INTACT ABORT TECHNOLOGY REQUIREMENTS

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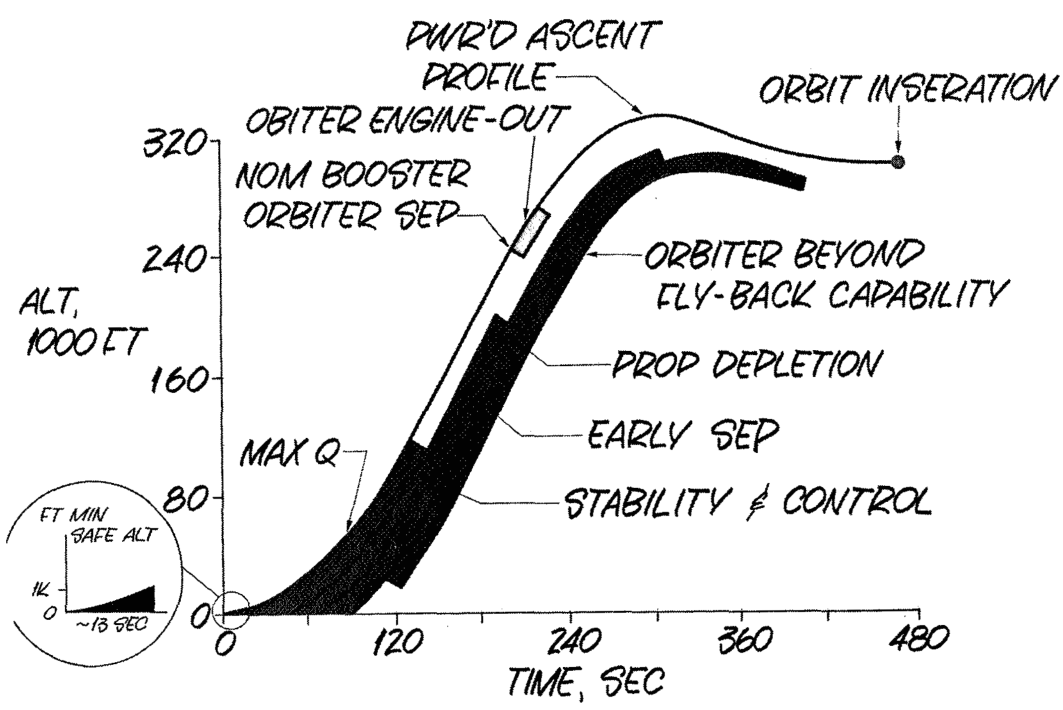
This material is based on studies of two-stage, fully recoverable, earth orbital shuttle systems. The studies indicate that the requirements for safe, intact abort capability in both the booster and the orbiter could have significant effects on the design of these vehicles. The purposes of this paper are to briefly identify these potential effects, to present some preliminary study results, and to recommend areas to be emphasized in future studies. The major study areas that have been considered thus far include:

- Minimum safe abort altitude
- Propellant depletion
- Orbiter ability to fly back
- Orbiter ability to abort-to-orbit

MAJOR ABORT STUDY AREAS



A complete study of abort effects on design should include the indicated potential requirements by mission phase. Means should be provided for rapid crew and passenger evacuation from cabin closeout to liftoff, and may require elevators, chutes, or slide wires. Because the orbiter engines will not be ignited at liftoff, there will be an unsafe separation period following liftoff that will depend upon the time to start those engines and separate. Based on a startup time of about 5 seconds, this period is estimated to be about 13 seconds following liftoff.

The requirements to be able to continue the mission (in addition to abort) with a single booster engine out must be weighed, although this does not appear to be a significant requirement for new boosters, which have a large number (9 to 11) of engines with emergency overthrust capability. It must be possible to adequately gimbal the orbiter engines for attitude control with the skirts retracted. The definition of attitude control requirements during separation in the atmosphere will require six-degree-of-freedom simulations that use the results of wind tunnel tests of mated and separated models. Following early separation, guidance steering techniques must be developed which provide transitions to various flight regimes within angular and angular rate limits. As discussed later, methods for providing propellant dump capability will probably be required, particularly in the orbiter.

