SUMMARY COMPARISON OF DYNA-SOAR REENTRY DEVICES

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A significant part of Dyna-Soar Phase Alpha studies was the preliminary design, to consistent ground rules, of broadly selected configurations on which research on the problem of controlled, manned reentry could be conducted. After the preliminary investigation of 21 configurations, 9 devices, shown in figure 1 along with the name of the principal contributor, were selected for detailed investigation. Technical details of these devices are presented in other papers at this conference. It is significant that these devices, with the exception of the drag brake, were designed for a common set of ground rules shown in table I. Hence, for the first time, these devices can be compared directly. The scope of the nine devices covers the broad range of parameters shown in table II. The wing-loading range from approximately 5 to 110 lb/sq ft and a range of hypersonic lift-drag ratios from 0 to 3.0 were studied. For proprietary reasons, the parameters and technical data for the Modified Mercury will not be presented.

One of the first areas of comparison is the weights of these devices. This comparison is shown in table III. Since a variety of structural concepts and heat-protection systems are used on the devices, it is appropriate to compare the sum of the structure and environmental-control weights rather than just the structure weight. 6

Arriving at the optimum system to accomplish a specific mission or objective is an evaluation process with emphasis on cost. When evaluation of the merits of the nine devices for the Dyna-Soar mission was formulated, it became apparent that there are four separate elements involved in the evaluation of these systems. These parts are not addable or combinable by any method other than considered judgment. The four parts are: technical confidence, value of technical results, development phasing, and costs.

The following portions of the paper include Boeing Airplane Company ratings in technical evaluation of the devices. Table IV presents the rank of the devices in technical confidence in aerodynamic technology required to accomplish successfully the program objectives. These ratings reflect predesign development-program timing to bring the devices to similar confidence levels. The aerodynamic rating is based on flight control, performance, and heating.

First in aerodynamic confidence rating is the drag brake. The flight-control problems are not severe because of its pure ballistic shape. The heating technology for this blunt shape is well known, and the ability to predict the performance is very high. It has a possible problem because the cloth which covers the umbrella-like drag device sags. The only heating problem is the sagging and heating of the partially open device.

Next in aerodynamic confidence are the M-1, $2.2\frac{L}{D}$ glider, and $3.0\frac{L}{D}$ glider. The M-1 has possible flight-control problems from its blunt, close-coupled shape which changes by ablation during the reentry process and possible center-of-gravity problems. The heating confidence is very high except around the control surfaces where stagnation areas occur. The performance-predicting ability is only slightly less than that for pure ballistic devices. The $2.2\frac{L}{D}$ glider has had extensive wind-tunnel testing up to the present time. There are some problems in the flight-control area, but these are not serious. The heating of this device is fairly well understood, except in certain detail areas. The ability to predict performance is not rated as high as that of the pure ballistic devices or as high as that of the M-1, but it is still relatively high. The $3.0\frac{L}{D}$ glider has also had extensive development time and is rated the same as the $2.2\frac{L}{D}$ glider. The $1.5\frac{L}{D}$ glider ranks next. It has had some subsonic testing; however, there are some possible hypersonic problems because the shape of this device has not been tested as yet. Very little is known about this glider in the flight-control area.

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The fold-wing device ranks next. There are unknown flight-control answers of this device, particularly in the subsonic directional-stability and subsonic pitchup problems. Heating confidence for this glider is relatively high, ranking only slightly less than that for the $2.2\frac{L}{D}$ and $3.0\frac{L}{D}$ gliders. Performance-prediction ability is the same as for the other glider devices.

Next in rank is the M-2b. The flight-control problems would be better than those of the M-1 except that this device has a landing problem as well. It has the least confidence of any of the systems in heating, particularly around the tip controls. The performance-predicting confidence is the same as that for any glider.

Last in ranking is the inflatable device. The problems of the flexible system and reaction control problems are reflected in low flight-control-system confidence. Also, new systems are required to make the flight-control system work. The heating problem is not very different from that of the $2.2\frac{L}{D}$ glider except for possible sagging problems. The ability to predict the performance of this device ranks the same as any glider.

The structures confidence of these devices ranks the M-1 structure as having the highest confidence. Possible problems are the hot control areas and long time ablators.

The gliders all rank approximately the same. They all employ refractory metals in one form or another, just to different degrees. The order of ranking is close with the $2.2\frac{L}{D}$ glider, $1.5\frac{L}{D}$ glider, fold wing, M-2b, and $3.0\frac{L}{D}$ glider in that order. There is a drop in confidence in the fold wing, however, due to the fact that its weights are considered optimistic. The fold-wing device employs extremely thin gages of nickel-base alloys, and more work would have to be done to ensure that this is a reliable structure. The basis for this ranking is the structural test programs, both successful and unsuccessful, which have been conducted to date during the Dyna-Soar study. The $3.0\frac{L}{D}$ glider employs a cooled nose cap which has not been tested to date. This is the main reason for its ranking lower in this rating.

