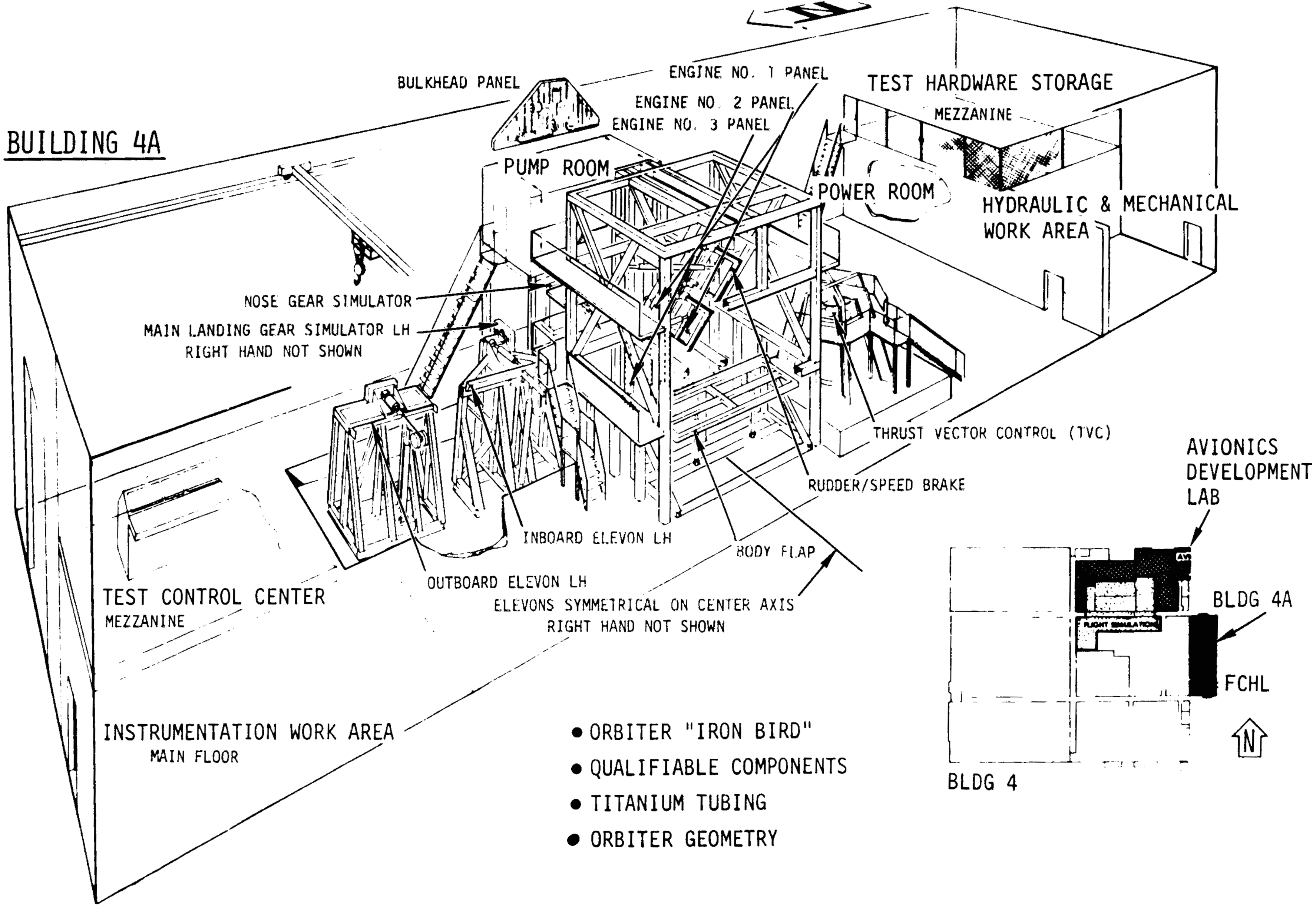
FIGURE 7-4

FLIGHT CONTROLS HYDRAULIC LABORATORY TEST ARTICLE DESCRIPTION

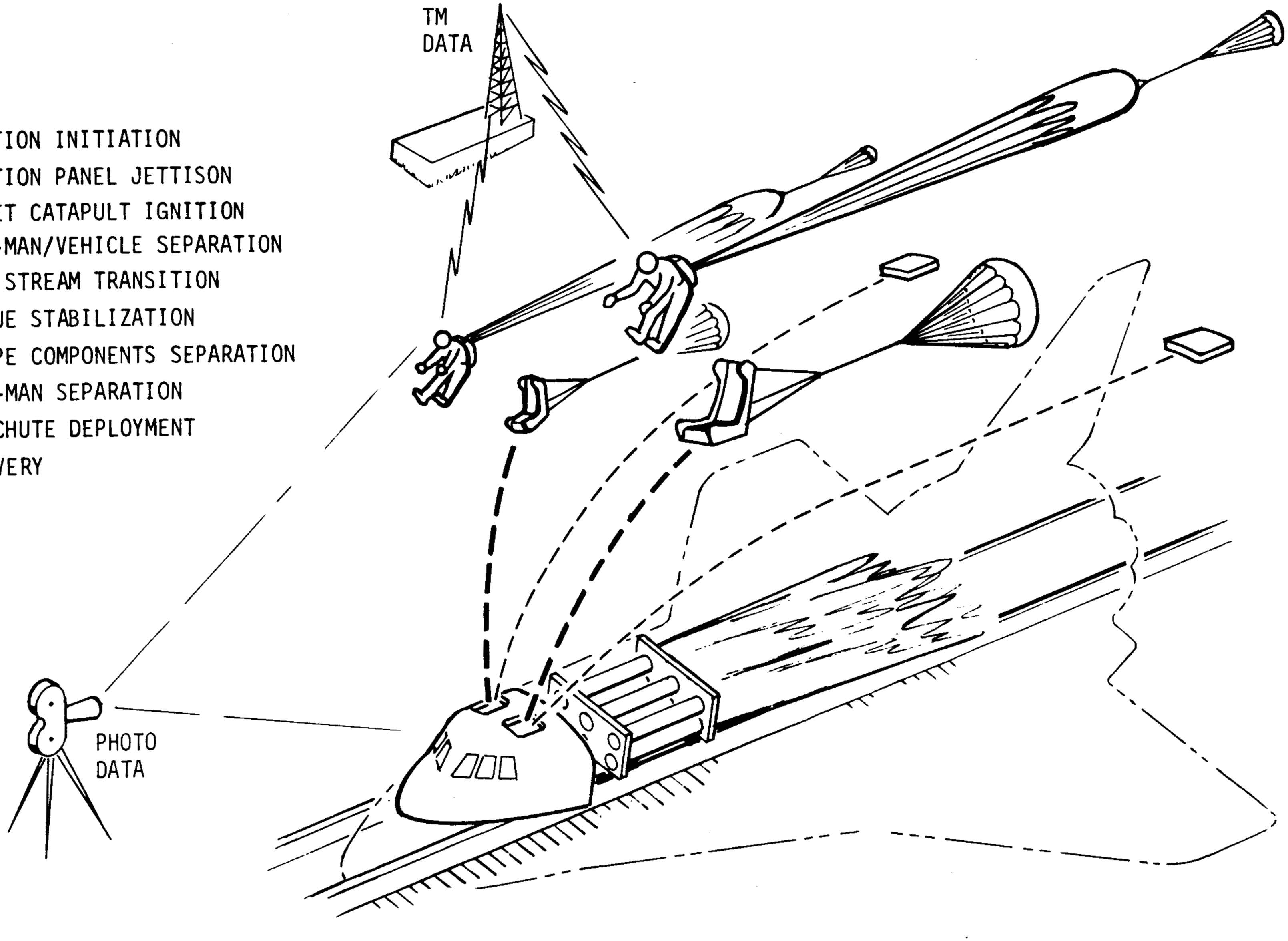


- ORBITER "IRON BIRD"
- QUALIFIABLE COMPONENTS
- TITANIUM TUBING
- ORBITER GEOMETRY

FIGURE 7-5

ESCAPE SYSTEM SLED TEST

- EJECTION INITIATION
- EJECTION PANEL JETTISON
- ROCKET CATAPULT IGNITION
- SEAT-MAN/VEHICLE SEPARATION
- FREE STREAM TRANSITION
- DROGUE STABILIZATION
- ESCAPE COMPONENTS SEPARATION
- SEAT-MAN SEPARATION
- PARACHUTE DEPLOYMENT
- RECOVERY



8.0 FLIGHT TEST PROGRAM

8.1 Introduction

Flight testing of aerospace vehicles possesses an inherent element of risk owing to the existence of many unknowns which cannot be resolved in analyses of the wind tunnels or other ground tests. The need for a flight test program of the Space Shuttle system is readily apparent given the unique configuration of the Orbiter and an assymetrical launch configuration which includes solid rocket boosters and the large external tank for the Orbiter's three rocket engines. Another new factor in the early flight tests is the use of the Boeing 747 airplane as a carrier vehicle for the Orbiter in the Orbiter/747 mated configuration, Figure 8-1. The extent of the flight test program is not yet fully defined or baselined. Experience has shown that major ground tests combined with flight tests provides a synergistic approach to defining the expected operational characteristics and understanding the problems associated with shuttle missions. The previous section covered the ground test program and indicated the limitations of this test program. The additional data expected from the flight test program is described in this section.

The flight test program involves the verification of mature systems and thus is not to be considered a development program. Verification means the process that determines that the Shuttle meets the design, performance, and safety requirements for flight. Specific requirements are chosen based on such criteria as (1) flight data is required to verify mission capabilities, (2) it is more effective to gather the data in-flight than by other methods, or (3) the data will answer questions remaining from the ground test program.

8.2 Shuttle Flight Demonstration Programs

The Panel is particularly interested in the process for:

a. Certification of the systems for the first captive and first free flights in the Approach and Landing Test Project (ALT). Certification includes both tests and analysis, i.e., design=requirements.

b. Certification of the systems for the first manned orbital flight with an all-up Shuttle System in the Orbital Flight Test Project (OFT).

The Panel is currently focusing on ALT and we will review OFT as that program matures.

To give the reader a sense of what has been accomplished and the work remaining here is a calendar of major milestones:

- Completed ALT Preliminary Design Review (PDR)	November 1974
- Completed OFT Preliminary Design Review (PDR)	March 1975
- Completed ALT Critical Design review (CDR)	April 1976

- Completed Delivery of Shuttle Training Aircraft (STA)	June/July 1976
- Orbiter 101 Rollout	September 1976
- Complete ALT Flight Software Verification	October 1976
- Complete First Approach and Landing Development Tests in the Flight Control Hydraulic Laboratory	December 1976
- Complete Design Certification Review (DCR) for First Captive Flight and First Free Flight	December 1976
- Complete the Flight Readiness Review (FRR) for the First Captive Flight	February 1977
- Conduct First Captive Flight (unmanned)	March 1977
- Conduct First Captive Flight (manned)	June 1977
- Complete FRR for First Free Flight (ALT)	July 1977
- Conduct First Free Flight (ALT)	July 1977
- Complete OFT Critical Design Review	August 1977
- Conduct First Manned Orbital Flight Test	March 1979

8.2.1 ALT Project

The ALT project together with analysis and wind-tunnel and ground tests is intended to evaluate the Orbiter's stability and control. In conjunction with subsystem operation, it will verify the vehicle's ability to meet airworthiness and performance requirements dictated by the terminal phases of the operational and ferry missions. In this case "terminal-flight phase" consists of all those activities conducted from an altitude of about 25,000 feet to roll-out. This project thus includes such areas as vehicle ground tests before the first drop test, preliminary flight evaluation, flying quality investigation subsystem verification, and demonstration of the unpowered terminal-flight phase.

The Orbiter 101 used in the ALT project generally will not include subsystems required only for space operations but will employ simulations of equipment as necessary to demonstrate the effects of such systems and payloads on approach and landing performance.

The Panel structures its efforts on the ALT project so it can provide:

a. A periodic report on the status of preparation for ALT.

b. A flight readiness assessment which the Administrator uses in his personal flight readiness review.

