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A TOW CONCEPT FOR THE SPACE SHUTTLE ORBITER APPROACH AND LANDING TEST

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16. Abstract

The towed concept provides the means for evaluating the orbiter aerodynamic performance and handling qualities in the same configuration as expected in actual space shuttle flight operation. Utilizing the NASA owned Boeing 747-100 aircraft as the tug, the orbiter can be safely towed from a 3050 m (10,000 ft.) runway to a test altitude of 6890 m (22,600 ft.). The 747 has engine-cut capability to tow the orbiter to an altitude that permits a safe orbiter approach and landing. The tow concept also provides a means for conducting a comprehensive ground test program before proceeding into the actual ALT flight operations. The implementation of the tow concept requires only a minor structural modification in the nose section of the orbiter vehicle; requires minor modifications in the 747 cargo bay; and makes use of those orbiter onboard systems installed in the ALT orbiter vehicle (#101). The 747 wake turbulence does not constitute a problem for the orbiter during take-off or climb to altitude. The impact that the towed concept would have on the cost and schedule of the space shuttle program was not evaluated in this study.

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A TOW CONCEPT for THE SPACE SHUTTLE ORBITER APPROACH AND LANDING TEST

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SUMMARY

The towed space shuttle orbiter concept for the approach and landing test (ALT) provides a means for evaluating the orbiter's aerodynamic performance and handling qualities in the same configuration as expected in actual space shuttle flight operation. Utilizing the NASA owned Boeing 747-100 aircraft as the tug, the orbiter can be safely towed from a 3050 m (10,000 ft.) runway to a test altitude of 6890 m (22,600 ft.). The 747 has engine-out capability to tow the orbiter to an altitude that permits a safe orbiter approach and landing. The tow concept also provides a means for conducting a comprehensive ground test program before proceeding into the actual ALT flight operations. The implementation of the tow concept requires only a minor structural modification in the nose section of the orbiter vehicle; requires minor modifications in the 747 cargo bay; and makes use of those orbiter onboard systems installed in the ALT orbiter vehicle (# 101). The 747 wake turbulence does not constitute a problem for the orbiter during take-off or climb to altitude. In specific terms, the performance of the tow concept provides a mission profile with an elapsed time of 24 minutes to climb to altitude and a total mission time of 45.5 minutes. By utilizing higher performance production engines (Pratt and Whitney JT9D-70 or CFG-50 engines), the orbiter test altitude can be increased to 8,230 m (27,000 ft.) and the total mission time can be reduced to 36.5 minutes. The 747 (with JT9D-7AW engines engine-out performance provides the capability to climb to 3,720 m (12,200 ft.) which would allow the orbiter to release, enter to the final flare position, and land. With the high performance engines, climb can be maintained to 5,120 m (16,800 ft.) which would allow the orbiter to perform a practice flare and then enter the final flare threshold and land. The take-off distance of the 747 (JT9D-7AW) with the orbiter in tow is 2,963 m (9,720 ft.), which is less than that required for the 747-100 aircraft at design take-off gross weight in commercial operation.

The minimum required steel tow-cable size is 1.90 cm (0.75 in.) diameter for a take-off tow load of 177,928 N (40,000 lbf.). The orbiter is towed from the forward nose wheel structural box and a test nose cap would be installed with the tow cable attachment fittings and release devices included. The most favorable tow position for the orbiter is directly aft of the 747 horizontal stabilizer at a trailing distance of 122 m (400 ft.).

A detailed analysis of the dynamic motion of the space shuttle orbiter (while attached to the tow cable) was not performed in this study. Orbiter/tow cable dynamic motion was considered however, and in light of previous work by the NACA and extensive experience by the military, is not expected to be a problem with the tow concept.

The impact that the towed concept would have on the cost and schedule of the space shuttle program was not evaluated in this study.

INTRODUCTION

In the course of developing the current "piggyback" method for performing the approach and landing test (ALT) on the space shuttle orbiter, an aerodynamic condition was discovered that required the installation of a large aerodynamic fairing on the aft end of the orbiter vehicle. The aft tail cone fairing is nonjettisonable and therefore must remain with the orbiter during approach and landing. The desirability to perform the ALT without the aft tail cone fairing (to achieve the best representation of actual orbiter characteristics) led to this study of the tow concept as an alternate method.

The Langley Research Center recently has studied the potential of towed aircraft systems. Early conceptual studies, reference 1, have identified configurations and performance potential of tow applications. Also, numerous aerospace contractors have conducted in-house studies of towed aircraft systems. The Lockheed Aircraft Corporation conducted design studies in 1973 of the application of the C-5 as a method of towing the space shuttle orbiter. The mission performance results of that study were very promising. The Boeing Company, in 1973, considered the feasibility of using the 747 as the tow plane for flight test and ferry of the orbiter. That study effort showed the advantages of high-altitude flight test capability which would permit verification of aerodynamic capability with substantial configuration fidelity. In a 1974 study by the LTV Corporation, the feasibility of towing the orbiter behind the C-5A aircraft was further verified.

The purpose of this paper is to provide an assessment of the tow concept by analyzing the integrated design of the Boeing 747 aircraft and the space shuttle orbiter (vehicle # 101) for the approach and landing test (ALT) mission. In the course of this study, numerous contacts were made with space shuttle orbiter project personnel at the NASA-JSC. This consultation and technical assistance (particularly as related to mission characteristics, specific orbiter subsystems, and onboard consumable requirements) was instrumental in allowing these tow concept studies to proceed. The NASA-LRC also consulted numerous experts in tow technology and related disciplines at other NASA centers (DFRC and Ames), aerospace contractors, FAA, and military agencies. Much of this consultation forms the foundation of this study document.

The study approach was to use the Boeing 747-100 aircraft (figure 1) with JT9D-7AW engines as the towplane, and also to evaluate the effects of higher performance production engines (JT9D-7FW, JT9D-70, and CF6-50). The space shuttle orbiter (figure 2), vehicle # 101, without the aerodynamic tail cone and with the landing gear in the down position, is the towed vehicle for the ALT missions. The basic criteria for the study were as follows:

- Shuttle orbiter vehicle # 101 (Table I)
  - Landing gear extended
  - Aerodynamic tail cone fairing off
  - Weight: 68,406 kg. (150,812 lbm) (minimum weight, forward center of gravity)
    71,659 kg. (157,984 lbm) (maximum weight, aft center of gravity)
  - RCC nosecap replaced with test nose cap
  - Onboard consumables and subsystems remain unchanged
- Boeing 747-100 (NASA-owned; stripped of all excess weight - Table II)
  - OWE 134,081 kg. (295,600 lbm) with JT9D-7AW engines
    134,171 kg. (295,800 lbm) with JT9D-7FW engines
    133,355 kg. (294,000 lbm) with CF6-50E engines
- Test mission location: Edwards AFB complex
  - Ambient conditions -
    Standard day
    Sea level and 609 m (2,000 ft.) take-off altitudes
- Take-off:
  - 747-100 with 0.17 rad. (10 degrees) flap deflection
  - 2,267 kg. (5000 lbm) water (with JT9D-7AW and FW engines)
  - Take-off distance from start to reach 10.6 m (35 ft.) altitude
  - Speed at 10.6 m (35 ft.) altitude to be equal to 1.2X stall speed
- Climb to altitude:
  - Constant V_e
  - Ceiling based on 1.02 m/sec (200 ft/min.) minimum rate of climb

The ALT mission characteristics--altitude, range, elapsed time, and airspeed at the start of the orbiter descent for approach and landing--as presented in references 2, 9, and 10, were considered to be basic requirements for tow concept performance. A condition of one-engine failure on the Boeing 747 was another requirement imposed on the tow concept.

This paper will address the following topics:

- Tow system elements
- Orbiter onboard subsystems
- Towplane wake turbulence
- ALT mission performance

SYMBOLS

The analysis computations in support of this study were performed in U.S. Customary (English) units. Results were converted to the International System of Units (SI) by using conversion factors in reference 3 and are presented in this report along with the Customary Units.

AFB	Air Force Base
ALT	Approach and Landing Tests
α	Angle of attack
APU	Auxiliary Power Unit
c.g.	Center-of-gravity
c_m	Pitching moment coefficient
cm	Centimeter
D	Drag
Deg	Degree
DFRC	Dryden Flight Research Center
F	Cable tension force
FAA	Federal Aviation Administration
θ	Cable angle
ft.	Feet
Fl't	Flight
h	Altitude
Hr	Hour
JSC	Johnson Space Center
in.	Inches
kg	Kilograms
km	Kilometers
kt	Knots
L	Lift
lbf	Pound force (aviordupois)
lbm	Pound mass (avoirdupois)
LRC	Langley Research Center
LTV	Ling-Tempco-Vought
L/D	Lift-to-Drag Ratio
m	Meter
m/sec	Meters per second
MSL	Mean Sea Level
$\mathcal{M}$	Mach Number
Max	Maximum
Min	Minimum
n.mi.	Nautical Miles
N	Newton
OWE	Operating Weight Empty
P_v	Vertical cable load component
P_h	Horizontal cable load component
Rad.	Radian
RCC	Reinforced Carbon Composite

Sec	Second
δ_e	Elevon deflection angle
TOGW	Take-off Gross Weight
V	Velocity
Ve	Equivalent airspeed
Vs	Stall velocity
s.mi.	Statue Mile
SSO	Space Shuttle Orbiter

DISCUSSION

TOW SYSTEM ELEMENTS

The integrated tow configuration for the ALT mission is shown in figure 3. The NASA-owned Boeing 747-100 aircraft was selected as the towplane. A minimum structural modification approach was taken for the towplane by locating the tow load attachment near existing fuselage load carrying structures. From reference 4, the location in the aft baggage compartment beneath the primary load carrying floor was selected for the tow load attachment (figure 4). The cable storage drum, rewind mechanisms and slip clutch device are located in the space between the upper and lower deck floors. The large floor beams provide an excellent shear-tie structure for the tow forces. A small external aerodynamic fairing to contain the cable guide is attached to the aft fuselage tail cone. The tow controls and operator personnel are located on the main deck. The military design consultants recommended that existing design techniques be utilized for rapid cable rewind capability. A slip-clutch would be incorporated in the cable reel system to prevent cable overload from dynamic loads encountered during tow operation. Emergency separation of the cable from the 747 aircraft is provided by pyrotechnic release devices mounted in the aft fairing structure. The emergency separation system would be interlocked to the tow cable load to prevent inadvertant separation of the cable when the SSO is on tow.

