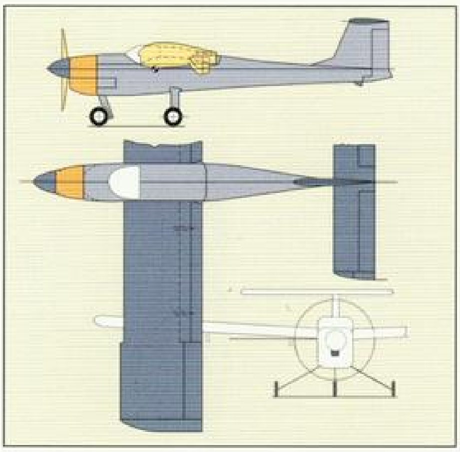
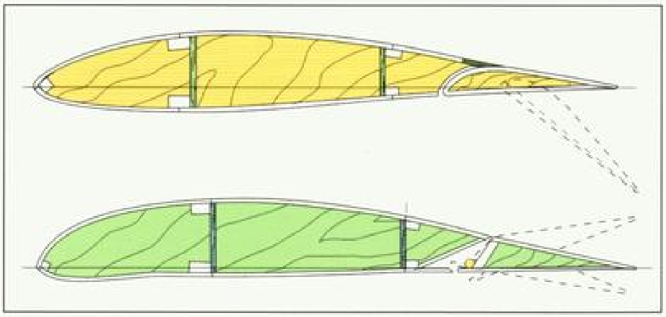
BASICS OF
R/C MODEL
AIRCRAFT DESIGN

PRACTICAL TECHNIQUES FOR BUILDING BETTER MODELS

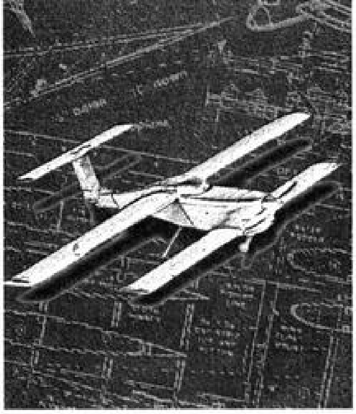
CHOOSING AIRFOILS • WING LOADING • CG LOCATION
BASIC PROPORTIONS • AEROBATIC DESIGN
—and much more!

BY ANDY LENNON





From the publishers of
MODEL
Airplane
NEWS



Chapter 22

Canards, Tandem Wings and Three-Surface Designs

History repeats itself. The first successful powered flights were made by canards; subsequent designs incorporated both a canard foreplane and a tailplane behind the wing, i.e. three surfaces.

Eventually, the wing and rear tail versions predominated, and they're now the conventional configurations. Recently, however, largely owing to Burt Rutan's efforts, the canard, the tandem-wing and the three-surface versions have reappeared (Figure 1). Today, Burt's latest designs are more conventional, but still unique, and in this chapter, I'll discuss the design of these three configurations.

ADVANTAGES

- **Increased safety.** For well-designed, full-scale canard, tandem-wing and three-surface aircraft, the major advantage of their design is that it frees them from the too-often-fatal, stall-spin-at-low-altitude crash. Though the foreplane may stall, the main wing does not.

- **Shared load; reduced main-wing area.** In a conventional aircraft, the wing does all the work; the horizontal tail is lightly loaded (downward in most cases) and simply controls the wing's AoA. On these three types of front-wing aircraft, their forward surfaces work hard and share the load with the main wing, which may, as a result, have a reduced area.

- **Main wing spar may be out of the way** at the rear of the cabin; the conventional version's spar goes through the cabin and interferes with passenger seating (particularly true of low- and mid-wing types).

- **Smaller, lighter, more compact airplane**—achieved by dividing the required wing area between two lifting surfaces.

DISADVANTAGES

- **Heavily loaded foreplane.** For stability, the foreplane must be much more heavily loaded (in terms of ounces or pounds per square foot of wing area). The foreplane's loading controls the aircraft's stall speed, which is considerably higher than the main wing's stall speed. Canard and tandem-wing types take off and land faster and need a longer runway than conventional aircraft. The three-surface design is better in this respect because its foreplane loading may be reduced, but three surfaces mean more interference drag.

The Swan canard pusher.

- **Limited aerobatic capabilities.** The high foreplane loading, combined with the inability to stall the aft wing, limits the aerobatic capabilities of these three classes. (See Chapter 4, "Wing Loading Design.")

AIRFOIL SELECTION

For all three types of forward-wing aircraft, airfoil selection is very critical. There are three broad categories of airfoil: heavily cambered (such as E214); moderately cambered (such as E197); and no-camber, symmetrical type (such as E168). (See Figure 7 in Chapter 1, "Airfoil Selection.")

Figure 2 compares lift with AoA curves for these three airfoils. Note that, though the heavily cambered E214 stalls at a lower AoA, it starts lifting at a higher *negative* angle than the other two. The symmetrical E168 starts to lift only at a positive angle, and its max C_L is the lowest of all three. (See the appendix for the section characteristics of these airfoils.)

Since all three configurations have both forward and main wings sharing the lift, two requirements are of *critical* importance for successful, stable flight:

- The front wing *must* stall before the main wing stalls. If the main wing stalls first, the scenario depicted in Figure 3 will result; at low altitude, a crash is inevitable.

- The main wing *must* arrive at its angle of zero lift before the foreplane achieves zero lift. If the foreplane ceases to lift while the main wing still lifts, the behavior shown in Figure 4 results.

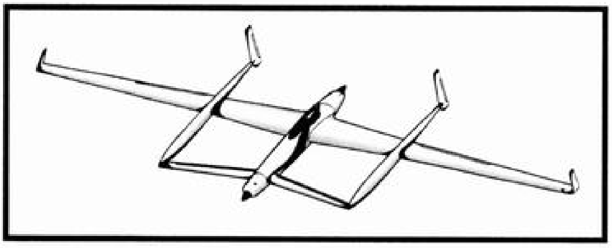


Figure 1.
Rutan's around-the-world Voyager.

