Technical Report TR-4

Rear Engine Boost-Gliders

Estes Industries 1963 By Gordon Mandell

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Introduction:

These are the preliminary findings of a research program conducted since March of 1962. Some fifty boost-glide vehicles have been constructed to date. To augment the findings, library research in aerodynamics has been conducted. Keep in mind that these findings are of a mainly qualitative nature, with expected accuracy in most other case (i.e.; quantitative findings) about plus or minus 10%, except as specified.

I. The Boost Phase:

A boost-glider is a model rocket which rises vertically in the manner of an ordinary fin-stabilized rocket, and returns in an aerodynamic glide. It is an aircraft and a rocket in one. Let us investigate the design requirements for a vehicle of this type. The first thing we must bear in mind is that we are designing a rocket, which is stabilized by locating the center of pressure behind the center of gravity in the manner detailed in Technical Report TR-1.

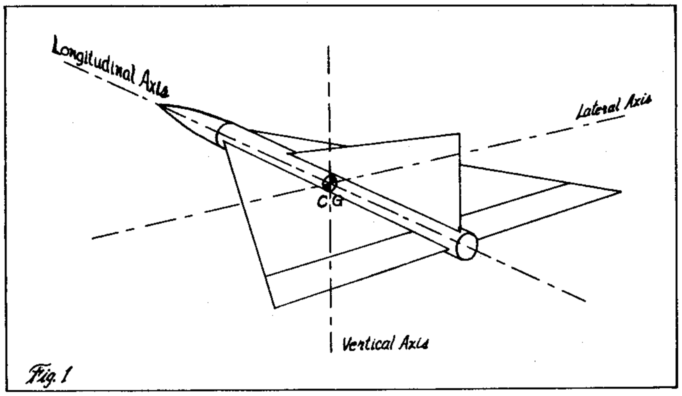

Fig. 1

This is going to have an obvious effect on the boost-glider. Its wings must be located so that they bring the CP of the top view behind the CG by a substantial margin, and also its directional stabilizing surface, the rudder(s) must be located so that it brings the CP behind the CG in the side view.

The distance between the CG and CP is called in physics a moment - arm, and the stabilizing force exerted by the moment arm, results in the corrective moment. This moment is, obviously, proportional to the force of the air hitting the surfaces, which in turn is dependent on two factors: The speed of the rocket and the angle that its longitudinal axis (body) makes with the relative wind. The ideal case of rocket stability is one in which very little corrective moment is applied because the rocket flies with little oscillation directly into he relative wind.

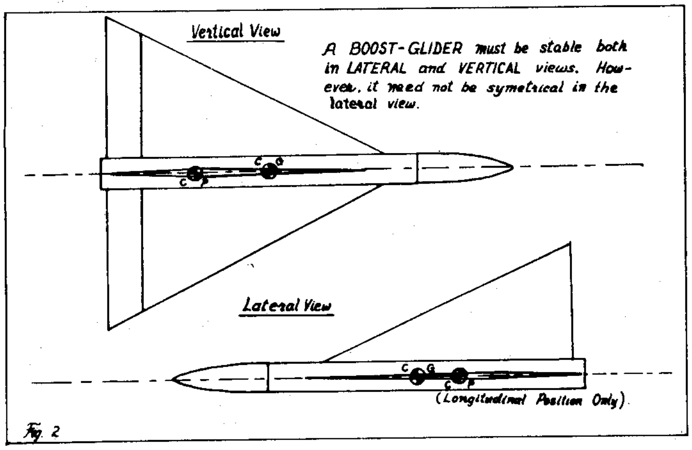

Fig. 2

While the air hitting the surfaces of an angle produces a component of force acting perpendicular to the body to push the rocket back into parallel with the relative wind, it also produces a component of force pointing directly rearward from the rocket, and parallel to the relative wind. This latter force is drag, and the more the rocket oscillates, the greater will be both corrective moment (if the rocket <u>is</u> stable) and drag. Because of its large surfaces, it is best to design the boost-glider so that its stability is greater than the needed for most other rockets. Generally the center of pressure should be at least 3/4 the body diameter behind the center of gravity.