The Panel therefore raises such questions in its review as:

a. What are the OFT risks that would have to be accepted if there were no ALT project?

b. What are the risks involved in the ALT?

c. How does the Shuttle Training Aircraft training program and other ground based programs minimize ALT risks?

d. What are the abort mode capabilities for the mated configuration and for the individual 747 and Orbiter?

e. Is the extent of the Development Flight Instrumentation for ALT sufficient to allow for anticipation of developing problems as well as for real-time problem resolution?

f. What is the extent of "sensitivity analyses" conducted to determine the effect of input parameter perturbations from external and internal sources, and what are the results to date?

g. What are the data collection and data reduction processes and problems?

h. What is the definition of piloted and automatic trajectories during free-flight and how they are matched? What are the provisions for auto-to-manual transition or vice-versa?

i. What is the process for developing the ALT Mission Safety Assessment Report?

As an example of the dialogue with the Program their response to the Panel's comments and questions in last year's report are included as Attachment 8-1. It covers four areas: (1) free fall deployment of the landing gear; (2) ALT risks vs benefits; (3) the role of man-in-the-loop; and (4) contingency analyses and range safety.

8.2.2 Orbital Flight Test Project (OFT)

OFT will demonstrate the total Shuttle system's flight-worthiness and capability to conduct actual missions. This project extends the Orbiter flight envelope from the ALT limits to include mated ascent with the ET and SRB's and then separation from them, orbital insertion and on-orbit operations of the Orbiter and then its entry and landing. This project also is to verify the ability to recover the SRB's. In summary the project will demonstrate the compatibility of the Shuttle elements for the phases of pre-mission operations, mission operations, and post mission operations.

The current OFT project contains a series of six-manned flights.

8.3 Observations on Approach and Landing Test (ALT)

As stated in briefings given to the Panel and as written in Shuttle program documents (such as JSC 08943, "Flight Test Requirements - Orbiter Approach and Landing")," the data and experience to be gained from the Approach and Landing Test (ALT) program justify performing the tests. No single test requirement justifies the effort; however, the aggregate return from the several tests does justify the test program".

Based on earlier discussions, prior briefings, and individual Panel member experience, it was assumed that the ALT program was a mandatory part of the overall Space Shuttle Master Verification Plan. However, the most current Panel/JSC discussions indicate that the ALT project is not a required precursor for the first manned orbital flight (OFT), but rather a very worthwhile program to be used in conjunction with analyses, wind tunnel tests and ground tests to evaluate, during approach and landing, the Orbiter's structural, avionics, electrical, hydraulic, environmental, flight control, and landing subsystems. This observation is reinforced by a comment in one of the discussions that the crew for OFT did not have to have ALT flight experience.

8.3.1 ALT Management

The organization that manages the various elements that make up the ALT and OFT projects within the Shuttle program are worth noting for several reasons: (1) the Panel cannot verify all decisions but must depend on the adequacy of the basic management system, (2) risk management decisions depend on the organization(s) involved in the decision making process, and (3) the review system and its ability to prevent things from "falling through the crack" is related to definition of organization responsibilties. The organization is outlined in Figures 8-2 and 8-3. Changes to this organization arrangement should be expected as the ALT and OFT projects evolve and there is a better understanding of the work to be done and where the emphasis should be placed. The remarks that follow identify the more salient details.

The Johnson Space Center Flight Operations Directorate has overall responsibility for planning and conducting the ALT project so it satisfies test objectives and test requirements. The development of an ALT program and technical management system was the work of the Orbiter Atmospheric Flight Test Office at JSC within the Flight Operations Directorate. While the Orbital Flight Test (OFT) program detailed plans and organization are being developed by the Operations Integration Office at JSC which reports directly to the Space Shuttle Program Manager.

Management reviews are of two types: (1) those dealing with the Orbiter 101 vehicle, and (2) those dealing with the ALT program itself. These reviews are similar in type to those described for other elements of the Shuttle program. An example of the reviews is the Orbiter 101 Configuration Review (Phase 1) conducted in February and March 1976 to assess whether Orbiter 101 subsystems and GSE were ready for the subsystem test phase. In the process a list of constraints was established which were to be worked off before or during the test program. Another milestone review is the Approach and Landing Test Critical Design Review (CDR) in March and April 1976. It gives management another opportunity to review in detail the test and test support operations to be performed, the facilities and equipment to be used, and the management and working relationships of the test organizations conducting the ALT project. This

CDR covered the activation of the ALT capability, the conduct of the test program, and the deactivation of the ALT capability. The Review teams for the CDR included KSC, JSC, DFRC, Rockwell, and Boeing personnel. There was a similar CDR for the Shuttle Carrier Aircraft which was conducted during the April-May 1976 time period to assure that the detailed production design meets the specified requirements.

The ALT baseline has been defined as to the number of flights, the configuration of the Orbiter (i.e., tail-cone on or off) for specific flights, data requirements and on-board computer capabilities, etc. These areas are covered in more detail in later sections of this report. NASA management at every level, from first-line supervisors to the Headquarters' Management have been and continue to give the ALT program a great deal of attention to assure that this most significant area has the decision-making system it needs.

8.3.2 Palmdale to DRFC

The Orbiter 101 can be moved the thrity miles from the Palmdale Assembly plant to the DFRC either by a ground transportation system or by a ferry flight using the 747 carrier aircraft. A number of factors were considered: (1) legal aspects of overland movement on and off of established roadways, (2) safety aspects of accomplishing a series of taxi tests at the Palmdale facility prior to actual ferry operation, (3) ability to abort the first flight, (4) relative costs involved in the move one way or the other, (5) and probability of Orbiter or 747 damage either way. The overland transportation of the Orbiter has been baselined. This decision was based to a large degree on the operational questions dealing with mated-taxi tests and flight out of Palmdale versus taxi and first flight at DFRC with regard to safety margins.

The configuration for the first flight, if made from Palmdale is:

-	Orbiter	150,000 pounds
-	Carrier	60,000 pounds of fuel using flaps at 20°
-	Mated	550,000 pounds and a velocity of rotation (V_r) of 136 knots

The Palmdale runway is 12,000 feet in length. The V_r = 136 knots would be reached at about 3650 feet, lift-off at 147 knots would occur at about 4600 feet and the following 17 seconds at the lift-off speed would be available for abort (i.e., from 4,600 feet to 8,850 feet along the runway). The remainder of the runway, from 8,850 feet to the 12,000 foot mark would be required to halt the mated Orbiter/747 vehicle. At the DFRC/Edwards AFB runway capability on the concrete is 15,000 feet and over 7½ miles on the lake bed. Thus there is greater flexibility available at DFRC to handle variations in take off and extended taxi tests. In fact there is a capability to go slightly beyond taxi tests to actual short-term very low altitude tests.

8.3.3 ALT Baseline

The ALT has for some time consisted of the following components:

- Test of modified 747 aircraft by Boeing and DFRC
- Mated 747/Orbiter taxi tests
- Mated flight tests
- Free flight tests after mated take off and flight

A typical tailcone off free-flight ALT profile is shown in Figure 8-4.

Various NASA and contractor organizations associated with the flight test program have been investigating the many aspects of ALT to maximize the information return versus the flight capabilities of the 747/Orbiter system. Studies concern such areas as 747-Orbiter separation altitudes and attitudes, 747 buffet problems associated with mated flight, separation velocities, effects of variations between wind-tunnel testing and actual flight aerodynamic performance, crew safety, data and data reduction requirements, crew training and the final approach trajectory from preflare to landing.

A major item affecting the implementation of the ALT baseline is the impact on the mated vehicle's flight performance and the associated buffet characteristics if you fly the Orbiter without a tailcone. All other concerns are of second order importance in defining the mated and free-flight program.

The mated Orbiter/747 will take off with a fixed Orbiter incidence angle of 4.5 to 7.5 degrees. The weight will probably be between 150,000 and 170,000 pounds. The mated vehicle will climb to a ceiling altitude (maximum climb thrust) and cruise for approximately 15 minutes. A special rated thrust will then be used to achieve a higher ceiling altitude at 200 feet per minute. The time duration of this special thrust rating is 10 minutes. Once the ceiling altitude is achieved, a descent maneuver will be initiated to accelerate the mated vehicle to the desired launch airspeed in an equilibrium glide condition. This will be based on derivatives of pitch rate, flight path angle, sum of aerodynamic and thrust pitching moments all equal to zero. The acceleration is performed after the thrust is reduced from the special rated thrust to the maximum continuous thrust level. The Orbiter elevon is to be positioned to a predetermined value to achieve a relative normal load factor of 0.75g and an Orbiter pitch acceleration of approximately 4.0 degrees/second^2. During the mated descent phase, the

747 will be configured to increase drag in order to enhance separation. Separation is to occur as the launch airspeed and equilibrium glide conditions are achieved. The typical ALT baseline is shown in Figure 8-5.

The baseline ALT program, taking into account the many studies conducted, is:

a. Reduction in the 747 tests by Boeing.

b. Mated tests with 747 and Orbiter with tail-cone on.
   Taxi tests plus 6 flights with inert Orbiter.
   Taxi tests plus 5 flights with active Orbiter.

c. Free flight tests conducted with tail-cone on.
   4 flights to land on the lakebed runway.
   1 flight to land on the concrete runway.

d. Free flights with tail-cone off if possible. This decision will be based on data obtained in all of the previous flights along with wind tunnel tests and a detailed analysis. Currently the program calls for 3 flights to land on the lakebed runway. This would be preceded by a mated active flight test with tailcone off. The number of flights and their content is under review.

The tailcone refers to the aerodynamic conical shaped body attached to the Orbiter to reduce drag and reduce buffeting of the 747 tail sections in particular due to carrying the Orbiter piggy-back. The extent of the buffeting with tail-cone off would be severe tests and analyses indicate that. The buffeting can severely reduce the structural life of the 747 tail particularly the aft body structure and vertical tail section. It can also prevent the crew from achieving necessary proficiency during the critical release and separation maneuver period. Finally it can generate a general fatiguing vibration during all portions of the mated flight. Uncertainties exist in scaling buffet loads from model scale to full scale because there is no real methodology to accomplish such scaling; therefore, additional critical areas could be affected. If buffet loads were in error by a factor of two, the resulting fatigue life calculations might be in error by a factor of as much as ten. Considering such uncertainties the Shuttle program has used a conservative approach to defining the expected fatigue life values.

The 1.4 hours of a single ALT test mission approaches the age life of the aft body section at the tail. The vertical tail section computed life is about 10 hours. These times can be increased through several means including the use of an 11.7 degree Body Flap Up and beefing-up the structure in the body and fin areas. This is being done to increase the lifetime to approximately 50 hours before the first crack appears. While flying the Orbiter with the tail-cone on relieves the buffeting problem, the aerodynamic performance of the Orbiter during free flight is not exactly equal to that which would be experienced with the true Orbiter configuration. This has also been examined and it has been suggested that the Orbiter with tail-cone-on can be made to behave more like the mission configured Orbiter by deploying the rudder speed brakes. This does appear though to cause a some degree of loss in pitch control.

For the reader to follow the evolution of the program it is worthwhile for the reader to understand the terms used (Figure 8-6), the requirements for unpowered landing (Figure 8-7), unpowered flight constraints (Figure 8-8), and the Autoland logic (Figure 8-9).

8.3.4 Deployment of Orbiter Landing Gear

The Panel was interested in the basis for confidence in the ability of the gear to deploy and lock into place prior to touchdown and the aerodynamic affect of having the gear deployed during mated flight.

The free-fall deployment system has been examined not only by the engineering and test personnel but also by the highest levels of Shuttle management to assure that it will operate properly. As a result of this review the free-fall mechanism has been augmented by additional spring devices. Once the doors are open and the gear are partially deployed the combination of initial downward momentum, aerodynamic forces and the mass of the gear appear sufficient to fully deploy and lock the gear. Hydraulic actuator deployment force is also available. There will, of course, be a detailed and thorough test program to provide further confidence in the adequacy of the system. The specification for the deployment window of time during which the gear must safely be lowered calls for a maximum of 10 seconds, but at this time analysis indicates that it will take about seven seconds. The gear retraction is accomplished only on the ground and cannot be done in flight.

