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NASA - Langley

PARAGLIDER LOADS, AEROELASTICITY AND MATERIALS

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INTRODUCTION

Improvements in paraglider aerodynamic performance characteristics indicated by recent wind-tunnel tests have prompted the Langley Research Center to investigate paraglider loads as a function of the aerodynamic parameters involved in the performance increases. An effort is also underway to attempt to calculate both the aerodynamic loads and performance associated with these configuration changes, to allow the evaluation of parametric changes without the need for extensive tunnel testing.

Structural analyses have been continuing which point up some interesting results as regards the problems of weight and materials.

It is the purpose of the present paper to present some of the highlights of recent research concerning loads, structures and materials, and to indicate by implication, the type of data which are available for use in the design of paragliders.

DISCUSSION

Uncertainties in the exact shape of the cloth membrane of the paraglider have been the biggest obstacle in calculating the air-load distribution over a representative canopy. Some early pressure data obtained on rigid conical models has suffered in application because of the aforementioned shape uncertainties. Recent force test measurements have been made on a semispan glider model with a cloth wing, which is shown in the first slide.

SLIDE I

The model shown here was mounted on two balances, one semispan balance which allowed the measurement of total load and another six-component balance which measured the load at the leading edge.

The variables covered were aspect ratio 2.5, 4.0, 6.0 and twist distribution indicated below by the values of washout at the .80 span station. Loads carried in the paraglider structure can be divided into two classes: (1) loads normal to the plane formed by the wing tip and keel, and (2) loads parallel to the plane of the wing tip and keel. These loads may be treated separately and added vectorially to arrive at a final loading, on which the design of the structure may be based.

SLIDE II

The next slide shows a comparison of the measured spanwise lift distribution obtained from pressure surveys on a rigid conical model, and calculated values using the twist distribution of the models. As might be expected the calculated values agree well with the measurements when the twist is known.

Spanwise lift centers are also shown on the slide. Here we have the lift center given by pressure tests, the calculated lift center, and spotted on for comparison is the lift center obtained from the semispan force test model. While only one point is shown here, good agreement with both theory and pressure tests was obtained throughout the "linear" angle-of-attack range and agreement is shown with the pressure measurements past the stall.

The lower part of the figure shows the extreme loading due to twist at a lift coefficient of zero.

Not much more can be said about the normal or lift distribution of load in the paraglider members without knowing the placement and number of the shroud lines, so let us look at the moments about the apex, in the plane of the leading edge and keel.

SLIDE III

Here we have plotted apex hinge moment as a function of angle of attack for an aspect-ratio-2.5 glider with canopies having different values of washout. The sketches show the relative degree of flatness of the canopies under load. The darkened symbols indicate the angles of attack at which $(C_L)_{max}$ occurred.

These data serve to illustrate a number of points: (1) increases in washout are associated with decreasing in-plane apex moment, and decreasing lift-drag ratio if the leading-edge sweep or wing span is held fixed. (2) the design of the glider frame for strength is fixed by the maximum lift-coefficient point. The data were taken through an angle of attack of 90°, and while not shown here the level of apex moment at $C_{L_{max}}$ or stall is not exceeded.

Below the stall you will notice that the slope of C_h with α is negative for the full canopy and positive for the flat canopy. In the case where the wing is flexible (e.g. can change sweep or span with changes in angle of attack) the slope of this line may effect the gust response of the glider. Note that with this full canopy a positive change in α reduces the tendency to close which might increase the span somewhat making the glider more sensitive to gusts while with the flat canopy positive angle-of-attack changes reduce span possibly alleviating the gust response.

Paraglider wings with flexible frames have been tested at Langley in connection with government sponsored programs for (1) the recovery of the Saturn booster in which the Marshall Space Flight Center is interested and (2) in connection with the recovery and launching of the Gemini spacecraft, which is of interest to the Manned Spacecraft Center.

Generally speaking the introduction of flexibility into the structure results in some saving in weight. The next slide (slide IV) shows some curves which indicate paraglider structural efficiency. Here is plotted the ratio of paraglider weight to gross weight for rigid and flexible systems. The scale on the right represents the volume required to stow the paraglider system, and is obtained by assuming a stowed density of 23 pounds per cubic foot.

Decreases in weight can be achieved if structural flexibility is allowed in the paraglider frame as shown here. It should be noted, however, that flexible gliders are much more difficult to analyze both aerodynamically and structurally because of the interdependence of aerodynamic load and configuration.

