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RECOVERY OF ORBITAL STAGES

By

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The reasons to be interested in the recovery of a stage that reaches orbital injection conditions (usually a second stage) are basically the same as for the recovery any other piece of space hardware:

1. Post-flight inspection affords the detection of design shortcomings and a better evaluation of the actual environment of the component (loads, heat input etc.).

2. Reduction of cost per pound of payload in orbit due to re-use of hardware.

3. Operational advantages of positive disposal of hardware and if possible return to the refurbishment and launch site.

While post flight inspection is always desirable from an engineers point of view in order to advance the state of the art, it looks like that the development of a recovery system can only be sold on the basis of points 2 or 3 above.

To prove the desirability of recovery on a cost basis alone would require that all developmental and operational costs referred to the reduced payload in orbit would come out cheaper than in the case of an expendable reference vehicle. Studies performed or contracted by MSFC in this area showed that this point could be proven for first stages assuming the present state of the art. The discussion of cross-over points, of course, is influenced very strongly by the basic cost assumptions. At the present time, it seems, that no cost reductions can be derived from second stage recovery.

The third and by no means less important aspect is the operational. It can be expected that the volume of launch operations in support of

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orbital operations, lunar and planetary missions will continue to grow and will reach dimensions where the controlled disposal of all spent space hardware will become mandatory. Taking an expendable vehicle with such a "disposal" system and its reduced performance as reference, it might prove that full recovery and return of all stages can become economical. The requirements for recovery forces will grow proportionally to the volume of the launch operations. It is obvious that the capability to return to the launch base has to be more and more incorporated in the vehicle. This would in turn speed up the refurbishment and increase the overall flexibility of the operation.

That means that the first stage requires sufficient propulsion for fly-back, and that the second stage glides back to the launch site after one or more revolutions around the earth and subsequent aerodynamic re-entry.

To study the sensitivity of various parameters of recovery the Marshall Space Flight Center sponsored three industry study contracts (NAS 8-1513/1514/1515) on the subject "Study of a Two to Three Million Pound Thrust Launch Vehicle". The basic mission was defined as two-stage to 307 N. M. orbit. Recovery was to be considered for both stages. Fig. 1 shows a typical mission profile.

An evaluation of the final reports of the three studies with respect to structural weight increases due to recovery was made and the results are shown in Fig. 2. The parameter shown is the weight of the recovery system in percent of the structural weight of the expendable reference vehicle, based on equal propellant ratio, i.e., on equal ideal velocity increment of recoverable and expendable stage. The data generated by the different companies scatter considerably. This is partly due to the different assumptions with respect to structural efficiency as indicated by the structure ratio of the expendable reference vehicle shown in Fig. 3, partly due to the relative novelty of a particular recovery mode. We expect to be able to smooth out some of the scatter in these data after a presently going study of fixed wing recovery systems* has been evaluated. In order to get a better feel for the performance penalty associated with orbital stage recovery by paraglider a conceptual design study was performed at MSFC, the results of which will be discussed later in some detail.

In the case of a two stage to orbit configuration we find that there is a payload decrease of about 1 lb per 5 lbs increase in first stage structure weight and a payload decrease of 1 lb per 1 lb increase in second stage structure weight.

In addition to that the increase in second stage structure weight due to recovery is considerably higher than that for first stage recovery. This is mostly so because of the more severe re-entry environment and the much longer glide and exposure times requiring heavier thermal protection.

This explains why second stage recovery is so expensive in terms of payload. Fig. 4 shows the effect of second stage recovery on the payload of a two stage to 307 N. M. orbit configuration with an initial weight of $2.4 \cdot 10^6$ lb and $3 \cdot 10^6$ lb thrust. First stage LOX/RP; Second Stage LOX/LH_2. The ascent trajectories utilized intermediate parking orbits and Höhmann transfer up to 307 N. M. altitude. The recovery factor, as defined by NAA, see Fig. 4 for equation, represents the ratio between the stage structure weight factors of the recoverable and the expendable reference vehicles. The figure shows on its left side for $K_2 = 1.0$, which means no weight added for second stage recovery, the payload performance of the corresponding lower stage (again with or without recovery) carrying an expendable second stage.