It is planned that during one of the mated (captive) flights that the Orbiter landing gear will be deployed during landing rollout. This will permit information to be obtained on the aerodynamic characteristics of the Orbiter as it will appear in actual flight just prior to touchdown. Current indications are that this will not cause undue buffeting of the 747 carrier aircraft.

Further discussions of this area of concern are found in the "Risk Management" section of this report.

8.3.5 Orbiter/747 Separation

The separation sequence, when free flights begin, is perhaps one of the more significant areas of concern. The overriding requirement is that there be no recontact between the vehicles once separation begins. The degree to which analysis can define the envelope of separation is dependent on the accuracy of wind tunnel data and the inherent aerodynamic uncertainties therein.

The variables associated with this maneuver are:

(a) Orbiter/747 aerodynamic uncertainties.

(b) Orbiter incidence angle (currently $6^{\circ} \pm 1.5^{\circ}$).

(c) Orbiter body flap, speed brakes, elevon positions and capabilities.

(d) Separation "g" requirements.

(e) Flight control system command mode and rates.

(f) 747 spoilers, thrust position and capabilities.

(g) Mated altitude and speed.

In order to obtain a greater degree of understanding of the ALT design and performance characteristics as well as the risks involved activity continues in the following areas: (1) Testing, particularly wind tunnel work, (2) analysis, particularly to uncover areas that can be improved, (3) simulations and pilot training, (4) refinements of flight test data and instrumentation requirements to get the most data for the effort involved.

Figure 8-10 shows pictorially the clearance requirements for separation. The design goal and maximum allowable motion are both shown.

Simulations have been conducted many times on the ALT flights. These have been run by the "Separation and Pilot Operations Group" at Rockwell and at least five pilots from the NASA/JSC astronaut corps.

Results from these simulations indicated that there would be no vortex clearance problems for either the tailcone on or off. The effect of Orbiter weight and c.g. location did not have a significant affect on the separation or Orbiter performance. While an increased launch speed from 260 to 280 Keas did not significantly affect the separation trajectory, it does appear to improve performance for the final approach condition.

The tailcone on configuration was noted to have a beneficial effect from two aspects: (1) Orbiter/747 separation was better with a near vertical deplacement of the Orbiter relative to the 747 for the first few seconds, and (2) Orbiter ALT final approach conditions were significantly better than for the tailcone off configuration.

The effect of wind/shear, discrete gust, and random turbulence were within the baseline capability and did not present a separation problem or appreciably affect the Orbiter handling qualities. As a result of the simulations and analyses to date, the following separation and post separation conditions have been established:

(a) Separation Initial Condition

1. Normal relative load factor = 0.75g.
2. Orbiter pitch acceleration = 4.0 degrees per sec^2.
3. Launch airspeed = 260 Keas.

4. Equilibrium glide.

(b) Post Separation Conditions for Orbiter

1. Autotrim enabled at separation.
2. Post separation (free-flight) FCS surface limits will be selected at separation.
3. Maintain 2^{o}/sec pitch rate command for 3 seconds followed by a 2 second stabilization period.
4. Maneuver to ALT interface.

(c) Post Separation Conditions for 747

1. Initiate 747 evasive maneuver (bank) at t_{sep} + 5.0 seconds 747 wheel command of 50^{o} for lo seconds with 747 FCS in autopilot mode.
2. There is a possibility that a recommendation will be made to use a bank maneuver of 30^{o} at approximately 10^{o}/sec. with the 747 FCS in a manual direct mode.

8.3.6 Crew Emergency Egress

Emergency egress during ALT means both escape from the 747 and escape from the Orbiter. The system for the Orbiter 101 vehicle consists of ejection seats traveling on rails with overhead ejection through doors cut in the top of the cabin. The emergency system for the crew of the 747 has been somewhat more difficult to baseline. After technical studies and management discussions it was determined that there should be a specific escape system placed into the 747. The design selected is a tunnel going from the flight deck where the two crewmen are located to a point on the lower left side of the 747 fuselage, Figure 8-11 The lower end of the tunnel is opened by a pyrotechnic severance system that cuts the fuselage thereby permitting the crew to exit from the flight deck to the outside. At the same time as the fuselage is cut it is necessary to equalize the pressure between the cabin and the atmosphere by blowing out (or in) windows and a portion of the lower right side skin. The Teledyne-McCormick-Self Company has been selected to provide this egress system. Tests and analyses will be conducted on this arrangement to assure the smooth cutting of the metal skin and the proper rate of decompression. Training, of course, will be required to assure the crew can and knows exactly how best to escape if the need arises. The system will be designed for the 20,000 feet to 24,000 feet range of altitudes.

The Orbiter ejection seat is a "zero-zero" seat. The first static test of the Orbiter 101 ejection seat is to take place at the Holloman AFB High Speed Test Track during January 1977. Hatch jettison tests would begin in March 1977. The first manned ALT flight (captive or mated) is set for May 1977. Testing of the overhead hatch has been in process for some time and qualification testing on the energy transfer subsystem is essentially complete. Two anomalies were noted regarding the operation of the hatch: (1) detonation velocity indication was lost during one test but the output of the charge was satisfactory, and (2) one 0.5 second time delay time-data was lost during testing. Neither of these appear significant and their resolution is expected soon.

The Critical Design Review on the outer panel severance system was completed. Qualification of this sytem is to start in May 1976. During the development testing of the inner panel severance system the following anomalies were noted: (1) failure of the panel to sever, and (2) gas leakage into the crew compartment. The inner panel failure was due to using the wrong material in the subscale test panels. A new test using proper materials is in the works now. The gas leakage into the crew compartment was due to expending tube rupture during overload or hot temperature nominal load tests. Apparently there is small margin between severing the panel with an 80% charge and containing the gas using a 115% charge. Before start of the qualification program this problem will have to be resolved. See Figure 8-12.

8.3.7 Additional Notes of Interest

8.3.7.1

The **Gulfstream** Shuttle Training Aircraft, as an inflight simulator, will provide some important data for the first free-flight of the Orbiter. However, the fidelity of the simulator is based on the wind tunnel data and it will be as good as the interpretation of the data by aerodynamicists. The USAF and NASA have frequently seen significant differences between wind tunnel data and flight data.

8.3.7.2

The 747 flight test team is in a monitor role with the 747 crew in control of "going ahead" and the Orbiter crew in control of the decision on separation or "abort" of the free-flight mission. There is to be no overlap of authority and the communications system is to in no way "shut off or overlap" the flight crews.

8.3.7.3

The factors which need to be accommodated in planning the Approach and Landing Test Project include (1) possibility of limited or no capability to carry and launch a tailcone-off Orbiter from the 747, (2) definition of the flight performance margins afforded by a tailcone-on first free flight, and (3) need for exercising ALT curtailment options for unanticipated contingencies, cost constraints, schedule constraints, etc.

8.3.7.4

A preliminary ALT manned Orbiter contingency operation plan has been produced. The evolution and implementation of this plan will be followed by the Panel. The purpose of the document is to describe the immediate actions and responsibilities to be used in the event of a catastrophic situation when the Orbiter is manned during the ALT operations. Procedures for catastrophic events occurring at other times will be described in appropriate documents for both the ground crew and the 747 teams.

8.4 Manned Orbital Flight Test Program

At this time the OFT guidelines are that the OFT will consist of six flights. The first flight will be manned and conducted with greater than nominal performance margings. The performance envelope will be gradually expanded staying within the operational design capabilities of the Shuttle vehicle.

Its crew will consist of two men on flights one through four with an option of four men on flights five and six. The data return requirements are to be principally for engineering information. Scientific data will be obtained on a non-interference basis. DFI will be flown on all six flights. Candidate payloads will be used whenever possible, consistent with the availability and cost effectiveness of the payload versus the mission to be flown.

The major areas of planning include the following:

(a) Definition of orbital flight test plans.

(b) Development of operating concepts and requirements.

(c) Development of training requirements and implementation of trainers and simulators.

(d) Development and implementation of control center and network requirements and capabilities.

(e) Development of flight planning capability.

(f) Development of the launch and landing ground operations and interface with flight control.

One problem noted during our JSC discussions was the use of "add-on" units containing large quantities of liquid ammonia to be used as part of a cooling system for DFI equipment. These add-ons were located in the Payload bay but the vent system was not discussed at that time, nor were the steps that would prevent corrosion due to the ammonia fumes. This area will be followed by the Panel in future reviews.

8.5 Addendum

The first flight of the modified shuttle carrier aircraft is scheduled for the end of November or early December 1976. The aircraft design gross weights have been stated as follows:

Taxi	778,000 pounds
Takeoff	775,000 pounds
Landing	565,000 pounds.

Most of the modifications made to this aircraft are shown in Figs 8-13,14.

The Orbiter flare techniques are still under study to assure that the selected mode will be most effective in achieving the objectives of the ALT project. Float time requirements, the time interval available to the pilot during which he can adequately perceive sink rate and adjust it to arrive at an acceptable value for touchdown, should fall near the following:

a. A minimum time of seven (7) seconds and an optimum of 11 to 14 seconds.

b. For precision landings the last three (3) seconds should be flown at essentially constant altitude.

The need to have a least one free-flight landing on the concrete runway at DFRC is predicated on the difference between lakebed surface and conrete runway surface on landing gear-wheel-brake effects. The difference in coefficient of friction and other surface effects on the gear dynamics and anti-skid tuning are sufficient to make a conrete runway landing worthwhile.

Landing gear test problems have occurred during the checkout and test work being conducted at Palmdale Facility when an uplock hook failed. In addition they have found that the other uplock hooks had cracks. Plans are for an investigation by RI/Space Division and NASA/JSC to be done in two phases: Phase I for Orbiter 101 and Phase II for Orbiter 102 and subs. Ground rules being utilized are:

a. Review all criticality I single point mechanical failures that can cause loss of vehicle or crew.

b. Both sides of the loaded interface will be reviewed for design criteria consistency, for example, the actuator load rating versus mechanical joint design load used in the analysis.

c. Phase I and II refers to hardware first usage and not loads.

ATTACHMENT 8-1

Free fall deployment of landing gear may introduce safety problems. Therefore, the use of a positive system for rapid extension of landing gear should be considered.

Response: The basic design of the landing gear system is conservative with four forces acting to deploy the gear, the up-lock actuator, the weight of the gear, the strut actuator, and the locking spring bungee.

The concern about positive rapid extension has been recognized. Plans to utilize pre-loaded springs as additional forces to pop the doors and speed the gear deployment are being investigated.

A comprehensive test program using both a nose gear and main gear simulators with flight type gear and door hardware with hdraulic systems and electrical systems in the OV 101 configuration will be tested at Rockwell International. Loads simulating aerodynamic forces obtained from wind tunnel tests, will be applied to the gear and door assemblies during these tests. Wind tunnel tests of a 1/3 scale model will be conducted for aero loads with gear retracted and deployed as well as tests on a 0.04% model for loads at incremental positions. Additional studies are continuing on the usefulness of extending the landing gear during a 747 captive flight.

> More information is needed on the risks of Approach and Landing Testing in comparison with the value of information which would be obtained in such flights.

Response: The Approach and Landing Test (ALT) program objectives are as follows:

1. Verify an Orbiter pilot guided approach and landing capability.

2. Demonstrate an Orbiter subsonic auto TAEM/auto land capability.

3. Verify Orbiter subsonic airworthiness, integrated system operations and selected subsystems operation for first orbital flight.

4. Demonstrate Orbiter capability to safely approach and land in various center of gravity configurations.

These important objectives can be accomplished with acceptable risks.

Extensive analysis, wind tunnel testing, and man-in-the-loop simulations have demonstrated the safety of the ALT test flights. A comprehensive matrix of separation configuration and aerodynamic parameter variations has been analyzed. There have been approximately 2,200 hours of wind tunnel testing, 200 piloted simulation runs, and 3,000 12 degree of freedom separation trajectories completed. Numerous variations in configuration, control modes, aerodynamic coefficients, altitude, velocity, and flight path angle have been studies. Safe, acceptable separations are produced within a large envelope of conditions.

The top launch concept has been employed successfully in the part. Programs employing the top launch concept include the British Mayo Composite Aircraft, the German Mistel, and the French Leduc.

