR PROGRAM DEVELOPMENT, AEROJET STRATEGIC PROPULSION CO.; HARRY L. CROSBY, VICE PRESIDENT FOR BUSINESS DEVELOPMENT FOR CHEMICAL SYSTEMS DIVISION, UNITED TECHNOLOGIES CORP.; ERNEST A. METTENET, PRESIDENT, HERCULES AEROSPACE PRODUCTS GROUP, HERCULES AEROSPACE CO.; JAMES R. SIDES, SENIOR VICE PRESIDENT AND GENERAL MANAGER, PROPULSION DIVISION, ATLANTIC RESEARCH CORP.; AND EDWARD G. DORSEY, VICE PRESIDENT AND GENERAL MANAGER, WASATCH DIVISION, MORTON THIOKOL

Mr. BROWN. Thank you, Mr. Chairman. I am very pleased to have the opportunity to appear. The testimony that I submitted covers the shuttle rocket redesign activities. I am going to address my remarks to a parallel or an alternative motor program that I feel NASA should embark upon.

We have proposed an alternate to NASA which would be conducted in parallel to the current redesign activity. This is a timely program. It is cost effective. It costs much less than the $350 million that Senator Gore referred to for the ongoing activity.

The Aerojet proposal actually would completely eliminate the field joint problem. This would be done by preassembling rocket motor segments as received from Thiokol and then insulating over the joints that are caused by that assembly, so that you wind up with complete continuous insulation over all the joints in the motor, except for the end joints, that is the igniter and the nozzle joints, which will exist in any event, and then inserting a core in the motor, in the cast pit, and then completing casting a single propellent grain.

You wind up then with continuous insulation over all of the joints plus the thickness of the propellent itself, which protects the joint from the hot gas in the motor. The joints never see the hot gas in that case.

So to me it is a complete and wholly reliable kind of a solution to the field joint problem. This design has been examined in detail by us, checked out with structural analysts at NASA, and has essentially the same structural margins that the segmented grain design has.

We are able to do this with a very strong sense of confidence because the flights that have been flown have flown with so-called factory joints that are built in this same way. They have complete insulation over them. They have propellent cast over the joint.

And they have had complete success in all of the flights to date with no anomalies or no indicater of trouble in any of the flight records that have been received by NASA to date.

So we really convert then a faulty field joint into a reliable factory joint. If you do a statistical reliability assessment of the design using the Morton Thiokol report as submitted to NASA, comparing the reliability of the so-called factory joints to field joints, you can actually get a 67 percent reduction in potential motor case failure causes. And that significantly improves flight safety, which is the objective that we started out with, with our design.

We can do this by assembling the solid rocket in an existing rocket facility in Dade County, Florida that has access to water through a canal. This facility was specifically designed and operated for a previous NASA program, a 260-inch rocket program. We developed and tested three 260-inch rockets there and a 120-inch rocket.

The facility was operating in the middle '60s. It is capable of being quickly reactivated in a timely manner so that we could conduct a program in parallel to, with a slightly longer time schedule, the current redesign program.

The question has been brought up in this regard, as Senator Hollings has referred to, of transportation. You have to barge a completely assembled rocket motor that weighs in excess of a million pounds.

Now, we have looked at the equipment that is required to do that, the cranes that are needed to lift it, the transport equipment that is needed to move it onto a barge and so on, and the equipment exists. It is off the shelf from various contractors throughout the United States to do this.

We don't consider that to be a major problem. It is something that has to be worked out in concert with NASA, particularly because the motors received at the Kennedy Space Center, have to be handled in the same way.

Senator RIEGLE. Let me just ask you a question there. In that research are you aware of anything else that we move around the country that would, in one unit, that would weigh as much as a million pounds? Is this something where there are other kinds of things? I know this is more delicate, perhaps, than other things.

Mr. BROWN. Yes, let me cite you one example. In the nuclear industry, where you have these nuclear reactors, pressure vessels and so on, they weigh well in excess of a million pounds. They are larger than the solid rocket motor that we are talking about here and they are being moved every day into remote locations, essentially, not a well-developed location like our plant or like Kennedy Space Center.

So equipment exists to do that, to do it safely and to do it reliably.

Senator RIEGLE. Thank you.

Mr. BROWN. The facility that we had, as I mentioned, was put there for the 260-inch rocket motor program. And this facility is capable of being reactivated and then producing the amount of propellent and casting that propellent in a large cast pit that still exists on the facility and doing it at the rate, essentially, that is required for the shuttle program.

The quality verification testing we have recommended to NASA be done at Kennedy Space Center. So there would have to be the addition of some quality facilities, including x-ray equipment and quality verification tests, just before it goes into the vertical assembly building.

Transporting the booster there in one piece has an advantage in that it takes all of the rocket segment assembly operations out of the vertical assembly building. There is quite a bit of time now that is involved in putting the rocket motor together in the vertical assembly building.

That would be done offsite at our plant, and we would transport a completely assembled motor in there, thus saving NASA that time lag in the vertical assembly building.

We feel that our large motor experience in the unique facility that we have at Dade County can provide for the production of what we refer to as a single grain solid rocket motor, recognizing that we still build up the motor hardware, the steel hardware segment by segment and use the existing hardware in the program, the existing O-rings and all of that, plus all of the existing process experience.

So the only thing that we are really changing is the propellent casting operation itself. And that is the thing I think that NASA has to look at in detail with us and satisfy themselves that it can be done safely and reliably.

We feel that NASA should really start this parallel program now. They have already embarked on a joint redesign. They have looked at many, many different designs for the joint. They have selected the one or the two or three that they are proceeding with and that they should now embark on something that is significantly different, a different approach, an approach that affords NASA the opportunity to significantly improve the flight safety of the shuttle system.

We feel this particular approach would do that. We think they should proceed now. Thank you.

[The statement follows:]

STATEMENT BY GEORGE G. BROWN, AEROJET STRATEGIC PROPULSION COMPANY

SUMMARY

Investigation of the Challenger accident revealed that the solid rocket motor (SRM) segmented design with O-ring joint seals must be modified to eliminate any possible hot gas leakage. Future Space Shuttle flights must be both safe and reliable for launching national payloads in support of the United States Space program.

Aerojet has recommended a recovery program that would be both timely and cost efficient when conducted in parallel with other candidate design modifications to reduce program risk for the NASA Space program. Aerojet would completely eliminate the O-ring seal failure problem and hot gas leakage path at the field joints while using all the existing solid rocket motor chambers and other components. Use of the existing qualified hardware and processes are possible by preassembling the existing Morton Thiokol Inc. (MTI) chamber segments without propellant, using the same seals and pins. The internal segmented chamber joint interfaces of the completely stacked motor case would then be completely insulated and the propellant cast; thus creating a motor with continuous insulation and single-grain that would prevent any possible hot gas leakage paths to the O-rings.

This single insulation and propellant grain design reduces the possible hot gas leakage paths from the five current seal failure points to only the two required at the igniter and the nozzle. Also this design reduces the debond failure point of the propellant/insulation to hot gas pressure, from the eight current interfaces to only the two required at the forward and aft ends of the solid motor. Reduction of these hot gas seals and potential debond interfaces reduces potential failure modes to improve flight reliability. Also, previous Shuttle flights have verified that this single insulator and grain assembly method used with MTI factory segments prevents any damage to the segmented joints. The joint seals are not pressure actuated and have the integrity of the casewall since they are sealed and thermally protected by not only the insulation, but also the propellant itself.

Aerojet would assemble the solid motor near a waterway for transportation to either the Eastern or Western Test Range. Such capability exists at the Aerojet Dade County Facility. This large rocket motor installation in Florida was originally designed and used for the successful NASA Large 260-in. Diameter Motor Program. One 120-in. diameter subscale and then three 260-in. diameter by 80 feet long, solid motors were successfully cast and tested using the single insulator and grain design. After Shuttle motor assembly and casting, the Solid Rocket Motor would be barged to the launch site as is currently done with all the Shuttle external tanks. The Aerojet Dade County Facility was originally capable of producing up to 14,000 pounds of propellant per hour using one continuous mixer and two vertical batch mixers. This facility still has the large cast pit, vertical propellant batch mixer and continuous mixer buildings, one continuous mixer, infrastructure and other facilities. Thus, the

existing facility could be activated and qualified for producing over two NASA Space Shuttle Solid Rocket Motors per month in not only the least time, but for the minimum amount of funding.

Currently all large solid motors in the United States use a single (monolithic) grain design, except for the Titan 120-in. diameter, and the Space Shuttle 146-in. diameter motors. These large motors were segmented to allow ground transportation from the manufacturer to the launch site. Both motor designs have recently experienced flight failure due to thermal damage to the segmented field joint O-rings or propellant debonds at the segmented interfaces. Industrial experience is available for the design and production of single grain motors to provide NASA an alternate low-risk and highly-reliable solid rocket motor program for future reliable Space Shuttle flights.

Any design or manufacturing process change will require requalification of the Solid Rocket Motors. X-ray inspection of the transported motor and qualification testing could be efficiently accomplished at the Cape. Use of existing qualified procedures and contractor and NASA personnel prior to providing hardware for single grain propellant casting and after single grain motor delivery to the launch site minimizes proven solid motor process changes and thus program risks.

This proposed Solid Rocket Motor manufacturing approach provides NASA and the United States a candidate solution to the Shuttle Solid Rocket Motor O-ring design problem. Thus, this program should be conducted in parallel with other current design approaches, to assure NASA that a reliable Solid Rocket Motor design is obtained for future Space Shuttle flights.

The approach that NASA has taken since the Challenger accident has concentrated on redesign of the field joint to incorporate additional O-ring seals and a capture feature in the clevis joint. They have explored a multitude of different designs to improve the reliability of the field joints and have selected the best design to develop and test in a very extensive program. It is appropriate that NASA should initiate an alternative approach that provides for an improvement to Space Shuttle Solid Rocket Motor reliability. The single grain Solid Rocket Motor provides that alternative approach.

A reliability assessment of the Aerojet design shows significant improvement over the segmented design. The SRM Failure Modes and Effects Analyses (FMEA) Report (TRW-10168) was the baseline for comparing potential failure modes against those identified for the current design. The results of this study indicate a possible 67% reduction in potential failure causes, and is summarized below. This study concluded

Failure Modes and Effects Analysis Summary

Component	FMEA-Identified Failure Causes Segmented SRM	Comparison Analysis Single Grain SRM
Case	53	34
Insulation	106	13
Propellant/Liner	54	24
Overall	213	71
Percent Reduction (Single Grain-to-Segmented Grain)		67

that SRM reliability (and therefore, flight safety) is significantly improved by the Aerojet Single Grain and Insulation SRM design.

This concept negates the importance of devoting significant resources to design studies leading to improved case segment joints, as sealing integrity is maintained by the internal insulation and propellant at each factory joint, and the current joint design, as well as the three O-ring modification, is acceptable.

When compared with the conventional segmented SRM, the added safety and reliability of the single-grain design were the most obvious and important features supporting this approach. However, other benefits and potential deficiencies, in any comparison between a single grain SRM and the segmented version, needed examination. Therefore, trade studies were conducted on performance, mass properties, reliability, processing, transportation, and handling. Summary information concerning these aspects is presented later in this statement. We have verified that other positive benefits can accrue in the area of performance and mass properties and that issues concerning processing, transportation, and handling can be dealt with in a routine, straightforward manner.

Therefore, it is recommended that NASA should immediately proceed with this alternative single grain solid rocket motor approach in parallel with the current redesign program to significantly improve reliability and flight safety in a timely and cost-effective manner.

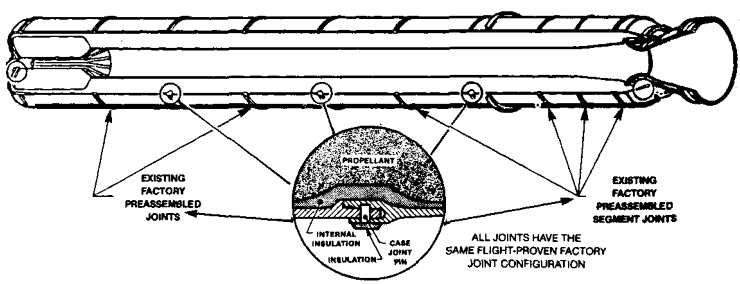
The fold-out page that follows presents a sequential illustrated program approach for this alternative program recommended to NASA for implementation. The availability of appropriate facilities represented by Aerojet's Dade Division is a vital factor underlying the viability of this alternative SRM program. These facilities permit a timely schedule, i.e., delivery of flight motors to Kennedy Space Center in 20 months. The buildings, roads, utilities and plant infrastructure at the Dade Division leads to an alternative program that is very cost-effective. This alternative program can be accomplished for significantly less funds than now being expended on the joint redesign activities.

At the initiation of the alternative program, Aerojet would conduct all design, analysis, laboratory and subscale testing operations and ignitor fabrication at the Aerojet Sacramento facility. At the Dade County facility, the chamber segments would be assembled, fully insulated and lined, the propellant mixed, cast, and cured and the nozzle, ignitor and tunnel assemblies installed.

The pages that follow present a program/facility description of the Dade Division activity.

SINGLE INSULATOR/GRAIN REDUCES SOLID ROCKET MOTOR (SRM) PROGRAM RISK

- Uses Existing Hardware Already Built for the SRM
  - Uses Existing Segmented Case Hardware to Reduce Risk
  - Reduces Cost and Time
  - Allows Use of Existing Tooling, Procedures and Experience
- Eliminates Hot Gas Exposure to Case Walls and Segmented Joints
  - Protects Case Material and Segmented Joints From Hot Gases
  - Prevents Propellant Debonds at Segmented Joints
- Flight-Proven Factory Joints
  - Qualified by Both Ground Test and Flight
- Conventional Single Propellant Grain and Single Insulators
  - Grain Stresses Are Lower Than Segmented Design
  - Removes Pressure Loads on Segmented Grains
  - Removes Tangential Instability
  - Will Be Barge Transported Like Shuttle External Tank



- **Single Grain Motor Will Substantially Improve Reliability and Safety With No Reduction In Performance**

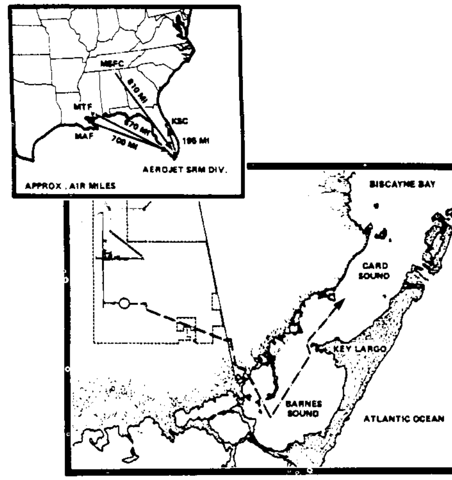
INSULATION/GRAIN FAILURE POINTS

	SEGMENTED	SINGLE
• CASE	53	34
• INSULATION	106	13
• PROPELLANT/LINER	54	24
TOTAL FAILURE POINTS	213	71

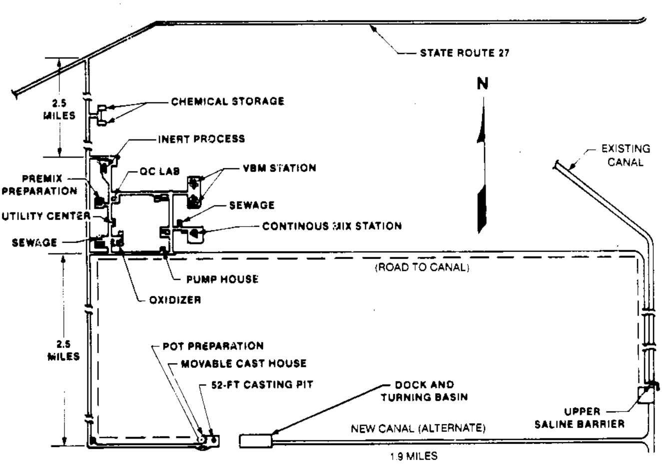
Single Grain Motor Trades Difficult Reliability Problems for Straight Forward Handling and Transportation Issues

EXISTING DADE COUNTY FACILITY

- Located Near KSC, Homestead AFB and Miami
- Facility Has a Benign Temperature Environment
- Accessible to Navigable Waterways for Safe Transportation to KSC and WTR

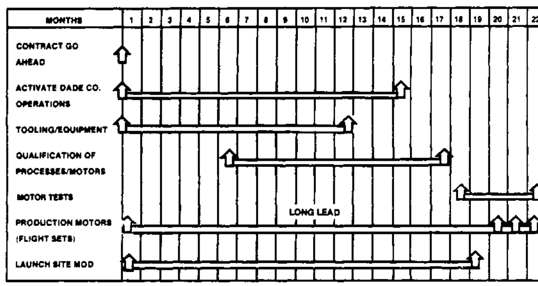


- Facility Was Constructed to Build Large NASA Solid Rocket Motors
- Existing Facility Can Be Reactivated to Produce at Least Two Solid Rockets Per Month
- Facility Has Growth Potential to Meet All NASA Shuttle Flight Requirements



SRM PROGRAM SCHEDULE

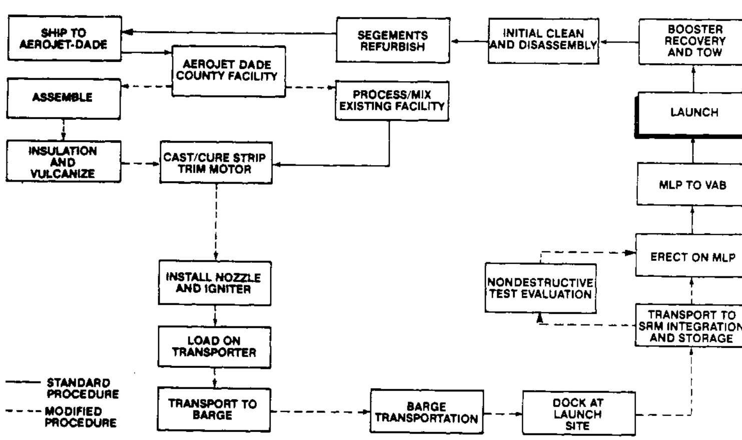
- Production Motors Can Be Delivered Within 20 Months After Contract Go-Ahead
- Use of Single Insulator and Grain With Existing Hardware Would Provide NASA a Low Cost Backup SRM Program



- Program Costs Are Low Due to Use of Existing Hardware/Facilities

SRM Manufacturing Approach - KSC

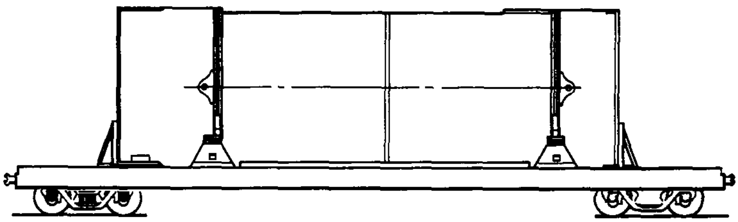
- Aerojet Dade Division Minimizes Change to Current NASA Solid Rocket Motor Processing



USE OF EXISTING SRM HARDWARE/PROCEDURES PROVIDES

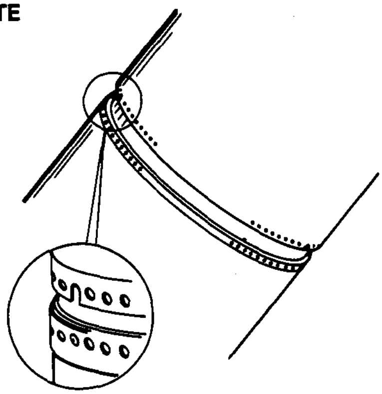
RECEIVE EXISTING CHAMBER HARDWARE

- Receive Case Segments at Dade County on Existing Standard Rail Cars
- Inspect and Transport to Assembly Area



STACK CASE SEGMENTS AND INSULATE

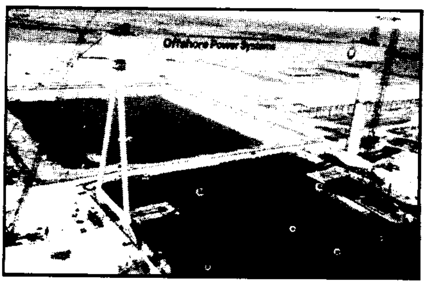
- Use Existing Procedures, Seals and Pins
- Insulate Segments and Vulcanize Using Qualified Material and Procedures to Provide Motor Insulator to Protect Chamber Walls and Joints

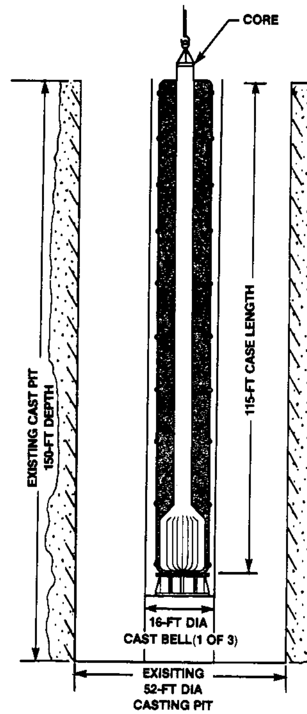


NASA A LOW RISK ALTERNATE PROGRAM

CAST AND CURE PROPELLANT

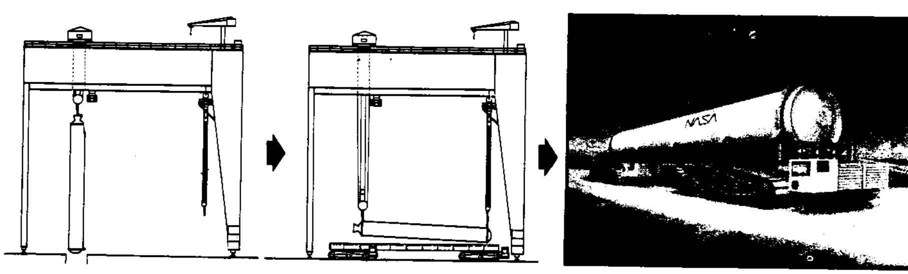
- Lift Motor Into Cast Pit and Install Core to Produce the Required SRM Thrust/Time Performance
- Vacuum Cast Single Motor Propellant Grain to Eliminate Hot Gas Leakage Path to the Single Liner, Insulator, Chamber Wall, and Segmented Joints
- Cure Propellant and Remove Core
- All Resulting Segmented Field Joints Have Same Flight and Ground Test Characteristics as Proven Factory Joints



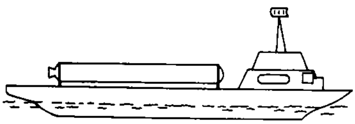


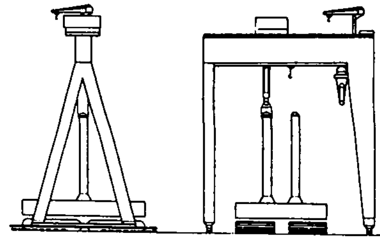
Assemble and Transport

- Install Assembled Solid Rocket Motor on Transporter After Installing Short Nozzle and Igniter
- Move Motor to Barge



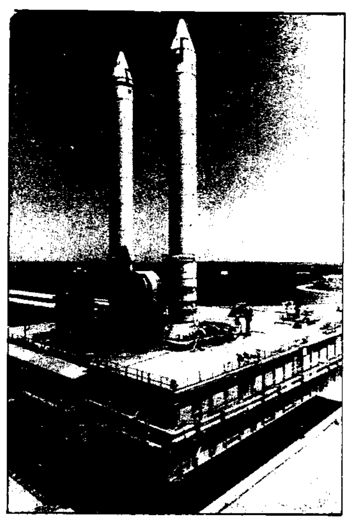
MOVE TO KSC/WTR BY BARGE





- Place on Barge at Dade County
- Transport to Launch Site

- Remove From Barge at Launch Site
- Assemble Into Space Shuttle Launch Configuration, Conduct Inspections and Load on MLP (KSC)



THE AEROJET PROGRAM PROVIDES NASA WITH A PROVEN ALTERNATE DESIGN THAT PREVENTS ANY FUTURE FLIGHT FAILURES DUE TO THE FIELD JOINTS

1.0 INTRODUCTION

In order to provide NASA with an alternate source for a safe, highly reliable large solid rocket motor (SRM) for the Space Shuttle Booster and other uses, Aerojet is proposing that the motors be filled with propellant (loaded) at its Dade County plant site. This facility provides the only current capability within the free world for loading such large solid rocket motors as a single unit — a feature which drastically reduces the potential for booster motor failure during flight.