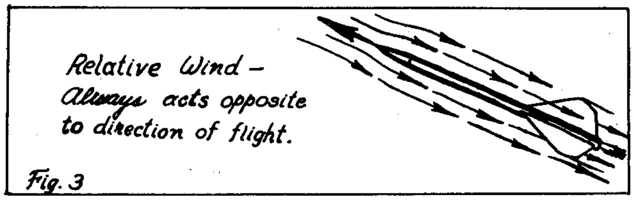

Fig. 3

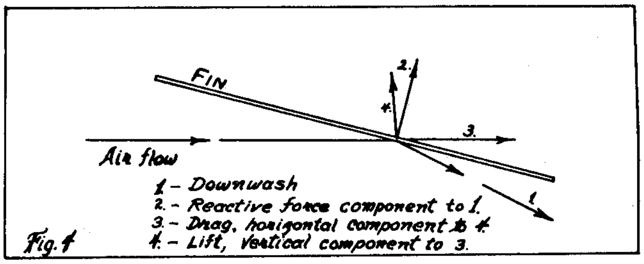

Fig. 4

II. The Glide Phase:

In glide phase, most rear engined boost-gliders use what is known as the flat-plate effect. (A fully symmetrical airfoil may be used, but it involves some difficulties in construction and alignment. The principles involved in this type of airfoil may be studied in most books covering aerodynamics.) The flat-plate effect simply makes use of the relative wind bouncing off the wing, which produces a component of force which is perpendicular to the wing (see Fig. 5). Since the wing is tilted at an angle to the relative wind, the force will also be tilted at this angle. Thus, when resolved into components parallel with and perpendicular to the relative wind, drag and lift, respectively, are determined for the wind surface.

For any lift to be produced in this manner, the wing must be inclined upward into the relative wind. This is accomplished by means of flaps located at the rear of the wind (in a delta or flying wing design), commonly called elevons. These elevons are tilted up at the rear, which means, by our previously stated principle, that air hitting these elevons will force the rear of the wing down. This, in turn, means that the forward end of the glider is forced up, meeting the relative wind at an angle, and the vehicle glides. Obviously, the extent of this force, called the moment of tail depression, is dependent on the speed of glide, the angle at which the elevons are set upward, and the size of the elevons.

To discover what size of elevon is best for a given glider, we must first take into consideration that there must be some force which makes the glider travel forward in the first place. In glide phase, the engine has been expended, and the only forces acting on the glider are those of air and gravity. After the rocket reaches flight apex and expels its engine, it begins to fall towards the earth. This produces a relative wind which is directly opposite to the direction of travel, i.e.; the rocket is falling down so the relative wind will be up (see Fig. 3). In almost every design imaginable, the CP will remain behind the CG after ejection of the engine. As a matter of fact, many designs experience a forward shift of CG as the engine ejects. Thus, the glider remains stable as a rocket, and with its corrective moments still effective, the nose turns toward the ground. However, since the elevons have been actuated by this time, the rear of the rocket is forced down by the air acting against them, and thus the nose is forced up and the flat-plate effect suspends the vehicle in gliding flight. In order to glide, the rocket corrective moment must be overcome by the flat-plate effect of the elevons.

Since setting the elevons up at an angle also produces drag, the boost-glider will, in glide, reach a terminal velocity of forward motion and will then keep this velocity rather constant. So we now know that our elevons, to be effective, must produce a depressive force greater than the rocket's corrective force at the terminal velocity of glide.

With these factors in mind, then, we can see that the size of the elevons required depends on: (1) the distance between the CP and the CG of the top view in glide and (2) the velocity of the vehicle in glide. The latter is itself dependent upon the size and the angle setting of the elevons, being from about five to fifteen miles per hour in the average glider. For a glider of approximately one half to one caliber rocket stability in glide phase and which has elevons located at the rear of the wing at an average distance from the CG, elevons of approximately 20 to 30 percent of the total wing area are needed for a good, easily adjustable glide.

This amount will vary down to about 10% for less stability in glide phase than in powered flight and up to about 35% for greater stability in glide phase. Any glider requiring more than 35% is not properly designed, and probably possesses an engine located very far to the rear for excessive rocket stability.