With these considerations in mind, look again at Figure 2. Obviously, airfoil E214 would be an excellent choice for the front wing. Its early stall and high *negative* angle of zero lift satisfy both requirements, and its stall is gentle.

For the main wing, airfoil E197 would again be excellent. Its higher AoA at the gentle stall and its lower *negative* angle of zero lift comply with both manda-tory requirements. E168 would not be suitable for either front- or main-wing airfoils, but it would be a good section for the horizontal tail-plane of a three-surface design.

An airfoil's stall pattern at C_L max and at the wing's flight Rn is another important consideration. Obvi-ously, for a canard or tandem-wing foreplane to have sudden-lift-loss or sharply stalling airfoils invites trouble. In the landing flare, if the foreplane were to stall suddenly, landing would be very hard and would probably damage the nose-wheel landing gear.

For the three-surface airplane with a horizontal tail and elevators, a sharp foreplane stall is desirable to prevent up-elevator action from stalling both the front and main wings. Elevator action would prevent a sudden nose drop. See Eppler E211—a foreplane airfoil with a sharp stall at low Rn—in the appendix. Note the reduction in the negative AoA of zero lift as Rn is reduced.

Using slotted flaps on the foreplanes of canard and tandem-wing models for pitch control has three effects (see Figure 5):

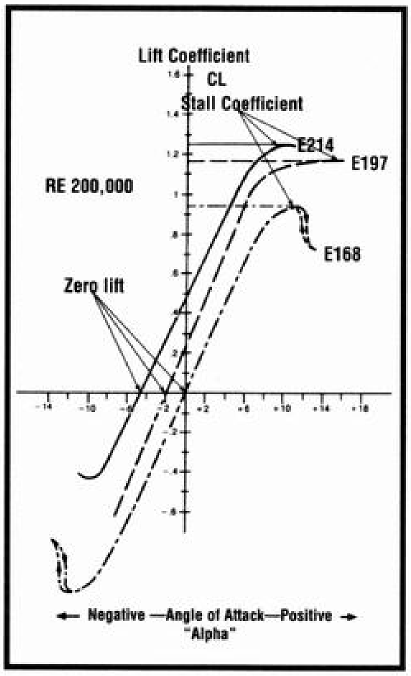


Figure 2.
Lift curves of three airfoil types.

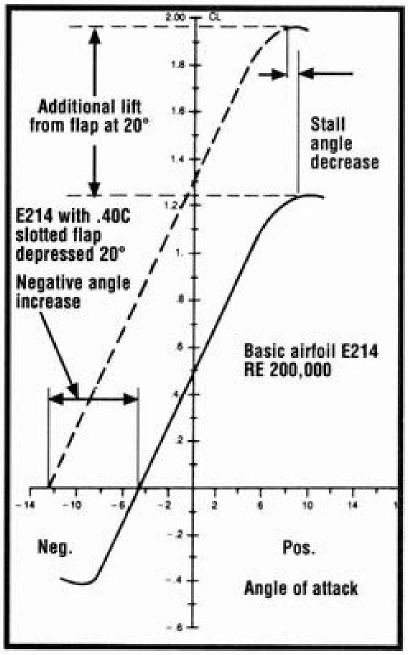


Figure 5.
Impact of a 40% chord slotted flap deployed to 20 degrees on airfoil section 214.

- The stall angle is reduced.
- The *negative* angle of zero lift is increased.
- C_L max is increased substantially.

REYNOLDS NUMBERS, ASPECT RATIO AND PLANFORM

High aspect ratios reduce the stalling angle (desirable for foreplanes) but result in lower Rns, particularly at landing speeds. Chords of less than 5 inches are to be avoided. (For more on these subjects, refer to Chapter 1.)

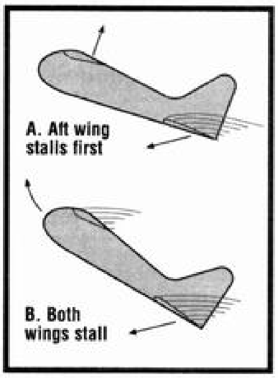


Figure 3.
Nose-up pitch as aft wing stalls first.

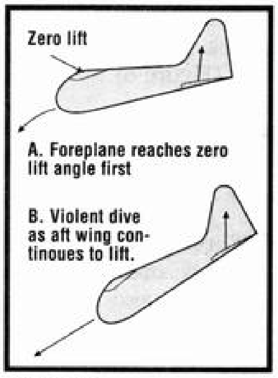


Figure 4.
Steep dive as foreplane hits zero-lift angle first.

Low aspect ratios increase the stalling angle (desirable for the main wings) of all three types. Shorter main wingspans improve roll response.

A mild forward sweep on the foreplane promotes root-stalling first (see Chapter 5, "Wing Design"). The result is a gentle, progressive stall as the angle of attack increases. Such forward sweep should not exceed 5 degrees on the ¼ MAC line. On a three-surface design, forward sweep would also benefit the horizontal tailplane.

DOWNWASH AND TIP VORTICES

Downwash is thoroughly discussed in Chapter 7, "Horizontal Tail Incidence", and charts for estimating downwash angles are provided. Each of the three, forward-wing aircraft is affected by downwash.

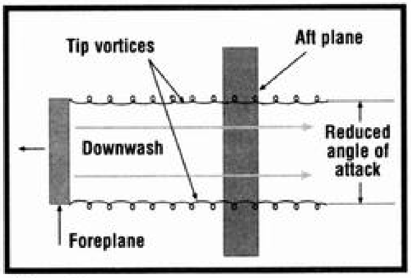


Figure 6.
Downwash impact on a canard.

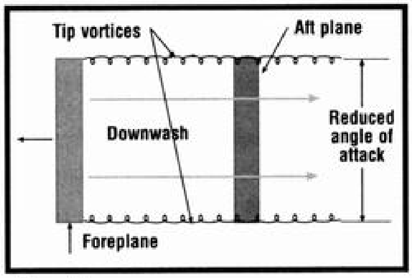


Figure 7.
Downwash impact on a tandem wing.

