unlikely that all LWT's will have strengths greater than LWT-2.

LWT Proof (or Acceptance) Test - In addition to the static test for buckling just described, which was performed on LWT-2 only, each production LWT receives a burst proof test as an acceptance test. These acceptance tests are run in the horizontal test stand facility at the Martin Marietta plant at Michoud, Louisiana. The acceptance test is designed to impose the "equivalent"1/ of 105 percent of limit load tension on all welds. The internal pressure alone is sufficient to proof load the axial welds, but five different combinations external loads are used in addition to the internal pressure to attain the proper loads on the circumferential welds. This proof test contributes nothing toward the verification of required compressive buckling strength of the LH_2 tank shell.

1/"Equivalent" is used here to indicate that the proof pressure was reduced to account for the reduced toughness of the 2219-T87 aluminum material at room temperature compared to the operating temperature of -423oF, i.e., pressures are divided by the factor 1.1. Since the high side of the flight ullage pressure regulation band is 34 psia and the LH_2 under flight acceleration is 6.4 psi then the proof pressure

P(proof) = (40.4 X 1.05)/1.1 = 38.6 psig

APPENDIX III

STABIITY OF SPACE SHUTTLE EXTERNAL LIGHT WEIGHT TANK (LWT)

David Bushnell and Bo Almroth

December 14, 1982

LMSC-D877306

LOCKHEED PALO ALTO RESEARCH LABORATORY
APPLIED MECHANICS: DEPT. 52-33, BLDG. 255
3251 HANOVER ST., PALO ALTO, CA 94304

STABILITY OF SPACE SHUTTLE EXTERNAL LIGHT WEIGHT TANK (LWT)

David Bushnell and Bo Almroth

ABSTRACT

The next and future launches of the Space Shuttle will include a redesign external (disposable) tank. This tank is of lighter weight than that used to date. It has been tested to design limit load, not to ultimate load. During a certain phase of the launch there are regions of the tank subjected to destabilizing loads generated by the thrust of the Orbiter engines. Recently, the Aerospace Safety Advisory Panel, a committee that advises NASA Headquartes on issues involving the Space Shuttle, expressed concern about the adequacy of the new design with regard to buckling. The committee recommended that experts in the field of shell buckling be called in to evaluate the new design, render an opinion of safety, and make recommendations about possible further analyses and tests. David Bushnell and Bo Almroth were selected by the Panel and by NASA Headquarters to perform these tasks. On December 9th and 10th Bushnell and Almroth visited the Martin Marietta Company, Michoud Division, New Orleans, in order to evaluate the light weight tank design with regard to buckling. On December 11th they, representatives from Martin Marietta, the Aerospace Safety Advisory Panel, and NASA officials met at NASA Headquarters to discuss the buckling issue. As a result of Bushnell's and Almroth's evaluations, it was decided that the light weight tank could be flown on the next Shuttle launch without further analysis, but that nonlinear analyses with the use of the STAGSC-1 computer program should be performed with an eye toward future launches, during which the destabilizing loads are expected to be somewhat higher than those on the next flight.

PARTICIPANTS

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Mike Weeks, Jerry Fitts, Dave Winterhalter, Raoul Lopez

NASA MARSHALL SPACE FLIGHT CENTER:

Jim Kingsbury and others

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DENVER DIVISION:

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NASA REPRESENTATIVES PRESENT AT MEETINGS AT MARTIN-MICHOUD:

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BACKGROUND AND PROBLEM DEFINITIONS

On Wednesday, November 24, 1982, Willis Hawkins, in his capacity as chairman of the Aerospace Safety Advisory Panel for NASA's Space Shuttle program, telephoned David Bushnell about a buckling issue in the Space Shuttle external tank. Hawkins asked Bushnell to call Grant Hedrick for details. That afternoon, Bushnell, Almroth, and Hedrick held a telephone conference in which Hedrick defined the issue.

Figure 1 shows the Space Shuttle external tank (ET). At a certain phase of operation following launch, local regions of axial compression develop just forward of longerons by means of which Orbiter thrust loads are transferred to the external tank. In this region the external tank, which contains liquid hydrogen and is internally pressurized to 32 psi, must be designed so that it will not buckle under the combined hoop tension and axial compression. The tank is stiffened internally by stringers with T-shaped cross sections, as shown in Figure 3. (First two rings in the foreground are typical.)

On Space Shuttle flights to date the disposable external tank has and an inert weight of 7100 pounds. This tank, henceforth called "heavy weight tank" (HWT) or "standard weight tank" (SWT), was tested under cryogenic conditions to an ultimate load of 1.40 times design limit load. Because of the need to reduce weight, a new lighter weight disposable tank has been designed, henceforth called "light weight tank" (LWT), with an inert weight of 60500 pounds. About half of the weight saving came from structure; the skin between stringers was reduced in thickness in certain areas, the cross sections of certain rings were reduced, and material was taken out of the aft portion of the large longerons by means of which orbital thrust loads are transferred to the LH_2 tank.

The new light weight tank has been tested to design limit load in the horizontal proof test stand at Martin Marietta's Michoud, Louisiana, plant. A new definition of ultimate load, 1.25 times design limit load, has been accepted. Buckling analyses conducted at Martin Michoud by Dale Karr indicate that the new tank will withstand the new ultimate load. The new tank will fly on the next launch, now planned for January, and on future Shuttle flights.

Due to the pressures of time and money there is currently no plan to test the new tank to the new ultimate load. This lack of a test on a stability-critical structure designed to a lower margin over design limit and than the previous tested tank worried Hedrick. Accordingly, as a member of the Aerospace Safety Advisory Panel, he advised that an independent evaluation of the analysis methods and the new design with regard to buckling be carried out. Bushnell and Almroth were consulted as experts in this field.

After the telephone conference with Hedrick, Bushnell called Hawkins on November 24 to request that Hawkins officially introduce Bushnell and Almroth to whoever at Martin Michoud has overall responsibility for the structural integrity of the Shuttle external tank. Bushnell and Almroth would then gather enough data from Martin in order to render an opinion.

On Friday, December 3 Gil Roth at NASA Headquarters contacted Bushnell at Lockheed. Roth requested that Bushnell contact Al Norton at Martin Michoud to set up a visit by Bushnell and Almroth on Decemer 9th and 10th at Martin in order to learn details of the geometry and buckling analysis conducted at Martin. Bushnell first called Norton, who directed him to Dick Foll. Foll knew about the proposed visit to Martin by Almroth and Bushnell; he was agreeable to the proposed dates of the visit; and he supplied the name, Jon Dutton, manager of the department reponsible for the analysis of the Shuttle external tank. Bushnell called Dutton in order to obtain certain details of geometry and loading that would permit some analysis to be conducted at Lockheed with PANDA, BOSOR4, and possibly STAGSC-1 before the visit on December 9th and 10th. These details were supplied to Bushnell on Friday afternoon, December 3 by Dale Karr.

Following the telephone contacts at Martin Michoud, Bushnell called Roth at NASA Headquarters to confirm the dates of Almroth and Bushnell's visit to Martin. Roth told Bushnell that there would be a meeting at NASA Headquarters on Saturday, December 11, in General Abrahamson's office to discuss the buckling issue and to learn the opinions of Almroth and Bushnell. This meeting would be attended by General Abrahamson, Gil Roth, Willis Hawkins, Grant Hedrick, Al Norton, Dick Foll, Jon Dutton, Bo Almroth, David Bushnell, people from NASA Marshall Space Flight Center (MSFC), and others.

On Friday, December 3 and Monday and Tuesday, December 6 and 7, Bushnell conducted buckling analyses of the local regions of the Shuttle external tank subjected to compressive stresses. PANDA and BOSOR4 runs were made. Results from these two programs agree with each other for cases in which both apply. A preliminary conclusion, from the data supplied by Dale Karr over the telephone and from PANDA and BOSOR4 calculations based on these data, is that the new, lighter weight Shuttle external tank has sufficient margin with regard to buckling.