Some of the scatter in the payloads shown can be explained by different staging orbit altitudes and different "kicker systems" to

*Conceptual Design Study of Ten Ton Reusable Orbital Carrier Vehicle NAS 8-2687/5037.

perform the transfer maneuver up to the target orbit. The recovery modes suggested for study in the "2-3 Million Pound Thrust Launch Vehicle Study" were "Paraglider" or "Fixed Wing". The lightest of these modes of course is the Paraglider, although, as you saw from Fig. 2, this sytem can amount to a sizable weight penalty. Increasing second stage recovery factor K_2 means heavier and more sophisticated recovery systems, usually associated with extended cruise capability.

I would now like to present some details on our parametric design study of the application of a paraglider to the recovery of an orbital stage.

The paraglider concept looked attractive to us because of its light weight, the simplicity of the system, the possibility to stowe it away in a fairly small volume along the stage which would not penalize the vehicle configuration during ascent, and the inherent stability of the paraglider configuration.

With respect to the mission we assumed that the payload shall be delivered in a 307 N. M. orbit using a two-stage plus "kicker-stage" arrangement. The second stage burns out at low altitude at a velocity equal to the local orbital velocity plus the velocity increment for Hohmann transfer up to 307 N. M. Then it was assumed that the empty stage plus payload were injected into orbit. After waiting in orbit the orbital stage was brought to re-enter with a zero altitude virtual perigee, corresponding in this case to a flight path angle of 92 deg at 400,000 ft altitude.

Starting from this condition we investigated the influence of paraglider wing loading and deployment altitude on the thermal protection requirements and the overall structural weight of the paraglider package. The characteristics of the stage were those of an early version of a Saturn second stage.

The wing loadings considered were 1.25; 5; 10 lbs/ft^2. The deployment conditions investigated were 400,000 ft altitude; maximum dynamic pressure, and finally Mach 5.

Upon entry into the sensible atmosphere a drag device would be deployed to stabilize the stage. This drag device would be retained after deployment of the parawing. The de-reefing of the wing was controlled to keep the normal acceleration of the stage below a certain limit. The following assumptions were made on the part of the paraglider system:

- The physical dimensions of the paraglider wing installations of different wing loadings are assumed to be geometrically similar;
- Keel length equals leading edge length for easy stowing;
- Wing leading edge sweep angle in fully deployed condition is $\varphi = 50°$
- C. G. location required to fly at subsonic L/D_{max} and 11% static margin is 0.65 $\bar{c}$ below wing leading edge, and 0.55 $\bar{c}$ behind leading edge of $\bar{c}$;
- The wing would be oriented at an angle of attack that yielded max. L/D for that particular wing/body combination; supersonic flow: $\alpha \approx 40°$; Subsonic flow: $\alpha \approx 25°$;
- The stage body is always oriented parallel to the flight path;
- The net structure weight of the stage, which is equal to the weight recovered was $W_n = 41,000$ lb;
- The basic structure weights of the paraglider packages were obtained by scaling with respect to wing loading;

W/S [lb/ft^2]	W_{5s}/W_n [%]
15	13
10	16
5	25
1.25	78

Assumes load factor n = 6

- In scaling of the structural weights from a 15 lb/ft^2 wing loading base point vehicle the following assumptions were made:

1. Wing structure weights scale proportional to wing area, i.e., inversely proportional to wing loading.

2. Cable weights scale inversely proportional to the square root of the wing loading under the assumption of a geometrically similar suspension system. (Only length affected. Loads and ϕ are same.)

3. Landing gear, control system and drogue body structural weights are roughly independent of wing loading.

We ran re-entry trajectories deploying wings of the different wing loadings at the different points along the trajectory. The results of these runs were fed into a thermodynamic analysis to determine the heat protection required. It was arbitrarily decided to use an ablative system. The basic stage structural material was changed from Aluminum 2014 to stainless steel.

