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# LAUNCH ABORT PHILOSOPHY FOR MANNED SPACE FLIGHTS

By Charles T. Hyle,
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MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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# PROJECT APOLLO

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# LAUNCH ABORT PHILOSOPHY FOR MANNED SPACE FLIGHTS[a]

By Charles T. Hyle,
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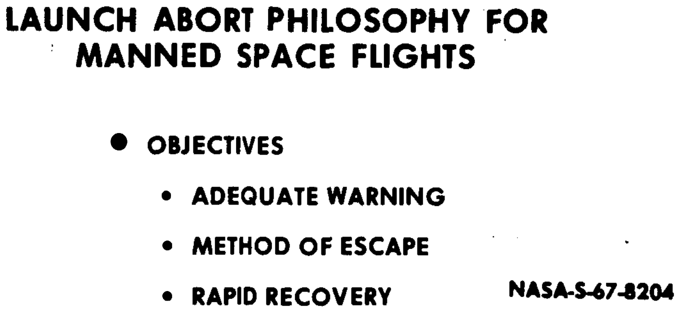
## INTRODUCTION

Since the launch phase is potentially the most dangerous part of any manned space flight, much premission effort is expended in insuring that an adequate crew warning technique and escape capability exist from the launch vehicle. A sound launch abort philosophy is thus obtained by defining, for any contingency, the crew warning technique, the method of escape from the launch vehicle, and the crew landing location for rapid recovery, as outlined in figure 1.



**LAUNCH ABORT PHILOSOPHY FOR MANNED SPACE FLIGHTS**

- **OBJECTIVES**
  - **ADEQUATE WARNING**
  - **METHOD OF ESCAPE**
  - **RAPID RECOVERY**

**NASA-S-67-8204**

Figure 1.- Launch abort philosophy for manned space flights.

## ABORT PHILOSOPHY PROCESS

Since Project Mercury, the increased capabilities of both the launch vehicles and spacecraft have brough significant changes in some of the abort methods used; however, the attainment of a sound abort philosophy or plan has remained basically the same and can be depicted as in figure 2.

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[a] Presented at the Astrodynamics Conference held December 12, 13 and 14, 1967, at the Manned Spacecraft Center, Houston, Texas.

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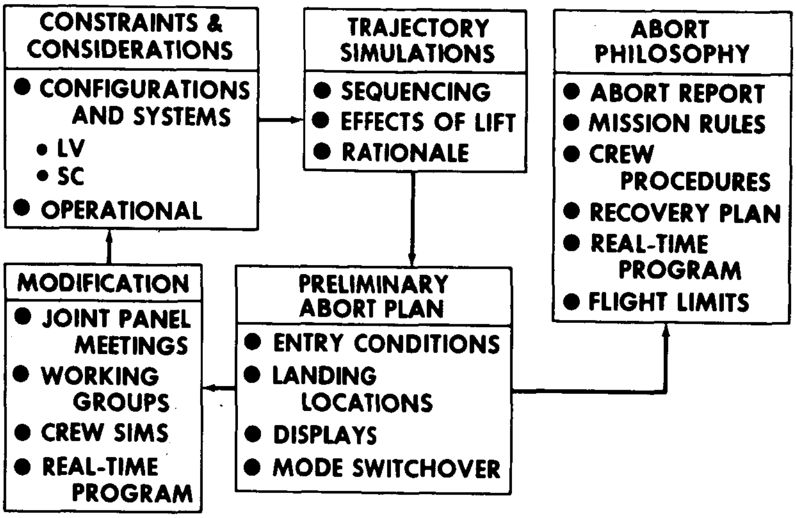


Figure 2.- Launch abort philosophy process.

In general, the process may be described as follows: The designed hardware of the spacecraft and launch vehicle, and mission constraints or objectives are used as a basis for simulated abort trajectories to investigate entry conditions, time requirements, landing points, etc. Throughout this process the crew, flight control, safety personnel, and other responsible groups review, discuss, and modify the simulation results until all parties are satisfied. The total abort plan for a particular mission eventually consists of several detailed documents, each concerned with a particular responsibility but all founded on the same assumptions. Among the documents which most closely reflect the total abort philosophy are the "Mission Rules", the "Abort and Alternate Mission Report", the "Crew Procedures Manual", and the "Flight Limits Document".