ET CONFIGURATION

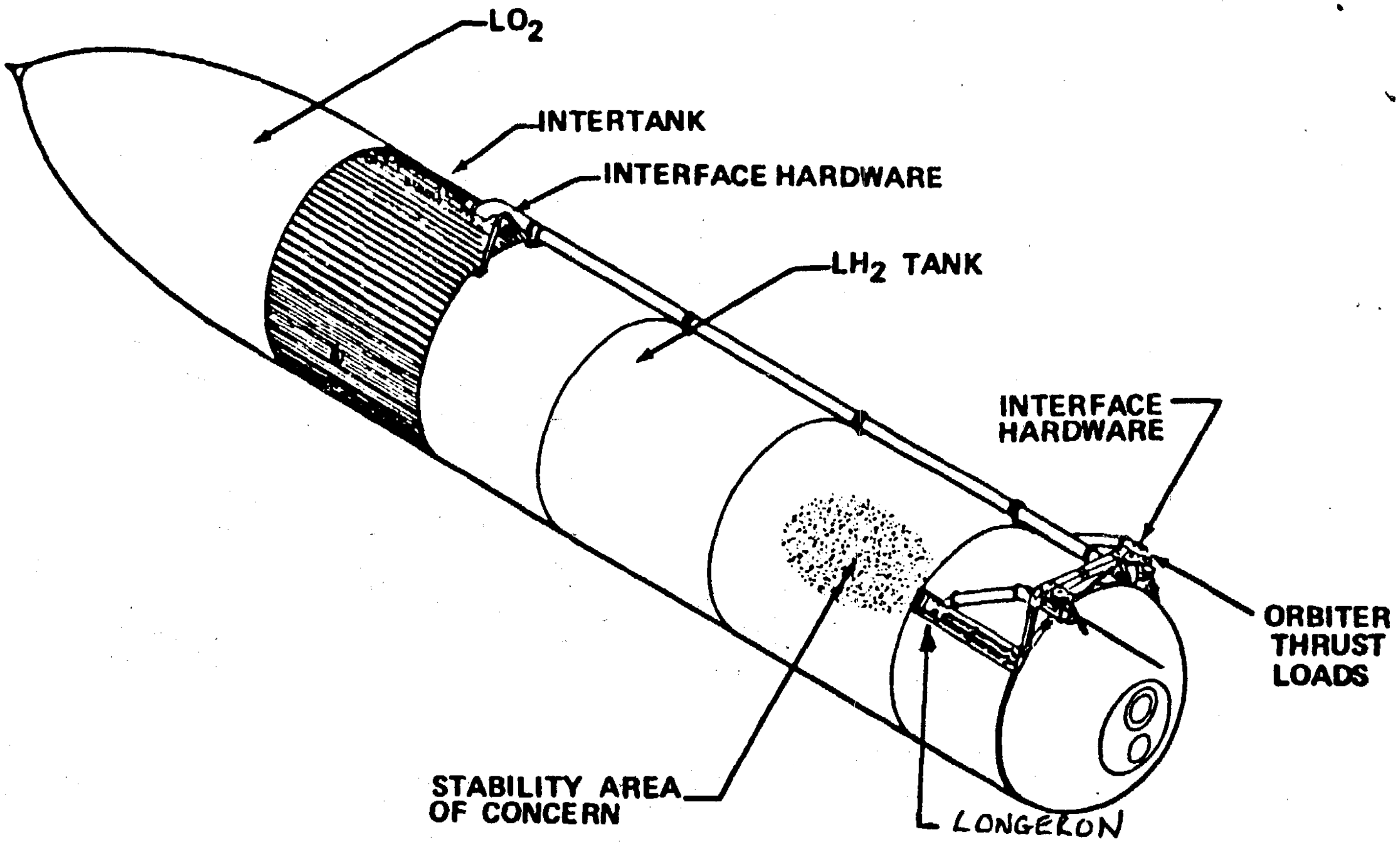


Fig. 1 External tank configuration showing area where buckling is possible

LH_2 BARREL - SKIN STRINGER

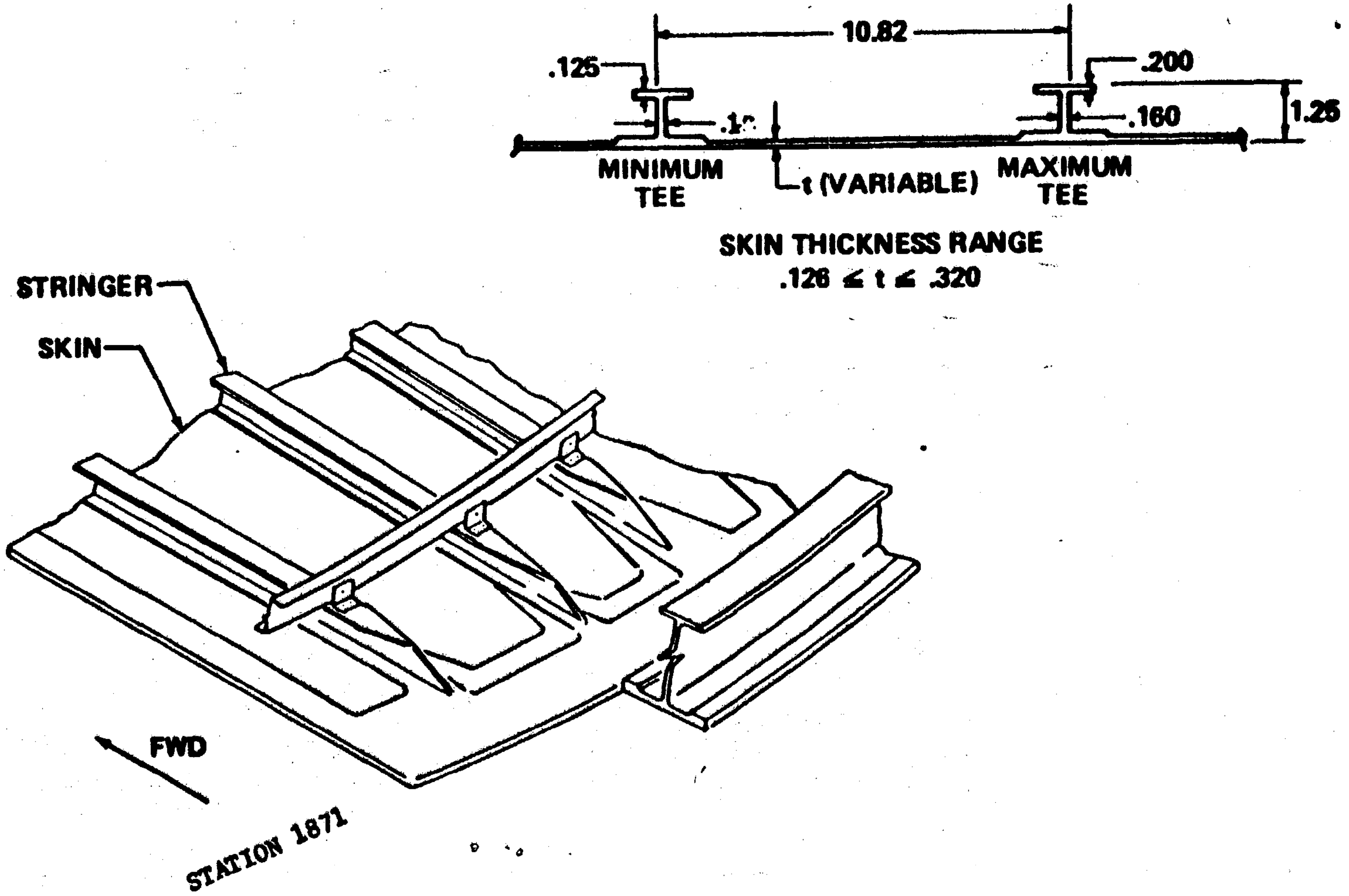


Fig. 2 Panel configuration in buckling-critical region

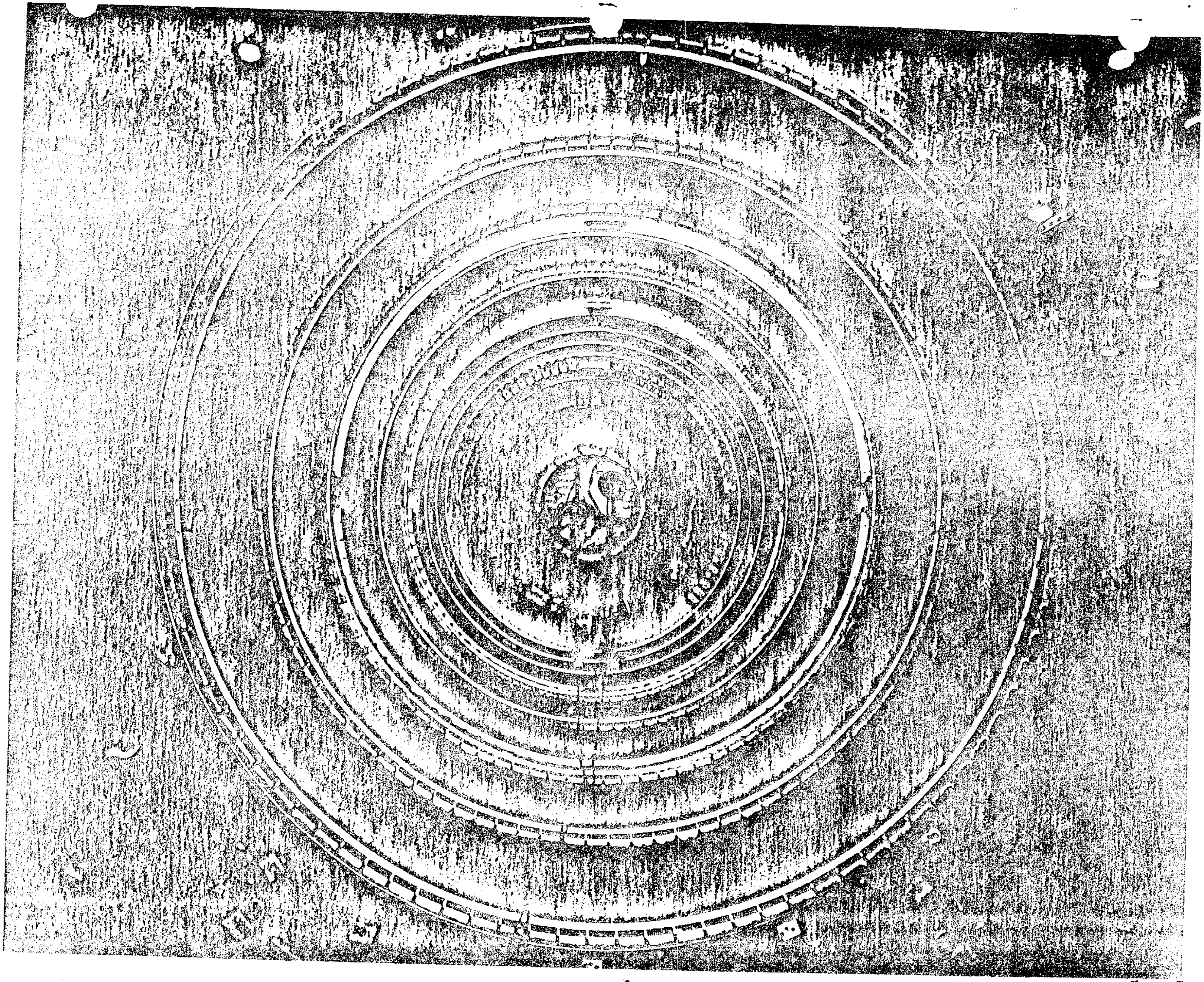


Fig. 3 Liquid Hydrogen Tank Interior (SWT) (Courtesy Martin-Marietta Corp.)

APPENDIX IV
MAIN ENGINE

September 29, 1982

TO: Willis M. Hawkins
FROM: Jerry Elverum and John McDonald
SUBJECT: NASA-ASAP Visit to Rocketdyne to Examine SSME Logistics and Support, September 28th

As noted in Gil Roth's memo of August 18th (page 2) we visited Rocketdyne, Canoga Park, to review the logistics and support aspects pertinent to the SSME. A detailed presentation was given to us and two copies (BC 82-223) have been sent by Rocketdyne directly to Gil Roth. The program was divided into two main parts:

(a) turn-around operations and maintenance together with support systems, and

(b) an outline of the precepts upon which the support activities are being based.

Vince Wheelock (SSME Logistics Manager) presented part "a" and his Chief of Schedule Management, Harvey Colbo, gave part "b". A copy of the Rocketdyne organization chart is attached hereto (attachment 1). Persons also attending are listed in attachment 2.

These notes will include a discursive commentary upon the material presented to us, together with selected charts, and will conclude with some more specific recommendations of a form suitable for adaptation to the ASAP annual report.

MATERIAL PRESENTED AND DISCUSSION

Opening comments were that flight data were being continuously analyzed for maintenance action but it was conceded that there were just not enough data available yet from the four flight to refine the assumptions made - really prior to STS-1. It was stated that thee studies really commenced in the definition phase beginning in 1972 and used extensive Saturn experince background.

External visual inspections on the SSME were described followed by the turbopump breakway torque and axial shaft travel pre-flight checks. Internal inspections of the entire powerhead assembly and the main combustion chamber were outlined - these consisting principally of borescope ports using both fibre-optic and rigid borescopes. Camera (35 mm) shots can be taken in some cases - mostly with rigid borescope applications. Drying purge of the combustion chamber and various leak checks were described including checks with throat plugs installed.

Electrical checks look fairly straightforward, probably the least familiar to mechanics being controller memory read-out. All the preceding checks are accomplished with the Orbiter in the horizontal position but some, such as high-pressure fuel turbopump removal are time consuming tasks as the unit has to be disconnected from its ducts etc., and slid out on "Thompson rails" (a piece of GSE) every second flight.

The Rocketdyne team at KSC to accomplish all this seems to number about 35 men, about half of whom are involved on each shift in the pre-launch activities. Some 13 technicians, 4 inspectors and 2 or 3 engineers are normally required but like all critical borescope viewing techniques the "Mark I eye-ball" confidence will probably be placed in just one or two men who possess great experience. This connotes a critical training problem as launch rates increase.

Readiness maintenance tests with the whole Shuttle assembly on the launch pad were described and a few unscheduled maintenance items have been identified. Environmental protection sets (covers) for the SSME and for the RCS and OMS engine were described, but their installation after landing is rather difficult and time consuming because of the height from the ground. More specifically, only three sets exist at present - one at KSC and the other being available to be ferried to White Sands, Hickam, Kadena, Rota or Dakar as the abort case might be. The SSME's would have to be removed to provide ferry range-weight capability out of Dakar, Hickam and Kadena.

When the craft is on the launch pad at KSC the availability of only one set of SSME GSE means that each engine at the present time has to be worked on in series. It apparently takes six shifts or approximately 48 elapsed hours to remove the old engine and install the new. The usual supporting logistics analyses including resources such as facilities, maintenance crews, training, spares, handbooks and manuals etc. appear to have been well thought out and are based upon a DOD philosophy - e.g., organizational, intermediate and depot levels and a maintenance plan has been established to suit. Training manuals have been prepared and courses planned.

MTBR studies have been made of all principle components and assemblies and engine overhauls have been scheduled based largely upon these values. Support of this wide base of materiel was said to be "in the short term" based upon existing vendors' facilities and production units whereas, "in the long term" it would revolve around "dedicated facilities and systems." The terms were not defined in years and we drew the conclusion, erroneous perhaps, that they were feeling their way both in terms of experience with the flight hardware and available funding downstream.

The all-components total MTBR plots for the period 1976 through 1980 based upon test stand data and earlier similar engine data are shown in attached Chart C-9 and Rocketdyne expressed confidence in the conservatism of these based upon their approach of factoring the MTBR value. Chart C-9 shows this overall engine life growth plotted upon a linear scale. C-10 shows the major components of the engine and the asymptotic sections beyond FY '84 are intended to indicate that they don't expect to gain a great deal of data above the fully certificated (and realized) life level. It is of significance that the most crucial components, namely the HPFTP and the HPOTP are at the bottom of the totem pole, while the LPFTP and the LPOTP are not really very much better. Much of this is due to the actual experience over the four flights and the higher FPL involved. Chart C-34 shows the estimated data replotted from October 1980 to Octoer 1981 resulting, in effect, in a zero gain in MTBR throughtout that period. In fact, the plot shows a somewhat retrograde trend but the dotted line reflects optimism which, in our opinion, may not be fuly justified. Even if the life growth rates shown in C-35 are realized the effect upon available SSME spares levels could well be serious and some launches could suffer delay. The following plots (Charts C-36 through C-41) indicate the same optimism and C-38 and C-39 for the HPFTP and the HPOTP respectively should be examined carefully. There appears to be little justification for the revised "projected improvement" dotted line.

Taking the foregoing a little further and examining Chart C-52 it will be seen that the overhaul projections are rather awkwardly "bunched" especially circa 1993-1994. Rocketdyne believe that the natural occurrences of failures and other aberrations will tend to minimize some of the "bunching" and this may well prove to be true, but it is an uncomfortable precept with which to start the program. The last Chart, C-53, summarizes the expressed confidence level in terms of the halved MTBR assumptions. The principal conclusion we drew upon the basis of the data presented is that additional spare SSME's or at least a larger spares float of high and low pressure oxygen and fuel turbopumps would provide some better insurance.

RECOMMENDATIONS (for the Shuttle program)

1. The MTBR analyses, while appearing to be very thorough in classical reliability study terms and rendered conservative by the "two times factor," do not appear to be in consort with the spectrum of early removals being experienced in the program to date. A comprehensive "best case - worst case" analysis should be considered covering the full range of reasonably possible contingencies, especially in the logistics and supply fields.

2. Results to date with a wide variety of "random failure" induced problems on the SSME indicate that the four pumps are likely to have MTBR's well below original expectations - at least for the next year or two. The high pressue fuel turbopump and the high pressure oxygen turbopump appear to be especially critical because of the limited spares available and the long lead times involved in procurement. Additional spare units would appear very desirable.

3. Planned grouping of the SSME overhauls should be re-examined to see if they could be more uniformly distributed over the period 1984 through 1994. While it is most likely that unforeseen incidents will affect the planned dispersion and tend to improve it, the present layout would appear to be prone to loss of overhaul technical skills in the workload "valley" periods and thus will run counter to safety and reliability requirements.

4. "Near term" support based purely upon "robbing" production hardware and placing reliance upon the vendors for overhaul and other technial service should be critically analyzed. The "near term" and "long term" time spans should be defined and very conscious steps taken toward the establishment of a properly based "dedicated overhaul facility," not the least

important of which will be the average age and experience level of the technicians employed. Employment stability and continuity is also an important factor in this respect.

5. From the overall safety and reliability viewpoints every possible effort should be made in planning to avoid dependence upon "cannibalizing," or robbing from production lines to meet flight date requirements. Such continuing support pressures inevitably run counter to safety because of the desire to adjust "red line," extend the life for just one more mission, and so on, to preserve intact the very expensive and highly publicly visible launch date schedules.

