ASSESSING CAPABILITY OF MODIFIED TITAN ICBM BOOSTERS FOR DYNA-SOAR TYPE VEHICLES

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SUMMARY

This Dyna-Soar Phase Alpha booster study has shown that the Titan ICBM, when modified to the Dyna-Soar booster mission ground rules, can be used for a Step I booster for any of the reentry devices examined. It cannot place any of these devices in orbit for Step I. The changes required to the ICBM for Dyna-Soar Step I are approximately the same regardless of the reentry device selected; for example, fins are required for all devices, as are structural modifications. The differences involved are not basic but are only differences in degree to which the given change must be made.

For Step IIA, this study has also indicated that the Titan II is not useful except for very small or lightweight reentry devices. For larger devices a "maximum growth" version of the Titan-Centaur will probably be required.

INTRODUCTION

Phase Alpha of Dyna-Soar Step I was a systematic evaluation of a wide variety of reentry devices for selection of the best configurational approach to the Dyna-Soar program. Extensive studies were made of the Titan and Atlas boosters to determine the effects of reentry device and mission requirements on booster modifications and performance. Since the Titan has been selected to be the Dyna-Soar Step I booster, this paper contains results of studies of the Titan, Titan II, and Titan-Centaur boosters.

REENTRY DEVICES TO BE BOOSTED

The Dyna-Soar reentry devices studied during Phase Alpha are shown in figure 1. The variety in shape of the boosted configurations is

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apparent. During boost the reentry device is mounted on a conical transition section atop the booster. The lifting characteristics of the device are the predominant factor in determining booster modifications. "Wing area" varies from 58.5 square feet for the M-1 lifting body to 405 square feet for the glider with a lift-drag ratio L/D of 3.0, as shown in table 1. Boosted weight, including the weight of the transition cone of the device, ranges from 5,380 pounds for the drag brake to 12,250 pounds for the L/D = 3.0 glider.

TABLE 1.- REENTRY-DEVICE WING AREA AND BOOSTED WEIGHT

Device	Wing area[a], sq ft	Boosted weight, lb	
		Step I	Step IIA
Drag brake	219	[b]5,380	[b]5,550
M-1 lifting body	58.5	7,410	7,820
M-2b lifting body	155	9,700	10,000
L/D = 1.5 glider	284	9,370	9,590
L/D = 2.2 glider	330	9,960	10,440
L/D = 3.0 glider	405	11,230	12,250
Folding wing	330	8,590	9,000
Inflatable	298	10,930	11,360

[a] Wing area of the device is the plan area of the view shown in figure 1. The drag brake, M-1 lifting body, and inflatable devices are nearly symmetrical. All other devices have side areas which are substantially different from plan areas.

[b] Each of these devices jettisons approximately 1,100 pounds at booster first-stage burnout.

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BOOSTER STUDIES

Several of the Dyna-Soar booster mission requirements are substantially different from those applied in the Titan ICBM design.

Step I of the Dyna-Soar program requires the use of a modified standard Titan ICBM booster to place a minimum-size manned reentry device in or near its equilibrium glide corridor for subsequent exploration of as large a portion of the hypersonic reentry regime as practicable. Burnout altitude for insertion of the reentry device into its equilibrium glide corridor varies, as a function of boost burnout velocity and lifting characteristics of the device, between 220,000 feet and 300,000 feet for most of the shapes. A zero (or horizontal) flight-path angle is required at burnout.

Step IIA will use a larger booster to place the manned reentry device into orbital flight. A once-around orbit is a minimum requirement. The orbital mission for a lifting device starts at an altitude of approximately 300,000 feet with a zero flight-path angle at a burnout velocity (relative for eastward launch) in excess of 24,500 feet per second.

Several additional rules were established to improve safety during boost:

1. Fins are required on all boosters studied to make the booster and reentry-device assembly have at least neutral aerodynamic stability during the first-stage boost.

2. The booster flight control system is designed to accept pilot control inputs both directly and superimposed on automatic commands. The pilot will also have a manual means of thrust termination.