Current plans provide for using existing prepared booster motor case segments. These will be shipped from Morton Thiokol in Utah by rail to Florida City and transferred to truck for shipment to the Aerojet plant site (preparation of the segments is not planned for this facility, although if requested by NASA, Aerojet would provide such a case segment preparation facility in an area like Florida City). All chemicals and other materials will be brought by rail or truck to Florida City and trucked to the site, or brought to the site directly by truck. The case segments will be assembled into a rocket motor case which will be filled with propellant and shipped as a complete unit by barge to the launch site(s).

Barges will travel from the site by canal to open water and will then follow the same route used by current barge/ship traffic in Barnes Sound, Card Sound, Biscayne Bay, Biscayne Channel, and the Florida Intercoastal Waterway. Competent barge design for the specific purpose of minimizing barge draft appears to preclude any need for dredging of the waterways.

Aerojet's Dade County facility was constructed during the 1960s and used to provide exactly this type of capability for loading large solid rocket booster motors as a single unit. However, contrary to preceeding operations, no rocket motor test firings will be conducted at this site. Recognizing the concern for the environment, Aerojet will conduct its operations in a manner consistent with all current regulations and other environmentally sound considerations. Particular attention will be given to the Everglades and Biscayne Bay and protection of such endangered species as the manatee and crocodile, and their habitats. It may be noted that at Aerojet's Sacramento, California facility over 100 bird species are indigenous to the site, among them 12 protected species including the Perigrine Falcon and Bald Eagle. Other wildlife, including deer, skunks, opossums, rabbits, wild turkeys, and bobcats also inhabit the site with no adverse impact from operations performed there. At Dade County, Aerojet will likewise avoid significant impact on the habitat of all wildlife indigenous to the area with fully appropriate consideration for all endangered species.

The following sections contain more detailed discussions of the activities proposed for the existing manufacturing facility. Descriptions of the modifications and additions necessary for the manufacture and assembly of the Solid Rocket Booster motors are also included. Additional project components described are water use, work force location and population, noise events, hazardous materials generation, site restrictions, and economic impact.

2.0 FACILITY OPERATIONS

2.1 Proposed Phasing

The implementation of this project will be accomplished in two phases. Phase I will encompass the reactivation of the existing facility. Phase II will provide the necessary modifications and additions to accommodate manufacture of increased quantities of the Solid Rocket Booster motors.

2.2 Proposed Operations

SRM fabrication and assembly operations will be performed at the Aerojet Dade County plant site. No rocket motor testing is planned at this site. This activity, although performed during the original use of the facility, is currently under consideration at locations where such testing is routinely conducted. It is thus expected that there will be no adverse noise events from the reactivated facility.

2.3 Manufacturing Process

The manufacturing and assembling of SRMs, independent of size, can be described as a four step process: (1) preparation of a propellant, (2) preparation of rocket motor inert parts to contain the propellant, (3) loading of the propellant into the inert subassembly, and (4) final assembly of completed motors. These four processes are planned to be conducted at the Dade County facility.

2.3.1 Propellant Manufacture

The composite propellant process flow shown in Figure 2.1 indicates the five basic steps in the process of manufacturing propellant.

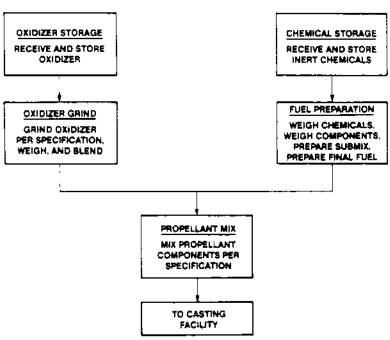


Figure 2.1 Solid Rocket Motors Composite Propellant — Process Flow

Oxidizer Storage — Ammonium Perchlorate oxidizer is received at the facility via railroad transport to Florida City and truck transport to the Aerojet plant site. The material is stored in above ground containers in a separate area from other chemicals as shown in Figure 2.1.1. It is estimated that approximately 12,000,000 lb of oxidizer will be in storage to properly support the propellant mixing activities. All oxidizer will be stored in above ground containers with fully adequate spill protection features and procedures provided.

Figure 2.1.1 Oxidizer Storage — Aerojet Dade Plant NASA-SRM Program, 1964-1966

Chemical Storage — All other propellant chemicals are received at the facility via railroad transport to Florida City (Figure 2.1.2) and truck transport to the Aerojet plant site. The materials are stored in one or more buildings reserved strictly for storage of chemicals. These chemicals consist primarily of innocuous non-toxic materials and will amount to approximately 500,000 lb. All chemicals will be stored in above ground containers with

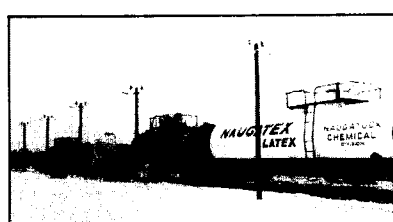


Figure 2.1.2 Chemical Receiving — Aerojet Florida City NASA-SRM Program, 1964-1966

fully adequate spill protection features and procedures provided.

Oxidizer Grind — The Ammonium Perchlorate oxidizer is handled in closed containers as shown in Figure 2.1.3. The oxidizer is ground to a specific particle blend in a fully enclosed system within the enclosed facility (Figure 2.1.4). An extensive dust control collection system is provided to preclude any emission of particulate material outside the building. Approximately 150,000 lb of oxidizer are present in the facility during processing.

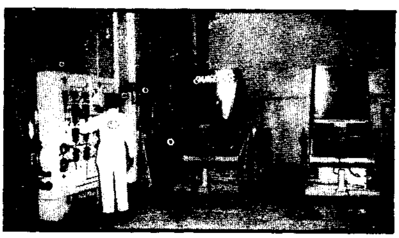


Figure 2.1.3 Oxidizer Handling — Aerojet Dade Plant NASA-SRM Program, 1964-1966

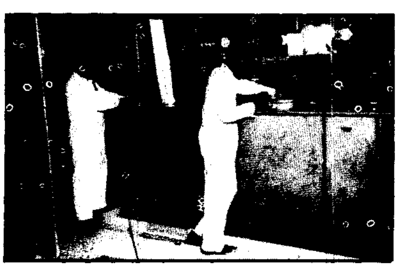


Figure 2.1.4 Oxidizer Blending — Aerojet Dade Plant NASA-SRM Program, 1964-1966

Fuel Preparation — Specific chemicals are weighed and mixed into a slurry called a submix. A separate group of chemicals is weighed and mixed to form a catalyst called the final fuel. All mixing is done in an enclosed system (Figures 2.1.5 and 2.1.6) under tightly controlled conditions to achieve process specifications as well as to control all potential emissions. Chemicals are dispensed into closed containers with adequate spill protection features and procedures provided. Approximately 150,000 lb of chemicals are present in the building during processing.

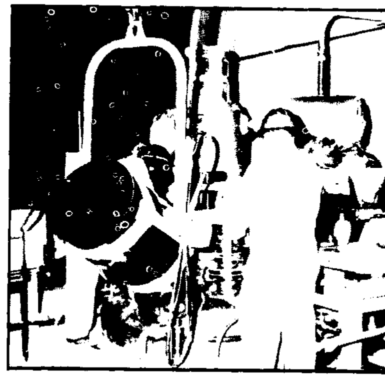


Figure 2.1.5 Fuel Liquids Addition — Aerojet Dade Plant NASA-SRM Program, 1964-1966

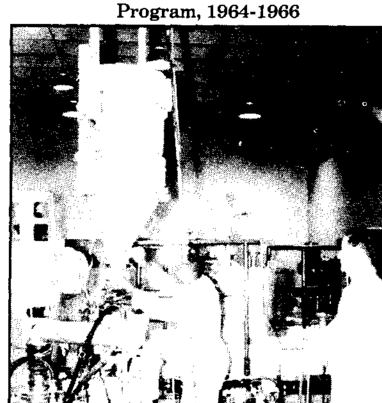


Figure 2.1.6 Fuel Solids Addition — Aerojet Dade Plant NASA-SRM Program, 1964-1966

Propellant Mix — The submix, final fuel, and the ground oxidizer are transported in closed containers to the propellant mix facilities, combined in the propellant mixer (Figure 2.1.7), and mixed into a homogeneous blend. The mixing is accomplished in a totally enclosed system (Figure 2.1.8) within the enclosed facility for process control. Consequently, all facility emissions and effluents are precluded.

Figure 2.1.7 Additions to Propellant Mixer — Aerojet Dade Plant NASA-SRM Program, 1964-1966

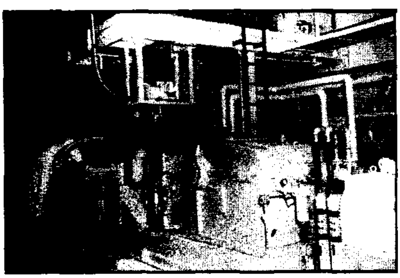


Figure 2.1.8 Propellant Mix Equipment — Aerojet Dade Plant NASA-SRM Program, 1964-1966

Solvents used to maintain cleanliness of the building interior and equipment are collected and disposed of in an environmentally approved prescribed manner. No floor drains exist in the building thus preventing any discharge of material by such means.

2.3.2 Building the Solid Rocket Motor

The typical motor process flow shown in Figure 2.2 consists of four basic steps in building the SRM.

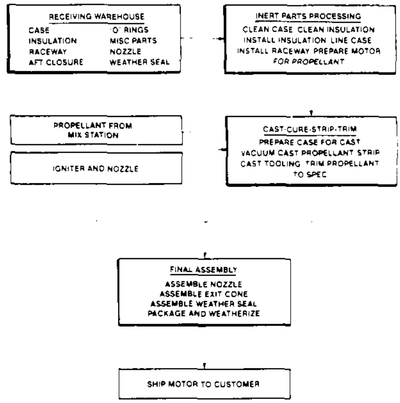


Figure 2.2 Solid Rocket Motors Process Flow

Receiving Warehouse — All rocket motor parts are received at the facility via railroad transport to Florida City and truck transport to the Aerojet plant site. When needed for manufacturing, the parts are moved to the manufacturing area by truck.

Waste generated (other than domestic wastewater) in this area will be confined primarily to packing supplies and will be disposed of according to local requirements.

Inert Parts Processing — The rocket motor case, internal insulation, case lining, raceway, and external insulation are combined into a subassembly (Figures 2.2.1 and 2.2.2) that is ready to receive the propellant. Processing waste (such as spent solvent, adhesives, contaminated rags, etc.) generated in this area will be collected and disposed of in accordance with approved environmentally sound procedures.

Cast-Cure-Strip-Trim — The inert parts subassembly is cast (filled) with the propellant (Figure 2.2.3) and warmed at a slightly elevated temperature to solidify the propellant. Tooling is removed from the subassembly (Figure 2.2.4), and any excess propellant is cut away (Figure 2.2.5) to provide a final solid propellant shape.

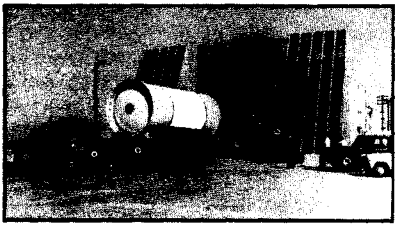


Figure 2.2.1 Receive Case Segments – Aerojet Dade Plant NASA-SRM Program, 1964-1966

Figure 2.2.2 Case Preparation for Loading – Aerojet Dade Plant NASA-SRM Program, 1964-1966

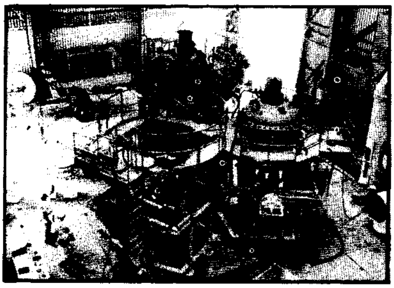


Figure 2.2.3 Propellant Casting Into Case – Aerojet Dade Plant NASA-SRM Program, 1964-1966

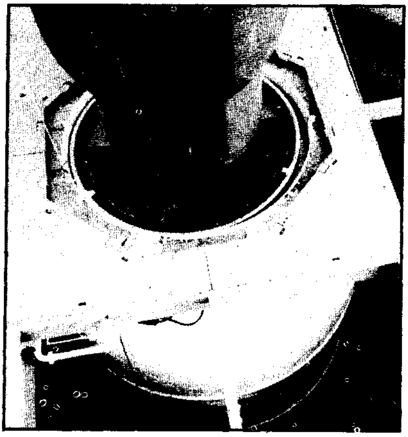


Figure 2.2.4 Casting Form Removal – Aerojet Dade Plant NASA-SRM Program, 1964-1966

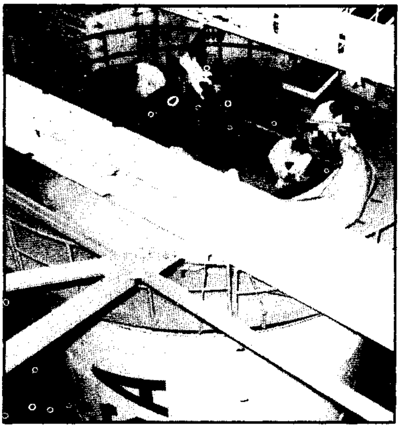


Figure 2.2.5 Solid Propellant Finishing – Aerojet Dade Plant NASA-SRM Program, 1964-1966

The casting of the propellant is done within an evacuated (vacuum) cannister inside the enclosed facility to assure adherence to process specifications. No gaseous products evolve from the process. Any waste propellant and other chemical waste generated during these operations is collected and disposed of in a prescribed environmentally approved manner.

Final Assembly — All remaining components and subassemblies consisting primarily of a nozzle and an ignition system are assembled (Figures 2.2.6 and 2.2.7) to form a completed solid rocket motor assembly.

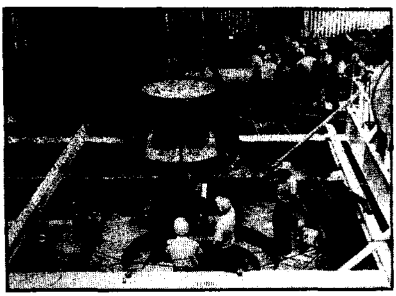


Figure 2.2.6 Rocket Motor Nozzle Assembly — Aerojet Dade Plant NASA-SRM Program, 1964-1966

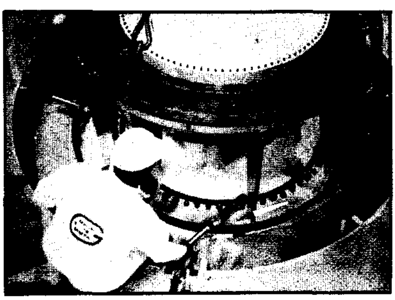


Figure 2.2.7 Rocket Motor Assembly — Aerojet Dade Plant NASA-SRM Program, 1964-1966

The completed rocket motor is then ready for shipment.

At the Dade County facility, the completed SRM assembly will be lifted vertically from the casting/assembly pit with a crane, as shown in Figure 2.2.8, and lowered to a horizontal position. It will then be placed on a diesel powered crawler transporter (Figure 2.2.9) for the short trip to the loading dock and subsequent barge loading for delivery to NASA.

All of the operations described above were previously performed when the Dade County facility was operational. The planned operations are the same as, or similar to, those previously performed using many of the same ingredients, processes, tools, and facilities. Advances in environmental controls, handling equipment, tooling, and manufacturing techniques will be incorporated into the planned manufacturing process.

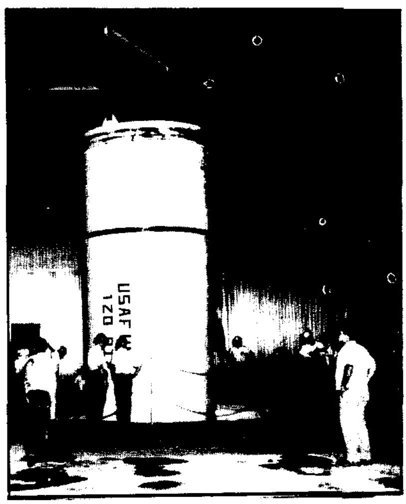


Figure 2.2.8 Rocket Motor Lifting — Aerojet Dade Plant NASA-SRM Program, 1964-1966

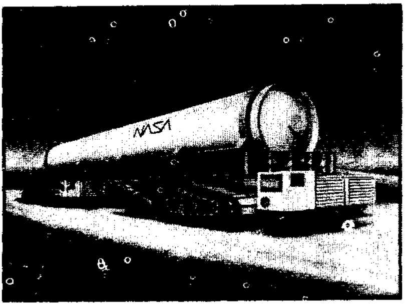


Figure 2.2.9 **Loaded Rocket Motor Move — Aerojet Dade Plant NASA-SRM Program, Future**

2.4 Land Use/Infrastructure

2.4.1 Access/Transportation

Current access to the Aerojet facility is from State Highway 27. No change in this access route is contemplated. Access to the facility will continue to be restricted and patrolled by security personnel.

Although access to the facility will be restricted, limited access will be provided to state and federal agency personnel and private parties that require access in order to exercise specific duties or functions. No firearms, hunting, or off-road vehicle use will be allowed on the facility.

Shipment of completed rocket motor boosters will be by barge through existing canals to Barnes Sound, Card Sound, Biscayne Bay, and out Biscayne Channel to deep water as shown in Figure 2.2.10. This barge traffic will follow established traffic routes in these areas. The minimal additional traffic generated by the Aerojet activity (approximately one barge every 10 days) is expected to have little effect upon existing conditions in this area. Barge designs which result in very shallow draft at the weights incurred during large solid rocket booster transport appear to preclude any need to increase depth of existing routes in Barnes Sound, Card Sound, Biscayne Bay, Biscayne Channel, or the Florida Intercoastal Waterway by dredging. In addition, barge designs will include features such as propeller guards, intake screens, etc. effective in protection of endangered water species.

The existing canal now has an earthen plug installed to control fresh water discharge and salinity intrusion. This plug will need to be removed and a gate or gates used to allow barge movement and control water flow. Aerojet is studying three alternative methods for controlling salinity intrusion or fresh water discharge and allowing barge traffic to pass. The three systems under study are a mechanical lock system, a hydraulically inflatable plug, and a single or double lock system. The final system will be constructed and operated in a manner which will strictly control water flow in an environmentally acceptable way.

2.4.2 Land Disturbance

The proposed reactivation and modification of the Aerojet Dade County facility will have minimal effect on the surrounding landscape. Any areas disturbed during construction will be rehabilitated through revegetation with native species. The existing access road to the canal will be graded to an approximate width of 30 feet to accommodate the diesel powered crawler type transporter depicted in Figure 2.2.9. This access road will not be surfaced.

To provide adequate loading and turning facilities for the barge traffic, it will be necessary to provide a turning basin and loading dock at the head of the existing canal. All work in this regard will be conducted under permit from the Corps of Engineers with disposal of all dredged material as directed by the permit(s).

As an alternative, it has been proposed that the C-111canal be extended to a point adjacent to the final assembly area, thereby negating the need to transport the large

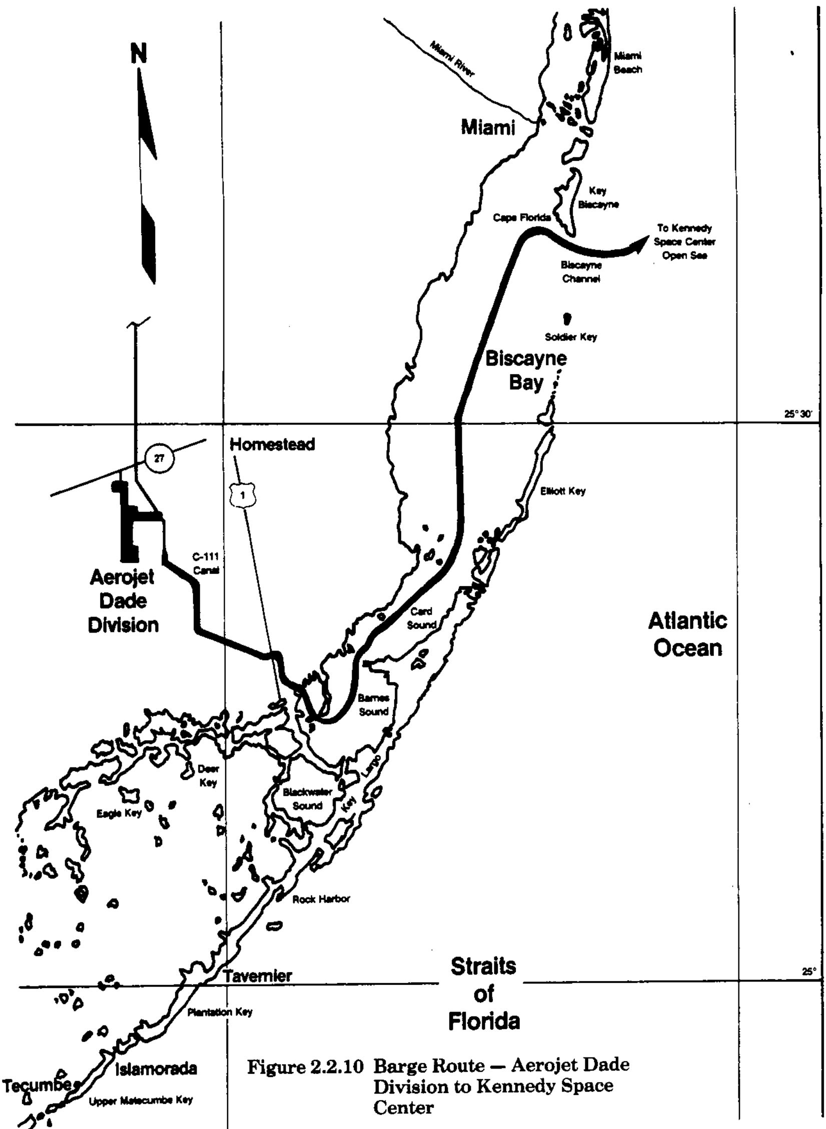


Figure 2.2.10 Barge Route — Aerojet Dade Division to Kennedy Space Center

booster motor over land. This has obvious operational advantages and will be considered if it can be shown to have a significant environmental benefit for example by enhancing the sheetflow of water in the Everglades Park area. This alternative would include the needed turning basin and loading dock mentioned above.

2.4.3 Facilities Infrastructure

The following is a list of the various services Aerojet has provided or will provide for the proposed operations. The services discussed below are water supply, roads, electrical power, and waste disposal.

Water Supply — The project will be supplied with domestic water from existing wells on the site. No new wells are contemplated at this time.

Roads — The existing road network will be utilized and maintained without major alteration except where necessary in the motor manufacturing area and the access road to the barge canal. Here, the modifications will be kept to an absolute minimum.

Electrical Power — The existing power supply to the facility will be adequate for all contemplated operations. Refurbishment with minimal modifications is required.

Waste Disposal — All waste generated (other than domestic wastewater) will be collected and transported off-site to an approved disposal site. Disposal of waste propellant will be accomplished by collection, packaging in durable corrosion proof containers, and shipment as DOT Class B explosive to an approved thermal treatment site. Thermal treatment of propellant waste will be prohibited at the Dade County facility unless accomplished within an enclosed system utilizing air scrubbers and liquid/solid separators which prevent emissions to the atmosphere and fully comply with EPA and other regulatory requirements. Existing facilities for the treatment of domestic wastewater will be refurbished and brought up to current standards.

2.5 Environmental Audit Committee

Aerojet will establish an internal Environmental Audit Committee to review proposed Aerojet construction activities to ensure environmentally sensitive issues are being addressed. As part of the project, Aerojet environmental staff will oversee permit compliance and ensure that proposed activities, including construction, are conducted in an environmentally sound manner.

2.6 Work Force Population

The Aerojet Dade County facility will employ approximately 150 to 200 full time people when utilized at maximum capacity for SRM production. It is expected that 70 percent of this workforce would be hired locally with the balance of technical personnel being transferred from other Aerojet facilities.