The ablation material weights were then determined, added to the glider structural weight and referred to the net structural weight of the recovered stage. The results are shown in Fig. 5.

In this figure it is considered that in the cases of deployment at 400,000 ft altitude the maximum resultant load factor almost independently of wing loading was not higher than 3 g's, and that in the cases of deployment at q_{max} and Mach 5, the max. resultant load factor incurred was 10 and 9 g's respectively.* The weight of the glider was then adjusted assuming that the structural weight scales directly proportional to the load factor.

The main trend of the curves on Fig. 5 seems to indicate an advantage in going to higher wing loadings, i.e., smaller wings. Furthermore the curves would indicate a preference for deployment at 400,000 ft altitude. However, there is a design difficulty in that it is hardly conceivable how the suspension cables with a diameter of in the order of

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* Normal load factor during deployment is kept at 6 g's

2 in. and an additional ablation coating of in the order of 1/2 in. could be stowed and then deployed within a split second without loosing the ablation coating. No such coating is required for the lower altitude deployments.

Therefore, our tentative conclusion at this time is to prefer to deploy the wing below Mach 5, preferably at subsonic speeds and to go to as high wing loadings as are compatible with the overall flight stability and glide capability to ensure safe automatic landings. We feel that even the application of a radiative cooling system for the case of deployment at 400,000 ft altitude would not change this preference. If the subsonic glide capability of a paraglider is not required, a very similar system can be based on a parachute. The resulting weight penalty would be very low but has to be bought at the expense of impact and retrieval problems.

At the present time it cannot be stated positively that orbital stage recovery will save costs, however it can be said that from the operational point of view it would be very attractive. Advances in the state of the art of recovery systems will reduce the weight penalty associated with reusability, and in general will tend to make orbital stage recovery also attractive from the economical aspect.

