Cozy Mark IV Aerodynamics

We will be examining the following:

- Configuration
- Structure
- Lift
- Drag
- Tip vortex
- Winglets
- Rudders
- Ailerons
- Natural stall limiting
- Deep stalls
- Elevator flutter
- Rudder flutter

For the purpose of this presentation, we will compare the Cozy Mark IV to a popular factory built 4-place, which we will refer to as the FB. The 3-view drawing of the FB is shown in Figure 1.

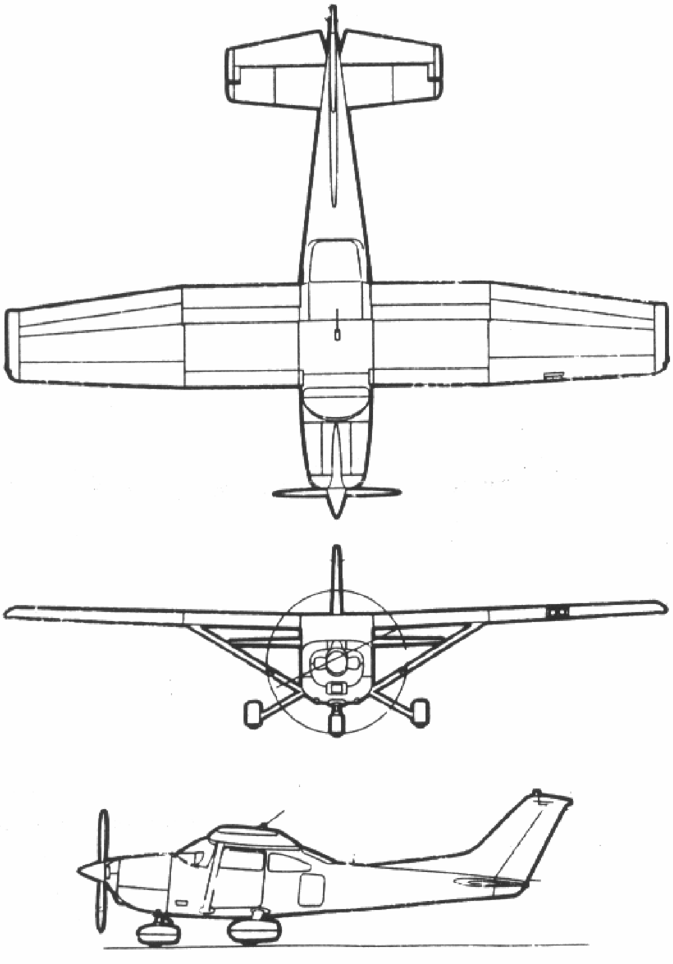

Fig. 1

And the 3-view drawing of the Cozy Mark IV, to the same scale, is shown in Figure 2. :

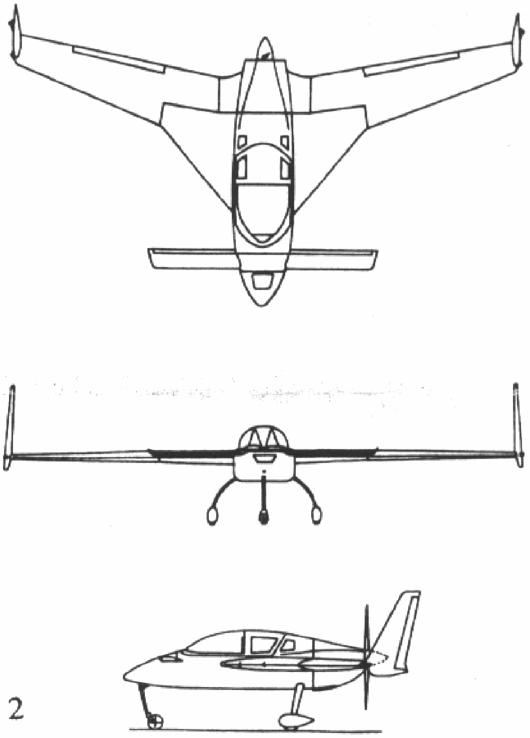

Fig. 2

The specs for the two airplanes, which are both 4 place airplanes, are shown in Figure 3:

Fig. 3 **Specification Comparison**
Mark IV vs Factory Built

Specification	Mark IV	FB
Empty weight – lbs.	1050	1918
Gross Weight – lbs.	2050	3110
Fuel – gal./lbs.	50/300	87/522
Net payload – lbs.	700	670
Engine – hp.	180	300
Cruise – kts./mph	164/190	140/162
Range – statute miles	1000	900
Cost - $	40K	300K

You will note that the FB:

1) Carries less payload
2) Even though it is much heavier
3) Has a much bigger engine
4) Which burns more fuel
5) But doesn't go as fast
6) Nor does it go as far
7) Yet it costs 7-1/2 times as much

Why do you suppose there is such a large discrepancy between these two designs? Let's examine the reasons:

First of all, let's look at the two different structures (Figure 4):