2.7 Economic Influence

The estimated cost of each Solid Rocket Booster motor is in excess of $5.0 million or greater than $10.0 million per Space Shuttle flight. Total value of the proposed project is therefore in excess of $150 million per year at the projected launch rate of 15 flights per year. Of this cost, it is estimated that approximately 25 percent or $36 million per year will be expended in the immediate Dade County area with significant positive impact on the local economy.

In addition, during the plant reactivation and addition phases, a significant local work force will be required with additional economic benefit to the area of $20 to $30 million.

2.8 Supplemental Project Motivation

Other potential work similar to that described herein for NASA is under both government and commercial consideration. This potential work would either supplant or supplement the specific Space Shuttle Booster motor work. Impact of this other work, although specifically indeterminate at this time, would appear to fall totally within the descriptions provided in this document, and could provide benefits of additional employment and positive economic effects in the area.

3.0 FACILITIES DESCRIPTION

A plot plan and location map of the Aerojet Dade County Florida facility is provided as Figure 3.1. The following is a listing and general description of each facility component to be reactivated together with the modifications which may be required for this project. The information includes general data on the building type, purpose, building description, waste generated, and methods for disposal.

3.1 Administration and Inert Area 01

Activities located in this area include:

- Administration and engineering offices
- Maintenance and support activities
- Receiving, storage, and shipment of inert materials and components
- Fabrication, assembly, and preparation of inert components.

Refurbishment with minimal modifications of the existing facilities is required. Only domestic wastewater and non-hazardous solid waste will be generated in this area.

3.2 Magazine Storage Area 10

This area will be used for the receiving and bulk storage of hazardous materials including:

- Oxidizers
- Fuel ingredients
- Assembled igniter(s).

Refurbishment with minimal modifications of the existing facilities is required. Only domestic wastewater will be generated in this area.

3.3 Chemical Processing Area 11

This area, shown in part as Figures 3.1.1 through 3.1.4, will be used for the preparation and mixing of solid propellant. Laboratory facilities for analytical control of raw material and material in process are located here.

Figure 3.1.1 Process Area 11

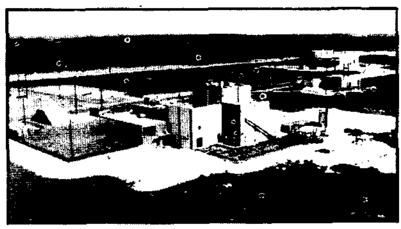


Figure 3.1.2 Oxidizer Preparation Building

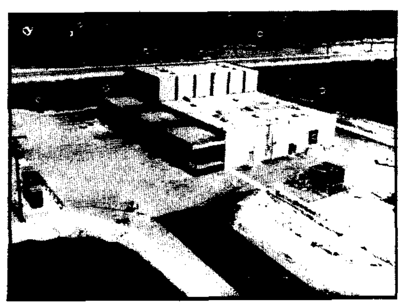


Figure 3.1.3 Fuel Preparation Building

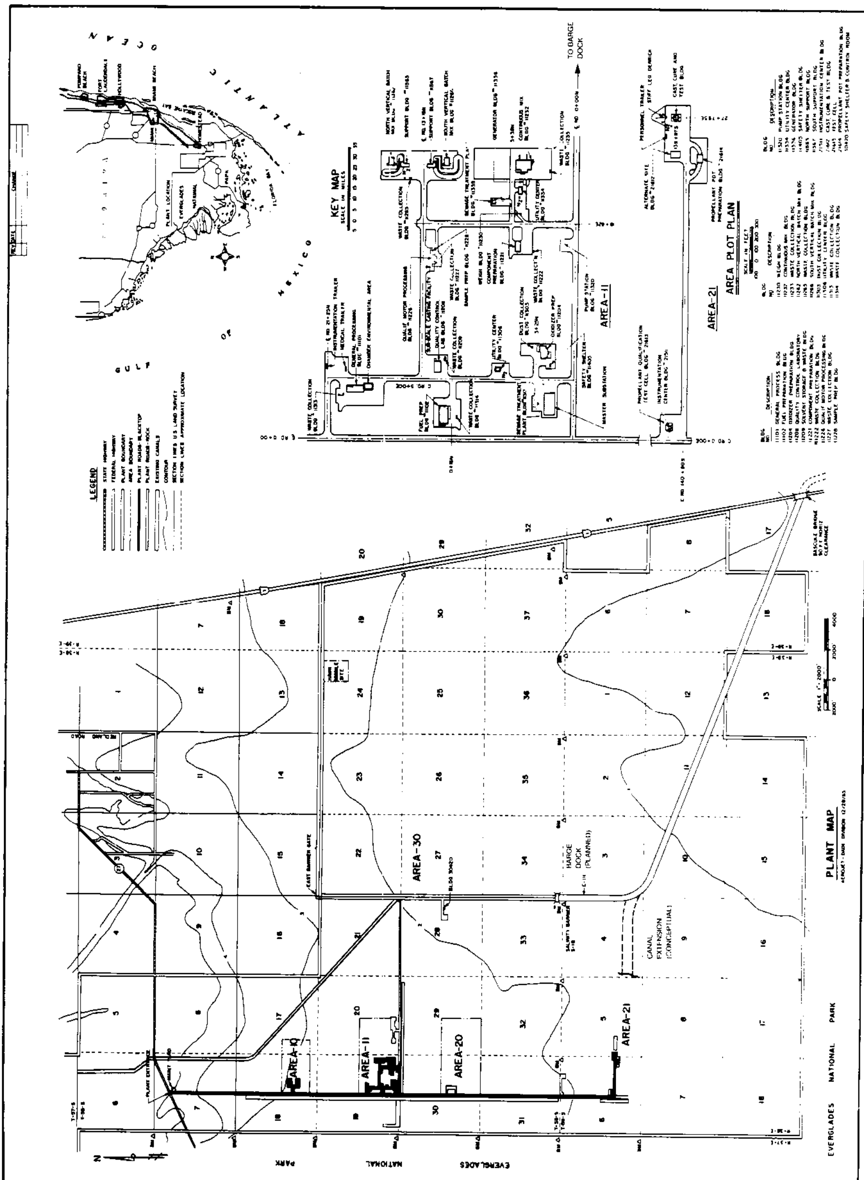


Figure 3.1 Aerojet Dade County Plant Map and Plot Plan

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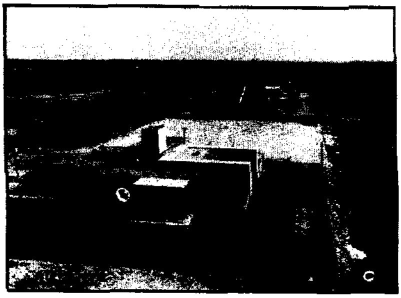

Figure 3.1.4 Propellant Mixing Buildings

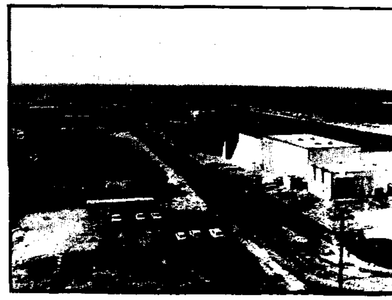

Figure 3.1.5 SRM Case Assembly and Preparation Building

Preparation and mixing of all chemical components is done under tightly controlled conditions. Virtually all operations are conducted within closed systems with substantial safeguards to prevent emission of fumes to the atmosphere. All chemicals will be stored in above ground containers with fully adequate spill protection features and procedures provided.

Refurbishment with minimal modifications to this area is contemplated. Solid waste generated in this area will consist primarily of off-specification chemical material, chemically contaminated rags, and spent solvents. All waste (other than domestic wastewater) will be captured and packaged and transported off-site to an approved disposal site. Domestic wastewater will also be generated in this area.

3.4 Motor Process Area 11

This area, shown in part as Figure 3.1.5, will be used for assembly and preparation of the large metal casing of the SRM for subsequent loading with propellant. Refurbishment with minimal modifications to this area will be made to accommodate improved manufacturing methods and the special requirements of the SRM Booster.

Solid waste generated in this area will consist primarily of chemically contaminated rags, and spent solvents. All waste (other than domestic wastewater) will be collected, packaged, and transported off-site to an approved disposal site. Domestic wastewater will also be generated in this area.

3.5 Motor Process Area 21

This area, shown in part as Figures 3.1.6 and 3.1.7, will be used for the manufacture of large solid rocket motors. Modifications

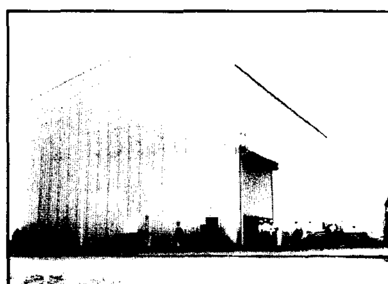

Figure 3.1.6 SRM Propellant Loading Building

to this area will be made to accommodate improved manufacturing methods and the special requirements of the SRM. Roads will be widened to accommodate the crawler transporters needed to move the motors. Modifications to the area will consist of replacing the structure with an enlarged building of similar construction and providing a crane capable of lifting the motor.

Waste generated in this area will be similar to that generated in area 11 with the addition of scrap propellant. All non-propellant waste generated (other than domestic wastewater) will be collected, packaged, and transported off-site to an approved disposal site. Domestic wastewater will also be generated at this site. Hazardous propellant waste will be collected, packaged in durable corrosion proof containers, and shipped as DOT Class B explosive to an approved thermal treatment site.

Figure 3.1.7 52 ft Dia by 150 ft Deep Propellant Loading Pit

4.0 DESIGN SUMMARY

During Aerojet's recent SRM Block II study activities, we conducted a design analysis of the SRM and identified design improvements that could be accomplished during an alternative program activity. An SRM design overview is offered in summary form as follows.

The primary objective of the four month Block II SRM study was to create a design that would be significantly more reliable than the current design and also highly producible at an acceptable life cycle cost. To this end, Aerojet elected to employ the existing qualified steel SRM chamber segments, assemble them completely in the factory, insulate the full length assembled chamber, and cast the existing PBAN propellant formulation to form a single unsegmented SRM. Thus, field joints, with the potential for leakage under operational conditions, are eliminated.

SRM Assembly — The single grain SRM design is characterized by the single-piece propellant grain and the completely single continuous insulation system.

There are no "field-joints", thus, the concern over leakage past joint O-ring seals under pressure and at low temperatures is overcome. There are also no grain-end restrictors, another area of potential failure initiation.

Performance requirements stipulated for the SRM are readily achieved by the monolithic grain design. Likewise, SRM mass property values and CG shift during propellant burning are within established limits.

Case — The well qualified D6aC steel segmented case will require only minor modification to meet desired nozzle and igniter sealing reliability improvements. The forward dome igniter boss face will be retrofitted with O-ring grooves to accommodate redundant O-ring seals. These seals will replace the gaskets now used at this interface. The nozzle boss on the aft dome segment will require a more extensive modification. A capture feature is proposed for the nozzle-to-case joint, with O-ring grooves machined on the case aft boss. The cylindrical case segments employing either the old, or the modified-joint configuration design, can be used with the Aerojet single grain approach.

Insulation — An insulation material to replace the currently-used asbestos-filled NBR has been selected and incorporated into the SRM design.

This material, designated A-380, is a Kevlar-filled EPDM rubber having better insulating and erosion-resisting properties than the NBR system. It is also about nine percent lighter in weight. This characteristic, plus the absence of heavy field-joint insulators and grain restrictors, results in an insulation system weighing approximately 7000 lbs less than the current design. In the high material loss regions near the nozzle, the carbon-filled EPDM system now used is retained to assure that a low-risk and well-proven material is used in this critical area.

The simplicity and effectiveness of the insulation at the process joints has been demonstrated. This approach, whereby uncured insulation is applied and vulcanized to previously cured insulation material to provide a continuous insulation, is well proven and used extensively within the industry. Laboratory tests conducted during the study showed rubber-to-rubber bond strength at joints processed in this manner exceeded that of the unbonded parent material.

Propellant and Grain Design — No change to the current propellant formulation is necessary. Aerojet has established through laboratory testing that the desired burning rate, mechanical and processing properties may be readily duplicated. In addition, a candidate liner system (SD-850-2), has been shown to produce excellent bonding between the propellant and the insulation.

The grain design essentially duplicates the MTI design — the major exception being the single-piece versus segmented configuration. The absence of grain-end restrictors adds reliability to the design; the absence of unrestricted free to (burn) grain-ends is compensated for by use of slightly longer fins in the forward dome and the addition of two small radial slots in the cylindrical section.

Grain stresses and strains resulting from worst case storage, transportation and flight conditions were analyzed and found to be generally equal or less than those induced in a segmented SRM.

Nozzle Assembly — As noted previously, the most significant design change in the nozzle results from the need to improve sealing reliability at the nozzle-case interface. It was Aerojet's position that the present redesign of this area, whereby 100 radial bolts are being added to assure joint closure under pressure, is not the preferred approach as 100 additional potential leak paths (at each bolt gasket) are introduced. The igniter propellant configuration is unchanged. As with the SRM case, all asbestos-filled insulators have been replaced by Kevlar-filled EPDM material.

The design selected, after several options were defined, incorporated a capture lip on the nozzle fixed housing. This feature assures no joint opening at the primary O-ring seal location. Both primary and secondary O-rings are verifiable in the proper direction. The aft dome-nozzle housing insulation interface is modified to preclude direct heat radiation or circumferential flow in the joint area.

Igniter Seals — Although there has been less concern expressed regarding the reliability of the seals at the various igniter interfaces, the multiple potential leak paths in this area pose a design shortcoming in Aerojet's opinion. Therefore, all gaskets (Gask-O-Seals and Stat-O-Seals) have been replaced by more reliable face-sealing O-rings. The igniter adapter (cover plate) has been strengthened to accommodate attachment to the igniter chamber from within, thereby eliminating all leak paths at this location and to assure that the joint remains closed under pressure at the primary seal.

Other Components — Aerojet does not plan any changes to other SRM components or systems as a result of this four-month study.

The Committee has requested that we include in our testimony comments on the proposed joint redesigns. Our comments are based on concept drawings and summaries of the extensive analysis performed by NASA in support of the design studies conducted. Obviously no attempt to check these analysis results was feasible within a short time; however, based on ASPC experience with both large boosters and strategic missile propulsion systems, the data provided is reasonable and within the range we would expect based on experience only.

The approach of our evaluation and critique was to compare the presented design approach results to the Presidential Commission recommendations and to determine the degree of compliance with each recommendation and to identify those areas in which full compliance was apparently not attained. A comparison was also made of the joint design against the design criteria utilized by ASPC in the design and use of O-ring seals. It was noted that the original SRM joint which failed during the Challenger's accident violated many of the most critical of our in-house design criteria. Of importance and concern to us in O-ring sealed joint designs are (1) compliance with manufacturers' and military standard design requirements, (2) maintenance of O-ring squeeze under all applicable loads and environmental conditions both static and dynamic, and (3) utilization of the seal and joint only under temperature conditions for which it was designed and qualified.

In the area of the redesigned field joints, we provided the following comments to NASA in a briefing at MSFC on 22 August 1986 relative to compliance with the commission recommendations:

(1) The integrity of the field joints should not be less than the case walls. The presented redesign represents a significant improvement in reliability of a field joint; however, the integrity and reliability was judged to be still less than the factory joint or case walls. One of the redesign concepts included a field joint to preclude the exposure of the joint (and O-ring) to motor pressure. Our evaluation leads us to believe that attainment of a reliable perfect bond during assembly operations when the bond surface is both blind and subject to tolerance and air entrapment problems is doubtful and therefore the O-ring seals at the field joints could be exposed to motor gases which does not occur at the factory joints.

(2) Integrity of the field joints should be insensitive to: dimensional tolerances; transportation and handling; assembly, inspection and test procedures; environmental effects, operating pressure; recovery and reuse effects and flight and water impact loads. The design and analyses presented support tolerance insensitivity of joint at least during its first use; however, changes which might occur in the joint, especially the interference fit of the capture feature during flight, impact, recovery and reuse, were not addressed in the design analyses and are of sufficient concern that determination of joint conformance after each use should be performed and the suitability of the design for the planned number (or any number) of recesses is not

assured until the data is available.

Insensitivity of the case/insulator/ propellant/inhibitors bonds at the forward joints to transportation and handling (and other effects such as aging) were not addressed. These areas are of concern because the highest bond stresses in the motor occur at the field joints and because these bonds in the field joint region were identified as the cause of the Titan SRB failure at Vandenberg Air Force Base. We would suggest that the integrity of these bonds and their insensitivity to transportation, handling and other environmental effects must be demonstrated in qualifying the redesigned motors for flight.

Insensitivity to assembly, inspection and test procedures must finally be addressed in the development of these procedures; however, some of the areas which should receive special attention to insure insensitivity are in the rounding and mating of the capture feature interference fit; and in inspection of hardware for dimensional changes especially of the rubber materials and loads at the field joints.

Insensitivity of the joint to temperature effects over the operating range is supported by the analyses performed and the failure potential of the joint over the entire operating range has been significantly reduced by the redesign. The redesign also improved substantially the joint integrity under the internal operating pressure of the motor for both dynamic (ignition transient) and static pressure conditions. It also appears that the redesigned joint does comply with our in-house practice for O-ring seal design and with standard industry and government standard practice recommendations. Because it appears difficult to assure an absolute seal of the motor gases from the field joint and its O-ring seals we would still evaluate the redesign as being less reliable than the factory joints.

In summary, our evaluation of the SRM field joint redesign indicates at least partial compliance with the Presidential Commission recommendations and the probability of failure of the joints will be reduced by this action. The redesigned SRM does, however, still retain five O-ring joints which may be exposed to motor pressure and gases during the entire action time of booster. Two of these joints at the igniter and the nozzle are required features in an SRM and have both an extensive design data base and an excellent reliability record. The additional three O-ring sealed joints are the field joints which are non-required features for either motor manufacture or operation. They are required only so that the booster can be broken down into segments which can be shipped from Utah or other inland locations to Kennedy Space Center or Vandenberg Air Force Base. We feel that inclusion of non-required design features which degrade reliability is a poor design practice and should be done only if no viable options exist.

An area of concern not addressed in the SRM reevaluation effort at the time of our evaluation involves the case to insulator, insulator to propellant, and propellant to inhibitor bonds at the field joints. The bonds which terminate at the joints experience the highest bond stresses of any location in the motor and failure of these bonds can lead to a catastrophic failure of the booster as demonstrated by the failure of a Titan 34D SRB shortly after launch at Vandenberg.

The approach selected for the SRM both originally and currently trades reliability in operation for ability to ship cross country by land, even though the option existed both times to eliminate the field joint and bond terminations. That option utilizes water transportation and planning for handling of a completely assembled and loaded SRB. This can be easily done using equipment and procedures well within industry experience.

5.0 CONCLUSION

Over the past several years we have made Aerojet experience and resources readily available to NASA in support of the Shuttle SRM program. During this time, for example, Aerojet has expended its own resources in developing and testing a nonasbestos insulation and liner system for the SRM. In addition, Aerojet has expended its own resources in support of the Shuttle SRM Block II study program with a preliminary engineering design for the reactivation of the Aerojet large solid rocket manufacturing facility in Dade County, Florida as a backup approach to the Challenger redesign activity.

The Aerojet approach focuses on increased SRM reliability through the elimination of the field joints as failure potentials by continuously insulating the assembled motor segments and casting a one-piece solid propellant grain. This approach is made readily possible by the existence of our large solid rocket manufacturing facility in Florida. This facility is currently idle, but it can be activated to deliver flight SRMs in 20 months. This unique facility is available to be totally dedicated to the Space Shuttle Program.

This alternative program would provide needed competition for Space Shuttle SRM procurement and provide NASA with opportunity for cost reduction and assured access to space.

We are prepared to discuss our support of a production effort with additional capital resources if NASA determines that it is in the best interests of the Government to proceed with contractor funding as opposed to NASA facilitization. Aerojet is further prepared to establish a price for the Dade County Large Solid Rocket Facilities and sell the facilities to NASA after the first production buy. The facilities could then be operated on a GOCO contract basis for each production buy, similar to the launch support operations presently performed at the Kennedy Space Center and Vandenberg Air Force Base, thereby ensuring a competitive market for SRM production.

Aerojet has a long history of commitment to NASA space programs ranging from the original 260-in. Booster Program, for which the Dade County Facility was originally constructed, to Gemini, Apollo, the OMS engine, and support of SSME Turbopump manufacturing and design. We are ready to offer our unique facility and our resources and experience toward the Shuttle Block II SRM which is of critical importance to our National Space Program.

Aerojet Strategic Propulsion Company

George G. Brown
Vice President
Program Development

20 February 1987

The Honorable Donald W. Riegle, Jr.
Senator From Michigan
Chairman, Subcommittee on
Science, Technology and Space
SD-105 Dirksen Senate Office Building
United States Senate
Washington, DC 20510

Dear Senator Riegle:

In response to your letter dated February 2, 1987, I am submitting the attached answers to your written questions for the record.

I appreciated the opportunity to appear before your Subcommittee and share your view that our common objective is a strong national space program conducted in the safest environment possible for users of the Space Transportation System.

The Aerojet proposal for a single grain solid rocket motor which eliminates the field joints is offered to satisfy that safety objective.

On Friday, February 6, 1987, I was pleased to host a visit to our Dade Division in Florida by J. R. Thompson and his staff from Marshall Space Flight Center. I was encouraged that they made this visit and are giving serious consideration to the single grain concept.

I wish to offer my compliments to you and members of your committee for your conduct of the SRM hearing and, more specifically, for your knowledge of the issues involved. This resulted in a penetrating series of questions to the witnesses that brought needed information into the discussions. Having been raised and schooled in Michigan I would like to say that Michigan is fortunate to be represented in the Senate by a gentleman with your capabilities.

Sincerely,

George G Brown

P.O. Box 15699C Sacramento, California 95852 (916) 355-5860

QUESTIONS AND ANSWERS FOR THE RECORD

1. On March 31st, Dr. Fletcher will provide this Subcommittee with a Long-Term Procurement Plan for solid rocket boosters. At that time, NASA will indicate whether or not a Block II solid rocket motor will be procured.

   Q. If NASA decides to proceed with a competitive Block II procurement, is there a consensus on this Panel that any Second Sourcing decision should be delayed until the Block II motor is designed, developed, tested and flown?

      A. Aerojet believes that a single grain SRM should be qualified in parallel to the NASA Redesign Program. This should be looked on as a competitive alternate program that can be used as a potential second source. This approach would provide, at the earliest possible date, a back-up for the existing redesign and a viable second source.

   Q. If a Second Source were pursued, would each of you bid if it were a fixed price contract?

      A. We at Aerojet have sufficient confidence in the single grain program to bid it fixed price assuming satisfactory contract provisions.

2. There has been much discussion today concerning the scope, timing, and schedule of the proposed solid rocket booster test program.

   Q. Based on your experience, how many full-scale, qualification motor tests should be run prior to the first flight?

      A. We do not have sufficient information about Thiokol's test program to offer a considered opinion. However, for the single grain, which utilizes existing hardware and has no joint dynamics consideration, we feel that four qualification tests are sufficient prior to flight.

   Q. Do you feel the new horizontal test stand at Morton Thiokol can duplicate the loads and conditions associated with the actual flight experience?

      A. We do not have enough information on the test stand or configuration to permit intelligent comment.

Q. Based on your experiences with solid rocket motors, are there any nondestructive examination techniques that can be used to verify the structural integrity of the redesigned solid rocket motors and the bands between the case and the insulation?

A. Examination of the redesigned solid rocket motor configuration in the field joint region, shows the areas of interest with respect to the O-rings and bonds are now more complex than before the redesign, The number and geometries of the interfaces and materials involved have increased in size and complexity making the measurement task more difficult.

In our experience a great deal of time and money have been spent in establishing NDE techniques for the verification of bonds. Bond verification is a difficult technical problem. The redesign, with the addition of the J-Seal deflection relief flap, makes the measurement task more difficult than before the redesign. Before the redesign the measurement techniques that had any chance of success were based on x-ray sampling plans and would be very difficult to develop and would require a research program. What can be said without a research or technique development program is that even with an assumed success, the results of the applied measurement would yield the probability of unbond detection over the entire 360 degree surface of much less than 1. A reasonable scenario can be calculated and yields a 20 percent chance of finding an unbond should one exist. It is also our estimate that developing a potential technique for the redesigned configuration has less than a 50% chance of success.