- **Canards:** foreplane downwash impacts on a portion of the aft wing (equal in span to that of the foreplane), reducing the angle of attack and lift in the downwashed area (Figure 6).

- **Tandem-wing aircraft:** the whole span of the aft wing is similarly affected (Figure 7).

- **Three-surface models:** the main plane is affected as in the canard (Figure 6); and the horizontal tail is affected by the downwash from that portion of the main wing that's "shadowed" by the foreplane downwash. The reduced AoA of the "shadowed" portion of the main wing may be compensated for as follows:
—For tandem wings of equal span: for level flight at the designed cruising speed, the aft wing's AoA should be increased by the downwash angle generated by the foreplane.
—For canards and three-surface airplanes: shadowed portions of the main wing should have an increase in AoA that's equal to the foreplane's level-flight downwash angle. The part of the wing that's out of downwash is left at the AoA calculated to produce adequate lift. This calls for a "jog" in the wing and was used on the Swan.

A variation of this is to use the NASA droop for that part of the wing that's out of downwash, so that the inboard ends of the droop are just behind the foreplane tips.

A simpler method, where the foreplane span is roughly half that of the main wing, is to increase the whole main wing's AoA by half the foreplane level-flight downwash angle. The main wing outboard portions will have higher lift coefficients, closer to the stall. The Canada Goose used this method.

A third method is wing washout with increased root AoA and reduced tip AoA. An accurate built-in twist is needed, but it results in an increase in wingtip stall margin and is stabilizing on a sweptback main wing.

In all cases, the net lift should equal the calculated lift needed.

To avoid the impact of foreplane-tip vortices on the main wing, a vertical gap between foreplane and main plane of half the aft wing's MAC is suggested—either the foreplane low and the main plane high, or the reverse may be used. The foreplane-tip vortices will then pass under or over the main wing. Longitudinal separation or "stagger," between ¼ MAC points of each wing, of two to three times the aft wing's MAC, is appropriate.

For the three-surface design, it is suggested that the horizontal tail be "T"- mounted on the fin where it will be more effective, and the stagger be 1 to 2 times the aft wing's MAC.

LOGICAL DESIGN STEPS

- **Power and control unit selection.** The power and control units together weigh 50 percent or more of most models' total weight. The first step in design is to choose these units and obtain their weights.

- **Overall weight estimation.** Obtaining a rough preliminary weight estimate while the model is still in the conceptual stage is essential but not easy. The data on weight estimating in Chapter 13, "Stressed Skin Design and Weight Estimating," will help. When the model's size and proportions have been established, a more accurate weight appraisal is advisable. Chapter 5, "Wing Design," also provides insight into obtaining this estimate.

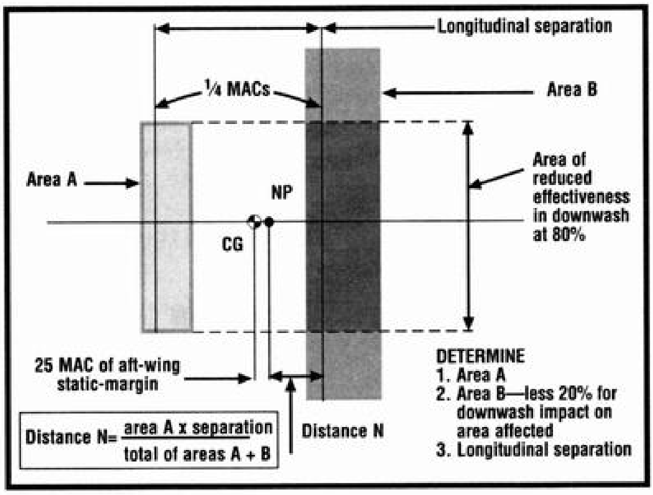


Figure 8.
Locating a canard's NP and CG.

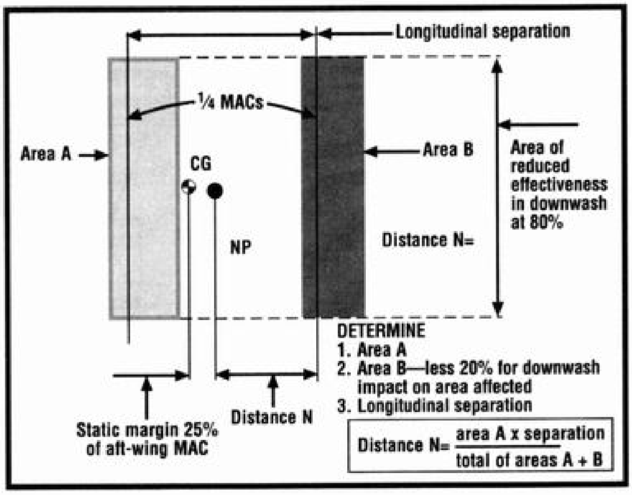


Figure 9.
Locating tandem-wing NP and CG.

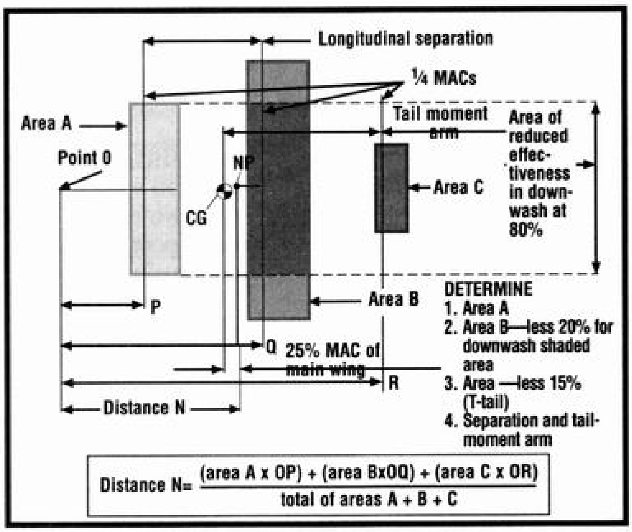


Figure 10.
Locating three-surface design NP and CG.

▪ **Wing loading selection.** The type of performance desired governs the choice of wing loadings. Chapter 5 suggests wing loadings in ounces per square foot of wing area.