ABORT STUDY REQUIREMENTS

PRELAUNCH

- RAPID CREW EVAC IN EVENT OF HAZARDOUS CONDITIONS

LIFTOFF THROUGH MINIMUM SAFE ALTITUDE

- ORBITER ENGINE STARTUP & SEPARATION

FROM UNSAFE SEP REGIMES TO NOMINAL SEP

- ABILITY TO CONTINUE MISSION WITH ONE BOOSTER ENGINE OUT
- BOOSTER/ORBITER SEPARATION SEQUENCE
- ATTITUDE CONTROL DURING SEPARATION SEQUENCE
- STARTUP OF ORBITER ENGINES IN ATMOSPHERE
- GUIDANCE STEERING TECHNIQUES FOLLOWING SEPARATION

Following early separation, it must also be possible to safely return the booster and the orbiter within temperature and limits. Return to the launch site would obviously be most desirable, and this should be possible with boosters which nominally do so. It may also be possible with orbiters which have air-breathing engines, as discussed later. The availability and desirability of ground assistance in the form of backup navigation (i.e., state vector updates, targeting, weather information) and other ground aids must be considered.

Orbiter aborts near nominal separation should probably be to a minimum safe orbit (50 x 100 n miles), if possible. Time-critical returns by means other than abort-to-orbit probably will not result in returns substantially earlier, and could require landing at long downrange distances. A redundant propulsive capability should be required to deorbit.

ABORT STUDY REQUIREMENTS (CONT)

FROM UNSAFE SEP REGIMES TO NOMINAL SEP (CONT)

- METHODS FOR PROVIDING PROPELLANT DUMP CAPABILITY
- ORBITER & BOOSTER RETURN WITHIN TEMPERATURE & "G" LIMITS
- AVAILABILITY & DESIRABILITY OF GRD ASSISTANCE

NOMINAL SEPARATION TO INSERTION

- ORBITER PROPULSION TO ACHIEVE SAFE INSERTION WITH ONE ENGINE OUT

ORBITAL INSERTION THROUGH DE-ORBIT

- REDUNDANT SYSTEM TO DE-ORBIT

Abort studies at Grumman have emphasized techniques for the orbiter to abort intact from any launch azimuth. These were "exploratory" studies done to a depth necessary to identify potential first-order design and operational effects. The five different techniques listed were each examined for applicability for aborts up to nominal separation. The cause for the abort was not considered. Further, it was assumed that a safe early separation was possible and that the orbiter has its full propulsion capability.

ORBITER ABORT TECHNIQUES BEING STUDIED

- USE MAIN PROPULSION TO NORMAL INJECTION (ABORT TO ORBIT), RETURN TO U.S. NEXT PASS
- USE MAIN PROPULSION TO CLIMB, TURN & RETURN TO LAUNCH SITE
- USE MAIN PROPULSION TO INCREASE VELOCITY TO EQUILIBRIUM GLIDE CONDITION, LAND DOWNRANGE
- WITHOUT PROPULSION, DUMP OXYGEN, CRUISE TO LANDING SITE WITH H_2
- PARTIAL USE OF MAIN PROPULSION FOR TRANSITION TO EQUILIBRIUM GLIDE, DUMP OXYGEN, AERODYNAMIC TURN & CRUISE TO LAUNCH SITE WITH H_2

For each orbiter abort technique studied, performance was determined by trajectory analyses within assumed constraints as shown. The maximum thermal protection system (TPS) underbody temperature of 1800-2000°F is typical for low cross-range orbiters. The total stagnation heat load is of interest to leading edges where ablators may be used. The maximum dynamic pressure, q, and $q\alpha$ are of interest in the development of loads. The total normal aero force (vehicle weight times normal g's) can be the critical design condition for wings and fins.

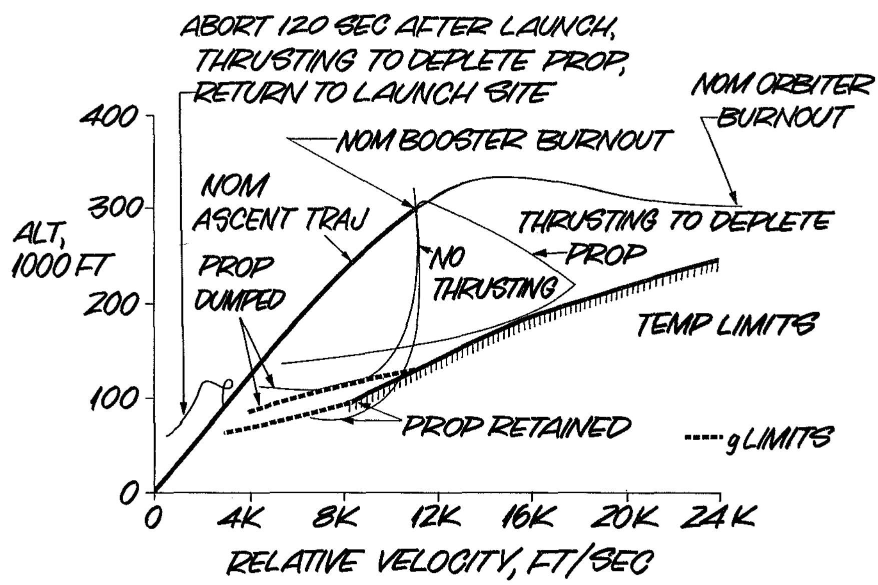
CONSTRAINTS REQUIRED FOR ABORT TRAJECTORY STUDIES