We are aware that even verification at a few points is sometimes considered better than no information, in this case we feel from a practical point of view such a bond verification scheme would lead to self illusion of integrity.

3. There has been and continues to be much discussion about the technical merit of monolithic solid rocket motors versus segmented solid rocket booster motors.

Q. Have you done trade studies of the technical merit of monolithic motors versus segmented motors? What are the tradeoffs?

Q. Do either offer the reliability required to support a manned program?

A. Table 1-2 summarizes some of the significant technical features in a comparison between a segmented and a single grain SRM design which was conducted by Aerojet during the NASA Block II SRM study.

TABLE 1.2. Technical Considerations; Monolithic and Segmented Grain Study

Item	Monolithic	Segmented
Case Field Joints (Potential Leak Paths)	0	3
All Case Joint Seals Verifiable Before Cast	Yes	No
All O-Rings Leak-Tested in Proper Direction	Yes	No
Joint Seal Gap Tracking Ability Critical	No	Yes
O-Ring Long-Term, Low Temperature, Compression Critical	No	Yes
Heaters Required at Field Joints	No	Yes
Current or 3 O-Ring Mod Case Segments Acceptable	Yes	No
Meets Ballistic Requirements	Yes	Yes
Significant Insulation Weight Savings	Yes	No
System Meets All Flight and Ground Structural Requirements	Yes	Yes
Propellant Grain System Stresses/Strains Meet Established Safety Factors	Yes	Yes
Fully Compatible With Filament Wound Case	Yes	Yes
Potential Case/Insulation/Propellant Unbonds at Field Joint Locations	0	6

Q. Based on the Challenger and Titan investigations, has industry's understanding of solid rocket motors been dramatically increased to where more reliable motors can be manufactured? Will there ever be a solid rocket motor that is "fail safe" for the two minutes it burns during space shuttle flight?

A. With a single grain motor the failure modes can be reduced by 67%, dramatically increasing reliability and flight safety, however, there are still other failure modes that remain. Neither liquid nor solid motors can be made completely fail safe. The record on single grain motors for past solid rocket programs demonstrates 0.997 reliability.

4. You are familiar with the National Research Council Panel's technical assessment of the proposed redesign and comments on the need for contingency planning and a better defined and more thorough test program.

Q. Would you please comment on the NRC recommendations, especially those recommendations concerning the need for a better defined and more thorough test program and the establishment of a priority criteria by which to evaluate the tests?

A. NRC Recommendation: Page 2, third para: "...NASA strengthen contingency plans for incorporating alternatives into the (test) program."

In response to this recommendation, and to others discussed below, Aerojet is handicapped by the fact that the content and details of the subject test programs, and the results to date, have not been made available nor discussed with the Company. In regard to the specific recommendation above, incorporating alternaives into the test program represents a sound philosophy and one that too often is omitted because of the pressures of schedule and budget limitations. In particular, the consideration and testing of the best alternatives proposed by the other solid rocket propoulsion companies should be included in contingency planning.

NRC Recommendation: Page 3, First Para: "...alternatives be established and special emphasis be placed on early meaningful tests of the (case-nozzle joint) design."

Aerojet strongly agrees with this recommendation. As pointed out in the recently-completed Block II Design Concept Study Report (AG-SRM-001, Vol. I), the proposed design with its 100 radial bolts is not the design solution favored by Aerojet. The Aerojet design incorporates a positive sealing feature which is not dependent upon the radial bolts, but instead closes at the primary O-ring seal upon pressurization. The current modification must be considered as strictly an interim fix, and must be well verified in both full scale static test firings and bench-level load simulation tests.

NRC Recommendation: Page 4, Second Para: "...NASA establish and maintain a directed program for continued evaluation and improvement in reliability... and preplanned block changes to the flight hardware to provide opportunities for incorporating desired improvements."

This is an important recommendation and one which is strongly supported by Aerojet. The Aerojet design approach to safety and reliability in large boosters for manned space flights features the single-piece propellant grain, whereby all case joints are sealed by a protective insulation system without joints and further covered by the propellant itself. This approach fits perfectly within the context of the NRC recommendation which goes on to state that "...completely new designs, possibly radically different from the current one, may be preferred;" and that..."(the) program cannot afford to continue to rely on older technology indefinitely into the future...we (NRC), believe that NASA should vigorously pursue a program to develop the next and future generations of motors. ..." Aerojet feels that funding and direction for developing and verifying the technologies proposed for boosters having substantially improved reliability must begin now if we are to achieve the goals envisioned by NRC.

The several NRC recommendations on technical issues, pages 5 through 7, deal with issues upon which, as stated earlier, Aerojet has not been adequately briefed as to plans, results, etc. All NRC recommendations are based upon sound engineering and technical assessment. Therefore the comments below will only highlight areas, or concerns, where Aerojet departs from, or strongly supports the NRC position.

Regarding the Case Joint - We strongly share the NRC concern regarding problems associated with refurbishment, inspection, and re-use of the new case joint.

Regarding Nozzle Ablative Materials - Aerojet's understanding of the proposed changes to the nozzle ablative liner(s) design concludes that the re-design will result in the desired improvements and the correct approach is being followed. The materials involved are all well characterized and proven and little would be gained from a series of sub-scale tests.

Regarding Analytical Predictions and Success Criteria Establishment Before Each Major Test - This is a critical element of the NRC report and one which shoud be vigorously enforced. Test programs of aerospace components and systems routinely incorporate these requirements.

Senator RIEGLE. Thank you very much, Mr. Brown. I know Aerojet has been working on this and it sounds like that is a very interesting approach that you are suggesting to us.

Mr. Crosby, you are with United Technologies. Let us here from you now.

Mr. CROSBY. Mr. Chairman and distinguished members of the committee, I have submitted a fairly lengthy response to the four primary issues that you asked us to address, so I will summarize each one of those in my response.

Before I address those four issues in turn, I would like to have it clearly understood that with regard to the planned redesign activity on the booster, we have not had any formal involvement in that redesign activity. And so the opinions and the perceptions and the views that I am going to offer here today are really based on the informal exchange of data that we have had with the NASA redesign team, on a rather frequent basis, but it nevertheless has been an informal involvement.

On the basis of those general understandings, though, we feel that the redesign concepts that are being——

Senator RIEGLE. Let me stop you there. That is an important point. Ought we to be moving beyond the informal stage?

In other words, for you folks to really be in a position to do the kinds of serious work to develop an alternative opportunity here, do you need something more than an informal contact and should we have something in place that is different than that?

Mr. CROSBY. Let me answer that this way: Shortly, very shortly following the *Challenger*, my company, and I suspect the rest of us here at this table, all offered our services to NASA, offering to come in in whatever capacity was reasonable to participate in the recovery activity.

The decisions were made that this sort of involvement should be handled, apparently, on an informal basis. In other words, there was no follow-up on the offers to be formally involved to my knowledge.

Senator RIEGLE. Is that true for the rest of you at the table?

Mr. BROWN. Yes. We actually have participated twice in a review of the design here that was gone over earlier, but we did come in even before the opportunity to do that and actually gave NASA lists of our specialist people in specific technical areas and said: These people are available to help you. If you want them to help you, please let us know. We were never asked specifically for any one of those individuals.

Senator RIEGLE. Let me just on that point, Mr. Thompson, you are still here in the room. We have all conferred among ourselves and we are a little concerned about that because, it seems to me, that if we are going to let ourselves move down this alternative track, even if we are for the time being going to work with a modified existing design, that these people have to be involved in a far more direct workman-like way.

Can you throw some light on that as to why these relationships have been "informal"? Should we be thinking about crafting something that creates a more formal relationship so that we can really harness this creative thinking in a way that, if there is a better design out there, we really can find it?

Mr. THOMPSON. Certainly, sir, we want to get that. Of course, the studies were formal. They were contracted by us. I personally have been involved with discussions with, say, Hercules management in getting them actively involved with Thiokol.

I think there are some 30 or 40 engineering people that are assisting us in that task and have had UTC down to brief me on the NDE, the nondestructive evaluation, as a part of their Titan work, to make sure we fold that in.

Any formal contractual arrangement beyond that, to me in the short term should be folded in with the contractor—we've got, Thiokol, I believe, and Atlantic Research and Hercules. We have done that and it is not trivial. It is a substantial number of engineering people.

Over and above that, this Block II has to be a very aggressive activity if, indeed, we pursue that. And that will become very formal.

Senator RIEGLE. That is really what I am addressing. I am addressing Block II. I am not surprised that you have had the other sort of interim relationships, particularly with Hercules.

I am really raising the question with respect to Block II. We ought to be moving on Block II now. What are we waiting for?

Mr. THOMPSON. We have gotten, I think, five excellent reports. We need within NASA in a very short period of time to digest this so we can come up with a plan that makes sense to Jim Fletcher and then back to you.

Senator RIEGLE. Why shouldn't there be at NASA somebody who is a take-charge person like yourself who isn't distracted by a lot of other things but whose job it is to take and drive this Block II process and to work with these folks and make sure that they are able to move at top speed so that we can find a superior design, that we can have it and start to move to bring it on line?

Mr. THOMPSON. I have elements within my organization to do that. We are on a very fast track to get our recommendations back into Dr. Fletcher. Within our project office, separate individuals, and within the John Thomas Redesign Engineering Team, people now that are dedicated to evaluate the merits of these proposals, now taking off and going to school on what we now know of our current joint.

Senator RIEGLE. Am I wrong in concluding that the Block II activities, though, are still in the informal stage rather than beyond that?

Mr. THOMPSON. The alternate study stopped. They furnished their reports at the end of December. We are in a hold period now for us to digest that and get back to you with a recommendation. We plan to do that by the end of March.

Senator GORE. Could I pursue this point while you are still at the microphone? Going back to the baseline redesign aspect of it for a moment, I am given to believe that the companies represented on this panel are, indeed, deeply involved in the Block II part of it.

This contract promises to be the biggest contract in the world. It is a source of a great deal of interest and they have been deeply involved. But on the baseline redesign, what Mr. Crosby just said and the others have agreed with, is that there was a kind of an informal and low intensity participation or review by these other companies of the baseline redesign.

Now, that strikes me as curious because normally if you have an event like this, there is an industry-wide redesign. In this case there was none.

Now, first of all, do you think that that is wrong? Second of all, is it because the keen interest in the biggest contract the world has ever known produces a desire on the part of all of the competitors to acquiesce in this sort of informal paper review of the baseline redesign and not aggressively push for an industry-wide redesign?

Mr. THOMPSON. What I have seen from the industry, they have come to me and ask how can they help. So we stay coherent on this, I have gotten Thiokol and their top management together. There are areas that they can help and are doing that.

I have talked to UTC, for example, to make sure I have got the continuity of the Titan information. I believe we are doing everything that is productive now on the baseline.

Senator GORE. Do you believe there has not been the kind of industry-wide effort that would be expected after the event of the kind we had?

Mr. THOMPSON. We have a good bit going. It is not industry-wide. One big team on the redesign, that is true. Thiokol is taking a lead on that. They are drawing on several of the other companies. We in NASA are pushing that, very much encouraging that.

Senator GORE. Did you provide them access to the subscale test data? You never got to that level of detail, did you?

Mr. THOMPSON. I don't believe so.

Senator GORE. Isn't that unusual?

Mr. THOMPSON. We have got a lot of folks looking at that.

Senator GORE. Isn't it unusual for there not to be industry-wide attention to that level of detail during a redesign of this magnitude?

Mr. THOMPSON. You know, it is hard to say when you say of "this magnitude" because this has been a very tragic. It has been a big failure. In other failures, say in propulsion systems, let me speak there, we have our liquid systems, Rocketdyne where we have problems. We bring in Pratt & Whitney for isolated problems and they have been very helpful. And now we have even expanded that and involved them in our alternate turbo pumps.

We haven't done it in the solid rocket motor to that degree. We have gotten them involved more for the bigger job long haul and not so much a big new team for just a short term. We have more here tried to pick in certain areas.

I don't want to play down the paperwork the FEMA/CIL part and all that, where independent eyes can go back and look at it later.

Senator GORE. They are playing it down. From what I know about it, it seems appropriate. I think the subcommittee ought, as a result, take with a big grain of salt the uniform endorsement of the redesign by all of the industry participants who acknowledge that they have only had an informal paper review, but I am using too much time at this juncture. I appreciate the Chairman's indulgence.

Senator RIEGLE. It is important that we pursue these things and that we do it where we can cross connect these observations between the contractor community and NASA. We are going to do more of that as we go along.

I want to make one observation that hasn't been made along the line today. That is, as I have attempted to understand the strategic implications of NASA's whole effort in the accident since the time that all of this took place, it has become clear to me that if we were to have another accident of this scale and to lose one of the remaining three shuttles, that for all practical reasons we are out of the space business for a very long period of time.

In fact, our capacity now is so low, until we can replace the orbiter that we have lost, that we have had to stretch out our program. There are all kinds of things that we are not able to do and so forth.

Should we lose another one, I think apart from the loss of life, as tragic as that would be, the strategic damage to this country in terms of our ability to function effectively in space is almost beyond description and calculation.

So the issue of solving this problem right in the short run, so that it works and that we don't, due to a repeat of the same reasons or other reasons, lose a shuttle at this point, is something of the highest urgency for this country.

So we cannot miss this next time around. And that is why I think all of us are saying that if the schedule has to slip, you let the schedule slip because when we go, it has to work. And because the front-end test here is so critical in terms of that next launch working successfully, which is why you have come back into the government to lend yourself to it, this is such that I really think we have to find a way to incorporate the industry-wide know-how to the maximum possible extent.

And that is not easy. It is a lot easier to say it than to do it. There is a lot of internal momentum, the contract relationships and what have you, but that was part of the problem in the past. I mean, that is one of the reasons that an avoidable accident happened.

So I feel very strongly that we have got to realize that this capability, which is, the national program, and national interest, is on the line. The strategic interests of every citizen of this country is at stake in our ability to perform.

And I want to see to it that every last key element of what we have as a nation to apply to this problem is applied. I am not too sensitive about people's feelings or momentum or for that matter even long-term contractual relationships because I think when you have got as much riding on it as we do, we have to have the amalgam of every last bit of talent coming to bear on this thing, both the redesign of this joint, if we are going to use this again, and the design of the possible new alternatives in Block II.

So it is just my personal feeling. And I think my colleagues probably share that view from what they have said.

The CHAIRMAN. Very definitely.

Senator RIEGLE. Mr. Crosby, we have interrupted you, so why don't you continue.

Mr. CROSBY. I see my time is up. However, I would like to make a couple of points. First of all, the intent of my comment there was not to criticize but to point out, as obviously has been substantiated by Mr. Thompson, that we have all participated, but on an informal (as opposed to contractual) basis.

My intent really was to make it clear that we do not have detailed information in some areas. So when I make an observation relative to an aspect of the current redesign activity, we are making that observation without having participated in the detailed analysis. That was really my purpose.

Again, on that basis, I would like to say that our position, the position of the people who have spent a good deal of time with J.R. Thompson and his people is that this redesign has corrected the problems that we know existed in that joint.

The issues of mechanical rotation, the temperature sensitivity, those issues we believe are in hand. And we think that this current joint will—let me put it this way—work as well as any joint will ever work in a solid rocket motor.

We, however, do believe that it is possible to design a motor that perhaps offers a high reliability and might be safer for the type of operation that the space shuttle is intended for, and that is to hopefully some day return to the time when we don't have to depend upon professional test pilot military crews to fly these, so we can really go back to the nonprofessional man in space type of operations.

On that basis, we suggested in our Block II study that an alternate design should be considered. And I will say just a few more words about that, but I would like to comment on a couple of other issues here that you have referred to that we will get into in the full testimony.

With regard to the test program, and I would like to sum up our feelings about the test program by saying that perhaps as an illustration of the fact that we are not as close as we might like to be in the program, we were under the impression that we were dealing with three motors in the test program. I learned today that we now have five, perhaps six before we fly again. I am much encouraged by that number of tests.

As a matter of fact, we feel that the test program is entirely adequate with the qualification that the motors be subjected to the real environment that they will see in flight. That means structural, temperature, all of the loads that they will see. And with those qualifications, we think that it is a realistic test program.

We are concerned with the planned installation of a second test facility at Morton Thiokol. I would just like to comment that I think that facility should be viewed as a national asset, and perhaps in that sense might be better located at a government installation much as is being done by the Air Force on the Titan program that we are currently working on.

Let me move on very quickly, in the interest of time. I would like to say that there are some aspects of a Block II motor that we believe should be seriously considered that have to do with increasing the potential for safety. These are systems that, while they might be serious technical challenges, we think should be very diligently examined, systems that would permit termination of the solid rocket motors in the event of a malfunction during the boost phase of flight.

Back in the late 1960s when the manned orbiting laboratory program was being considered by the Air Force, we designed such thrust termination systems into the Titan boosters that would have been used on that program. We believe that they should be reconsidered and every effort should be made to try to incorporate a system of that type on these boosters as soon as possible, not necessarily before we resume initial flights, but before we get into operations with nonprofessional personnel again.

On the issue of the Block II design motor itself, we find ourselves in the situation of agreeing that a monolithic rocket motor today, we believe, makes more sense for this type of operation. The approach that we would take to this type of a motor uses exactly the same hardware that is in the inventory today. We would install a continuous seamless layer of insulation on the interior surface of that motor and cast a propellent grain in one piece, transporting the motor with existing equipment, as you have heard Mr. Brown describe.

We believe all of those things are entirely practical and possible today. We believe it would contribute to lower cost in the program, for many of the same reasons that Mr. Brown mentioned, such as reduced turnaround time during the solid motor build-up phase of operations.

We think it is an approach that needs to be very seriously examined. We personally believe it is a good way to go in combination with a system that would permit turning off the rocket motor in the event of a problem.

And I think I would like to just close my summary comments at that point.

[The statement follows:]

STATEMENT OF HARRY L. CROSBY, VICE PRESIDENT OF BUSINESS DEVELOPMENT FOR UNITED TECHNOLOGIES CORPORATION'S CHEMICAL SYSTEMS DIVISION

Mr. Chairman and distinguished members of the Science, Technology and Space Subcommittee; thank you for this opportunity to express our views on the on-going space shuttle solid rocket booster recovery activities, and on the current planning for alternative solid booster development and second sourcing. My testimony will begin with a brief description of my company's qualifications, then continue with comments on each of the four topics identified in your invitation.

Chemical Systems Division (CSD) has designed, developed, and manufactured solid propellant rocket motors since the late 1950's. We have extensive experience, unique to ourselves and Morton Thiokol, with large segmented rocket motors. CSD is responsible for the entire Titan segmented solid motor booster stage and has produced well over 150 of the Titan Boosters under fixed price contracts at CSD since 1965. Because of our background in large segmented solid booster technology, we have participated by NASA request in a series of meetings and reviews with the shuttle booster redesign team, exchanging information on segmented motor design and performance. These meetings have provided us with a general knowledge of the current redesign concept and some aspects of the anomaly investigation and redesign validation test program. My testimony today is based on both CSD's background in segmented solid rocket technology, and on our current general understanding of the shuttle booster redesign effort.

I will first offer some general comments on the on-going effort to redesign the segment field joints and nozzle attach flange joint. It must be understood that CSD is not directly involved in the redesign effort. Therefore, our understanding of the planned design improvements is based entirely on data exchanged during meetings and conferences with the booster redesign team. On the basis of our understanding, we feel that the selected concepts adequately address the previous joint sealing and associated mechanical rotation (displacement) problems. The previous segment field joint and nozzle joint designs were susceptible to leaking and potential burn-through when subjected to the combined effects of excessive displacement of sealing surfaces due to motor operating pressure, unusual (narrow) O-ring gland design, and limited resilience of O-ring material with cold temperatures. The redesign effort has addressed and appears to have significantly improved the joints in these previously deficient areas. In addition to addressing known problem areas, the redesigned joints incorporate redundant features to further protect against mechanical displacement and leakage.

We believe that the current redesign activity should result in solid rocket boosters that will permit a resumption of flights to support National Priority missions in the 1988 to 1992 time period. At the same time we are concerned that the redesigned boosters will present cost and assembly problems as a result of the complexity of the redesigned joints. We are convinced that a Block II booster can be developed to support flights in the early 1990's that will have higher inherent reliability and will cost much less in terms of both basic manufacturing cost and the costs incurred during shuttle vehicle assembly at the launch site. I will expand on this thought later in my testimony.

Our comments on the proposed testing program for the current booster redesign effort fall into three categories. First, we feel the materials and component tests currently in progress will provide important information and will help establish necessary final design details. We believe that this program is adequate as presently planned.

In the second test category, that of full scale motor firings, we feel that three (3) full scale tests are sufficient to confirm the adequacy of the design improvements if the motors are subjected to loads and conditions that are realistic and fully representative of preflight and flight environments. We consider truly representative motor test structural load and environmental conditions to be the key element in successfully confirming the adequacy of the redesigned motors to support a renewal of flight operations. We will continue to monitor the planned test program and will offer suggestions and recommendations based on our experience where and when we believe it is appropriate.

Third, with regard to the planned installation of a new motor test facility at the Morton Thiokol plant in Utah, we feel that such a facility should be viewed as a national asset. Therefore, it is more appropriate that this test stand should be located on an existing government (NASA or Air Force) facility as has been done at the Air Force Rocket Propulsion Laboratory in support of the Titan program. The new test facility would then be available to other organizations to support an alternate (Block II) shuttle booster, second source qualification, or other future booster development program.

Having addressed the current booster redesign effort and the associated test program, I would now like to comment on alternative shuttle booster design concepts and activities. CSD, supported by other UTC divisions with relevant capabilities, initiated company funded improved shuttle booster studies immediately after the *Challenger* tragedy. These studies have continued through the NASA funded Block II Shuttle SRM Conceptual Design Studies, and have convinced us that improvements in reliability, safety, and cost are available from a second generation solid motor design. The design that we have recommended to NASA in our final report for the "Space Shuttle SRM Block II Conceptual Design Study" under NASA/MSFC contract No. NAS8-37300, dated 2 September 1986, provides the above mentioned improvements while utilizing most of the existing and planned inventory of motor case hardware and booster subsystems.

The recommended CSD design will solve the field joint leakage problem by converting all field joints to factory joints as now exist in the current booster. The factory joints are protected by a continuous layer of vulcanized rubber insulation that precludes any possibility of joint leakage. In this design the current segmented propellant grain is replaced by a "monolithic" or one piece propellant grain that is cast into the existing motor case segments after they have been joined together and insulated with a seamless insulator which has been vulcanized to the interior surface of the entire motor case.

Additional design improvements will provide higher performance for a "heads-up" flight trajectory and for increased payload. CSD studies have also included detailed investigations of one piece motor processing, shipping, and handling. The results indicate that the monolithic motor concept is practical and that the required handling and logistic equipment and techniques are available. The initial investment in the monolithic motor design will pay off not only in improved reliability and safety, but also in overall cost savings that result from greater payload capacity, reduced vehicle assembly time at the launch site, and lower manufacturing cost.

We strongly recommend that a Block II booster development program be started with FY'88 funding, with the firm objective of introducing a more reliable, higher performing, and lower cost monolithic solid booster motor in 1992. This schedule will support projected requirements for Space Station deployment and provide a significant improvement in critical aspects of space shuttle operations.

Finally, I would like to comment on the issue of second sourcing. CSD has been vitally interested in the space shuttle solid rocket booster program since the original competition in 1973. We have supported all of the studies to date on second sourcing and will continue to do so. However, it is our view that any decisions relative to second sourcing should be delayed until the current booster redesign effort has been completed, the shuttle is flying, and an improved Block II booster design has been selected and has progressed far enough in its development cycle to provide confidence that major design changes will not subsequently be required. Even then, the real economies of a competitive second source should be compared to the cost of a single source under a *fixed price* contract. As stated earlier in my testimony, CSD has produced Titan solid rocket motors that are very comparable to the shuttle solid motors under fixed price contracts for over 25 years. We believe that cost reimbursement type contracts are inappropriate for programs of either the current or Block II SRM type and that lower overall program costs will result from fixed price contracting for economic production quantities. In the final analysis, any decision to proceed with second sourcing should be based on comparison of the real costs of establishing and maintaining multiple sources compared to the cost of fixed price contracting for larger and more economic production quantities.

This concludes my prepared testimony. I will be happy to answer any additional questions that I can.