The ALT program decreases overall Space Shuttle Program risk. The Orbiter is a highly sophisticated combination aircraft/spacecraft with a digital, fly-by-wire, flight control system. ALT provides for the detection and correction of problems in the important approach and landing regime prior to the orbital flight tests. The ALT tests will essentially verify the aircraft capabilities of the combination aircraft/spacecraft Orbiter.

The remaining issues being examined relate to the launch altitude of the Orbiter from the 747 and the launch configuration of the Orbiter (tailcone on or tailcone off). These issues are being reviewed by the OSF Management Council with JSC and FRC on October 8, 1975.

> The role of man-in-the-loop, especially during landing, rollout and braking, needs re-examination as the program reaches the point where avionics capability and limitations are better known.

Response: The Space Shuttle Program engineering simulation activity has been reviewed as a part of the overall avionics development plan. This review reconsidered all the simulation requirements and adjusted the plan to better balance the design freeze dates with the availability of adequate engineering data. The final decisions on the role of man-in-the-loop particularly during landing have not been made and are not scheduled until early 1976. During this time period, ADL testing including some tie with the hydraulic systems will have further defined the control system characteristics. Gain and brake characteristics together with landing aids analysis need more work before final decisions in this area are committed. The program is in agreement with the necessity for good judgment coupled with adequate data in this area. Reviews of the specific landing characteristics and techniques are planned.

Contingency analyses especially for aborts, ditching, landing accidents, and range safety should be completed early enough to assure design solution rather than operational work-arounds.

Response:

ABORTS

(a) The present abort analysis effort is being concentrated on those cases with the highest probability of occurrence. These are the intact abort cases and include the following:

1. Loss of thrust from one SSME.
2. Loss of TVC for one SSME.
3. Loss of thrust from one OMS engine.
4. Loss of TVC for one axis of SRB.

The aborts with a low probability of occurrence are referred to as the contingency abort cases. These cases are being studied, but to a limited degree, in consonance with their low probability of occurrence. Contingency abort cases include the following:

1. Loss of thrust from two or three SSME's.
2. Loss of TVC for two or three SSME's.
3. Loss of TVC for two or more axes of an SRB.
4. Premature Orbiter separation.
5. Failure to separate SRB from Orbiter/ET.

For certain situations, it is not practical to provide for abort solutions. For these cases, appropriate safety margins and high factors of reliability have been included in the Space Shuttle design to preclude their occurrence. These cases include the following:

1. Major structural failure.
2. Complete loss of guidance and/or control

3. Failure to ignite one SRB.
4. SSME or SRB hardover.
5. Failure to separate Orbiter from ET.
6. Premature SRB separation.

Ditching

(b) Orbiter ditching tests have been conducted at Langley Research Center. Based on these tests, the Orbiter should be able to land safely on the water, assuming no major structural breakup. Preliminary structural analysis indicates structural breakup will probably not occur for reasonable ditching conditions. There is a possibility of the side egress door jamming during ditching. Alternate ways are being studied to evacuate the Orbiter in case the egress door is jammed during ditching.

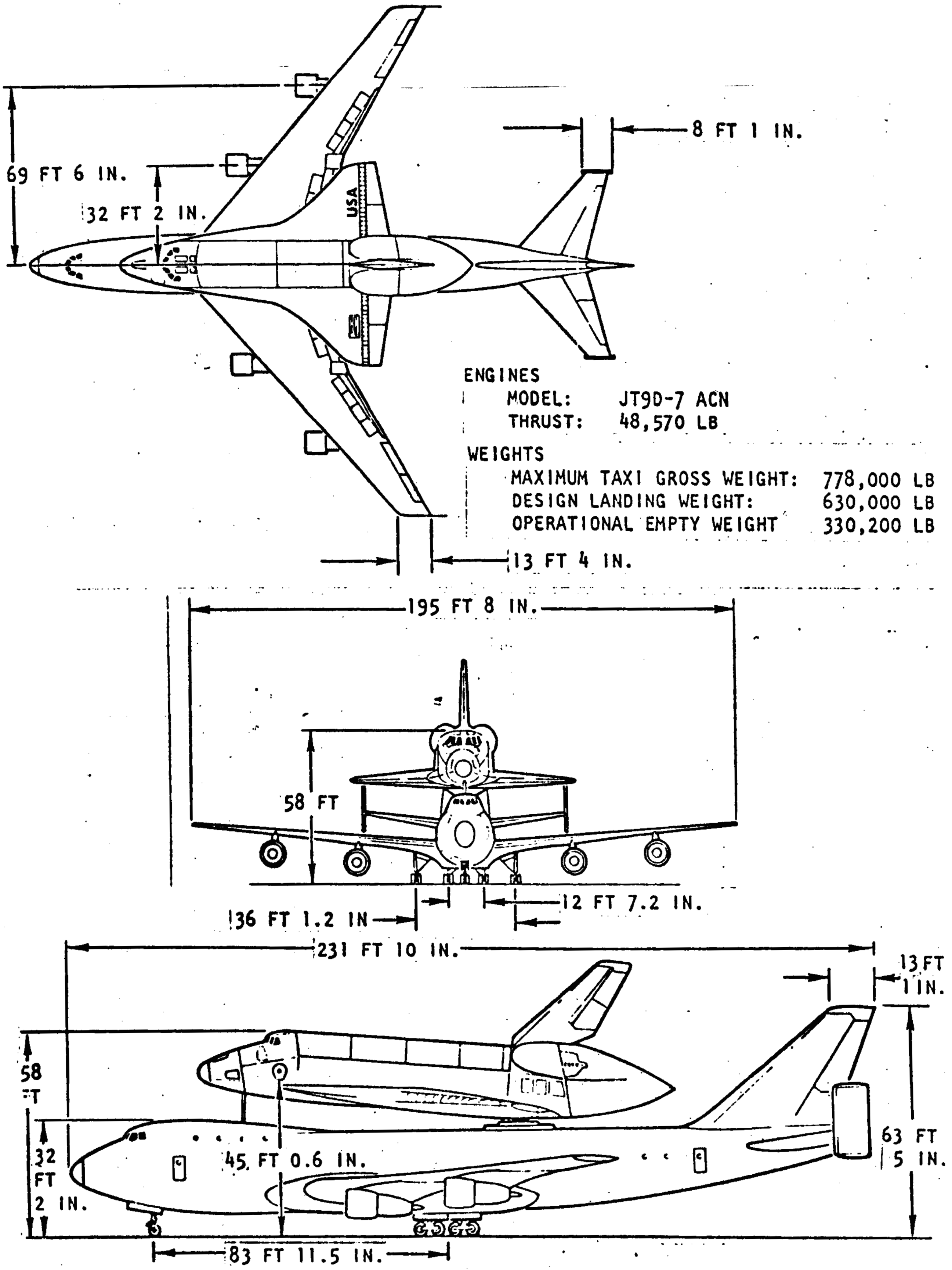
Landing Accidents

(c) Analysis is being conducted by JSC and LRC on the energy absorption capability of the Orbiter during landing accidents. The purpose of the analysis is to determine the ability of the crew compartment aft bulkhead to absorb payload loads resulting from landing accidents.

Range Safety

(d) The Range Safety System PDR is scheduled for October 15 through November 7, 1975. This system, baselined over a year ago, has not yet been approved by the Air Force Eastern Test Range (AFETR). In order to resolve the issues raised concerning range safety requirements, a joint NASA-USAF Ad Hoc Committee is being formed to conduct a technical analysis of the hazards of Space Shuttle flights, both developmental and operational, and to trade off hazards against related launch azimuth constraints and vehicle reliability in order to determine a logical approach to assuring public safety. Alternatives will be recommended to NASA management and the Commander, AFETR, for decision.