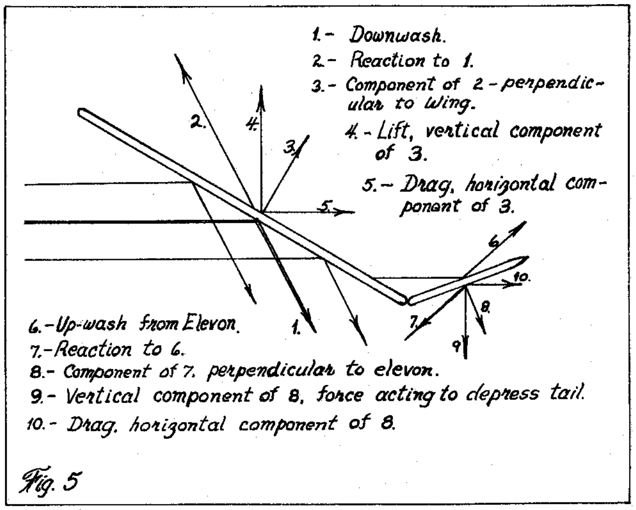

Fig. 5

An interesting variation on elevon-controlled gliders is the canard design. Canard gliders may be constructed in several ways. First, an explanation of "canard" might be in order. A canard is defined as any lateral stabilizing surface (that is, one that prevents pitching) located forward of the main lifting surface. Canards may also provide lift. When equipping canards with flaps, we must remember that, since the canards are forward of the CG, to induce the nose to angle upward we must deflect air downward by means of our canard-mounted elevons. Therefore, while we build rear mounted elevons to flip upwards at engine ejection, we must construct canard flaps so that they flip downwards at this time. Construction of mechanisms or various types of flap actuation will be covered in Part III. One advantage of canard flaps is that, besides inducing an inclination to the relative wind of the main lifting surfaces, they also provide a small amount of lift themselves, since they deflect air downward and by the principle of action and reaction are acted upon by this air in an upward direction.

Designs which have only canard-mounted elevons usually are of rather high aspect ratio (the aspect ratio is the wing span divided by the average wing width, or chord) than other designs, and experience a slight rearward shift of CG after ejection. Since they have a longer moment-arm through which to act, canard flaps usually do not need to be as large as the flaps in other designs. Canard designs offer slightly more drag then others and are all but useless when the nose is very heavy, since this shortens the moment-arm through which the flaps can act. Very successful canard designs have been constructed with elevons on both the main wing and on the canards, connected by thread to each other. However, these also suffer when the nose is heavy and consequently must be built with very light noses.

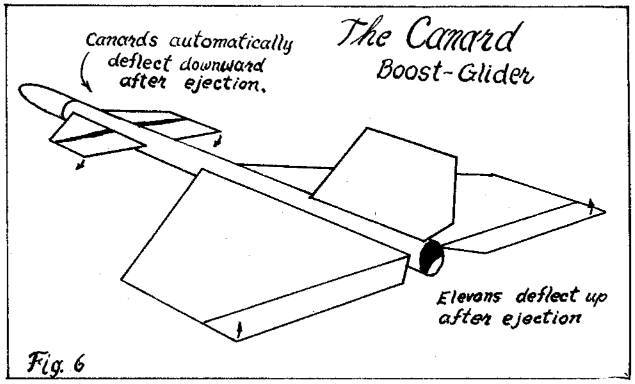

Fig. 6

There is no definite rule as to the best aspect ratio for delta or flying wing designs. It seems that high aspect ratio wings give faster response to thermal currents than low aspect ratio wings. Low aspect ratio wings are slower to recover from dives. However, structural considerations also come into the picture, as we shall see in Part III.

Just about any rudder large enough to give stability as a rocket in a side view is sufficient to directionally control the vehicle in glide. It has been noted, however, that a glider is more susceptible to spiral diving during turns when its center of directional guidance (the center of lateral area of the rudder) is more than 3/4 caliber behind the center of lift (the center of lateral area of the wing in flat-plate airfoil models). This has been found to be at least partially caused by a flow of air crosswise on the forward part of the wing, allowing excessive side slip and turning, which results in a spinning, nose-down attitude.

A boost-glider will have better resistance to rolling in glide when its center of directional guidance lies above the CG, as when the rudder is located on top of the body tube. There are yet no definite rules for wing-tip rudders and for dihedral angle of lifting surfaces. However, it is known that dihedral angle in moderate amounts improves glide by giving a "pendulum effect" while it does not detract noticeably from rocket performance. The glider need not be symmetrical in side view, as are most rockets.

Another factor to be considered in designing boost-gliders is wing loading. This figure is widely used in professional engineering, and is arrived at by dividing the area of the lifting surfaces by the weight of the vehicle in glide condition (without engine). The higher the wind loading, the greater will be the rate at which the glider descends during glide. Obviously then, one way to attain a good glide is to use wings as large as possible and body tubes as light as possible. However, this too is subject to structural limitations. Increase in lift may also be obtained by increasing the angle of attack to the relative wind. However, this also increases drag, and past a certain point drag slows the vehicle to the point where lift begins to decrease again.