Elastically and dynamically-scaled inflatable models of both relatively rigid and flexible paragliders are being fabricated under contract with G. A. C. These models will be used to study the paraglider deployment characteristics along with the effects of aeroelasticity. In addition these models reproduce the buckling in the inflated structural tubes which is important in defining aerodynamics.

These data should be available to evaluate the trade-offs between weight and performance previously mentioned.

The last curve on the slide shows further improvement in the weight picture through the use of different gas tight materials, in this case a film-fabric construction of dacron and mylar similar to the sample I have here. Should such a material prove feasible and allow the omission of the elastomer which weighs as much as the fabric, significant weight savings would result.

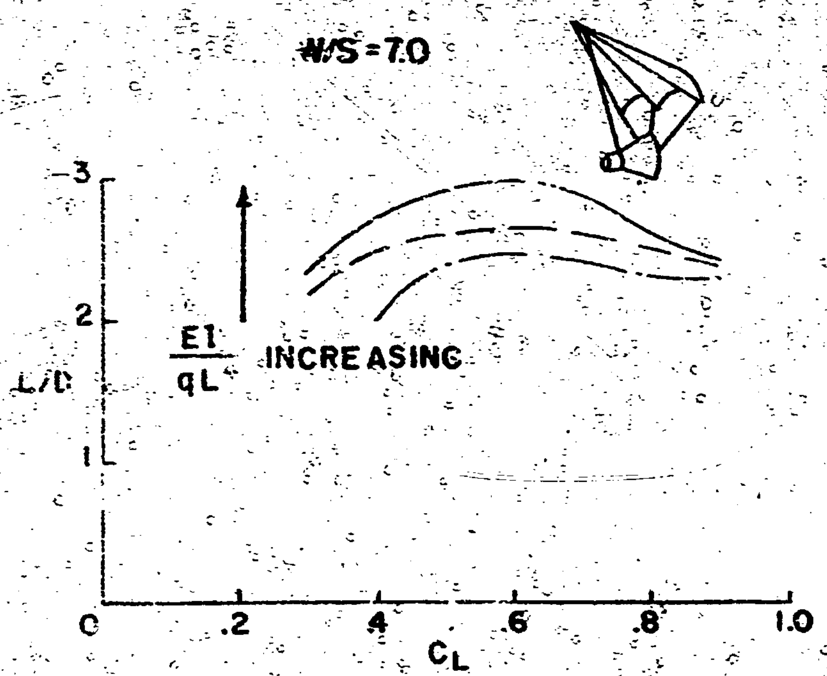
We will discuss more about materials later.

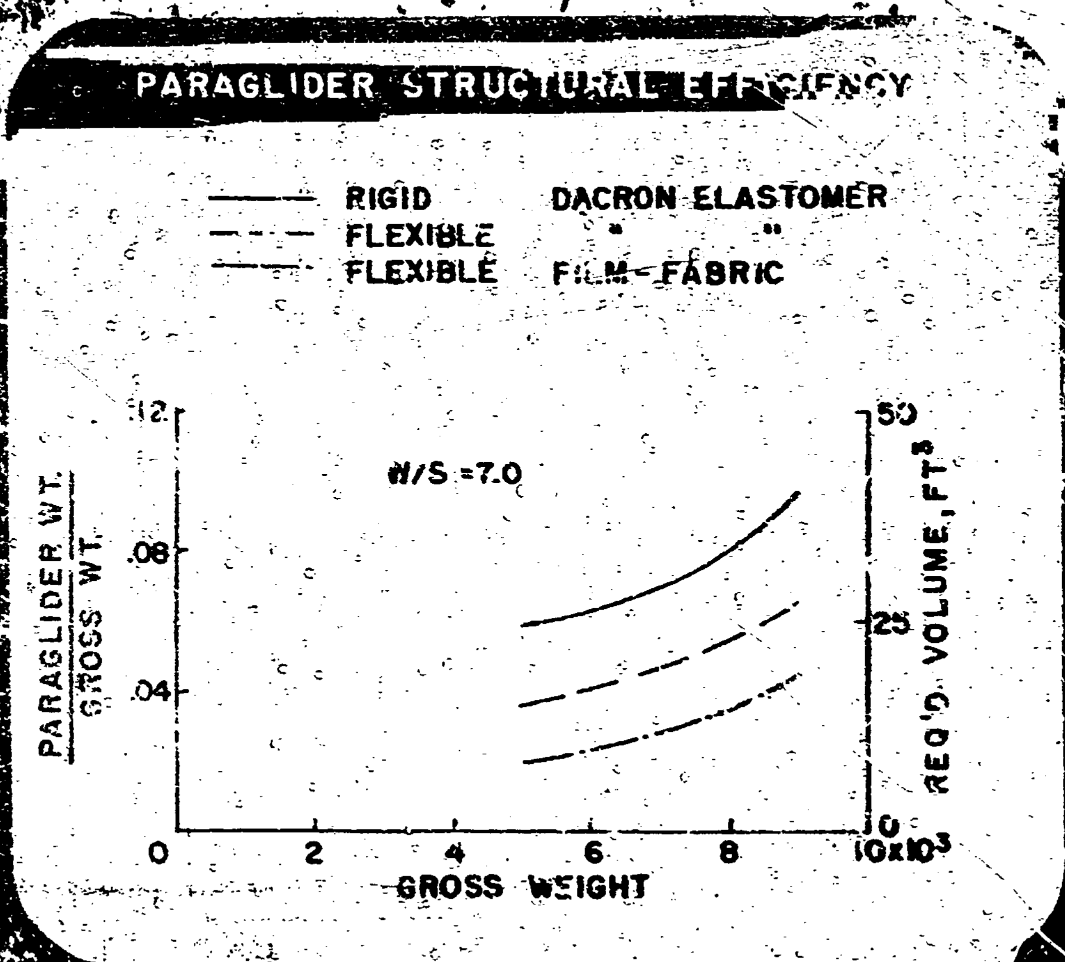
In addition to being more difficult to analyze, flexible paragliders usually suffer some degradation in performance. The next slide shows aplot of L/D against C_L for the Gemini-paraglider configuration. The three curves represent the aerodynamics of gliders having three stiffnesses. The degradation in $(L/D)_{max}$ is obvious but note that at higher C_L the curves tend to merge, so that if touchdown conditions are more important in a particular application than range considerations the requirement for stiffness in the glider frame may be relaxed to yield a somewhat lighter weight and more readily stowable recovery system.