RECOMMENDATIONS (for the NASA-ASAP group)

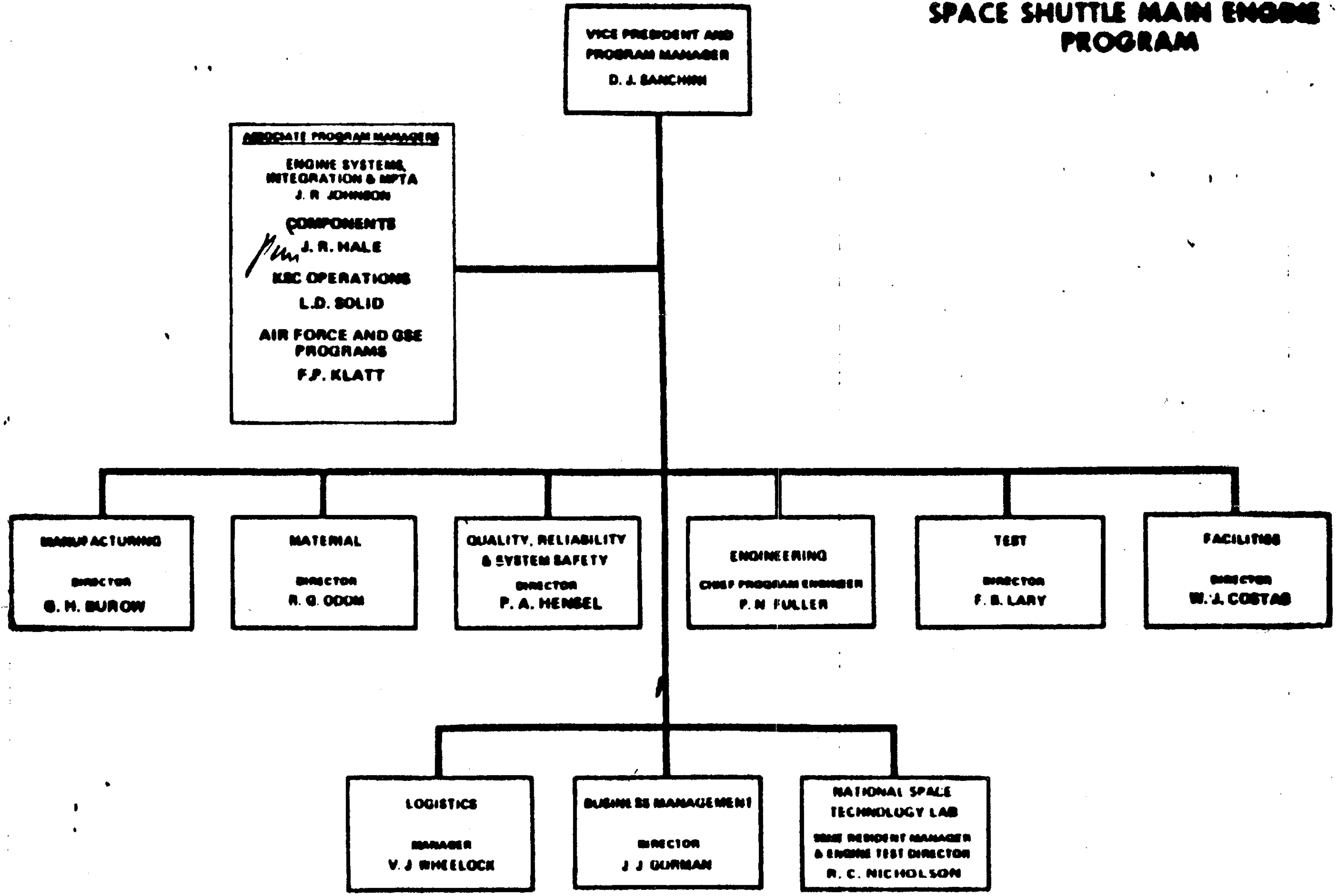
It became clear in the course of the excellent Rocketdyne SSME presentation that the engine and related systems are much too highly specialized - and spread over too narrow a base in terms of the four Orbiter vehicles - to permit any other group than Rocketdyne to accomplish the overhaul and support tasks - or even for that matter, the critical pre-flight inspections. Further, it became more apparent at each logistics and support presentaton that if we, as a Panel, are to really understand the enormity of this task and to make valid suggestions, we have to spend much more time on visits and studies. Certainly the somewhat intangible, but never-the-less real, effects of logistics and support philosophies upon overall system safety warrant further attention.

cc: Parmet
Grier
Himmel
Battin

Attachment
1. Rocketdyne Organization Chart
2. Attendance list
3. Selected presentation charts

Enclosures

SPACE SHUTTLE MAIN ENGINE PROGRAM



VICE PRESIDENT AND PROGRAM MANAGER
D. J. SANCHINI

ASSOCIATE PROGRAM MANAGERS

ENGINE SYSTEMS, INTEGRATION & MPTA
J. R. JOHNSON

COMPONENTS
J. R. HALE

KSC OPERATIONS
L.D. SOLID

AIR FORCE AND GSE PROGRAMS
F.P. KLATT

MANUFACTURING
DIRECTOR
G. H. BUROW

MATERIAL
DIRECTOR
R. G. ODOM

QUALITY, RELIABILITY & SYSTEM SAFETY
DIRECTOR
P. A. HENSEL

ENGINEERING
CHIEF PROGRAM ENGINEER
P. N. FULLER

TEST
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LOGISTICS
MANAGER
V. J. WHEELOCK

BUSINESS MANAGEMENT
DIRECTOR
J. J. GURMAN

NATIONAL SPACE TECHNOLOGY LAB
SSME RESIDENT MANAGER & ENGINE TEST DIRECTOR
R. C. NICHOLSON

ATTACHMENT 1.

7-27-82

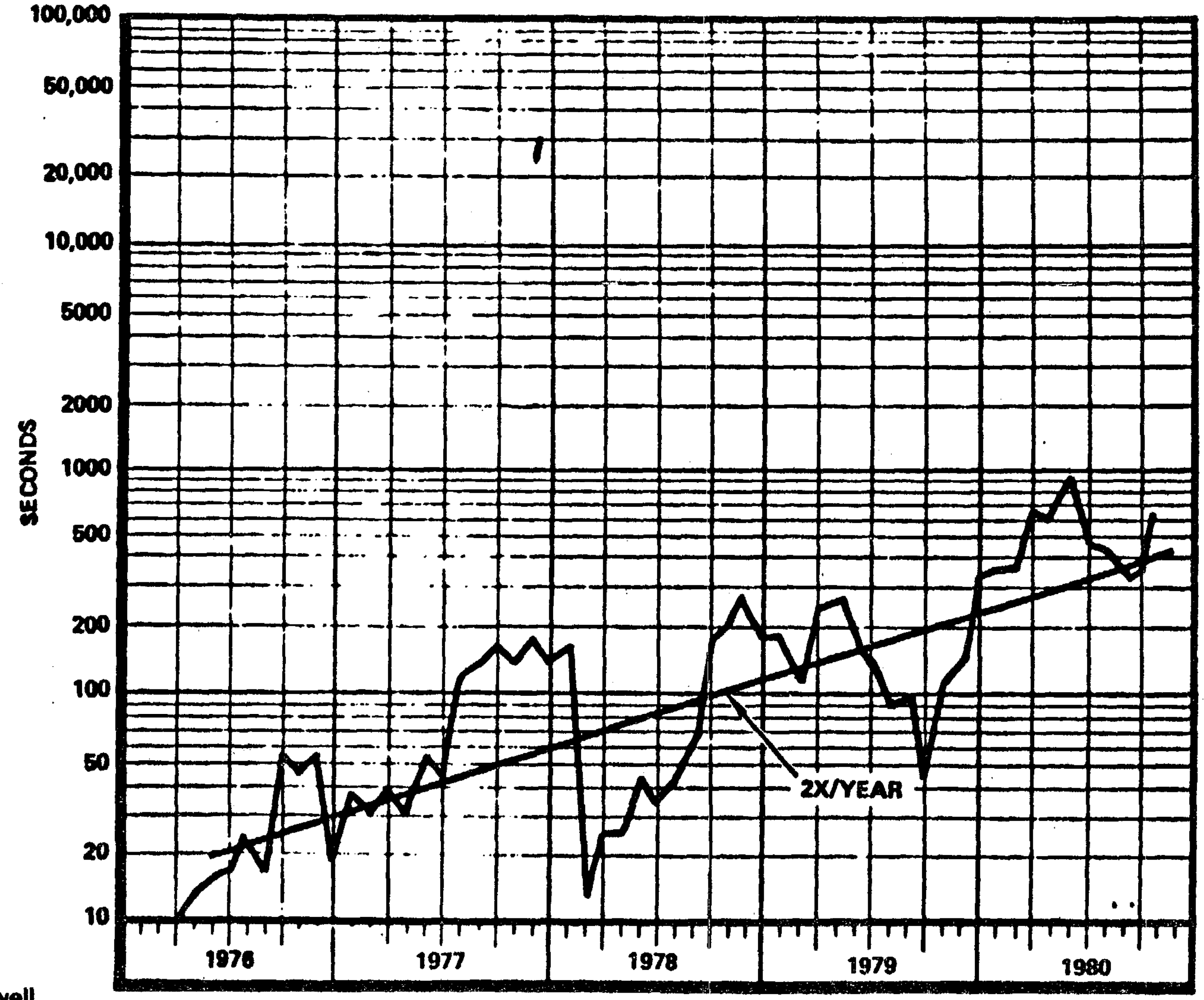
Rockwell International
Rocketdyne Division

Attachment 2

Name	Organization	Position	Phone No.
Vince Wheelock	Rocketdyne	SSME Log Manager	X 2254
John F. McDonald	NASA (ASAP)		843-8311
Jerry Elverum	NASA (ASAP)		535-2374
Jack Weil	NASA/RKO	Project Mgt. Office	710-2261
Bill Mitchell	MSFC/SA-52	Logistic Management SSME Project Office FTS	872-0088
Norm Dingilian	Rocketdyne	Supply Support Mgr.	x 3095
Harvey Colbo	Rocketdyne	Schedule Management	x 3335
Frank Klatt	Rocketdyne	Assoc. Program Mgr. AF, GSE, SSME	710-3078

ATTACHMENT 3.