## THE ROLE OF TRAJECTORY ANALYSIS

Because of the important influence of trajectory simulation in the abort philosophy process, the remainder of this paper will briefly compare the trajectory analysis done for the Mercury, Gemini, and Apollo programs. The principal systems to be simulated are those of the Mercury, Gemini, and Apollo spacecraft and the associated propulsion capabilities, as shown in figure 3. Major differences between the spacecraft that affected the analysis were (1) the Mercury and Apollo spacecraft were equipped with an escape tower and the Gemini spacecraft had ejection seats and (2) the lift, orbit maneuver, and onboard computing capabilities of the Gemini and Apollo spacecraft were not available on the Mercury spacecraft.

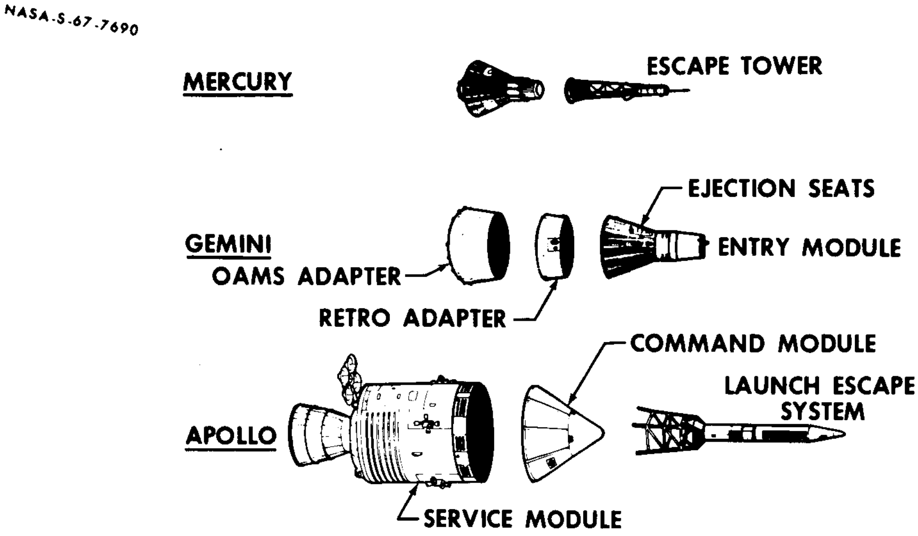
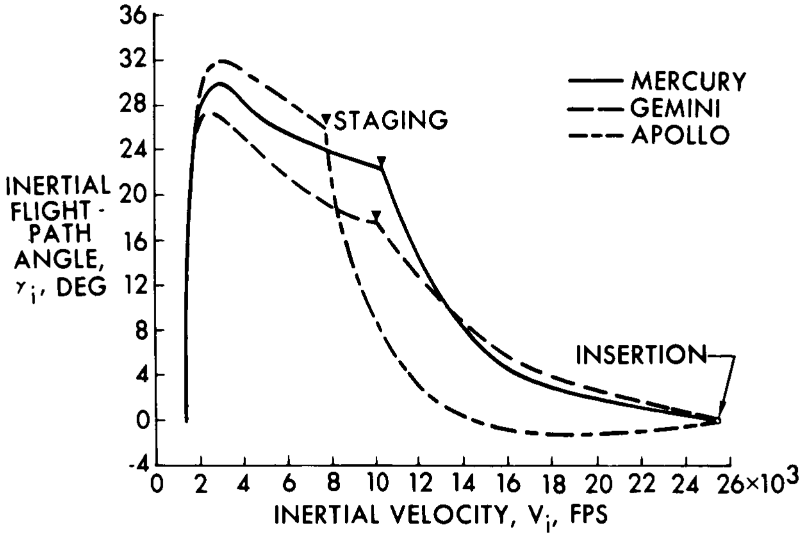