The hot-fabric-covered devices are lowest on the scale, but the drag brake does not require air tightness to the same degree as the air inflatable device and, therefore, has higher confidence. Development of the wire-mesh fabrics which are covered by a silicon compound with glass frits in it is not complete at this time. The confidence in the weight of the drag device is low, however, mainly because it does not satisfy the ground rules in the areas of landing sites and reusability. If this device is rated on its performance in other areas based on this weight, the confidence must be lowered.

Table V shows the rank of these devices in value of technical results for Dyna-Soar objectives. Many facets of comparison were examined to arrive at this rating. They are listed without detail. The devices were examined for ability to make lateral aerodynamic maneuvers, for ability to grow to superorbital reentry capability, for ability to make a conventional landing, rather than merely impacting intact, for ability to explore various corridors during reentry, for ability to obtain a wide variety of research data applicable to future military reentry systems, for ability to obtain research data not available from the extension of existing programs, for the ability of the pilot to make orbit corrections, for the ability of the pilot to assist in landing-site selections, for the ability of the pilot to assist the test program as an operator with judgment, for the ability of the pilot to aid in the emergency modes, for the ability of the devices to sustain orbit, for the ability of the devices to research military subsystems, for the ability of the devices

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for potential military payloads, for the ability of the devices to incorporate military equipment, and for the growth capability of the devices.

When all of these facets of value of technical results were taken into account, the following ranking results. First in value is the $3.0 \frac{L}{D}$ glider. Second in value is the $2.2 \frac{L}{D}$ glider closely followed by the fold wing and the $1.5 \frac{L}{D}$ glider, in that order. Next comes the inflatable-wing device closely followed by the M-2b. The M-1 is followed by the drag brake which is last in the rating.

Next some of the technical aspects of the study will be examined. Figure 2 shows the efficiency ratio, which is the ratio of weight of payload plus pilot to the boost weight of the reentry device, as a function of L/D. As might be expected, low values of L/D result in higher efficiency.

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Figure 3 shows the efficiency ratio in terms of the boost weight of the reentry device as a function of lateral maneuverability. Here, the basic reentry device has been provided with a maneuver rocket (with a specific impulse of 410 and a propellant-loading fraction of approximately 0.88), which is fired a quarter of the earth's circumference before landing. This rocket is considered as part of the boost weight of the reentry device. The plot shows that for different lateral maneuverabilities the relative ranking of these devices changes completely. The solid portions of the curves are those devices which can be boosted with a modified Titan-Centaur booster; the dashed portions of the curves are those devices which cannot be pushed into orbit by that booster.

Table VI presents the comparison of the aerodynamic maneuverability of these devices and a comparison of their landing characteristics with those of the X-15 device. This comparison has been made with the method of reference 1. It is interesting to note that providing for a conventional landing capability insures a hypersonic L/D of 1.5 or greater.

In closing it is appropriate to remark upon the evaluation process used. Shown in figure 4 is a 3-axis system, schematically representing the evaluation process used. Each device has an appropriate value as a research system, a cost of the research program, and time to accomplish the program objective. Technical confidence comes into this evaluation process in that time and money have been provided to the best of present ability to bring the technical confidences to a similar level. However, lack of technical confidence at this time must also be considered as possible perturbations in time, money, and value. Selection of the optimum device to accomplish the objectives of the Dyna-Soar program will then depend upon considered judgment as to combination of these factors of technical confidence, value, time, and cost. The rankings

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contained herein reflect an evaluation made by Boeing Airplane Company and do not reflect or imply results of evaluations made by any other group that had access to the Phase Alpha design studies.

REFERENCE

1. Matranga, Gene J., and Armstrong, Neil A.: Approach and Landing Investigation at Lift-Drag Ratios of 2 to 4 Utilizing a Straight-Wing Fighter Airplane. NASA TM X-31, 1959.