If the design is to incorporate flaps, then higher wing loadings are in order. When deployed, their additional lift and drag will provide reasonable landing speeds. With weight and wing loading established, the wing's total surface area is easily calculated:

Wing area (sq. in.) =

$$\frac{\text{Weight (oz.)} \times 144}{\text{Wing loading (oz./sq. ft.)}}$$

▪ **Level-flight speed estimate.** This is essential in determining the angles of attack of the fore and aft wings.

▪ **The neutral point and CG location.** The NP concept is discussed in the Chapter 6, "CG Location." For the three types of forward-wing models, both CG and NP will fall somewhere between the two lifting surfaces. Precisely calculating their locations is very complex and beyond the scope of this article. In full scale, the calculations are confirmed by wind-tunnel tests or actual flight tests with the CG at various locations.

A simplified method is proposed; it considers areas and their separation and effectiveness. Figure 8 covers NP and CG locations for canards, Figure 9 for tandem-wing designs and Figure 10 for three-surface models. The normal static margin for stability is 10 percent of the main wing's mean aerodynamic chord (MAC). Use of a 25-percent static margin as suggested leaves a 15 percent margin of error. Test-flying the model with cautious rearward CG movement will confirm your calculations.

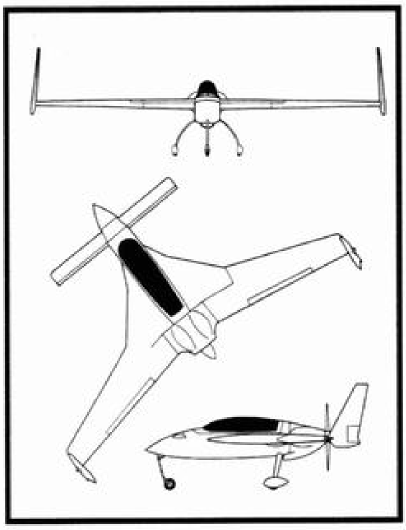


Figure 11.
Three-view drawing of the Rutan Long-EZ.

▪ **Sizing of fore and aft wings.** The total wing area, having been established, must be divided between the two lifting surfaces.

CANARDS

From the discussion of NP and CG locations, it is apparent that the smaller the foreplane, the farther back NP and CG will be and vice versa. The area relationship between the two lifting surfaces determines NP and CG.

The heaviest component is the power unit. Its location dictates the area relationship of fore and aft wings. A pusher-engine design would require an aft CG, a small canard and a large wing. A front-engine design would reverse this situation.

If flaps are used, they must provide balanced lift when extended. Too much additional lift from either fore or aft wings would result in very serious pitch problems—either a dive or a stall. Obviously, both sets of flaps must be extended simultaneously for balance.

With a small canard of 15 percent of the aft wing in area, flaps on the aft wing would be much more powerful than those on the foreplane. Another disadvantage of a small canard and rearward CG is the reduction in moment arm to the MAC of the vertical tail surface(s); it necessitates very large vertical areas. Burt Rutan solved this problem by using aft-wing sweepback and placing the vertical surfaces at the wingtips (Figure 11). This substantially increases the moment arm. The Canada Goose design, with a modest 5 degrees of aft-wing sweepback, had the same philosophy applied to it.

Sweepback reduces lift. As model airplane designer John Roncz put it, "You get around 14 percent more lift per degree of angle of attack at zero sweep than at 30 degrees of sweep."

The Swan had a straight aft wing,

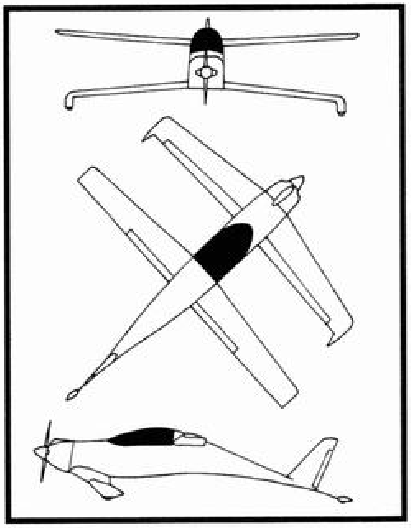


Figure 12.
Three-view drawing of the Rutan Quickie.

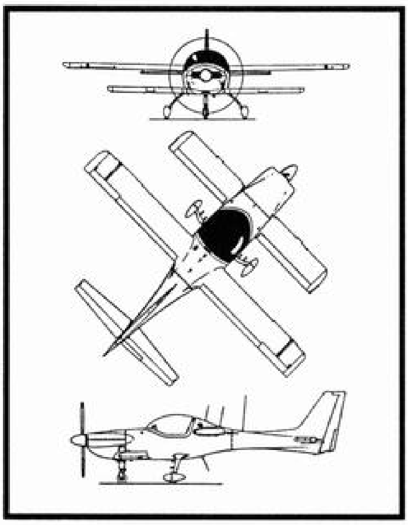


Figure 13.
Roncz's Eagle three-surface trainer.

but its vertical surfaces projected behind the wing. Twelve ounces of ballast were needed to correctly position its CG—as had been anticipated after doing the "Balancing Act" (see Chapter 6) for this model. The minimum canard area is 15 percent of that of the aft wing. For a front-engine aircraft, such as the ill-fated "Pugmobile," a foreplane area of close to 60 percent was used.

The Canada Goose had 31 percent foreplane; the Swan had 37 percent. Using a foreplane of 30 percent as an example, total wing area would be 130 percent.

For a total wing area of 600 square inches, foreplane area would be:

$$\frac{30 \times 600}{130}$$

or 138.5 square inches; and aft wing area would be:

$$\frac{100 \times 600}{130}$$

or 461.5 square inches in area.

The designer needs to take the area relationship into consideration.

TANDEM WINGS

This type has wings with close to equal area. The NP and CG are well forward. A pusher engine *behind the aft wing* would present an impossible CG problem.

Rutan's Quickie (Figure 12) illustrates a front-engine tandem-wing version, with its vertical tail mounted on an extension of the fuselage.