For the ALT mission tow concept, a nominal cable force of 178,000 N (40,000 lbf) was determined using a selected cable angle of .10 rad. (6 degrees) with a $L/_D$ of 6.1 based on the orbiter pitch rotation of .19 Rad. (11 degrees) prior to liftoff, (reference 5). Figure 5 shows this design point and the effect of tow cable angle and orbiter $L/_D$ ratio on the tow cable load. To assure a small tow cable angle, the orbiter is towed at a trailing distance of 122 m (400 ft.). The design load of 178,000 N (40,000 lbf) can be safely handled with a high performance tow cable, currently in military use. The existing cable is of steel construction, 1.9 cm (0.75 in.) diameter, and has a breaking strength of 356,000 N (80,000 lbf), which provides a factor of safety of two for the SSO tow mission.

The orbiter attachment concept is shown in figure 6. The nose attachment concept was selected to: provide a "line of pull" passing approximately through the center of gravity of the vehicle; minimize the impact on the orbiter structure; and allow incorporation of a subassembled test nose cap with attachment and redundant separation devices. This test nose cap would have the basic mold lines of the RCC orbiter nose cap and would also provide ballast capability for center of gravity adjustments. From several methods of disengagement of the tow cable from the orbiter that were considered, a mechanical release system similar to current sailplane separation techniques was selected for its basic simplicity. To provide disengagement redundacy, a pyrotechnic nut and bolt was incorporated with the primary mechanical system. The tow cable loads are distributed to the nose wheel forward bulkhead structure by structural beams in the test nose cone. A minor structural modification is required in the orbiter nose structure to install a horizontal shear shelf from the nose gear box to the outboard skin structure as shown in figure 7. This shear shelf would be "clipped-in" to the side-wall frames and attached at the aft bulkhead location. This modification would not be a major weight factor on the ALT mission. The scope of this study did not include a detailed investigation of the cable reel/slip clutch mechanisms and their controls; however, the military consultants indicated that standard systems are available from present Navy and Air Force operations.

ORBITER ONBOARD SUBSYSTEMS

The orbiter vehicle #101 has several subsystems that have been modified to support the current "piggyback" ALT mission. The mission design time for the electrical power subsystem and fuel cell cooling has required the use of onboard kits for critical consumables (oxygen, hydrogen and ammonia) as shown in figure 8. The amount of consumable fluids required is determined by the ALT mission duration. The ALT tow concept mission would utilize these same subsystems with less consumable quantities because of a shorter total mission time (discussed later in this document). This shorter mission time would also benefit the critical life cycle constraints on the SSO-APU subsystem. Certain critical APU components, such as the gas generator, are experiencing short operational life (less than the design goal of 50 hours). Therefore, a reduction in mission time would enhance the total mission reliability and reduce the refurbishment costs of these components.

TOWPLANE WAKE TURBULENCE

The wake turbulence behind large aircraft such as the 747 has been thoroughly investigated through analysis and flight test programs, reference 6. Pertinent wake turbulence information for this study was obtained through experts at LRC, Ames, DFRC and the Boeing Aircraft Company. Most of these expert consultants were directly involved in recent flight test programs investigating turbulence behind the 747 aircraft (reference 7 and 8). In these flight tests, the Cessna 206, Convair 990 and the highly instrumented T-37 aircraft were flown at various positions behind the 747 aircraft with the 747 in both a cruise and take-off (high lift system and landing gear deployed configuration. Some general results of these tests indicate that, with the 747 in the cruise configuration, the air stream inboard of the wing tips and behind and along the centerline of the aircraft is essentially turbulence free. The wing tip vortices, with their attendant strong upsetting flow characteristics, remain very concentrated 3.048 m (10 ft.) to 6.096 m (20 ft.) in diameter as far back as 3700 m (2.0 n.mi.) behind the 747. With the 747 in the take-off configuration, the air stream behind and along the centerline, particularly above the aircraft, is basically turbulence free. Therefore, it is desirable to tow the orbiter at a slightly high position on the spanwise centerline behind the 747, where basically undisturbed air would exist for all configurations of the 747 aircraft.

MISSION PERFORMANCE

Take-off Mode:

Two operational modes by which the Boeing 747 and SSO take-off maneuver may be accomplished were evaluated. In one mode the 747 would lift-off just prior to the SSO lift-off, thereby providing a slight nose pullup force to the SSO. This would in turn allow the use of minimum elevon rotation control power to achieve the required angle-of-attack for SSO lift-off. The angle-of-attack requirements for SSO (at minimum and maximum weight) lift-off are given in figure 9 and the tow cable and SSO incident angle designation is defined in figure 10. Specifically in this case, the 747 would begin the take-off run with a .17 rad (10 degree) flap setting and would accelerate to lift-off velocity of 96.7 m/sec (190 kt). Just after lift-off of the 747, at a speed of 98.5 m/sec (192 kt), the SSO elevons are deflected to rotate the SSO to an angle-of-attack of .19 rad (11 degrees) that is required for lift-off. The take-off distance required for the 747 to clear a 10.67 m (35 ft.) obstacle was found to be 2970 m (9720 ft.) (figure 10) using the JT9D-7AW engines and with the SSO at minimum weight. Other take-off distance requirements using different engines (thrust data from ref. 13 and 14 is tabulated in Table III herein) at both minimum and maximum SSO weight are presented in figure 11.

In the other take-off mode the SSO would lift-off prior to 747 lift-off. Specifically, at a speed of 92 m/sec (180 kts) the SSO would rotate to an angle-of-attack of .21 rad (12 degrees) and climb to a high position, clear of the 747 downwash. The 747 would then lift-off at 96.7 m/sec (190 kts) and proceed to climb as in the previous mode. Take-off distance requirement for this mode is approximately the same as in the other mode.

Climb and Cruise:

For the tow concept ALT airdrop mission a NASA-LRC mission analysis computer program was used to evaluate mission performance. Aerodynamic data for the 747 aircraft and the SSO was obtained from reference 11. Figure 12 shows the tow concept mission profile (without the tail cone and with the landing gear down), in which the performance is presented for the baseline 747 engines (JT9D-7AW) and higher performance production engines (JT9D-7FW, JT9D-70 and/or CF6-50). The orbiter vehicle # 101 is towed at a constant Ve of 103 m/sec (200 kt) to an altitude of 6,888 m (22,600 ft.) and a range of 167,000 m (91 n.mi.) in an elapsed time of 24 minutes. At that altitude and speed, level cruise is maintained for 19 minutes until the orbiter separation position is reached at a range of 20,917 m (11.3 n.mi.) from threshold (orbiter landing site). By using the JT9D-7FW higher performance engines on the 747, the altitude capability is increased to 6,949 m (22,800 ft.) and the total mission time reduced to 40.5 minutes. More significant performance changes are shown with the CF6-50 or JT9D-70 class engines which increase the altitude capability to 8,230 m (27,000 ft.) and reduces the total mission time to 36.5 minutes. These performance capabilities are based on the minimum orbiter weight 68,407 kg. (150,812 lbm.) case, reference 12. For the maximum orbiter weight of 71,660 kg. (157,984 lbm) the altitude ceiling is not significantly reduced— from 6,888 m (22,600 ft.) to 6,664 m (21,800 ft.) with the JT9D-7AW engines and from 8,230 m (27,000 ft.) to 7,925 m (26,000 ft.) with the highest performance engines. The tow concept mission characteristics are listed in Table IV.

Alternate Climb Routine:
Since a major portion of the total mission time for the tow concept is the long cruise time to return the orbiter to the drop threshold range position, a large spiral climbing turn to altitude, as shown in figure 13, could reduce the mission time to orbiter release by 47%.

Engine-out Performance:
The 747 engine-out performance was investigated to determine if sufficient altitude could be reached to effect a safe orbiter release and landing (figure 14). With the baseline JT9D-7AW engine a minimum climb gradient of 1.02 m/sec. (200 ft/min) can be maintained to an altitude ceiling of 4,145 m (13,600 ft.) and down-range position of 20,917 m (11.3 n.mi.), which is adequate for the orbiter to obtain the proper approach speed and accomplish a flare maneuver to a safe landing. The higher performance engines (CF6-50 or JT9D-70) would provide a significant increase in total mission capability with one engine inoperative. An altitude ceiling of 5,943 m (19,500 ft.) can be obtained which would allow the orbiter to perform a practice flare after orbiter release and proceed with the normal approach and landing sequence.

Preflight Ground Tests:
The tow concept provides the capability to perform a series of ground verification tests before proceeding into the actual ALT flight operations. These tests would evaluate the complete system capability for the ground acceleration take-off mode as well as the orbiters capability for the landing ground-rollout condition. The orbiter vehicle would be towed up to test speed on the runway and tow cable release would be effected. The 747 aircraft would continue to accelerate and take-off after orbiter vehicle release to allow the orbiter vehicle to conduct landing ground-rollout tests on the runway, free of possible interference from the 747.

These tests would be conducted at the Edwards AFB complex (figure 15). The lakebed runway 35 provides a total length of 12,070 m (7.5 s.mi.) with sufficient lateral width to conduct directional control and steering effectiveness tests. The runway 4, which is concrete, would be used for orbiter braking effectiveness tests.

CONCLUDING REMARKS

The NASA-owned Boeing 747-100 with JT9D-7AW engines is a suitable tow airplane to accomplish the ALT mission for the space shuttle orbiter vehicle. The tow cable attachment on the orbiter vehicle requires a minimum modification to the orbiter structure. The tow concept would make use of the same orbiter onboard subsystems as currently planned for the "piggyback" mission. Installation of the tow cable attachments in the Boeing 747 requires only simple structural attachments in the aft cargo compartment floor and ceiling. The military has considerable recent experience with high performance aircraft tow operational systems. This developed technology would be utilized in the detail design of the orbiter tow concept (cable, reel, rewind and slip-clutch devices).

The orbiter can be towed to the required test separation threshold altitude without an aerodynamic tail cone and with the landing gear down. Separation of the SSO from the Boeing 747 at test altitude is a simple, reliable, proven procedure. With an engine-out condition, the 747 tow aircraft can still maintain a 1.02 m/sec. (200 ft/min.) climb gradient to a ceiling altitude above 3,660 m (12,000 ft.) where separation, a normal entry, final flare and landing of the orbiter can be effected. The use of the high performance production engines on the 747 can significantly increase the ceiling altitude and reduce the total mission time. The total mission time for the towed concept can be reduced to about 50% of that for the current "piggyback" concept, thus reducing the onboard consumables and minimizing the life cycle effects on SSO systems.