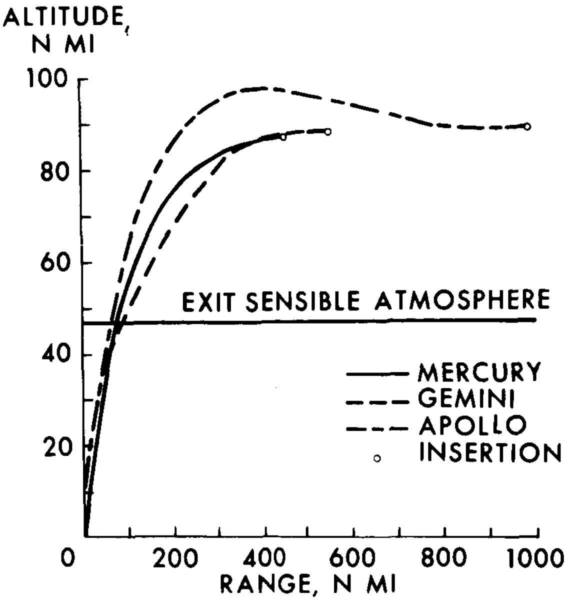
Figure 3.- Spacecraft escape systems.

The kinds of environment from which the given hardware - i.e., spacecraft - must provide a safe escape is determined largely by the planned, or nominal, launch trajectory. Probably the most meaningful parameters describing such trajectories are inertial velocity, flight-path angle, altitude and distance down range, as shown in figure 4(a) and (b).



(a) Flight-path angle versus velocity.

Figure 4.- Typical manned mission launch trajectories.



(b) Altitude versus range.

Figure 4.- Typical manned mission launch trajectories - Concluded

The point at which the trajectory exits the sensible atmosphere is important since malfunctions occurring afterward are less time critical. That is, structural breakup with the associated overpressure and fire hazard is less probable since aerodynamic loading of the structure has decreased rapidly after this point. It is also noted that the Saturn launch vehicle inserts the Apollo spacecraft well down range of the Mercury and Gemini vehicles.

Abort simulations are then made using these trajectories as initial conditions and utilizing available spacecraft propulsion systems for separating the spacecraft from the launch vehicle. The resulting separation, entry, and landing characteristics are then evaluated with respect to the known constraints and objectives.

The final outcome of this effort is the definition of the abort modes.

## LAUNCH ABORT MODES

Since a safe escape procedure must be provided throughout the launch phase, and since the escape tower or ejection seats are adequate only for the atmospheric portion, additional methods, or modes, of abort must be established. The prime objective of the safe escape dictates that the mode use the minimum number of systems, and be consistent with crew performance and system sequencing as well as insure rapid recovery. Adherence to these considerations, during abort trajectories simulated from the nominal trajectories resulted in the abort mode definitions as shown in figures 5, 6, and 7. In general, mode I utilizes the escape tower or ejection seats to perform the time critical escape from an impending launch vehicle explosion during atmospheric flight. A mode II abort may take place after exiting the atmosphere where there is little chance of a launch vehicle explosion. It consists simply of a separation from the launch vehicle, followed by orientation to entry attitude and an uncontrolled landing in the Atlantic.