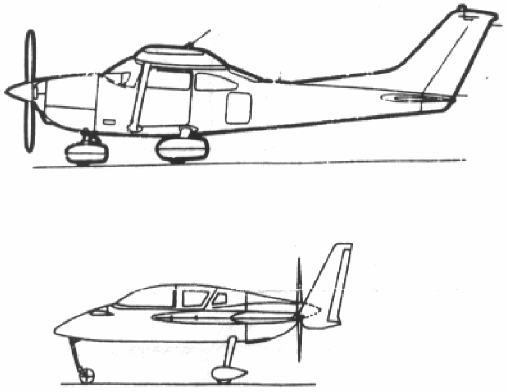

Fig. 4

Both of these airplanes carry the same amount of payload. The cabins of both are the same width (42 inches). The FB cabin is 48 inches high, and seats its passengers in an erect position, so they can see over the engine. The MKIV cabin is 39 inches high, and seats its passengers in a semi-supine position, which is more comfortable, especially on long flights, and still provides better visibility over the nose. Both airplanes are pictured in the same scale. The fuselage of the FB is 29 ft. long. That of the Mark IV is 15.8 ft. long. It is obvious that the MKIV makes much more efficient use of space.

It is interesting to analyze the loads placed on each structure (Figure 5):

Notice that the FB has only one lifting surface (the wing), but two downloads. The download ahead of the wing is the weight of the airplane and its payload. The aft download is the aerodynamic download on the tail. If the download on the tail is 20% of the weight of the airplane and its payload, then the total lift required is 1.2 times the weight of the airplane and payload, or 3,732 lbs..

In contrast, the MKIV has two lifting surfaces (the canard and the main wing), and only one down load, the weight of the airplane and its payload. The down load is carried between the two lifting surfaces. If the canard carries 20% of the weight of the airplane and its payload, then the main wing only has to lift 80% of the total weight, or 1640 lbs. This is less than half the work of the wing on the FB.

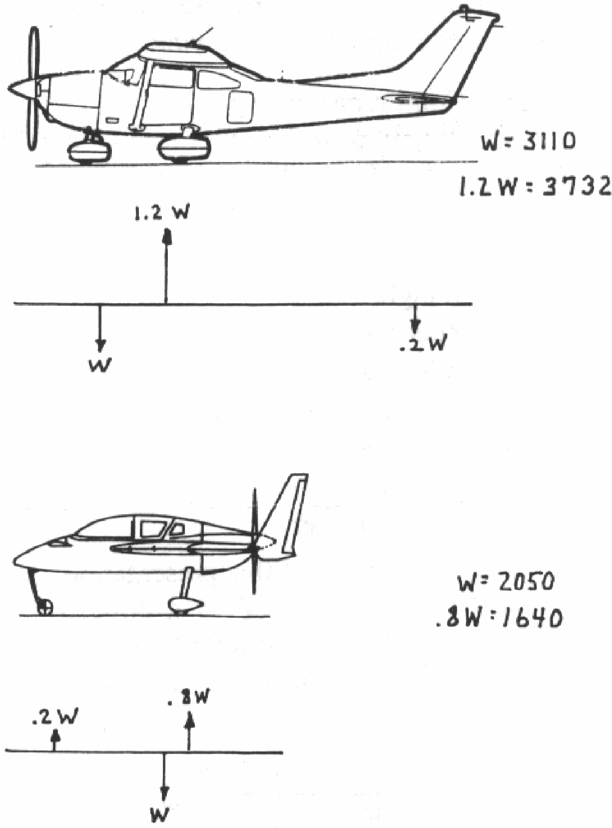

Fig. 5

Because the loads on the FB are not only greater, they are spread farther apart, so the structure must be stronger. Also, these loads are not applied as efficiently on the FB as they are on the MKIV. For example, with the FB the lift is applied at the top of the cabin, the landing load at the bottom of the cabin, the engine weight at the front of the cabin, and the tail download at the rear of the cabin, and the occupants sit in the middle. In the case of the MKIV, all of the loads (lift, engine weight and landing loads) are applied to the center spar and the occupants are suspended between the center spar and the canard, with 80% applied to the center spar and only 20% carried forward to the canard.

This analysis goes a long way to explain why the conventional tractor configuration is much heavier than that of the canard configuration.

Let's move on to aerodynamic considerations, starting with drag.There are two main components to drag: Parasite drag and induced drag, as shown in Figure 6. Parasite drag is skin friction, and all other parts of the airplane which do not contribute lift, including frontal area (shape). Induced drag is the drag induced as a by-product of lift. It is the horizontal component of the lift force vector.