SSME MEAN TIME BETWEEN COMPONENT REMOVALS
ALL COMPONENTS TOTAL



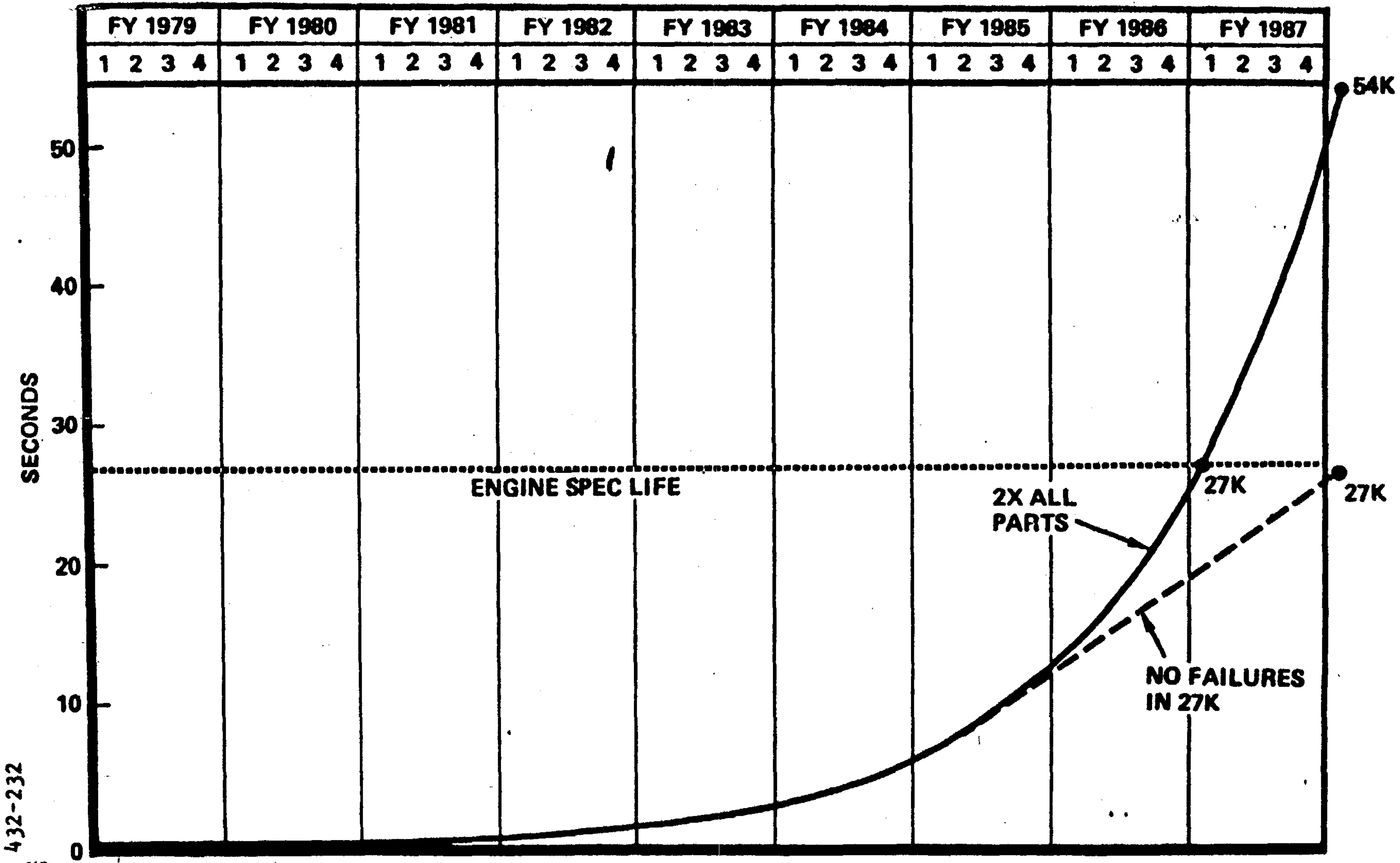
● 3 MONTH MOVING AVERAGE

430-383A

Rockwell International
Rocketdyne Division

SSME OVERALL MTBR PROJECTION

3-15-82



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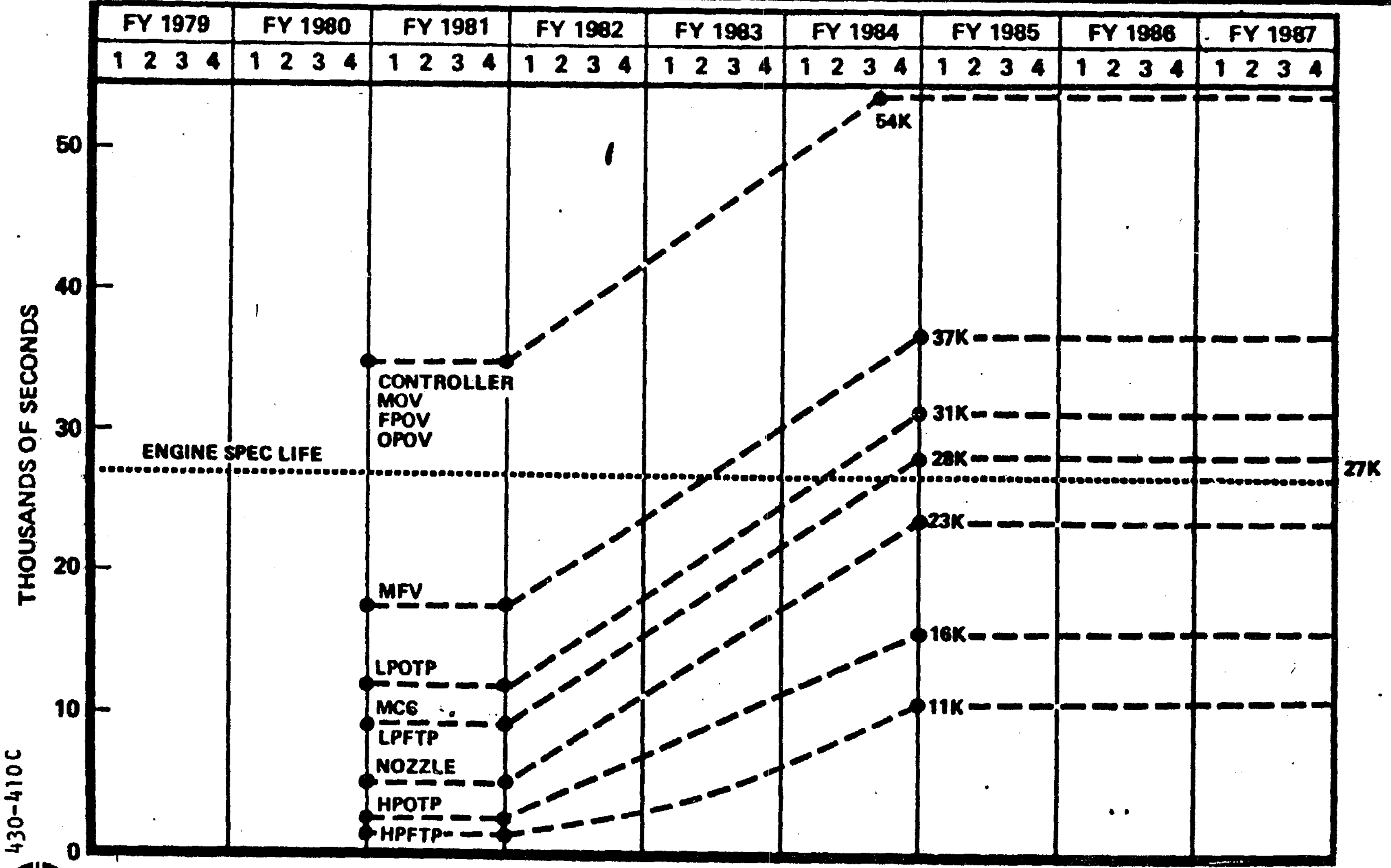
Rocketdyne Division

SSME COMPONENT MTBR PROJECTION

3-15-82



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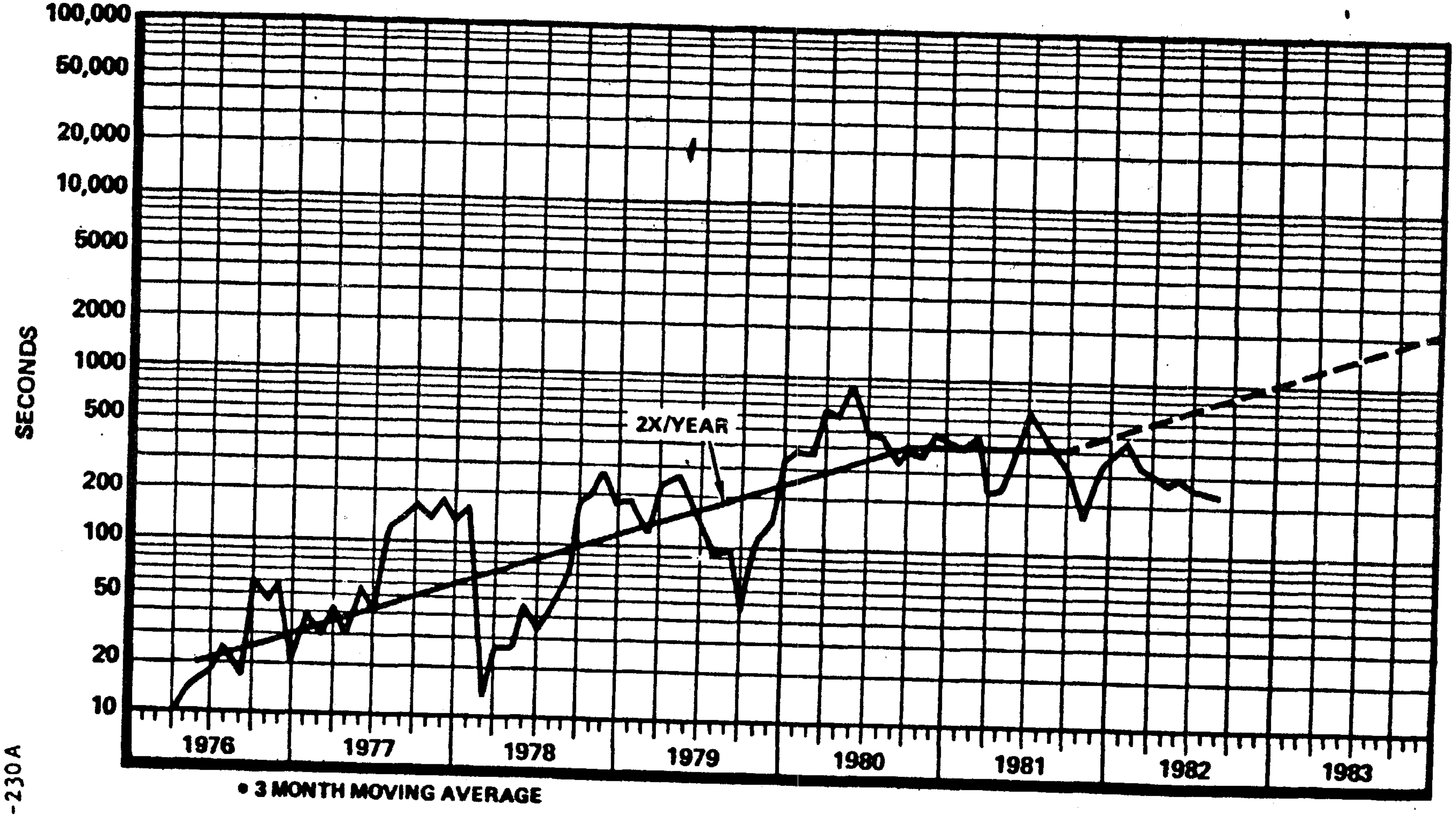
Rocketdyne Division

SSME MEAN TIME BETWEEN COMPONENT REMOVALS

23 SEPT 82



• 3 MONTH MOVING AVERAGE

432-230A

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International
Rocketdyne Division

MTBR PROJECTIONS FOR SPARE PARTS PLANNING

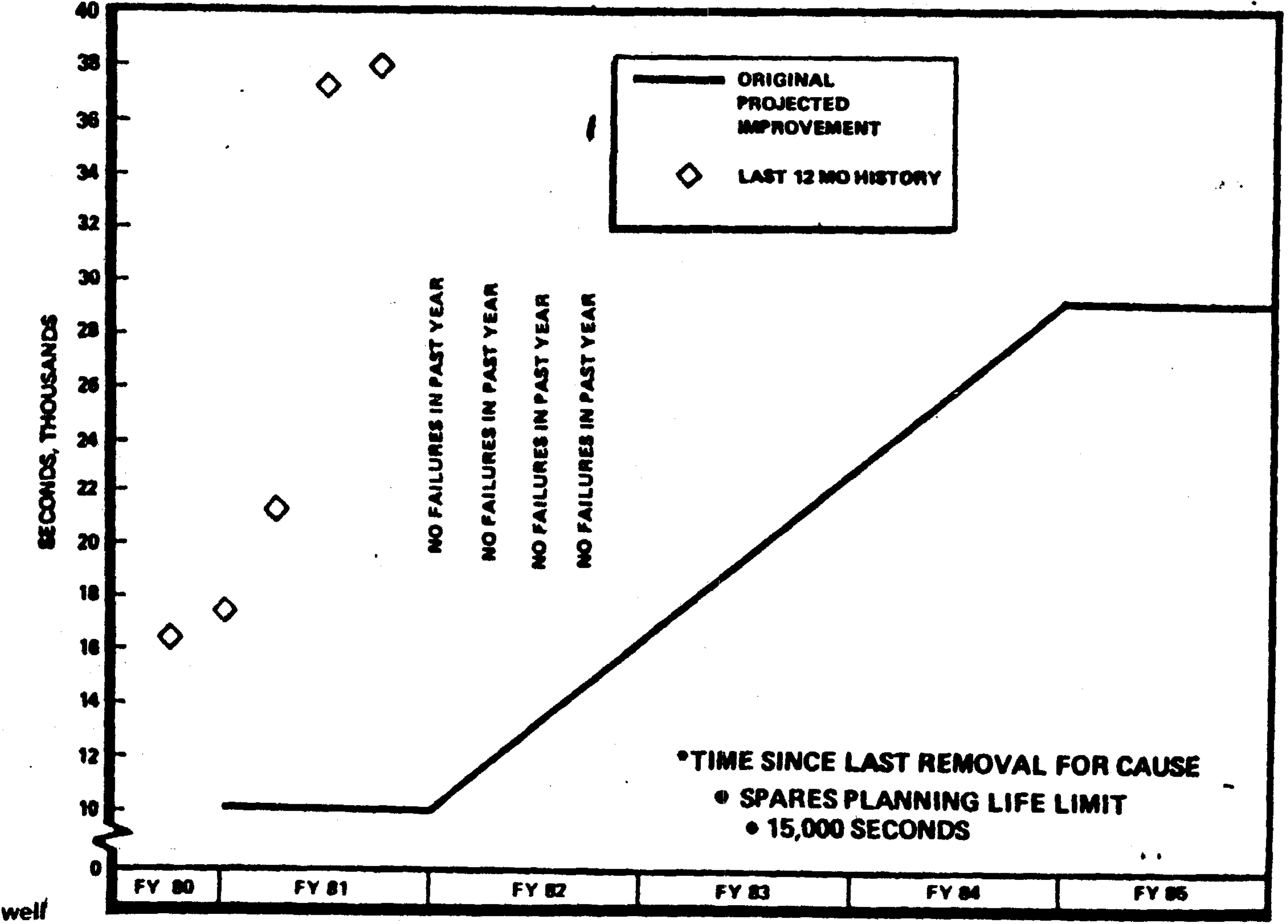
	FY82 MTBR (SEC)	FY83 MTBR (SEC)	FY84 MTBR (SEC)	FY85 & SUBS MTBR (SEC)
MCC	NF	NF	NF	NF
NOZZLE	30,000	30,000	30,000	30,000
HPFTP	1,500	2,000	4,000	6,000
HPOTP	2,500	3,000	5,000	7,000
LPFTP	16,000	16,000	16,000	16,000
LPOTP	8,000	10,000	15,000	20,000

