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Presentation Title:	Application of Paragliders to S-1 Booster Recovery for C-1 and C-2 Class Vehicles
Presented By:	Lewis L. McNair Marshall Space Flight Center Aeroballistics Division
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TITLE: Application of Paragliders to S-1 Booster Recovery for C-1 and C-2 Class Vehicles

This presentation will be a summary of the results of a feasibility study to investigate the "Rogollo Flex Wing" for use in dry landing booster recoveries. Feasibility studies were initiated concurrently with North American Aviation, Inc. and Ryan Aeronautical Co. in January of 1960 and terminated in August of 1960. Main emphasis was placed on the "Rogollo Flex Wing" or paraglider as applied to the recovery of the S-1 stage of the C-1 and C-2 class Saturn vehicles.

The program objective (slide #1) was to demonstrate the technical and economical feasibility of the paraglider for S-1 stage dry land recovery. Dry land recovery was a basic ground rule that was imposed at the time of this study, because of the low confidence level of the reuseability of materials recovered from salt water. This restraint may not necessarily be imposed on future recovery techniques. Salt water tests of propulsion units are proving to be much less obstructive to engine materials than at first expected.

The development of the flex wing represents a major advancement in the field of aerodynamic structure providing an extremely lightweight, aerodynamic lifting surface. Langley Research Center had prior to this study demonstrated the feasibility of the paraglider concept both in the wind tunnels and flight tests. Also, Ryan Aeronautical Co. had designed and built a manned utility vehicle incorporating the "Flex Wing" principle. The experience and test data derived at Langley and at Ryan, and the obvious structural weight and packaging advantages, suggested this concept as a highly desirable solution for the recovery of larger boosters.

The program study scope (slide #2) may be divided into four phases. (1) Preliminary design of the recovery system. This phase includes the parametric analysis necessary to define the wing geometry, and sufficient detail study of general characteristics to insure booster and wing compatibility for control during main fly back time and landing phase. (2) Method of attachment with minimum modification to booster. Since the S-1 stage at this time had been almost completely designed, extreme care had to be placed on the packaging of the wing within reasonable boundaries of the stage such as not to impose adverse aerodynamic and structural problems during flight. Special emphasis was placed on attachment of wing design to booster to insure adequate control during fly back and landing phase. (3) Complete operational and cost analysis. It is probably clear to everyone that the addition of a booster recovery system to a space vehicle program requires additional functions otherwise not needed if expendable boosters are employed. Typical of such functions are the recovery package operations of installation, checkout, and booster refurbishment after recovery. Other functions, such as transportation of boosters from the manufacturing site to the launch site, would be changed to the extent that such operations are required to support a given launch frequency. Cost analysis will very much depend on the operational sequence. These items will later be covered. (4) Detailed research and development. A R&D program would definitely be recommended for the C-2 type vehicle, but as of today (1962) the C-2 vehicle is not in the NASA overall program.

The S-1 booster physical characteristics are given on slide #3. The booster not including interstage has an overall length of 66 feet and a diameter of 257 inches. The booster cutoff weight is 120,866 pounds which includes about 15,000 pounds of residual fuels. The center of gravity at cutoff of booster is slightly toward the rear of the booster. For the case of fuel residuals at bottom of tanks, the CG would be at station 331 and for fuel residuals at top of tanks the CG would be at station 344. Stations are referenced from engine or base end of booster.

The configuration selected by Ryan and its mode of attachment to the booster is shown on slide #4. The wing is 100 feet long for the keel and leading edges with a wing area of 7,070 square feet, and a wing loading of 15 pounds/feet^2. The wing has a flat planform sweep-back angle of 45 degrees and inflated in flight to a sweep angle of 50 degrees. The wing membrane material may be either fabric or foil gage material depending upon the temperature requirements. The keel and leading edges would be of rigid aircraft structure design - rivited sheet metal construction.

A spreader bar located at approximately the 58 per cent keel and leading edge stations for minimum bending, is of tubular construction and deploys the leading edges to the desired sweep angle. Fixed cables attach the wing to the control bar and operating cables attach the control bar to the booster. The cables from the control bar to the booster allow for both pitch and roll control.

The booster cutoff velocity versus altitude is given on slide #5 for the various missions for both the C-1 and C-2 type vehicles. The various missions are escape, low orbit satellite, re-entry and Dyna-Soar. In comparing, one can see that the C-1 burn out velocities and altitudes are by a factor of three to four times as great as the C-2 values. It turns out, as we will see later, that these C-1 cutoff conditions are detrimental for flying back to land. The high altitudes coupled with the high velocities also produce excessive temperatures on the booster.

The anticipated C-2 sequenced mission profile is shown on slide #7 (similar for C-1 mission profile). Down range, lateral range, and altitude corresponding to the time of flight and associated event of flight are given.

The recovery system necessary for dry landing must permit scheduled energy dissipation under all boost missions and expected environmental conditions. Shortly after first stage burn out, a chute, approximately 36 feet in diameter, is deployed for stabilization (pitch and slide slip) and energy dissipation. The wing is deployed about 15 to 20 seconds after burn-out of first stage and the large chute is then ejected immediately. (This time period of 20 seconds permits a reasonable range of wing sizes to be deployed at lift coefficients up to C_L maximum and to maintain tolerable deployment loads). Shortly thereafter, a preset 30 degree bank angle command is initiated and a 180 degree turn is performed. The 180 degree turn indicates a desire to return to or near the original launch site. Fly back to the flare position is then made with a near $\frac{L}{D}$ maximum condition. The existing energy at the flare position is then used for execution of the final landing phase.

The C-1 glide or fly back to land capability for various winds and no wind conditions is given on slide #6. The range or impact footprints is given for an azimuth 110 degrees East of North. From a range safety viewpoint, this is about as far south as firings would be allowed. The wind magnitudes given as 97% and 95% probability levels are defined as values that will not be exceeded during the worst month of the year (March) at and surrounding area of Cape Canaveral not more than 3 and 5 percent, respectively.

The wing loading was 4.0 pounds/feet^2 which was determined mostly from loads and heating viewpoint.

The two outer circles show impact points for the vehicle flying with a tail wind, which indicates for these assumptions the booster would have a possibility of landing on some of the down range islands. Unfortunately, we cannot live under the assumptions of always being assisted by winds to gain more range; it is just as likely that the booster would be flying under head wind conditions which would confine the impact points to the inner most two circles. The middle circle shows the impact points for glide under no wind conditions.

The important thing to be gained from this slide is that no guarantee can be made for dry landing for the C-1 type booster. Since dry landing was a ground rule of this study, the idea of recovering the C-1 type booster will be dropped at this point and the remainder of this discussion will concentrate on the recovery of the booster for the C-2 type vehicle.

The effect of wing loading on range is shown on slide #8. Two representative extreme cutoff conditions were chosen, namely, the re-entry test mission and the Dyna-Soar mission. The effects of winds both head and tail for the 97% probability of occurrence along with the no wind case are shown. Since tolerable loads and temperatures did not prove to be exceeded during flight, the wing loading was chosen on the basis of achievable range. Thus, as indicated by slide, the wing loading is chosen to be 15 lbs/ft^2.

With this wing loading, the C-2 fly back capability is given on slide #9. The assumed firing azimuth of 45 degrees East of North was chosen only for convenience. The most adverse case, the Dyna-Soar Mission, was chosen for demonstration of fly back capability. Here, as in the C-1 case, the range impact areas are shown for the various wind and no wind conditions. This points out that it is possible to return to the vicinity of Cape Canaveral for all considered environmental conditions with the exception of the 97% probability head wind which is slightly marginal.

At this point, it is noteworthy to point out that this range capability is achieved only with the $\frac{L}{D}$ values obtained from the wing with rigid leading edges. The $\frac{L}{D}$ values obtained from the inflatable leading edge wing are somewhat smaller and will not return the vehicle to the Cape.

Slide #10 shows main advantages and disadvantages of the rigid leading edge wing and the inflatable leading edge wing. The rigid leading edge wing provides a maximum $\frac{L}{D}$ of 3.85; whereas, the inflatable leading edge only produces a maximum $\frac{L}{D}$ of 2.5. This difference in $\frac{L}{D}$ is sufficient to render no dry landing capability for the inflatable leading edge wing, whereas, the rigid leading edge wing provides sufficient range for all cases except the Dyna-Soar Case (highly improbable).

The structure weight of total system for the rigid leading edge is estimated to be about 8% of recovered weight. The inflatable leading edge wing combined with system structure is estimated to be between 6 and 8% of recovered weight. These weight estimates are given by the Ryan Aeronautical Company. North American Aviation weight estimates of the different constructed wings are about twice as great. This, of course, is a significant difference in results of the companies.