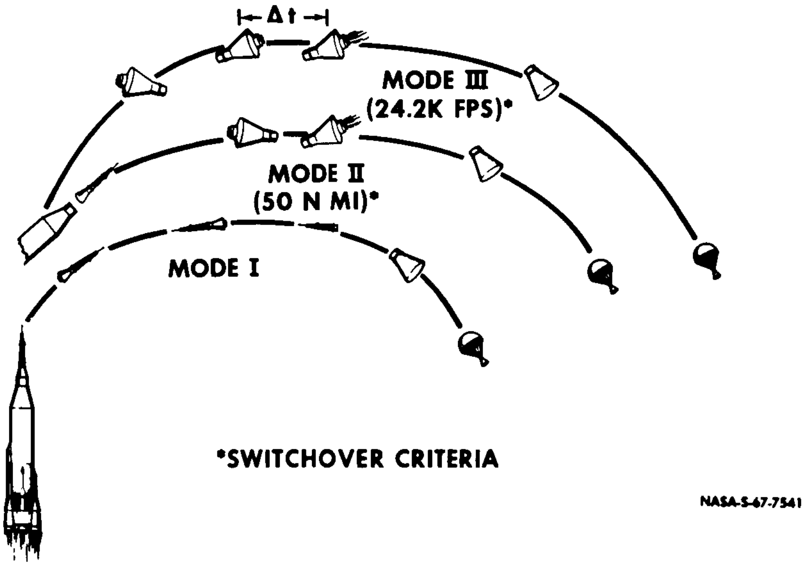


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Figure 5.- Mercury launch abort modes.

As the flight progresses and the inertial velocity increases, the time increment between launch vehicle cutoff and a retrograde maneuver becomes an effective means of controlling the spacecraft landing point. This launch abort technique is referred to as a mode III abort.

Should a contingency arise in the last few seconds of a Gemini or Apollo launch phase, when trajectory conditions are still suborbital, it becomes possible for the spacecraft propulsion system to provide the transition to an orbital state. Such a procedure, mode IV, is not an abort in the strict sense of the word in that it does not produce an immediate return of the crew to earth. Since initiation of either of the other two feasible abort modes in this flight regime could result in a wide range of undesirable landing locations, a primary advantage of the mode IV procedure is that it provides landing site selection opportunities. In other words, after obtaining an orbital state, the crew may travel through part of a revolution until a desired landing area is approached, and then perform the usual entry maneuver. If sufficient propellant remains after the transition maneuver, and the original contingency does not require flight termination, mission objectives can still be accomplished.

Determining the switchover criteria from one abort mode to another is also an important part of the analysis. Note the Gemini switchover criteria shown in figure 6.

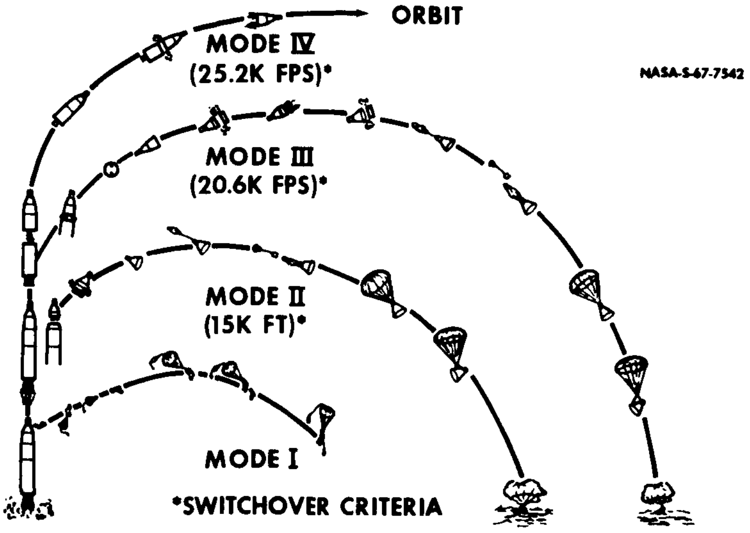

Figure 6.- Gemini launch abort modes.