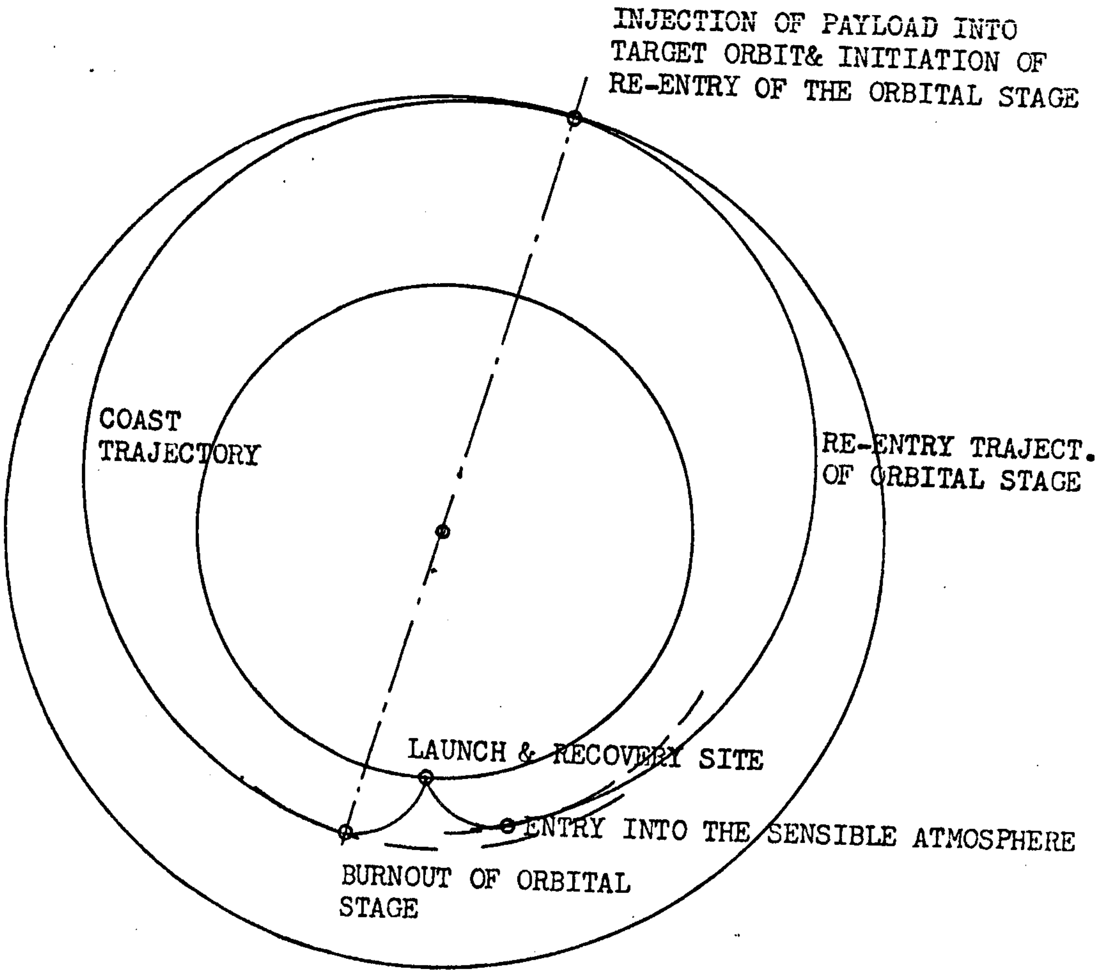


Fig.1 TYPICAL ORBITAL MISSION PROFILE INCLUDING RECOVERY OF THE ORBITAL STAGE IMMEDIATELY AFTER ONE REVOLUTION AROUND THE EARTH.

