[redacted]

N72-71008

DYNA-SOAR GLIDER-CONFIGURATION EVOLUTION

By R. L. Rotelli
Boeing Airplane Company

INTRODUCTION

The major effort of the Boeing Airplane Company on Dyna-Soar reentry devices has been in the development of a winged glider. The purpose of this paper is to show the external configuration evolution of the glider from the time of the initial proposal in March 1958 to the current status. Time does not permit a review of all of the configuration steps taken during this two-year period, nor is a comprehensive review of any one configuration possible. Four configuration steps with brief explanations of significant reasons for each transition will be presented.

The first configuration was developed by an Industry team headed by Boeing to meet the requirements of the U.S. Air Force request for a proposal. All subsequent configurations have been influenced by Air Force-NASA critiques, Air Force, NASA, and Boeing analytical and test programs, industrial companies collaborating with Boeing as team members, scientific consultants throughout the nation, and any other source from which data were obtainable.

There have been a total of 51 configuration steps, of which 9 were sufficiently significant to warrant construction of models and 4 are worthy of further discussion here. As shown in figure 1, these models include (1) the initial configuration proposed in March 1958, (2) the Phase I model of December 1958, (3) the Phase I model of April 1959, and (4) the Phase Alpha model of March 1960.

7

INITIAL CONFIGURATION OF MARCH 1958

At the time of the initial Dyna-Soar competition the design objectives were as noted in figure 2. Throughout the 2-year development period these objectives have not changed and remain the same today.

The design approach used in meeting these objectives was as noted in figure 3. The small size is necessary to keep booster costs and

[redacted]

[redacted]

development time to a minimum by modification of existing ICBM boosters. The use of existing hardware is to minimize the development costs and time not essential to Dyna-Soar research. The versatile test stores bay is to provide research flexibility. The simple passive structure is to get maximum reliability with structure that is dependent upon itself for survival rather than upon an active subsystem. Maneuverability provides large course corrections so that a maximum of research flight envelope and a maximum means for the pilot to get the machine back safely are available. The growth to military use is to avoid "dead-end" testing by planning a logical transition to an operation system. The "once-around" range is to demonstrate an orbital capability.

Based on this design approach the configuration is as shown in figure 4. The weight at launch is 8,260 pounds, wing area is approximately 250 square feet, the test payload is 510 pounds, and the landing speed is 150 knots. The configuration has a leading-edge sweep of 75°, and the lower-surface dihedral is a constant 20°. There is one dorsal fin and two ventral fins. A single-pilot canopy is located forward for landing vision. Pilot escape is by a stable capsule which occupies the forward third of the glider.

The initial work of the Phase I effort started with this configuration, and some major problems soon evolved. These were

(1) The large base area produced high subsonic drag with a corresponding low lift-drag ratio L/D of 3.25

(2) The hypersonic L/D of 1.85 gave insufficient lateral range

(3) The 20° dihedral together with the interaction effects of two upper and two lower control surfaces produced large roll-yaw cross-coupling effects

(4) At hypersonic high angles of attack the beam line (intersection of the lower dihedral surfaces) and the leading edges of the ventral fins were experiencing temperatures in excess of known passive materials capability

(5) Because of the wedge shape the location of equipment caused the center of gravity to be too far aft so that stability characteristics were very poor and trim could not be obtained with surfaces of reasonable size

(6) The impingement of the ventral-fin shock wave on the lower surface produced temperatures in excess of passive material capability.

[redacted]

[redacted]

PHASE I CONFIGURATION OF DECEMBER 1958

The solutions to these problems and the creation of new ones is shown in the configuration identified as Phase I model of December 1958. The design objectives at that time were the same as in March 1958. The design approach differences from those used in the March configuration are shown in figure 5.

L
1
1
1
1

Landing without thrust power is necessary to avoid the massive costs to produce and to use a booster capable of putting a glider sized and weighted to carry such an engine installation into orbit, particularly if the engine has no other purpose than to assist the pilot in landing. Escape throughout the flight profile was considered a good idea for any manned system if it could be done within acceptable cost penalties. Full time stability augmentation was found to be necessary for good pilot flying characteristics; integrating pilot control was to allow the pilot the opportunity to add to the reliability of the system. The "go-around" landing engine for air launch was to aid in the pilot training and development of landing techniques. The "twice-around" range and altitude of 300 nautical miles was to assure sizing the glider for growth to a useful military potential. The use of system redundancy by duplication was necessary to approach a survival reliability objective of 0.998.