Deployment may be made at high q values with the rigid leading edge wing; whereas, the inflatable rigid leading edge is thought to require low q deployments. For best use of energy dissipation, it appears necessary for fly back to Cape missions to have early deployment and turn around after first stage cutoff.

Slide #11 shows a more detail view of the Ryan selected rigid leading edge wing configuration attached to the booster. Since the proposed glide technique of recovery employs no auxiliary aerodynamic or jet reaction controls, very careful attention has to be given to the manner of booster suspension from the wing.

An aft end view of booster and wing combination is shown on the left hand side of the slide. The cables leading from the strong points of booster (both front and aft end) to the control bar are movable and are for pitch and roll control. Control is accomplished by properly controlling the total mass center of the system. The array of cables leading from control bar to the leading edges and keel are held fixed.

The right hand side of slide shows a side view of wing attached to booster. Longitudinal wing position and angle of incidence depend on the required booster angle of attack for various trimmed flight conditions or the pitch attitude desired for landing. For maximum range, the booster should fly with a near zero angle of attack. It is possible to fly with adequate stability at a wing angle of attack (α_w) up to 20 degrees, which corresponds to just above $\frac{L}{D}$ maximum. A greater α_w value usually results in a radical pitch up as a result of normal transient conditions encountered during the trajectory.

During the flyback portion of the trajectory, wing incidence is commanded by the ground operator to keep the vehicle along the desired flight path. Phugoid motion will occur at nearly constant angle of attack but the automatic trimming system will damp out the phugoid mode, while preventing variations of wing angle of attack to angles not consistent with $\frac{L}{D}$ maximum.

The system as shown here may be considered completely rigid, thus eliminating requirements for interrelated booster dynamics with respect to the wing.

The actual flight path during flare will be determined to some extent by the variable vehicle configuration and variable inflight conditions upon initiation of the flare maneuver. The flare command system is not designed to establish a fixed flight path during flare, but rather a specifically commanded sink rate as a function of altitude. This method results in an appropriate utilization of the energy available during flare. In general, this means that systems with excess energy perform longer, slower flares to dissipate energy as a result of drag. Systems with less or minimum energy will initiate flare automatically at an altitude at which the system is capable of a successful flare. Conceptually, the control commands during flare are computed by a ground-based computer and transmitted to the wing control system by radio link. The ground base computer utilizes altitude and range information to compute the error equation.

A typical example of the system performance during flare is given on slide #12. The simulated system performance is measured against the commanded sink rate. Touchdown was accomplished with less than 5 ft/sec vertical velocity. The final landing gear design is based on landing skis with conventional energy absorbing oleo struts.

Since the subjects of control, flare, and landing requirements for the paraglider system is going to be covered in later talks by Langley Research Center, I will not dwell further on these subjects.

A schematic diagram of the rigid wing packaging attachment to booster and deployment sequence is given on slide #13. The rigid wing is packaged between a single lox and fuel tank. Next to the wing between adjoining fuel and lox tanks, the keel and control bars are housed. In the nested position, the wing, fairing door, and control bar will be attached to the booster at approximate stations 187 and 771. There will be clips welded to the tanks to accommodate straps across the wing to minimize deflection and vibration. Clips will also be added to accommodate cables crossing over tanks from the control bar to wing.

Cartridge ejection separates the package from the booster. This ejection mechanism is attached to the top leg of the forward spider and will operate on tracks. An ejection hammer strikes the folded aft end of the keel, imparting a rotational moment. A second lip on the ejection hammer then strikes the wing apex. This system is sequenced in such a manner as to impart translational and rotational energy to the keel to insure positive separation and unfolding of the

100 foot keel, Ejection of the undeployed wing also causes, by cable attachment, control bar separation from the booster. Cable tension, within the wing and control bar, causes spreader bar action which forces both wing and control bar in their operating geometry.

It may at this point be well to point out that very little is known of deployment characteristics of such a wing for high dynamic pressures.

The main steps of the booster re-use cycle are shown on slide #14. The addition of a booster recovery system to a space vehicle program requires additional functions otherwise not needed if expendable boosters are employed. Typical of such functions are the recovery package operations of installation, checkout, and booster refurbishment after recovery. Other functions, such as transportation of boosters from the manufacturing site to the launch site, would be changed to the extent that such operations are required to support a given launch frequency.

The installation and checkout of recovery package would be done on pad at launch or within the near area depending upon installation requirements. Transportation from landing site to refurbishment site would probably be done by large trucks with special equipment for transporting boosters. Then, after refurbishment is complete, the boosters may either go to storage or back to the launch site for further action.

All of the steps in the re-use cycle have definite inputs to the cost analysis of such a program.

A booster program savings versus average launch per booster is shown on slide #15. The program cost without recovery for a launch rate of 12 per year for a 12 year period was estimated at 1.3 billion dollars. The parameter E is defined as the ratio of refurbishment cost to original cost of booster. E was chosen to be .2, .4, and .6 respectively. This graph was based on recovery mission reliability of 60% and an average payload of 40,000 lbs. to low orbit. (C-2 configuration)

A most probable range relative to number of launches per booster is from 2.4 to 3.7. These limits are based on the flex wing recovery system reliability analysis, which is converted from probability of booster re-use to launches per booster. The minimum point, and most conservative, within the probable range (2.4 launches per booster and a 60% of booster cost allowance for refurbishment) indicates a total program savings of 185 million dollars; while the maximum point and most liberal (3.7 launches per booster and a 20% of booster cost allowance for refurbishing) shows a total program savings of 644 million dollars.

The last slide, #16, gives a summary of conclusions and recommendations. The conclusions are as follows:

(1) Boosters for C-2 type vehicles may be recovered on dry land (Cape area) by application of paragliders.

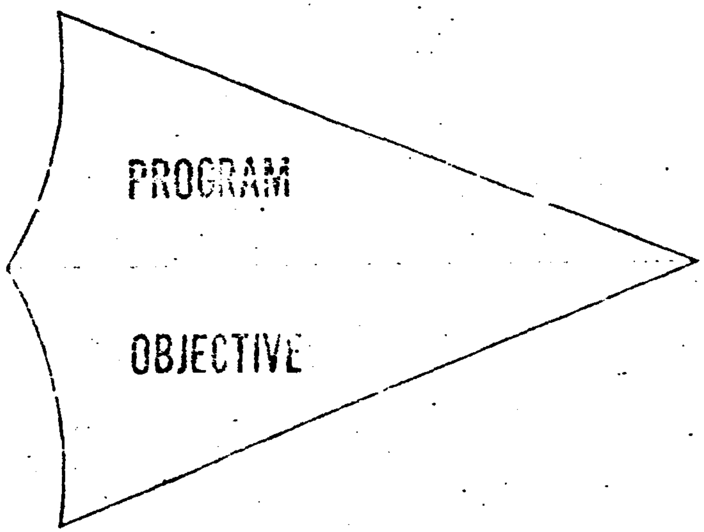
(2) Packaging of the wing system could be done within contours of C-2 booster.

(3) A general package type recovery system could be installed on booster. This implies almost no modification to booster structure.

(4) Recovery system weight is about 8% of recovered weight.