The Wasp is another tandem-wing version. The pusher engine is just behind the front wing. The aft wing and vertical surfaces were supported on booms. This model was very stable, but it had no flaps owing to its low wing loading.

THREE-SURFACE AIRPLANES

The comments on wing sizing for a canard apply to the fore and main planes of the three-surface type. The presence of a horizontal tail causes both NP and CG to move rearward (compared with a canard). The tail's elevators provide pitch control. Slotted flaps on both fore and aft planes permit higher wing loadings with reasonable landing speeds.

Figure 13 shows John Roncz's "Eagle"—a successful trainer that proved safe and easy to fly. Its forward wing area is 67 percent of the main wing area, and both wings are equipped with slotted flaps.

Rutan's "Catbird" (Figure 14) is another three-surface design. Note the slight forward sweep of both canard and horizontal tail. The Piaggio P180 "Avanti" is a twin-pusher-engine, three-surface, slotted-flap airplane (Figure 15). The author's "Wild Goose" was built according to the design approach outlined in this chapter and flies very well. All four illustrate the added flexibility offered by this three-surface configuration.

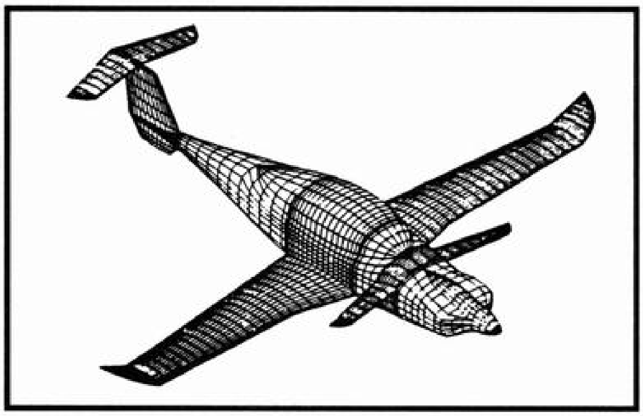


Figure 14.
Rutan model 81 Catbird (VSAERO model); note three surfaces.

■ **Aspect ratio and planform selection.** In addition to determining the areas of the wings, you must also select their aspect ratios and planforms as previously discussed.

■ **Longitudinal and vertical separation.** Longitudinal separation (stagger) measured from the 25-percent-MAC points ranges from 1 to 3.25 times the aft wing's MAC.

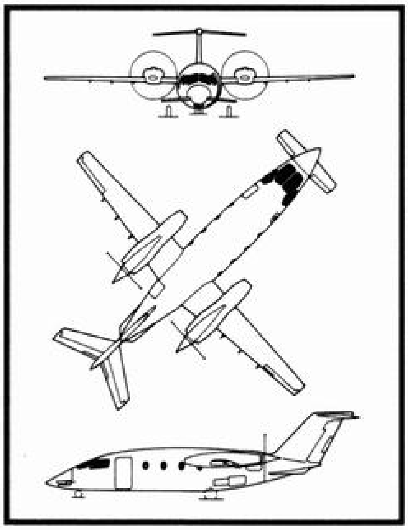


Figure 15.
Piaggio P 180 Avanti three-surface twin.

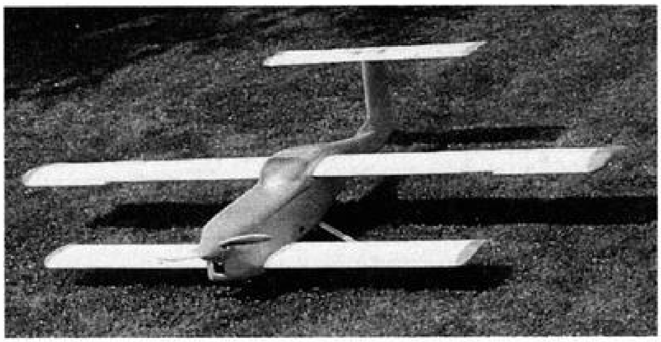
Vertical separation (gap) should be ½ the aft wing's MAC as discussed.

Tail surfaces of a three-surface design should have a tail-moment arm as outlined in Chapter 7. A T-tail design is favored.

■ **Airfoil selection.** As previously explained, this is critical for stable flight. Additional information and formulas can be found in Chapter 1. The horizontal tail airfoil of a three-surface design should be of symmetrical section

LEVEL FLIGHT

In level flight, at the selected cruising speed, the fore and aft wings must support the model's weight. The calculation of the weight distribution, leading to loadings for both wings, is shown in Figure 16. The foreplane must, however, support



The Wild Goose, a successful three-surface design.

an additional load beyond that resulting from weight alone. This results from:

- The fore and aft wing's pitching moments always being nose-down or negative.
- Propeller thrust loading.
- Drag moments of both fore and aft wings.

Explanation and evaluation follows:

Pitching moments are explained in Chapter 1, and Formula 10 of Chapter 1 permits the calculation of these moments in inch-ounces. Symmetrical airfoils have no pitching moment.

If the propeller thrust is above an imaginary horizontal line drawn through the CG, a nose-down (or negative) moment results. Below that horizontal line, thrust produces a nose-up moment that reduces the foreplane load. If the CG is on the thrust line, there is no thrust loading. The thrust, in ounces, required to propel the model at the design's level flight speed is difficult to evaluate; an estimate would be 40 percent of the model's gross weight. For a weight of 100 ounces, thrust would be 40 ounces.

Figure 17 provides formulas for calculating the wing pitch and thrust-related foreplane loads in ounces. Fore- and aft-plane drag moments consist of the total of profile and induced drags, in ounces, multiplied by the distance, in inches, the wing's ¼ MAC is above or below the CG. If it's above the CG, the moment is nose-up, or positive, and below it, it is nose-down, or negative (see Formulas 5 and 9 of Chapter 1).

Figure 18 provides simple formulas for establishing the effect of drag moments on the foreplane load in ounces. The total foreplane load is composed of its share of the model's weight plus the net sum of the moment source loads, pitching moments, thrust moments and drag moments (in ounces). Both thrust and drag loads may be positive or negative; take care to identify each so that the net value will be correct.