The resulting configuration is shown in figure 6. Significant changes from the last configuration are:

(1) Equipment is installed in a body with wings attached in lieu of a thick wing

(2) The base area is reduced with resulting improvement in subsonic L/D to 4.25

(3) Vertical fins are moved to the wing tips so that resulting control forces are acting more nearly through the center of gravity

(4) The flat bottom is to improve stability characteristics and reduced local skin temperatures

(5) The leading-edge sweep is reduced to 73° to provide some improvement in landing characteristics and to permit a better fixed equipment arrangement for the same wing area

(6) The nose is bent up 4° to permit trimming at higher lift coefficient C_L hypersonically

[redacted]

[redacted]

(7) The wing area is increased to 330 square feet to reduce the wing loading to help compensate for the increase in temperatures resulting from using turbulent flow in lieu of laminar flow

(8) Conventional elevons and a center elevator are used

(9) The weight has increased to 9,200 pounds due principally to added systems for redundancy, larger wings, and a more detailed weight analysis

(10) The hypersonic L/D has increased to 1.95.

L1111

Subsequent analysis and testing of this configuration brought out some problems as follows:

(1) The temperature of the lower surface was greater than predicted and about 500° F beyond the capability of super alloy materials. Structural temperature limits at this time were 4,000° F for nose, 2,700° F for leading edges, and 2,000° F for all other surfaces.

(2) The hypersonic L/D was below the expected value because of excessive body cross-section area.

(3) The temperature of the lower leading edge of the vertical fins was excessive (about 3,700° F) and beyond a passive structure capability.

PHASE I CONFIGURATION OF APRIL 1959

These problems led to the next configuration of April 1959. The design objectives remain the same. The design approach, however, is becoming more specific as noted in figure 7. The 14,000-foot maneuver corridor was established to provide a safety margin of at least 6,000 feet as a minimum for pilot safety based on a 45° bank at all speeds. Equipment redundancy was virtually eliminated to obtain a lower wing loading to reduce lower-surface temperatures and to limit the amount of refractory-coated insulated panels, a new addition to the glider. The 500-pound payload limitation is another way of reducing the wing loading. The 2500-nautical-mile lateral turn was considered necessary to maintain the objective of potential military value. The air launch to a Mach number greater than 1.5 is a new requirement to explore the critical supersonic flight regime.

The resulting configuration is shown in figure 8. Significant changes from the previous configuration (fig. 6) are:

(1) The body cross section has been reduced

[redacted]

[redacted]

(2) Molybdenum-insulated panels have been added to the forward part of the lower surface; the 2,000° F limit for surface temperature was abandoned

(3) The lower leading edge of the vertical fins has been eliminated by elimination of the area below the wing

(4) The weight has been reduced to 7,800 pounds, while a wing area of 330 square feet has been maintained. The hypersonic L/D has increased to 2.2 and the subsonic L/D to 4.5.

Problems subsequently determined were as follows:

(1) Trim was not possible at low supersonic speeds because of the large camber in the wing upper surface

(2) The leading edge and nose temperatures were higher than predicted so that the 14,000-foot maneuver corridor could not be obtained

(3) The center elevator created booster interstage difficulties and interferences with the installation of the air launch liquid rocket engine.

PHASE ALPHA CONFIGURATION OF MARCH 1960

During the period through April 1959 the Air Force was conducting a phase I computation in which one of the items of work was to develop the glider design requirements. It was not until after the source selection of April 1959 that the Air Force published their design requirements to the winner of the competition. Based on these, the design objectoves remained unchanged; however, changes were reflected in the design approach as shown in figure 9.

The configuration resulting from these requirements is shown in figure 10. The significant differences from the previous configuration are:

(1) The weight has been increased to 9,283 pounds, primarily because of the return of 1,000 pounds of payload and subsystem redundancies.

(2) The entire lower surface has been covered with coated-molybdenum insulated panels because of higher temperatures due to the higher wing loading and because of a requirement that the temperature be based on a 100-percent equipment blocking of the inward radiated heat.