3. The minimum factor of safety on limit loads for the booster basic structure for manned flight will be 1.40. The flight factor may be reduced to 1.25 for unmanned flights to allow more severe environmental tests.

4. The reentry device shall never be boosted to any condition from which it cannot safely recover. The boost trajectory must not pass through the reentry-device recovery ceiling either in normal operation or as the result of premature thrust termination.

The Phase Alpha booster studies were for the most part conducted concurrently with the design studies of the various reentry devices shown in figure 1. As a result of this study procedure it was necessary to conduct the booster studies on a parametric basis which involved making numerous assumptions regarding the reentry-device characteristics and total vehicle configurations. First, a nine-point matrix of reentry-device weights (6,000, 9,000, and 12,000 pounds) and wing areas (40, 250, and 500 square feet) were established. The smaller wing-area devices were assumed to be ballistic shapes, whereas the larger wing-area devices were assigned lift and drag characteristics as a function of wing loading. It was then necessary to assume typical center-of-pressure and center-of-gravity locations and to assume a configuration and weight for the transition section between the reentry device and the booster. A standard lift-curve slope of 0.03 per degree was used for all reentry devices throughout the parametric study. A limit angle of attack of 5° was used at maximum dynamic pressure for structural sizing of the boosters.

For performance calculations, appropriate drag characteristics were assumed for each reentry device. The vehicle was launched from

Cape Canaveral at an azimuth angle of 110°. The thrust-weight ratio at launch was generally maintained above 1.25 to avoid drift problems.

Typical boosters studied for Phase Alpha are shown in figure 2. The Titan ICBM is shown only for comparison, with the Lot J type having been used as a technical reference point. The modified Titan for Step I and the three larger Step IIA Titan boosters are shown for the midpoint of the parametric weight-area study matrix.

Characteristics of these typical boosters are shown in table 2. The Step I modified Titan represents the minimum changes required to the ICBM for performance of the Dyna-Soar Step I mission.

For Step IIA orbital capability, the Titan II and two different versions of the Titan-Centaur were studied. Primary interest for Step IIA was centered around the 400,000-pound-thrust Titan-Centaur. The Titan first stage used for this combination was increased in size to allow the addition of 105,000 pounds of LO_2/RP-1 propellant, and the two ICBM engines are uprated to 200,000 pounds of thrust. The second stage CENTAUR B uses optimum propellant loading for the combination and has two 20,000-pound-thrust (Pratt and Whitney) RL10B-2 LO_2/hydrogen engines. Since the growth of the first stage of the larger Titan in terms of both size and engine thrust, was considered to be near the growth limits of the 10-foot-diameter Titan, a smaller version was also investigated for orbital capability. This 360,000-pound-thrust Titan first stage had 66,000 pounds of propellant added to the ICBM first-stage capacity and used engines uprated to 180,000 pounds of thrust.

Fin sizes required to provide static stability during first-stage boost are shown in figure 3. Note that fins are required even for the smallest size reentry device, since all the boosters are inherently unstable without fins. These fin sizes are determined by assuming a normal-force-curve slope of 0.03 per degree for the reentry device and 0.06 per degree for the fins. Body lift and aeroelastic effects were included. The curves of figure 3 show only pitch-fin area required. In addition, yaw fins were required, which were the same size as the pitch fins for symmetrical ballistic reentry devices. The various glider reentry devices required yaw fins whose area was only 40 percent of the pitch-fin area. The fins used in all cases had a taper ratio of 2 with an unswept 50-percent-chord line.

Booster-structural-weight increases were computed for a given reentry device by using a limit angle of attack of 5° at maximum dynamic pressure to establish body bending loads. The weights required for such structural modifications were combined with the fin and fin-attachment weights to produce the total structural-weight increase for the Titan

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and Titan-Centaur as shown in figure 4. The reference weights shown are basic dry-structure weights of each booster before modification. Note that for the Titan a boosted 9,000-pound device with a wing area of 400 square feet requires doubling the basic structural weight. The Titan-Centaur curve is for the 400,000-pound-thrust Titan first stage previously described. Nonlinearity of these curves is due primarily to the predominance of axial loads for small reentry-device wing areas, whereas bending loads predominate for the larger lifting shapes.