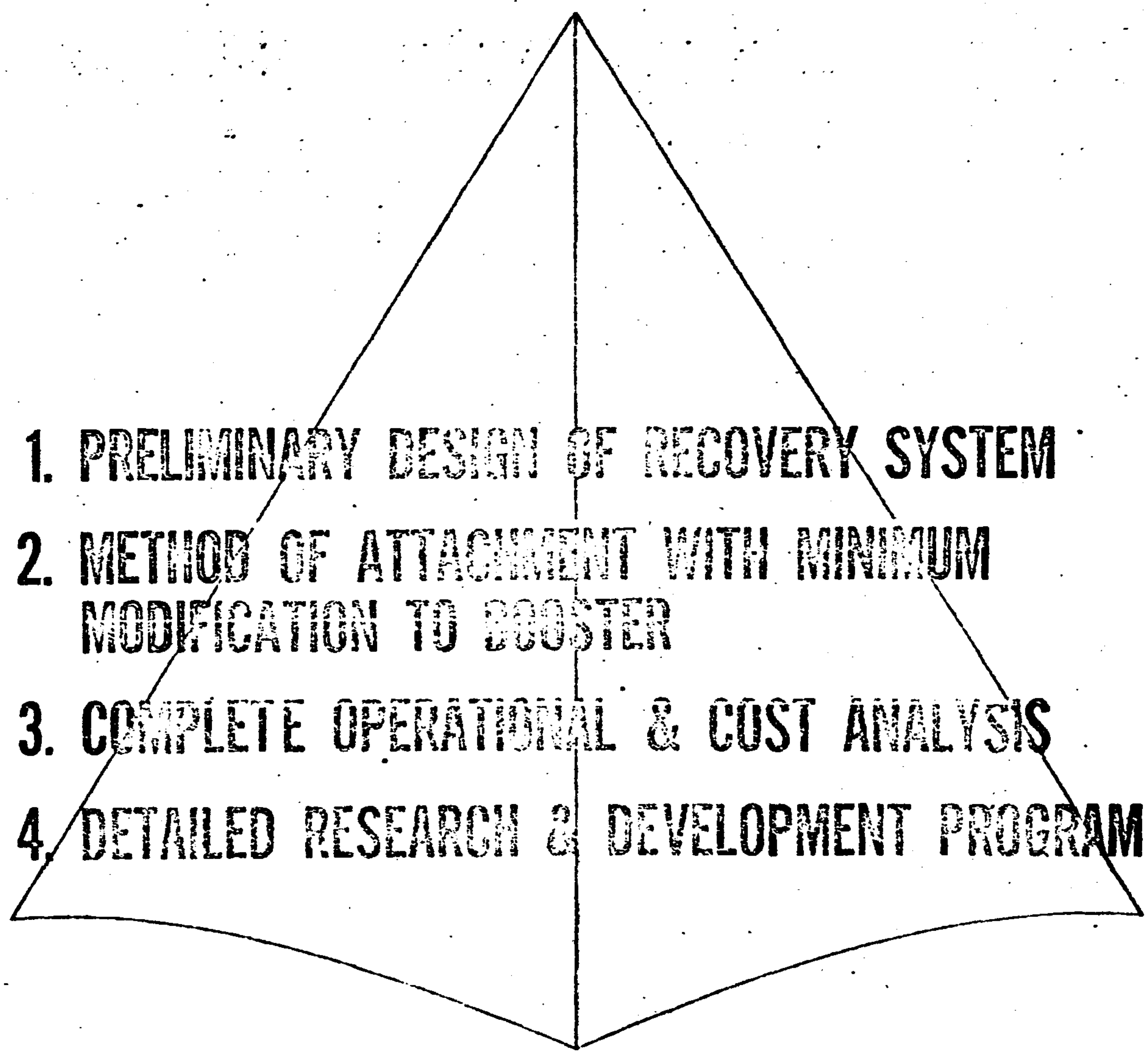
(5) Sink speeds of 5 ft/sec or less are possible to obtain during flare and landing.

The recommendations at the time of study (1960) were to start immediately on a program of development which included hardware testing, etc. Unfortunately, the C-2 type vehicle is now not in the plans of NASA launch vehicles; thus, no development plans are in progress.



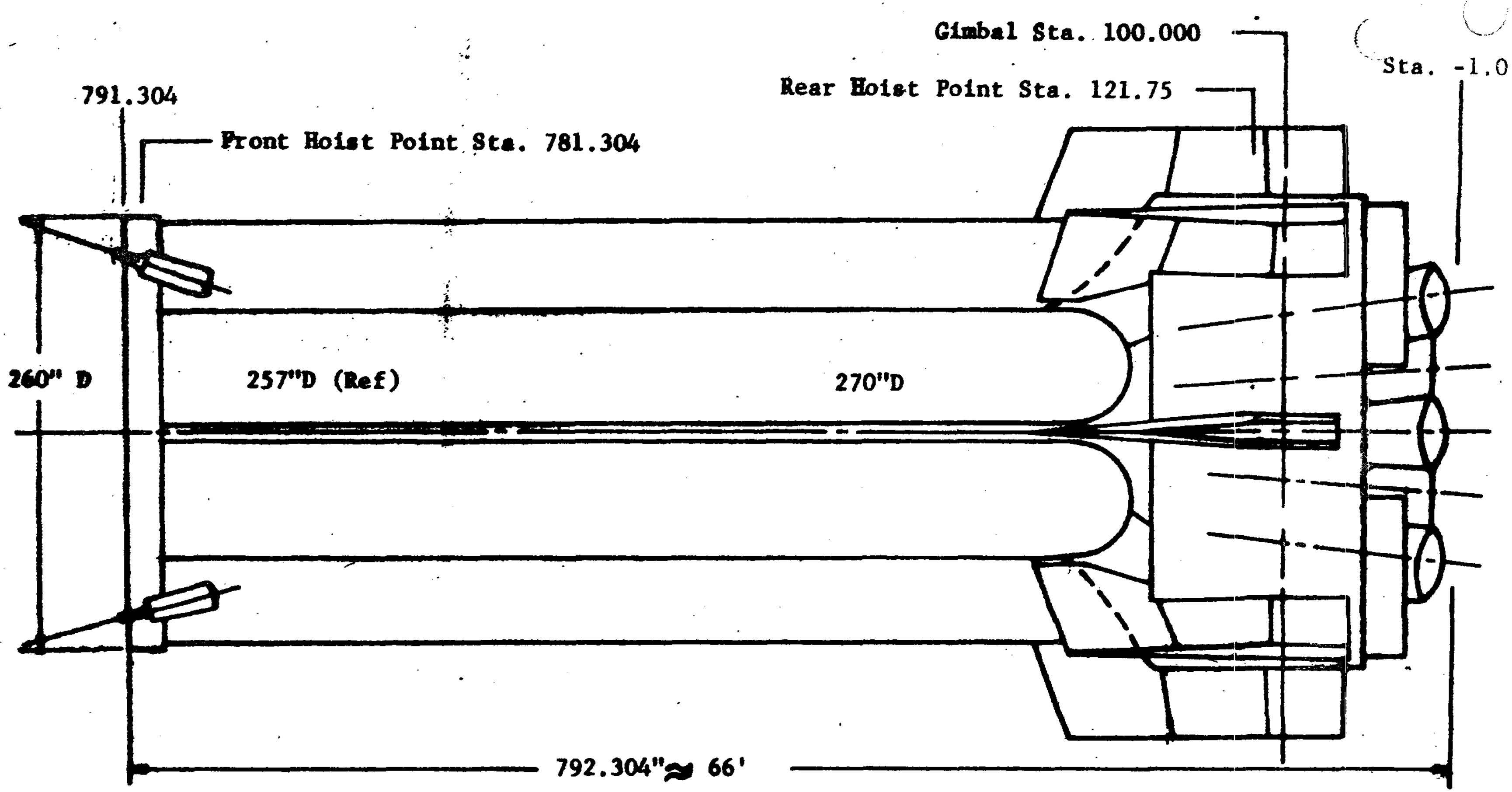
TECHNICAL AND ECONOMICAL FEASIBILITY OF THE RUGALLO "FLEX WING" FOR SATURN S-1 BOOSTER DRY LAND RECOVERY