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TABLE I

GROUND RULES

- PILOTED (ONE CREWMAN)
- 1,000-POUNDS RESEARCH EQUIPMENT
- 75 CUBIC FEET VOLUME FOR EQUIPMENT
- ONCE-AROUND OPERATING CAPABILITY
- "SAFE" BOOST
- LAND WITHIN 10 SQUARE MILES
- CONSISTENT SUBSYSTEMS
- REUSABLE FOR FOUR FLIGHTS
- AT LEAST NEUTRAL STABILITY
- ESCAPE PROVISIONS
- 6,000-FOOT MARGIN WITH CRITICAL HEATING

TABLE II

PARAMETER COMPARISON

STEP IIA (ONCE-AROUND)

DEVICE	W_{BOOST}, LB	$W_{REENTRY}$, LB	$(\frac{W}{S})$ REENTRY, LB/SQ FT	$(L/D)_{M=20}$
DRAG BRAKE	5,260	4,123	W/C_DA=1.8/36 LB/SQ FT	0
M-1 LIFT BODY	7,275	6,509	110	.5
M-2b LIFT BODY	9,391	9,196	59.1	1.3
1.5 (L/D) GLIDER	8,590	8,346	29.4	1.5
2.2 (L/D) GLIDER	9,719	9,455	28.7	2.2
3.0 (L/D) GLIDER	11,291	10,570	26.1	3.0
INFLAT. WING	11,069	9,860	5.5	1.7
FOLD WING	8,298	7,952	13.4	2.0

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TABLE III

SUMMARY WEIGHT COMPARISON

STEP II A (ONCE-AROUND)

DEVICE	W_{INJECT}, LB	$W_{STRUCT.}$ ENVIRON. CONTROL (INJECT.), LB	W_{OTHER} SUBSYSTEM (INJECT.), LB	W_{PILOT} AND PAYLOAD, LB
DRAG BRAKE	4,140	2,197	743	1,200
M-1 LIFTING	6,657	3,617	1,840	1,200
M-2b LIFTING BODY	9,391	5,371	2,820	1,200
1.5 (L/D) GLIDER	8,590	4,650	2,740	1,200
2.2 (L/D) GLIDER	9,719	5,776	2,743	1,200
3.0 (L/D) GLIDER	11,291	6,988	3,103	1,200
INFLAT. WING	1,1069	6,334	3,525	1,200
FOLD WING	8,298	4,298	2,800	1,200

TABLE IV

RELATIVE TECHNICAL CONFIDENCE

RANK IN AERODYNAMICS	RANK IN STRUCTURES AND MATERIALS
DRAG BRAKE	M-1
M-1	2.2 L/D GLIDER
2.2 L/D GLIDER	1.5 L/D GLIDER
3.0 L/D GLIDER	M-2b
1.5 L/D GLIDER	3.0 L/D GLIDER
FOLD WING	FOLD WING
M-2b	DRAG BRAKE
INFLATABLE WING	INFLATABLE WING

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TABLE V

VALUE OF TECHNICAL RESULTS

RANK IN VALUE FOR DYNA-SOAR OBJECTIVES

3.0 L/D GLIDER

2.2 L/D GLIDER

FOLD WING

1.5 L/D GLIDER

INFLATABLE WING

M-2b

M-1

DRAG BRAKE

TABLE VI

MANEUVER AND LANDING COMPARISON

DEVICE	LATERAL MANEUVER FROM 23,000 FPS	LANDING METHOD AND COMPARISON TO X-15
DRAG BRAKE	0	BASIC DEVICE (55 FPS)
M-1	150	PARACHUTE (30 FPS)
M-2b	800	CONVENTIONAL - EQUAL
1.5 L/D GLIDER	1,100	CONVENTIONAL - BETTER
2.2 L/D GLIDER	2,150	CONVENTIONAL - BETTER
3.0 L/D GLIDER	3,500	CONVENTIONAL - BETTER
INFLAT. WING	1,400	CONVENTIONAL - BETTER
FOLD WING	1,700	CONVENTIONAL - BETTER

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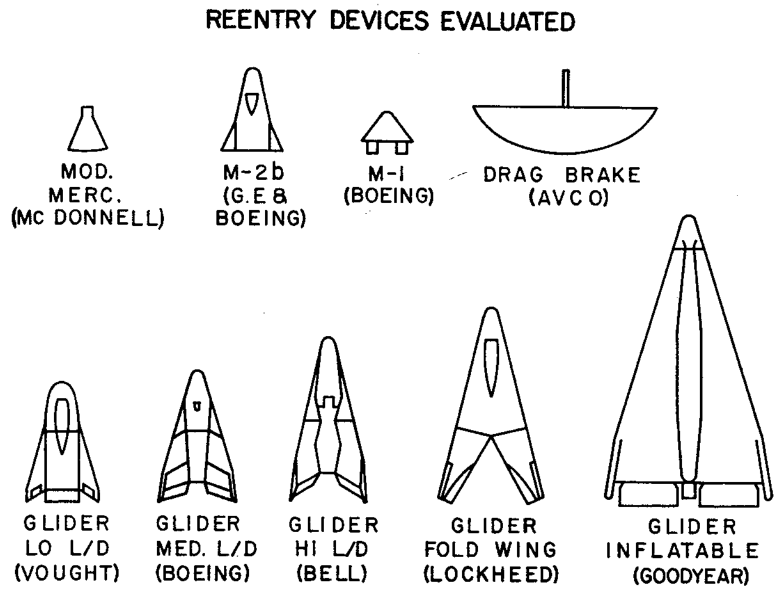