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A typical Step I boost trajectory is shown in figure 5. The recovery ceiling, dynamic-pressure q limit, and temperature limit are indicated for an intermediate L/D glider reentry device. The initial phase of the trajectory is a vertical boost to 200 feet per second followed by a gravity turn through first-stage burnout. After first-stage separation, a gravity turn is continued to a relative velocity of approximately 14,000 feet per second at an altitude of 260,000 feet, at which time a constant angle-of-attack pitch program of 12° is initiated and maintained until just prior to second-stage burnout. This pitch program, with the angle of attack held constant for approximately 40 seconds, is required to produce a zero burnout angle in the proper glide corridor.

The staging operation for separation of the first stage from the second-stage—reentry-device combination was varied somewhat, depending on the booster. Initial staging concepts for the Titan booster included a 20-second coast period between the first-stage burnout and separation. Such a Step I coast was used throughout the parametric studies. However, results of feasibility studies of the "fire-in-the-hole" technique indicated that the second-stage engines could be ignited and brought up to a 70-percent nominal thrust prior to separation. This technique then allowed staging at considerably higher dynamic pressures than were originally considered feasible, so that Step I staging could be accomplished without coast following first-stage burnout. The Step I performance trade shown in figure 6 indicates a burnout velocity $V_{B.O.}$ increase of approximately 150 feet per second if no staging coast is required.

A staging refinement study was not conducted for the Titan-Centaur. All Step IIA data include a 10-second coast between first-stage burnout and Centaur separation. For Step IIA this coast occurred at a higher altitude than for Step I, and the dynamic pressure at Centaur separation was in all cases less than 10 pounds per square foot.

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BOOSTER PERFORMANCE SUMMARY

The booster parametric-performance summary for Step I is shown in figure 7. Step I boosted weights and equivalent wing areas for each of the eight reentry devices considered are also shown. These reentry-device points have been corrected in terms of equivalent wing area to account for actual physical characteristics of the reentry device in such a fashion that the burnout velocities read from figure 7 for each device are truly comparative. The Step I burnout-velocity—weight trades are as follows:

$$\frac{\Delta V_{B.O.}}{\Delta W_1} = -0.10$$

$$\frac{\Delta V_{B.O.}}{\Delta W_2} = -0.59$$

where $V_{B.O.}$ is the burnout velocity and W_1 and W_2 are the weights of stages 1 and 2, respectively. Although figure 7 represents comparative Step I performance data from the parametric booster study, it does not necessarily represent the ultimate Step I performance achievable for any specific booster—reentry-device combination. For example, a design refinement conducted for the intermediate L/D glider—Titan-booster combination indicated that a burnout-velocity improvement of approximately 1,000 feet per second over the parametric-data value might be achieved through improved transition and fin design and with careful trajectory optimization for such a specific vehicle combination.

Step IIA orbital capability of the various Titan boosters is shown in approximate form in figure 8. It was assumed for this comparison that a relative burnout velocity of 24,600 feet per second would be required at an altitude of 300,000 feet to produce a once-around orbital mission. These data indicate that the Titan II will be adequate for Dyna-Soar Step IIA only for very light, small reentry devices. The 400,000-pound-thrust Titan-Centaur, on the other hand, will be adequate for a large number of the reentry devices studied.

The Step IIA booster-performance trades are as follows:

$$\frac{\Delta V_{B.O.}}{\Delta W_1} = -0.15$$

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$$\frac{\Delta V_{B.O.}}{\Delta W_2} = -0.82$$

Again, it should be noted that these parametric data are somewhat conservative in terms of orbital capabilities shown herein. A design refinement which results in an increase in thrown weight on the order of 1,000 pounds would make the Titan-Centaur adequate for Step IIA for all the reentry devices except the high L/D glider. Such a capability increase can probably be achieved through (a) use of a Titan II storable first stage with increased propellant loading, (b) optimization of fins, structure, and transition section, and (c) reduction of the fin requirements.