LIFT COEFFICIENTS

Having determined the wings' areas in square inches and their loadings in ounces, the level-flight design speed estimated (see Formula 7 in Chapter 1) permits calculation of the lift coefficients required for each wing's airfoil. Applying "Special Procedures" A and B will determine the angles of attack to provide those lift coefficients.

Decide which of the procedures will be used to compensate for the reduction in AoA caused by the downwash affecting the aft wing behind the foreplane.

The foregoing provides conditions for level flight at the design speed; any variations from that speed will require the same trim adjustments as for a conventional model.

■ Stability test. Two points of critical importance for longitudinal stability are:

—The foreplane must stall first.

—The aft plane must hit zero-lift first.

Now that the angles of attack of both wings have been calculated, it is time for this test:

Using "Special Procedure" C in Chapter 1, determine the stalling angle for each wing and the zero-lift angles from the airfoils' curves at the landing speed Rns.

Compare the spread from AoA to the stalling angle, but *before* estimating the downwash compensation. Raising the foreplane's lift by lowering its flaps will bring it to its stall attitude; the increased lift produced by both the foreplane and its flap will increase the angle of downwash, increasing the aft wing's stall margin, but only for that portion of the aft wing in the foreplane's downwash; that part out of downwash isn't affected. If your foreplane's calculated angle of attack is 3 degrees and it stalls at 12 degrees, there's a spread of 9 degrees. With an aft wing at 1 degrees, stalling at 14 degrees, the spread is 13 degrees so that the foreplane stalls first.

Similarly compare the spread from zero-lift angles of attack to your calculated angles for both wings. That of the foreplane should be substantially higher than that of the aft

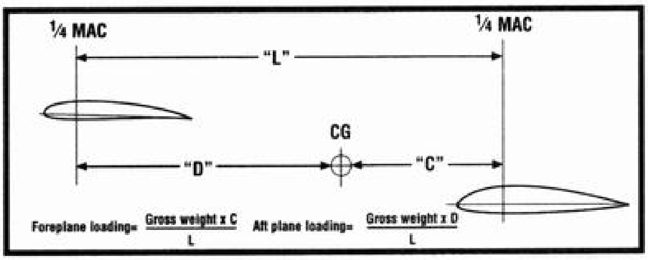


Figure 16.
Calculation of wing loadings due to weight only.

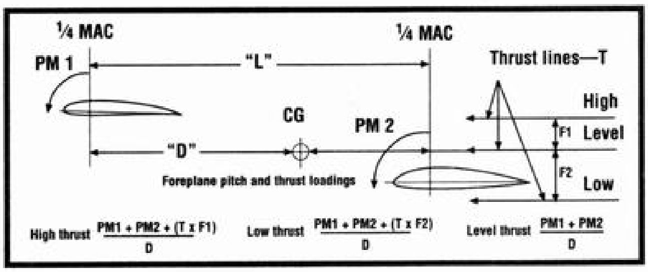


Figure 17.
Additional foreplane loading from wing pitching moments and thrust.

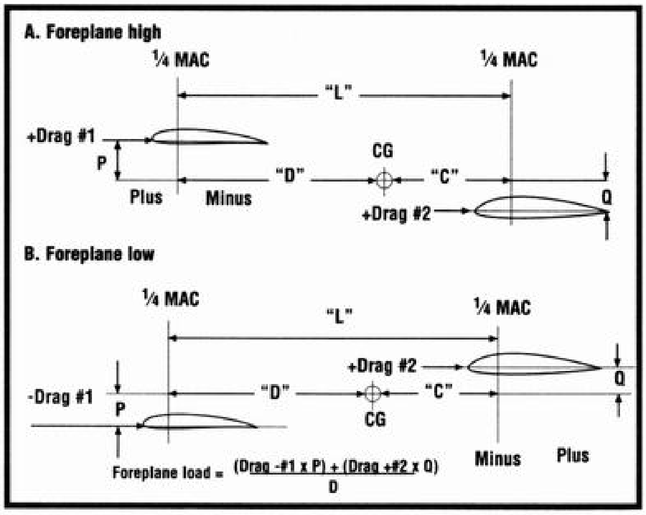
plane. As the foreplane moves toward zero lift, its downwash angle is reduced, increasing the aft wing's lift in the downwashed area and increasing the spread from zero lift to actual AoA.

Eppler E214 has a zero-lift angle of minus 4.75 degrees; if set at 3 degrees, as above, the spread is plus 3 degrees to minus 4.75 degrees, or 7.75 degrees. Eppler E197 has a zero-lift angle of minus 2 degrees. Set at plus 1 degrees, the spread is plus 1 degree to minus 2 degrees or 3 degrees, leaving a healthy margin of 4.75 degrees.

THREE-SURFACE AIRPLANE

This type presents more options than either canard or tandem wing configurations as regards the lift distribution between all three surfaces.

1. The canard and main wing provide all the lift needed. The horizontal tail provides no lift at the selected speed, but its elevators control pitch and trim.
2. Have the canard provide most of its share of the needed lift with the horizontal tail providing a compensating download.
3. Have all three surfaces share the lift. This author's choice would be "1" above—canard and main wing doing all the lifting. Calculation of wing loads would be that for canards and tandem wings described previously.



Foreplane load = $\frac{(\text{Drag -\#1} \times P) + (\text{Drag +\#2} \times Q)}{D}$

Figure 18.
Foreplane loading from fore and aft wing-drag moments.

■ **Unique behavior of the three-surface configuration.** Flight tests of the Wild Goose disclosed unique behavior that relates directly to the three options outlined above. Option 1 had been selected for this model. During its design, the airplane's wing loadings were calculated to be 46 ounces. per square foot for the foreplane and 22 ounces. per square foot for the aft plane in level flight at 60mph.

The foreplane's loading consisted of 18 ounces. per square foot for its share of the model's weight, plus 28 ounces per square foot due to the nose-down load from the airfoils' pitching and the airplane's thrust and drag moments. This high foreplane loading was of concern; but slotted flaps on both fore and aft wings were calculated to bring takeoff and landing speeds to reasonable levels.