[redacted]

[redacted]

(3) The radius of the leading edge and nose has been increased approximately 1 inch to recover the minimum maneuver safety margin of 6,000 feet

(4) Retractable fin tip stabilizers have been added to reduce the aerodynamic center shift and thus to provide positive aerodynamic stability throughout the flight profile

(5) The center elevator has been removed and the area added to the elevons

L
1
1
1
1

(6) The wing upper surface camber has been removed to solve the subsonic trim problem

(7) The nose gear has become a skid to save weight by eliminating the cooling system required to protect a normal type nose gear.

This configuration is one month old and three problems have appeared, as follows:

(1) The escape capsule appears to be too complex and costly.

(2) It is very desirable to reduce the temperature on the lower surface to limit the extent of molybdenum shielded panels.

(3) The stability characteristics at hypersonic low angles of attack are unsatisfactory.

Solution to these problems is now in progress.

Figure 11 shows the current inboard profile for the ground-launch configuration.

Figure 12 shows the current inboard profile for the air-launch configuration. The pertinent equipment is identified.

SUMMARIZATION

Figure 13 compares the significant areas of change in the evolution of the Dyna-Soar gliders. The fluctuation of weight is due primarily to the choice made as to which of two influences was greatest at the time, the structural-material temperature capabilities or the aerodynamics-maneuver safety margin. As can be seen, aerodynamics is at present ahead.

[redacted]

[redacted]

From this review, one might conclude that the designers were in a "rut" in staying so closely to a given shape and size and simply making refinements. This is not true. Throughout the development period many "excursions" and trade studies were made. Consideration was given to a range of devices from a 3,000-pound unmanned vehicle to 15,000-pound vehicle with a two-man crew. Wing loadings from less than 20 to greater than 40 were studied. Leading-edge sweep was varied from 70° to 80°. In all of these excursions, the designers were always forced back to the configuration shown herein by three constraints or "road blocks." These are (1) the current ICBM booster capabilities, not only in the thrown weight but in the modifications required for winged, manned payloads; (2) the temperature limits created structural materials capabilities for long time exposure; and (3) the Dyna-Soar requirements of such things as pilot control, conventional landing, positive aerodynamic stability, hypersonic maneuverability, and orbital velocities. These constraints led the designers to return to a wing loading of 20 to 30 lb/sq ft, a weight of 8,500 to 9,500 pounds, a hypersonic L/D of 1.5 to 2.5 and a subsonic L/D of 4 to 5.

L
1
1
1
1

Whether subsequent work will remove any of these constraints to allow for a better compromise between structures, aerodynamics, and requirements will have to await decisions concerning the next configuration milestone, which as is shown in figure 1, is scheduled for early spring of 1961.

[redacted]

[redacted]

CONFIGURATION EVOLUTION

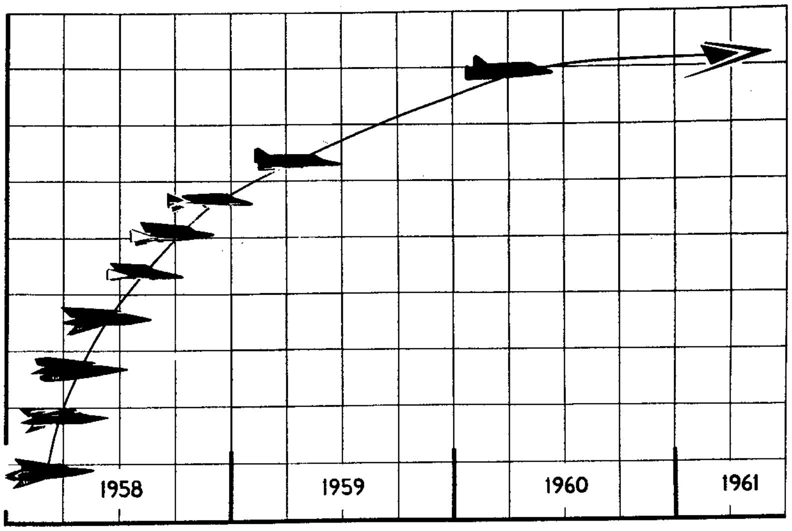


Figure 1

DESIGN OBJECTIVES
MARCH, 1958

- CONCEPTUAL GLIDER DEVELOPMENT
  - SIGNIFICANTLY ADVANCING TECHNOLOGY
  - SUBSEQUENT MILITARY APPLICATION
  - DEMONSTRATING MANNED FLIGHT
    - HYPERSONIC BOOST GLIDE
    - ORBIT
    - RE-ENTRY
    - CONVENTIONAL LANDING