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During the final portion of the Phase Alpha studies, primary interest in the reentry devices centered about several intermediate L/D glider configurations. A study refinement was conducted for one such device on a Titan(storable 400,000-pound thrust)-Centaur booster as shown in figure 9. Fins were reduced in area below that required for stability throughout the first-stage boost, but they were maintained large enough to provide a 5° angle-of-attack control authority within the first-stage engine gimbal limits $\left(4\frac{1}{2}^{\circ}\right)$ and to provide static stability at first-stage burnout. Burnout velocity, with the glider shown, was increased to 24,800 feet per second (relative). Further growth capability may be achieved through additional uprating of the first-stage engine thrust.

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TABLE 2.- TYPICAL BOOSTER CHARACTERISTICS

Booster	Launch weight, kilopounds	Propellant	Usable propellant, lb	Thrust, kilopounds	I_{sp}, sec
Titan Lot J ICBM Stage 1 (sea level)	227.3	$LO_2/RP\text{-}1$	164,240	300	249
Stage 2 (vacuum)		$LO_2/RP\text{-}1$	41,250	80	307
Titan modified, Step I Stage 1 (sea level)	239.2	$LO_2/RP\text{-}1$	164,240	300	249
Stage 2 (vacuum)		$LO_2/RP\text{-}1$	47,270	80	307
Titan II, Step IIA Stage 1 (sea level)	335.4	N_2O_4/50% UDMH - N_2H_4	244,810	400	253
Stage 2 (vacuum)		N_2O_4/50% UDMH - N_2H_4	61,030	80	310
Titan-Centaur, Step IIA 360K stage 1 (sea level)	290.1	$LO_2/RP\text{-}1$	230,000	360	253
Stage 2 (vacuum)		LO_2/LH_2	31,250	40	418
Titan-Centaur, Step IIA 400K Stage 1 (sea level)	331.9	$LO_2/RP\text{-}1$	269,170	400	254
Stage 2 (vacuum)		LO_2/LH_2	31,250	40	418

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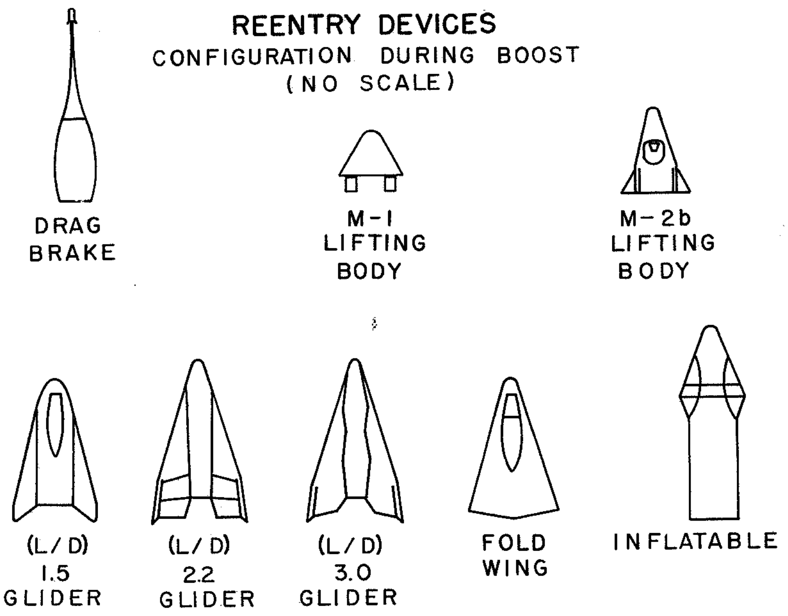