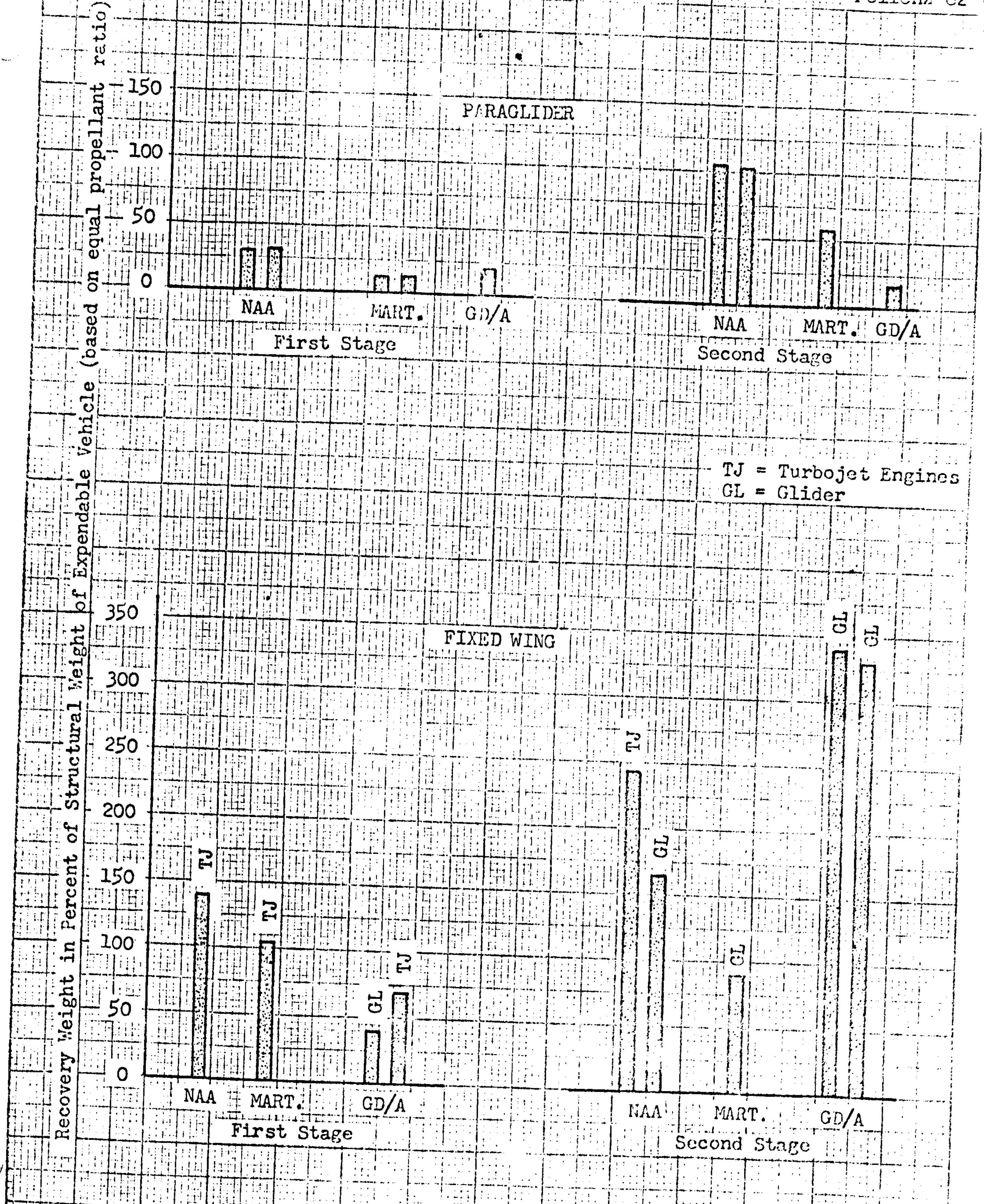

Recovery Weight in Percent of Structural Weight of Expendable Vehicle (based on equal propellant ratio)
PARAGLIDER
150
100
50
0
NAA
MART.
GD/A
First Stage
NAA
MART.
GD/A
Second Stage
TJ = Turbojet Engines
GL = Glider
FIXED WING
350
300
250
200
150
100
50
0
TJ
TJ
GL
TJ
TJ
GL
GL
GL
GL
NAA
MART.
GD/A
First Stage
NAA
MART.
GD/A
Second Stage