Figure 2

[redacted]

[redacted]

DESIGN APPROACH – MARCH 1958

- SMALL SIZE
- MAXIMUM USE OF EXISTING HARDWARE
- VERSATILE TEST STORES BAY
- SIMPLE PASSIVE STRUCTURE
- MANEUVERABLE IN GLIDING FLIGHT
- RELIABLE AND SAFE
- MILITARY POTENTIAL
- ICBM BOOSTERS
- RANGE "ONCE-AROUND"

Figure 3

GENERAL ARRANGEMENT
MARCH 1958

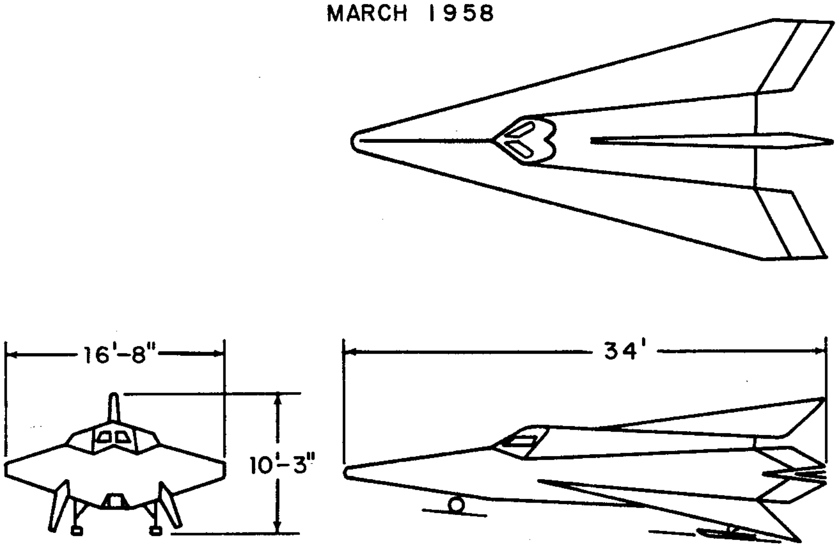


Figure 4

[redacted]

[redacted]

DESIGN APPROACH
DECEMBER, 1958

- SAME AS MARCH, 1958, EXCEPT-
  - GOOD LANDING WITHOUT ENGINES
  - ESCAPE THROUGHOUT FLIGHT ENVELOPE
  - 3-AXIS-FULLTIME-STABILITY AUGMENTATION
  - INTEGRATED PILOT CONTROL
  - "GO-AROUND" LANDING ENGINE FOR AIRLAUNCH
  - RANGE "TWICE-AROUND"-ALTITUDE 300 N.M.
  - REDUNDANCY FOR ADDED SAFETY

Figure 5

GENERAL ARRANGEMENT
DECEMBER 1958

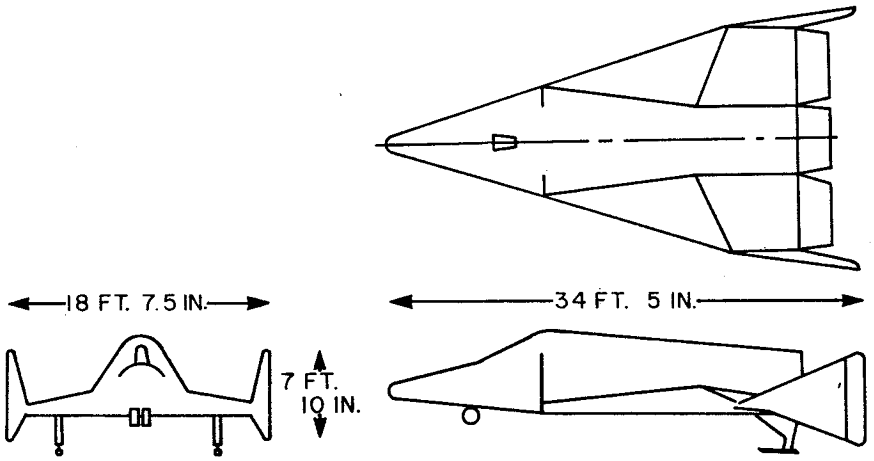


Figure 6

[redacted]

[redacted]