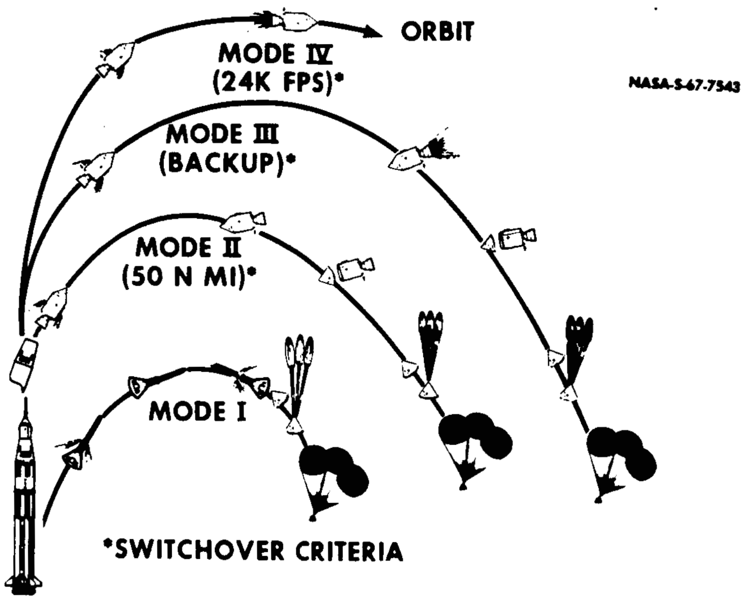

Figure 7.- Apollo launch abort modes.

The mode I abort utilized ejection seats for abort conditions up to an altitude of 15 000 ft. Since this mode would have jeopardized crew safety after this, another mode was required. The simplicity of firing the retrorockets in the direction of travel provided the separation technique which become mode II. Following separation the crew oriented to a heatshield-forward entry attitude for a simple free fall into the Atlantic with no control over the landing point. The switchover from mode II to III was based on the landing point control available at the higher velocities.

The mode III to mode IV switchover was based on the desire to avoid African landings and on the capability of the spacecraft to obtain an acceptable orbit from the abort flight conditions.

## THE INFLUENCE OF LANDING POINT CONTROL

At this point it becomes appropriate to discuss the role of landing point control on the launch abort modes. More specifically, how landing point control dictates that a mode III abort should be initiated rather than a mode II, or a mode IV abort instead of a mode III.

Since the Mercury, Gemini, and the Apollo spacecrafts require water landings for structural as well as rapid recovery considerations, it is very desirable to have the abort modes produce landings into the Atlantic Ocean. However, as orbital velocity is approached, it became impossible for the fixed-impulse entry systems of Mercury and Gemini to produce the necessary braking to land short of Africa in the Atlantic. Recalling that a mode III abort utilized a time increment from launch vehicle shutdown to a retrograde maneuver, we can examine with the aid of figure 8 the effects on landing range of a minimum and maximum time increment. The minimum time delay increment is the least amount of time in which the crew can perform an entry maneuver following a launch vehicle shutdown. The maximum delay time is the longest time the crew may wait, following launch vehicle shutdown, to perform the entry maneuver and still have time to get rid of the retrothrust equipment prior to atmospheric entry.

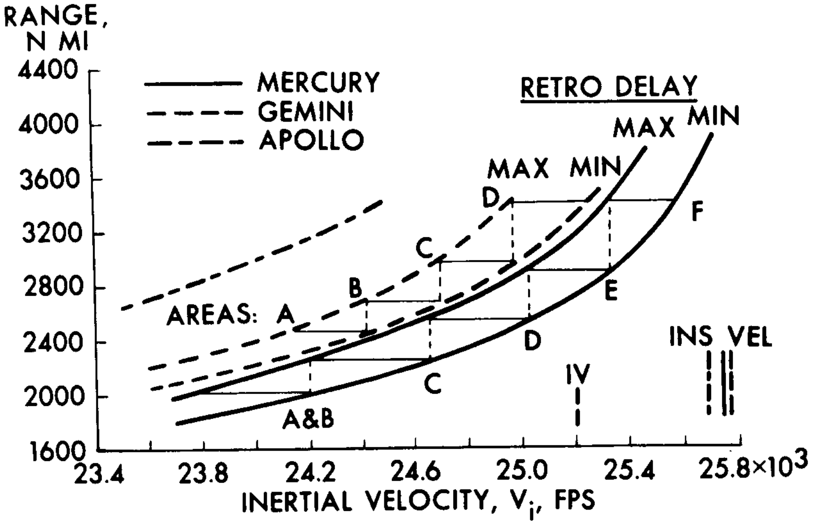

Figure 8.- Abort landing point control through retro delay.

It is noted from the figure that there is little utility in doing a mode III abort at the lower velocities since the minimum and maximum landing points are so close together. As the inertial velocity increases, however, these two procedures exhibit a very useful characteristic by producing widely separated landing points.