Fig. 1



PROGRAM SCOPE

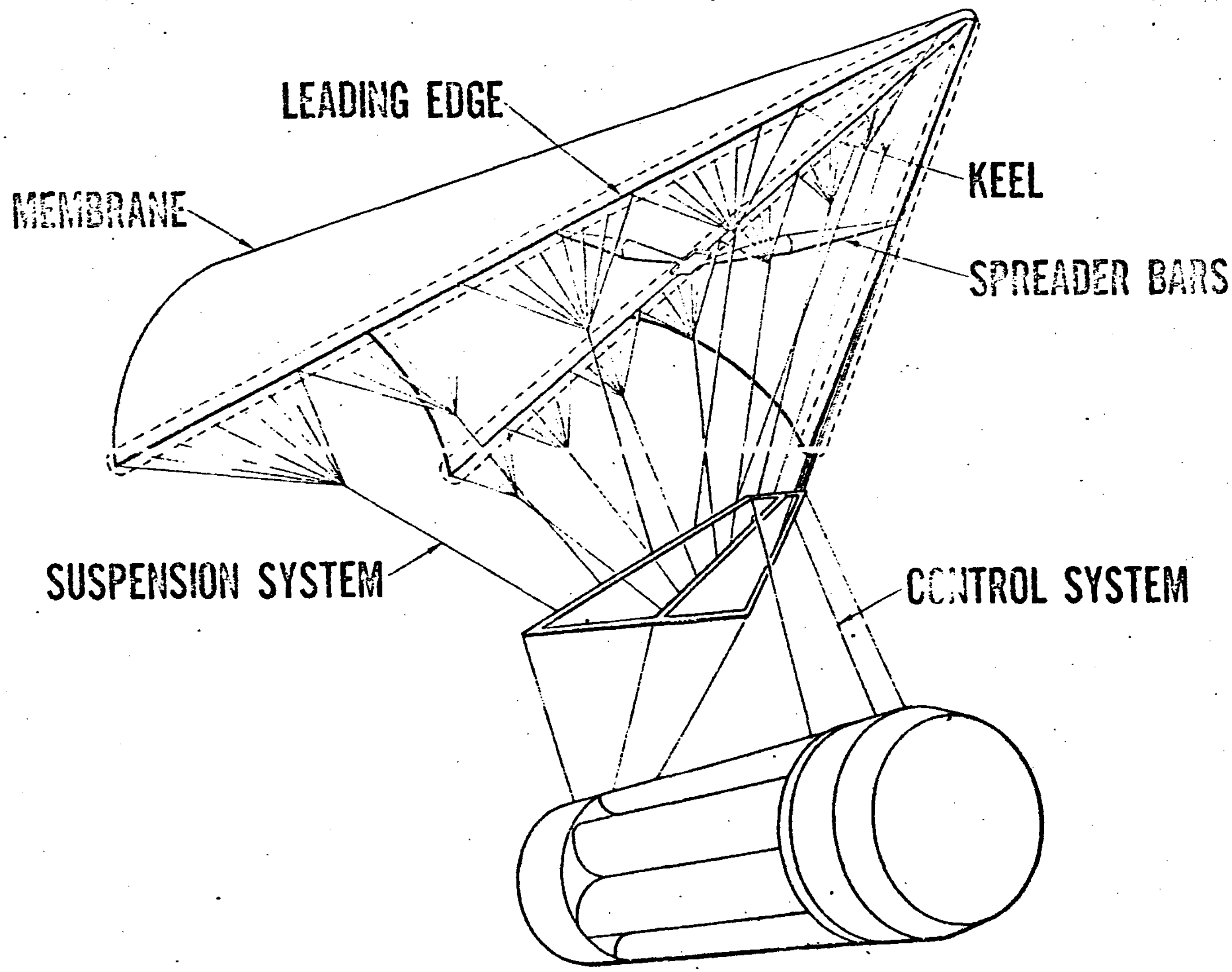
Fig. 2



C-2 VEHICLE, S-1 STAGE PRELIMINARY MASS CHARACTERISTICS

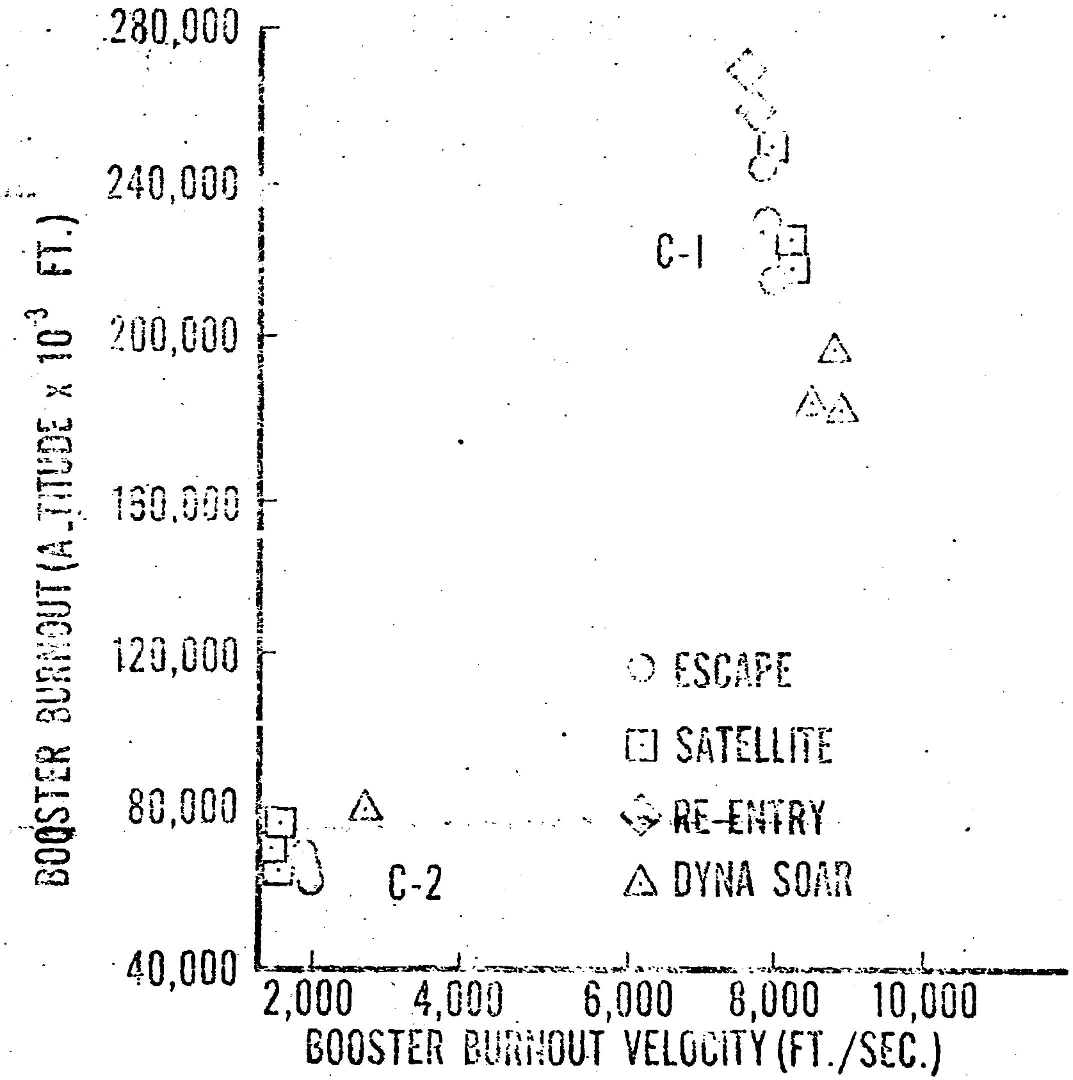
	Weight (lb)	C.G. Sta.	Moment of Inertia Pitch	Roll
Dry Booster (Including Fins)	88,000	307	217,168	15,808
A. Front Hoist Point Load	25,785	781.304		
B. Rear Hoist Point Load	62,215	121.750		
Dry Booster with S-1/S-11 Inter. Sect. Retro Rockets, & Recovery Package	106,000	344	284,331	22,099
Booster at Separation (Separation Sta. 868.304)				
Case 1. With Residual at Bottom of Tanks	120,866	331	303,897	24,598
Case 2. With Residual at Top of Tank	120,866	344	318,812	24,598