DESIGN APPROACH
APRIL 1959

- SAME AS DECEMBER 1958 EXCEPT
  - 14,000 FT. MIN. BETWEEN MAX. L/D EQUILIBRIUM AND MAX. L/D HEAT LIMIT
  - LIMITED REDUNDANCY
  - 500 LB. PAYLOAD FOR MANNED FLIGHTS
  - 2500 N. MI. LATERAL TURN
  - AIR LAUNCH TO MACH 1.5 MINIMUM

Figure 7

GENERAL ARRANGEMENT
APRIL 1959

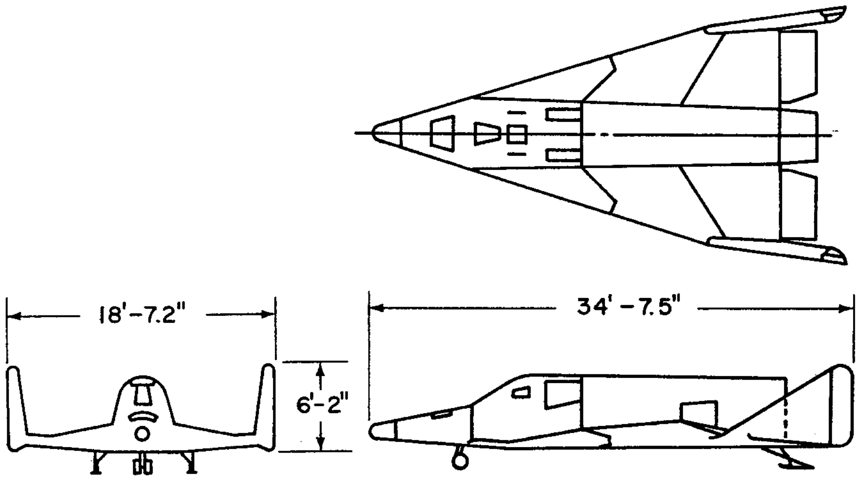


Figure 8

[redacted]

[redacted]

DESIGN APPROACH
MARCH 1960

● PAYLOAD	1000 LB & 75 CU. FT.
● BOOSTER	MODIFIED TITAN ICBM
● VELOCITY	26,000 FPS (INERTIAL) @ 400,000 FT. ALT.
● LANDING	CONVENTIONAL
● LATERAL RANGE	2000 NAUT. MI. (MIN.)
● FLIGHT CORRIDOR	30,000 FT. (MIN.)
● GLIDER LIFE	4 FLIGHTS (MIN.)
● STABILITY	NEUTRAL - LAUNCH TO LANDING
● RELIABILITY	REDUNDANCY OF CRITICAL COMPONENTS

Figure 9

GENERAL ARRANGEMENT
MARCH 1960

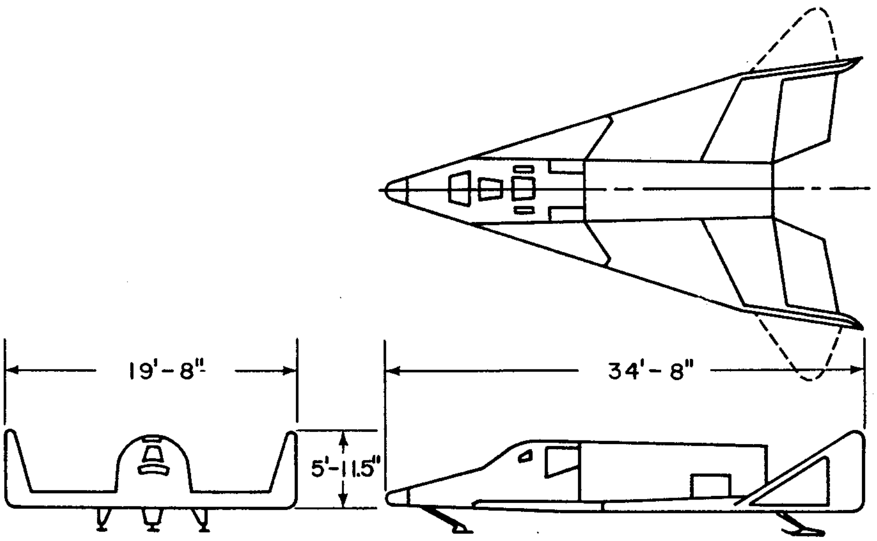
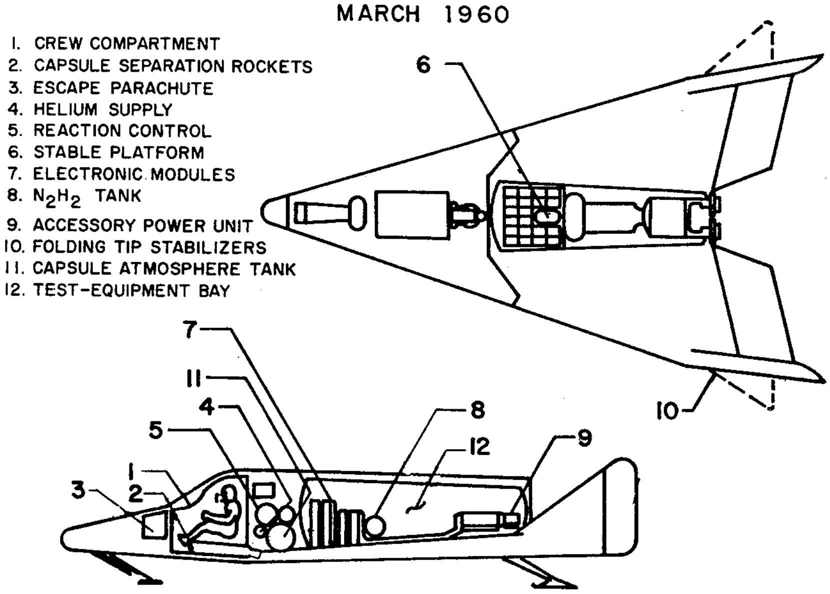