III. Structural and Flying Practice:

It would indeed be gratifying if we could use as high aspect ratios, as large surfaces, and as light construction as its dictated by ideal theory. Unfortunately, structural practice is controlled by the forces which a boost-glider must withstand in flight, and the dictates of these stresses often run opposite to those of theory.

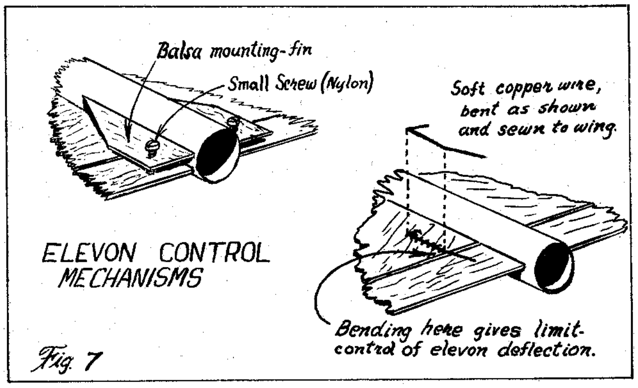

Fig. 7

The extent of these forces, caused by acceleration and air drag, is dependent upon the size of engine used and the number of engines or stages. The greater the acceleration and the duration of that acceleration, the greater the speed and hence the drag. In first considering the forces acting on the aerodynamic surfaces at constant acceleration, the force will vary as the square of the velocity, as stated in the equation for drag. In general, a balsa thickness of 1/16” has been found adequate to withstand all air forces produced by Series I engines, provided the aspect ratio of the wing or other surface does not exceed about 4; that is, if the span of the wing divided by the width, or chord, does not exceed this number. Above this number, the wind begins to twist the surface, producing the same effect as warp.

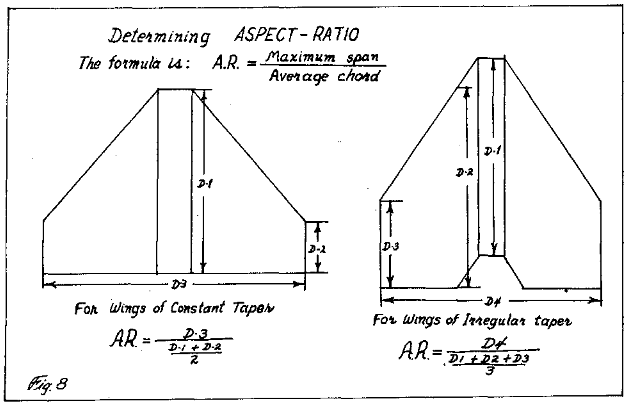

Fig. 8

Also of importance is the effect of acceleration during boost. A one-ounce model’s wings may weigh 23 times their normal weight for a short time during boost. For this reason, wings should be kept as light as possible consistent with adequate aerodynamic strength. Also, wings which have their CG closer to the body tube, or with low aspect ratios, will be more resistant to being torn loose from the body tube by acceleration forces.

The strongest wing-body joints are possible when the wings are joined together with each other and the body at the underside of the body and the connection reinforced by 1/2 inch wide strips running parallel to the body at the joint. The grain on these strips should be at a right angle to the end by the use of gauze or silk reinforcing, by using thicker balsa for the wings, and by using the longest practical wing-body joint.

Internally-operated elevon actuators, such as pistons driven by the ejection gases, have been tried, but have been found to be not as reliable and more difficult to construct than those actuated by the ejection of the engine. The simplest system to employ is one in which a piece of wire or balsa is held depressed by the engine casing.

When one end of the actuator is held in place by the engine, the other end of the stiff wire or balsa is attached to the elevon, so that the elevon is in neutral position with the casing in place. A piece of elastic thread is fastened to the elevons in a manner which will pull them up (or canard flaps down) when the engine leaves the body tube and allows the wire depressor bar to travel to the actuating position (see Fig. 9). When the depressor bar runs rearward from the elevon to the casing, it should be held down by the casing; when forward it should be held upward by the casing, which will push the elevon down to neutral.