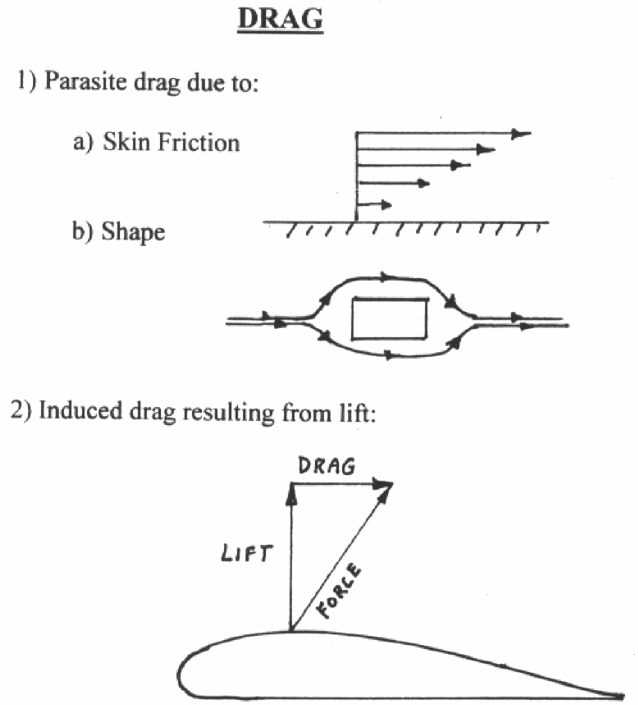

Fig. 6

Experts say that for most airplanes the two forms of drag, parasite and induced, are about equal. So let's see how these two configurations compare: Looking at Figure 7, it is easy to see that the FB has more frontal area and skin than the MKIV, so the parasite drag is significantly greater.

When it comes to induced drag, look again at Figure 5. Recall that the FB has a much heavier structure because the loads are spread much farther apart, and not applied as efficiently. It also has a configuration penalty (download on the tail) that requires that the lift be 20% more than the weight of the airplane plus payload So the induced drag will be significantly higher with the FB.

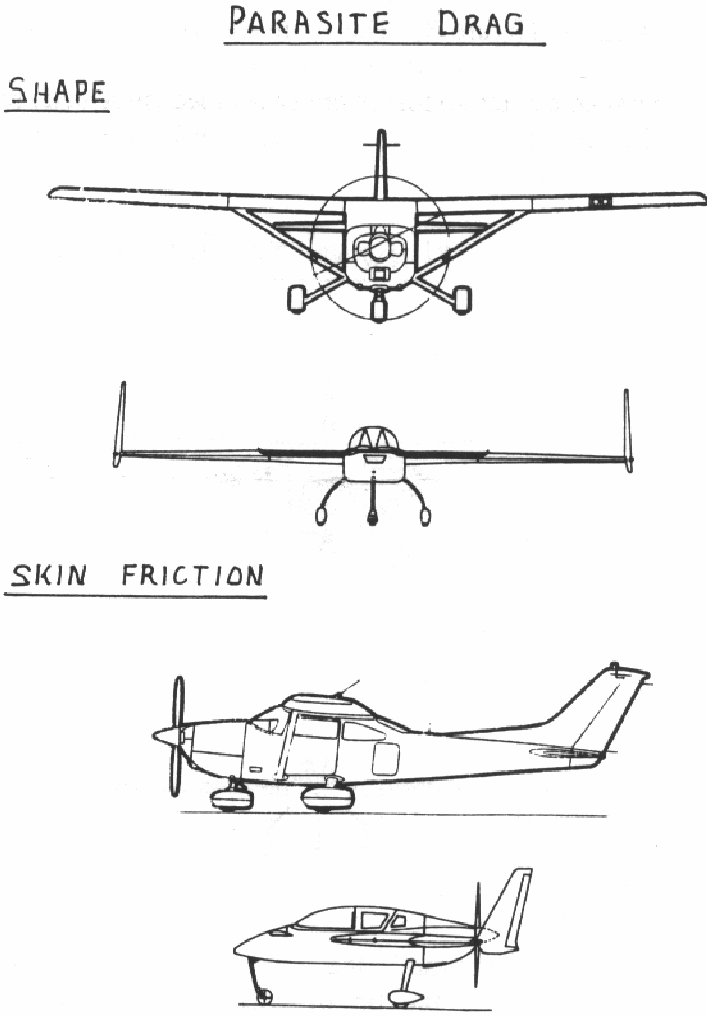

Fig. 7

We know that the total drag goes up as the square of velocity, so the much greater parasite and induced drag for the FB goes a long way to explain why it needs much more horsepower, yet doesn't go as fast or as far as the MKIV, nor can it carry as much payload.

We have already covered the fact that the FB has a larger cabin (taller but not wider), but is not as comfortable because the occupants are seated upright, rather than reclined. It is also notable that over-the-nose visibility in the FB is obstructed by the engine, and therefore not as good as in the MKIV, a safety concern.

Moving on to some of the unique features of the MKIV canard configuration, let's consider the winglets (figure 8). These are the vertical surfaces at the tip of the wings. They are called Whitcomb winglets because they were developed (invented) by Dr. Whitcomb, at NASA. They perform a number of functions:

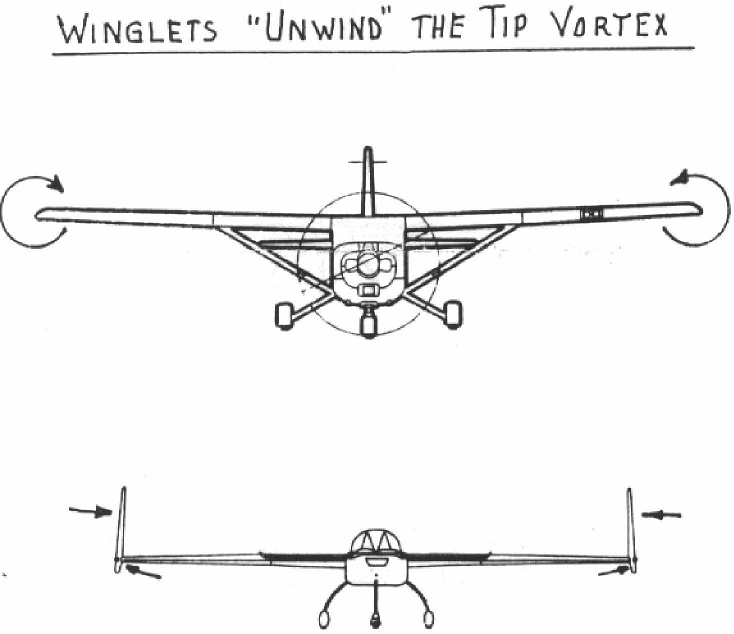

Fig. 8

1) They "unwind" the vortex that normally develops at the tip of wings. This vortex is caused when the high-pressure air underneath the wing comes up around the tip to neutralize the low pressure air above which is trying to generate lift. The vortex not only renders some of the wing at the tip, maybe a couple of feet, useless, but it also creates drag. So the wings on the FB create drag due to the vortex in addition to the drag induced by lift. Both upper and lower winglets are required to "unwind" the vortex. The inboard surface of the upper winglet is cambered the same as the top of the wing, to protect the low-pressure area. The inboard surface of the bottom winglet is cambered the same as the bottom of the wing, to protect the high-pressure area. The combination of upper and lower winglets increase the effective span of the wing without an increase in wing root bending moment.

2) The winglets provide lateral stability in the same way that wing dihedral would. If yo notice, the winglets are canted inboard (Figure 9). Since the inboard surface is the same as the top of the wing, a force is generated toward the longitudinal axis of the airplane. If one wing drops, it's winglet produces a force which tends to lift that wing, and the opposite wing's winglet produces a force which tends to drop it to a level position. So these two forces act to hold the aircraft level.

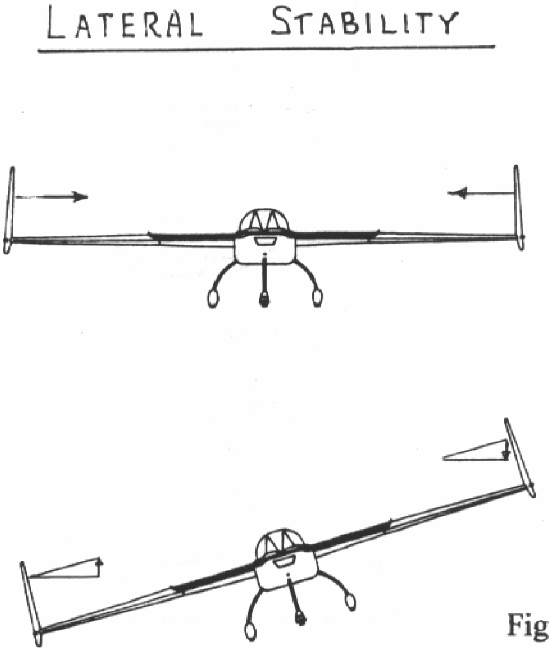

Fig. 9

3) The winglets also produce a small amount of thrust (Figure 10), because the force vector has a small forward component. The result is that the thrust produced overcomes the winglet drag, so that the directional stability provided is free.

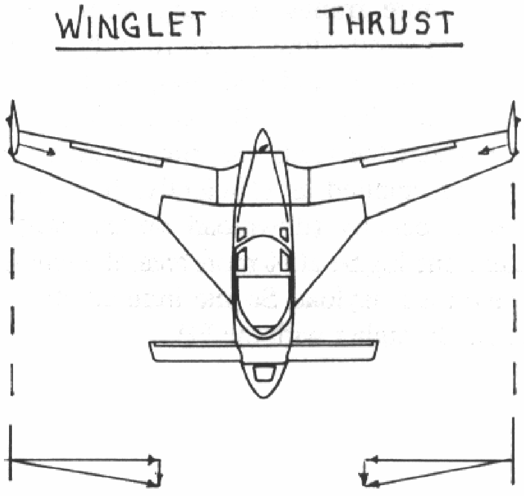

Fig. 10

4) The winglets on the Mark IV mount rudders which only deflect out-board. So if one is making a left turn, only the left rudder is used. And similarly, when making a right turn, only the right rudder is used (Figure 11). The rudders on the Mark IV are at a proportionately greater distance from the aircraft center of gravity than on the FB, so they are much more effective.