High temperature materials are also under investigation by Langley Research Center in connection with the micrometeoroid paraglider experiment which will have to survive reentry temperatures (1000° F). For the inflated members of the paraglider, Langley Research Center is investigating the feasibility of a fiberglas-silicone combination. Since silicone is difficu't to "work", seams and junctures represent a considerable problem which is being studied. Firings from White Sands Missile Range are scheduled for next summer.

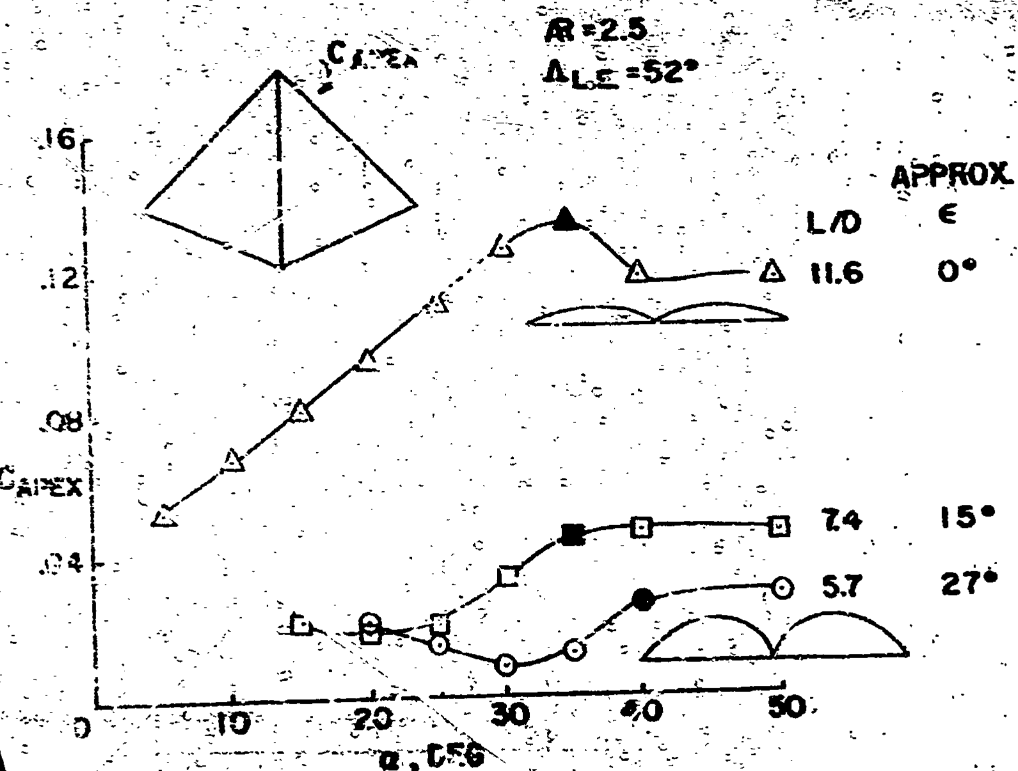
In conjunction with the aerodynamic and materials studies, Langley Research Center continues investigations in structural analysis. While structural design analysis procedures have been developed for paragliders with co-planar leading edges and keel (these procedures have been used for free-flight models, wind-tunnel models and the micrometeoroid paraglider), the recent inovation of the utilization of helical leading edges, discussed by Mr. Sleeman, represents a new structural problem. Langley Research Center has a program underway to define its structural problem areas; it is hoped that the material and geometric coefficients being developed by testing by Goodyear and North American under a MSC contract will suffice to allow an evaluation of the problem. Should a favorable solution to this problem be indicated, it is anticipated that scaled models will be used for test purposes since it has been found that designs can be scaled without use of "exotic" materials.