Figure 1

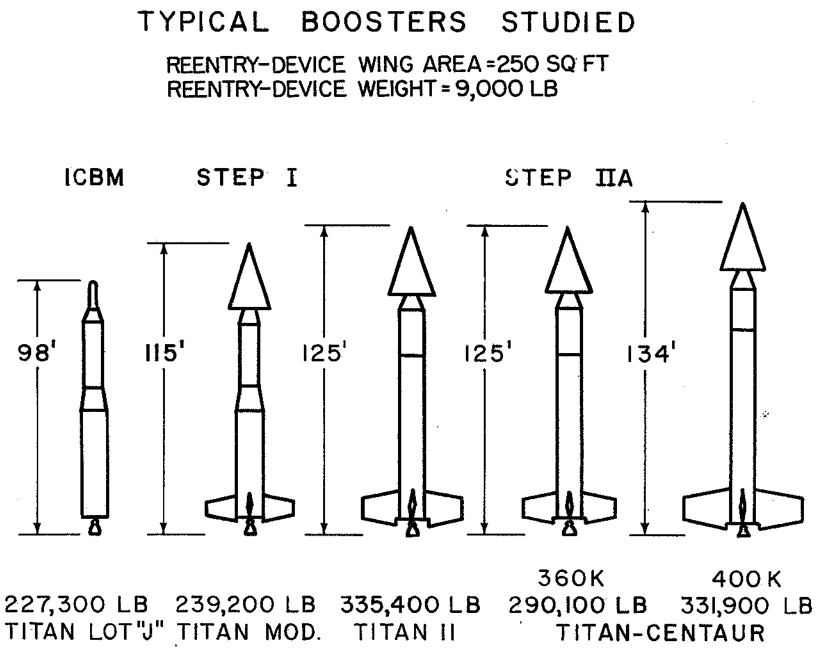

Figure 2

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FIN SIZE REQUIRED

9,000-LB REENTRY DEVICE

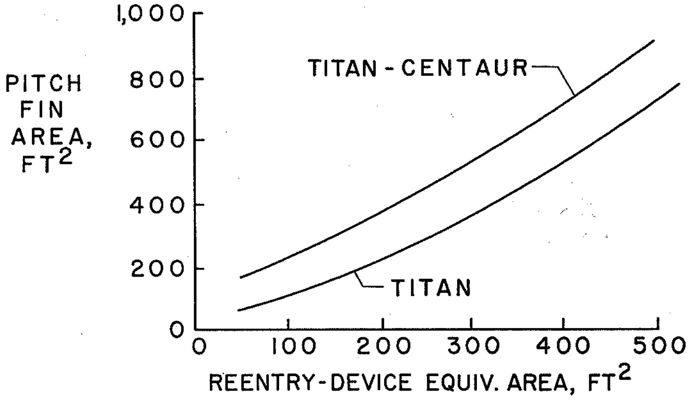

Figure 3

STRUCTURAL-WEIGHT ADDITIONS

9,000-LB REENTRY DEVICE

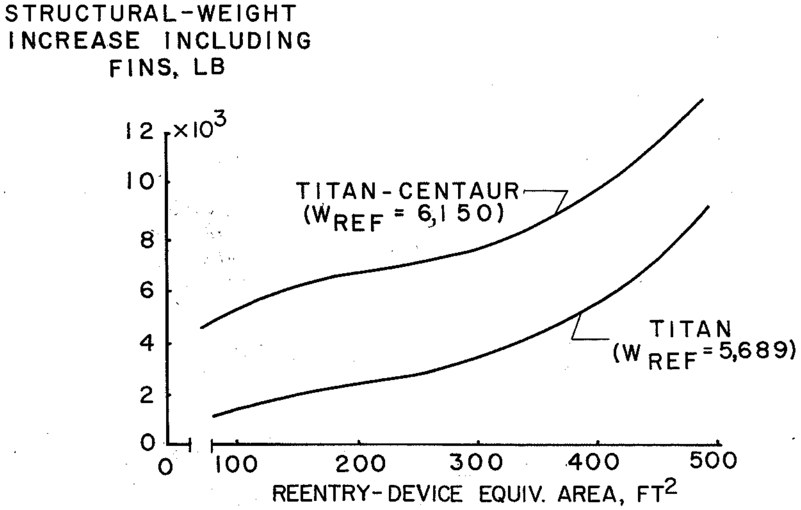

Figure 4

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TYPICAL STEP I BOOST TRAJECTORY