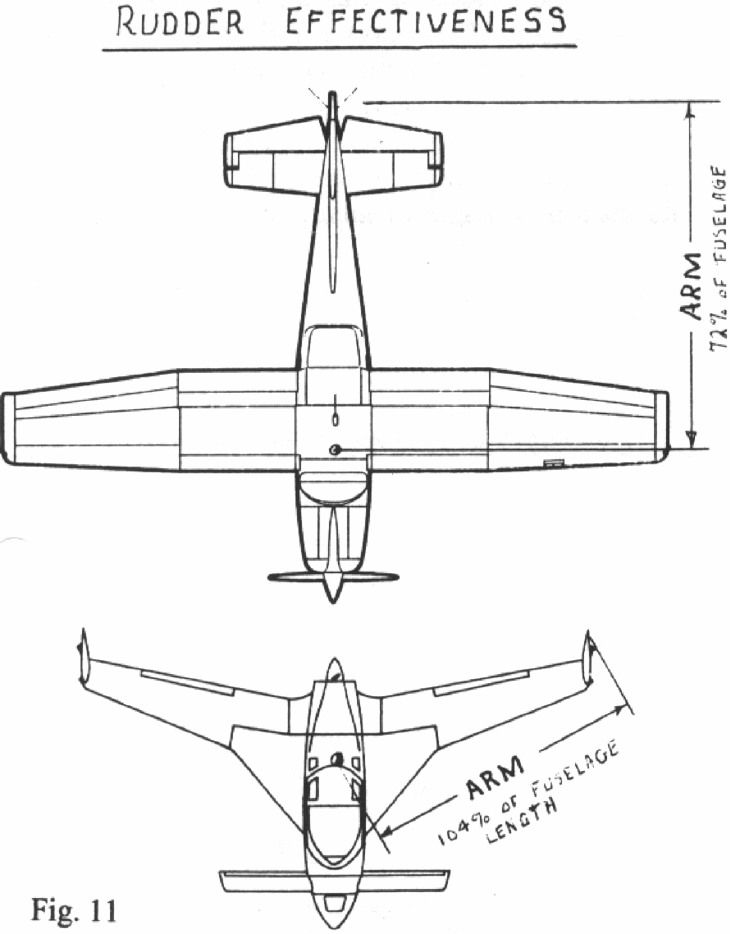

Fig. 11

5) Each rudder on the Mark IV, when it is used, increases the drag on its wing, causing that wing to slow down, lose lift, and drop down, assisting the ailerons in the banked turn. The rudder is a continuation of the winglet airfoil (Figure 12), so the low-pressure on the inboard side holds the rudder against its stop. This allows low rudder forces at low speed where rudder is needed, but high breakout forces at high speed where there is little or no requirement for rudder control. Because the rudders are independent of each other, both can be used during a descent to landing, to create drag that increases the angle of attack during descent.

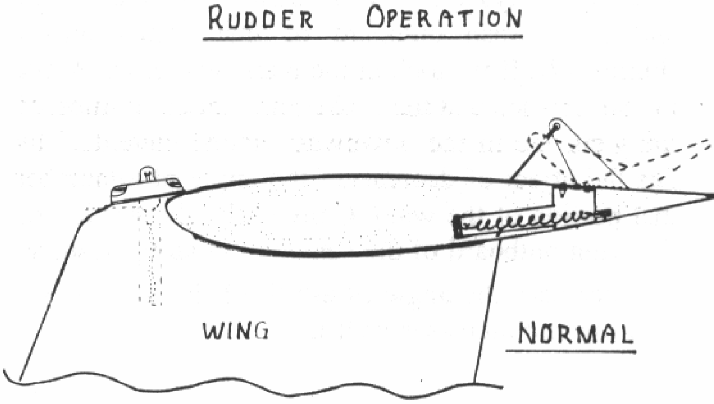

Fig. 12

The Mark IV uses Frieze ailerons (Figure 13). They are statically balanced by embedding a counter-weight in the leading edge, which is ahead of and below the hinge point. In making a banked turn, the leading edge of the one aileron extends down below the bottom surface of its wing, creating additional drag on that wing, causing it to slow down, lose lift and drop. It works in conjunction with and aids the rudder on the same wing. The two together result in no adverse yaw when initiating a banked turn.