CONSTRAINT	TYPICAL VALUE
• MAX TPS UNDERBODY TEMP	1800°-2000°F
• TOTAL STAGNATION HEAT LOAD	40,000 BTU/FT^2
• MAX DYNAMIC PRESSURE, q	500-800 LB/FT^2
• MAX $q\alpha$ (LESS THAN M=6)	4000 LB-DEG/FT^2
• TOTAL NORMAL AREO FORCE	900,000 LB

Four of the five potential orbiter abort techniques studied are illustrated here. The top line illustrates the altitude vs velocity history of an abort-to-orbit from the nominal separation point. The use of main propulsion to climb, turn, and return to the launch site appears feasible for aborts up to about 120 seconds after launch. Aborts later than this will place the orbiter too far downrange to return by this technique. Use of main propulsion to increase velocity to an equilibrium glide condition (labelled "thrusting to deplete propellant") is shown for an abort near nominal separation. Although large downrange distances are possible, land landings are not possible for all launch azimuths from KSC.

Two aborts are shown from nominal separation, assuming no orbiter thrust. One illustrates that if propellant is not dumped, temperature and g limits will be exceeded on entry. The other indicates that even if propellant dump is provided, the ability to enter from this condition without thrusting to increase velocity may only be marginally acceptable. Thus, it is concluded that if abort capability with no orbiter thrust (no ability to burn off propellant) is required, propellant dump will be required. Dump rates will have to be near the normal rate of propellant consumption, around 100,000 lb/min. Preliminary studies indicate that these rates may be achieved by normal tank pressurization with large vents. An area to be studied is the best means of providing this pressurization if the main engines are not functioning.

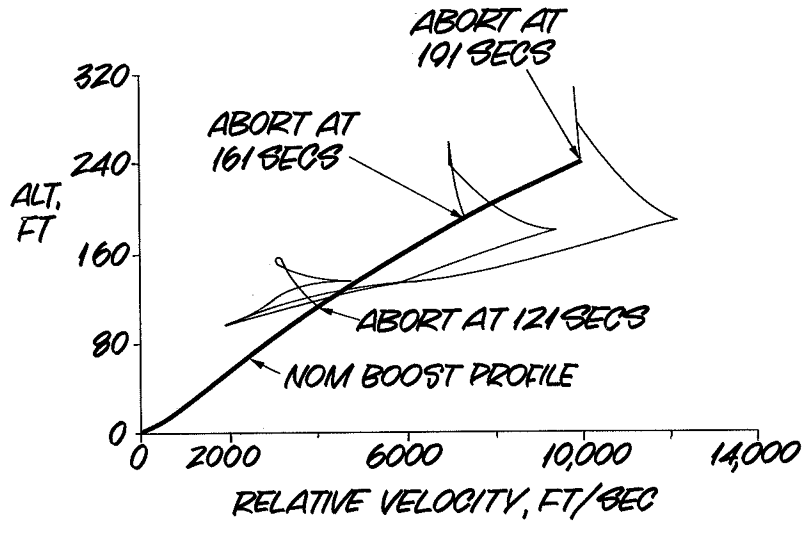
TYPICAL ABORT TECHNIQUES



The most promising technique for returning the orbiter to the launch site from abort late in boost is as follows. The procedure includes a coast period between separation and the onset of atmospheric effects. At the entry interface (sensible g = 0.05) the main engines are ignited to rapidly reduce vehicle weight and to perform a transition to a safe equilibrium glide reentry trajectory. Simultaneously with the burning of the main engines, oxygen is dumped. The H_z not used during the main-engine burn is used as fly-home propellant.