Systems have been tried in which the arrangement is one continuous bar fastened to both wings, and where there are two bars, one for each wing. The latter has been found to be more practical, as it allows individual setting of each elevon. Setting is accomplished either by a small balsa brace with a set screw which, depending on how far the screw is turned up or down, will regulate the elevon accordingly, or by a single-strand, soft copper wire, which can be bent to the degree of elevon desired, and will stop the eleven’s upward travel depending on how far it is bent.

With early types of gliders, in many cases the engine was set forward of the aft end of the body tube to move weight forward further. This, after a number of firings, tended to burn away some of the body tube. This was corrected by the application of a solution of sodium silicate (waterglass), a chemical used as a flameproofer and egg preservative, to the inside rear of the body tube. Waterglass has the disadvantage of blistering and ablating into the exhaust gases, leaving a flaky residue and unsightly appearance, as well as impairing the fit of the engine into its mountings. For applications involving the protection of elevons or rudders from exhaust gases, aluminum oil was found much more satisfactory, the foil being glued to the surface in question.

An even better alternative involves the use of an expended engine casing to shift weight forward. The nozzle is drilled or chipped out of the old casing and the casing is then glued or taped to the front of a live engine. Thus, when the engine is ejected, it will take the expended casing with it, lightening the nose for a good glide. This method gives much greater boost stability. The current world’s record holder of glide duration was equipped in this manner.

For the early recessed-engine models, and for multi-staging, it has been found necessary to arrange some system by which the depressor bars will not interfere with the stage joint. Obviously, a system using depressor bars which extend rear of the body tube to be operated by an engine which sticks out of the rear of the tube is impossible in recessed engine models, and interferes with mating of the stages. Instead, ports are cut in the body tube forward of the elevons, and the depressor bars are operated through these ports. This adds to drag and is more difficult than external-bar arrangements, but is the only proven method of meeting these special requirements. This method is also used to operate canard flaps, which are located far forward on the body.

Ports too near the front of the engine casing have caused ejection failure. In general, ports should not be cut less than about 3/4 inch to the rear of the point where the forward end of the engine casing will rest in flight. In this way, pressure does not escape from the ports at ejection charge activation.

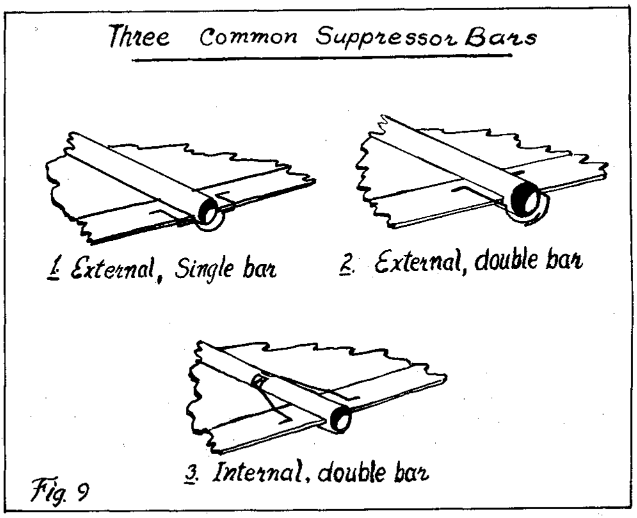

Fig. 9

Elevons in the rear and canard flaps in the front can be operated together if the rear elevon actuator is made according to standard practice, and then strands of ordinary thread are attached to the elevons, as far to the rear as possible. The thread is then brought forward, crossed over the body tube, and attached to the canard flaps. Thus the left elevon will, when released, lower the right canard flap, and the right elevon the left canard flap. The canard flaps are, of course, equipped with elastic thread to pull them down when the thread is slackened, which happens when the rear elevons are actuated. Gliders using this system can be made to stay in the air for more than two minutes, single staged.

Research on cluster-engined boost-gliders has so far shown that they are not as practical to build and fly as single-engined gliders, due to the large concentration of weight at the rear of the body. This requires that rocket stability be increased by placing the wings very far to the rear, with the result that the CG moves forward a considerable distance at the ejection of the engines. This in turn makes extremely large elevons a necessity.

CONCLUSION:

The design and construction of good boost-gliders is still an art and requires a high degree of skill in the modeler. But there are few things in any area of modeling which can compare with the satisfaction of building and flying a good glider. This is a field with a genuine challenge for the builder and those who accept the challenge will find themselves plunged into a search for new methods, materials, and principles that results not only in an expanded knowledge of the physics of flight, but also in contributions to the entire art of model rocketry.