NF = NO FAILURES

B7359

MCC
MEAN TIME BETWEEN REPLACEMENT

23 SEPT 82



*TIME SINCE LAST REMOVAL FOR CAUSE

- SPARES PLANNING LIFE LIMIT
  - 15,000 SECONDS

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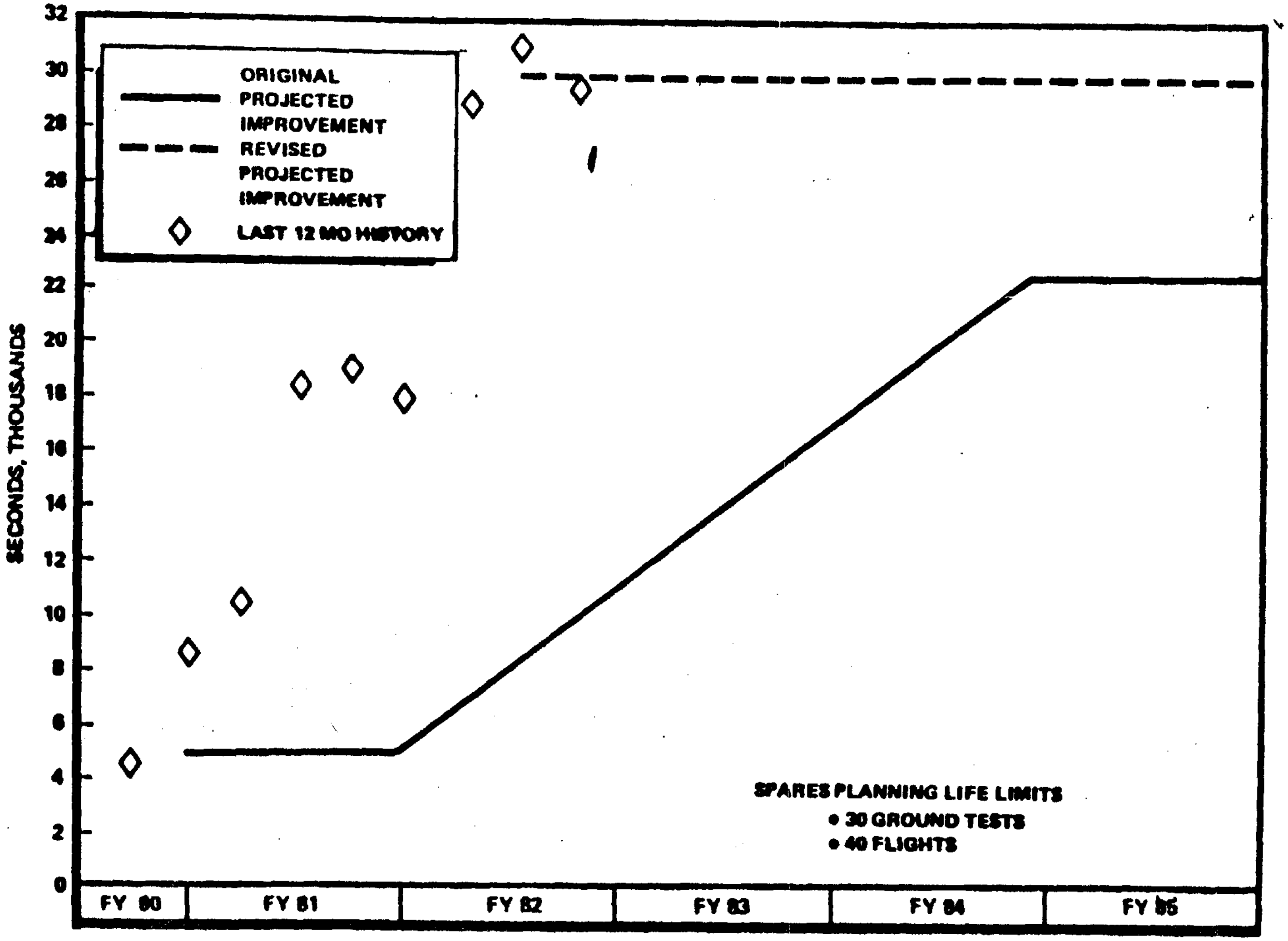
NOZZLE
MEAN TIME BETWEEN REPLACEMENT

23 SEPT 82



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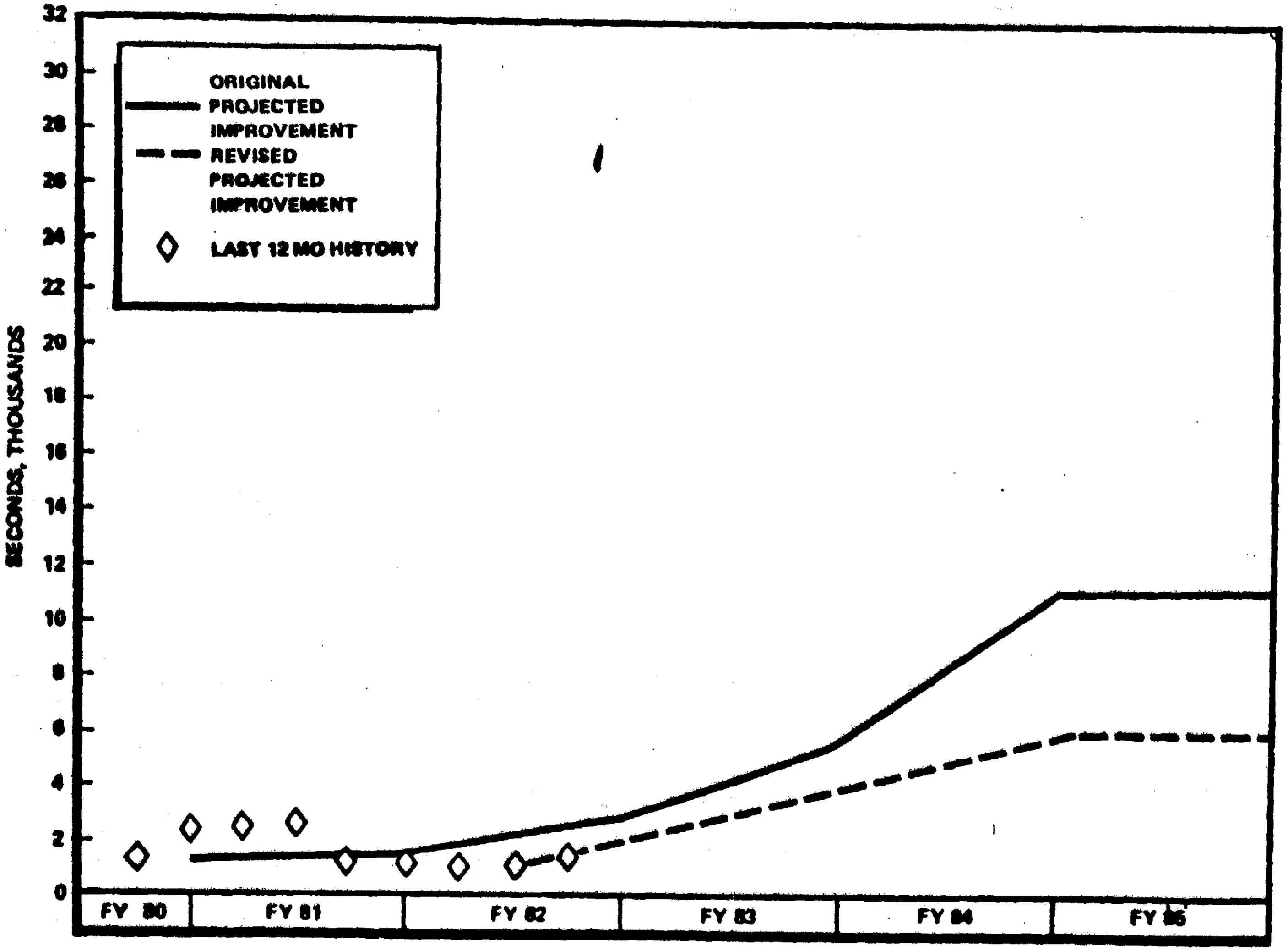
75

SPACE SHUTTLE

HPFTP
MEAN TIME BETWEEN REPLACEMENT

23 SEPT 82



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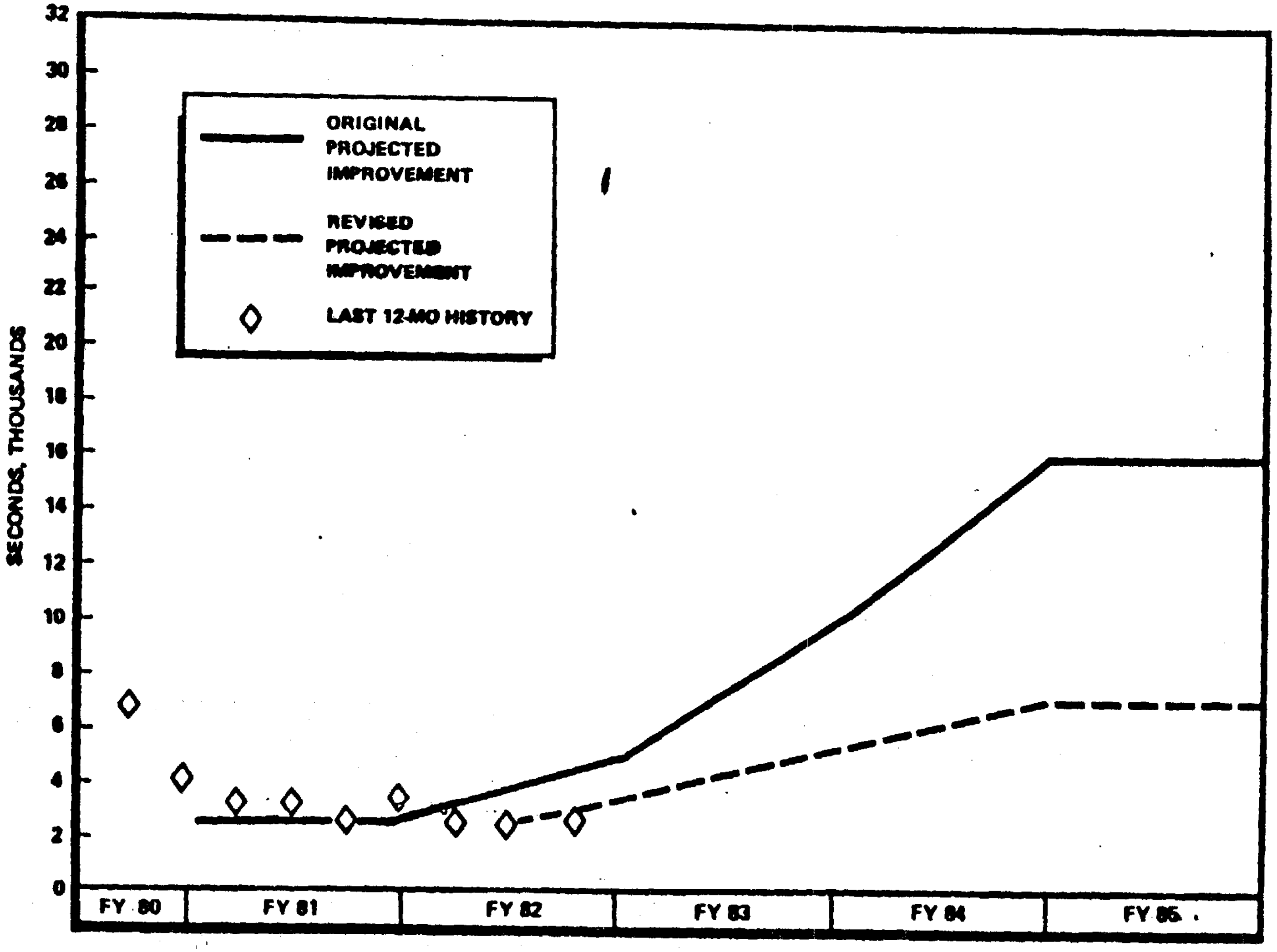
HPOTP
MEAN TIME BETWEEN REPLACEMENT

23 SEPT.82



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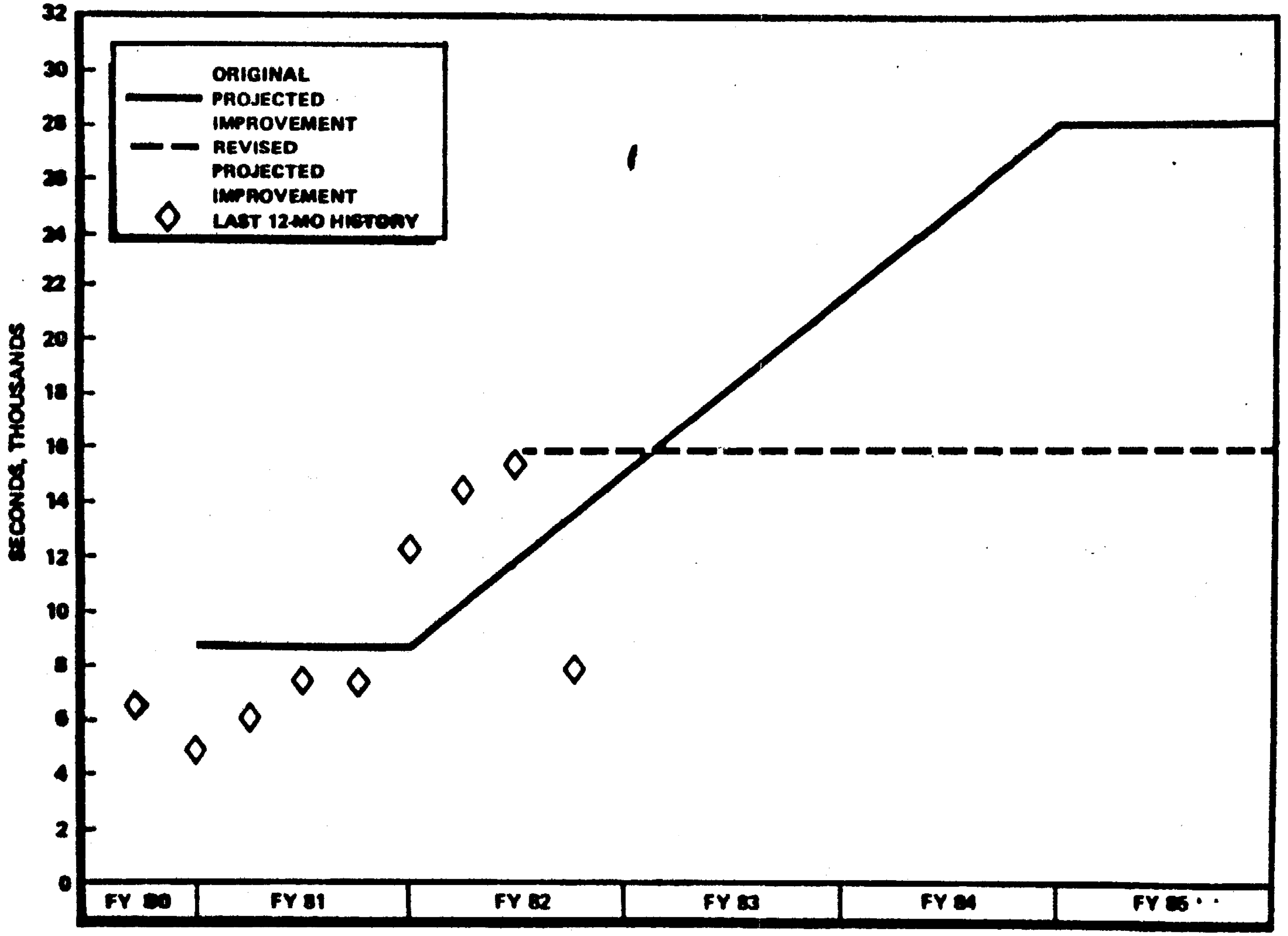
LPFTP
MEAN TIME BETWEEN REPLACEMENT