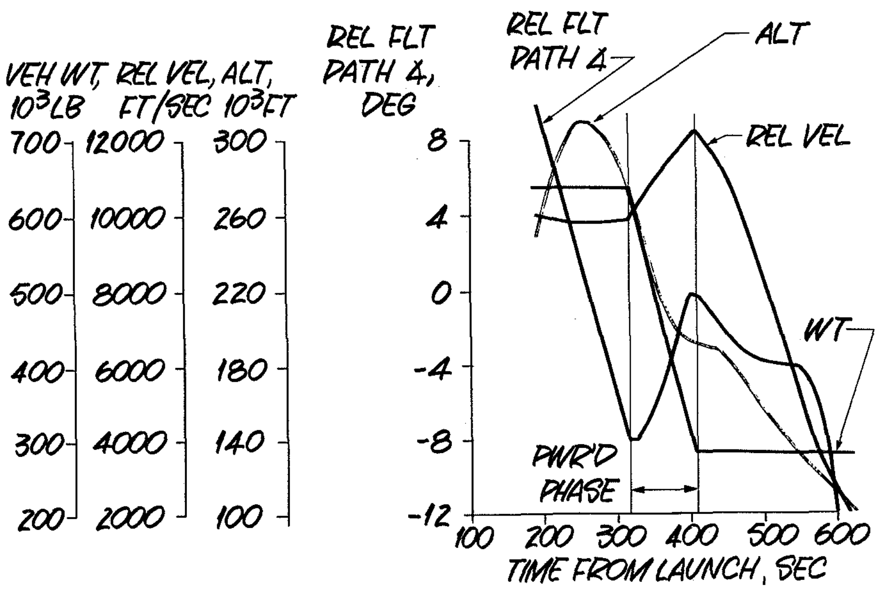
This abort technique permits aborts to be performed within the orbiter constraints while providing orbiter fly-home capability. The technique has been found to work on a typical design up to about 190 sec after liftoff, or nearly to nominal separation.

ORBITER ABORTS TO LAUNCH SITE



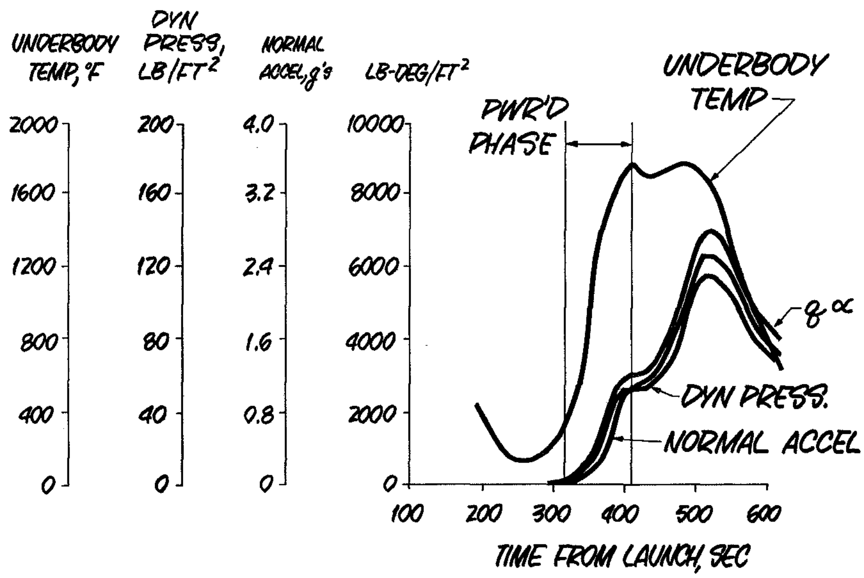
The orbiter abort previously shown at 191 sec is more fully described here. After about 310 sec, the main engines are ignited to increase velocity and reduce flight path angle. The thrust vector was 60 deg from the velocity vector and roll angle was modulated to result in burnout at the desired flight path angle. Following burnout, the angle of attack was maintained at 60 deg and roll angle was again modulated to turn as tight as possible within thermal and load constraints. (In some cases it has been found necessary to also modulate angle of attack to stay within these constraints.)

ORBITER LAUNCH ABORTS AT 191 SEC



The behavior of the orbiter during this abort is shown to be within the established constraints. The maximum underbody temperature was maintained below 1800°F, and the peak g's were less than 2.5. Maximum q is low, and although q α exceeds 4000, it occurs at hypersonic (M greater than 6) velocities.

