Estes Industries Technical Report No. TR-7

FRONT ENGINE BOOST GLIDERS

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Introduction

Perhaps the most revolutionary development in model rocketry since Estes Industries created the first boost-glider in 1961 has been the introduction of the forward engine boost-glider. The new type of glider is so radically different from its conventional predecessor that many formerly accepted ideas about design must be changed to fit the special cases encountered in forward engine design if the best configuration is to be achieved. This report contains the findings of a research program conducted since June, 1963, which succeeded in determining the requirements for good forward engine design. As flight testing was the major research method, many criteria are qualitative, but due to the fine tolerance demanded in forward-engine design the uncertainty in quantitative data is only plus or minus 5%.

The Boost Phase

Despite its airplane-like appearance the front engine boost-glider must, to meet the definition of its type, be capable of a vertical liftoff without relying on lifting surfaces. It must have a straight and true boost trajectory and must enter quickly and smoothly into the gliding recovery phase of flight after engine ejection. Here as elsewhere conflicting demands of aircraft and rocket design must be met to obtain a workable vehicle. As detailed in Technical Report TR-4 the glider must have its surfaces located so as to bring the center of pressure far enough behind the center of gravity to produce enough corrective force in case of oscillation. Fortunately the arrangement of the front engine model makes this fairly easy since weight is concentrated in the nose when the engine is in place. In building and flight testing nearly fifty vehicles not a single case of instability due to misplaced CP location was encountered.

This aid to design is countered by several undesirable features including the high degree of asymmetry of most forward engine models. The most serious of the results of asymmetry is the offsetting of the thrust line from the CG along the vertical axis. This produces a down-pitching effect whose moment-arm is equal to the offset distance and whose magnitude is equal to this distance times the engine's thrust (figs. 2 and 3). If the CP is similarly displaced, as it often is, the resulting pitching will also affect the flight. This effect, however, is normally small.

Fig. 1 Forward-Engine Nomenclature

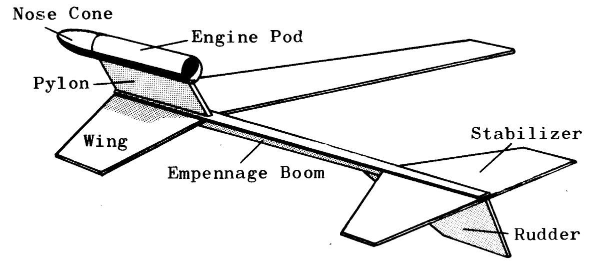
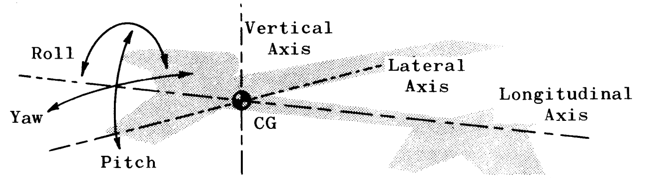


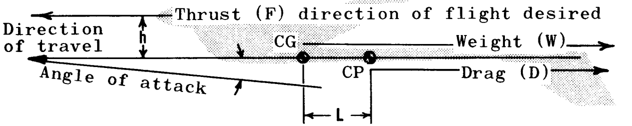
Fig. 2 Aerodynamic Axes and Rotational Movements



Longitudinal axis is no longer always the centerline of the body tube as is the case in rear-engined gliders

Fig. 3 Boost Phase Forces

h = Perpendicular distance from thrust line to longitudinal axis



Corrective moment = $L \times \sin \times \alpha \times D$
$F \times h$ = Down-pitch moment induced by engine thrust

By using low pylons and large amounts of dihedral (the angle of the "V" formed by two-panel wings) the engine-induced down-pitch moment can be greatly reduced and sometimes entirely eliminated. Carrying the practice to extremes is not wise since the structure will be weak and the exhaust blast may damage the tail section of the glider. Within normal limits the tendency to pitch or loop is readily countered by normal positive stability and an additional type of stability which we shall call stick, or trailing member, stability. This inherent stability, possessed by some front engine and many odd-ball designs, is present when the engine nozzle (or point of origin of thrust) is located ahead of the CG. The CG tends to trail or hang below the suspending and accelerating force of the rocket engine, thus adding to the model's stability.