This interesting characteristic allows, with the aide of figure 8, the accomplishment of three important objectives. Starting at the West African coast, connecting the minimum and maximum landing point curves and then dropping at a constant velocity to the minimum curve, and repeating, a graphical "stair step" can be drawn down to the lower velocities. The results are:

1. A minimum number of recovery areas - ships.

2. The maximum probability that an abort will land short of Africa.

3. One simple technique which provides a safe abort mode for a continuous range of velocities or flight conditions.

The actual time delay for a mode III maneuver to land at a desired recovery area is computed and relayed by the ground to the spacecraft. A mode II or uncontrolled landing point abort would, therefore, be initiated for any contingency up until the launch vehicle had attained the velocity to provide an area B landing. For aborts at velocities higher than those to land in the Atlantic, the Gemini spacecraft with the OAMS tanked for rendezvous, was capable of thrusting into an acceptable orbit - mode IV. Because of the large propulsive capabilities of the Apollo spacecraft, the mode II abort will be used for launch vehicle cutoffs prior to ground-predicted African landing and a mode IV maneuver will be performed for the higher velocity aborts. Typical launch abort landing areas are shown in figure 9 for a Gemini rendezvous flight.

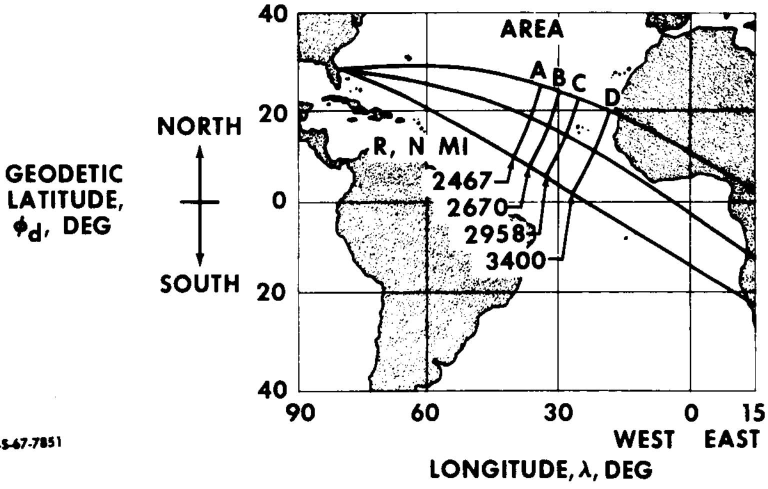

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Figure 9.- Typical Gemini launch abort recovery areas for a rendezvous mission.

## THE INFLUENCE OF NON-NOMINAL LAUNCH TRAJECTORIES

We have now shown that the spacecraft components can be used with simple techniques to provide safe crew escape modes and rapid recovery throughout the nominal launch environment. Since many failures can result in non-nominal flight conditions, the abort modes and procedures must be adequate when initiated from a launch vehicle which is deviating.

Essentially, there are two types of launch vehicle deviations. The first type includes those malfunctions which rapidly lead to castastrophic results. The time-critical nature of these malfunctions require that the crew or an automatic system initiate the abort based on an observed or sensed violation of pre-established limits. Radar and telemetry transmission delays along with evaluation time requirements eliminate possible ground help in making such abort decisions. The automatic abort systems were primarily for the extremely time-critical aborts possible up through the maximum dynamic pressure region. These automatic systems for the respective manned programs were

1. Mercury - abort sensing and implementation system (ASIS).
2. Gemini - malfunction detection system (MDS).
3. Apollo - emergency detection system (EDS).

Vehicle attitude rates and thrust chamber pressures are the primary quantities used to trigger the automatic abort. The flight crew would initiate a manual abort after observing excessive attitude rates, attitude errors, total attitude dispersions, or angles of attack. The automatic systems, complemented by the crew using onboard displays, window views, and physiological cues, comprise an adequate "system" for contending with rapid launch vehicle deviations. This fact is assured by computer simulation of the most probable vehicle failures in order to establish the required limits for the automatic and manual abort. For the most part, these rapid deviations such as an engine hardover, would result in a mode I abort; however, during the launch phase, the ground, through tracking information, advises the crew when they enter each of the abort regions to insure that the correct mode is used.