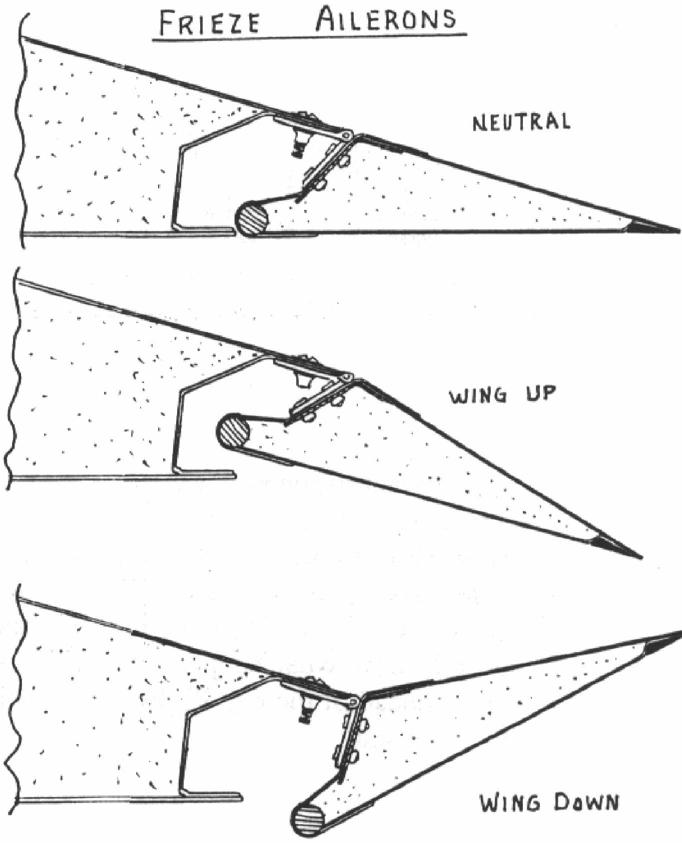

Fig. 13

There is always a downwash behind a lifting airfoil, and an upwash outboard of that lifting airfoil (Figure 14). If we look at the plan view of the Mark IV, we can see that the strake and inboard portion of the wing are in the downwash of the canard. This has the affect of decreasing the angle of attack for that portion of the wing. Conversely, the portion of the wing outboard of the canard is in an upwash, so that increases the angle of attack of that portion of the wing and increases its lift.

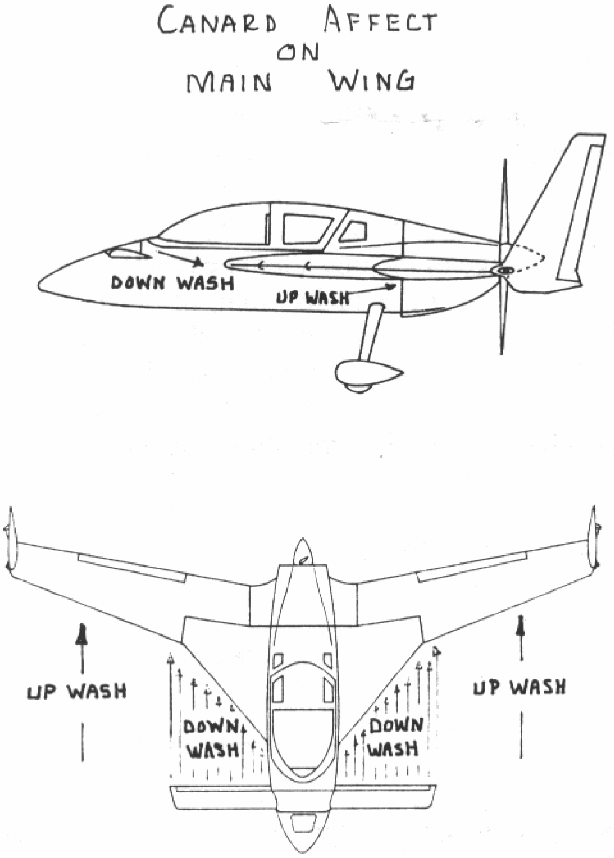

Fig. 14

If we consider what happens as we move the c.g. aft, the canard does not have to work as hard, so both the downwash from the canard and the upwash outboard of the canard are decreased. This moves the center of lift of the main wing inboard and forward. You all know what happens if the lift of the main wing is ahead of the c.g. Right? The result can be a main wing stall.

In the mid-70s, Burt Rutan presented a paper to the *Society of Experimental Test Pilots* in which h discussed the way that the Varieze uses the canard configuration to provide natural stall protection. The concept is to select airfoils such that the canard reaches its maximum coefficient of lift at a lower angle of attack than the main wing. Then the canard will not lift the nose high enough to stall the main wing. The airfoils he was talking about were the GU (Glascow University) airfoil for the canard and the Eppler airfoil for the main wing. He published coefficient of lift curves for the two airfoils as shown in Figure 15, where the coefficient is shown as a function of angle of attack. The canard reaches its maximum angle of attack at about 14 degrees, and cannot raise the angle of attack of the airplane high enough to stall the main wing. This is known as natural stall limiting.

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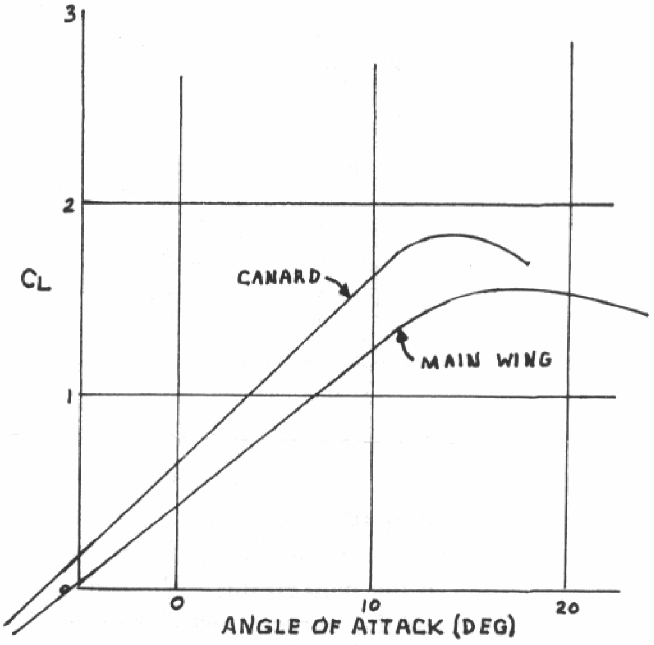
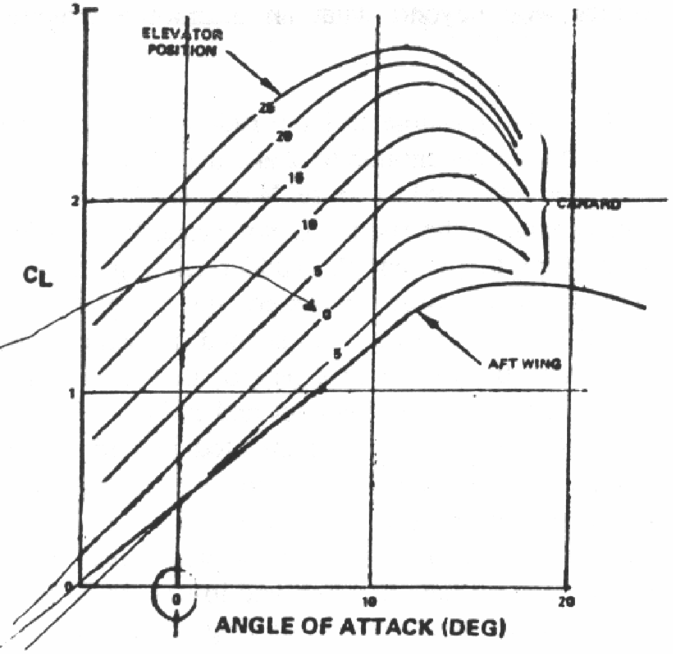