Figure 1

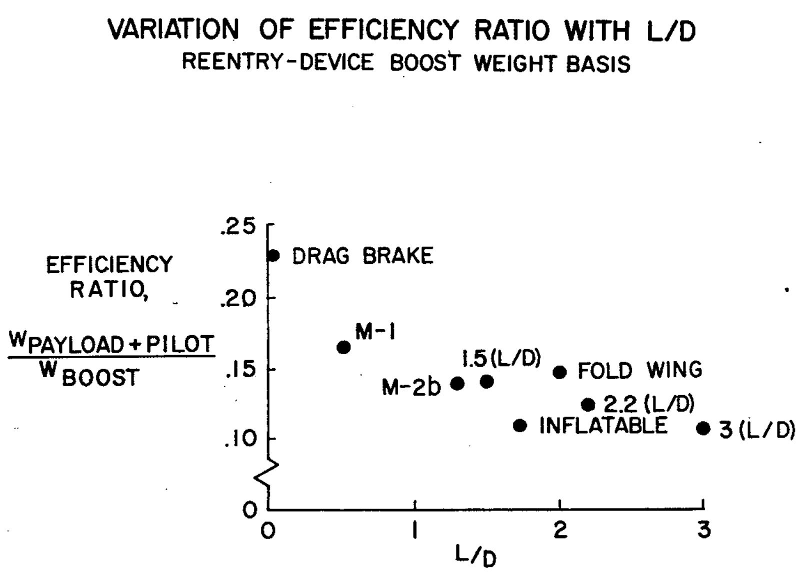

Figure 2

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LATERAL MANEUVER CAPABILITY

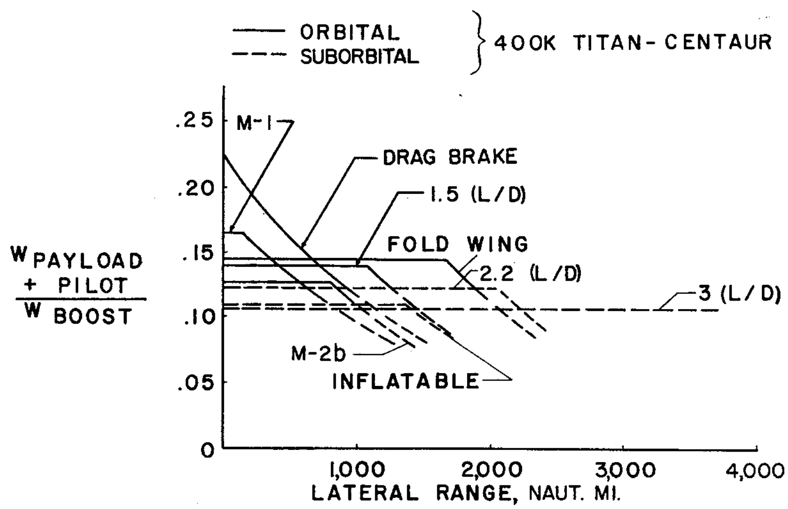

Figure 3

EVALUATION PROCESS (SCHEMATIC)

- DEGREE OF TECHNICAL CONFIDENCE ALREADY ACCOUNTED FOR IN TIME AND COST
- DEGREE OF TECHNICAL CONFIDENCE ALSO CONSIDERED AS POSSIBLE PERTURBATIONS ON VALUE, TIME, AND COST
- CONSIDERED JUDGEMENT TO ARRIVE AT DECISION

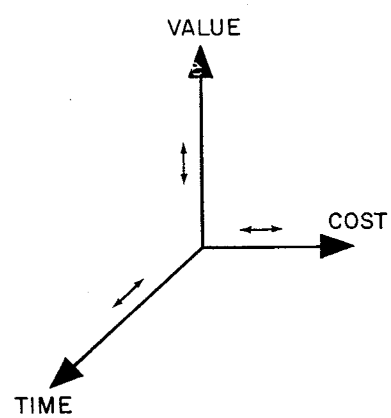

Figure 4

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