It was determined from the take-off analysis that two (2) operational modes are feasible for take-off; one in which the 747 would lift-off prior to the orbiter to minimize orbiter elevon power required to effect orbiter rotation and another in which the orbiter would lift-off prior to the 747 to achieve a high tow position clear of 747 downwash effects. The take-off distance for the 747 (JT9D-7AW engines) with the orbiter in tow is less than that required for a fully loaded commercial 747-100 aircraft. The SSO/747 take-off distance can be reduced 10% by use of the high performance engines (CF6-50 or JT9D-70).

The orbiter tow concept provides the opportunity to perform preflight ground tests at the Edwards AFB complex prior to proceeding into actual ALT flight operations.

The wake turbulence behind the 747 aircraft would not be a major concern for the tow locations of the orbiter vehicle.

The effect of tow cable dynamics on the stability and control of the towed vehicle has been studied by the NACA (ref. 15) and extensively analyzed and evaluated by the military. In light of this previous experience the space shuttle orbiter tow cable dynamics are not expected to be a problem. However, a detailed analysis of this condition should be performed if the tow concept is to be implemented.

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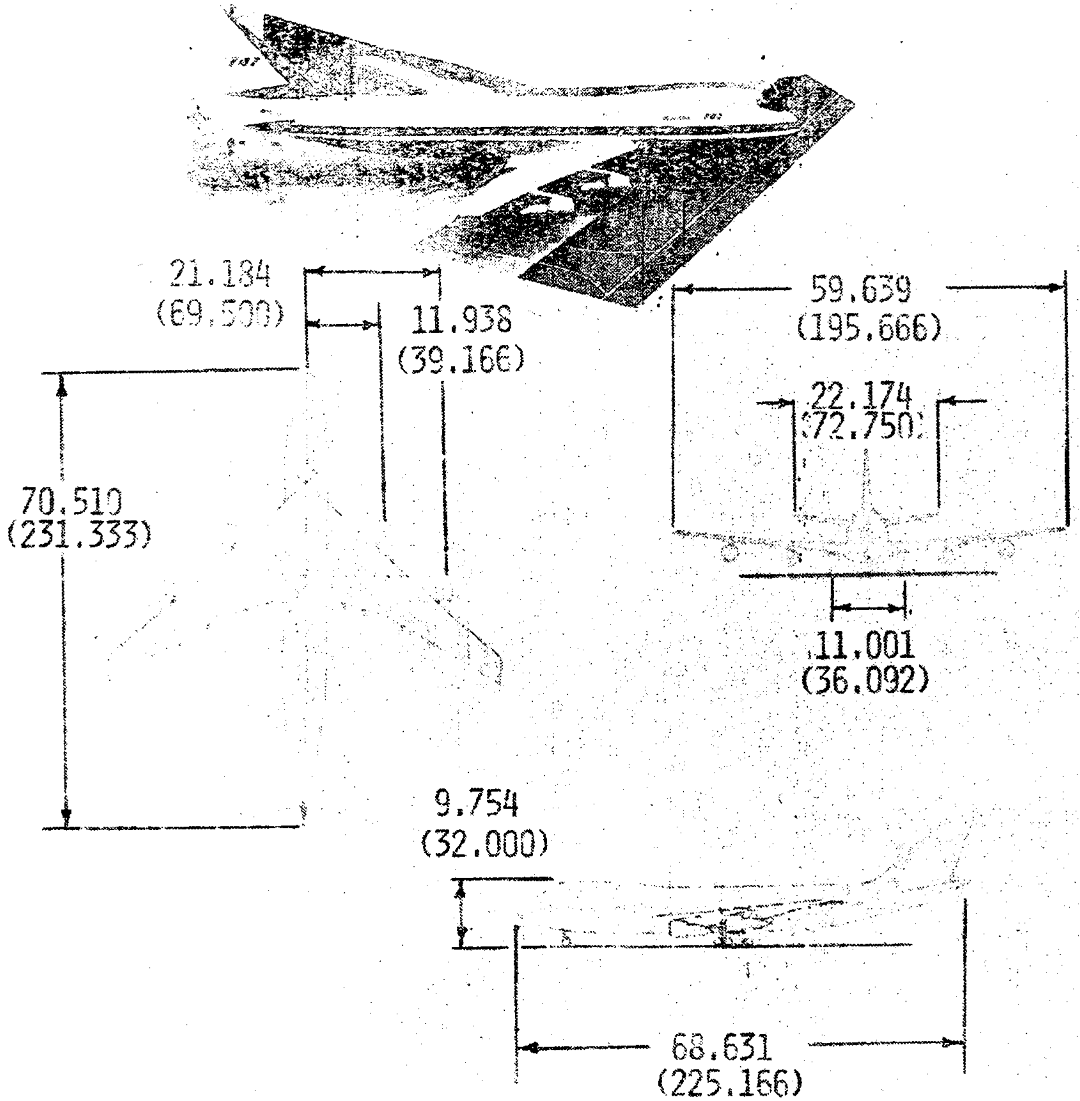