C_L vs. angle of attack for wing and canard.

Fig. 15

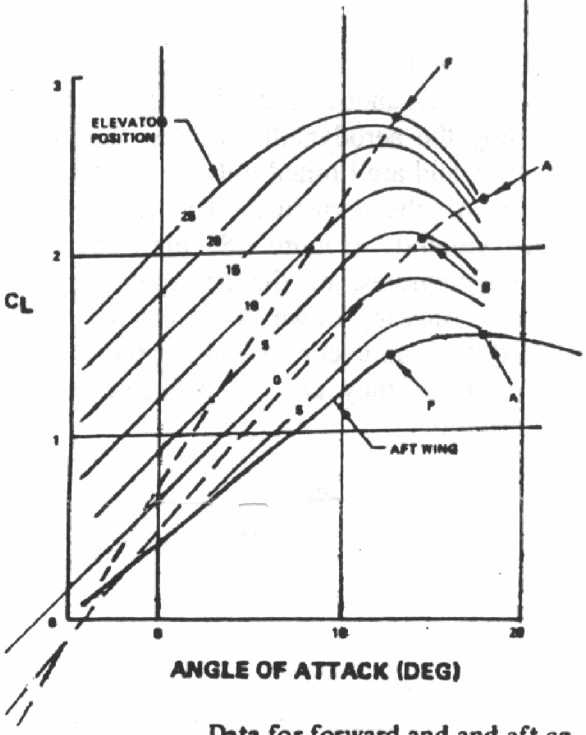
Now the situation gets a little more complicated, because the elevators are located on the canard, so there are really a family of coefficient of lift curves, each representing a different elevator position, as Burt showed in Figure 16. It is still true, however, that for any elevator position, the maximum coefficient of lift occurs at an angle of attack of 14 degrees.



–C_L vs. angle of attack for wing and canard.

Fig. 16

Burt used these curves to show what happens at two different c.g.s; a forward c.g. and an aft c.g. (Figure 17). At the forward c.g. limit, the canard has to produce its maximum lift, which corresponds to full elevator deflection, but only about 12 or 13 degrees angle of attack. However, at the aft c.g. limit, it takes much less elevator deflection to reach the same angle of attack, but even going to full elevator deflection, the nose only goes up a few more degrees, and still not enough to stall the main ving



Data for forward and and aft cg.

Fig. 17

These curves were for the GU airfoil on the canard.. The curves for the Roncz airfoil, which is used on the Mark IV, are slightly different, but the relationship to the main wing curves is similar.

If the c.g. is moved far enough aft, aft of the aft limit, the canard can raise the nose high enough to stall the main wing. The sensation is one of the nose suddenly pitching up and the rear of the airplane sinking out from under. This is accompanied by the airspeed dropping toward zero. If the c.g. is not too far aft of the aft limit, and recovery is instituted (by dumping the stick) while the aircraft still has some forward momentum, controlled flight can be regained. However, if recovery is not instituted immediately, all air flow over the canard and main wing will be lost, and a deep main wing stall can result. This could then be unrecoverable.

During our flight testing of the Mark IV, before we installed the lower winglets and shortened the canard span, we were able to stall the main wing, but we instituted recovery as soon as we saw the airspeed start to fall off. After installing the lower winglets and shortening the canard span, we were no longer able to stall the main wing not only within the desired c.g. range, but up to 1.2 inches aft of the aft c.g. limit.

Flutter usually refers to control surfaces, and is a condition which results when a control surface is not properly balanced. Instead of the inertia forces dampening the aerodynamic forces, they reinforce each other, and are limited only by the strength and elasticity of the structure. The control surface vibrates violently (Figure 18) until the structure either disintegrates, or the aerodynamic force is reduced by slowing down. With the Mark IV, this type of flutter can occur with either the elevators or the ailerons, if they are not balanced to a nose-heavy situation.