Fig. 3



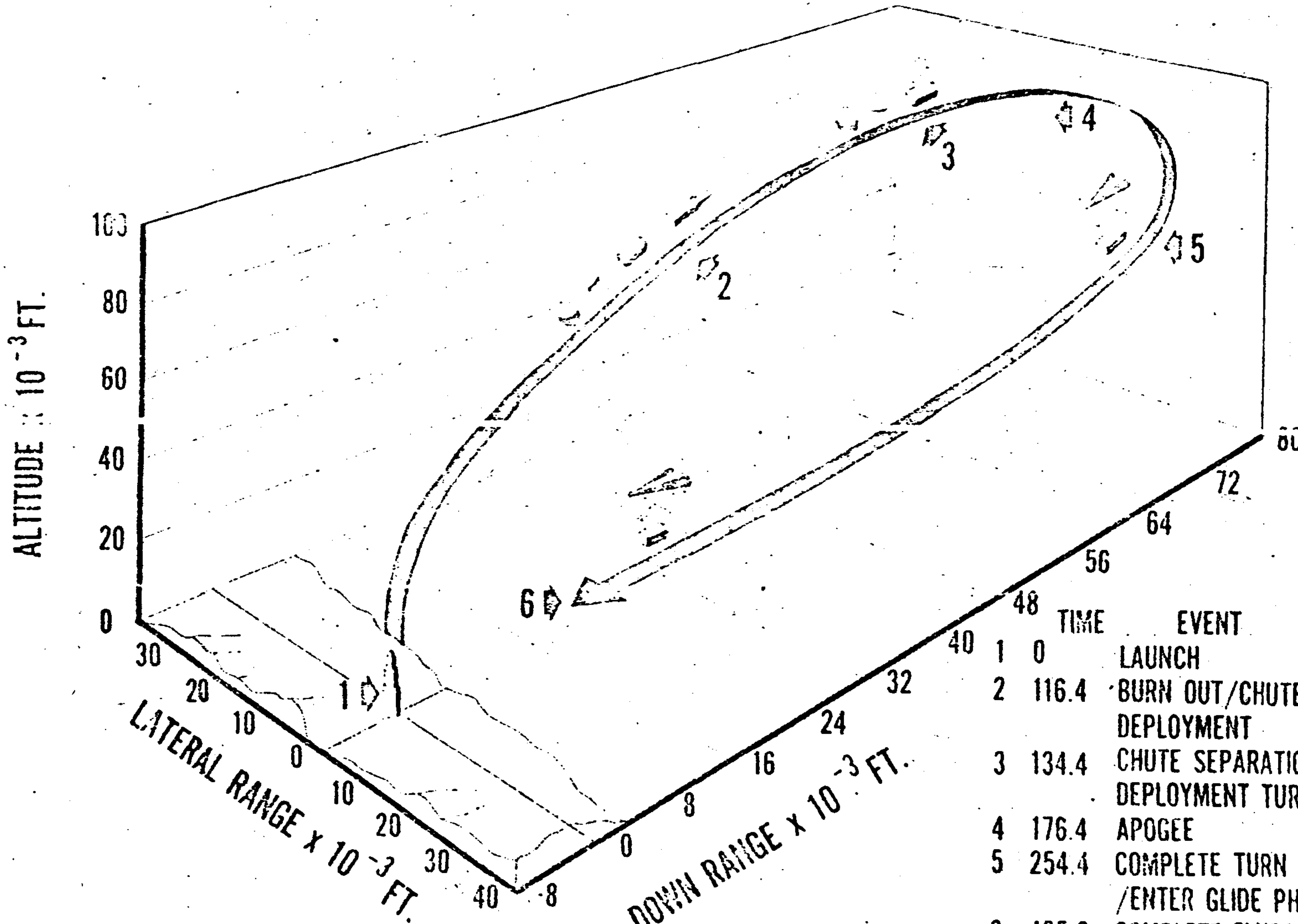
FLEX WING CHARACTERISTICS

Fig. 4



BOOSTER BURNOUT STUDY CONDITIONS

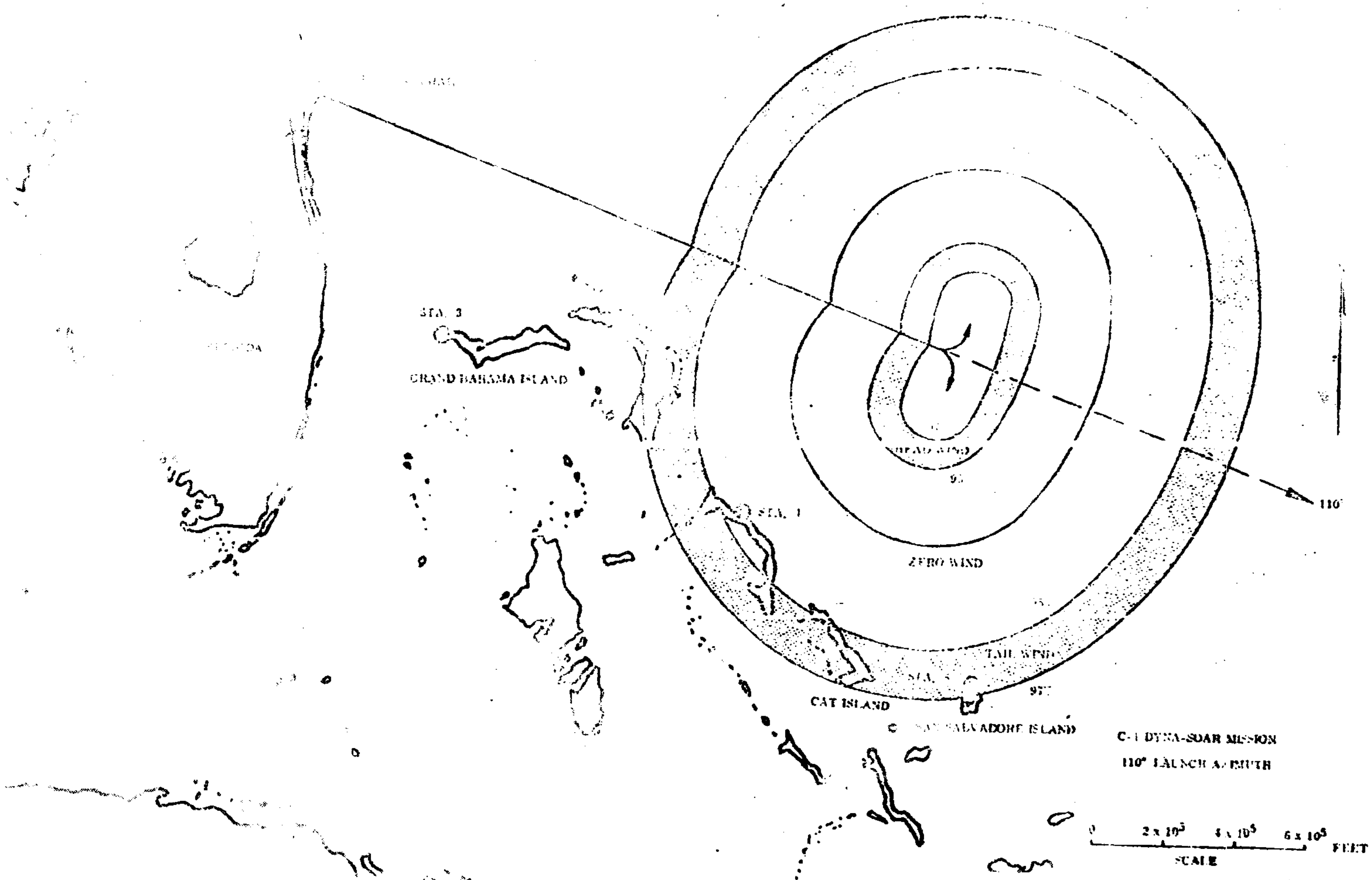
Fig. 5



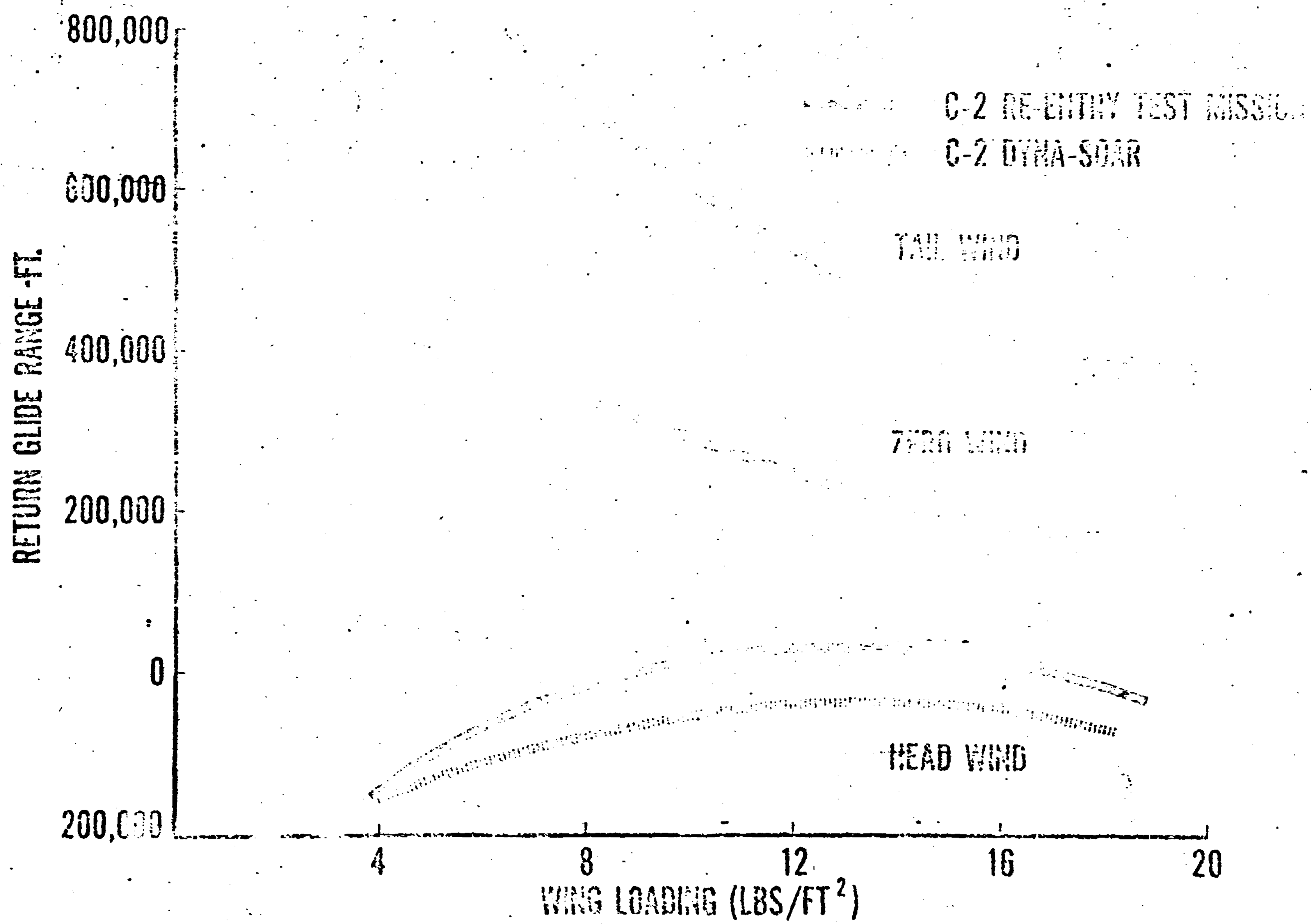
	TIME	EVENT
1	0	LAUNCH
2	116.4	BURN OUT/CHUTE DEPLOYMENT
3	134.4	CHUTE SEPARATION /WING DEPLOYMENT TURN EXECUTION
4	176.4	APOGEE
5	254.4	COMPLETE TURN AROUND /ENTER GLIDE PHASE
6	425.0	COMPLETE FLYBACK USE REMAINING ALTITUDE FOR EXECUTION OF LANDING PHASE