During test flights, two unusual characteristics became very evident:

- Elevator pitch control was *very* sensitive.

- Landing speed, *flaps-up,* was more in keeping with the aft wing's lower loading and comparatively slow—an estimated 25mph.

The explanation of this surprising behavior was reasoned as follows: a conventional, tail-last, airplane with its CG well ahead of its wing's center of lift requires a tail-down load (up-elevator) for level flight. The CG of the three-surface design is well ahead of the aft wing's center of lift, and in level flight, the

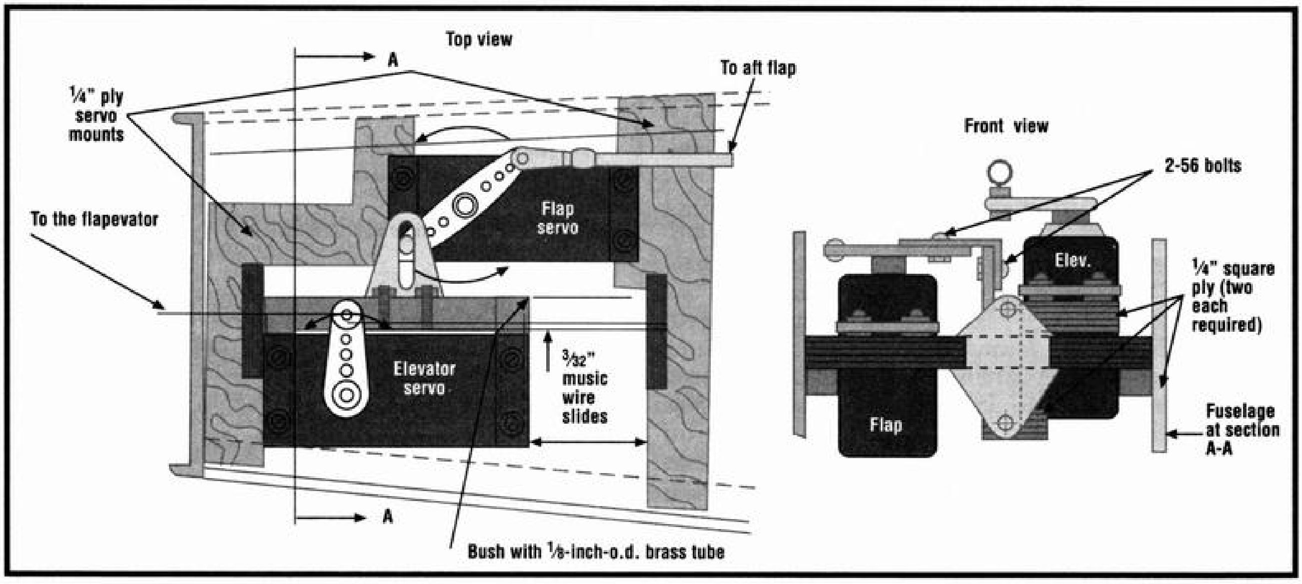


Figure 19.
Elevator-flap servo installation.

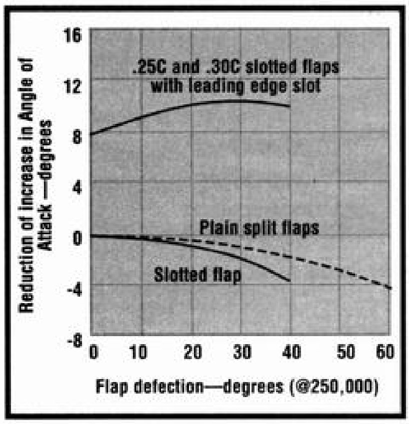


Figure 20.
The effect of flaps and leading-edge slots on the angle of maximum lift.

foreplane's lift provides the balancing upward lift. Up-elevator downloads the tail and unloads the foreplane, reducing its wing loading substantially. The foreplane's *surplus* lift is then adding to the up-elevator action, causing the elevator sensitivity.

This results in a very beneficial reduction in landing and takeoff speeds, both flaps-up and flaps-down. This unique behavior has an impact on the three options listed above.

Option 1 is considered above; option 2 would reduce the foreplane's wing loading, its angle of attack, its lift coefficient and its downwash angle. The aft wing's loading would increase, requiring an increase in its angle of attack. This would bring both wings' airfoils closer to dangerously unstable conditions, but it could reduce elevator sensitivity.

Option 3—having the horizontal tail lift upward—would add to the foreplane's loading and would result in even greater elevator sensitivity.

In this author's opinion, option 1 is best. Elevator sensitivity may be overcome by use of the elevator's *low* dual rate, or by reducing the elevator's area to 20 or 25 percent of the horizontal tail's area instead of the Wild Goose's 40 percent.

■ **Longitudinal control methods.** The dominant pitch control for canards is a slotted flap on the canard. Another method is a flap on the foreplane and simultaneous up or down action of ailerons on the aft wing. The major method for tandem wings is a plain flap of full or partial span on the foreplane. The horizontal tailplane's elevators are the sole pitch control for three-surface designs.

If option 1 is chosen and fore and main planes provide the necessary lift, the horizontal tailplane's AoA should be zero degrees to the downwash from the main wing. That downwash angle is based on the level-flight lift coefficient generated by the main wing, which is, itself, in the foreplane's downwash! Chapter 7 provides charts for estimating downwash.

■ **Directional control.** Chapter 9, "Vertical Tail Design and Spiral Stability," provides the basis for obtaining good directional control. For tandem-wing and three-surface models, the moment arm from CG to MAC of the vertical tail surfaces is large enough to permit reasonably sized surfaces.

Canards, particularly those with small foreplanes and pusher engines, do not have adequate moment arms. Recourse is:

—Larger vertical surfaces
—Booms or fuselage extensions supporting smaller surfaces.
—Aft wing sweepback and wingtip vertical surfaces.