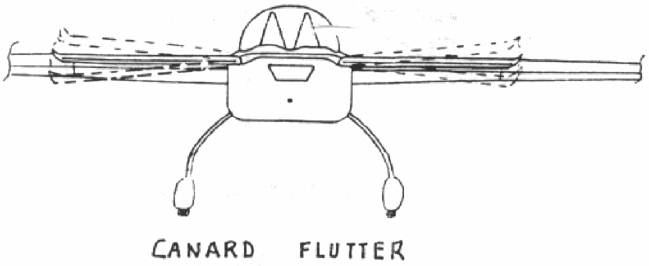


Fig. 18

Figure 19 shows a cross section of an elevator which is properly balanced, and one which is not. When properly balanced, the c.g. of the elevator will be ahead of the pivot point (hinge). If a gust of wind or sudden control stick input causes the tip of the canard to go up, the center of gravity ahead of the elevator will cause the trailing edge of the elevator to go up, which will counteract the lifting force, and cause the canard tip to go down.

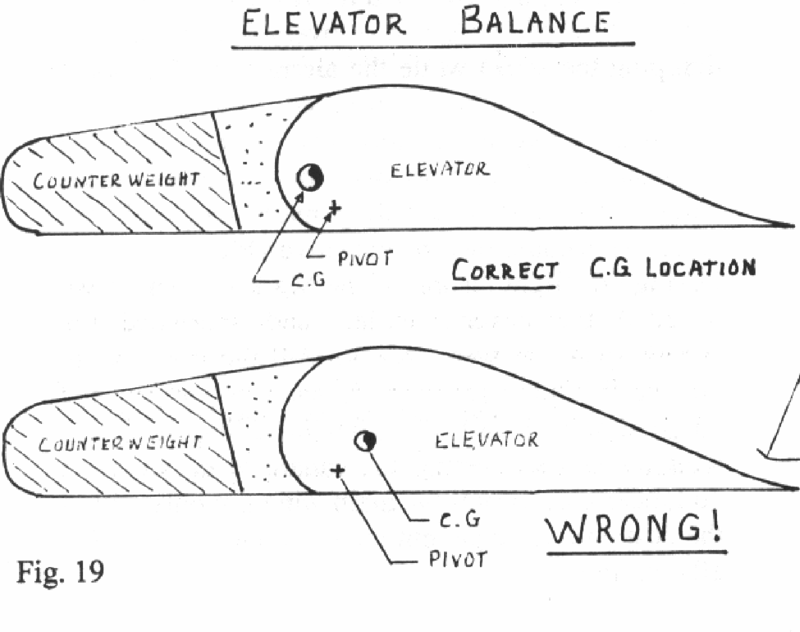


Fig. 19

But if the c.g. of the elevator is aft of the pivot point (hinge) a sudden lifting of the canard tip wi cause the elevator trailing edge to go down, causing even more lift, so the canard tip will go up even farther, until the elastic limit of the structure is reached. Then the structure drives the tip down, which causes the trailing edge of the elevator to go up, driving the tip of the canard down, until the elastic limit of the structure prevents it from going down any further, and then it will spring up again, and the whole process is repeated. The canard tip will oscillate violently up and down (many times a second) until the structure fails, or the pilot reduces airspeed. Fortunately, composite structure can resist flutter well beyond what an aluminum structure could withstand, and no Mark IVs have ever been lost due to elevator flutter.

It is also possible to have rudder flutter, which could be violent enough to shake the whole airplane and even tear a rudder loose. With the Mark IV, this can happen if the rudder is not properly installed, with stops to prevent the rudder from going past center. As has been discussed, the winglet is an airfoil with its cross-section shaped the same as the wing, and the rudder is a part of that airfoil. Th resultant force on the winglet and rudder, which is called lift on the wing, is directed inward on the winglet. This force holds the rudder against its stop. If the stop is not properly located, or if it is non-existant, the rudder could travel past center, as in Figure 20, and then the high and low pressure sides of the rudder will reverse, driving the rudder first inboard and then outboard, at a very high frequency, causing the entire aircraft to shake. If not arrested (by slowing down and applying pressure on the rudder pedals) the rudder could actually be torn loose. This would not necessarily be fatal, but could require extra skill in landing.

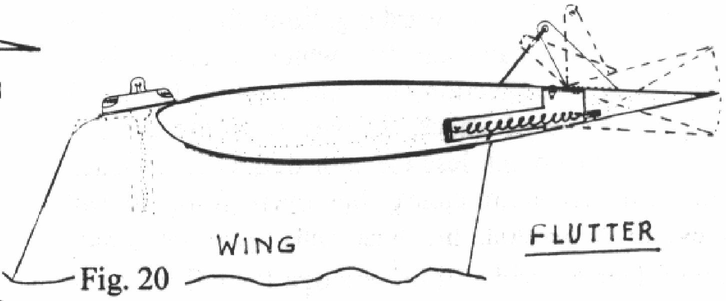


Fig. 20

We hope that the preceding discussion explain why the Cozy Mark IV is exceedingly efficient for a 4-place, and some of the unusual attributes of this design.