FIGURE 1 - BASIC BOEING 747-100 GENERAL ARRANGEMENT

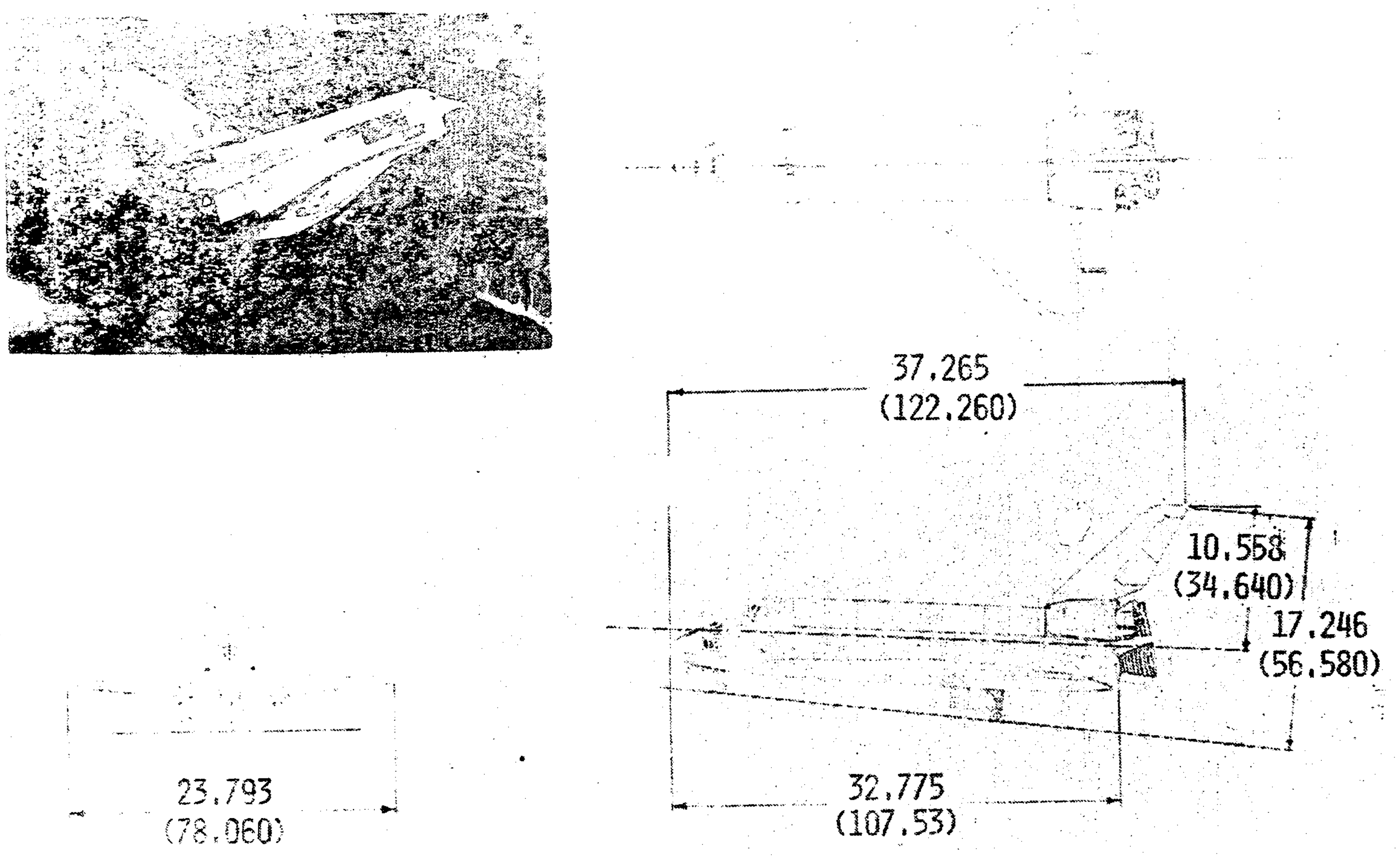

FIGURE 2 - ORBITER GENERAL ARRANGEMENT

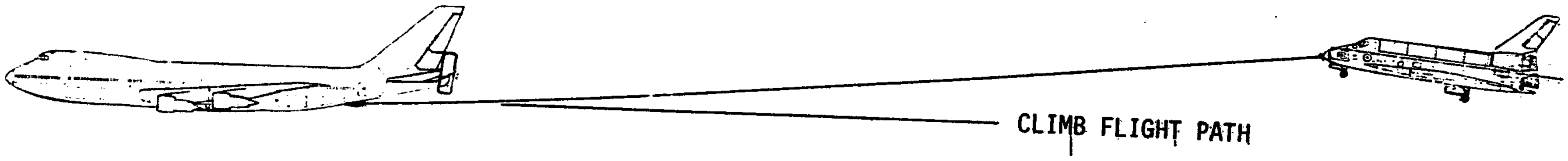

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FIGURE 3 - TOW CONFIGURATION (CLIMB), ALT MISSION

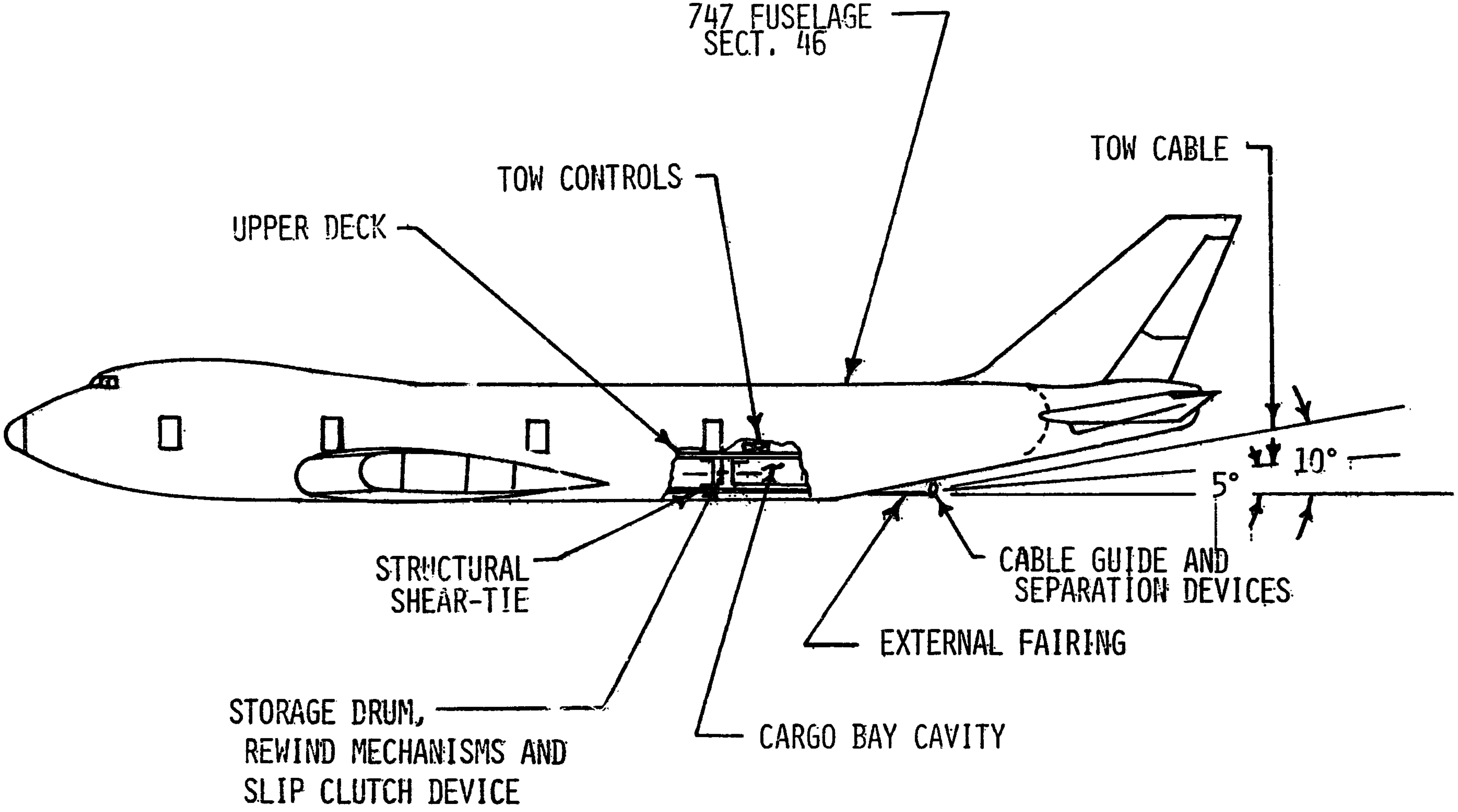


FIGURE 4 - TOW SYSTEM ATTACHMENT CONCEPT

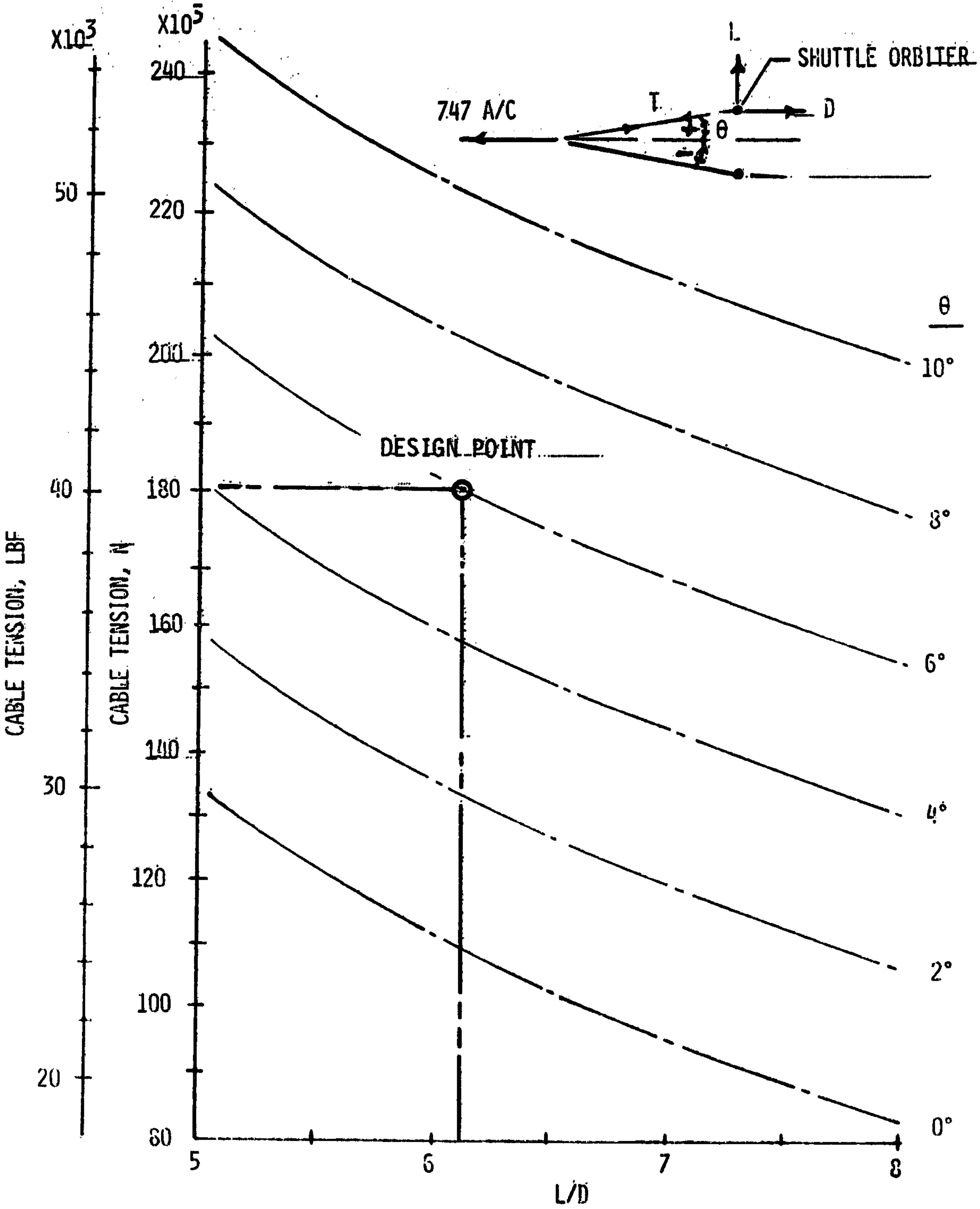


FIGURE 5 - CABLE TENSION, AS A FUNCTION OF ORBITER L/D AND TOW CABLE ANGLE

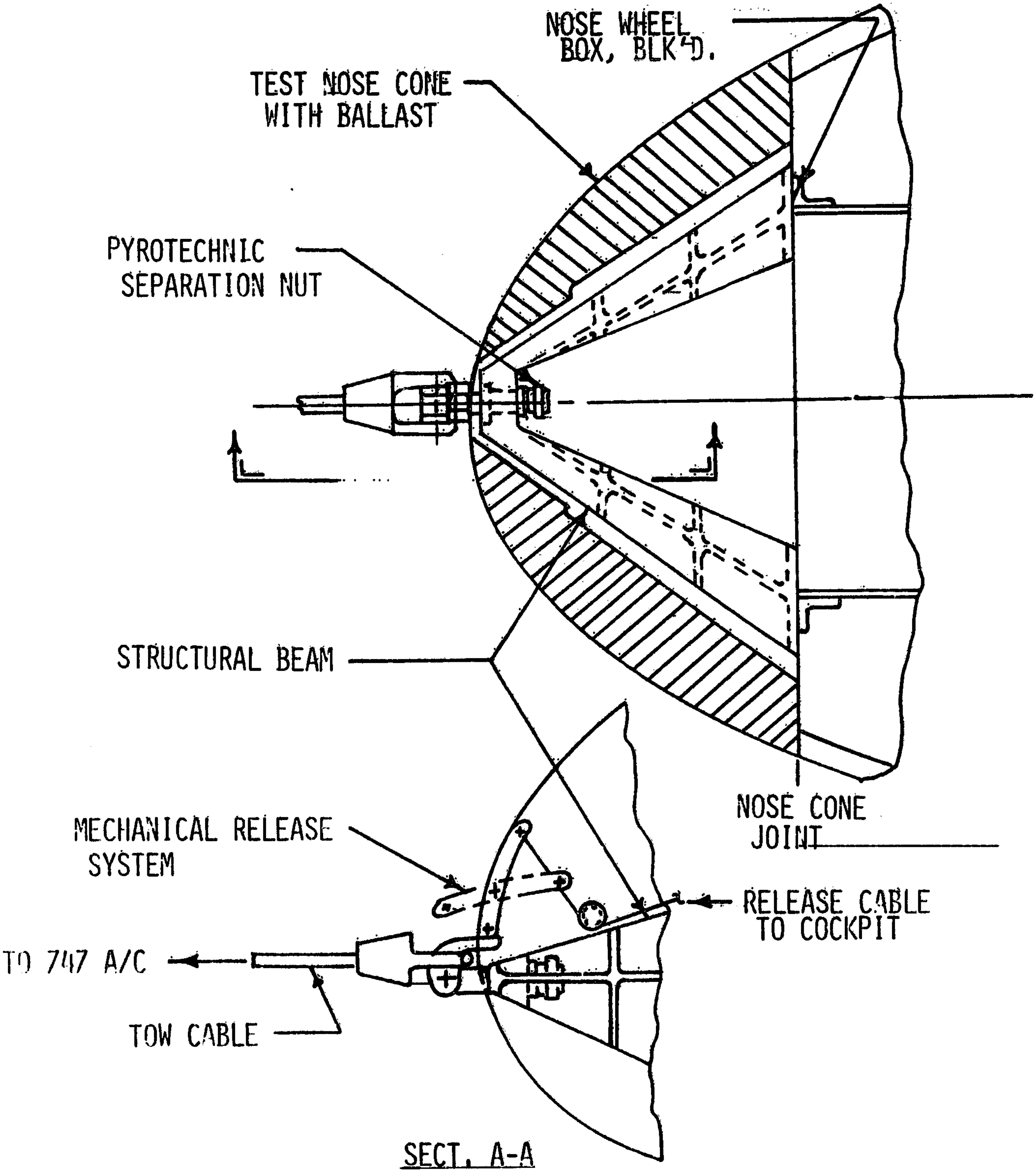


FIGURE 6 - SHUTTLE ORBITER FORWARD ATTACHMENT CONCEPT

NUMBER	SHUTTLE ORBITER LOCATION (XOSTATION)	DESCRIPTION STRUCTURAL REINFORCEMENT
1	235 - 262.5	TEST NOSE CONE (WITH SEPARATION DEVICES & BALLAST)
2	237 - 262.5	FITTING - LOAD TRANSFER TO NOSE WHEEL BOX
3	262.5 - 378	LOCAL FRAME STIFFENING
4	262.5 - 378	SHEAR SHELF CAP TO EXISTING FRAME
5	378	BULKHEAD ATTACHMENT AND LOCAL STIFFENING