ORBITER/CARRIER AIRCRAFT



ENGINES

MODEL: JT9D-7 ACN

THRUST: 48,570 LB

WEIGHTS

MAXIMUM TAXI GROSS WEIGHT:	778,000 LB
DESIGN LANDING WEIGHT:	630,000 LB
OPERATIONAL EMPTY WEIGHT	330,200 LB

FIGURE 8-2

THE ALT ORGANIZATION

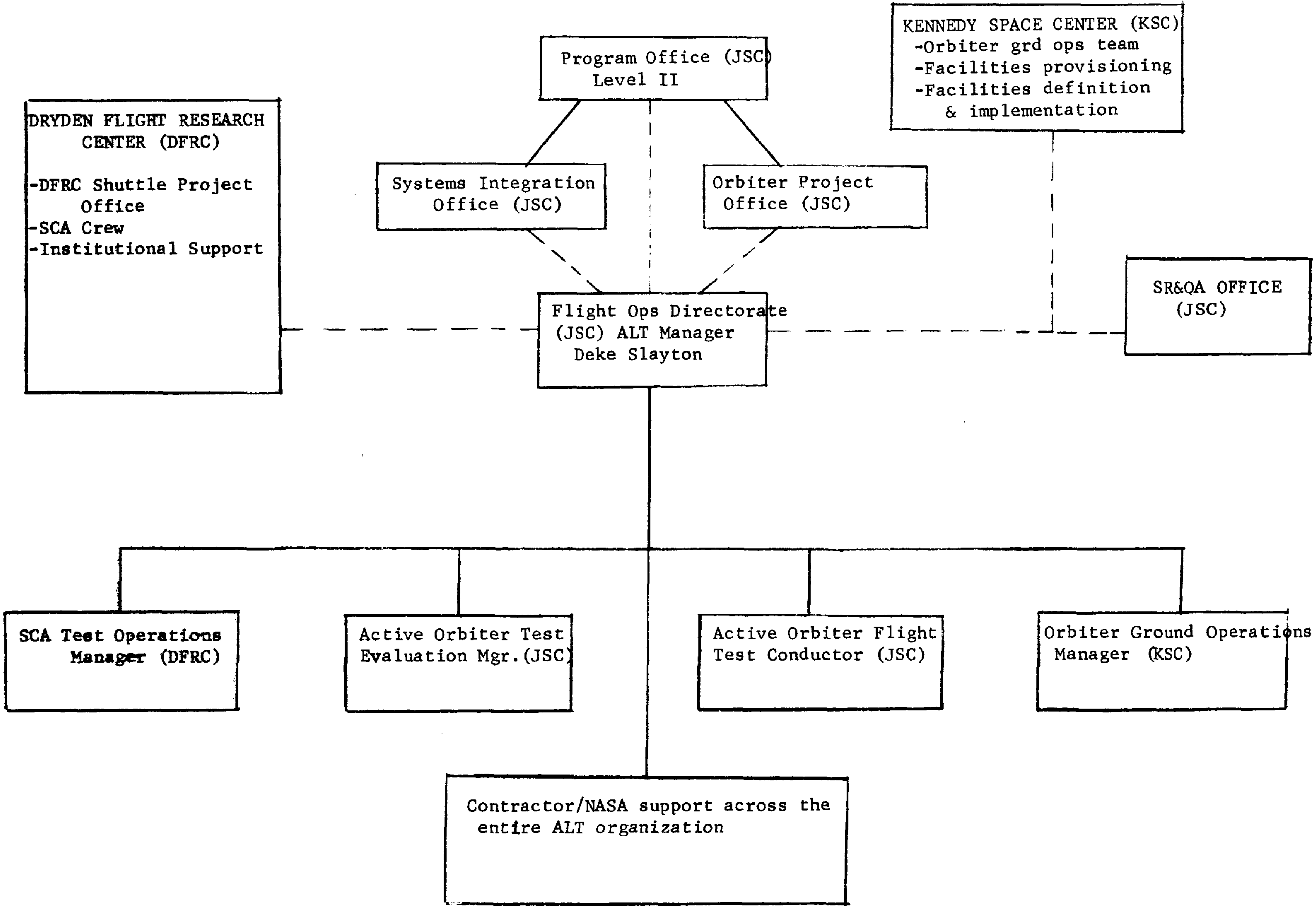


FIGURE 8-3

THE OFT ORGANIZATION

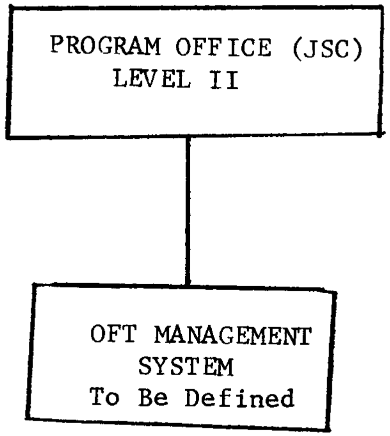


FIGURE 8-4

TYPICAL ALT PROFILE

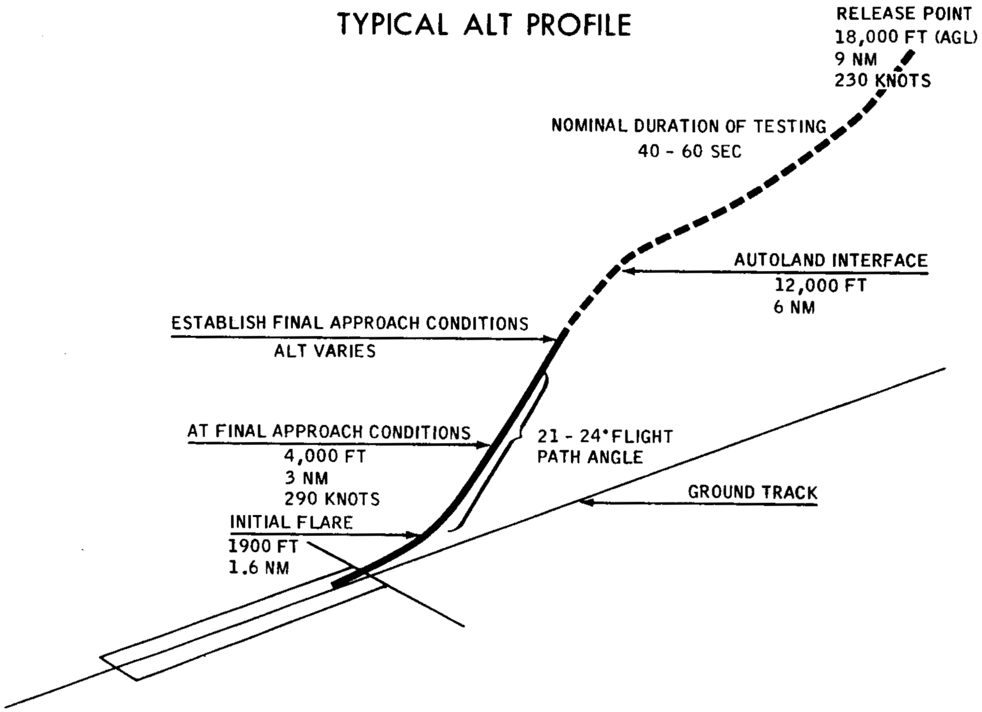


FIGURE 8-5

BASELINE ALT MISSION PROFILE

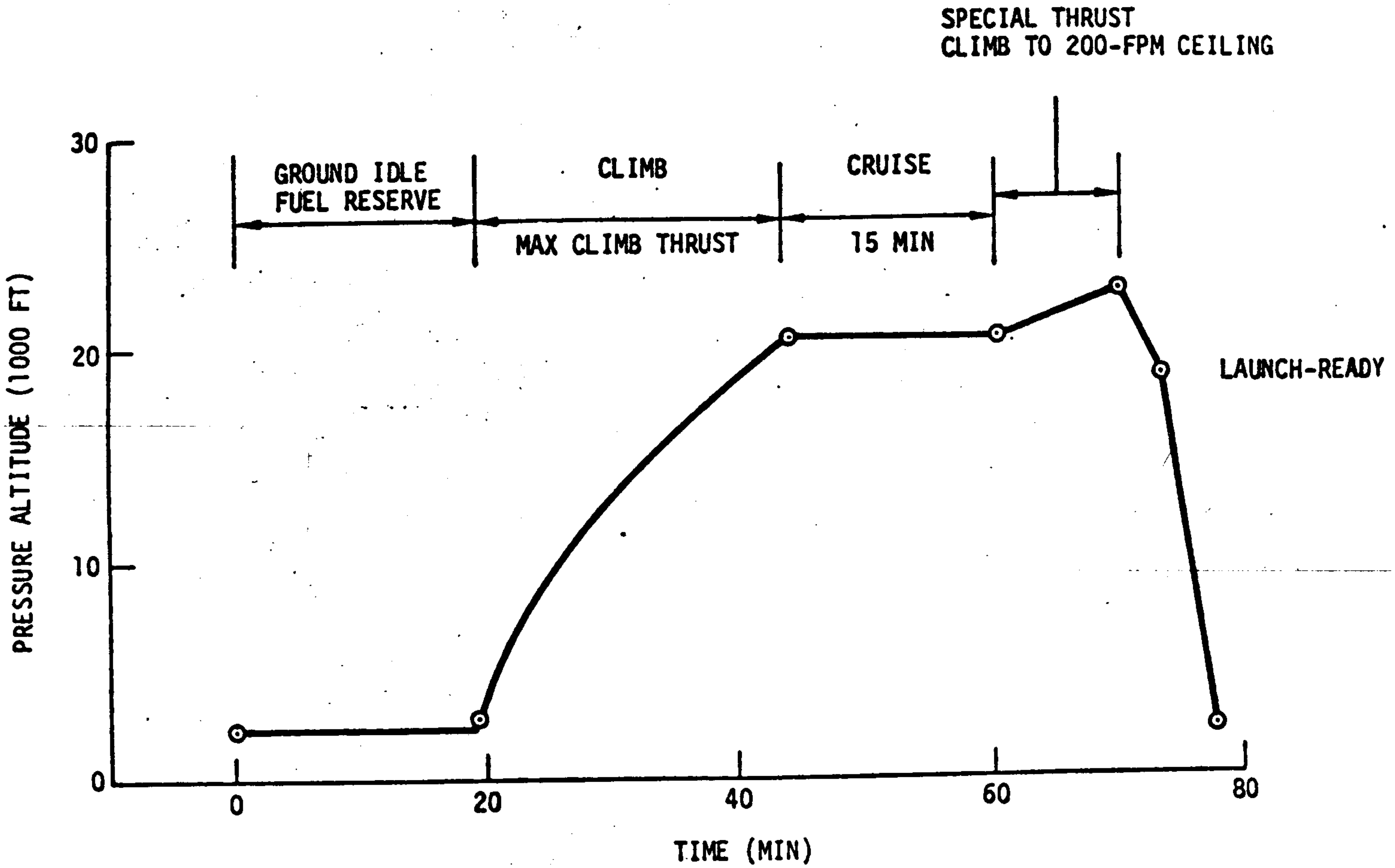


FIGURE 8-6

DEFINITION OF TERMS

- FLOAT TIME: THE Δt, ON THE NOMINAL TRAJECTORY, BETWEEN THE TIME OF TOUCHDOWN AND THE TIME THE VEHICLE FIRST ACHIEVES AN ACCEPTABLE TOUCHDOWN $\dot{h}$ (~10 FPS)

FINAL MANEUVER MARGIN: THE Δg CAPABILITY OF THE VEHICLE AT THE DESIGN TOUCHDOWN POINT

- ENERGY MARGIN: THE FLIGHT TIME POTENTIAL REMAINING AT THE DESIGN TOUCHDOWN CONDITION

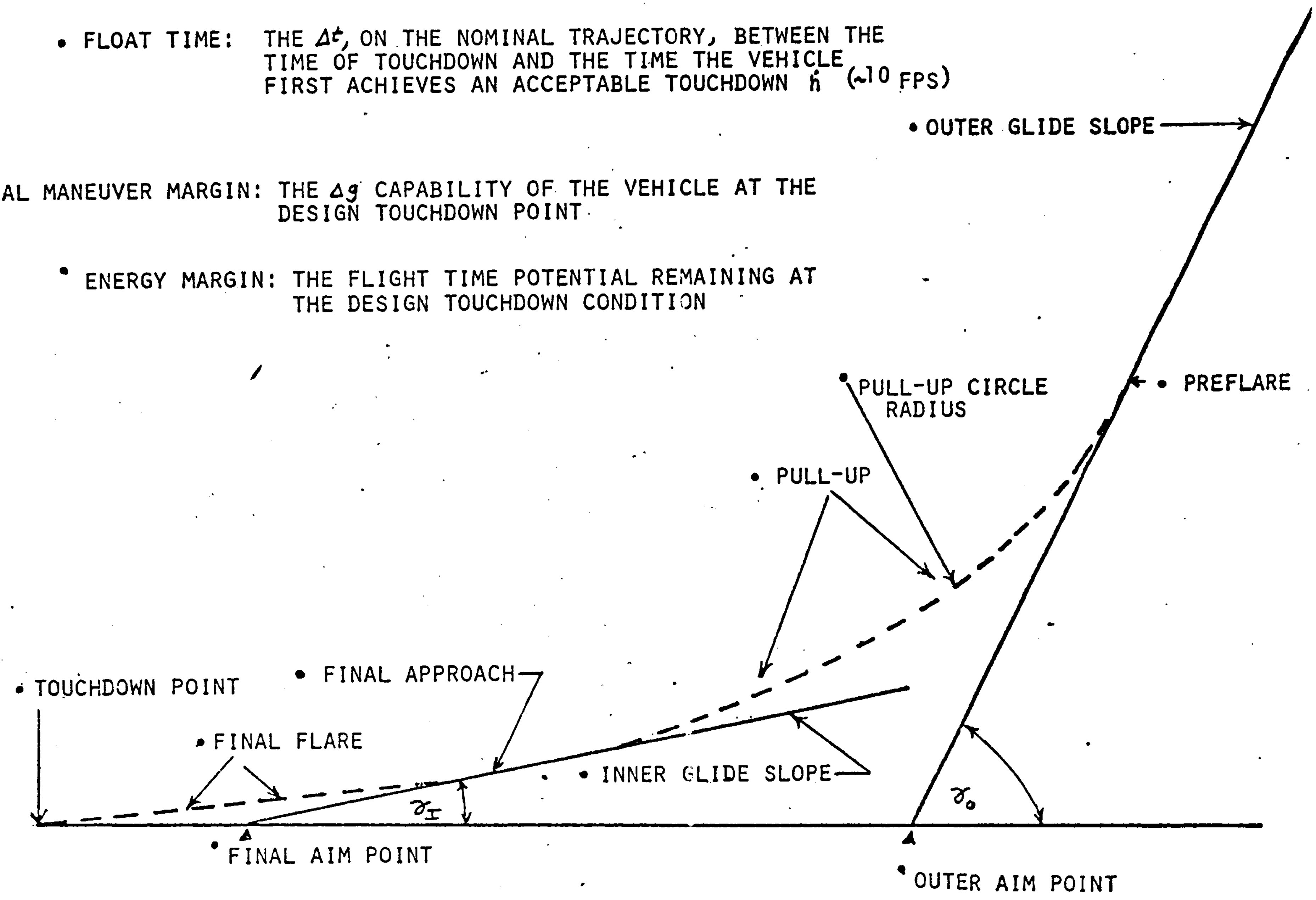


FIGURE 8-7

REQUIREMENTS FOR UNPOWERED LANDING

BASIC PROBLEM

- VEHICLE PERFORMANCE IS DEFINED RELATIVE TO AIR MASS
- GUIDANCE PERFORMANCE IS DEFINED RELATIVE TO R/W
- BOTH PROBLEMS MUST BE CONSIDERED CONCURRENTLY