Fig.2

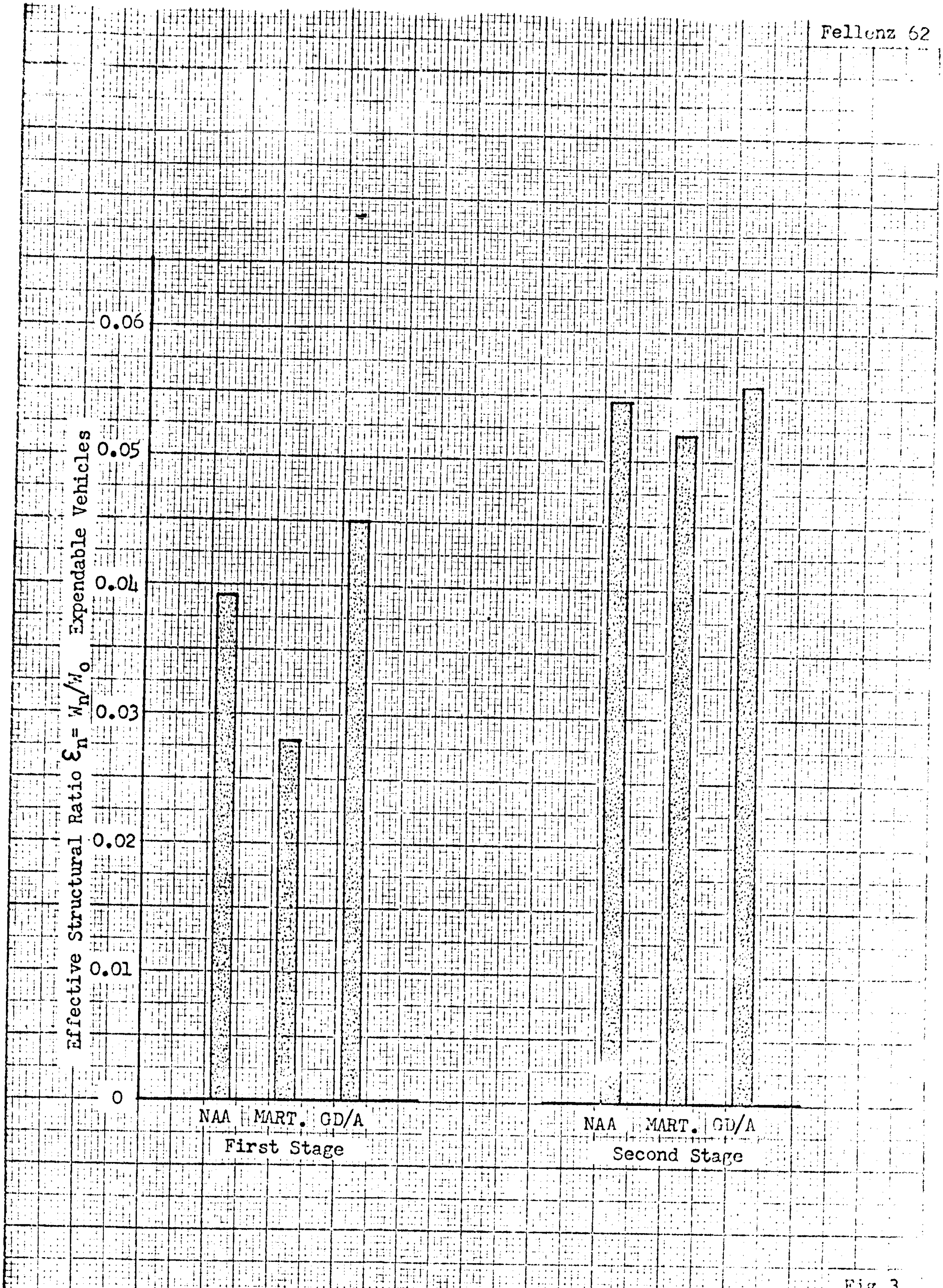

Effective Structural Ratio $\varepsilon_n = W_n/W_o$ Expendable Vehicles
0.06
0.05
0.04
0.03
0.02
0.01
0
NAA
MART.
GD/A
First Stage
NAA
MART.
GD/A
Second Stage