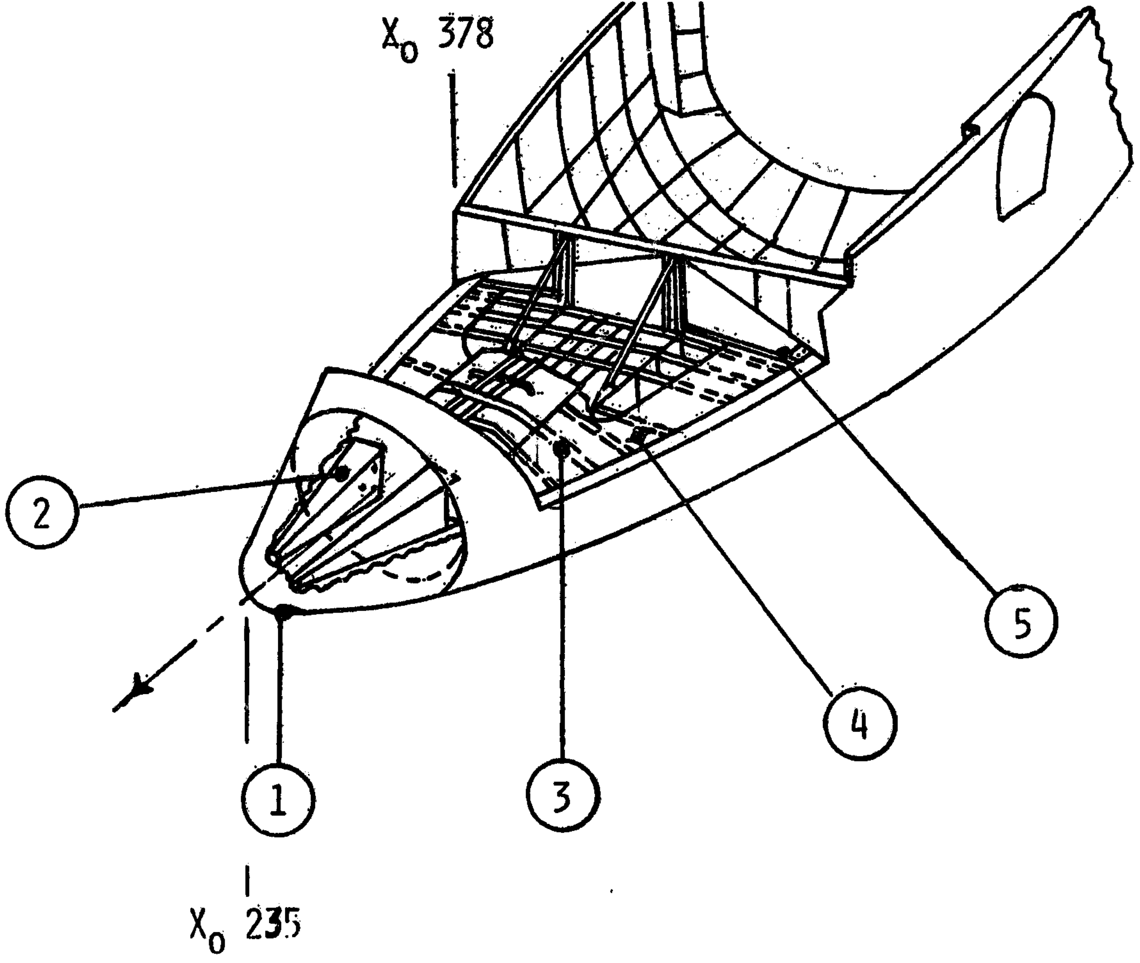


FIGURE 7 - STRUCTURAL REINFORCEMENT FOR ATTACHMENT LOADS

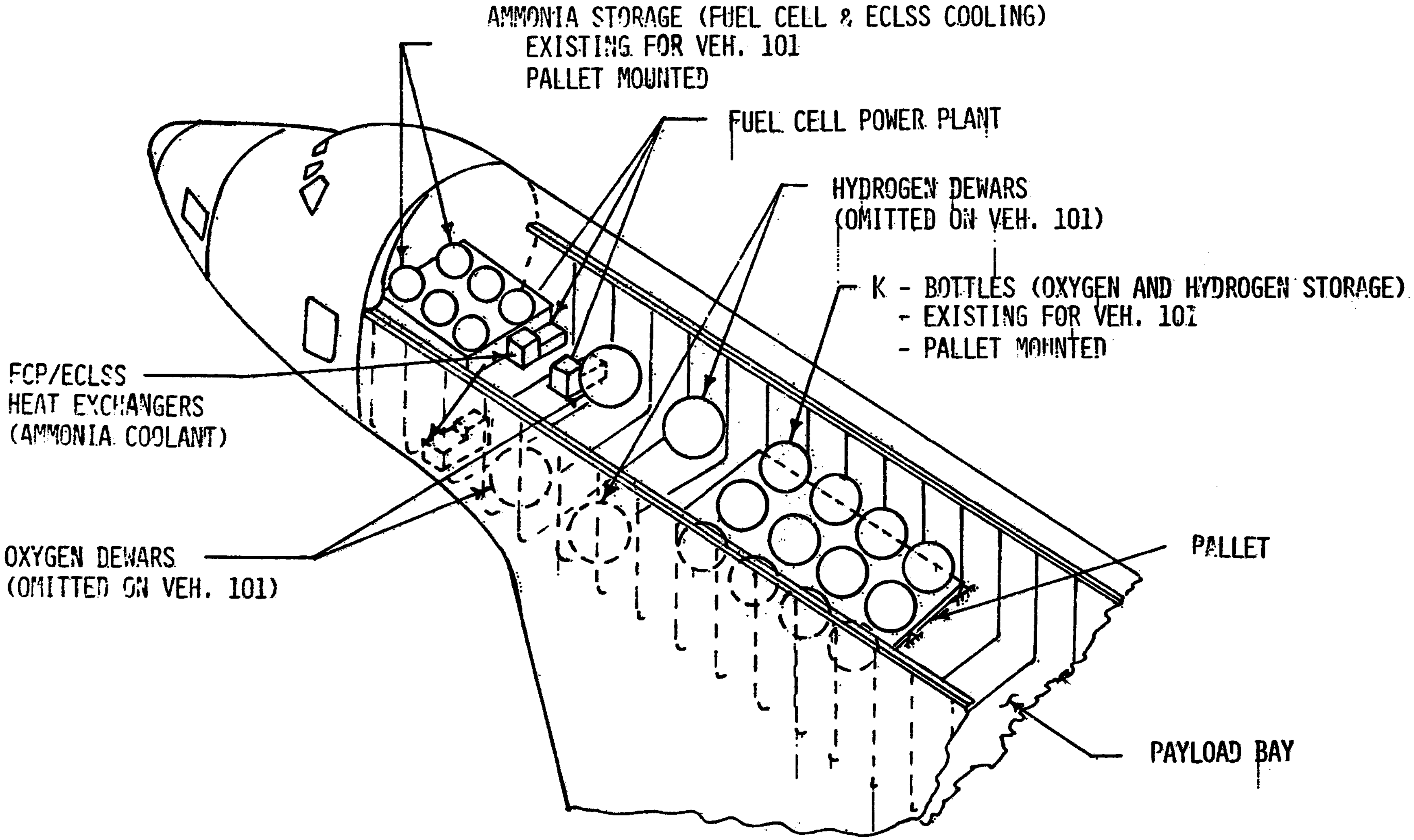


FIGURE 8 - ORBITER ELECTRICAL POWER SUBSYSTEM AND COOLING

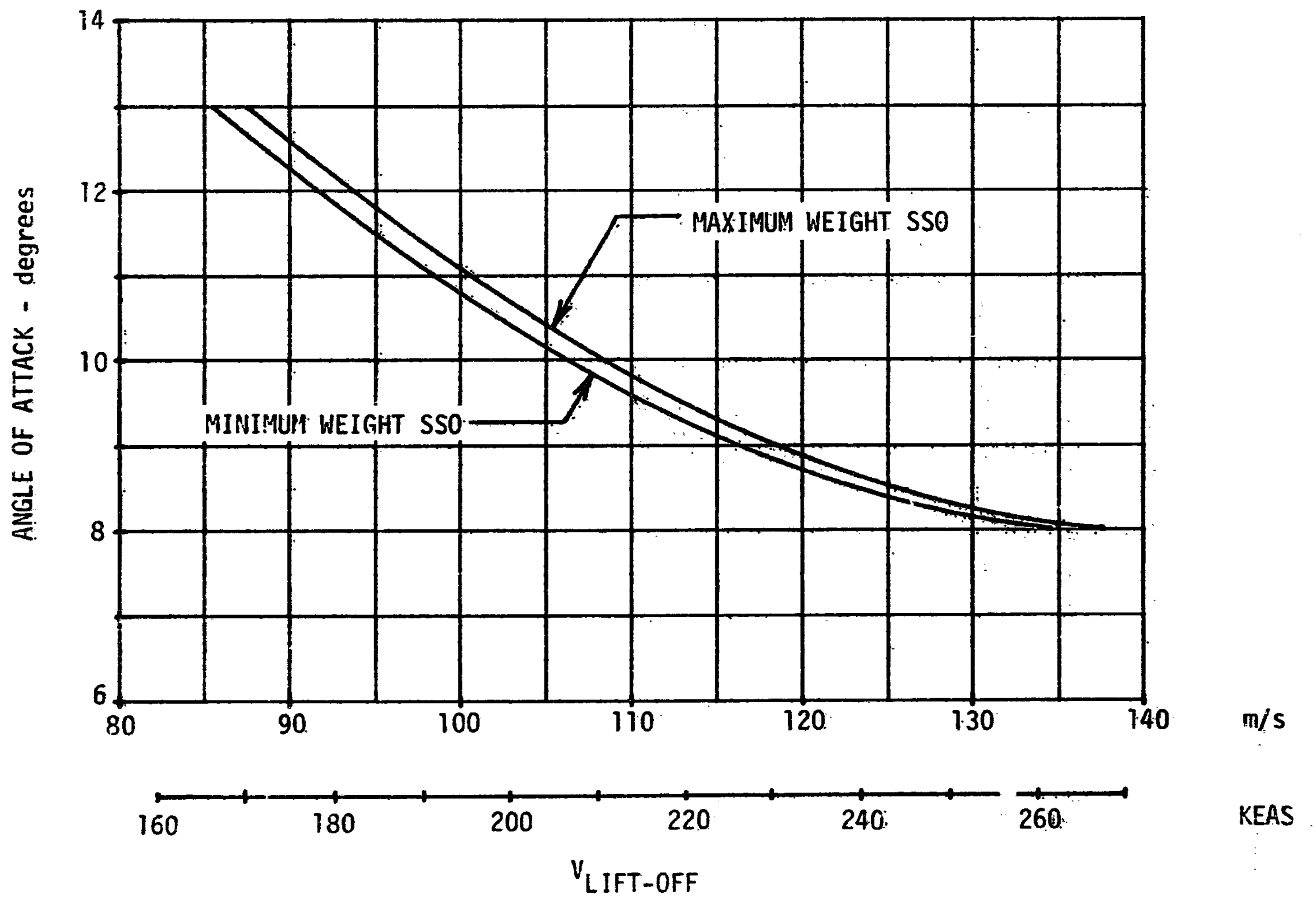