UNITED TECHNOLOGIES CHEMICAL SYSTEMS

P.O. Box 50015
San Jose, CA 95150-0015
408/778-4371

Harry L. Crosby
Vice President
Business Development

1 April 1987
HLC-055-87-BD

Honorable Donald W. Riegle, Jr.
United States Senate
Chairman, Subcommittee on
Science, Technology and Space
Committee on Commerce, Science and
Transportation
Washington, D.C. 20510

Dear Senator Riegle:

Please accept my apologies for the delay in answering the subcommittee's questions which were addressed to me in early February regarding the space shuttle Bloc II booster program. The attached answers to those questions represent the current position and recommendations of Chemical Systems Division on these important subjects.

We at CSD agree wholeheartedly with your opinion that the solid rocket motor industry as a whole must be involved if the space shuttle is to resume safe flights in a reasonable period of time. In that regard, we have eagerly accepted a request from Marshall Space Flight Center Director James R. Thompson and have appointed a very senior and highly experienced solid motor technical expert to support NASA's reviews of the shuttle booster redesign and test/verification program.

I would like to thank you and the other members of your subcommittee for the opportunity to express our views and recommendations for the future of the shuttle SRM program. I also want to assure you of our willingness and desire to continue to work closely with you and the NASA team in the future.

Sincerely,

United Technologies Corporation
CHEMICAL SYSTEMS DIVISION

Harry L. Crosby, Vice President
Business Development

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CSD ANSWERS TO

"QUESTIONS FOR THE RECORD"

Answers to "Questions for the Record" addressed to Harry L. Crosby, Vice President, Business Development for United Technologies Corporation, Chemical Systems Division resulting from January 22, 1987 shuttle solid rocket motor redesign and Bloc II hearings before the United States Senate Committee on Commerce, Science and Technology in Washington, D.C.

1. On March 31st, Dr. Fletcher will provide this Subcommittee with a Long-Term Procurement Plan for solid rocket boosters. At that time, NASA will indicate whether or not a Bloc II solid rocket motor will be procured.

   Question:

   If NASA decides to proceed with a competitive Bloc II procurement, is there a consensus on this Panel that any Second Sourcing decision should be delayed until the Bloc II motor is designed, developed, tested and flown?

   CSD Answer:

   The Bloc II solid motor program will require a major commitment of resources to development, equipment, and launch facilities. While it might be possible to reduce the cost of qualification of a second source by integrating second sourcing activities during the Bloc II development phase, it may be more cost effective in terms of available annual funding to delay the introduction of a second source until after the Bloc II motor has been qualified for flight. This may be particularly true in the case of a monolithic configuration for the Bloc II motor wherein a major investment in production facilities and handling equipment will be required of either NASA or the selected Bloc II contractor.

   If, as CSD has recommended in its Bloc II study, a monolithic motor configuration is selected, an option which we believe the NASA should seriously consider is that of a Government Owned-Contractor-Operated (GO-CO) manufacturing facility to produce the solid motors. In this approach, the selected motor development contractor would be responsible for the design and construction of a cost effective manufacturing plant as well as for the design and qualification of the Bloc II monolithic solid motor. Since the production plant and the solid motor design would be owned by the Government, a competition could be conducted on a bi- or tri-annual basis to select the lowest priced operating contractor to produce a given quantity of motors once the new motor has entered production.

Such future operating contractor competitions would occur only after the Bloc II motor was fully developed and qualified for flight.

Question:

If a Second Source were pursued, would each of you bid if it were a fixed price contract?

CSD Answer:

If a Second Source for the existing Shuttle SRB is pursued, Chemical Systems/United Technologies would have to carefully evaluate the future potential of the program relative to any required investment in facilities. Our decision to bid would be based on our assessment of the economic potential for reasonable return on investment. A fixed price contract would be the usual and expected contract type for a production second source contract of this type.

2. There has been much discussion today concerning the scope, timing, and schedule of the proposed solid rocket booster test program.

Question:

Based on your experience, how many full-scale, qualification motor tests should be run prior to the first flight?

CSD Answer:

Full scale testing should include a sufficient number of tests conducted at a sufficient number of conditions to demonstrate the ability of the motors to perform at conditions which exceed the operational environment of the system - that is assure that "demonstrated margins of safety" exist. The quantity of tests for qualification (assuming no development tests are required - new nozzles, insulation systems or propellants) would be predicated on the following:

1. Test at high temperature - demonstrate operation at maximum pressure.

2. Test at low temperature - demonstrate insulation and nozzle survival at maximum duration.

3. Sufficient replicate tests at ambient to demonstrate reproducibility.

These tests would total about 4 to 6. However, superimposed would have to be load simulation tests and the evaluation of potential failure modes in the critical field joint interfaces. These additional test requirements might add 1 to 2 full scale tests. A critical failure modes analysis would help define the various potential problems that need to be addressed.

Question:

Do you feel the new horizontal test stand at Morton Thiokol can duplicate the loads and conditions associated with the actual flight experience?

CSD Answer:

The horizontal test stand at Morton Thiokol should be capable of duplicating or bounding many of the loads associated with launch and flight. A thorough loads analysis and test stand evaluation is needed to determine if all critical loads are imparted to the test motors.

Since the motors will be assembled in a horizontal orientation normal flight build-up is not duplicated. Also, the motor will sag prior to motor ignition - again a condition that does not exist at launch.

Question:

Based on your experience with solid rocket motors, are there any non-destructive examination techniques that can be used to verify the structural integrity of the redesigned solid rocket motors and the bonds between the case and the insulation?

CSD Answer:

The Titan 34D recovery program has developed a number of automated and semi-automated NDT methods of 100% inspection of the loaded propellant segments - most of these could be applied to Shuttle SRM's.

A critical part of Shuttle's integrity is the assembly of the field joints and the bonding of the interfacing segment insulators - this is a blind operation with no post assembly inspection possible. Leak tests can be conducted on O-rings but this will not identify potential failure modes existing in the insulation interface. Tight controls will be needed on assembly procedures to minimize the chance of a problem developing. This again is why the full scale testing must address potential non-detectable assembly problems.

3. There has been and continues to be much discussion about the technical merit of monolithic solid rocket motors versus segmented solid rocket booster motors.

Question:

Have you done trade studies of the technical merit of monolithic motors versus segmented motors? What are the tradeoffs?

Do either offer the reliability required to support a manned program?

CSD Answer:

We have completed trade studies of monolithic motors versus segmented motors and have presented the results of these studies to NASA in our Bloc II booster study final report. Our results show that the monolithic motor offers higher potential reliability and lower cost, along with an increase in performance for the STS application. Our studies indicate that while either a segmented or a monolithic solid booster can provide the reliability needed to support a manned program, the monolithic approach offers significantly higher potential reliability and should therefore be seriously considered for manned programs.

Question:

Based on the Challenger and Titan investigations, has industry's understanding of solid rocket motors been dramatically increased to where more reliable motors can be manufactured? Will there ever be a solid rocket motor that is "fail safe" for the two minutes it burns during space shuttle flight?

CSD Answer:

The Challenger and Titan investigations have produced information and inspection techniques that can be applied to improve the reliability of solid rocket motors in the future. We believe that the application of this information and the use of the new NDT techniques in combination with new safety systems will provide solid rocket boosters that can approach the goal of being "fail safe." A monolithic booster will inherently be closer to this goal than will a segmented booster.

4. You are familiar with the National Research Council Panel's technical assessment of the proposed redesign and comments on the need for contingency planning and a better defined and more thorough test program.

Question:

Would you please comment on the NRC recommendations, especially those recommendations concerning the need for a better defined and more thorough test program and the establishment of a priori criteria by which to evaluate the tests?

CSD Answer:

The NRC recommendations can be grouped into the following general categories:

1. Increase and strengthen contingency planning for incorporation of alternative designs and materials if required.

2. Establishment of a priori test criteria based on the most current data and analysis available against which each subsequent test will be evaluated and any deviations or discrepancies fully and completely explained.

3. Increased subscale testing of all critical design areas and materials.

4. Provision for a second test stand fully capable of simulating all predicted flight loads and conditions.

5. Additional full scale tests prior to first flight.

CSD agrees in principle with these recommendations and suggests only that each recommendation should be re-evaluated as the re-design effort proceeds to prevent unnecessary effort where it can be shown that such effort is unlikely to provide any real advantage vs the selected baseline approach.

We are in complete agreement with the recommendations calling for additional subscale testing and for re-evaluation and updating of all models and analytical techniques on the basis of test data as it is developed. We concur with the recommendations that a new test stand, fully capable of simulating all flight conditions be provided. However, we urge that this new test stand be constructed on a government facility as opposed to Morton-Thiokol property.

Finally, we are also in agreement with the recommendations that qualifications tests number 7 and 8 should be completed prior to the first flight with the re-designed boosters.

Senator RIEGLE. Thank you. Mr. Mettenet.

Mr. METTENET. Thank you, Mr. Chairman, members of the committee. I am Ernest Mettenet, president of Hercules Aerospace Products Group. Hercules is the largest manufacturer of solid rocket motors for the Department of Defense.

As a natural extension of this, we have for the past five years been aggressively promoting the introduction of competition for SRMs. Specifically, we have been preparing to compete for the shuttle rocket motors as a second source contractor.

This preparation has included technical design, schedule and cost analysis and, more importantly, a commitment by Hercules Incorporated to build and have in place a $150 million dollar solid rocket motor plant, the most modern in the free world.

It was designed and built for three or four principal directions. One, safety of operations. Two, built-in low costs, and reliability and quality. We feel with this rocket motor plant, we can build the lowest cost production motor today.

Now, our specific involvement with NASA and the shuttle, we were selected to develop the filament wound case for the SRM program. During this program, we developed the so-called capture feature for the SRM field joints. A modification of the capture feature has been talked about today. We also were awarded one of five SRM Block II design study contracts, which were recently completed.

On this contract we reported on a number of alternate design configurations that offer improvements in performance, reliability and safety. In addition, like the others, we have supported the Marshall Space Flight Center on several occasions to assist in the investigation of space shuttle motor variations and anomalies.

I, too, have got to qualify my remarks by stating that we have not been under contract for direct participation in formulating the SRM joint redesign nor the test flight. Our understanding of the technical problems, solutions and results are derived from the above participation.

Lacking the details of the test results, we cannot provide a complete technical evaluation of the proposed redesign. We believe that the NASA redesign joint configuration can support recovery to a reliable operational status. Test plans and results must confirm that design adequacy.

We believe the proposed NASA joint redesign can meet the manned space flight criteria and the reduced movement expected in the redesigned seal elements and use of the captive feature are very positive steps.

The adhesive method for joining the insulating material between segments will do the job, assuming the assembly operation is error free. However, it will be difficult to ensure a perfect bond each and every time. And there are proven design techniques that do not require this critical assembly and inspection operations with the adhesive bonding approach.

A new nozzle joint should be eventually incorporated with a closing feature to avoid the radial bolts. The incorporation of these features could be either through second sourcing now or through Block II competitions.

Again, we lack the require detailed information to fully evaluate the test program. It does appear that a thorough subscale component level test program has been conducted. Lacking sufficient data on the full scale test plan, we can only make the recommendation that the final redesigned flight configuration be incorporated in every full scale test used to certify motors for flight and that test be conducted at the temperature extremes.

Relative to the second source issue, we believe that a second source should be under contract during the development and qualification for the redesign Block I motors. We also believe that this timely contractor selection would provide the greatest benefits to the system in terms of schedule, cost savings and the availability of technical resources to support an improved recovery program.

We are convinced that simpler and lighter weight nozzles, cases and other components can be designed based on information from existing STS flight history and the strategic missile database. In addition, improvement in the propellent charge would improve mission capability.

As I mentioned earlier, Hercules has invested in facilities for this competitive production. These facilities are operational and ready to go.

Finally, we believe that the segmented motors and monolithic case remain the correct choice for the shuttle system. Safely handling and transporting over one million pounds of propellent in one unit presents some very, very special problems. The unit is basically propulsive in that state and you have a million pounds of it. You also have the problems associated with inland waterways, high traffic level and this propulsion unit in the waterways or the Panama Canal.

The monolithic rocket motor would require extensive and expensive on-site modifications which would induce schedule delays with no net systems benefit. In addition, the monolithic case would still require two major field joints which must undergo the same scrutiny required of any joint seal.

O-rings in our industry are not a big problem. Cold flying rocket motors in our industry are not a big problem. Every strategic motor has O-rings. Properly designed with an closure-type capture feature at a field joint, it is technically within our technical capabilities.

Thank you, Mr. Chairman.

[The statement follows:]

STATEMENT OF ERNEST A. METTENET, PRESIDENT, AEROSPACE PRODUCTS GROUP, HERCULES, INC.

Thank you Mr. Chairman and good afternoon ladies and gentlemen.

I am Ernie Mettenet, President of the Hercules Aerospace Products Group. By way of background, Hercules is the largest manufacturer of solid-rocket motors for the Department of Defense. As a natural extension of our DoD rocket motor involvement we have, for the past five years, been aggressively promoting the introduction of competition for solid propulsion space launch motors. Specifically, we have been preparing to compete for the shuttle booster motors as a second source contractor. This preparation has included technical design, schedule and cost analyses and the construction of a new automated facility capable of competitively manufacturing shuttle SRM boosters. This state-of-the-art facility, built with $150 Million dollars in corporate funds, is the largest, most modern complex of its type in the free world and was designed to optimize safety and provide the highest quality and most reliable product at the lowest possible cost.

Our specific involvement with NASA and the Shuttle program includes our selection to design and develop the Filament Wound Composite Case for the shuttle booster motor. During this program we developed the so-called capture feature for the SRM field joints to reduce the movement of field joints that occurred at SRM ignition. A modification of this feature is being developed for incorporation on the redesigned case that is the subject of this hearing. We were also awarded one of the five NASA SRM Block II Design Study contracts which were recently completed. On this contract, we explored and reported on a number of alternate design configurations that offer improvements in performance, reliability and safety for the shuttle SRM. In addition, we have supported the Marshall Space Flight Center on several occasions with technology and technical expertise to assist in the investigation of space shuttle motor variations and anomalies. However, I must qualify my following remarks and comments by stating that we have not been under contract for direct participation in formulating the SRM joint redesign nor the test plan. As a result, our understanding of the technical problems and solutions is derived from our prior participation in the Filament Wound Case Program, the Block II study, our activities in preparing for a Second Source competition and the limited data released by Marshall Space Flight Center on the subject of redesign.

I would now like to direct my comments toward the specific topics outlined in your invitation for testimony.

NASA REDESIGNED BOOSTER

Lacking details of test results, we cannot provide a complete technical evaluation of the proposed redesign, but do have some recommendations based on our experience and understanding of the SRM. Based on this understanding we believe that the NASA redesigned joint configurations can support recovery to a reliable operational status provided the test results confirm design adequacy.

Hercules recognizes that the designed options incorporated in the proposed booster redesign have been constrained by schedule. The principal constraints have been the need to avoid the long lead times associated with significant changes in the major forgings required to manufacture the case and construction of the necessary structural testing facilities as well as the time needed to conduct full scale verification testing.

The proposed redesigned joint solution, as we understand it, has taken steps to reduce the movement between sealing elements through the incorporation of the capture feature. Reducing movement of the seal is a step in the right direction; in fact, elimination of this movement is desirable and achievable through design options.

The proposed adhesive method to be used in joining the insulator material between segments at the field joints is an approach to provide an additional sealing element upstream of the primary joint seals, designed for that purpose. This approach, if accomplished in a stacking process 100% of the time, will certainly do the job. However, the difficult task will be to insure that a perfect seal is accomplished each and every time. From our point of view, inspection and certification of the bonded insulation joint represents a difficult task that deserves maximum attention by the NASA redesign team. Additionally, destacking of an assembled motor, as sometimes occurs, also presents challenges when separating the adhesive joint, as bonds must be broken in the process which subjects the segment insulators to damage.

Finally, the redesigned nozzle joint incorporates an approach to reduce seal movement through the inclusion of a number of radially oriented attachment bolts in a location between the two nozzle joint sealing elements. As a result, each bolt must also be individually sealed to provide for redundancy. We would encourage the NASA redesign team to thoroughly evaluate or reevaluate other concepts for the seal which don't rely on individually sealed bolts, and we recommend critical attention to the precise definition of and adherence to assembly procedures, since the assembly of such a joint is critical to its proper function. We further recommend a broad testing program to evaluate the nozzle joint/seal under various loading and assembly variables if such plans are not a part of the existing recovery program.

TEST PROGRAM

We lack the required detailed information on the test program to fully evaluate. However, based on our limited knowledge, it appears that a thorough subscale component level test program has been conducted on the selected redesign configuration. It is reported that the tests have successfully reproduced the failure mode for the *Challenger* anomoly and have demonstrated that the redesigned case joints have performed successfully within the same test condition parameters.

The structural testing of full scale components is constrained by facility capabilities and schedule. We believe the stated design objective to provide equivalency of the joint sealing and strength to the case wall is proper, and that a demonstration of that equivalency along with the statistical variations on margins of safety is an important test objective that should be part of the plan.

We believe that horizontal testing is technically equivalent to vertical testing and can provide all the required loading extremes and, at the same time, avoid damage to a number of components which would result from prolonged acoustic exposure that does not occur under normal flight conditions. Our recommendation would be to ensure that the final redesign flight comfiguration be incorporated in every full scale test used to certify the motors for flight, and that these tests be conducted at temperature extremes.

SECOND SOURCING

We strongly believe that a second source for the SRM is not only desirable, but necessary if the space shuttle is to remain the mainstay of the U.S. space launch capability. Program exposures resulting from a single source of supply for a major component like the SRM presents unacceptable risks for program disruption from a natural disaster or some manufacturing process caused catastrophe. This industrial base capability protection alone is sufficient in our minds to justify second sourcing the SRM. The additional benefits are cost savings, technical synergism and improved product quality.

We believe that a second source should be under contract during the development and qualification for redesigned Block I motors. We also believe that this timely contractor selection would provide the greatest benefits to the system in terms of schedule, cost savings and the availability of technical resources to support an improved recovery program.

Multiple contractor participation at an early date will also improve management flexibility for the government and provide accessibility to a broader range of industrial resources during restart and recovery to full operational status. The second source contractor can be a part of the redesign team and participate in the qualification and verification testing, support initial development flights, provide an independent point of view and, in the process, acquire the necessary program familiarization.

We further believe that competition elevates system effectiveness by ensuring the industry's best technologies are made visible and available to the system during the competitive phases. This provides the Government the opportunity to identify and select the best solutions to satisfy both the recovery program and future operational requirements.

Finally, we note that only through credible competitive opportunity can the Government provide the incentive necessary for industry investment in new and more efficient capabilities. It is this investment which is the foundation for advancement in both technical and manufacturing capability which are needed to drive down costs and still maintain adequate profits for the investors. While there are many examples of the immediate benefits in cost reduction resulting from even the threat of competition, the underlying force which maintains the momentum for improved contractor performance is this investment in improved capability.

ALTERNATE BOOSTER DEVELOPMENT

If, in NASA's opinion, higher performance is required of the SRM then we believe that an alternate booster development program should be initiated with specific performance objectives and improvements. Hercules Block II studies identified a number of design and material improvements that would maintain system reliability and provide significantly higher performance.

We are convinced that simpler and lighter weight nozzles, cases and other components can be designed based on information from existing STS flight history and the strategic missile data base. In addition, improvement in the propellant charge would significantly improve mission capability.

Our schedule and economic studies have shown that any alternative booster development should be accomplished in parallel with Buy III of the redesigned (Block I) motors. Designs for alternative boosters are already underway as a result of the NASA initiative for Block II Design Study programs. As I mentioned earlier, Hercules has invested in facilities for the competitive production of shuttle solid rocket motors. These facilities are operational and ready for either second sourcing the redesigned Block I motors or for an alternative booster development and qualification program.

I believe it is worth a brief moment to note the role that the filament wound composite case could play in meeting increased performance requirements for defense and space station needs. As it is currently configured, this case provides nearly 5,000 pounds of additional payload capability for the shuttle system. While the design has passed all the current verification and qualification tests, testing has been terminated as a result of difficulties with non-FWC test assembly components and the need to support structural testing of the redesigned steel case. There are some minor modifications to the current filament wound case that would be required to bring it into compliance with the new joint design criteria and to maintain compatibility with new steel case components. If the opportunity to optimize the design of the composite case were provided as part of a Block II program, a dramatic increase in performance could be achieved.

We believe that segmented motors remain the correct choice for the shuttle system. Segmented motors enable the transportation of motor segments from any of the established and existing manufacturing sites to both coasts without the risks of open sea transport or the security risk of transport through the Panama Canal. Safely handling and transportation of over 1 million pounds of propellant in a single unit presents some special problems. In particular, under the current proposals, the monolithic case motor would be propulsive during shipment and would develop a high thrust if ignited. Inland waterways, with their high traffic level and population centers, could be threatened under these conditions.

The monolithic rocket motor would require extensive launch site modifications which would enduce significant schedule delays. In addition, successful resolution of new environmental impact issues that would be raised by a manufacturing facility and the case motor transportation problems must occur. Also, monolithic case motors will require two major field joints which must undergo the same scrutiny required of any joint and seal and are no less critical than a segment seal. Any perceived advantage of a monolithic case would be negated by these impacts.

Highly reliable joint seal design utilizing existing and proven technologies are available and commonplace in the solid rocket motors produced in this country. The temperature extremes required for shuttle operations are not a technology challenge to solid rocket motor sealing. Hercules has a wide variety of existing solid rocket motors that successfully operate at higher pressures with more stringent sealing requirements over temperature ranges from −65°F through +350°F.

It must be also recognized that all solid rocket motors require at least two major joints in their manufacture; one at the forward closure and one at the aft nozzle attachment. Design of all joints for a large space booster application must include adequate reliability and safety margins for manned space flight and provision for system safety in the manufacture, transportation and assembly. The motors must be capable of disassembly into a more manageable segment size and made non-propulsive for transportation and launch site handling. These criteria can be met by maintaining the current four segment configuration which would avoid front end system cost and schedule penalties which could delay the recovery program.

CONCLUSION

Ladies and Gentlemen, I would like to summarize what I consider our four most important points. First, it is our belief that the NASA redesigned configuration for the field joints can support a recovery to safe operational status and that proper testing will verify the adequacy of this redesign; second, early selection of a second source provides the Government with a number of short and long-term program benefits as well as providing the competitive framework that will reduce costs; third, we believe that the initiation of an improved performance (Block II) design and development effort for the Solid Rocket Motor represents the greatest opportunity for a maximum payback on the national investment in the space shuttle program; and fourth, the segmented motor remains the only logical choice for solid rocket motor configuration.

Let me thank you once again for giving me the opportunity to place our views before the Government in a direct and open forum. I would be pleased to answer any questions.

HERCULES

Hercules Aerospace Company
Aerospace Products Group
P. O. Box 30181
Salt Lake City, UT 84130-0181
(801) 262-9393

2 March 1987

The Honorable Donald W. Riegle, Jr., Chairman
Subcommittee on Science Technology and Space
Committee on Commerce, Science and Transportation
The United States Senate
Washington DC 20510

Dear Senator Riegle:

Please accept my thanks for again offering us the opportunity to present our viewpoint on matters regarding the procurement of shuttle rocket motors for the space shuttle system. We have carefully considered the questions you have submitted to us and have attached our answers to this letter.

We have for several years been vigorously promoting a more open participation of the solid propulsion industry in the perfection and production of the solid rocket motors for the shuttle system. However, we have been continually frustrated in these attempts. This has substantially limited the accessibility by NASA to the background and experience of our firm regarding a wide variety of nozzle, joint, casing, and propellant design and development issues.

As an example of the benefit of wider industry participation of which I speak, we can point to the introduction and development by Hercules of the capture latch feature on the joint of the Shuttle filament wound case. This was accomplished after Hercules' insistence that this feature was required to control the rotation and concentricity effects on the O-ring extrusion gap. The redesigned joint currently under evaluation for the steel solid rocket motor case now includes the basic features of this capture latch.

I review this history with you to point out and emphasize again that the risk of isolating the Shuttle SRM program should not be continued, and that one objective of any procurement strategy should be abatement of this risk. The clock is running.

Once again, I wish to thank you for the opportunity of participating in the deliberations of the Senate, as we together seek rapid, safe recovery of our nation to a premiere position in space. You may be assured that Hercules will cooperate in every reasonable way to expedite and support the policies and programs that result from these deliberations.