C-2 MISSION PROFILE

Fig. 6

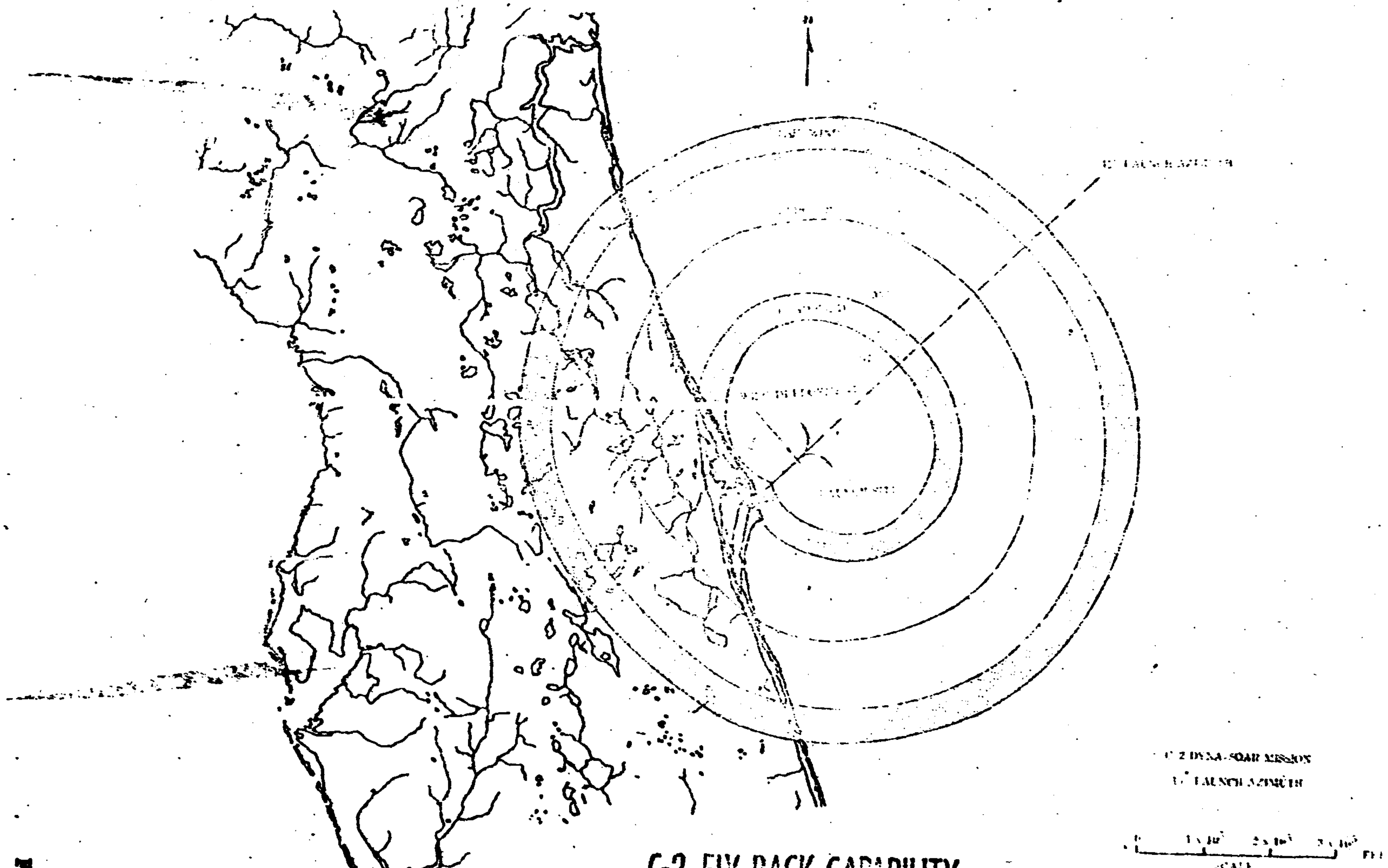


GLIDE CAPABILITY



GLIDE RANGE vs WING LOADING

Fig. 8



C-2 FLY BACK CAPABILITY

Fig. 9

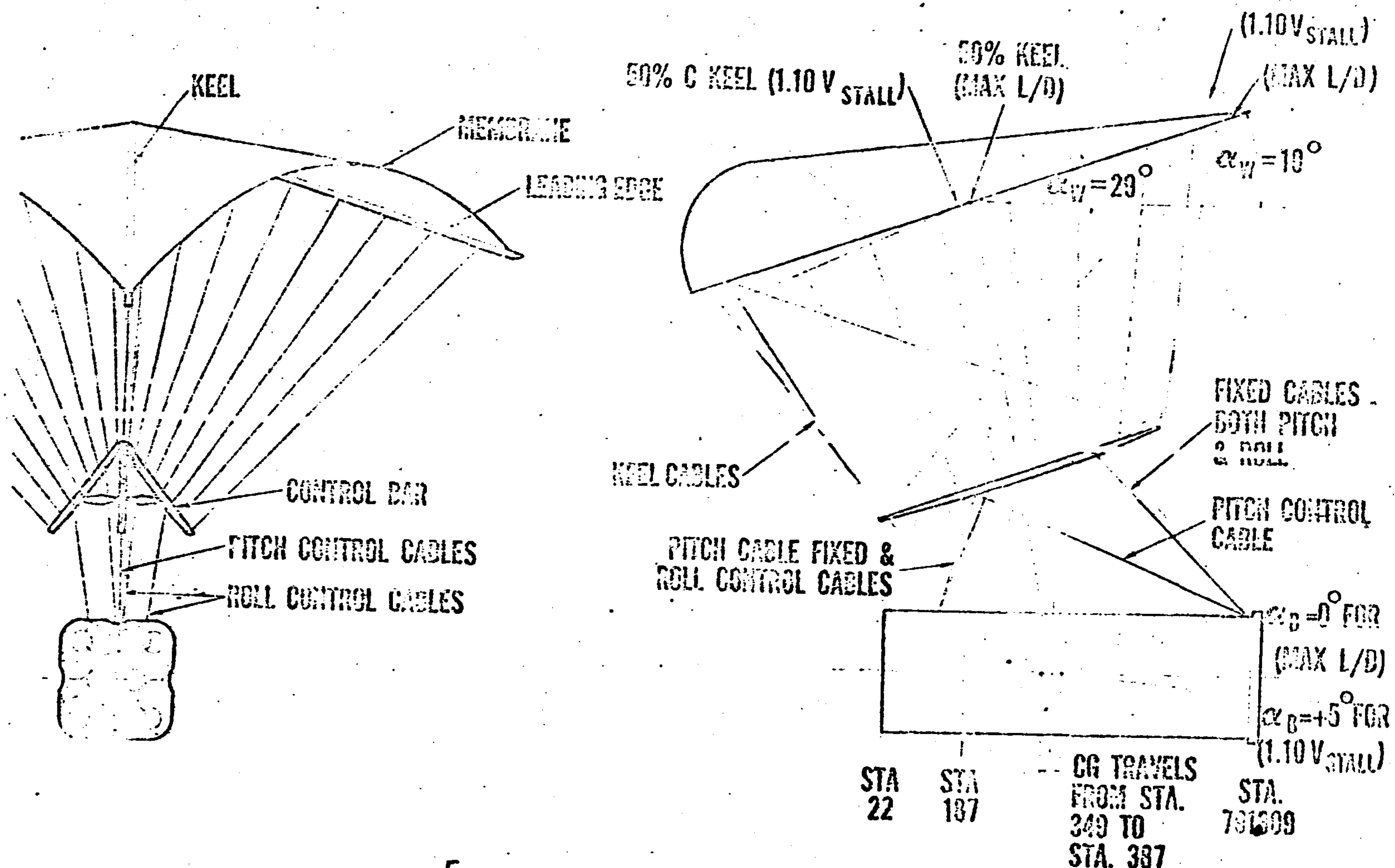
	RIGID LE	INFLATABLE LE
MAXIMUM GLIDE	$L/D = 3.35$	$L/D = 2.5$
	DRY LANDING CAPABILITY FOR [illegible] G - 2 [illegible] [illegible] - SOAR	NO DRY LANDING CAPABILITY
STRUCTURE WEIGHT	8% RECOVERED WEIGHT	6% TO 8% RECOVERED WT.
PACKAGING	MORE DIFFICULT	COMPARATIVELY SIMPLE
DEPLOYMENT	HIGH "G" DEPLOYMENT CAPABILITY	LOW "G" DEPLOYMENT CAPABILITY