EFFECT OF STIFFNESS ON L/D

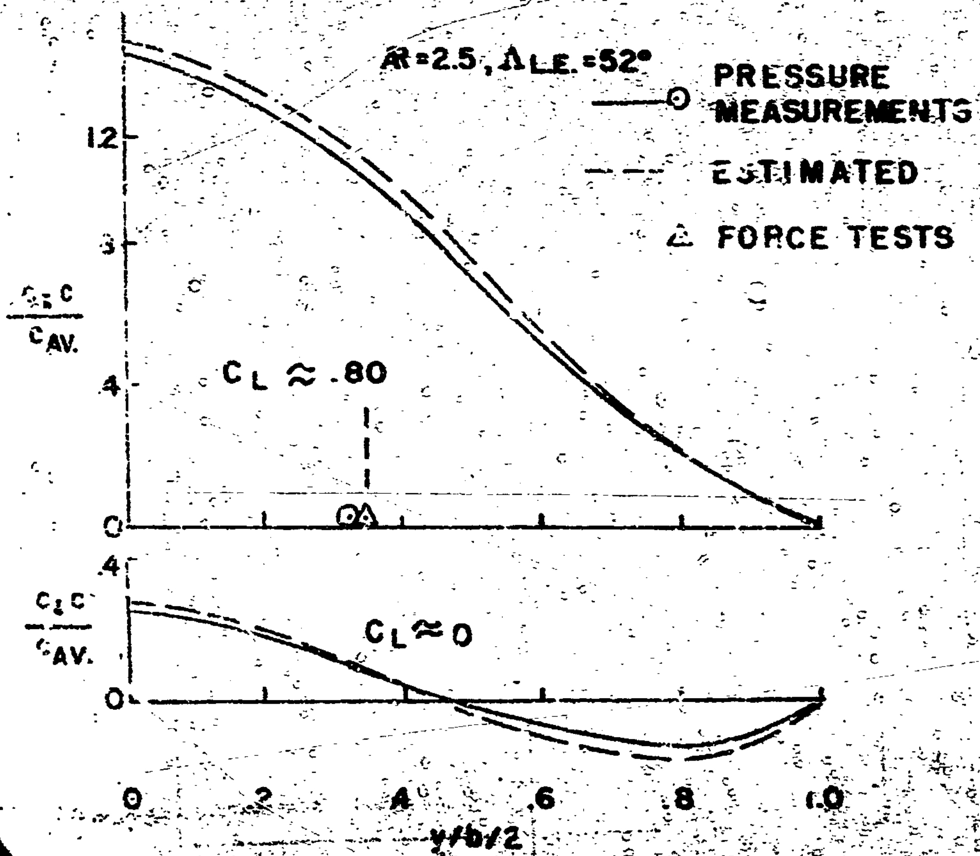



PARAGLIDER STRUCTURAL EFFICIENCY
RIGID DACRON ELASTOMER
FLEXIBLE " "
FLEXIBLE FILM-FABRIC
W/S =7.0
PARAGLIDER WT. / GROSS WT.
.12
.08
.04
0
2
4
6
8
10x10^3
GROSS WEIGHT
REQ'D. VOLUME, FT^3
50
25
0

EFFECT OF TWIST ON APEX HINGE MOMENT (IN PLANE)



SPANWISE LIFT DISTRIBUTIONS



SEMI-SPAN WIND TUNNEL MODEL