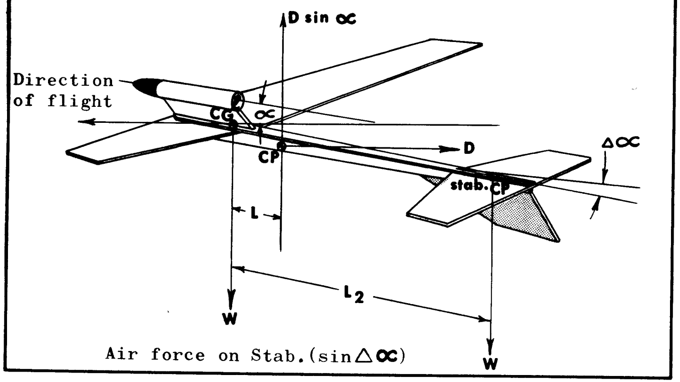
When the various opposing factors are combined and the results analyzed by flight testing we find that minimum stability for front engine boost-gliders is about 3/4 body diameter.

The Glide Phase

The big advantage of the front engine boost-glider lies in its method of attaining and maintaining a gliding attitude following engine ejection. Although a number of front engine designs use ailerons and other high-lift devices to increase the lift/drag ratio, the basic front engine configuration has no moving parts. It relies solely on the shift of the CG and the loss of weight that accompanies ejection to initiate the recovery phase, and so can be more reliable than many conventional designs.

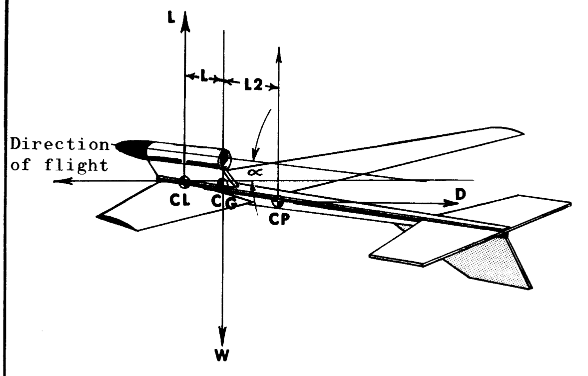
There are two major methods of designing the glider to automatically initiate glide. One is the addition of negative incidence to the horizontal stabilizer, i.e., placing a small shim of balsa under the stabilizer trailing edge so that the stabilizer forms a slight negative angle with the empennage boom. This angle, never exceeding one degree, makes possible the use of very thin wings, and even wings with no airfoil at all. Its disadvantage is that it often produces poor boost characteristics, especially a nose-up pitching moment which greatly reduces altitude and occasionally results in loops and crashes. An extremely delicate balance must be maintained between the nose-down engine moment and the nose-up stabilizer moment, a balance far more critical than that commonly found in free-flight model airplanes. Such a condition can not be easily produced, and once produced, can not be reliably duplicated. It is thus unacceptable for general use.

Fig. 4A Pitch Stability by Negative Incidence in Stabilizer



A second method which largely solves the problems encountered with the first is the use of an airfoiled wing. The wing airfoil operates on a principle discovered by the Swiss physicist Daniel Bernoulli, producing a lifting force even when held at zero angle of attack to the relative airstream. Bernoulli found that when air moves rapidly its pressure decreases. The upper side of the wing, being more highly curved than the often flat and sometimes undercambered lower side, forces the air to move more rapidly around it. This produces a low-pressure area directly above the wing into which the wing is forced by the relatively high pressure below it. Since such a wing may be mounted at zero angle of attack and since it "stalls," or loses lift, when at a high angle of attack, it produces little pitch-up moment in boost phase, allowing a smoother vertical flight while producing a superior glide.

Fig. 4B Pitch Stability by Lifting Wing

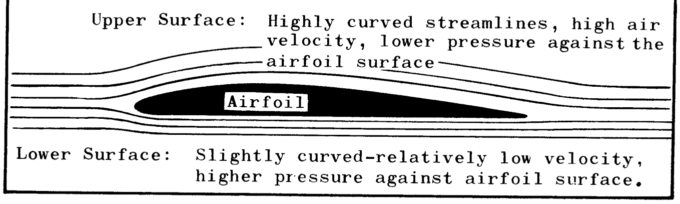


Angles here and in Fig. 4A are exaggerated for clarity. In actual flight, direction of flight is angled slightly down, and force in direction of flight is produced by the component of gravity acting in the direction of flight.