23 SEPT 82



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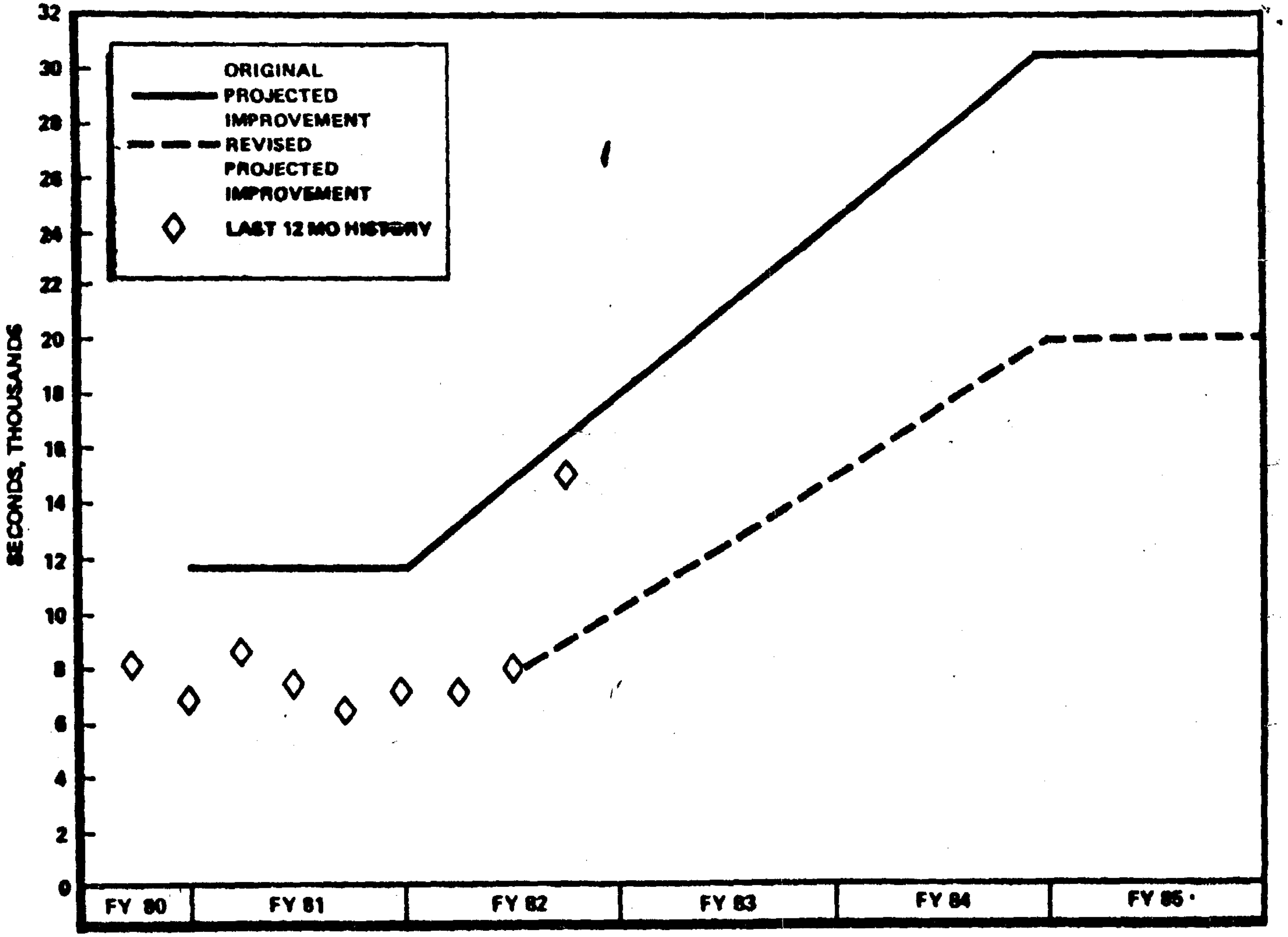
432-2388

LPOTP

MEAN TIME BETWEEN REPLACEMENT

23 SEPT 82



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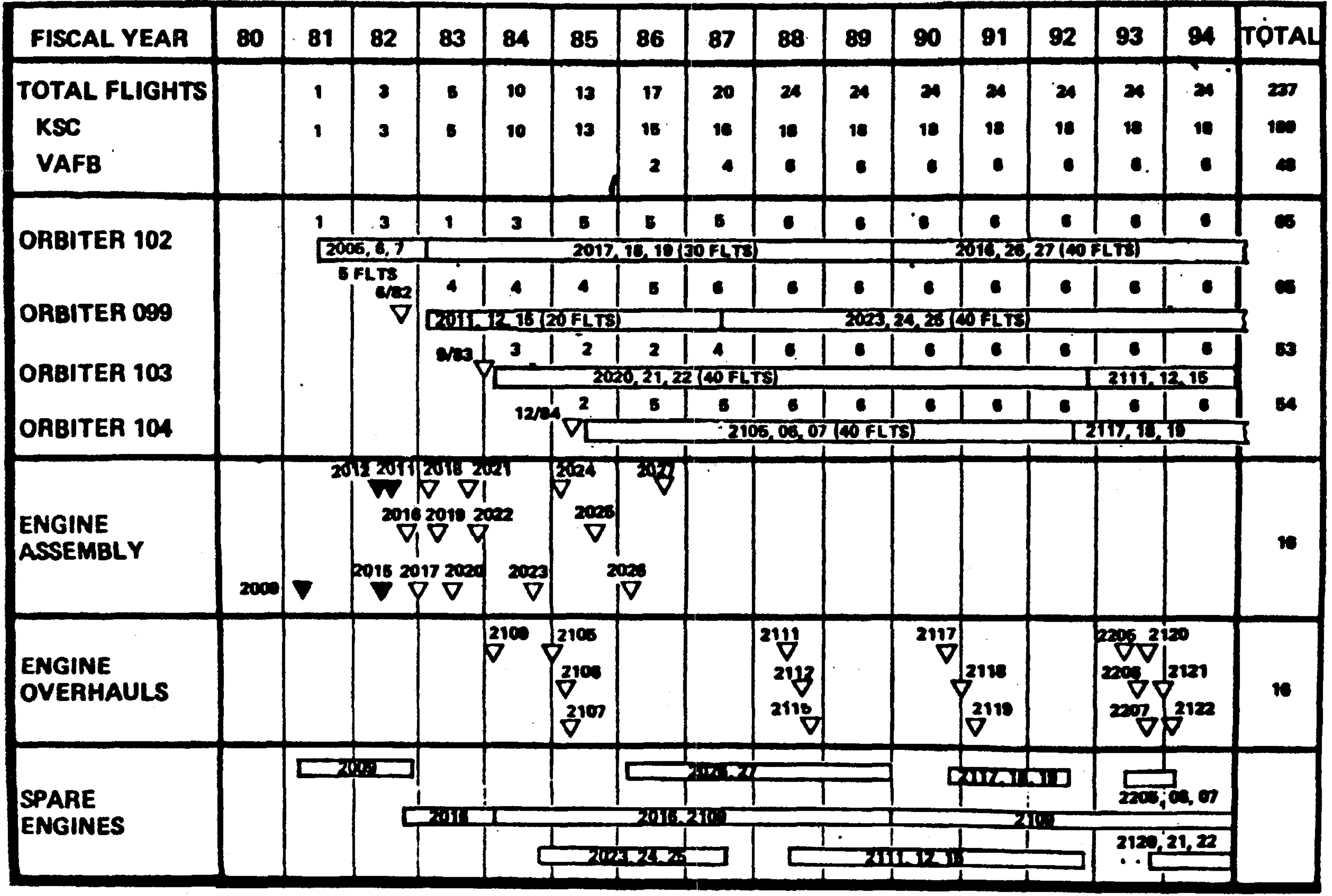
VEHICLE/ENGINE UTILIZATION AND OVERHAUL SCHEDULE
(32 FLIGHTS THRU FY 85-24 FLIGHTS/YR MAX)
POP 82-2

6-18-82



FISCAL YEAR	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	TOTAL
TOTAL FLIGHTS		1	3	5	10	13	17	20	24	24	24	24	24	24	24	237
KSC		1	3	5	10	13	15	16	18	18	18	18	18	18	18	189
VAFB							2	4	6	6	6	6	6	6	6	48
ORBITER 102		1	3	1	3	5	5	5	6	6	6	6	6	6	6	65
ORBITER 099				4	4	4	5	6	6	6	6	6	6	6	6	65
ORBITER 103					3	2	2	4	6	6	6	6	6	6	6	53
ORBITER 104						2	5	5	6	6	6	6	6	6	6	54
ENGINE ASSEMBLY																16
ENGINE OVERHAULS																16
SPARE ENGINES																

IV-18

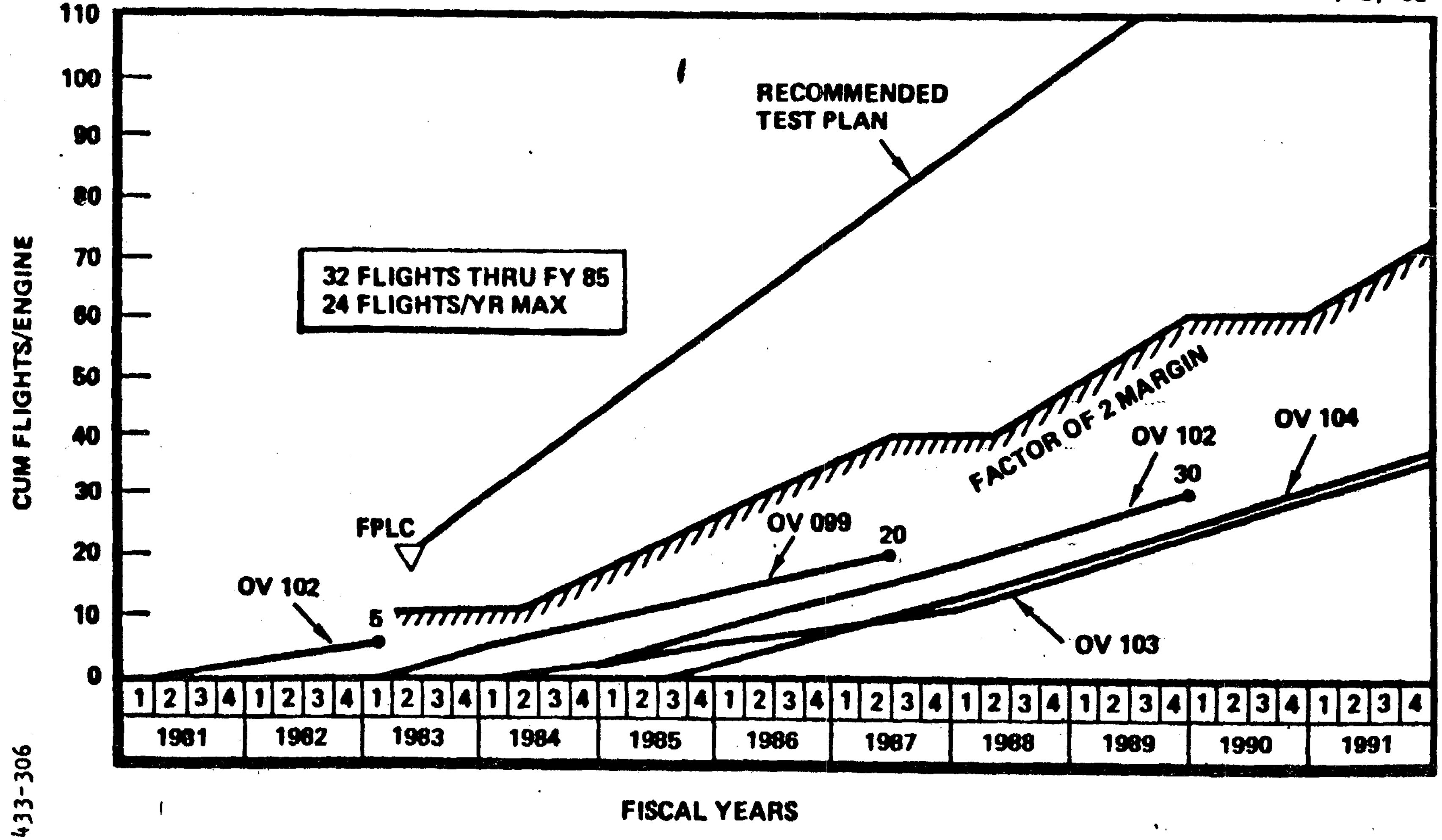
308-585U

08

Rockwell International
Rocketdyne Division

LIFE/MAINTENANCE TESTING PLAN EXCEEDS FACTOR OF 2 MARGIN REQUIREMENTS

7-27-82



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Rockwell International
Rocketdyne Division

APPENDIX V

NOTES ON RELATIONSHIPS OF SHUTTLE PROGRAM TO COMMERCIAL AIRLINE LOGISTICS

1. INTRODUCTION

Now that STS-5 has been completed and with OV-099's first flight drawing near, some of the potential problems in logistics, spares and support can be viewed in somewhat clearer perspective. This rather rambling and discursive commentary represents some observations made in the light of extensive airline experience, both in operating and design fields. Some viewponts are undoubtedly contentious and represent only the writer's opinions and not necessarily those of the Aerospace Safety Advisory Panel as a whole.