FLAPS

Flaps were previously mentioned, and their limitations were briefly outlined. Since both fore and main wings share the provision of lift, the additional lift provided on flap extension *must not upset* the lift distribution between the wings. Too much lift from either wing would result in dangerous nose-up or nose-down pitch. Both sets of flaps must be lowered simultaneously for the same reason.

Both of this author's canard designs—the Swan and the Canada Goose—had slotted flaps on both wings. The foreplane flaps also provided pitch control as "flapevators." On both models, one servo actuated the foreplane slotted flap for pitch control, but it was mounted on a slide that permitted it to move backward under control of a second fixed servo (Figure 19), lowering both the fore and aft plane flaps simultaneously—foreplane flaps to 20 degrees deflection and aft-plane flaps to such deflection as balanced the increased foreplane lift.

Slotted flaps provide their maximum additional lift at 40 degrees deflection so that the foreplane flap, still under control of the first servo, may move up to neutral or down to the full 40-degree deflection from its 20-degree position for pitch control. Deflecting the foreplane flap results in a substantial increase in downwash on the aft wing, reducing its lift and that of the aft flaps in the area "shadowed" by the foreplane's downwash.

Any attempt to calculate the aft flap deflection angle to balance the front flap's 20-degree deflection would have been very complex. Instead, cautious flight tests were performed, progressively increasing aft flap deflection on each flight, until balance was achieved. Bear in mind that the foreplane flap could be raised or lowered to correct any minor imbalance, and if the imbalance was major, retracting both sets of flaps would restore the model to normal, flaps-up, flight. This worked; the Swan's aft wing slotted flaps, of partial wingspan, were extended to 35 degrees in balancing the foreplane's full-span slotted flaps deployed to 20 degrees.

In flight, lowering the flaps caused the model to "levitate"—at much slower speed, but with no up or down pitch—and the foreplane flap continued its function as

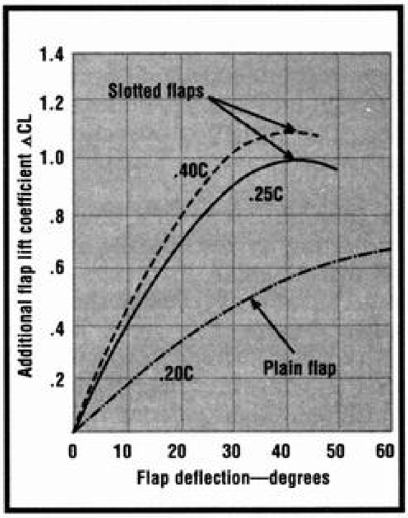


Figure 21.
Additional flap C_L example: .40 slotted flap depressed 20 degrees provides Δ C_L of 0.80 to lift of basic airfoil section.

elevator under control of the first servo. Almost full foreflap deflection was needed, in ground effect, to raise the nose for a gentle landing.

Flap deflection reduces the stalling angles of both fore and aft wings and greatly increases the foreplane's angle of zero lift (Figure 20). For three-surface designs, the same comments regarding balanced flap lift and simultaneous extension of both sets of flaps apply. However, the foreplane flap serves only as a flap; pitch control is effected by the tailplane's elevators so that the foreflap may be deflected 40 degrees.

Slotted flaps on a tandem-wing design would present the same problems as canard flaps. Slotted flaps with chords of up to 40 percent of the wing's chord may be used on foreplanes, as shown in Figures 20 and 21. Use of such wide-chord flaps on the aft plane is not recommended. Chapter 14, "Design for Flaps," provides insight into flap design, construction and actuation.

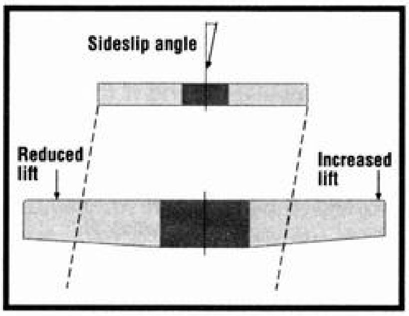


Figure 22.
The aymmetric canard downwash due to sideslip.

■ **Dihedral.** Foreplane downwash impacting asymmetrically on the aft wing in a side slip creates a powerful dihedral effect when the plane yaws (Figure 22). John Roncz's three-surface "Eagle" has no dihedral; its wings are "flat." Flight tests confirmed that dihedral was not required. The same would apply to canards and, to a lesser extent, to tandem-wing design

■ **Landing-gear design.** Chapter 16, "Landing-Gear Design" covers this subject. The stalling characteristics of the foreplane govern landing-gear design, for all three versions.

■ **Structural design.** The discussion of stressed-skin design in Chapter 13 applies to all three types of front-wing-first airplanes. Use of this type of structure would simplify weight estimating and provide optimum weight-to-strength ratios.

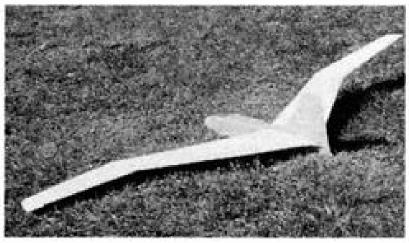
GLIDER EXPERIMENT

At first glance, the "Plover" appears to be a tailless glider; in fact it's a canard. The forward-swept inner panels are the aft plane, and the unswept outer panels are the canard. The inner and outer panel aerodynamic centers are shown in Chapter 26, "Construction Designs," as are the area's airfoil sections' neutral point and CG locations.

First test glides, with a vertical surface of normal size, were a disaster and the treacherous behavior of swept-forward wings was forcibly revealed.

When yawed, the retreating panels' centers of drag and lift move outboard. The advancing panel's centers move inboard. The drag imbalance greatly exaggerates the yaw, and the lift imbalance causes a violent roll in the opposite direction. After a couple of damaging crashes and some pondering, the vertical surface was enlarged by 300 percent of its original area. The model then flew well.

The forward panels were readily damaged on landing. After a summer of repeated flying and repairing, it was put to one side. The basic concept has merit; it avoids the impact of foreplane downwash on the aft plane. A powered version would be an interesting design challenge. ▲



The Plover glider canard.