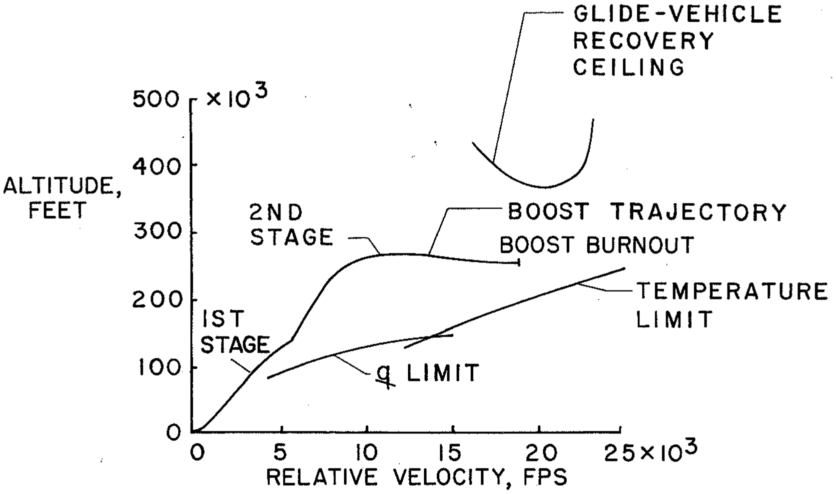

Figure 5

STAGING DURING BOOST

STEP I - TITAN
-COAST FOR PARAMETRIC
-NO COAST FOR FINAL

STEP II - CENTAUR
-COAST TO q=10 psf

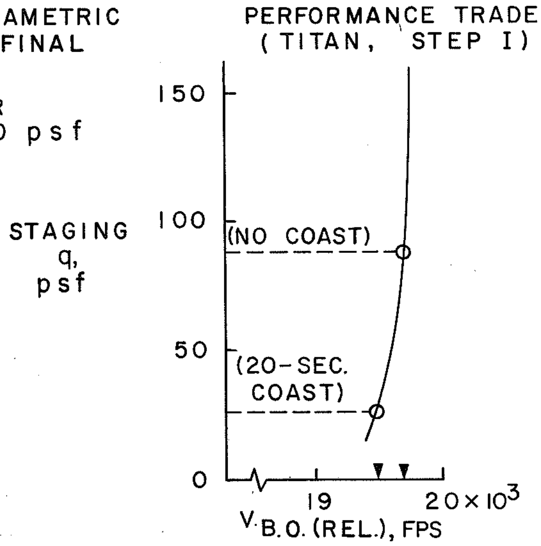

Figure 6

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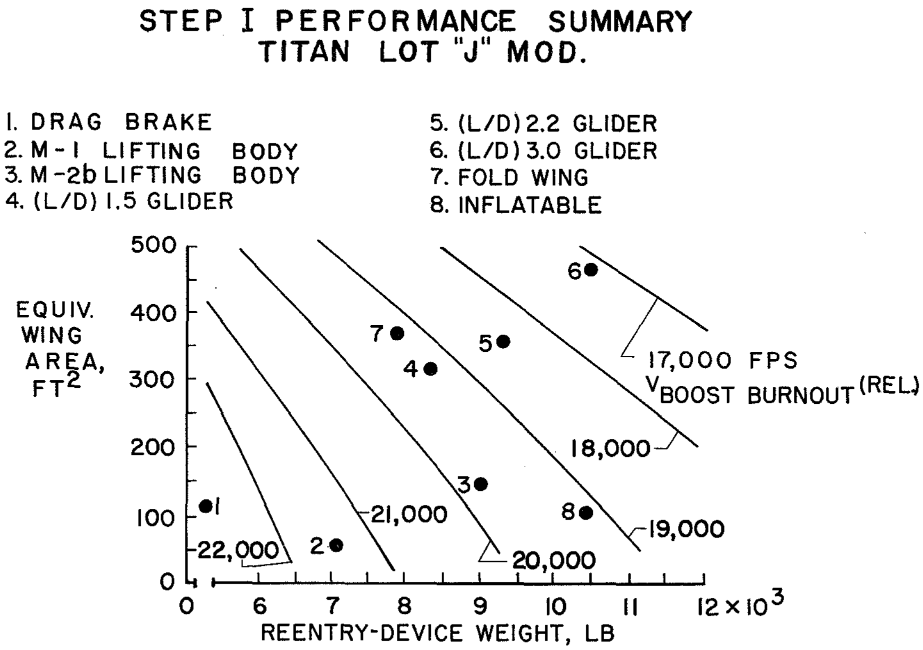