The malfunctions whose effects are not immediately obvious to the crew may be referred to as slow deviations. In general, these are due to attitude reference or guidance failures and are not nearly so time critical. The results of such malfunctions usually show up on the ground monitoring displays as deviated flight conditions compared to those of the nominal trajectory. In order to provide the crew with the required abort decision, the ground controller must know the extent to which he can allow the trajectory to deviate before the ensuing abort procedure could violate a crew or spacecraft constraint. Such constraints as entry deceleration forces or crew procedure time requirements, etc., allow the formulation of these slow deviation trajectory constraints. A comparison of the Mercury, Gemini, and Apollo ground abort decision boundaries is shown for typical launches in figure 10.

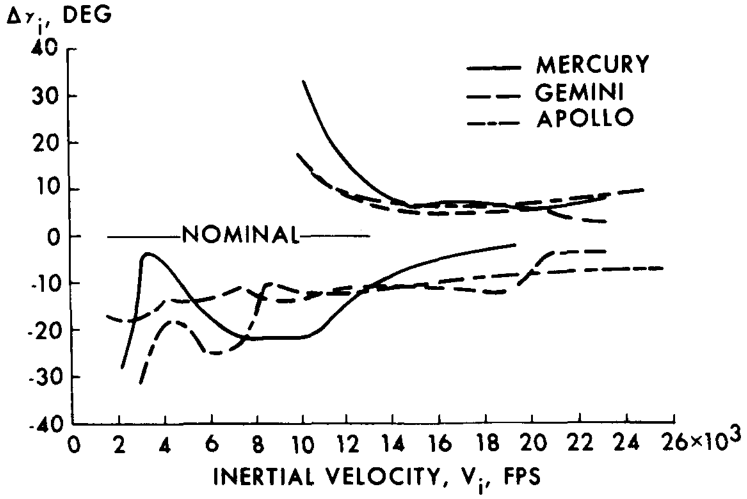

Figure 10.- Ground control display constraints.

Typical constraints and the protective boundaries are shown in figure 11 for a Gemini launch display.

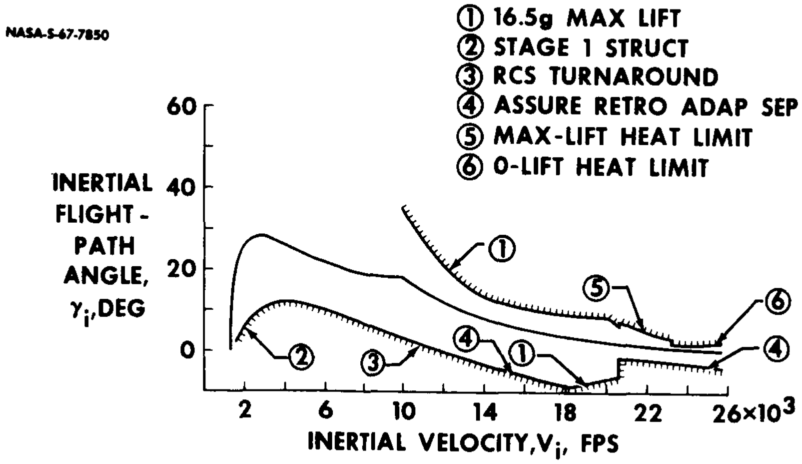

Figure 11.- Typical launch abort ground display limits for Gemini.

The last few seconds of a launch are particularly critical in that the ground must advise the crew at launch vehicle cutoff whether the trajectory was satisfactory, Go, or whether a mode III or mode IV was required, No Go. This important decision is facilitated largely through a ground display such as figure 12. The decision is therefore readily available once the boost trajectory plotting pen stops to the left or to the right of the curved decision lines. The figure compares the insertion region for the three programs by showing the mode IV regions for Gemini and Apollo compared to the simple Go or No Go curve of Mercury. It is noted that Mercury and Gemini used 1.5 revolutions as the Go-No Go criteria and mode IV requirement while Apollo uses a more conservative 75-n. mi. minimum perigee. A dispersed trajectory cutoff in this region may require preplanned decisions for fast response to questions other than the Go-No Go. Some of these other decision areas are shown in figure 13 for typical Apollo trajectory.