$\underbrace{\text{HIGH "G" DEPLOYMENT CAPABILITY}}_{\text{REQUIRED FOR MISSION}}$

REQUIRED FOR MISSION

RIGID LEADING EDGE
VS
INFLATABLE LEADING EDGE

Fig. 10



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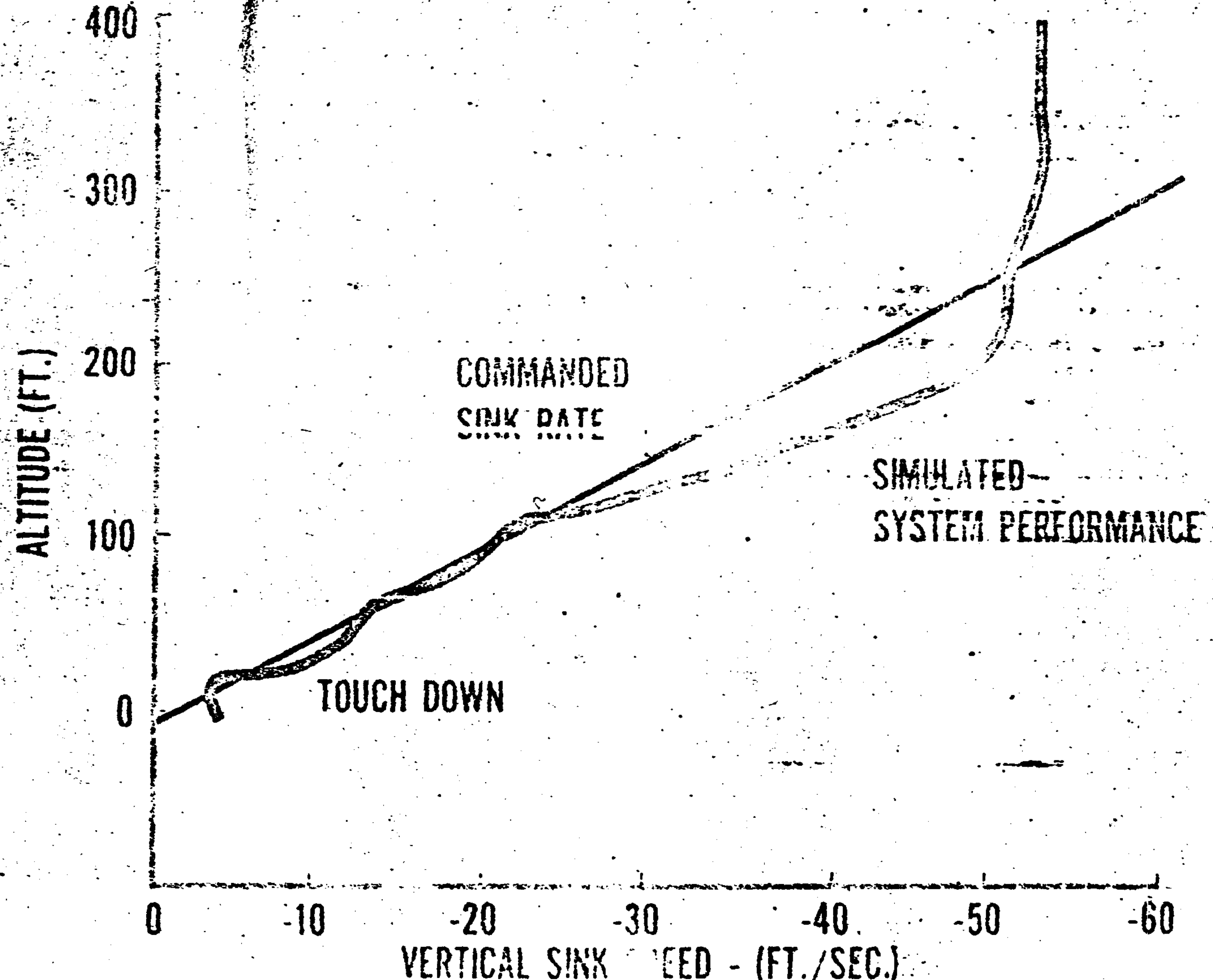
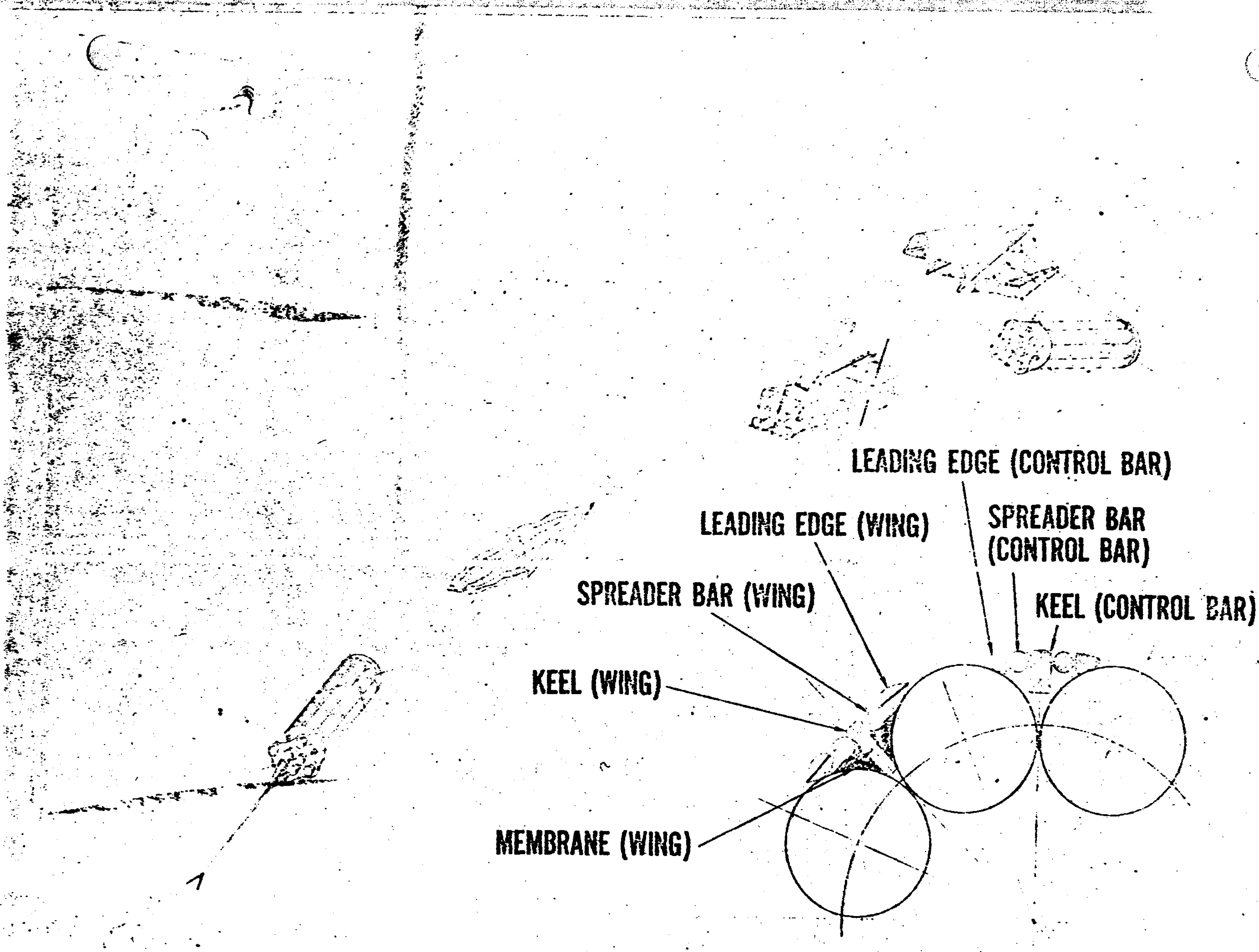
[illegible] L DING [illegible] DESIGN CONFIG[illegible]ATION