Figure 10

[redacted]

[redacted]

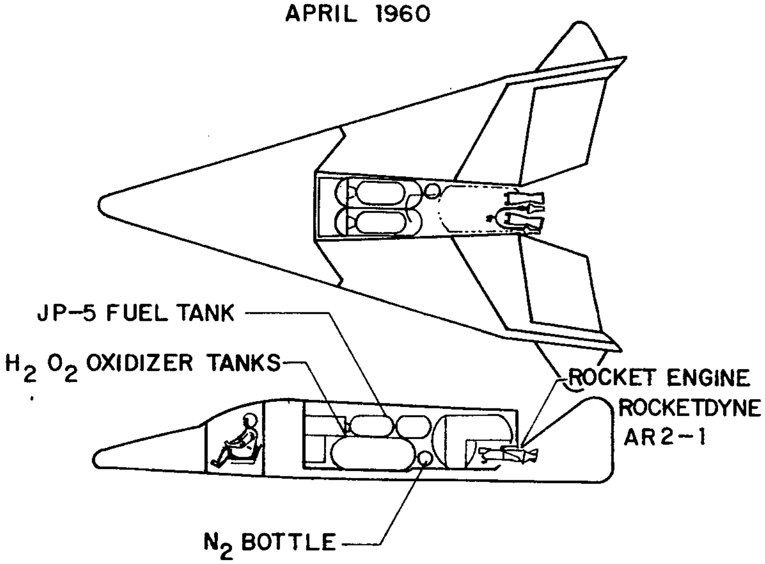


INBOARD PROFILE, GROUND LAUNCH

MARCH 1960

1. CREW COMPARTMENT
2. CAPSULE SEPARATION ROCKETS
3. ESCAPE PARACHUTE
4. HELIUM SUPPLY
5. REACTION CONTROL
6. STABLE PLATFORM
7. ELECTRONIC MODULES
8. N_2H_2 TANK
9. ACCESSORY POWER UNIT
10. FOLDING TIP STABILIZERS
11. CAPSULE ATMOSPHERE TANK
12. TEST-EQUIPMENT BAY

Figure 11



INBOARD PROFILE - AIR LAUNCH

APRIL 1960

Figure 12

[redacted]

[redacted]

DYNA-SOAR GLIDER DATA

MODEL	MAR.'58	DEC.'58	APR.'59	MAR.'60
DESIGN LAUNCH WEIGHT, LB	8,260	9,200	7,800	9,283
PAYLOAD, LB	510	1130	500	1,000
WING AREA, SQ FT	250	330	330	330
$(L/D)_{\text{HYPERSONIC}}$	1.85	1.95	2.2	2.2
$(L/D)_{\text{SUBSONIC}}$	3.25	4.25	4.7	4.5

Figure 13

[redacted]