As in an airline, the relationship of overall safety to logistics and maintenance for a continuously operating Shuttle fleet is absolutely central. It is perhaps more so because the national prestige and multi-million dollar business commitments to established launch dates make it imperative that these will be met in a planned and orderly support manner, rather than by "cannibalizing" and borrowing from the production line. At the extreme end of this launch-at-any-cost spectrum would be the unwise extension of major component overhaul life or the expedient adjustment of operating "red lines."

At some point there must be a transition from the traditional NASA R&D mode to a rational operational pattern but there can be little comparison to that of a safe and successful airline. Some of the issues in these differences will be discussed later, but the major paradox in the Shuttle program appears to be that maximum utilization, amounting to a projected twenty-two day turn-around (Ref.1) will occur circa 1990 when many of the support and supply sources will have dried up. Even in the so-called "near term" there is an obvious paucity of airframe and engine spares, exacerbatd by the unique nature of the components and the lengthy lead times entailed in ordering and manufacturing them.

2. THE SMALL FLEET

The fleet size of four Orbiter (or five if OV-105 is ever funded) is such that, if any comparison to airline terms were possible, a fleet of say four B-747 aircraft would be considered impractical from the economic viewpoint. About the only way in which such an airline fleet could be made acceptable from the maintenance and support viewponts would be to become a hypothetical part of a larger carrier's fleet of B-747's and to "piggy-back" on those maintenance programs. Obviously nothing of the sort is applicable to the Shuttle programand the airline-Shuttle comparison therefore becomes somewhat academic and misleading. There are, however, some airline control and management techniques which could probably be transplanted with advantage.

Small airline fleets of large, specialized aircraaft depend heavily upon spares pooling arrangements, common engine and major component overhaul facilities, and the like. They have a grand common denominator with other carriers in that the prime manufacturer obtains, resolves and distributes maintenance operating data - especially safety related issues - from all sources. This is reinforced by the regulatory activities of the FAA and thus there are probably more "checks and balances" than could ever be possible with the nature of the Shuttle program. Consequently it would appear that the tightest overall program management control possible will only be just good enough for the Shuttle in the absence of some of the advantages cited.

3. THE DETAIL DIFFERENCES IN VEHICLES

One of the inherent problems of a fleet of vehicles which are almost alike is that it requires special vigilance to avoid the mistakes of apparent maintenance familiarity. For example, in the case of an actual B-757 fleet of the writer's acquaintance there are now, in seventeen aircraft no less than five gross, landing and zero fuel weight combinations, four different engine configurations (all Pratt & Whitney), four different cockpit layouts and it is difficult to find more than two aircraft for which you could use the same wiring diagram manual. The moral to this story is that it is infinitely more difficult to manage systems which are almost alike and this canard applies equally to the four Orbiter OV-099, 102, 103 and 104.

Comprehensive individual wiring manuals are essential, rather than recourse to masses of blueprints to unravel the differences at the flight line or launch pad level. This will become a sine qua non around say 1990 when some of the continuity of the devoted cadre of experts has disappeared through attrition and retirement. Economies in maintenance publications now will reap their own negative reward later, but a format like the airlines' universal ATA Spec. 100 series offers great flexibility in permitting the operators to do their own revisions without the requirement for off-set printing.

4. THE INABILITY TO "BORROW" SPARES

One of the interesting characteristics of large commercial carriers is that, while competing intensively on the traffic route and fare structure fronts, they do, in general, co-operate with each other to a remarkable degree on the maintenance and engineering fronts. The IATP (International Airline Technical Parts Pool) system, initially organized under IATA airline auspices, is a good example of this highly developed interchange system but its roots are, of course, in the degree of common units and parts between each of the carriers, including the use of each other's engines upon specified rental and return agreement terms. Clearly no such advantages are possible with the unique nature of almost all of the functional system components of the Orbiter and its supporting ground systems, but the purpose of this recital of the obvious is to avoid the danger of making logistics and spares support comparisons which are significantly influenced by airline techniques.

Airline methodology has certainly some lessons which could be of value to the Shuttle program but in this instance it is more likely that military techniques (shorn of some of their traditional overbuying excesses) would provide a better model. The comparatively leisurely utilization rates (in peacetime) would seem to provide a more accurate counterpart from the specific viewpoint of spares, although the length of the supply lines for the Shuttle involve a great deal of expedited special air transport methods - especially critical as turn-around time become shorter.

5. THE SLOW RATE OF MATURING (LOW UTILIZATION)

Since the fleet base of the Orbiters is so small, and the rate of accumulation of hours and cycles so slow it may well be that the entire system will barely attain real maturity co-incident with obsolescence. This problem is intensified by the very low number of test hours compared with the development of a commercial airline and particularly by the absence of a broad "service test" phase among many different operators all around the world. Even so, commercial airlines occasionally suffer disastrous problems at a stage when it would be reasonable to assume that the entire structure and functional systems had reached maturity. There is also the reverse situation to attaining maturity in which increasing age has uncovered unexpected problems necessitating major remedial programs especially in structural aspects.

Maturity of the SSME will probably be interrupted by the use of progressively increasing power levels necessitated by payload demands. Any support program should guard against excessive optimism in terms of anticipated and uninterrupted linear development of MTBR and MTBF values. The HPOTP and the HPFTP pumps are especially critical in view of their extraordinarily high performance with respect to material temperature limits and operating margins. The complete engine test stand facilities offer few alternatives in the event of damage due to an uncontained failure, which, it would seem statistically is likely to happen with the number of engines in the entire program through, say, the year 1990.

6. THE UNEVEN PREDICTED WEAR-OUT POINTS

The multiplicity of functional components in the Orbiter are at least double and probably closer to triple those in a large commercial transport aircraft. A large proportion of these are of brand new design and it is going to be extremely difficult to rationalize the preventive maintenance programs in terms of MTBR and MTBF to suit. A sophisticated aircraft like the Lockheed L-1011 would probably provide the best comparison but even so most of the functional system components in this case are derivatives of earlier designs and thus there has been a broad historical base upon which to predict an initial maintenance program which could be acceptable to the FAA's MRB - Maintenance Review Board - see Ref. 1) at the outset of operations.

To achieve an equivalent degree of confidence at the commencement of Shuttle operations is plainly not possible but the vital nature of this data foundation gleaning every piece of experience, test and early use information in a collective and systematic way for the entire system - would appear to be imperative especially in view of production lead times and batch size impoverishment. The magnitude of the task of producing comprehensive FMEA's (failure modes and effects analysis) for all critical components may result in an encyclopedic paper analysis which will be completed too late for economic supplies re-ordering. The judicious use of actual flight-line experience rather than somewhat abstract analyses should therefore be encouraged and some spares procurement gambles made as a form of insurance for the 1990's. Obviously the MEA's for the selected list of critical high-value components must be completed first.

7. DATA FEED-BACK FROM OPERATOR TO PRIME

The mechanism of operating experience data feed-back from the Shuttle operations groups to the prime manufacturers warrants some discussion insofar as it relationship to an airline is concerned. In the airline case the aircraft manufacturer not only collects all his own data from his resident representative upon airframe problems but also acts as a "clearing house" for information on all significant vendor component problems. Some of the larger vendors also have their own representatives at the main airline base. This information chain is constantly endorsed by a lively defect reporting system produced by the airline itself and the whole process is enforced by the sometimes unwelcome attention of the FAA who have their own series of safety related directives and reports.

Parellels of some of the above do not appear to exist in the Shuttle program but, on the other hand, some of the liaison engineering procedures are probably more closely coupled, especially in the R&D phase. The presence of such large groups of contractor personnel at KSC, for example, at every launch has not parallel in commercial airline operation. In the airline case a small introductory team of factory experts is invariably stationed at the main M & E base for the first few months. These groups include personnel who can help establish the entire maintenance and overhaul programs for the airline operators and assist in securing FAA operating approval if necessary.

Since NASA and the prime contractors appear to act as their own "police force" - there being no counterpart of the FAA - the overall perspective of data reporting requirements may not be as clear as in the commerical airline case. This will be especially true when the craft have been in operation for a decade or more and are considered to be a "mature system." The danger of dedicated channels of information from the larger prime contactor contingents at Kennedy and Vandenberg for the rather exclusive use (even if unintentionally) of the principal factory always exists in a program wherein the manufacturer-operator relationships are manifestly incestuous.

8. THE SPC PHILOSOPHY - STRENGTHS AND WEAKNESSES

The Shuttle Processing Contract philosophy now being developed deserves some comment, particularly because, as a concept it has arrived rather late in the day. Clearly it will not save money as opposed to leaving the processing activities in the hands of knowledgeable and responsible prime contractors. What it can do is to try to makeup for some of the inherent shortcomings of such a small-fleet-base R&D pattern but it must consciously avoid the danger of internecine warfare, especially in information channels. It would appear that since the transfer of experience of the launch techniques must inevitably involve the acquisition of some key personnel, there would perforce be some "pirating," at KSC in particular. Perhaps this would be necessary eventually in any case to permit NASA to disengage itself progressively from its all-absorbing Shuttle role and move on to other programs.

The greatest inherent weakness in the SPC approach seems to revolve around the extraordinarily specialized nature of the Orbiter and the learning curve issues which are germane thereto. Equipment knowledge and overhaul repair techniques and faciliteis are so specialized and unique that it would seem to be impractical, for example, to every subcontract the support of the SSME's to any group other than Rocketdyne (see Ref. 3). There must be other crucial systems in the Orbiter of the same nature, that is to say, cases in which attempts to transfer authority for apparent contractual advantage would prove unproductive.

9. SUSTAINING ENGINEERING

The somewhat euphemistic term "sustaining engineering" seems to embrace a combination of the function of what the airlines know generically as "engineering" and the manufacturer as "customer support" - or at least the in-service modification and development engineering aspects of support. The tendency among the larger trunk airlines today is to reduce their own airline engineering activities (reductions from approximately 150 persons to 35-50 during the past three or four years being not uncommon) an depend more heavily upon the manufacturer's support engineering services. Top airline management personnel are now more frequently of a legal or financial persuasion and the era of major influence of the key engineering personality has gone (see Ref. 4). Consequently the likelihood of bigger airlines doing their own corrective engineering re-design, as was the case in the early post WW II period has disappeared upon economic grounds, and the situation may have some sort of applicability to the Shuttle program.

To the outside observer of the Shuttle program it appears that a degree of investigative engineering is being done on both sides of the house - NASA and the prime contractors. In the present R&D phase this is undoubtedly the right course to pursue but when NASA eventually moves into being the operator it would appear logical to keep the corrective engineering responsibility squarely with the prime manufacturer (if their prices aren't too impossibly high!). This field of "sustaining engineering" will be in need of careful delineation of interface relationships under the SPC concept to avoid duplication of responsibilities or worse, abdication.

The commercial transport aircraft is in reality a very complex and therefore imperfect machine made practical to great extent by the skills of the mechanics and technicians who maintain them. This is also true to a somewhat lesser extent for military aircraft, but since the design is almost never optimum the maintenance and operational people have to circumvent the shortcomings by ingenuity and adaptability - a process sometimes known rather grandly as "the learning curve." It is frequently true that there is not, and should not be, a solution to every problem by redesign. Indeed, the smaller the vehicle fleet basis the less practical it is to start upon a redesign in cases where operator ingenuity could alternatively solve the problem. In short, "sustaining engineering" activities should be examined and re-examined and where they have no effect upon safety they should be reviewed through the "pay-back criterion" bearing in mind that nine-tenths of all cost-effectiveness justifications of this type are illusory in the full term.

10. SUMMARIZING COMMENT

If one should be unwise enough to try to summarize such admittedly unsupported impressions as the foregoing, the encapsulation would be something like the following. If nothing else some of the points might provide stimulus for future discussion.

a. The Shuttle program does not appear to have the amount of spares that an airline would require at a comparable period in the opeational development of a new fleet.

b. It would appear that, due to the specialized and unique nature of the Shuttle program more, rather than less spares would be needed, than for an airline.

c. The maintenance publication programs must not be curtailed as a cost-saving expedient - othewise we shall pay for it later in continuous delays and possibly safety.

d. An overall maintenance control program covering all aspects of Shuttle program including the entire propulsion system along the lines of an FAA Maintenance Review Board should be prepared.

e. The Shuttle Processing Contract concept is already late and if it is not to be implemented until the end of 1983 some irrecoverable lead time will be lost. Alternatively, some expedient gambles on spares procurement should be taken by the existing channels now to reduce cannibalization and borrowing from the production line.

REFERENCES

1. "Shuttle Ground Turnaround and Launch Projections" by George Page, NASA KSC October 27, 1982 (at JSC).

2. FAA Advisory Circular AC 121-22 Maintenance Reveiw Board (MRB).

3. Memorandum: Elverum and McDonald to W. M. Hawkins - NASA-ASAP visit to Rocketdyne, Canoga Park, September 29, 1982.

4. "The Sporty Game" by John Newhouse published by Alfred A. Knopt 1982.