Fig.3

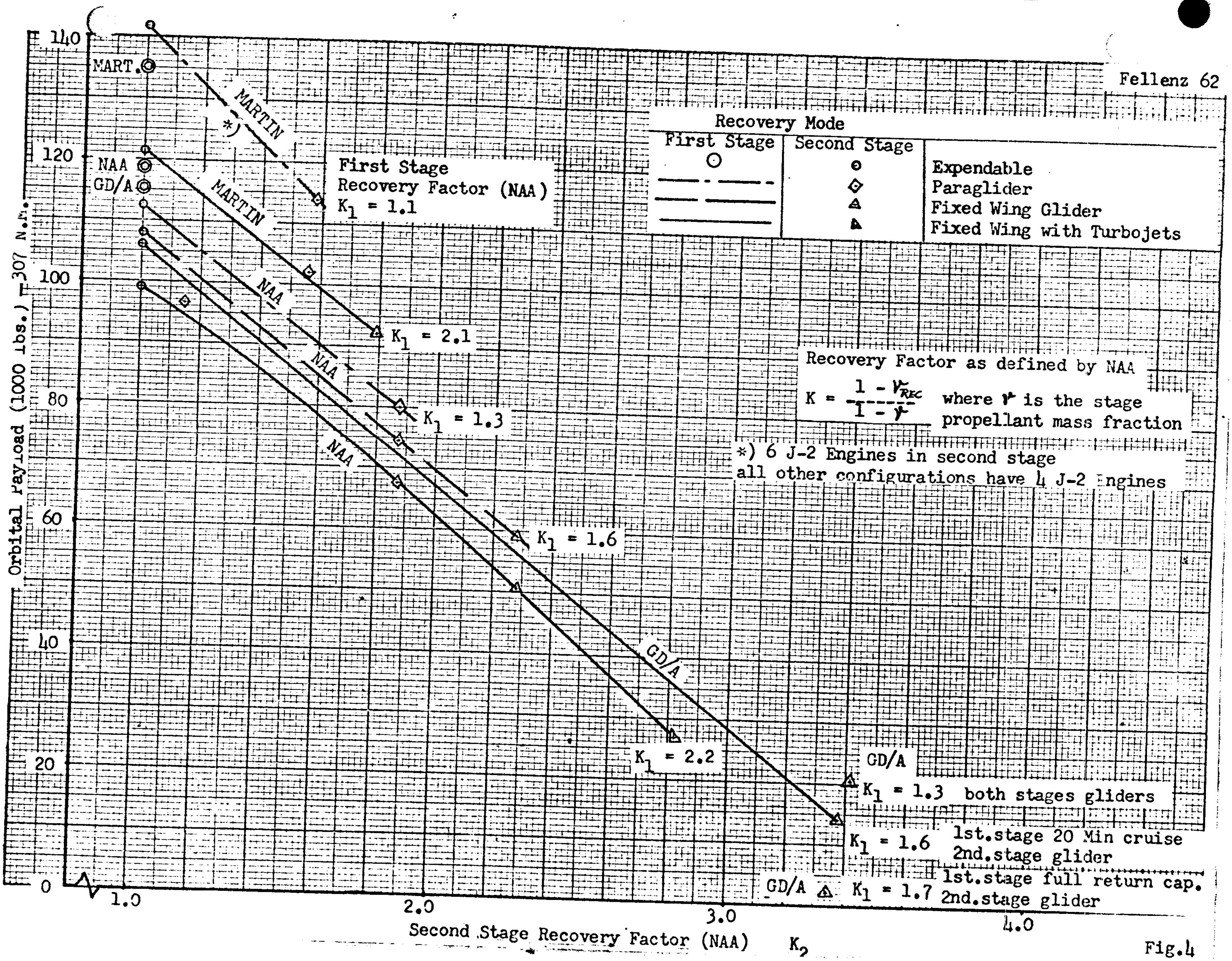
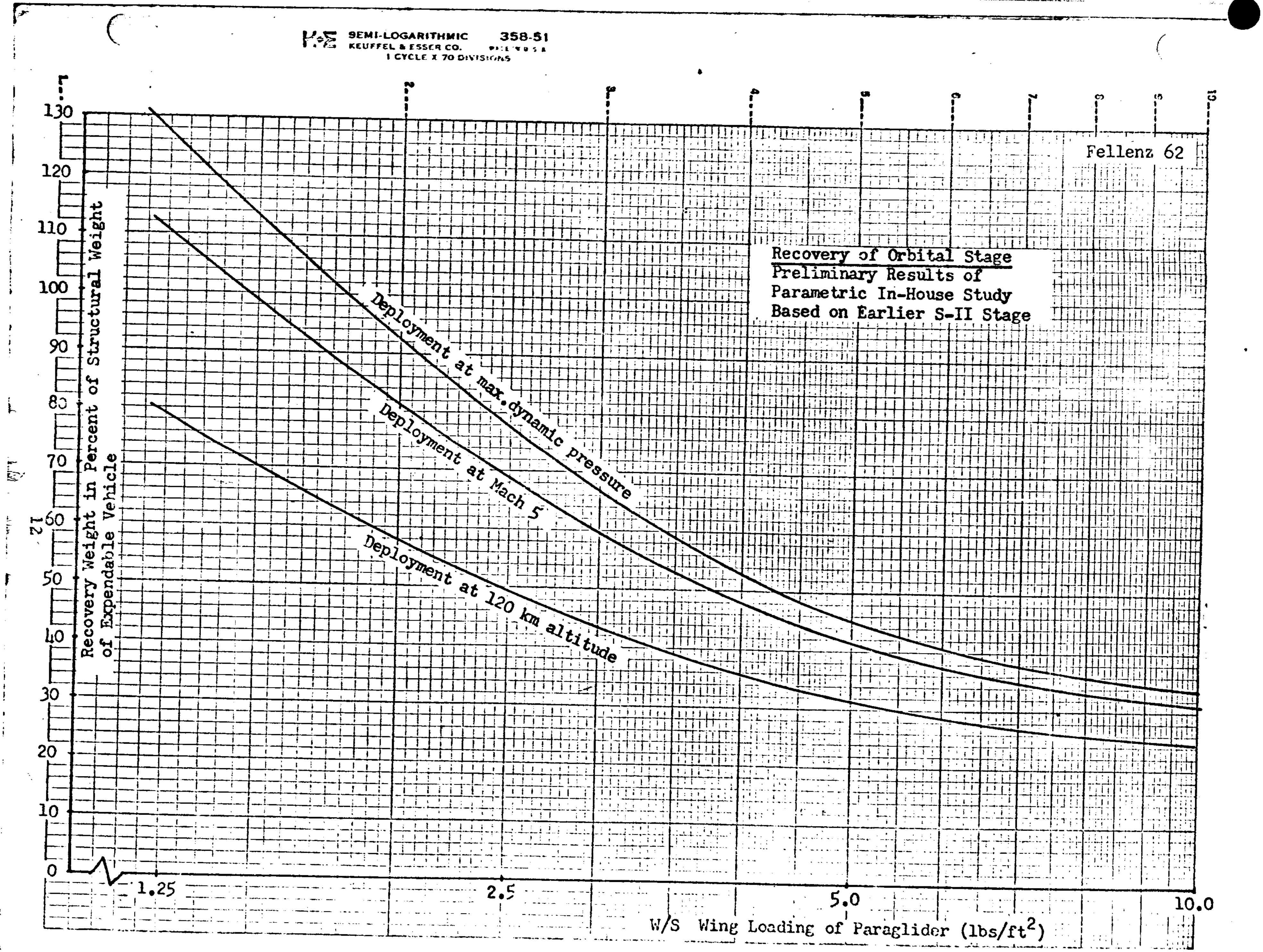