FIGURE 9 - ORBITER LIFT-OFF VELOCITY VS. ANGLE OF ATTACK

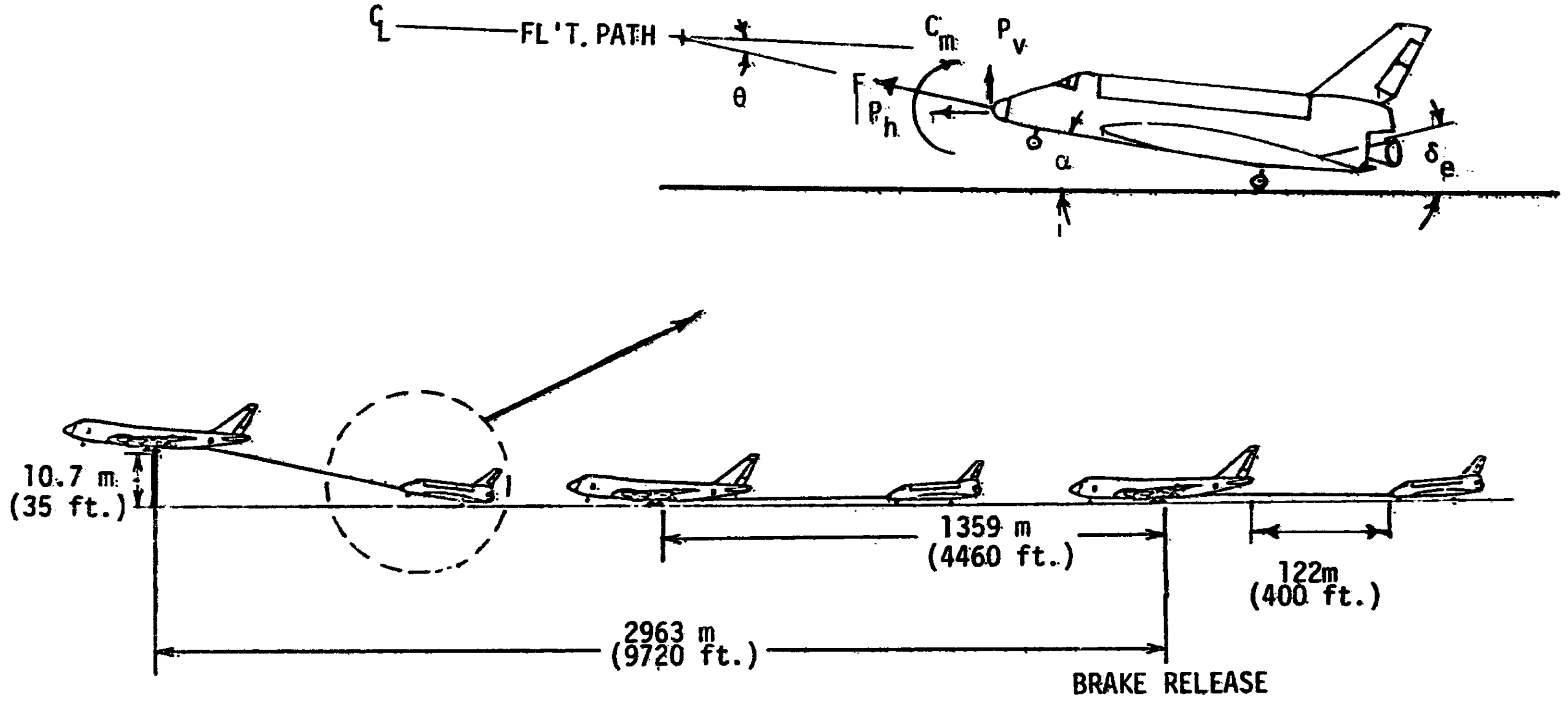


FIGURE 10 - SSO/747 TAKE-OFF-ROTATION MODE

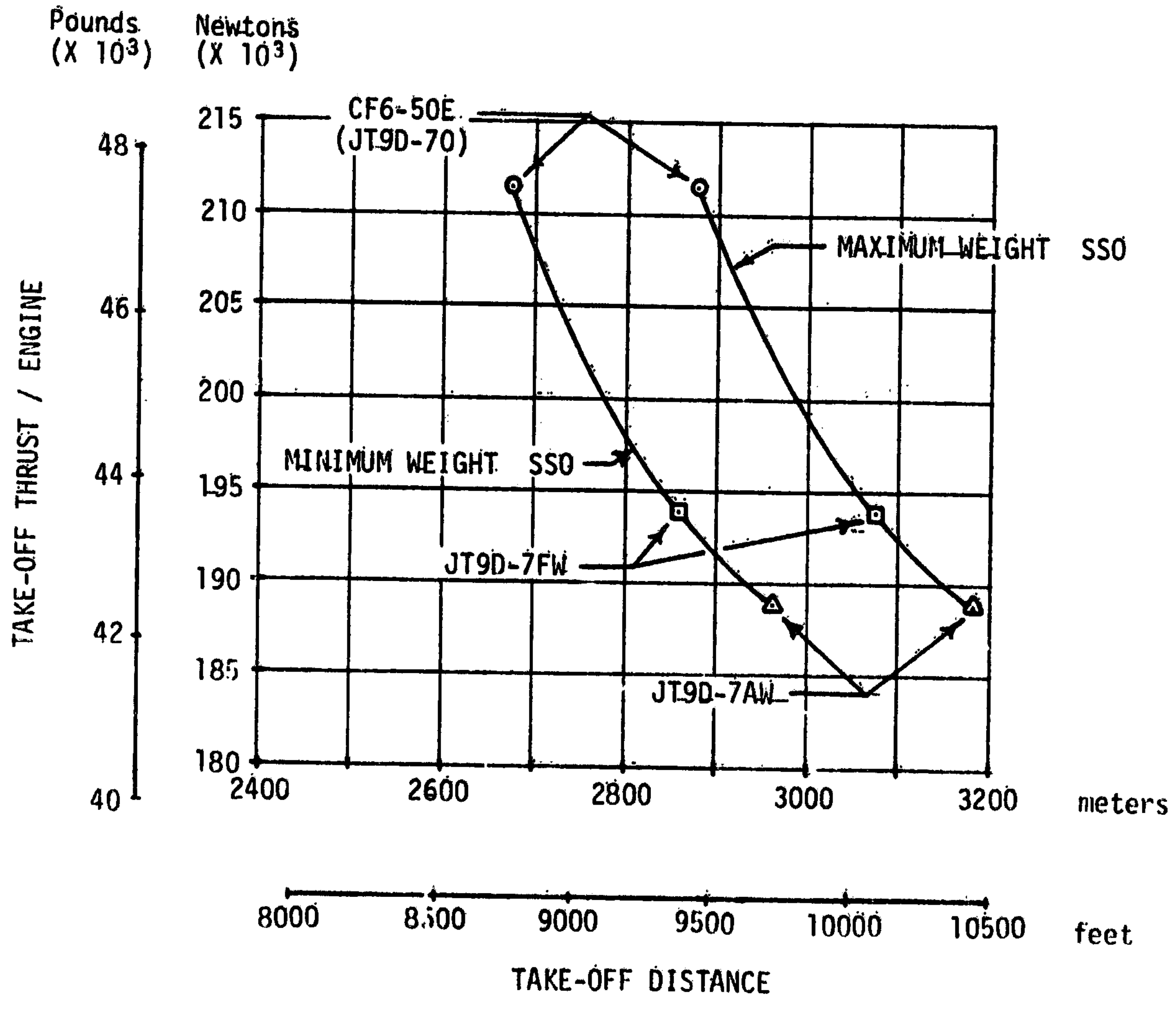
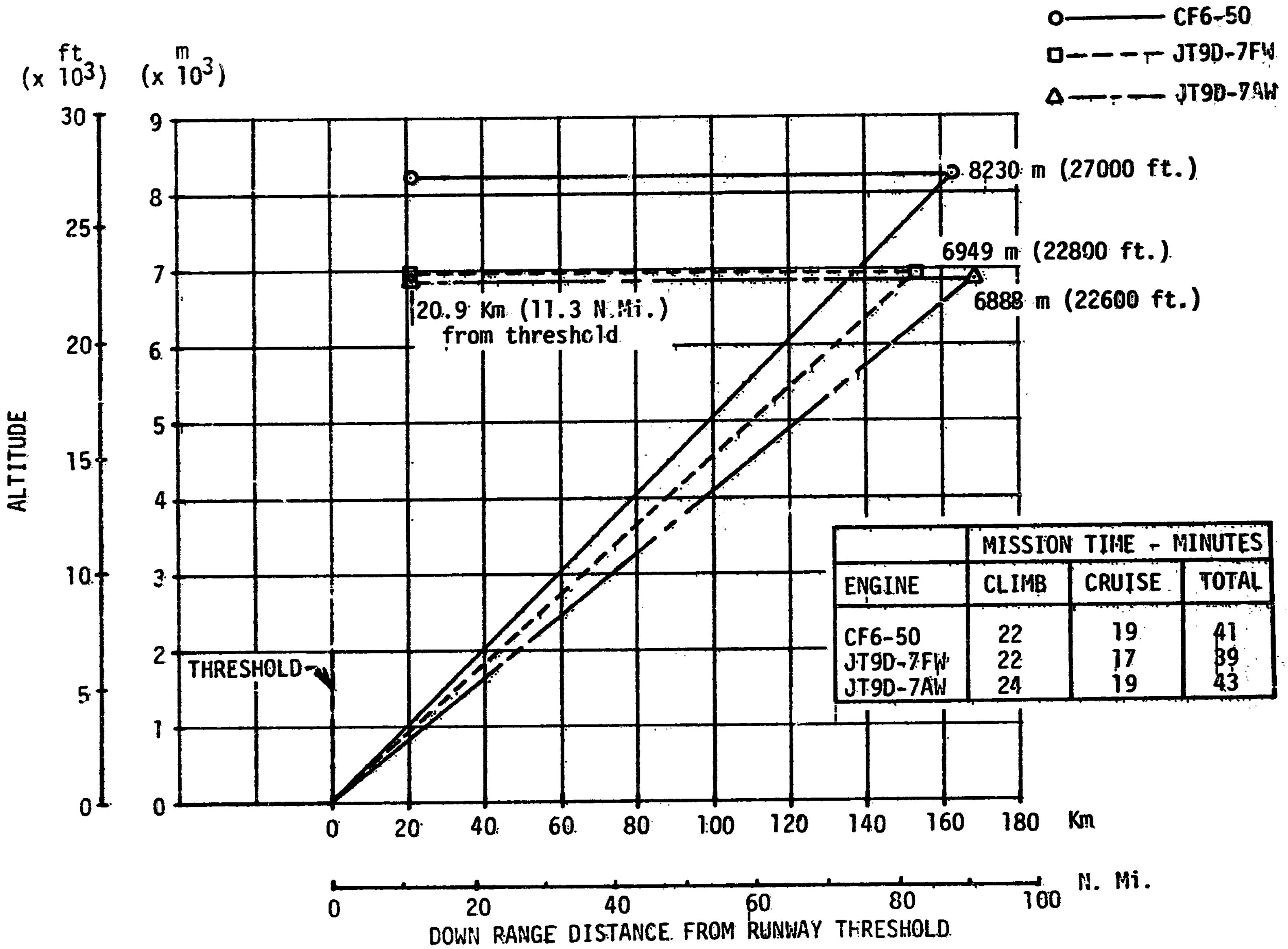