Very truly yours,

~~E.~~ A. Mettenet, President
Hercules Aerospace Products Group

HERCULES

Hercules Aerospace Company
Aerospace Products Group
P. O. Box 30181
Salt Lake City, UT 84130-0181
(801) 262-9393

ANSWERS TO QUESTIONS FOR THE RECORD

REQUESTED FEBRUARY 2, 1987

UNITED STATES SENATE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY AND SPACE

DONALD W. RIEGLE JR., CHAIRMAN

ITEM 1: BLOCK II PROCUREMENT

Question:

If NASA decides to proceed with a competitive Block II procurement, is there a consensus on this panel that any second sourcing decision should be delayed until the Block II motor is designed, developed, tested, and flown?

Answer:

We believe there are real and substantial benefits from having additional knowledgable industrial contractors involved in the final steps of the current recovery process provided they are engaged at the earliest possible time. This involvement is the only mechanism by which the experience of the rocket propulsion industry can be brought to bear on the final design review and evaluation process. With all due respect to the skills and experience of those members of the academic community and leaders in the related industries of aircraft and spacecraft, there is no substitute for the direct experience and knowledge of those within the solid propulsion industry who have been responsible for the successful development of this technology over the past 40 years. However valuable this service might be, it nevertheless does not alone constitute a suitable basis for competition at this time.

An immediate second sourcing competition would provide the benefits that always have been attributed to the second source concept, that is, protection of schedule, national security, safety, and cost reduction. Under the current circumstances, however, it does lock the incumbent into a long time continuing position as one of the contractors, and would tend to inhibit the incorporation of improvements that can be achieved as a result of relaxation of the specific constraints that were imposed on the redesign program. While it must be clearly understood that flights will not be resumed until the solutions that are currently undergoing evaluation are thoroughly proven to have met the requirements for flight safety, it is equally clear that these solutions are in some instances cumbersome, inelegant, costly, and heavy compared to what could be accomplished in a less constrained and more patient environment.

Furthermore, the cumulative result of safety improvements throughout the shuttle system has inevitably resulted in a substantial reduction in launch capability. This capability can be recovered by applying the lessons learned in the years since the existing shuttle motors were first conceived, but only through the medium of a Block II competition and development program. This then becomes a rational basis upon which to conduct a competition, in which both the future needs of the shuttle, and possibly a heavy lift unmanned launch vehicle, could be considered together such that the investment and assets of the country in a system of this capability can be most effectively utilized. With this understanding, one can now address the question of timing and sequencing of selecting one or more contractors for the Block II development and production.

In recent procurement by the Department of Defense, in which dual sourcing was understood to be an objective from the very beginning, a combined procurement was conceived such that both contractors were selected at the beginning in open competition. Under this approach, both contractors participate in the early development and evaluation activity on the basis of a leader, who is the competition winner, and a follower who is judged next best in capability. While the leader bears full responsibility for the design and development of the product, the follower is concurrently aware of the design issues, and available to the government for supplementary functions. It then becomes a relatively minor matter to complete the qualification of the follower contractor at such time as the national interest or production requirements suggest, generally prior to the first production buy. We believe this procurement strategy is appropriate for the solid rocket motor Block II Program and recommend it be considered for adoption. A prompt procurement in this regard can provide nearly the entire resources of the solid propulsion industry to apply not only to the conception the design and development of a Block II motor , but perhaps as well, to the completion of the evaluation and verification of the Block I Redesign.

Question:

If a Second Source were pursued, would each of you bid if it were a fixed price contract?

Answer:

Yes. Hercules has worked to fixed price constraints in the past and has made similar offers to NASA for qualification of SRM production.

ITEM 2: SOLID ROCKET BOOSTER RECOVERY TEST PROGRAM

Question:

Based on your experience, how many full-scale qualification motor tests should be run prior to the first flight?

Answer:

In our experience, the number of motor tests that should be run varies widely, depending on the type of motor that is being qualified and the range of variables and conditions under which it must function. For smaller motors used on tactical weapon systems, the number often exceeds twenty in order to provide a suitable statistical confidence that the motors will perform under widely ranging temperatures which are as low as -65°F and as high as 165°F. In addition, these motors must have been subjected to a wide variety of storage temperatures,aeroheat conditions, shock, vibration, and cycling associated with their exposure to air or land operating environments.

For larger motors such as are used on strategic weapons system which are subject to a much narrower range of environmental conditions and are better protected during handling, transportation, and installation, the number may be far fewer, typically about ten depending on the number of prior development tests that have been run.

In the case of large space boosters, the problem becomes more difficult as these tests typically cost of the order $20 million each. For this reason the qualification strategy is changed in order to provide confidence of the safe function of many major components and subcomponents by prior testing in subscale and special fullscale tests. In addition, much more time is spent to develop a complete and thorough analytical model describing the behavior of the rocket motor system so that the variabilities associated with changing environments and loads can be explored by means of these models rather than a fullscale test for each variable combination. The function of development and qualification test firings then becomes directed as much to validate and verify these models as it is to generate a statistical validation of performance under a given set of conditions. This procedure is not unique to the rocket motor industry, but is based on a long standing and successful approach used by the aircraft and spacecraft industries as well. Therefore, the answer to the question of how many test firings should be conducted is related to an evaluation of the competency of the modeling and the range of test variables that can be accommodated in a single test.

In the case of temperatures, loads and resulting mechanical stresses, there are adequate tools to precisely model and analyze the mechanical behavior of rocket motor components and systems. These tools must be applied with intelligence to plan, design, and manage a fullscale test program in order to achieve the required objectives at a reasonable cost.

In particular, the models may be used to design special fullscale tests that simulate the critical conditions of a motor firing in a simpler and less expensive configuration. The test apparatus called "The Joint Evaluation Simulator" at Morton Thiokol and the "Transient Pressure Test Motor" at Marshall Space Flight Center are capable of such tests. With this type of testing, many additional tests which explore the extremes in environment and loading can be conducted at reasonable cost, and therefore reduce the number of fullscale firings that are required.

In addition to model validation, the principal objectives of a fullscale firing are the evaluation of ballistic performance, insulator performance, and nozzle performance. Issues of structural integrity and sealing must have been completely settled prior to a fullscale firing, since the failure of a fullscale static firing is an event so serious as to have a similar devastating effect on the development program as the failure of a flight.

and military applications, then the supply of segments must be made available to both coasts. There is clearly no location in the continental U.S. where a manufacturing plant could be located that could supply both coasts with single segment rocket motors without a long passage through open water or through the Panama Canal, or both.

Risks are incurred during transportation both to the product and to the environment through which the product is transported. In the case of the current four segment motors, the risks are minimized by the fact that the motors are open at both ends and therefore are non-propulsive. That is, should there be an ignition incident, although a fire would occur, the fire could be contained to the point of initiation and would threaten a relatively small adjacent area.

However, an incident with a single segment motor if shipped with nozzle installed would generate the same thrust as the motor during launch, approximately 3 million pounds. Such a thrust could not be contained at the point of incident if it occurred on a barge or ship. If the motors were shipped without nozzle or igniter, a thrust exceeding 0.7 million pounds is developed due to the mass of propellant present in relationship to the size of the openings in the case. The extent of the threat is significantly increased by the mass of propellant that would be involved and the probability of transition from a fire to explosion is also much higher.

The water routes that are usually identified during the discussions of plant site locations at this time generally involve the inland waterway or rivers on the east coast and therefore threaten a sizable area of dense population from such an event.

The third phase of system safety begins with the unloading operation at the launch site and continues until launch. In this phase, there appears to be little significant difference between single segment and multiple segment motors. Since the assembly of multiple segments into a single segment occurs within this phase and creates the same level of threat as would be associated with a single segment motor.

The fourth phase of the system safety study involves the actual launch and flight. During this phase, the risk of human injury includes the flight crew, which may in fact be substantially lower than the human risk in earlier phases of the production and operation of the shuttle. However, the risk to national security and property becomes extremely high due to the value of the shuttle system that depends on the rocket boosters.

In this phase, the issue of safety is focused on the design and function of all the joints in the rocket motor, including the forward joint and the nozzle joint, which are unavoidable even in a single segment motor. It must be recognized that these joints have not been a source of failure in the thousands of solid fuel rockets that have been tested and flown in previous years for the Department of Defense as weapons systems. The effects of

Hercules has conducted trade studies of single piece case versus segmented case rocket motors on the basis of performance, safety, and cost. The question of performance is easily answered and can be dealt with first. Based on our studies, we have found there would be no significant difference in performance between motors with single piece cases or segmented cases. Propellant charged designs can be conceived which will provide the same ballistics for any of these configurations although monolith is more difficult to manufacture, and the weight differences would be very minor. This issue is not a discriminator.

The issue of system safety needs to be subdivided into several components. First, there is manufacturing safety. This includes the likelihood of an incident during the manufacturing process in which the property or lives are at risk. There is a well established relationship between the size and quantity of explosive materials in a given location and the risk of damage to property and lives. This relationship has been used for many years to identify the minimum location distances between operating buildings and the type of protection required for containment of fire and explosive events. Using this relationship, there is clearly a higher manufacturing risk associated with the manufacture of a one piece case rocket motor compared to the manufacture of four segments.

Another issue associated with manufacturing safety is the risk of product loss due to damage or error during the manufacturing process. The effect of error is generally directly related to the size of the item, hence, if an error occurs, the consequences of the error are much more costly in the case of a single piece motor casting than if the error affects only one segment. Therefore, segmentation tends to minimize loss of product risk.

Both loss of product and threat to life are incurred as a result of incidental damage which can be experienced during the manufacturing process. While our review of the capabilities of industry to lift, move, and handle large products has shown that there is capability to handle a one piece case and casting, the threat of damage can be related to the mass and energy of the item being handled. Furthermore, the solid rocket motor industry is not accustomed to manufacturing and handling products of this dimension, and our experience would indicate that a very significant time must pass before the introduction of such a significant increase in scale in the fundamental operations can be managed with the required assurance that handling incidents and damage would not occur. The record clearly shows that such incidence were occurring with the handling of the four piece segments, and it is unreasonable to expect they would not occur with the handling of a single piece segment. Therefore, one must associate a higher level of threat to a single segment motor.

The next phase of system safety is the transportation of the finished segments from the point of manufacture to the assembly point at the launch site. Our studies have shown that it is feasible to transport segments of the current dimension and up to twice as large as the current dimension, using rail overland techniques that are currently available. Segments larger than two times the current segment would have to be transported by barge or boat on water routes. If one accepts that the very large booster motor is a national asset that would be utilized on launch systems on both coasts for both civil structural integrity of the redesigned solid rocket motors and the bonds between the case and the insulation?

Answer:

Hercules has been working at the leading edge of nondestructive technologies for large rocket motors for many years. In this regard, we have installed the largest computer aided tomography X-ray system for examining the integrity of solid rocket propellant and case bonds currently in the free world. We also operate 100% scanning ultrasonic inspection of the filament wound case, and have always performed 100% radiographic (X-ray) inspection of all motors we produce.

As a part of our contribution to the Block II Design Study recently conducted by the Marshall Space Flight Center, we convened a panel of experts to explore a broad range of new and emerging technologies which might be useful in nondestructive evaluation of large rocket motors. The result of this exploration was the identification of a number of very promising approaches which could detect case unbonds and evaluate specific structural integrity issues. These included radiography, thermography, and ultrasonic technologies. We note that a number of these are being explored currently as a result of the Titan failure and as a part of the Titan recovery program. This is an area of special need with regard to the support of both technology development and technology implementation. The application of a number of these technologies is now limited by the size of available apparatus, and support is needed to provide the incentive for designing and building the size of apparatus that is needed for shuttle booster motors.

ITEM 3: MONOLITHIC CASE ROCKET MOTORS

Question:

Have you done trade studies of the technical merit of monolithic motors versus segmented motors? What are the tradeoffs?

Answer:

First, it must be understood that there are no monolithic motors. There are monolithic or one-piece cases, but every motor must have at least three major components which are assembled with two major joints between them. All solid motor cases have openings at the forward end and at the aft end which are required to cast the motor and to insert afterwards an igniter on one end and a nozzle on the other. It must be remembered that in the case of the shuttle rocket motor the aft joint between the nozzle and the motor case was the first joint to show distress, and the joint which continually showed the worst distress prior to the failure. This is the joint that on one flight was completely destroyed in the primary seal and nearly failed in the secondary seal. The conclusion one must reach is that a totally reliable joint is a prerequisite for a successful solid rocket motor. And this prerequisite is not relaxed if the motor has a one piece case. Therefore it is essential that the joint design issue be resolved first, and then the number of joints that are required is a matter of logistics, system safety, and cost.

In demonstrating the achievement of these objectives, we feel that at least two firings are required to validate the ballistic performance and in particular, the reproducibility of ballistics between one motor and another within the required tolerance for balance of a shuttle pair. The effect of temperature should primarily be directed toward the sensitivity of the ballistics to temperature since motor performance, internal pressures, and other functional parameters are a function of temperature, and it is for this reason that low temperature and high temperature firings are desired.

Within this group of four firings, it is normally possible to accommodate all of the final verification tests of nozzle function and insulator performance. The term final verification is key to this philosophy. It implies that no changes have been made in this series of tests and that all design and processing features have been demonstrated during the development program in at least one fullscale firing. This may require from three to four prior development firings depending on the degree of change that has been incorporated into the new design and the techniques used to increase the level of confidence and margins of safety for the initial firings.

Question:

Do you feel the new horizontal test stand at Morton Thiokol can duplicate the loads and conditions associated with the actual flight experience?

Answer:

Although Hercules attempted to open the design, development, and installation of the second test stand to competition, this eventuality did not occur, and we have not been briefed with regard to the design of the test stand currently planned. However, as a result of our participation in the filament wound case program and information received informally through channels at NASA, we understand the nature of the horizontal vs vertical test configuration question, and have explored to some extent, the fidelity of the simulation of peak loads developed in the horizontal configuration to the loads experienced in flight. On this basis, we believe that the peak loads imposed on the case during a horizontal firing are at least as severe as those experienced in flight.

While the addition of special loading apparatus to modify the loads normally experienced in the horizontal position has been the matter of some controversy, it does not appear to us that the addition of this apparatus makes a significant contribution to the fidelity of the test or the objectives of a static firing program. We believe that such structural behavior should be explored prior to a fullscale static firing through the use of fullscale simulated firing apparatus such as the joint environmental simulator. This approach can evaluate all of the temperature and loading variables at a much lower cost and at a much greater speed than can be done in fullscale firings.

Question:

Based on your experience with solid rocket motors, are there any nondestructive examination techniques that can be used to verify the temperature, joint rotation, and case bond were identified and resolved in the mid-sixties to mid-seventies period for these systems and subsequently, have not failed on a wide variety of rocket applications which operate from -65°F to 165°F. The tragedy of Challenger was not that the design was flawed, though it was, but that the flaw was known and was permitted as "acceptable risk". One should not indict the concept under this circumstance, and recognize that this was not a technical failure of unforeseen events, but a failure of management to correct a known technical error.

Let us now explore for a moment the sensitivity of the reliability of a flight system to the number of joints in a motor case. If one accepts that there are at least two major joints in every motor and therefore four in every flight, the acceptable reliability of a joint can be established.

Reliabilities may be quoted in terms of the probability of a single failure in a specified number of operational events. Thus, one might say that an acceptable reliability be no more than one flight failure in one thousand launches. According to the rules of combining the effects of multiple failure sources, this would mean that a single joint could not fail more than one time in four thousand operations if there were four joints on every flight.

Given that the previous plan was to fly 24 shuttles each year and the current plan is to fly perhaps twelve, but considering also the commonality of what might be shuttle and heavy lift launch vehicles, and with future Titan launchers, one could expect the launch rate of large solid rocket boosters to be at least 24 and perhaps more each year. Hence, there could be as many as five-hundred flights associated with a joint design technology over the lifetime of a heavy-launch/shuttle type motors.

The probability of one flight failure in one thousand flights does not provide much comfort due to the randomness of this occurence. We thereby see the reliability of a single joint must be increased from one in four thousand to probably one in ten thousand before one will feel comfortable about the acceptable safety of flight, even with single segment motors.

Two questions now arise, first what is the effect of having more joints in a motor once the reliability of a joint is of the order one in ten thousand, and second, can a joint with such a reliability be designed and built?

The answer to the first question is easily calculated according to the rules of combining the risk of multiple failure sources. If a single joint has a probability of failure of one in ten thousand, then the probability of flight failures from this cause in a flight motor set which includes four joints is four in ten thousand. If the motor sets were built as today with four segments in each motor, there are five joints in each motor, or ten joints in a motor set, and the probability of a flight failure using such joints is approximately ten in ten thousand. Therefore, the increased risk due to a four segment design as compared to a single segment design is approximately six events in ten thousand flights.

The implication of this thought process is very clear, and it is that the primary requirement of the technology we need is to design and build a totally reliable joint, since such joints cannot be avoided. However, having done so, the difference in reliability between a motor set with one segment vs four segments is not significant, and the number of segments can be selected on the basis of other system requirements, particularly system safety during other phases of manufacture and operation.

The final phase of operations is the recovery and refurbishment of the motor case hardware. While this phase does not contain the explosive hazard of the propellant manufacturing and operating phases, there is still a major uncertainty, with regard to capability of removing the insulator from a single segment motor case. This operation has never been demonstrated before.

Finally, one must recognize the lack of experience in building a single segment motor of this size. As has been previously pointed out, the entire history of comparable experience consists of four rocket motors at least one of which did not operate properly. The satisfactory scaleup of present experience and the reduction of that technology to routine practice must constitute a very large uncertainty in scheduling and costs.

With regard to adequate reliability to support a manned program, both concepts can provide the needed reliability. It should be remembered there are many weapons systems currently in use which use solid propulsion and are manned rated. Typically these systems are launched from aircraft or from weapons carriers on which men are present. While in general, the proximity of the propulsion to the men occurs for a short period of time, it is that period of time during which the motor is being pressurized and subject to leakage of joints and other transient phenomena which is most critical. The history of reliability and safety of these systems has been outstanding.

Furthermore, the question of manned versus unmanned risk must be given very careful consideration. It is clearly evident from the circumstances in which the country now finds itself that the reliability of unmanned systems must be as high as it can be made. The value of payloads and launch facilities and the strategic value to national security is so high that nothing less than the best available technologies will be acceptable for those missions also.

Question:

Based on the Challenger and Titan investigations, has industry's understanding of solid rocket motors been dramatically increased to where more reliable motors can be manufactured? Will there ever be a solid rocket motor that is "fail safe" for the two minutes it burns during space shuttle flight?

Answer:

While it is true that the most recent Titan failure and the most recent shuttle failure of propulsion elements were solid motors, it is clear from the record of the failure investigation of both failures that the failures were the result of management and policy error rather than a lack of understanding or inadequate technology. As we pointed out above, in the case of the shuttle failure, the flaw in the design was clearly identified and understood long before the shuttle flight was destroyed. The design of the shuttle joints did not meet the sealing industry's standard requirements for configuration or deformation during loading and it violated all previous experience in this regard. The solid propulsion industry was never given an opportunity to evaluate, criticize, or participate in corrective action with regard to this element until after the failure had occurred.

With regard to the Titan failure, it must be noted that current activity is underway to inspect and identify acceptable segments and rejectable segments based on inspection techniques and technologies which were certainly available two years ago. An understanding of the importance of case to insulation bond integrity and the need to perform inspections to ascertain this integrity is not new. Such inspections have been conducted routinely on Department of Defense strategic and tactical motors for the past fifteen years. It should be noted, however, that the use of steel motor cases on both of these space boosters makes the inspections more difficult than the use of composite motor cases as has been the practice in the strategic motors and also for the filament wound case of the STS SRM. It is our understanding that no such inspections were performed on the Titan segments and only a sampling of segments for the shuttle rocket motor were so inspected. Once again, we must emphasize, that this is not a matter of understanding, but a matter of policy which was negotiated between the supplier and the government.

The influence of temperature on the performance of elastomeric O-ring seals was thoroughly explored in the middle-seventies by Hercules and the Air Force as a result of random failures at -65°F during static testing of Sidewinder motors that had previously been qualified without failure. This investigation identified the role of the material properties and the rotation of joints which was very similar in concept to the behavior and findings relative to the shuttle joint. Material testing of the O-rings identical in concept to that which has currently been done for the shuttle O-rings was performed at that time and the findings published. Hence, some of the industry at least, and some of the Air Force at least, were thoroughly aware of the nature and solutions for this type of sealing problem. This experience was eventually reported by Hercules to the NASA Redesign Team in March of 1986 at an informal meeting at the Marshall Space Flight Center, after the Challenger failure.

It is worth noting that in the very recent past, the prior two failures of the Titan launcher, a failure of a Delta launcher, a failure of the Atlas launcher, and a failure to orbit of a shuttle main engine all were liquid system failures. The often quoted advantage of liquid systems in providing an operational test mode on the launch pad prior to launch appears not to be exercised or not to have the claimed advantage in preventing flight failures. The failure of a shuttle main engine, which created a dangerous abort to orbit situation, also threatened both lives and mission. In addition there have been two starts and shutdowns on launch pad with the crew in place which must be considered as liquid system failures on the shuttle. All of this points out that space flight still includes a significant risk to life and property whether it be from solid motors or from liquid systems. And neither at this time can guarantee a 100% fail safe condition during the boost to orbit. In fact, our review of solid and liquid propulsion history shows very similar reliabilities for both.

The concept of fail safe must be distinguished clearly from the concept of fail free. Fail safe implies that if the motor's performance falls outside of acceptable limits, some corrective action can be taken such that life and perhaps property of the system can be protected. The approach used by liquid propulsion is to turn off the flow of fuel to the combustion chamber thereby stopping the combustion process and shutting down the thrust. This can be fail safe if the problem lies downstream of the fuel valves and if the resulting loss of thrust does not create a subsequent failure mode.

While it has not been practiced for space motor propulsion, a system for stopping the thrust of solid motors has been in use for defense systems for many years. The system is called thrust termination or thrust reversal. It involves the use of port openings in the forward end of the motor which can be opened on command, thus rapidly dropping the internal pressure in the motor and creating a neutral thrust condition, or under some circumstances, actually reversing the thrust of the motor. If this system were applied to space boosters, the logic for generating a thrust termination signal could be based on a variety of out of specification or out of tolerance conditions during the operation of the shuttle boosters.

The appearance of new jets of gas at the forward end of the motor certainly creates a new condition for the orbitor and tanks, however, it is clearly a final resort emergency and under these conditions some damage to orbitor and tank can be tolerated, provided it does not cause destruction. The jets would be directed away from the primary incidence on other components, and the time during which the jets are active is only a few milliseconds until the solids are ejected. It appears feasible to conduct such a thrust termination without a subsequent destruction of the orbitor or tanks.

Finally, a comment on the possibility for designing and building more reliable solid rocket motors. A solid rocket motor is fundamentally a very simple machine with almost no moving parts and with literally centuries of evolutionary development behind it. In its modern form, it has become more complicated by virtue of steerable nozzles, pulse starts and stops and other enhancements to make it more versatile. However, we now have also a large inventory of high performance materials and insulators with which to build and defend the structure and mechanism. We believe that we have the materials and can obtain the knowledge required to make the motor as reliable as it is needed.

ITEM 4: THE NRC RECOMMENDATIONS

Question:

Would you please comment on the NRC recommendations, especially those recommendations concerning the need for a better defined and more thorough test program and the establishment of all priority criteria by which to evaluate the tests.

Answer:

The recommendations of the NRC panel contain remarkable agreement to the recommendations and comments that Hercules has given both NASA and the NRC panel at various times during the past year. We agree totally in substance and detail with the statements contained therein.

We particularly agree with the comments relative to contingency planning and parallel development of alternative concepts for a field joint that closes under pressure, and for a new nozzle-to-case joint that avoids the additional leak paths and bolts that are included in the baseline design.

On the issue of the insulation at the case field joint, Hercules remains concerned that the proposed baseline is sensitive to processing variables, and cannot be verified after assembly is completed. The risk is that a defect will remain after completion of this bond that can initiate a failure mode that has not been evaluated during the development and qualification test program. For this reason we agree with the NRC recommendation that the vented configuration be evaluated with equal emphasis and urgency.

It has been our position that the vigorous pursuit of alternatives from the baseline concept would be enhanced by the addition of another contractor with uninhibited and undistracted resources dedicated to the success of the alternative. Only within this environment can the alternatives be assured an equal evaluation.