Airfoil Shape

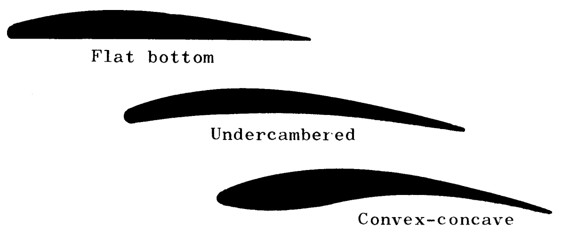
There are many airfoil shapes, some more efficient than others. The boost-glider is an unusual case of very small size and low velocity (when gliding), both of which tend to make the Reynolds Number quite small. Boost-glider Reynolds Numbers range from 25,000 to 100,000 in most cases, while those for full size aircraft are well up in the millions. A full discussion of Reynolds Numbers is not in order here, and may be found in most aerodynamics texts if further information is desired. The important effect, however, is that airfoils suited for larger and faster vehicles are relatively poor on the boost-glider. It has been found that thin, flat-bottomed sections with a maximum thickness of seven to ten percent of the wing chord (the distance from the leading to the trailing edge) and with the maximum thickness between 25% and 35% back on the wing are satisfactory. Little work has been done with airfoils other than flat-bottomed, but experience to date indicates that the range of available types is quite broad.

Fig. 5 Pressure Distribution on Airfoil



The proportions and areas of the various parts of a forward engine boost-glider and their relations to each other have great effect on its performance. For instance, front engine boost-glide designs operate best with a wing area between 20 and 40 square inches. Less area results in high wing loadings and a rapid descent, while more area results in excessive drag and susceptibility to warping. The balsa empennage boom must not be too short, or a loss of stability results, while too much length adds weight. The best length is between 0.9 and 1.1 times the wing span. The area of the horizontal stabilizer whould not fall below 30% of the wing area when zero-incidence airfoiled wings are used, but areas over 40% add excessive weight and drag. The rudder area, including stabilizer tip plates (if any) should generally be between 8% and 15% of the wing area, since less area results in loss of control and more in unnecessary drag. As the rudder is normally below the empennage boom to avoid the exhaust gases, a large one will also reduce roll stability and may result in spiral diving. There is a wide range of usable dihedral angles for wings. Values between 0° and 28° have been used successfully. Best results come between 4° and 16°. In this range the dihedral does its job of increasing roll stability without any shortcoming.

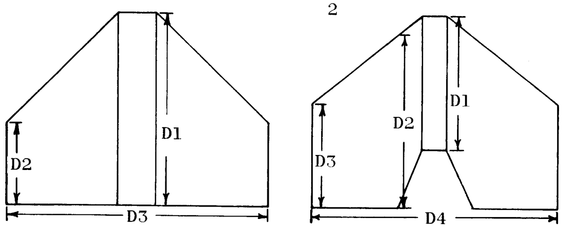
Fig. 6 Basic Airfoil Types



Front engine gliders can usually use higher aspect ratios than rear engine models (normally up to 4.5) with the upper limit imposed by structural requirements. Taper ratio (fig. 8) should be between 0.3 and 0.6. Lower ratios reduce roll stability and higher ones are subject to structural limitations. There is a wide variation allowable in the selection of sweep angle. Successful models have been built with sweeps from 15° to 55°, but the best compromise between structural and aerodynamic requirements lies between 40° and 45°. The sweep of the wing (within certain limits) increases the effectiveness of dihedral.

Fig. 7 Determining ASPECT-RATIO $AR = \frac{\text{Maximum Span}}{\text{Average Chord}}$

For Wings of Constant Taper $AR = \frac{D3}{\frac{D1 + D2}{2}}$



For Wings of Irregular Taper $AR = \frac{D4}{\frac{D1+D2+D3}{3}}$

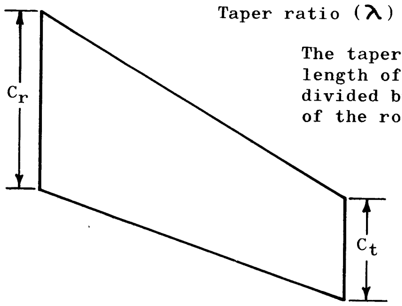
A final item to consider with forward engine designs is wing loading. This is the factor which, along with the high lift/drag ratio, helps explain the superior performance of a well-designed front engine glider. The average loading for a forward engine model is between 0.17 and 0.3 pounds per square foot as compared with 0.25 to 0.7 for most rear engine designs. Loadings higher than these result in rapid descent and short duration, while lower ones raise doubts as to structural strength.

Fig. 8

Taper Ratio

Taper ratio (λ) = $C_t \div C_r$

The taper ratio is the length of the wing tip divided by the length of the root.