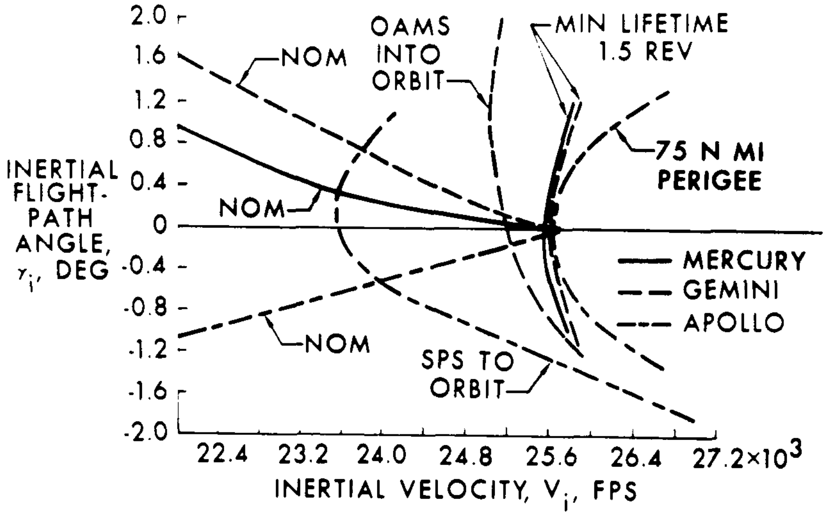

Figure 12.- Spacecraft capability to achieve orbit.

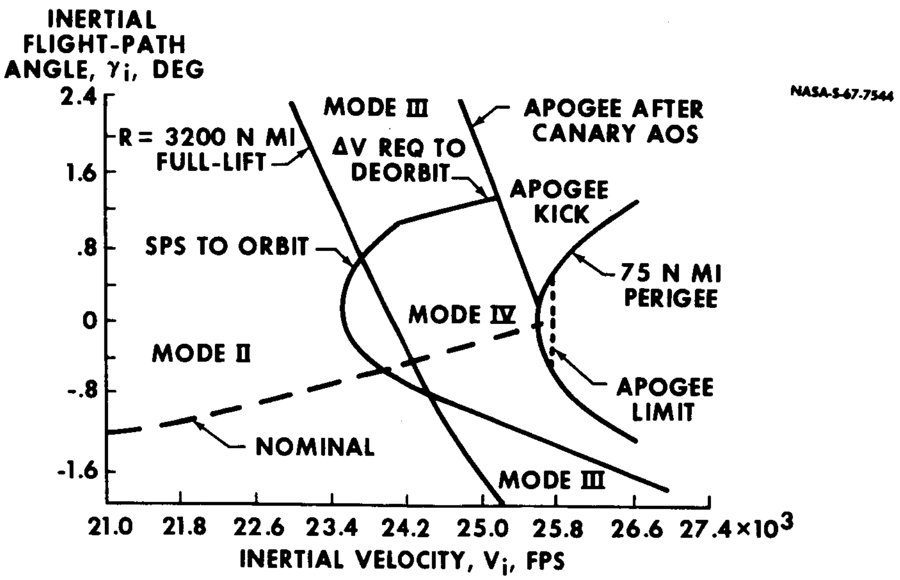

Figure 13.- Near insertion abort decisions for Apollo.

## CONCLUSIONS

A brief description of some of the processes involved in assuring a sound launch abort philosophy for the Mercury, Gemini, Apollo programs has been presented. In particular the connective role of trajectory analysis in defining escape modes and providing ground display limits has been emphasized. Because continuous efforts at improvement have substantiated previous program techniques, a high level of confidence has been established in the launch abort philosophy.