Recovery Mode
First Stage
Second Stage
Expendable
Paraglider
Fixed Wing Glider
Fixed Wing with Turbojets
First Stage
Recovery Factor (NAA)
K1 = 1.1
Recovery Factor as defined by NAA
K = (1 - ν_REC)/(1 - ν) where ν is the stage propellant mass fraction
*) 6 J-2 Engines in second stage
all other configurations have 4 J-2 Engines
MART.
NAA
GD/A
MARTIN
*)
MARTIN
NAA
NAA
NAA
GD/A
K1 = 2.1
K1 = 1.3
K1 = 1.6
K1 = 2.2
GD/A
K1 = 1.3 both stages gliders
K1 = 1.6 1st.stage 20 Min cruise
2nd.stage glider
GD/A K1 = 1.7 1st.stage full return cap.
2nd.stage glider
Orbital Payload (1000 lbs.) 307 N.M.
140
120
100
80
60
40
20
0
1.0
2.0
3.0
4.0
Second Stage Recovery Factor (NAA) K2

Fig.4



K&E SEMI-LOGARITHMIC 358-51
KEUFFEL & ESSER CO.
1 CYCLE X 70 DIVISIONS
Fellenz 62
Recovery of Orbital Stage
Preliminary Results of
Parametric In-House Study
Based on Earlier S-II Stage
Deployment at max.dynamic pressure
Deployment at Mach 5
Deployment at 120 km altitude
Recovery Weight in Percent of Structural Weight of Expendable Vehicle
W/S Wing Loading of Paraglider (lbs/ft2)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
1.25
2.5
5.0
10.0

Fig.5