ORBITER ESCAPE CONCEPT

CONCEPT:

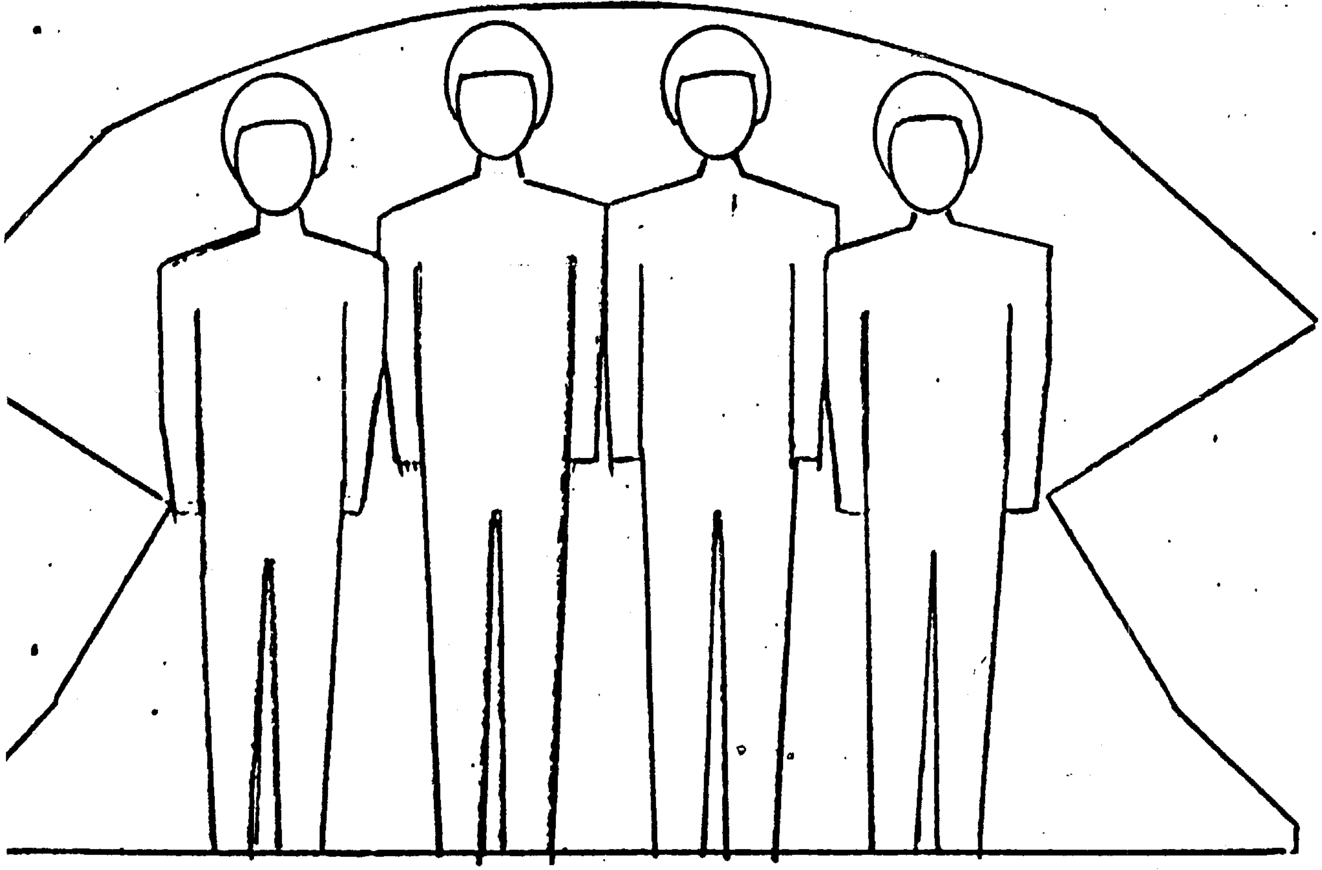
- BASED ON YANKEE SYSTEM DEMONSTRATED IN EA^{3}B STENCEL SLED TESTS (≈B-66)
- REAR SUPPORTS FLAT ON ASCENT WITH FOLD-DOWN (BICYCLE) SEAT FOR ENTRY
- A PROPERLY DESIGN STRAP SYSTEM COULD ELIMINATE ANY FOLD-DOWN SEAT REQUIREMENT ON ENTRY
- COMMANDER AND PILOT SEATS SLIDE BACK ON RAILS FOR EJECTION ESCAPE
- REAR SUPPORTS FOLD UP FOR STORAGE IN ORBIT
- SEATS/SUPPORTS CONTAIN ROCKETS, PARACHUTES AND STRAP SYSTEMS

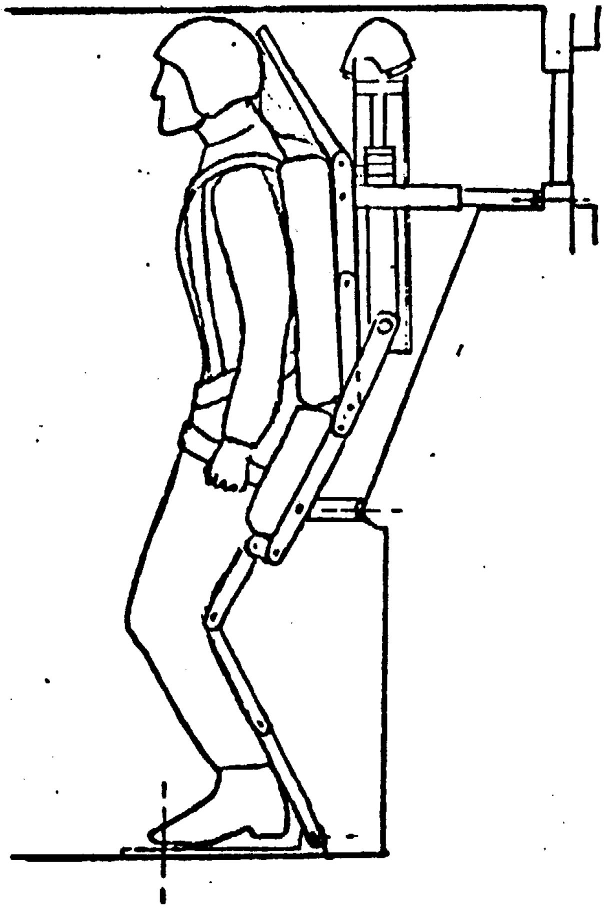
OPERATION:

- BLOW HATCH AWAY
- EJECT FOUR REAR CREWMEN
- SLIDE FRONT SEATS TO REAR
- EJECT COMMANDER AND PILOT
- ~2.0 SECONDS OR LESS BASED ON SLED TESTS

BENEFITS:

- FLAT-BACK SUPPORTS MORE COMFORTABLE ON PRELAUNCH/ASCENT AND WITH STRAP SYSTEM ACCEPTABLE ON ENTRY
- ENTIRE ESCAPE SYSTEM (SUPPORTS, ROCKETS AND CHUTES) CONSIDERABLY LIGHTER THAN PRESENT SIX STEEL ORBITER SEATS





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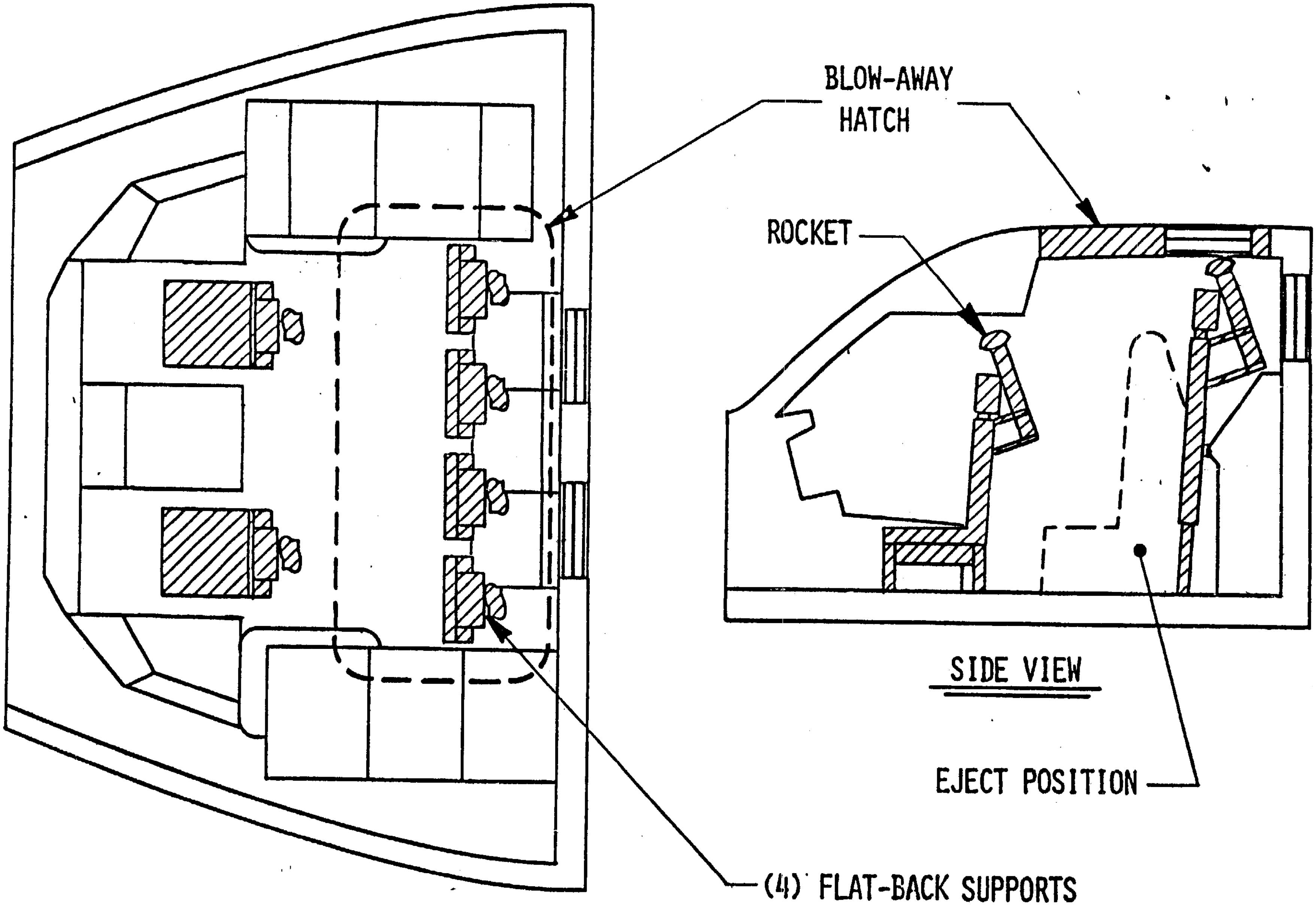

TOP VIEW

SIDE VIEW

RELATED SYSTEMS

AIRCRAFT	SYSTEMS DELIVERED	LIVES SAVED
A-1E	220	30
A-1G	40	
A-1 H/J	204	33
T-28	56	17
T-28 MAP	43	
T-28D-10	144	NO DATA
RSRA	6	*
A-300	1	*
LEARFAN	3	*
ENFORCER	3	*
GERMAN FAN TRAINER	100	1/84 DELIVERY

* HAS NOT BEEN USED IN EMERGENCY TO DATE

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APPENDIX VII

Mr. Willis M. Hawkins
Senior Advisor
Lockheed Corporation
Burbank, CA 91520

September 13, 1982

Mr. James M. Beggs
Administrator NASA
Washington, DC 20546

Dear Jim:

During one of the past meetings you asked the Aerospace Safety Panel to review the safety aspects of flight operations at the NASA Centers. Lee Davis of the ASAP accepted the assignment and has now visited Langley, JSC, Ames, and DFRF. His recommendations are as follows:

a. Walter Williams addressed this subject in March. His recommendations are sound and should be implemented, specifically:

   (1) Headquarters NASA should update and issue Management Instructions 7910.1 and 7910.2. (The ASAP would be happy to review drafts before official issue.)

   (2) The Intercenter Operations Group (ICOG), consisting of the flight operations chiefs should be reconstituted and meet quarterly to exchange information on operational and flight safety problems.

   (3) Flight Safety should be recognized as a distinct discipline and experienced pilots should be assigned to

assist the Flight Operations Chief at each Center in fulfilling his safety responsibilities.

(4) Flight Test Engineering should be a distinct and official function at the Research and Engineering Centers. Regardless of the character and duration of any flight program, plans and schedules should be drawn up, preferably by Flight Test Engineering, and approved by approprite levels of management.

b. There should be greater exchange of flight safety related information between the operations branches of the Centers. This could be a function of the ICOG, (2) above. An example, JSC has had several flameouts (some dual) in T-38 operations. Some weeks late DFRF which operates a T-38, had not heard of the problem, or its solution.

c. Line management should be certain that flight safety issues are brought to their attention, and decisions thereon are not based on personalities. Example: The Flight Operations Chief at JSC had recommended a policy forbidding nonstop flights from the Cape to Ellington in T-38s. (Sound reasons: limited range, flameout problems, weather and congestion in the Houston area.) JSC management over-ruled, apparently influenced by the opinions of some of the astronauts.

Davis feels that flight operations at the Centers are in the hands of competent experienced managers. It is clear that the functin of Flight Test Engineering with its planning and judgment inputs would enhance safety margins if the responsibility of assessing risks were assigned to such an organization by Flight Operations managers. Lee Davis specifically commends that suggestion of Williams to your attention. His overall attitude is that no apparent immediate hazards exist but inconsistencies from Base to Base and too-long familiarity with past practices suggest that new emphasis from Headquarters is imperative along with sincere follow-up.

Very sincerely yours,

Willis M. Hawkins, Chairman
Aerospace Safety Advisory Panel