FIGURE 11 - SSO/747 THRUST VS. TAKE-OFF DISTANCE



	MISSION TIME - MINUTES		
ENGINE	CLIMB	CRUISE	TOTAL
CF6-50	22	19	41
JT9D-7FW	22	17	39
JT9D-7AW	24	19	43

FIGURE 12 - SSO/747 TOW MISSION PROFILE TO SEPARATION

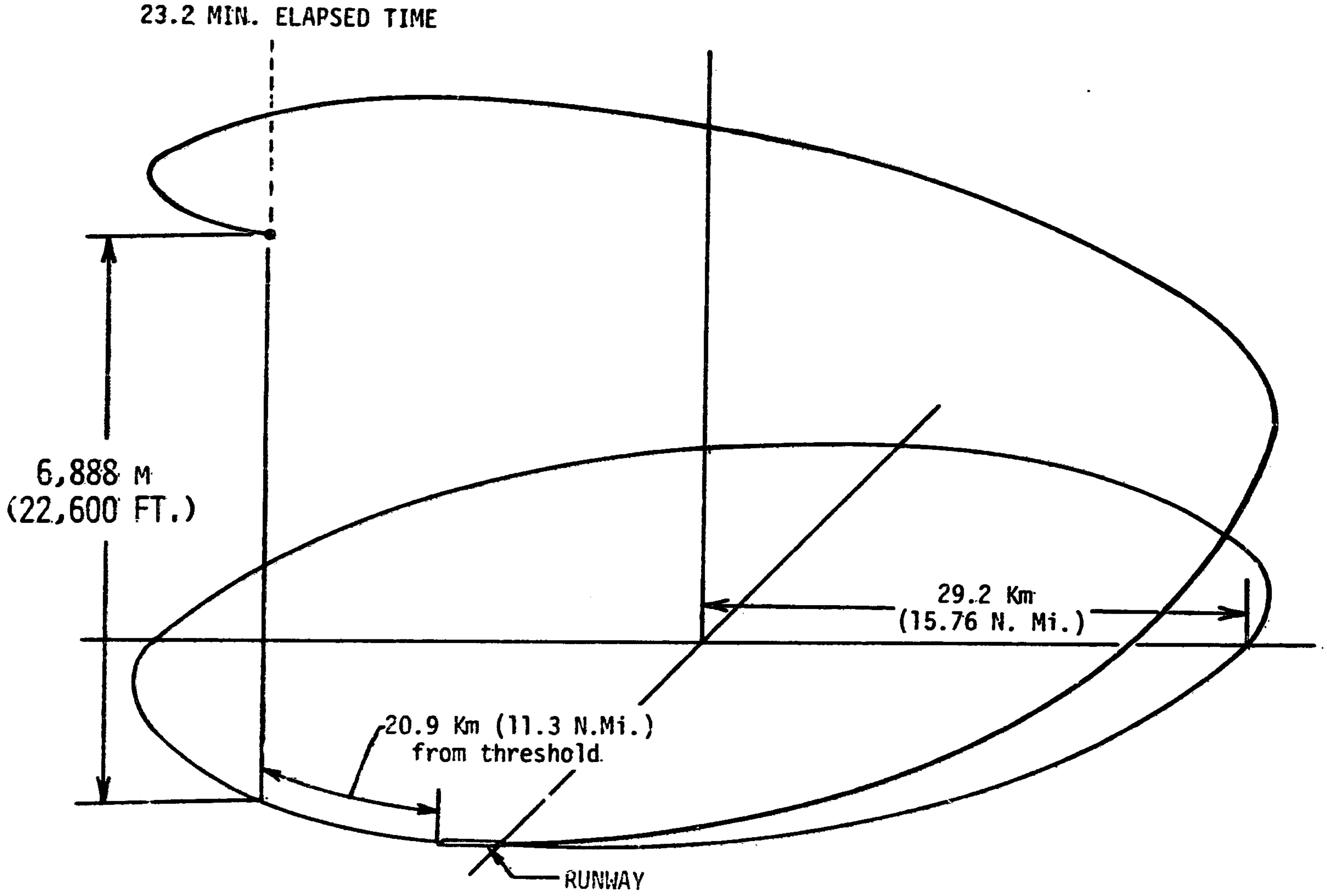
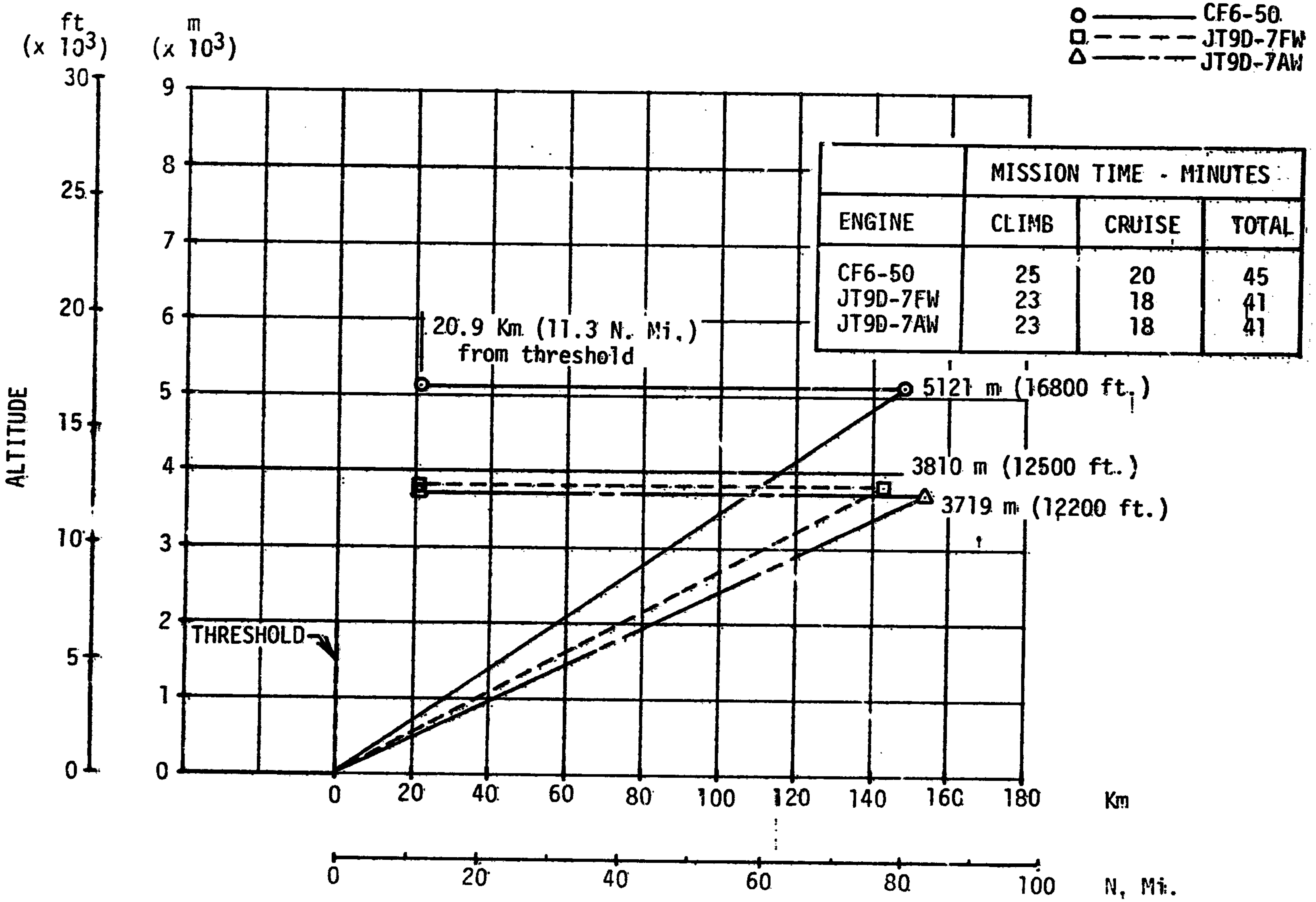