The Space Transportation System represents a very significant investment in money, talent, and lives by this country into a space capability. However, we in the industry recognize it remains developmental in nature, a characteristic that cannot be expected to change in the near future. Neither do we have the luxury of discarding the current system concept and beginning anew. Therefore, the NRC Panel recommendation for pre-planned changes and periodic incorporation of incremental improvements is the correct operational strategy to protect and extend the value of the investment already made.

We agree that heaters are an extremely undesirable feature to add to the Shuttle Booster Motor and that a complete and final solution to the system of materials comprising the joint and seals will not require such heaters.

The NRC Panel discussion of vented and unvented insulation at the field joints is pertinent. In Hercules experience the unvented designs have inevitably incurred a flaw which resulted in failure. As the NRC panel points out, tests with imposed flaws are particularly important for determining the adequacy of this design concept. Difficulties are the inability to predict in advance all of the possible defects and flaws that could occur, and of the fact that there exists today no acceptable method of inspecting this adhesive joint after assembly is completed.

The vented design, however, uses the cool gas already present inside the motor prior to firing to insulate the seals, and prevents the mixing of hot and cool gas by a variety of engineered devices which are inspectable prior to assembly and are not modified by the assembly process. Since these engineered features are large in comparison to the size of possible defects in an adhesive bond, it is technically feasible to conduct a post-assembly inspection to assure the quality and condition of the assembly. To Hercules' knowledge there has never been a failure of a field joint designed according to these principals when combined with a sealing mechanism that closes upon pressurization.

Nozzle ablatives were also under study before the Challenger failure. Changes which have resulted include process modifications and design modifications which now will be evaluated in fullscale static firings. As the NRC Panel pointed out, this is one area that requires a full duration firing test. However, not necessarily a fullscale test. NASA currently does not have a subscale solid propulsion development motor that can be used to evaluate technology or design changes. We feel this is a serious deficiency in view of the cost of development tests for a fullscale shuttle motor, and like the NRC Panel, we recommend that NASA proceed promptly to develop and qualify such a subscale test and evaluation motor. We are prepared to compete for this task which could be based on derivatives of existing motor hardware.

As we have noted above, an important part of the testing program is a thorough exploration of the extreme values of loading and environmental variables in fullscale special tests such as the joint evaluation simulator and in particular, a special task to evaluate the effect of high temperature gas flow in the ports in the center port of the motor on the heat exchange to the field joints between the motor segments. This particular test is of special value in answering the question of whether such joints should be vented or unvented and we recommend that further testing with this test motor to evaluate a variety of concepts and the total range of possible defects that might occur in the assembly of the different design concepts.

It is in this phase of analog and fullscale testing that participation by others in the propulsion industry should be encouraged in order to provide a thorough evaluation of the test data and to participate in the identification of optum solutions as testing reveals the needs for further improvement. Such participation certainly need not be associated or identified with competition for subsequent motor development or production contracts. Certainly in the eventuality that schedule slippage is required to provide the necessary credibility for the redesign concept, the ability of others in the industry to support evaluation both theoretically and experimentally should be reviewed.

Finally, the use of fullscale tests, whether they be simulations, analogs, or actual motor firings is frequently directed toward verification of analytical models which are then in turn used to validate the design for various combinations of load and environment. This function of the tests is only valid if the predictions of the model are known prior to the tests. The comments of the NRC panel in this regard are exactly correct. That is, that the model must be thoroughly exercised and the predictions therefrom declared in complete and full documentation prior to the conduct of the test. If the "predictions" of the model can only be made after the test because some element of the test observation is used to make the prediction, then clearly the model is not independent and unable to satisfy the requirements of predicting behavior under other circumstances. While this situation frequently does exist in the early phases of the program as certain phenomena are adjusted for differences between fullscale and subscale behavior, the condition must be resolved prior to the validation of those models in the final qualification test series.

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Senator RIEGLE. Thank you very much. Mr. Sides, let's hear from you, please.

Mr. SIDES. Thank you, Mr. Chairman, and members of the committee. We have submitted a concise statement for the record. I would like to take this opportunity in the interest of time to briefly summarize our formal testimony.

We made our statement available to your committee, the press and all of the participants of this panel. I would appreciate it if your committee report would print our statement in its entirety.

My name is Jim Sides and I am senior vice president and general manager of Atlantic Research Corporation's Propulsion Division, headquartered in Gainesville and Alexandria, Virginia and Camden, Arkansas.

We propose to produce our redesigned SRM at ARC's ultramodern facility in Arkansas, where we made in 1986 more composite propellent than any other facility in the United States. The kind of propellent we produce in Arkansas is similar to that used in past SRM production. And we are currently producing this kind of solid rocket propellent at the rate of one and a half million pounds per month. Over the last year, we have produced enough of this propellent to load 15 SRMs.

I will have to add the same caveat as my friends have, as far as our comment on the baseline redesign. Our involvement was comparable to what I have heard Aerojet, UTC and Hercules state.

We do believe that the Morton Thiokol/NASA joint redesign and the test program for that redesign, address the failure modes encountered in the *Challenger* disaster. Nevertheless, we foresee the possibility for assembly and case reuse problems.

Some of the questions, Senator Hollings, that you asked this morning were very astute. With regard to those problems, the new clevis and tang joint does have a high risk of O-ring and hardware damage.

With regard to case reuse, my concern is that Morton Thiokol and NASA have substituted a complex design for the simple tang and clevis joint. And the more complex design, the capture feature, has tolerances that are so close that repeated use of the motor case is doubtful.

To avoid these and other problems, ARC has selected, as part of our Block II study, a single bolted joint design which was the original design work done by NASA Langley. We have expanded on their design.

The most significant feature of our design is that the bolted design closes on pressurization. It seals itself on pressurization. We have a model of this design sitting on the floor. I think it pretty much speaks for itself, but I will comment briefly on it.

Our design, and I would like to answer your questions on it, is basically what you can see. Bolts and a face seal using metal O-rings are as the basic concept of our design. It has been made possible due to recent improvements in technology and manufacturing techniques.

These improvements were not really available to the designer when the solid rocket motor was originally designed and selected many years ago. We now have the technology also for asbestos-free insulation which reduces the inert weight of each motor by over

4300 pounds. And, further, we can reduce inert weight by another 600 pounds by new manufacturing methods which will extend the motor case segments to twice the length of the current one. The double-length case eliminates the need for factory joints.

We strongly believe that our bolted joint constitutes the lowest technical risk.

One disadvantage of the bolted joint is increased weight, but our asbestos-free insulation and a double-length case more than offset any weight penalty.

I might add that I consider the replacement of the asbestos-containing insulation in this rocket motor, as well as other components that contain asbestos, to be a priority concern and does represent a serious threat to the shuttle schedule. Manufacturers of components that contain asbestos in this country are rapidly dealing with trying to get out of the business, for obvious reasons.

Mr. Chairman, let me conclude my summary by emphasizing my company's willingness to set aside propriety interest and work openly with our industry for improvements in solid rocket motor flight safety.

What we would like this committee to consider is that the United States Government structure an alternative program in such a way that two teams of two or more companies could create competitive designs.

The winning design team could then compete within itself for production, possibly on a leader/follower basis. Such an approach, Mr. Chairman, would focus all of our technical resources in this industry on the program without compromising the legal requirements for competition.

I look forward to answering your questions, Mr. Chairman.

[The statement follows:]

STATEMENT OF JAMES R. SIDES, SENIOR VICE PRESIDENT AND GENERAL MANAGER, PROPULSION DIVISION, ATLANTIC RESEARCH CORP.

Mr. Chairman and distinguished Members of the Committee, thank you very much for this opportunity to summarize what we strongly believe are the advantages of the Atlantic Research Corporation redesign of the Shuttle solid rocket motor. Throughout my testimony, I shall call this motor the "SRM."

My name is James Sides. I am the Senior Vice President and General Manager of ARC's Propulsion Division located in Gainesville and Alexandria, Virginia, and Camden, Arkansas. We propose to produce our redesigned SRM at ARC's ultramodern facility in Arkansas, where we made, in 1986, more composite propellant than any other facility in the United States. The kind of propellant we produce in Arkansas is similar to that used in past SRM production, and are currently processing this kind of solid rocket propellant at a rate of 1.5 million pounds per month. Over the last year, we have produced enough of this propellant to load over 15 SRMs.

In our Block II Design Study submitted to the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration on December 31, 1986, we provided detail about our plans to expand our Arkansas facility to produce redesigned SRMs for the NASA shuttle program, and our plans to move the boost segments to Florida or California.

But the detail your Committee is most interested in is our proposed redesign, a model of which we have brought to this Committee room, and two exhibits of which are attached to my testimony. In your letter of invitation dated December 23, 1986, you also asked me for our considerations on the proposed test program, and other related matters.

Let me initially respond to your request for comment on our proposed Shuttle solid rocket motor design.

In our Block II design study, we proposed the SRM bolted flange joint and a double-length case segment. Before we selected this solution, we evaluated all segmented and monolithic SRM design concepts with emphasis on joints and seals. We devoted particular attention to eliminating those deficiencies identified in the Report of the Presidential Commission on the Space Shuttle Challenger Accident, as well as those identified through a detailed review of SRM literature and in NASA's very helpful August 14, 1986 SRM briefing to industry. In this context, Atlantic Research wishes to thank NASA for its open door policy. NASA officials have been very helpful to us as we conducted our research on Block II, and we appreciate the open door reception we have been given personally by NASA Administrator James Fletcher, and Marshall Space Flight Center Director J. R. Thompson, Rear Admiral Richard Truley, NASA's Associate Administrator for Space Flight.

The bolted joint concept was selected by Atlantic Research for three reasons. First, the bolted design eliminates joint rotation at the sealing surfaces. Second, the bolted design provides simple, straight forward assembly techniques. Third, the bolted design will support the requirement of 19 reuses.

Bolted joints have been successfully used for many years in a variety of applications beginning with high pressure and temperature steam systems, liquid engine environments such as those seen in the Space Shuttle Main Engine, and finally in nuclear reactor applications. Bolted joints were successfully used in many solid rocket motor applications in the formative years of this industry, being replaced only to permit lighter joints for weight critical applications. The bolted joint with metallic seals does not require pressure actuation.

The bolted joint concept selected was thoroughly designed and analyzed by NASA Langley Research Center. We have worked closely with NASA Langley and feel that our combined design and analysis efforts have resulted in a joint that will assure Shuttle flight integrity. Like NASA Langley, we are convinced that the bolted joint will make a superior and more reliable primary sealing surface during maximum pressurization.

Atlantic Research Corporation's Block II design concept features, in addition, a double-length case and improved performance, non-asbestos insulation. The Block II case length will equal the current casting segment length, eliminating case-to-case factory joints. The weight savings produced by these features more than compensates for the increased weight of the bolted flange joints. Decreased inert weight of 4,954 pounds and increased propellant weight of 1,839 pounds will allow more than 1,000 pounds of Space Shuttle payload increase.

We were briefed by NASA on the Morton Thiokol-NASA modified design. We have not had an opportunity to analyze the design in the detail NASA and Morton Thiokol have, but in the spirit of your request for our comment, we believe the failure modes encountered in Challenger have been addressed. Specifically, the primary "O" ring should not lose its "squeeze" as a result of joint rotation due to motor pressurization in the new design. We further believe that the "capture feature" addresses this failure mode.

We are, nevertheless, concerned about two new problems created by this fix. First, the new clevis and tang joint has a higher risk of "O" ring or even hardware damage. Although we feel any potentially catastrophic defects should be picked up by leak check, the need for rework might be great and expensive. Second, the interference fit between the capture feature and the clevis may result in metal damage which will preclude reusing the case hardware the required 19 times.

Morton Thiokol's verification program calls for only two full-scale development and two qualification motors prior to the next Shuttle flight. Therefore, with such limited full-scale firings, it is essential that a great quantity of reliable data be collected on each of the four planned tests. These results should be extensively reviewed and analyzed.

For the test related to our bolted flange redesign, we are proposing a more rigorous program. Atlantic Research Corporation has designed and produced the overwhelming majority of man-rated solid rocket propulsion systems for the U.S. Department of Defense, and we are used to extensive test programs.

What we are proposing is a test program that would require exposure to maximum pressures and temperatures three times longer than the current NASA joint test. For our Block II SRM, we recommend a series of component, subscale, and full scale tests to develop and verify our improved SRM, component tests of the case, case and nozzle field joint, insulation, the nozzle itself, and the igniter. Subscale testing will include 40-inch diameter segmented motor firings designed to verify the bolted flange field joint performance under 25-second exposure to maximum SRM pressures and temperatures. We will complete the verification with full scale firings of four development and four qualification motors.

To provide a viable alternative to the current redesign, Atlantic Research Corporation submitted on January 13, 1987 to NASA Marshall Space Flight Center a proposal to demonstrate the SRM bolted joint concept.

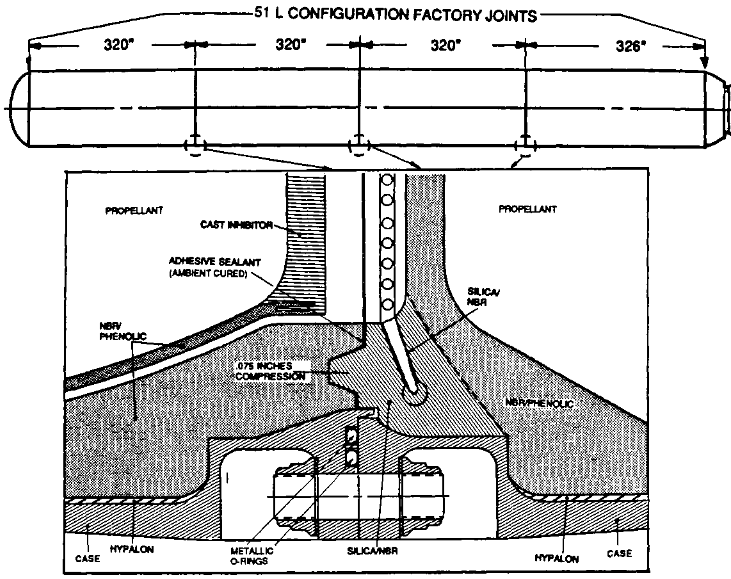
Mr. Chairman, I would like to conclude my testimony by reiterating an idea we surfaced on July 31, 1986 before Congressman Jack Brooks' Committee on Government Operations. We proposed a team approach to the solution of the Shuttle SRM program. It seemed to me then, and it appears just as true today, that there ought to be some way by which all the talents of the American solid rocket industry can focus on this problem of immense national importance.

All of us again here today are capable of designing, making and testing a Shuttle SRM. But each of us has particular strengths. Atlantic Research, for example, is particularly strong in the areas of low cost propellant production and loading, asbestos-free insulation, and in the design of man-rated systems where reliability is essential.

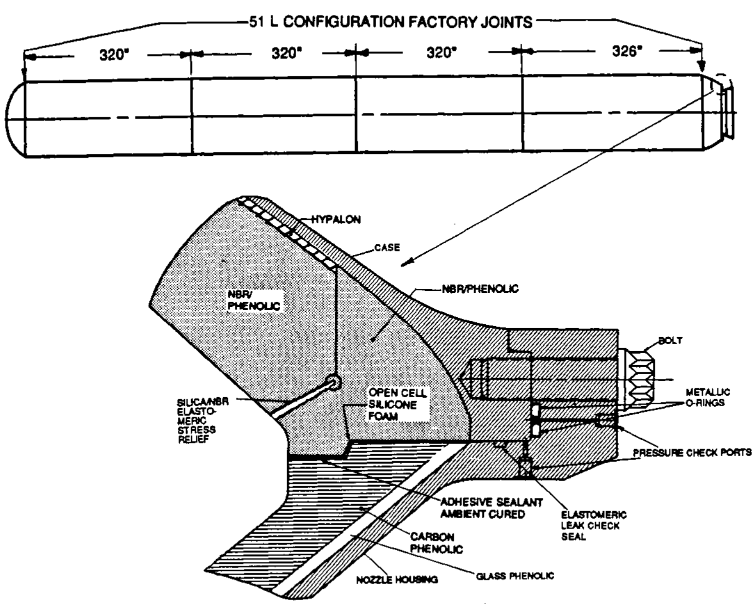
What we would like this Committee to consider is an acquisition strategy similar to a recent Department of Defense strategy. Contractor teams would jointly develop the design on a cooperative basis. Both members of the winning team would then be qualified to competitively produce the final design. This approach assures a broad technical base, separate production facilities, and built-in competition. Such an approach, Mr. Chairman, would focus all of our technical resources on the program without compromising the legal requirement for competition.

Thank you, Mr. Chairman. I would be glad to address any question, as well as questions from those of any member of your Committee.

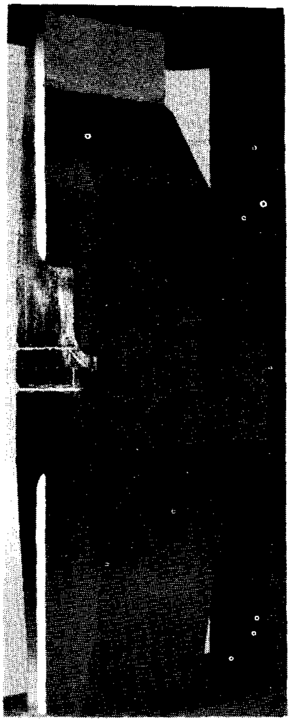
Attachments: A. Case Field Joint, B. Case-to-Nozzle Joint, and
C. Photograph of Exhibit

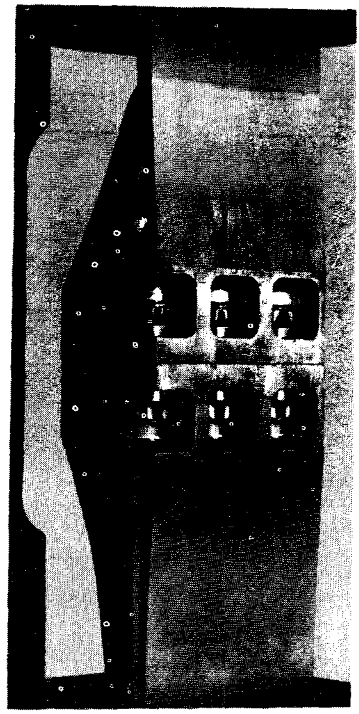


A. CASE FIELD JOINT



B. CASE-TO-NOZZLE JOINT





ATLANTIC RESEARCH CORPORATION
PROPULSION DIVISION 7511 WELLINGTON RD. · GAINESVILLE, VIRGINIA 22065-1699 703-642-6000

13 February 1987

United States Senate
Committee on Commerce, Science, and Transportation
Washington, D.C. 20510

Attention: The Honorable Donald W. Riegle, Jr.
Chairman, Subcommittee on Science,
Technology, and Space

Dear Senator Riegle:

Thank you for the opportunity to speak to the Subcommittee. ARC believes SRM flight safety is a national imperative, and we have made a committment to participate in the Space Shuttle Program.

Responses to your questions are attached. If additional information is desired, please do not hesitate to contact me.

Yours very truly,

ATLANTIC RESEARCH CORPORATION

James R. Sides
Senior Vice President and
General Manager

QUESTIONS FOR THE RECORD

1. On March 31st, Dr. Fletcher will provide this Subcommittee with a Long-Term Procurement Plan for solid rocket boosters. At that time, NASA will indicate whether or not a Block II solid rocket motor will be procured.

Q. If NASA decides to proceed with a competitive Block II procurement, is there a consensus on this Panel that any Second Sourcing decision should be delayed until the Block II motor is designed, developed, tested and flown?

If a Second Source were pursued, would each of you bid if it were a fixed price contract?

A. ARC recommends that NASA and this committee consider an acquisition strategy for the Space Shuttle SRM similar to a recent Department of Defense approach. Contractor teams would jointly develop an improved design on a cooperative basis. Both members of the contractor team would then be qualified to competitively produce the final design. This approach assures a broad technical base, separate production facilities, and built-in completion.

ARC would bid on a second source program under the right business conditions. We observe that the current baseline redesign program is a cost reimbursable contract.

2. There has been much discussion today concerning the scope, timing, and schedule of the proposed solid rocket booster test program.

Q. Based on your experience, how many full-scale , qualification motor tests should be run prior to the first flight?

A. As recommended in our Block II study report, we proposed to complete the verification of our bolted flange design with full-scale firings of four development and four qualification motors. With regard to the number of tests of the baseline redesign, we believe the NASA test program will address the failure modes encounted in the Challenger disaster. However, due to the limited number of these tests (four full-scale tests scheduled prior to the next scheduled Shuttle flight), it is essential that a great quantity of data be collected, reviewed, and analyzed on each subscale, simulator, and full-scale test. It is also important that pretest predictions and success criteria be established for each test.

Q. Do you feel the new horizontal test stand at Morton Thiokol can duplicate the loads and conditions associated with the actual flight experience?

A. ARC cannot answer this question because we have never seen the new horizontal test stand at Morton Thiokol, nor have we ever been briefed on its capabilities. We are concerned that flight loads cannot be realistically duplicated in horizontal or vertical test stands. Since flight safety will rely on analysis of SRM structural behavior under flight loads, analytical methods and predicted design safety margin should be carefully reviewed.

Q. Based on your experiences with solid rocket motors, are there any non-destructive examination techniques that can be used to verify the structural integrity of the redesigned solid rocket motors and the bands between the case and the insulation?

A. The following non-destructive examination techniques can and are used to verify structural integrity: (1) proof tests of pressure vessels, (2) x-ray of propellant grains, (3) ultrasonic inspections to check for unbonds, and (4) leak tests to verify seal integrity.

3. There has been and continues to be much discussion about the technical merit of monolithic solid rocket motors versus segmented solid rocket booster motors.

Q. Have you done trade studies of the technical merit of monolithic motors versus segmented motors? What are the trade-offs?

A. Our trade studies on the technical merit of monolithic motors versus segmented motors highlight the following trade-offs: (1) Even though joint reliability of the monolithic motor is higher than that of the segmented motor, overall reliability of the monolithic approach is somewhat lower due to technical uncertainties associated with the propellant grain, propellant bond system, and insulation for the monolithic motor. (2) ARC estimates that the monolithic approach will produce a 2,050 pound increase in payload capability over the segmented approach, due to lower inert weight and increased propellant loading. (3) Total life cycle cost of the monolithic approach is estimated to be 72 percent higher than the segmented approach, due to increased handling, test, transportation, and facilities cost. (4) Shipping safety is a critical issue for the monolithic configuration, due to its propulsive nature if accidentally ignited. For these four reasons, our trade studies showed that, on balance, the segmented approach is decisively superior to the monolithic approach.

Q. Do either offer the reliability required to support a manned program?

A. ARC believes that a segmented SRM with improved field joints offers the most reliable approach for manned flight.

Q. Based on the Challenger and Titan investigations, has industry's understanding of solid rocket motors been dramatically increased to where more reliable motors can be manufactured? Will there ever be a solid rocket motor that is "fail safe" for the two minutes it burns during space shuttle flight?

A. Atlantic Research has been producing reliable, man-rated rocket motors longer than any other member of the American solid rocket motor industry. Thus, while we learned a great deal about the causes of the Challenger tragedy, our understanding regarding the reliability of solid rocket motors has not been dramatically increased.

One simply cannot guarantee the "fail safe" nature of any rocket -- solid or liquid -- as well as any other component of the shuttle, or any other sophisticated aerospace system. We believe, however, that we could manufacture a Shuttle solid rocket motor as reliable as our many thousands of man-rated rocket motors we have produced in the last quarter century.

4. You are familiar with the National Research Council Panel's technical assessment of the proposed redesign and comments on the need for contingency planning and a better defined and more thorough test program.

Q. Would you please comment on the NRC recommendations, especially those recommendations concerning the need for a better defined and more thorough test program and the establishment of a priori criteria by which to evaluate the tests?

A. We agree that a better defined and more thorough test program is needed. We believe the purpose of an engineering test should be to confirm predictions, not to find out what will happen. Thus, a priori criteria must be established by which to evaluate the engineering tests.

We particularly agree with the NRC recommendation (bottom of page 2 of their report to NASA Administrator James Fletcher dated January 15, 1987) in which they state: "The (National Research Council's) Panel still believes that contingency planning should include the design, fabrication, and testing of a case field joint that closes under pressurization." The bolted flange design selected by Atlantic Research Corporation for our Block II effort does close under pressurization.