REQUIREMENTS

- VEHICLE MUST HAVE SUFFICIENT EXCESS ENERGY TO ACHIEVE $\gamma = 0$
- VEHICLE MUST LAND ON, AND STOP ON, R/W

CONTROLLED PARAMETERS

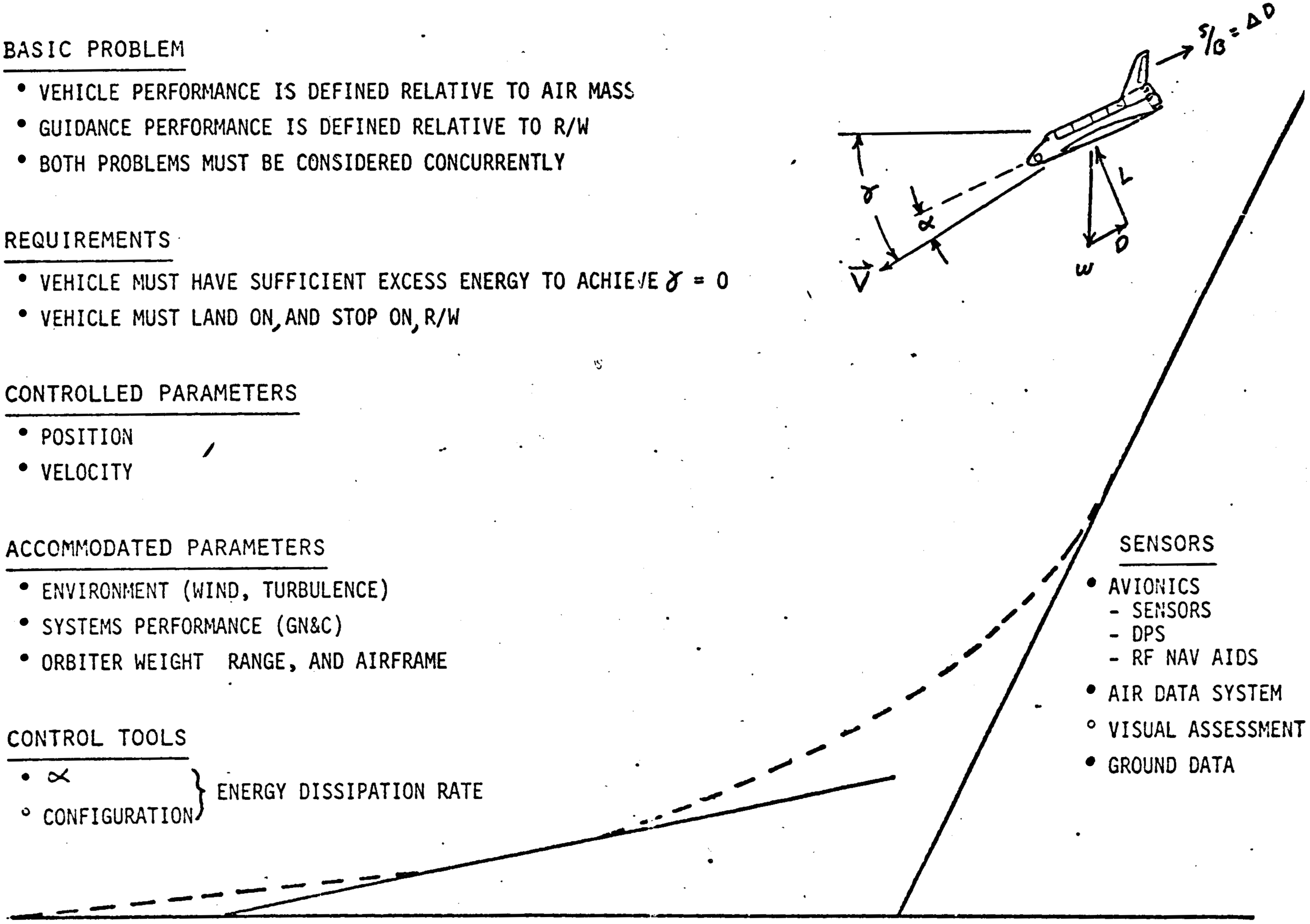
- POSITION
- VELOCITY

ACCOMMODATED PARAMETERS

- ENVIRONMENT (WIND, TURBULENCE)
- SYSTEMS PERFORMANCE (GN&C)
- ORBITER WEIGHT RANGE, AND AIRFRAME

CONTROL TOOLS

- α } ENERGY DISSIPATION RATE
- ° CONFIGURATION }



SENSORS

- AVIONICS
  - SENSORS
  - DPS
  - RF NAV AIDS
- AIR DATA SYSTEM
- ° VISUAL ASSESSMENT
- GROUND DATA

FIGURE 8-8

CONSTRAINTS

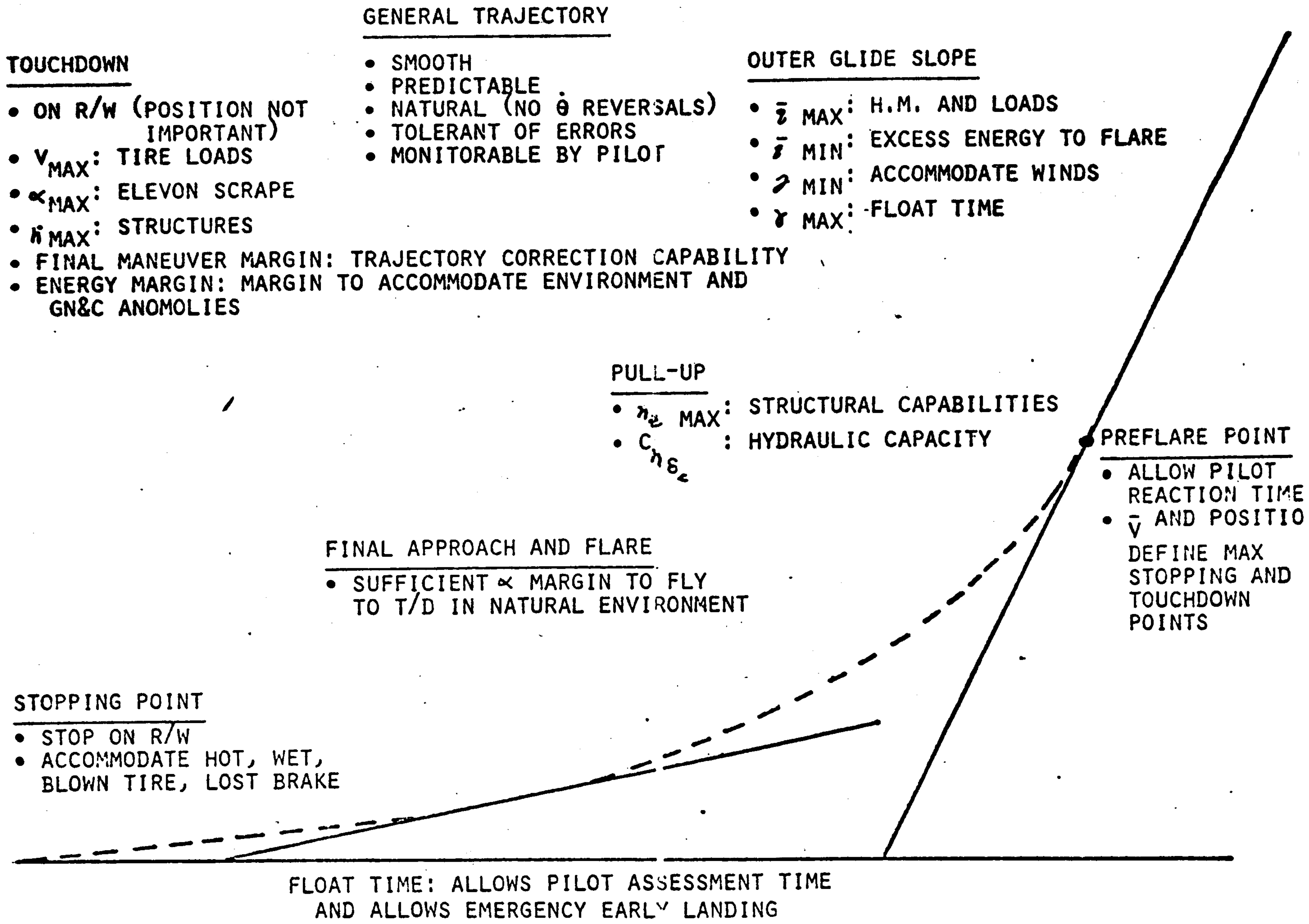


FIGURE 8-9

AUTOLAND APPROACH LOGIC

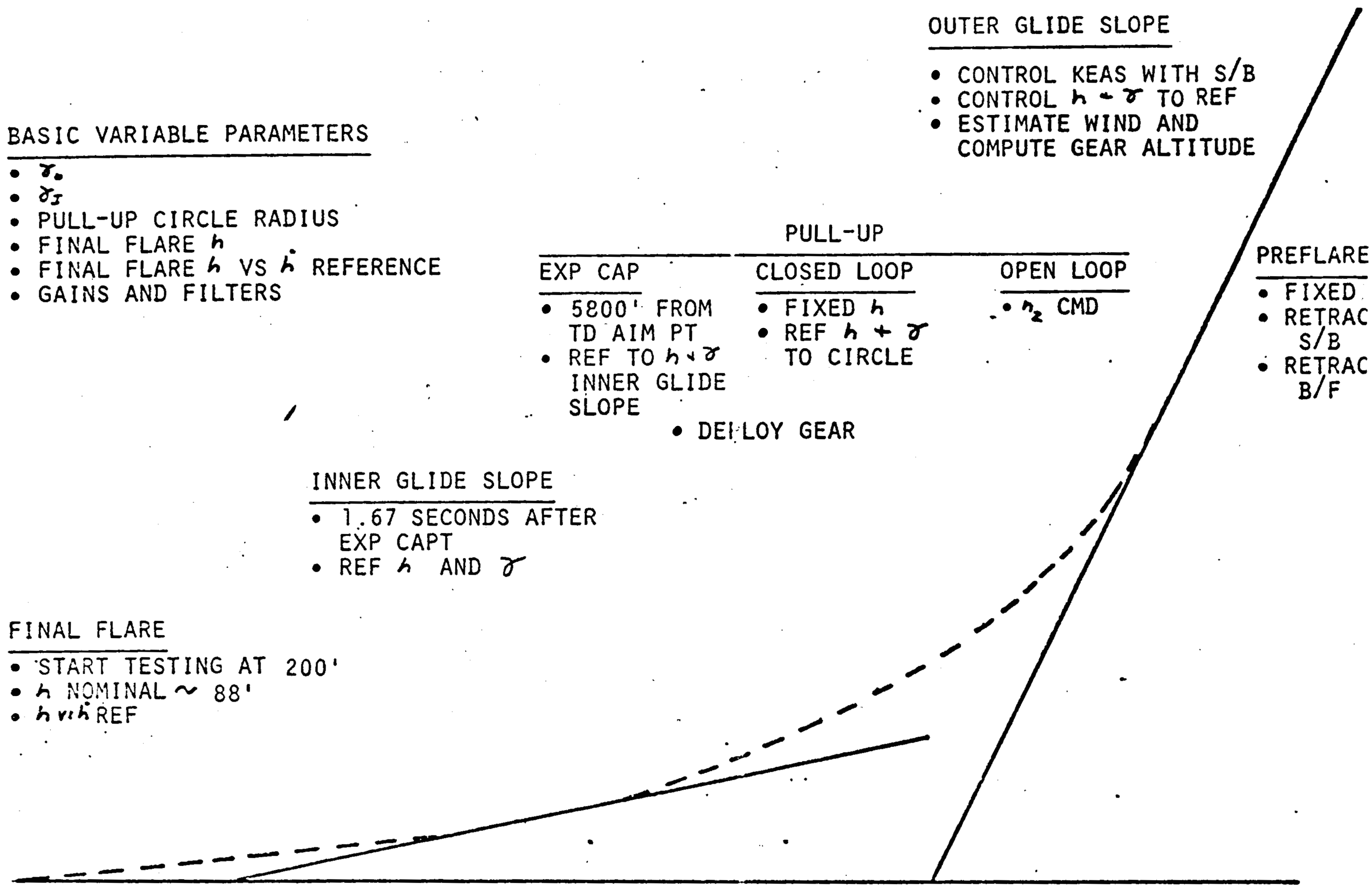
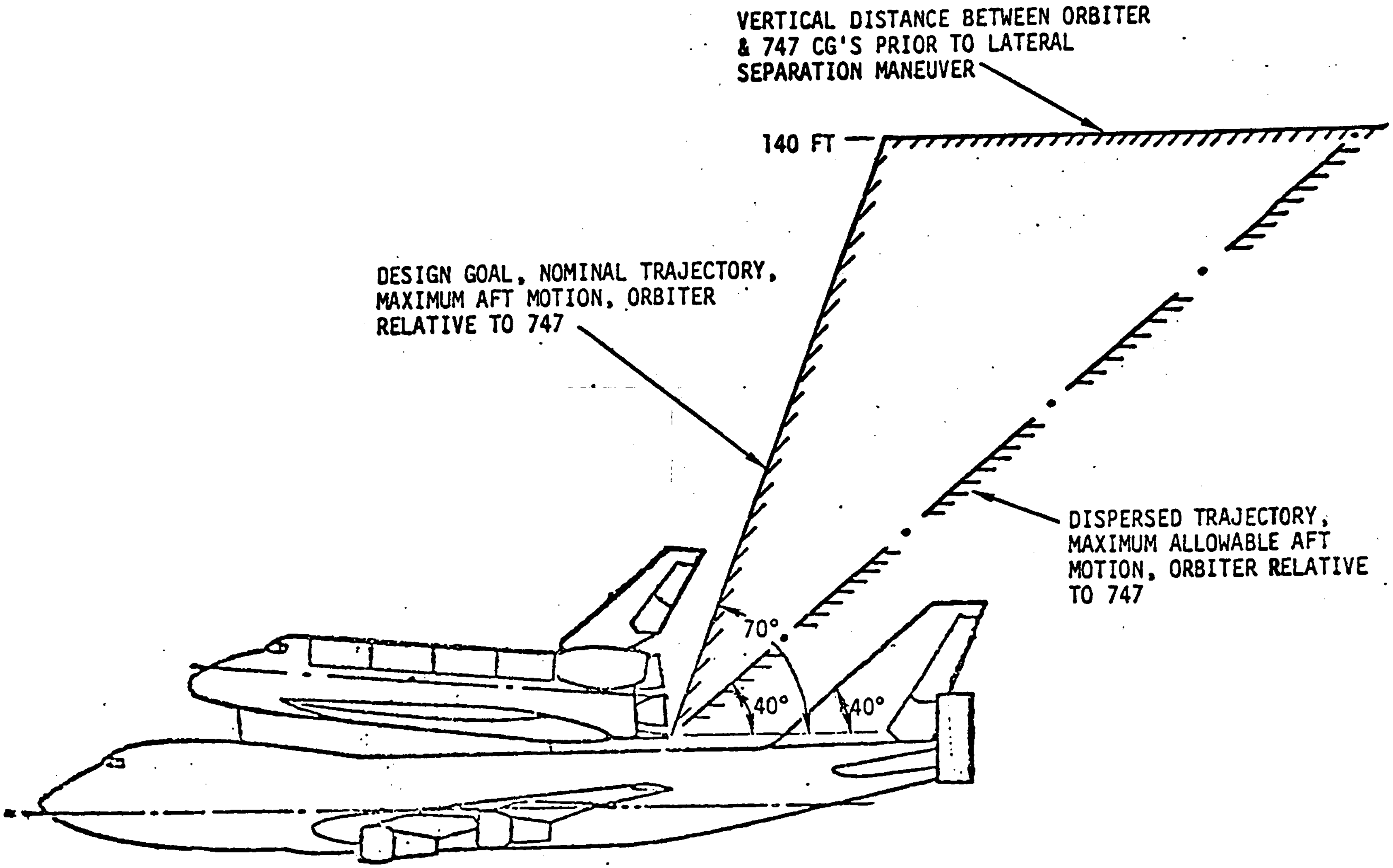