Fig. 11



SYSTEM PERFORMANCE DURING FLAIR

Fig. 12



PACKAGING & DEPLOYMENT

Fig. 13

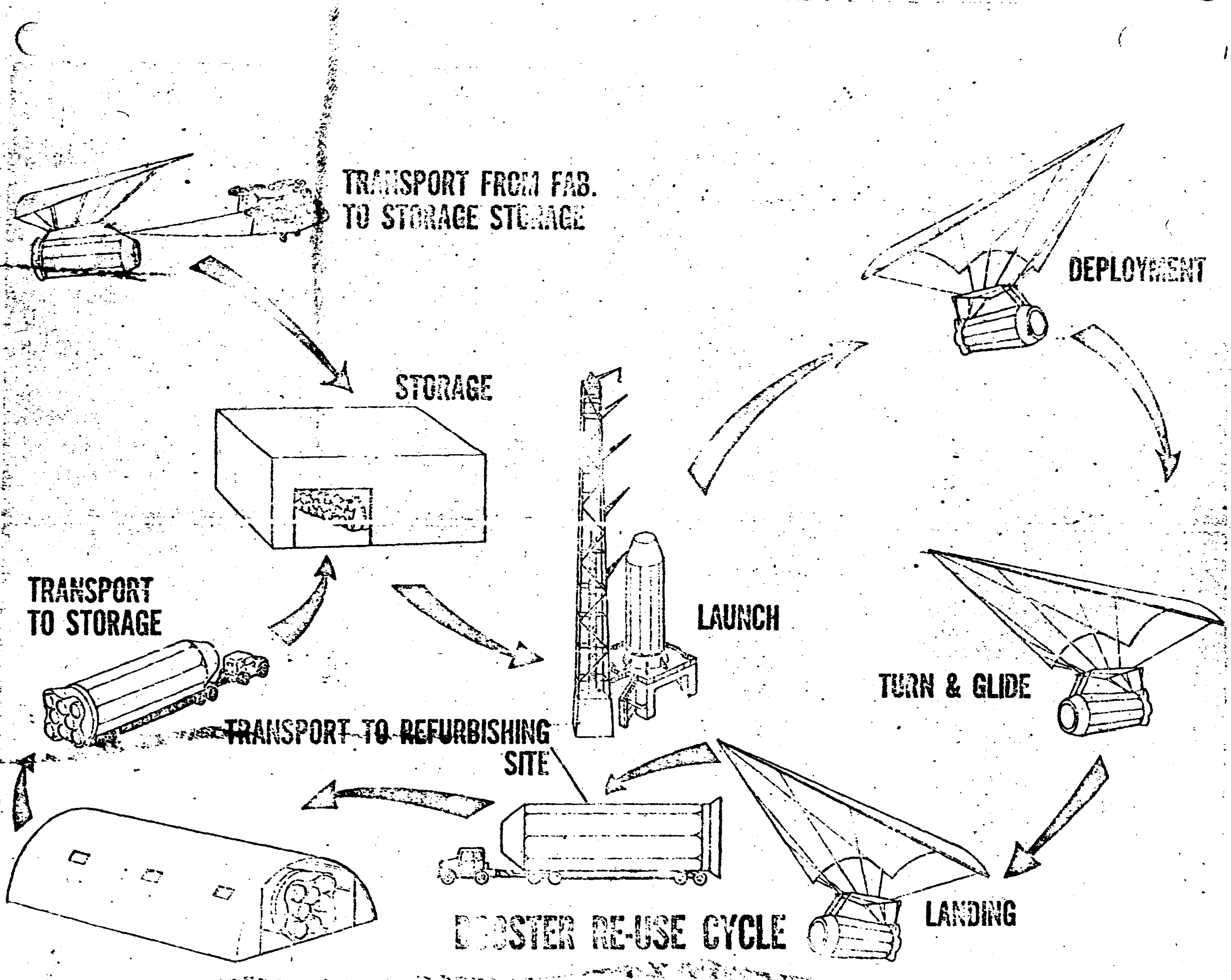
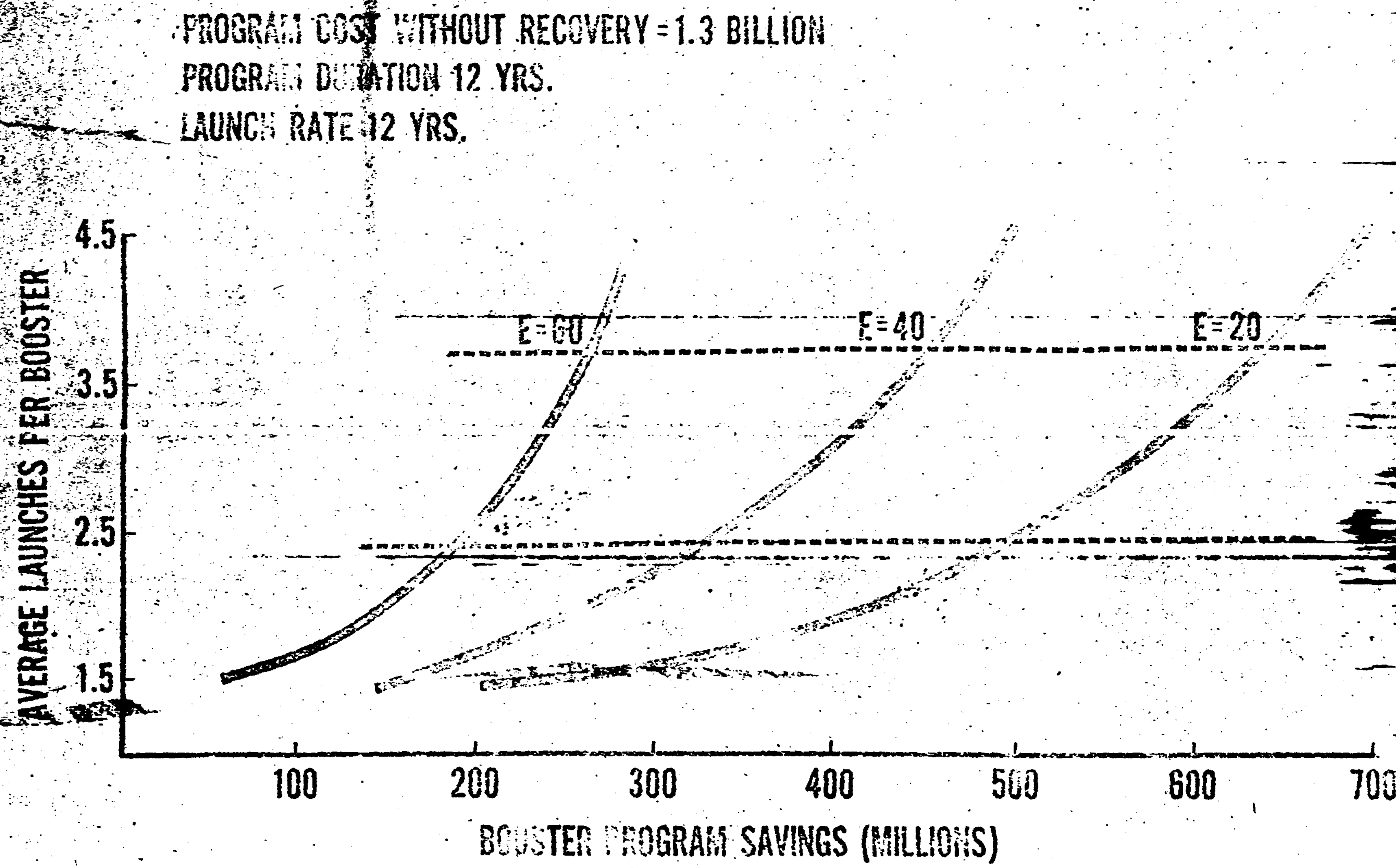

TRANSPORT FROM FAB.
TO STORAGE STORAGE
DEPLOYMENT
STORAGE
LAUNCH
TRANSPORT
TO STORAGE
TURN & GLIDE
TRANSPORT TO REFURBISHING
SITE
LANDING
BOOSTER RE-USE CYCLE

Fig. 14



AVERAGE LAUNCHES PER BOOSTER vs BOOSTER PROGRAM SAVINGS

Fig. 15

CONCLUSIONS

1. C - 2 DRY LAND RECOVERIES ARE POSSIBILITIES

2. PACKAGING WITHIN C - 2 ~~COUNTERS~~ ConTours IS POSSIBLE

3. PACKAGE "TYPE" RECOVERY SYSTEM INSTALLATION IS POSSIBLE

4. RECOVERY SYSTEM WEIGHT EQUALS 8% OF RECOVERED WEIGHT

5. SINK SPEEDS EQUAL TO 5FT./SEC. OR LESS ARE POSSIBLE

RECOMMENDATIONS

1. PROGRAM DEVELOPMENT

Fig. 16