Senator RIEGLE. Thank you. I will just give you a little news that you may not have heard or may not necessarily want to hear, and that is the latest weather report is to the effect that we may have 15 inches of snow coming in.

What I think it means is that I think people are going to have a hard time making their way home. And so we are going to, in very short order, I think, conclude today, not because we wouldn't like to take more time, but because I think in the interests of everybody's wellbeing here that has got some distance to travel, that people ought to do that before the snow gets any deeper than it now is.

I want to say two things. I will ask generally then, if this is acceptable to the subcommittee, that we will put the questions in the record. We are going to ask our witness in the next panel to come back another day because I don't want to do a bobtailed session on that. However, Dr. Stever's statement will be included in today's hearing record. I want to get the careful review of what the independent group has to say in terms of their assessment of this. And I do not want to hurry it, and I will not hurry it.

I want to say one thing with respect to your involvement, however, in the redesign of the O-ring area, and also the Block II activity. Senator Hollings and I together put into the appropriation last year money precisely for this purpose. And it became law and the money is being dispensed. And it was for two reasons. Part of it was to be used for Block II design alternative work, and part of it was to be used to support the redesign team decisions.

And it was very clear that we wanted both things done because if we miss on the first go-around, you know, I am not sure what our future is in the second. The point is, both of these things have to be done and done properly.

So it was clearly our intent in providing that money that you should be involved in a meaningful way in the redesign of this joint. And I don't mean informally or casually or what have you. We wanted the full brain power of this industry to have a chance to focus along with the principal players that have been involved on precisely this question, so that we get it right and so that we really apply ourselves as a nation; that we have all the talent focused on this thing so that we made the best bottom-line judgment that we can, at the same time that we start down the track on this alternative design approach.

So you ought to be involved on more than an informal basis. It was the intent that you should be. It was the intent that you would be paid to be. And I am frank to say to you that I want your best brain power on that problem because we have got to get it right.

And I think in this case the more brains, the better.

It is not like having 25 people cooking a meal in one kitchen, but I think we have got to really understand that we have had the kind of cross-checks of intelligence and capability that this industry possesses as a whole on a matter of this kind of critical importance to the country because we have to get it right.

So, in any event, I just say that to you. Mr. Dorsey, let us hear from you and then after we have, we will submit what questions we have for the record and we will finish for the day.

Mr. DORSEY. Thank you, Mr. Chairman. My statement will be brief.

I have submitted a longer statement for the record and with your permission, I will give an abstract of that at this time and I request that my more detailed statement be placed into the record.

Senator RIEGLE. It will be.

Mr. DORSEY. Thank you, Mr. Chairman. As you mentioned, I am Edward Dorsey of Morton Thiokol, and I am the vice president and general manager of the Space Division, located in Utah.

In the Block II studies that we performed, the subject I am addressing at this time, one of the first things that we did was to make a review of the industry experience, both with the monolithic and segmented motors. And we made that review because we recognized that significant changes from past design practice and experience do add some degree of uncertainty to a new design.

More specifically, if you look at the history of the aerospace business, and I don't care whether it is the solid rocket motors, jet engines, airplanes, tanks, trucks, you name it, the very successful designs come by through a process of evolution, testing, experience and refinement.

And when we looked into that, the assessment we made on the monolithic motor was influenced by the fact that there was very little experience with very large monolithic motors. A shuttle segment weighs 300,000 pounds.

In the entire history of the solid rocket motor business, not only in this country but, of course, in the entire world, there have only been four motors larger than a single shuttle segment which have ever been built and static tested. The entire industry history is four such motors.

Of those, the largest one of those when it was static fired, there were ballistic anomalies in the pressure trace of the motor. It did not deliver the ballistic performance that was predicted. And it simply illustrates the fact that in any new design or development, the design does not always turn out as intended by the design engineers.

You have to go through a process of testing experience. If anomalies or difficulties are found, then you have to correct those and test again. We also would note that those four motors, the only four that ever existed larger than a single shuttle segment, were cast with propellent and static fired in place.

There is no aerospace experience whatsoever with the transportation, vehicle assembly and flight of very large monolithic motors. Based upon that and the belief that the design or the evolution that we are on is a very good evolution, we concluded that a segmented design is, in fact, the lowest risk approach for the Block II solid rocket motor because we can use the development, production, tests, transportation and launch facility experience and capabilities that exist.

Also, the Block II joint design, whatever it may be, can inherit some confidence in the analysis and testing from the very experiences that we are going through right now for the redesign of the space shuttle joint. Those analysis methods, and there has been much development in that, and the test techniques, the development of the specialized test facilities, can carry over to substantiate and verify similar hardware designs in the future.

Also, I would like to comment about the schedule aspects of that. If one thinks about the attention and scrutiny that any new rocket motor, whether it be monolithic or segmented, would get, and the kind of test program, all the way from materials to subscale to special vehicles to full-scale full duration motors, and the design reviews that will take place, our assessment is that the first development static test of any new design where there is some significant change, you are looking at the first static test in about 33 months, and that with design certification, we are probably looking at a number of full-scale motors to be fired after that, there would be approximately a total time of 56 months, followed by delivery of the first flight set of motors.

So our assessment is, Number 1, it is best to build upon the experience that the industry has. Number 2, there is very little experience with large monolithic motors. Number 3, a segmented motor of whatever joint design is the preferred choice. And Number 4, that realistically we are looking at a period of time of, say, 30 to 33 months for the first test of any new design.

We have completed a very detailed report outlining these findings, have submitted it to NASA, as pointed out by Mr. Thompson. That plus the other four reports are under review.

Mr. Chairman and members, that concludes my remarks.

[The statement follows:]

STATEMENT OF EDWARD G. DORSEY, JR., VICE PRESIDENT AND GENERAL MANAGER, SPACE DIVISION, MORTON THIOKOL, INCORPORATED; WASATCH OPERATIONS

Mr. Chairman and distinguished members of the Committee, I am Edward G. Dorsey, Jr., Vice President and General Manager of the Space Division of Morton Thiokol, Inc. located in Brigham City, Utah.

I am pleased to appear before this Committee to discuss the alternative Shuttle Solid Rocket Motor (SRM) designs that were developed in the Block II SRM Conceptual Design Studies. I will review the results of Morton Thiokol's study and the considerations which led to the recommended Block II SRM concept. As the development and production contractor for the Space Shuttle SRM, Morton Thiokol has previously completed the complex tasks of development, verification, production, and flight for this important element of the Space Transportation System. We have drawn on this experience to develop concepts for a Block II SRM.

The objective of the study was to identify a Block II SRM concept that may offer performance and/or reliability and safety margin improvements.

Groundrules for the Block II SRM Conceptual Design Studies were established to ensure compliance with existing STS requirements for the high performance solid rocket motor (HPM) while allowing flexibility for design concepts that offered potential improvements in reliability, performance, and cost. The Block II SRM studies were conducted in parallel with the ongoing qualification of the Redesigned Solid Rocket Motor (RSRM) and requirements were adjusted to agree with the applicable new criteria. In addition, previous NASA studies have projected increased payload capability for the Space Shuttle flown in a "heads-up" trajectory with a new thrust-time history provided by the SRM. The higher thrust requirements to meet the heads-up criteria for the SRM were included as a desirable goal for Block II SRM concepts as long as reliability and safety were not compromised.

Concepts for a Block II SRM were required to eliminate asbestos-filled insulation and were open to alternate designs to improve reliability and performance, such as case changes, different propellants, modified burn rate, etc. Limitations were placed on SRM changes such that the outside geometry would not alter the physical interfaces with other Space Shuttle elements and would have minimum impact on the aerodynamic and dynamic characteristics of the Space Shuttle vehicle. Morton Thiokol's criteria for selecting among the Block II SRM options were prioritized to: (1)

assure system reliability; (2) maintain/increase performance; and (3) enhance cost effectiveness.

Our study recognized that significant changes from demonstrated successful solid rocket industry experience would add uncertainty for system safety, reliability, performance, cost, and development risk (schedules and cost). For this reason a review of industry experience was completed early in the study and was a factor in selecting the preferred motor configuration.

Three large solid rocket motors, containing more than 50,000 lbm of propellant, have been developed, qualified, and brought to production and flight status: the Shuttle SRM, the Peacekeeper Stage I motor, and the Titan booster motor. The unitary propellant grain of a Shuttle SRM segment weighing approximately 300,000 lbm is the largest cast in a production program.

Large monolithic motors have been fabricated in previous technology demonstration programs. For the largest of these motors, 1.65 million lbm propellant grains were cast and the motors tested in-place which avoided transportation issues. Three tests were conducted with marginal results due to difficulties with the propellant grain in the third test. A single demonstration test of a 156-inch diameter motor is the only other experience for casting solid propellant grains larger than a Shuttle SRM segment.

Our assessment of a monolithic Shuttle SRM concept was influenced by this lack of industry experience. This concept requires casting unitary propellant grains almost four times the weight and length of a current Shuttle segment. Questions relative to the ability of manufacturing processes to control the integrity of the propellant grain and other critical features exist because the monolithic SRM represents a substantial departure in scale from previous successful experience. From a programmatic viewpoint, less confidence can be placed in the success of key demonstrations that are necessary at full scale including: ballistic reproducibility and motor pair thrust balance; consistency in processing and casting propellant to produce acceptable mechanical properties with control of voids and porosity; and insulation quality and bonding integrity during extended motor processing.

A Block II SRM concept is best assured of success if it builds on a substantial base of experience. Segmented designs can benefit from the production and operations with the Shuttle SRM and other large motor programs. No large deviation is required from demonstrated facilities, processes, transportation systems, and launch site handling approaches if a new segmented design is selected.

The present effort to redesign the SRM will verify the reliability of a new field joint concept before Space Shuttle flights resume. Subsequent production and flight operations will accumulate an expanding demonstrated database. Block II SRM concepts that can benefit from this experience in manufacturing and operations will have additional credibility for successful development and reliable flight performance.

A segmented design is recommended for the Block II SRM. The selected configuration and component designs were chosen to provide a payload increase for the Space Shuttle based on performance estimates using the exchange ratios provided for the study. A payload increase can be provided with no significant change in design reliability for the Block II SRM by using a higher performance propellant. A steel case material is selected to ensure reusability and maintain the cost benefits demonstrated from recovery and refurbishment of large metal components in the Shuttle program. A new case configuration is proposed with the potential for improvement in the integrity of assembly joints.

After balancing the factors of seal gap control, structural integrity, ease of manufacturing and assembly and inert weight impact, a clevis joint was selected for Block II over several bolted configurations that were evaluated. The Block II clevis joint includes a capture feature barrier seal plus primary and redundant clevis seals to ensure sealing reliability. The design includes the leak check and alignment features necessary for assembly and verification of the integrity of the mated joints.

The Block II clevis design, shown in Figure 1, will inherit much of the experience and knowledge developed in the Redesigned SRM qualification efforts. Valid analytical models supported by confirming tests are easily applied to its design and the similar sealing concepts will be completely demonstrated in the present test program. Other advantages of the clevis joint concept have been demonstrated in current Shuttle hardware. Joint dimensions can be held to very tight tolerances. Reusability of a clevis/tang joint has been demonstrated via tests and actual refurbishment of SRM flight hardware. The improvements proposed in the Block II clevis joint preserve these advantages and further increase the reusability of the hardware.

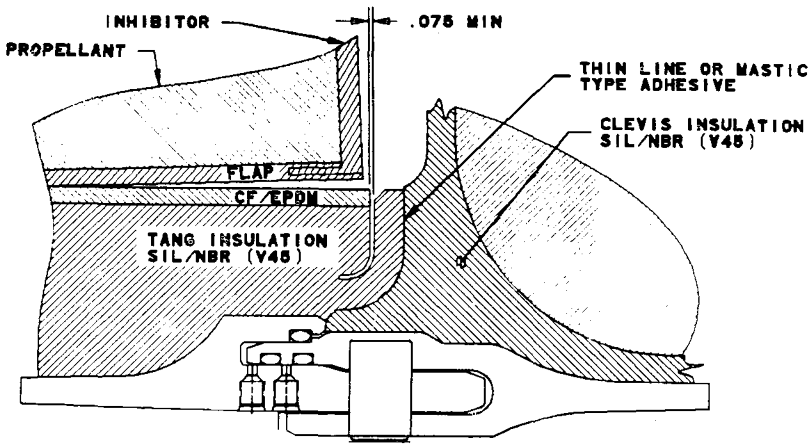


Figure 1. Block II SRM Field Joint Configuration

Because the motor maximum design pressure is 10 percent higher to meet "heads-up" performance requirements the Block II clevis joint is configured to a more robust version of the Redesigned SRM joint. Dimensions are strategically increased and a higher strength steel is specified. The joint is offset from the membrane line of action to reduce the gap openings. The joint has improved structural safety factors and seal gap control.

An insulation configuration is selected that is bonded across the case field joint at assembly and thereby prevents combustion gases from reaching the joint seals. This J-seal is fabricated as an integral part of the insulation on the tang side of the joint. The aft leg of the J-seal is configured to assure that it will maintain contact with the insulation on the clevis side of the joint at assembly. As the segments are mated the J-seal leg is pressed into contact with the clevis insulation and seals the gap between. This seal is assured by an adhesive that bonds the J-seal to the mating clevis insulation.

For the Block II SRM an integral one-piece aft dome and conical fixed nozzle housing is used to close the aft end of the case and provide structural support for the movable nozzle. The welded configuration that is selected is shown in Figure 2 along with an alternative two-piece bolted configuration. This steel component is fully insulated and combined with the forward section of the nozzle to form an aft closure subassembly which eliminates the present nozzle-to-case joint. This aft closure subassembly is attached to the aft segment after the propellant is cast and cured. The aft closure is assembled to the aft segment at the factory using a tang and clevis structural joint that is identical to the Block II SRM field joints.

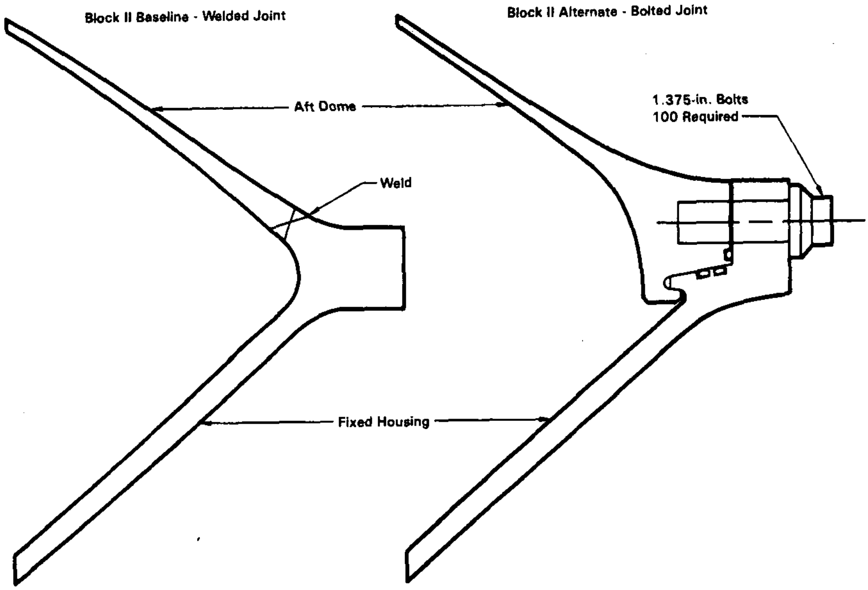


Figure 2. Aft Dome and Nozzle Fixed Housing Structural Configuration

The recommended Block II SRM concept is largely compatible with the existing infrastructure for development, production, and operation of the SRM. Elements of this infrastructure include the management, engineering, and production team; analysis tools; component test equipment; motor test facilities; review procedures; quality assurance and NDE systems; safety assessments and procedures; material suppliers and subcontractor teams; production facilities and tools; manufacturing plans and documentation; logistics system; storage facilities; transportation system; launch site facilities and ground support equipment; launch support team; recovery equipment; disassembly facilities; and refurbishment facilities and equipment. Being able to utilize these capabilities provides a significant cost benefit for a future Block II SRM program.

SUMMARY

Our study concluded that a segmented design is the lowest risk concept for a Block II SRM. Consistent motor performance and hardware quality have been demonstrated in production of large segmented solid rocket motors up to the size of a Shuttle SRM segment. This approach can lower development costs by using the production, test, transportation, and launch facilities that are currently ready for full operation.

The Block II SRM joint design can inherit confidence from the present qualification program for the redesign of the Shuttle SRM joint. The analysis methods and test techniques can carry over to substantiate similar hardware designs.

A new SRM design can contribute to increased Shuttle performance, if desired. Our Block II SRM concept, using a new steel case design, component enhancements, and a higher performance propellant offers potential for increased payload capability while retaining the cost benefit of reusing major motor components.

A realistic assessment of the development and verification schedule for a Block II SRM suggests a first development static test in 33 months, and design certification after 56 months, followed by delivery of the first flight sets of motors.

This concludes my prepared testimony. I appreciate this opportunity to appear before the Committee. Let me assure you that as individuals and as a corporation, we at Morton Thiokol share your dedication to ensuring the success of our Space Transportation System.

Thank you.

Senator RIEGLE. I want to thank everyone on this panel for your testimony and for your patience today. I want to say to my colleagues on this committee as well that I appreciate the very substantial involvement that we have had today as a subcommittee.

And I think just in concluding that you have seen today the fact that we have turned a new page in this situation and in the relationship between NASA on these issues and the Senate.

We are new teams on both sides of the table, for the most part, and we intend to continue in the vein that we have started today, and that is a constructive, active, working partnership.

And so we will be talking with you and we want to hear from you as we go along because we are after the same goal. And it is only by working that way that we are really going to get there.

So I thank you, and the committee stands in adjournment.

[Whereupon, at 1:33 p.m., the hearing was adjourned.]

[The following information was subsequently received for the record:]

STATEMENT OF H. GUYFORD STEVER, CHAIRMAN, PANEL ON TECHNICAL EVALUATION OF THE REDESIGN OF THE SPACE SHUTTLE SOLID ROCKET BOOSTER, NATIONAL RESEARCH COUNCIL

Thank you, Mr. Chairman. I am pleased to appear before you today in my capacity as Chairman of the National Research Council's Panel. Prof. James Mar, Vice-Chairman of the Panel, and Dr. Myron F. Uman, Project Director for the NRC, appear with me.

The Panel was organized at NASA's request in response to a recommendation of the Presidential Commission for the accident investigation, chaired by William Rogers. Our study began in June, 1986 and will conclude with a final report after we review the data on the performance of the SRBs during the next flight. (The list of members is Attachment A.)

The Panel is charged with providing the Administrator with an independent technical evaluation of the progress of the redesign at intervals in the program. We do not have the heavy responsibility of approving or disapproving designs or other decisions in the program; that responsibility rests with the appropriate government authority, NASA, which is free to accept our recommendations or not. While our assignment makes us critics and critics tend to dwell on problems, our intention is to play a constructive role, to help NASA produce a safer and more reliable SRB.

We provide our evaluations in reports to the Administrator. Three reports have been issued thus far. (Copies of the reports, dated August 1, 1986; October 10, 1986; and January 15, 1987, respectively, are Attachments B, C, and D.)

In my testimony today, I shall briefly summarize the findings, conclusions, and recommendations contained in the reports.

NASA's goal is to return a safe and reliable Shuttle to service at the earliest possible date. To meet the goal, the redesign team has adopted a baseline design aimed at correcting inadequacies of the previous design that affect safety. Only safety-related "mandatory" changes will be made for the next flight. We concur with this approach but recommend that NASA establish a program to continue to evaluate and improve the SRB's reliability after flights are resumed.

Since the Shuttle program began, capabilities for estimating loads and evaluating stresses and structural integrity have improved. To assure the highest degree of safety, stress analyses of the booster and its parts should be carefully reviewed and, as appropriate, recalculated using the best data and most up-to-date models. This is already being done with the aft skirt, which cracked during a recent structural test, and the aft strut, which connects the SRB to the External Tank at the lower end of the rocket.

The test program itself is success-oriented. That is, the schedule reflects an assumption that each test will produce results that are expected and understood; there is little room in the schedule for modifying the design if that becomes necessary. It is prudent, therefore, for NASA to plan for contingencies, particularly for aspects of the design for which substantial uncertainies remain: the case field joint, case-to-nozzle joint, and configurations of insulation at both joints.

The baseline case field joint employs a capture feature to restrict the relative motion of the gap that the O-rings must seal. We agree that the design will significantly constrain the motion. Concerns remain, however, including assembly and disassembly of loaded segments and refurbishing in new design for reuse. NASA's backup design uses the previous joint with stiffener bands wrapped around the outside of each case. It is also possible to make a joint that inherently has no relative motion of its parts, but it cannot be made using existing hardware. The lead time to make test hardware with a no-motion joint is long; we believe that the cases should be ordered as a contingency.

The program currently has no alternative for the baseline design of the case-to-nozzle joint, which incorporates a large number of new bolts and bolt holes, hence complicated stress patterns and potential leak paths. Uncertainties about the design of the nozzle and case-to-nozzle joint are now greater that for the case joint. Furthermore, the redesigned nozzle will not be tested until late in the program. These factors highlight the importance of developing contingency designs in this area. Alternative designs may require new forgings.

The baseline designs of joint insulation use adhesives to bond facing surfaces during assembly. These bonded or unvented designs are intended to prevent combustion gases from reaching the O-ring seals. Alternative, vented designs allow gases to reach the seals but assure that the gases have cooled. A number of designs of both types are being tested. The details of these designs are likely to continue to change; additional tooling should be obtained to enhance the flexibility of the program.

Materials for which contingencies should be in the program include ablatives in the nozzle, O-rings, and rust inhibiting grease.

The layup of nozzle ablative materials has been redesigned because of problems experienced in the past. Tests of the new design, which has no back-ups, will not be performed until late in the verification program.

New O-ring materials, which have better low temperature characteristics, have been found not to work as hoped because of interactions with the grease used on the case to inhibit rust. NASA therefore intends to use the previous O-ring materials with heaters to maintain an appropriate temperature. We are concerned with this development for several reasons and have urged NASA to look for or develop an alternative grease as soon as possible.

Procedures must be instituted to control the properties and quality of materials for the test and verification program as well as for building the flight articles. Thiokol appears to be working in this direction.

Quality control is also essential for assuring that the insulating liner is bonded to the metal case. The Air Force has been developing advanced techniques for evaluating these bonds nondestructively. We have urged NASA to learn from that experience and the Agency appears to be working on the problem.

The proof of the redesign depends on the results of the verification program. Since that program is just getting underway, it is premature to judge the relative safety and reliability of the new design. The verification program relies on both test and analysis. When performing verification tests, the redesign team should make predictions of the outcomes and establish criteria for successful verification beforehand. When relying on computational models to verify the design, tests should be conducted to validate the models.

While we continue to see progress in the definition of the total test program, it is difficult to relate the objectives of each of the numerous tests to specific design requirements or to develop a sense of the coherence of the test program as it supports the development effort. Thiokol has staff working on a layout of the test program as a function of program requirements.

The capacity for testing full scale hardware is being expanded. The new horizontal test stand capable of simulating dynamic loads experienced at launch and during flight is a major and welcomed addition to the program. Additional test hardware has been committed to the Joint Environment Simulator (JES) and Transient Pressure Test Article (TPTA) so the rate at which studies can be conducted on these test facilities can eventually be increased. The results of the tests conducted thus far on the JES have demonstrated the value of this type of test, even though it simulates only the first 0.6 seconds of the firing. If additional hardware does not result in an increased test rate, another JES facility should be built at Thiokol.

Finally, it is important to remember that a solid fuel rocket can only be fired once. As a consequence, its manufacture must be diligently controlled so that each one is as much like another as possible. The test program would not be meaningful otherwise. As it is, the expense of testing the motors in full scale, full duration firings limits the amount of data from which the reliability of the design can be accurately judged. Confidence in the reliability of the redesign would be enhanced if additional full scale, full duration firings, particularly with structural deformations to simulate dynamic loads, were added to the program before the next flight.

I would like to conclude my testimony by expressing the Panel's appreciation for the cooperation and assistance provided by NASA and Thiokol personnel and by others outside the program whom we have consulted. The redesign team is working hard and deserves praise for its dedication and accomplishments to date.

My colleagues and I will be happy to try to answer your questions.