Figure 7

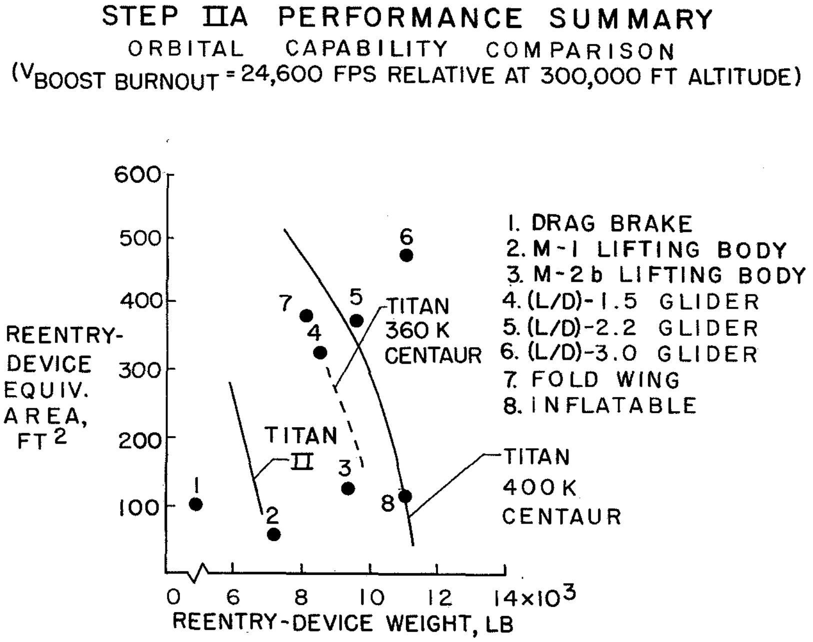

Figure 8

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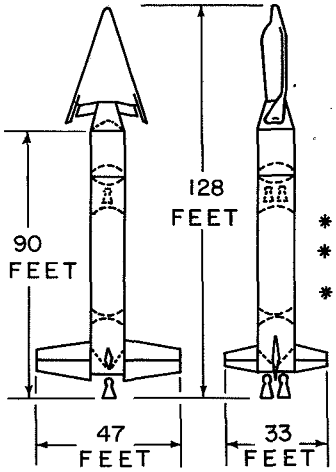
STEP IIA BOOSTER REFINEMENT

TITAN (400 K-STORABLE) CENTAUR
INTERMEDIATE L/D GLIDER REENTRY DEVICE

$V_{BOOST\ BURNOUT}$ (REL.) = 24,800 FPS



GLIDER	
LAUNCH WEIGHT, LBS	9,720
WING AREA, FT^2	330

BOOSTER	STAGE 1	STAGE 2
* LAUNCH WEIGHT, LB	335,100	
* PROPELLANT, LB	270,000	31,250
* FIN AREA, FT^2	160Y 400P	NONE
THRUST, LB	400K S.L.	40K VAC
I_{sp}, SEC	253 S.L.	418 VAC

*CHANGED FROM PARAMETRIC

Figure 9

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