FIGURE 13 - ALTERNATE CLIMB ROUTINE



	MISSION TIME - MINUTES		
ENGINE	CLIMB	CRUISE	TOTAL
CF6-50	25	20	45
JT9D-7FW	23	18	41
JT9D-7AW	23	18	41

FIGURE 14 - SSO/747 TOW ENGINE-OUT MISSION PROFILE TO SEPARATION

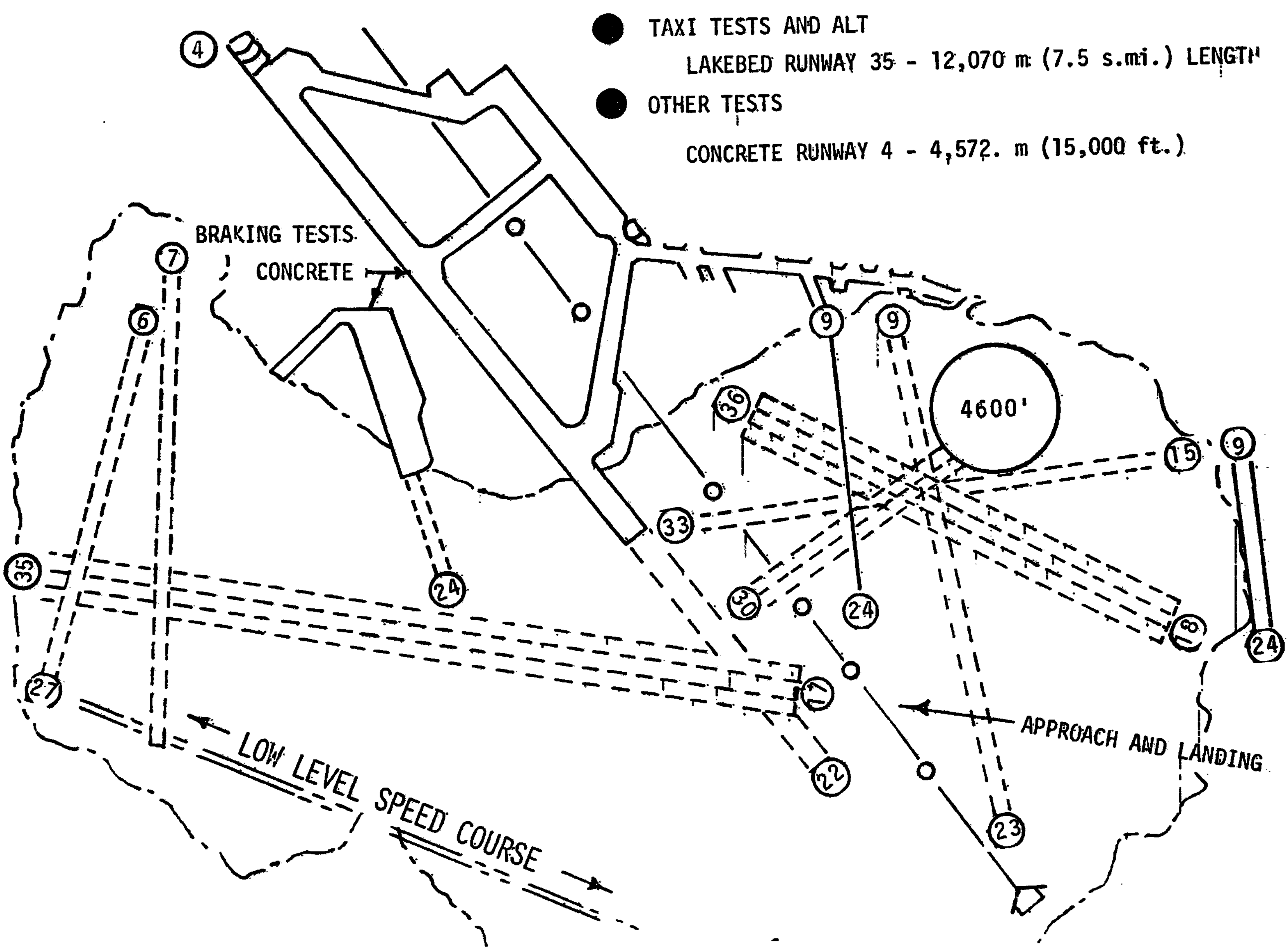


FIGURE 15 - PREFLIGHT GROUND OPERATIONS EDWARDS AFB COMPLEX

TABLE I

SPACE SHUTTLE ORBITER VEHICLE 101
APPROACH AND LANDING TEST

SUMMARY WEIGHT STATEMENT

CODE	SYSTEM	WEIGHT Si kg.	WEIGHT (English) LBM
1.0	Wing Group	8,076.6	(17,806.0)
2.0	Tail Group	1,540.4	(3,396.0)
3.0	Body Group	24,429.0	(53,853.0)
4.0	Induced Environmental Protect.	573.3	(1,264.0)
5.0	Landing and Auxiliary Systems	2,869.9	(6,327.0)
6.0	Propulsion-Ascent	14.5	(32.0)
9.0	Prime Power	1,889.2	(4,165.0)
10.0	Electrical Conversion and Distr.	3,131.6	(6,904.0)
11.0	Hydraulic Conversion and Distr.	821.9	(1,812.0)
12.0	Surface Controls	1,218.8	(2,687.0)
13.0	Avionics	1,681.4	(3,707.0)
14.0	Environmental Control	2,090.1	(4,608.0)
15.0	Personnel Provision	568.8	(1,254.0)
17.0	Flight Test Provisions	8,349.7	(18,408.0)
18.0	Payload Provisions	5.4	(12.0)
	Inert Weight	57,260.7	(126,239.0)
20.0	Personnel	627.3	(1,383.0)
23.0	Residual and Unusable Fluids	681.3	(1,502.0)
24.0	Ballast	6,811.1	(15,016.0)*
25.0	Reserve Fluids	49.9	(110.0)
26.0	Inflight Losses	368.3	(812.0)
30.0	Tail Cone Equipment	—	None *
	Prelaunch Weight	68,406.8	(150,812.0)

* Add extra ballast instead of tail cone to maintain desired prelaunch weight.

TABLE - II
747-100 WEIGHT TABULATION
STUDY AIRCRAFT/STRIPPED VERSION
WITH VARIOUS ENGINES

ITEM	ENGINE NOMENCLATURE					
	4/JT9D - 7A(W)		4/JT9D - 7F(W)		4/CF6 - 50E	
	SI Units	English	SI Units	English	SI Units	English
	Kg	Lbm	Kg	Lbm	Kg	Lbm
Structure	100856	222350	100856	222350	100856	222350
Propulsion	20706	45650	20797	45850	19981	44050
Systems & Equipment	11385	25100	11385	25100	11385	25100
Empty Weight	132948	293100	133039	293300	132222	291500
Operating Items	1134	2500	1134	2500	1134	2500
Operating Weight Empty	134082	295600	134173	295800	133356	294000
Water (H_2O)	2268	5000	2268	5000	N/R	N/R
Fuel (JP-4)	14696	32400	14606	32200	15422	34000
TOGW	151046	333000*	151046	333000*	148778	328000

* Includes Water

TABLE III

BOEING 747 ENGINE THRUST RATINGS
UNINSTALLED THRUST, IDEAL NOZZLES

	JT9D-7A(W)	JT9D-7E(W)	JT9D-70A	CF6-50E
Take-off, Dry (Sea level, static)	208,833.N (46,950 lbf)	213,514.N (48,000 lbf)	235,755.N (53,000 lbf)	233,530.N (52,500 lbf)
Take-off, Wet (Sea level, static)	216,049.N (48,570 lbf)	222,410.N (50,000 lbf)	---	---
Maximum Climb (35,000 Ft. M = .85)	49,330.N (11,090 lbf)	52,489.N (11,800 lbf)	57,382.N (12,900 lbf)	55,914.N (12,570 lbf)
Maximum Cruise (35,000 Ft. M = .85)	47,462.N (10,670 lbf)	49,153.N (11,050 lbf)		
Initial Airplane Delivery	Current	Current	April '76	Current

TABLE IV

SSO/747 PERFORMANCE CHARACTERISTICS - PARAMETIZED WITH 747 PRODUCTION ENGINES AND ORBITER WEIGHTS

SPACE SHUTTLE ORBITER (VEH 101) PRELAUNCH WEIGHT	747 ENGINE		CLIMB*					CRUISE			MACH. NO.
	TYPE	NUMBER	ALTITUDE		RANGE		TIME MIN.	RANGE		TIME MIN.	
			S.I. UNITS	(ENGLISH)	S.I. UNITS	(ENGLISH)		S.I. UNITS	(ENGLSIH)		
S.I. UNITS (ENGLISH)	JT9D-7AW	4	6888 m.	22600 ft.	168 Km.	91 N. Mi.	24	148 Km.	80 N. Mi.	19	.425
		3	3719 m.	12200 ft.	154 Km.	83 N. Mi.	25	133 Km.	72 N. Mi.	20	.340
68,406 Kg. (150,812 Lbm)	JT9D-FW	4	6949 m.	22800 ft.	154 Km.	83 N. Mi.	22	133 Km.	72 N. Mi.	17	.425
		3	3810 m.	12500 ft.	143 Km.	77 N. Mi.	23	122 Km.	66 N. Mi.	18	.345
	CF6-50E (JT9D-70)	4	8230 m.	27000 ft.	163 Km.	88 N. Mi.	22	143 Km.	77 N. Mi.	19	.435
		3	5121 m.	16800 ft.	148 Km.	80 N. Mi.	23	128 Km.	69 N. Mi.	18	.375
S.I UNITS (ENGLISH)	JT9D-7AW	4	6645 m.	21800 ft.	170 Km.	92 N. Mi.	24	150 Km.	81 N. Mi.	19	.425
		3	3353 m.	11000 ft.	146 Km.	79 N. Mi.	24	126 Km.	68 N. Mi.	19	.335
71,646 Kg. (157,954 Lbm)	JT9D-7FW	4	6858 m.	22500 ft.	170 Km.	92 N. Mi.	24	150 Km.	81 N. Mi.	19	.425
		3	3566 m.	11700 ft.	144 Km.	78 N. Mi.	23	124 Km.	67 N. Mi.	19	.340
	CF6-50E (JT9D-70)	4	7925 m.	26000 ft.	161 Km.	87 N. Mi.	22	141 Km.	76 N. Mi.	17	.435
		3	4877 m.	16000 ft.	148 Km.	80 N. Mi.	23	128 Km.	69 N. Mi.	18	.370

*CLIMB CEILING - Defined as the altitude at which the rate of climb was reduced to 61 m/min (200 ft/min)