FIGURE 8-10

SEPARATION CLEARANCE REQUIREMENTS



747 CREW ESCAPE SYSTEM

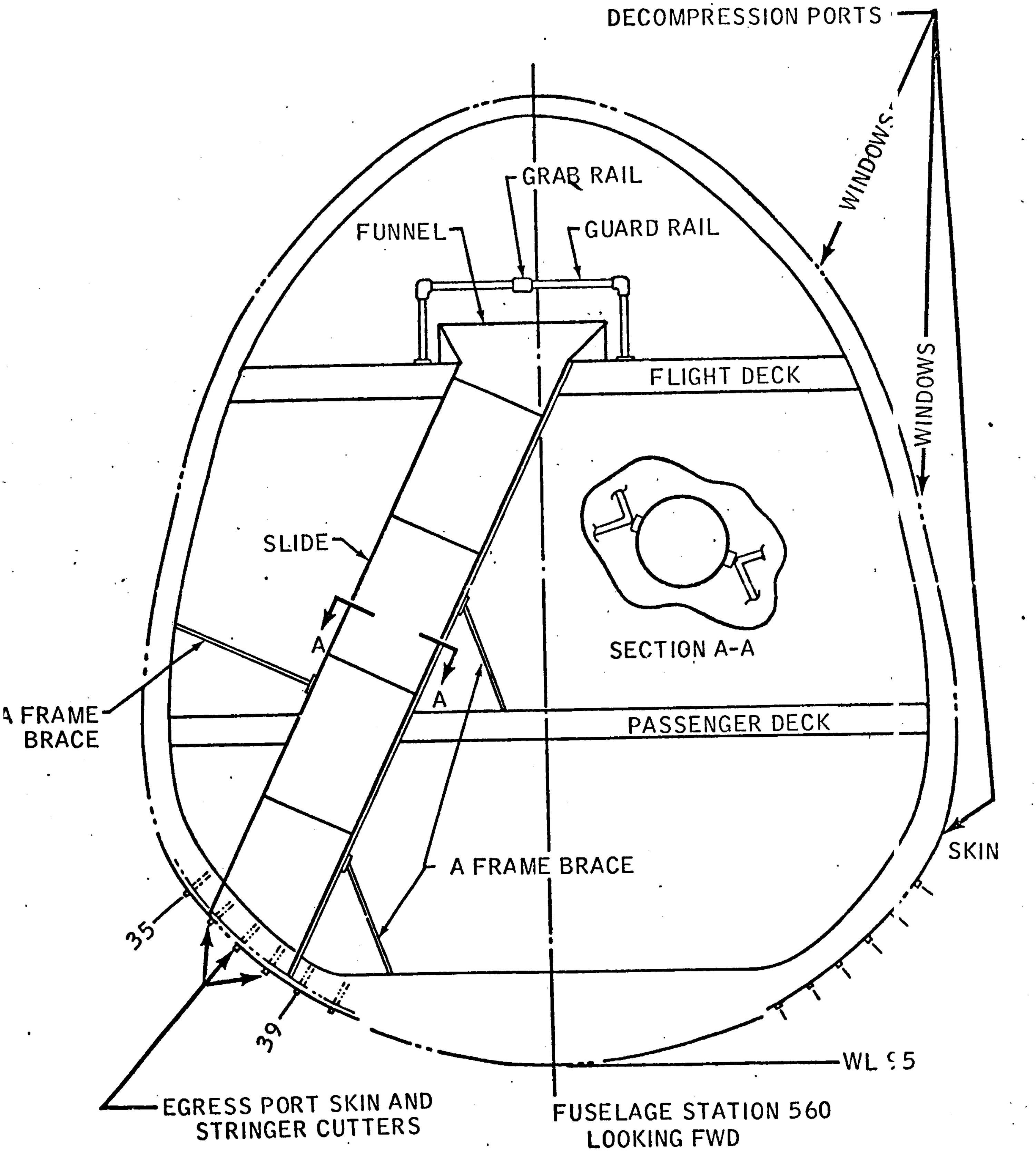


FIGURE 8-12

INNER AND OUTER PANEL SEVERANCE SYSTEMS

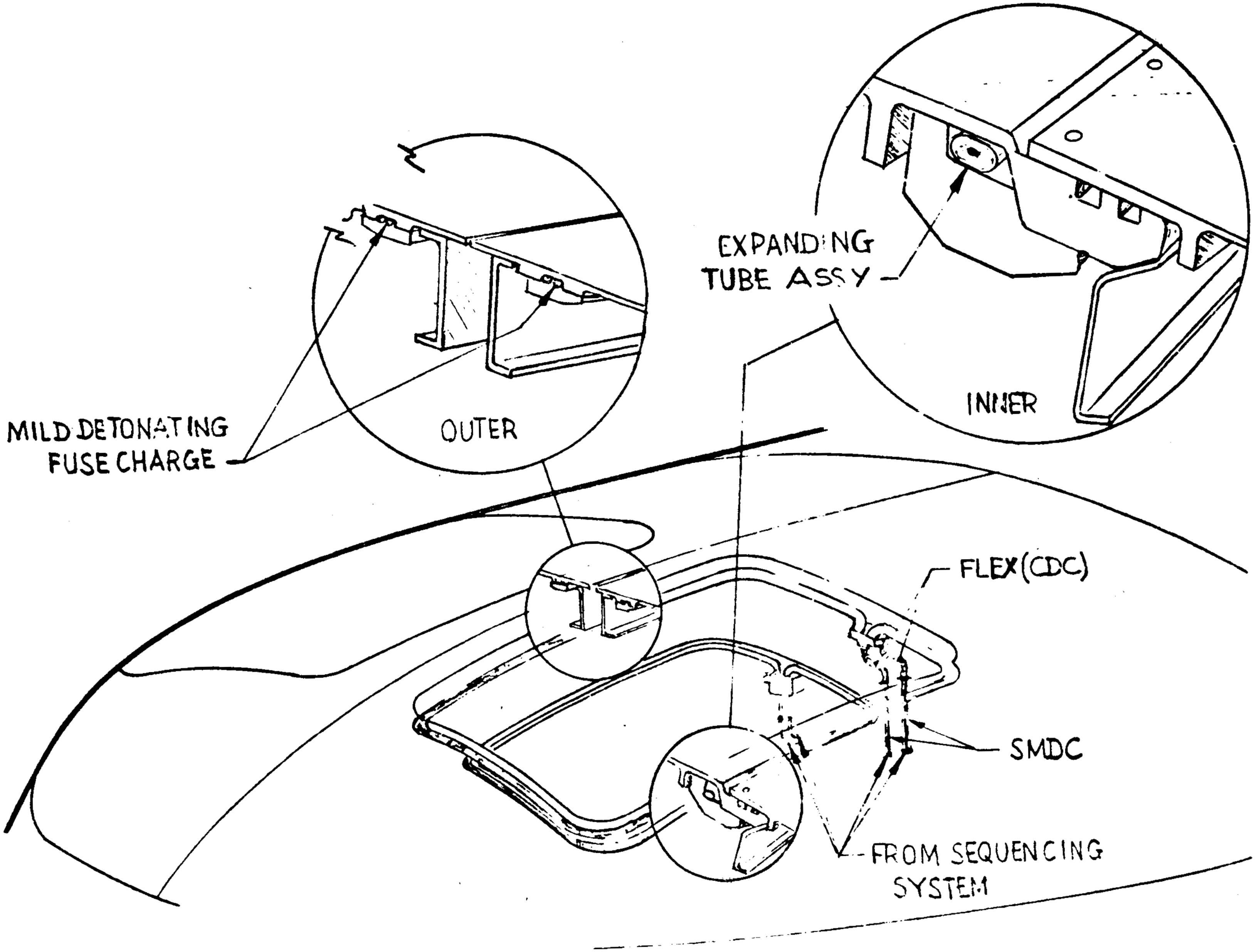


FIGURE 8-13

Permanent (Type I) Structural Modifications

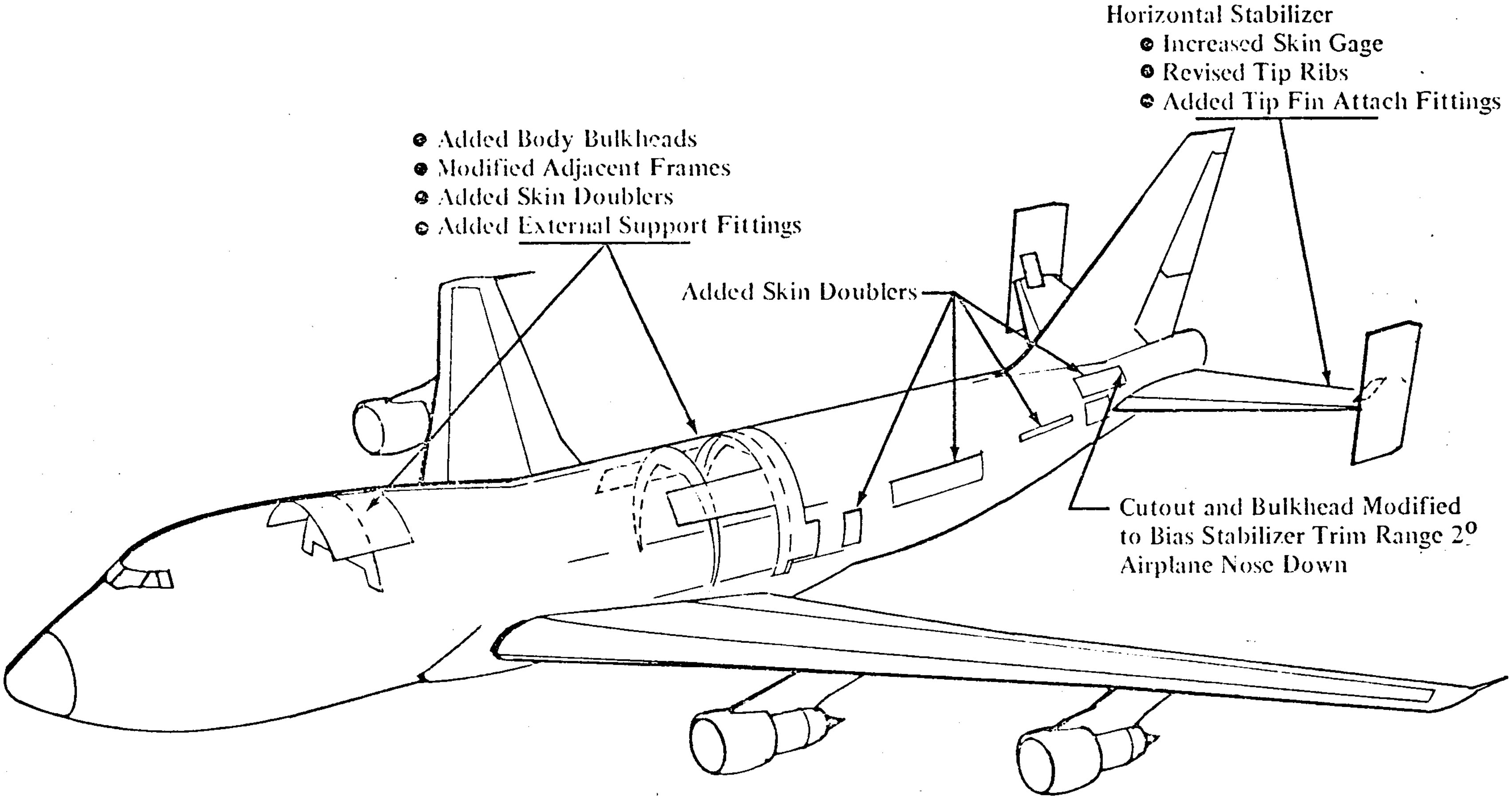
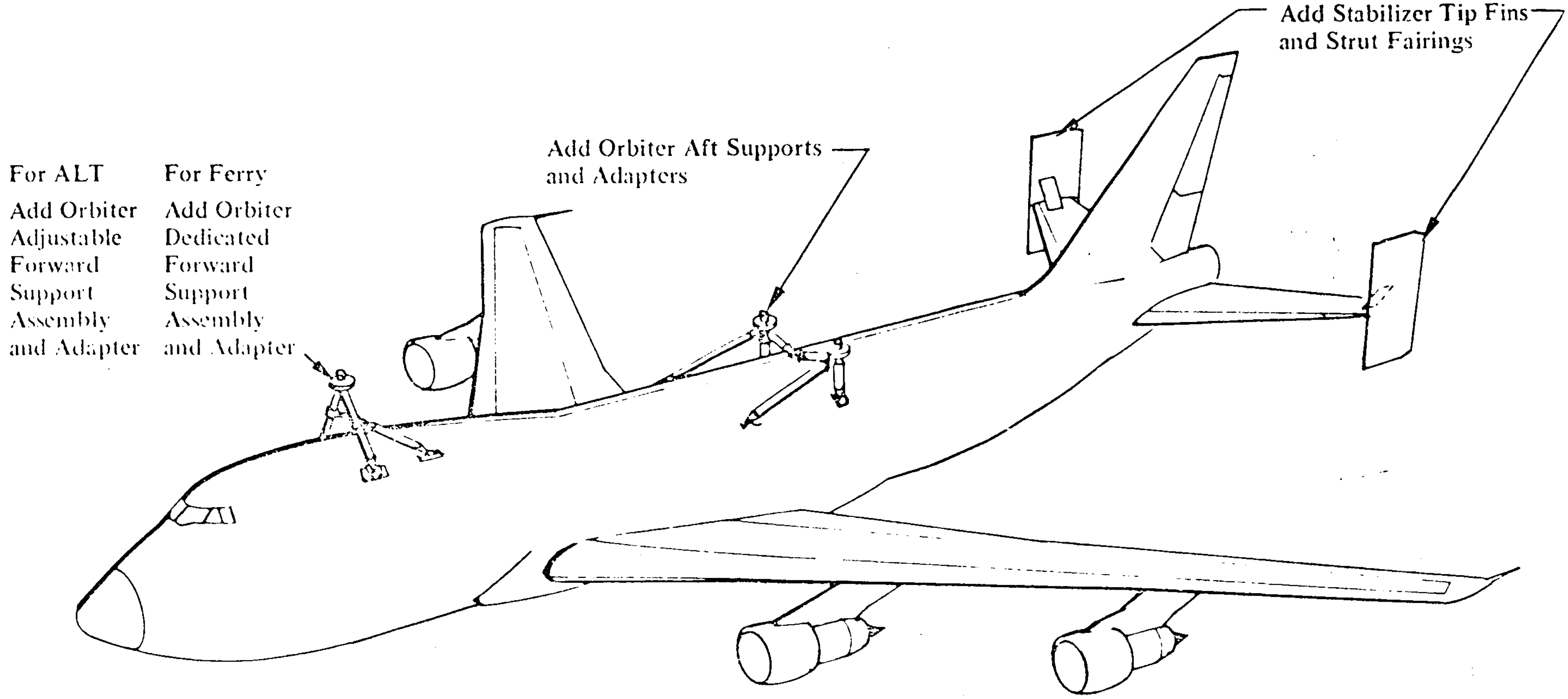


FIGURE 8-14

Removable (Type II) Structural Modifications



9.0 EXTERNAL TANK

9.1 Introduction

Information contained in this section of the report is current through the second quarter of calendar 1976. The latest data includes information for the period through the External Tank Quarterly Review in May 1976, which was conducted at the Michoud Assembly Plant in Mississippi. This overview covers the design status, weight status, development and qualification tests, significant concerns and issues associated with this program. The results of hazard analyses and failure modes and effects analyses are contained in Section 6 (Risk Management) of this report. Discussion of schedules and milestones are provided where it is felt that they have a bearing on the status and/or problem resolution or interfaces with other Shuttle elements.

The External Tank consists of five systems - (1) structures, (2) propulsion, (3) electrical, (4) thermal protection, and (5) interface hardware. Related ground support equipment is discussed in the GSE section of this report.

9.1.1 Background Description on the System

Most active components for the propellant system are contained in the Orbiter to minimize throwaway costs. At liftoff, the External Tank (ET) contains approximately 1,550,000 pounds of usable propellant. The liquid hydrogen tank volume is 53,000 ft^3 and the liquid oxygen tank volume if 19,500 ft^3. These volumes include a 3% ullage provision. The hydrogen tank is pressurized to a range of 17-19 psig and the oxygen tank to 20-22 psig. Antivortex and slosh baffles are mounted in the oxygen tank to minimize liquid residuals and to damp fluid motion. Five lines, three for the hydrogen and two for the oxygen, come together with the same number of lines in the Orbiter at the ET/Orbiter interface. Both tanks are constructed of aluminum alloy skins with support or stability frames as required, and their skins are butt-fusion-welded to provide reliable sealed joints. Spray-on foam insulation (SOFI) is applied to the complete outer surface including the sidewalls and the bulkheads. SLA-561 ablator material is applied to selected areas, such as the attachment structures, where shock impingement causes increased heating.

9.1.2 Structures

Structural design is complicated by the need to meet the interactive load effects resulting from (1) the temperatures and pressure requirements of the internal propellants, (2) external heating and pressures due to aerodynamics, and (3) the loads associated with Orbiter and Solid Rocket Booster interactions during the ascent phase of the mission. The hydrogen tank is a fusion-welded assembly of barrel sections, I-Ring frames, and dome sections. A frame at the juncture of the forward dome and forward barrel contains an integral flange which joins the hydrogen tank to the intertank and also provides the structure for the Orbiter forward attach point. The oxygen tank is of ogive shape to reduce aerodynamic drag and aerothermodynamic heating. A ring frame at the juncture of the dome and cylindrical section contains an integral flange for joining the oxygen tank to the intertank. The intertank is a skin/stringer/frame structure of cylindrical shape and includes a heavy beam which spans the intertank. The ends of the beam contain the SRB thrust fittings which are the ET/SRB forward interface points. Flanges at either end of the intertank provide the attachment to both the oxygen and hydrogen tank elements. A frame at the juncture of the aft dome and the aft barrel of the hydrogen tank contains the structure for the aft SRB attachment and also the structure for the aft Orbiter attachment.