ORBITER LAUNCH ABORTS AT 191 SEC (CONT)



Another potential effect of aborts is on tank pressure requirements. Startup of the orbiter engines requires greater engine inlet pressures when at low altitudes than when they are normally started, due to the greater back-pressure. The inlet pressure difference between low- and high-altitude starts can be greater than 14.7 psi, because the engine is sensitive to pressure ratio rather than pressure differential.

Providing increased engine inlet pressure at low altitudes can require relatively high oxygen tank ullage pressures if the oxygen tank is located aft in the vehicle, and the hydraulic head is, therefore, low. This is illustrated for a typical orbiter, assuming that the booster is able to provide a thrust-to-weight ratio of at least 1.0 as the orbiter engines are started. If the fuel tank was located ahead of the oxygen tank, the maximum ullage pressure required increased from 38 to 71 psia for a sea level abort. If this increased tank pressure was provided it would result in about a 1500-lb inert weight penalty. Reversing the hydrogen and oxygen tanks eliminated this penalty.

TYPICAL EFFECT OF ORBITER TANK ARRANGEMENT ON ULLAGE PRESSURE REQMTS

TANK ARRANGEMENT	MAX ULLAGE PRESS REQ'D, PSIA			
	FUEL		OXIDIZER	
	NORMAL	SL ABORT	NORMAL	SL ABORT
FUEL FWD OF OXYGEN	36	36	37	71*
OXYGEN FWD OF FUEL	38	39	38	38

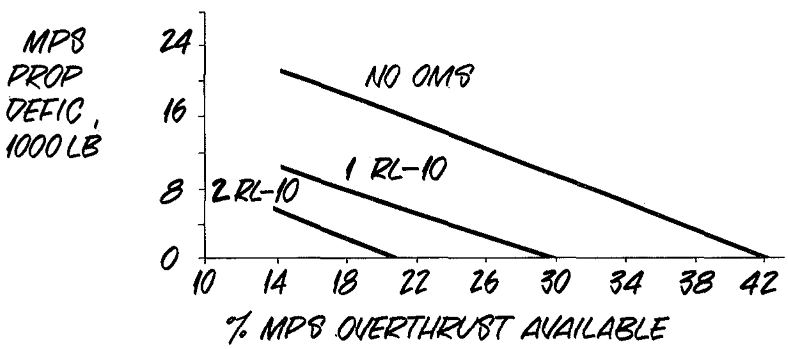
* INCREASED PRESS. FROM 37 TO 71 PSI RESULTS IN APPROX 1500 LB VEHICLE WEIGHT PENALTY

The last example of potential abort effects is concerned with this requirement for the orbiter to abort to orbit with one engine out. The loss of an engine will increase the gravity delta-V losses.

Studies have shown that a typical three-engine orbiter with an initial thrust-to-weight ratio (T/W) of about 1.2 can still abort to a safe orbit with one engine out by using part of the on-orbit propellant. However, a two-engine orbiter with T/W = 1.2 may have more difficulty with one engine out. The example shows how one typical two-engine orbiter cannot achieve orbit with one engine out without increasing the over-thrust capability of the engine and/or adding orbital maneuvering system (OMS) engines.

TYPICAL ABORT TO ORBIT REQMTS

- TWO 400K ENGINES (ONE ENG OUT)
- OLOW = 637,250 LB
- PROPELLANT QTY = 391,400 LB



The studies previously described, although quite preliminary, have indicated the potential nature of the effects that abort requirements may have on the design and operation of the shuttle.

PRELIMINARY RESULTS

- IF COMPLETE LOSS OF ORBITER THRUST IS A DESIGN CONDITION, PROP DUMP CAPABILITY IS REQD
- IF PROP DUMP CAPABILITY EXISTS IN THE ORBITER, SUBORBITAL ABORTS WHICH RETURN TO THE LAUNCH SITE MAY BE POSSIBLE ANYTIME FROM THE UNSAFE SEP REGION TO NORMAL SEP
- AFTER SEP, THE PRIMARY MODE OF ABORT SHOULD BE TO ORBIT
- THE AREAS POTENTIALLY AFFECTING VEHICLE DESIGN THAT SHOULD BE EMPHASIZED ARE:
  - SEPARATION IN THE ATMOSPHERE
  - STARTUP OF ORBITER ENGINES IN ATMOSPHERE
  - METHODS OF PROPELLANT DEPLETION

Acknowledgement

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