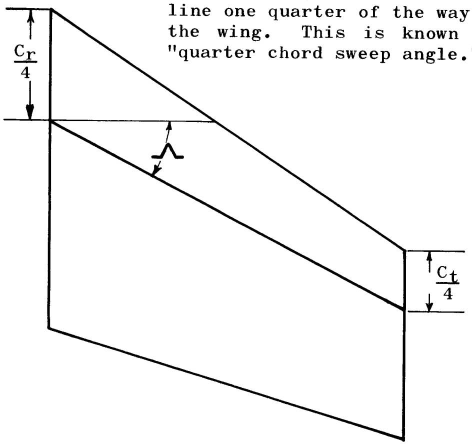
—Structural Considerations—

Structural considerations as limiting factors for aspect ratio, wing loading, etc. have already been discussed. Some other criteria peculiar to front engine designs also deserve mention, including wing structure. There are two basic types of wing construction: solid and built-up. The first is the common sheet blasa wing with a sanded-in airfoil and the second is a framework of ribs and spars with a covering of silk or treated paper such as "silkspan." In large model airplanes the built-up wing is used almost exclusively since it offers a considerable saving in weight. The advantage of the built-up wing, however, is not so great on the boost-glider as the actual weight saving often amounts to only a few tenths of a gram. The difference in wing loading between solid and built-up versions is usually negligible and the built-up wing is worth the extra effort only when the most exacting requirements are enforced. Even here the builder must choose his rib and spar arrangement carefully or he may actually exceed the weight of a solid wing.

Fig. 9

Sweep Angle

The sweep angle is measured along a line one quarter of the way back on the wing. This is known as the "quarter chord sweep angle."

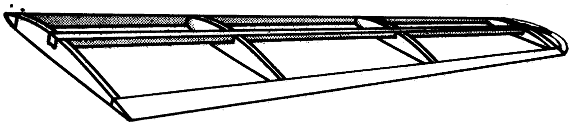


Sweep angle ($\Lambda_{C/4}$) = Λ

In selecting an empennage boom the builder must consider the forces produced by the stabilizer and rudder as well as the likely accelerative loadings. For most models boom cross-sections of from 1/4" square to 1/4" by 1/2" are adequate. A "T" shaped cross-section made up of 1/8" or 1/16" sheet balsa often gives more strength with less weight than a solid boom.

Fig. 10

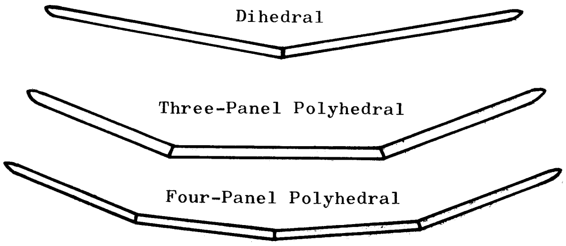
Simple type of Built-Up Wing (Single Spar)



From a structural standpoint the standard tail configuration of a horizontal stabilizer with a single subrudder (and sometimes small tip plates) is best. A "V" shaped, or butterfly, tail has produced a good glide but is more apt to break and tends to catch the firing clips during launch. This tendency is also present with standard tails, but can be combated by mounting the firing leads on a short length of dowel or rod about three inches from the launch rod. The clips will then fall to a position along the "gantry" rod rather than vertically along the launch rod.

Fig. 11

Wing Angles



The best height for the engine pod pylon is approximately a half inch. Higher pylons are weaker and result in greater nose-down moment during boost. Lower pylons generally result in exhaust damage to the empennage boom and tail structure. It is helpful to have the pylon angled as far forward as possible to increase both aerodynamic and trailing-member stability; the maximum forward sweep, however, is limited to an angle of 15° or more with the longitudinal axis. Less angle results in engine damage to the pylon trailing edge and often in a noseheavy configuration. Pylon angles of 30° to 45° are generally best.

Structural strength could impose an upper limit on wing dihedral, but in practice this limit need not be considered as maximum aerodynamic efficiency is reached at a point well below the structural maximum. Polyhedral wings, however, will encounter difficulties if they are not sufficiently thick to resist warping caused by accelerative and aerodynamic loads on the wingtips.

———Flying Practice———

Front engine boost-gliders have been multi-staged with some success, the booster stage simply consisting of a length of body tube. However, stability is reduced, the stages are difficult to retrieve undamaged, and the larger, multi-staged gliders often give shorter duration then small, light single stage vehicles.

One last structural requirement arises when it is not desirable to allow the engine to fall free following ejection. This requirement can be met by constructing the engine pod from a larger diameter body tube than is a glove-fit for the engine and taking up the added diameter with streamer material taped on the engine. A six to eight inch streamer may thus be used on the engine casing and will unroll from the engine after ejection.