9.1.3 Propulsion System

The ET contains all the hydrogen and oxygen for the Orbiter's main engines. Also, the ET propulsion system serves the primary function of delivering the oxidizer and fuel to and from the propellant tanks and the Orbiter interface. Delivery rates to the Orbiter are approximately 45,300 gpm for liquid hydrogen and 17,000 gpm for liquid oxygen. All controls and valves are located in the Orbiter except for the LOX and LH_2 vent/relief valves, the tumbling-system pyro valve, check valves in the helium inject line, and those valves integral to the interface disconnects. Propellants are loaded and off-loaded through the Orbiter into the ET. As for loading rates, maximum flows are 12,000 gpm for hydrogen and 5,000 gpm for oxygen.

9.1.4 Electrical System

The electrical system provides for propellant level sensing, instrumentation functions, electrical power distribution, tumbling capability and lightning protection. There are two distinct sets of instruments, the operational instrumentation and the development flight instrumentation. The development flight instrumentation is carried on the first six flight articles. Subsequent flights will have only operational instrumentation, which is hard-wire interconnections of sensors without ET electronics. All ET electrical power is derived from the Orbiter.

9.1.5 Thermal Protection System

The TPS performs a multipurpose role during prelaunch and flight phases. Its major functions are (1) to maintain the primary structure and subsystem components within design temperature limits, (2) control prelaunch boil-off rates, (3) contribute to maintenance of proper propellant temperature at Orbiter interfact, (4) prevent liquefaction of air on the hydrogen tank surface, and (5) help prevent accumulation of ice on the external surfaces of the ET.

During the ascent phase the TPS helps to minimize the unusable liquid hydrogen resulting from thermal stratification. During entry of the ET, structural temperatures and tank pressure contribute to the tank fragmentation process and the resultant debris size and impact footprint. The TPS assures safe separation from the Orbiter and low altitude fragmentation to meet a required 100 x 600 n.mi. footprint.

The types, areas of location and thicknesses were designed to handle worst case environments induced by an "abort-once-around: condition. Briefly the TPS materials and their application are as follows:

> SLA-561 is used in two forms, molded (SLA-561m) and sprayed (SLA-561s).
>
> CPR-421 is a fluorocarbon-blown, rigid-foam (polyisocyanurate).

with strength characteristics, and dimensional and thermal stability at low or high temperatures, that exceed those of standard urethane foam. A more complete description of the TPS usage is shown in Table 9-1.

9.1.6 Interface Hardware

The External Tank interfaces with the two Solid Rocket Boosters, the Orbiter, and with the launch facility. SRB interfaces are six flight-separable structural attach points and electrical connections to allow Orbiter-to-SRB communication and control. Orbiter inter-