CANARDS
THE MYTHS AND THE REALITIES

by Albert W. Blackburn

Presented at the XX OSTIV Congress, Benalla, Australia (1987)

Summary

This paper compares the merits of canard configurations versus conventional aircraft with horizontal stabilizers in the rear. Drag, stability and control, the stall, performance, and weight and balance considerations are addressed. Test results of flying prototypes support the findings of computational aerodynamic studies. Of principal interest are two motor glider experiments. There is no evidence that a canard configuration can equal the performance, handling qualities and structural efficiency of the conventional aircraft.

canard, n. 1. an extravagant or absurd report or story set afloat to delude the public; a fabricated sensational report or statement . . . ; a hoax.

2. a duck.

3. a type of pusher airplane having the elevator. . .etc., in front of the supporting planes.

Webster's New International Dictionary
(unabridged)

Back around the turn of the century, airplanes sporting canards were all the rage. A couple of fellows from Dayton were into gliders and always seemed to end up with the elevator out front. Maybe with the rudders in the back, putting the elevators ahead of the wing seemed to balance things out.

Once they got the hang of flying their gliders off a sand dune into a strong wind, they decided to go for a bit more range and hung a motor between the wings of their biplane. The engine drove a couple of pusher propellers mounted behind the wings. In seeking to keep the unknowns of the world's first motor glider to a minimum, the Dayton experimenters (a.k.a. the Wright brothers) left the aerodynamic configuration pretty much the same as for their unpowered models.

Thus the first manned powered flight took place in a canard (definition 3 from above). A number of the other early aeronautical trailblazers followed the Wright lead.

Quite rapidly, however, the elements of lift, drag and thrust were joined by their essential handmaidens, stability and control. Elevators joined the rudder in a common aerodynamic and structural member known as the empennage. This arrangement has generally characterized the tails of most modern aircraft after the first-blush romance with canards in the earliest days of powered flight faded and gave way to a more rational marriage of convenience and efficiency.

There have been a few random experiments with canards along the way to this second half of the twentieth century. One example was the Curtis XP-55 Ascender which had its first flight in 1943 and was shelved shortly thereafter.

In the homebuilders' world, the past decade has been crowded with, if not dominated by, aircraft featuring canards. One such design, the *Speed Canard*, has actually been certified, but not by the FAA. Recently approved for production and sales in West Germany by the LBA, it is a variation on the Rutan *VariEze* created exclusively for the homebuilder market in the U.S.

For several years, the world of executive turboprops has seemed poised on the brink of a commitment to the canard that is quite mind boggling. Since 1980, at least four new turboprop designs, all mounting canards on their noses and engines with pusher props in the rear, have been trembling in the start gate with the promise of bringing highly touted advances in speed and efficiency to the travelling executive. But the realization dates keep slipping into the future.

There remains a question that is yet to be clearly answered. In what way is a canard configuration superior to a similar aircraft mounting a more conventional tail in the rear? And please take note that this discussion is concerned only with subsonic aircraft.

1. Drag

Here's a regime in which the canard configuration must surely be a winner. If we replace the normal down load carried by the tail in conventional aircraft with a lifting load on the canard up front, surely the overall drag must be less.

Apparently, this is not necessarily so. An exhaustive study of the aerodynamic efficiency of canard configurations in comparison with more conventional designs was completed recently at the University of Missouri. The researchers, Michael W. Keith and Bruce P. Selberg, report: "All canard configurations were less efficient than a forward wing with an aft horizontal tail . . ."[1]. In discussion of his research with Mike Keith, it turns out that he was a canard enthusiast and undertook the program to demonstrate the clear aerodynamic superiority of ducklike airplanes. In seeking a combination that would work the best, he carefully examined a wide range of parameters in terms of gap, decalage and stagger as well as the ratio of wing area to canard area. Perhaps it is of some interest that among the better canard configurations was one for which the ratio of wing area to canard area was 1.0.

Quite obviously, as the value of that ratio approaches 1.0, the configuration becomes more a tandem wing than a canard. Once it exceeds 1.0, it is a conventional aircraft, albeit one with a large tail. Other studies have shown that for conventional aircraft, a wing-to-horizontal-tail ratio of between 7 and 10 gives best overall performance.[2]

Certainly related to the findings of Keith and Selberg were those of some aeronautical engineering graduate students at Stanford several years ago. In seeking to optimize a canard configured sailplane, their computer-based analysis program kept telling them to increase the size of the canard and reduce the wing area. When they were through, the optimum design featured a canard that was roughly five times the size of the wing.

A more recent study of canard, conventional and trisurface configurations by Selberg and Rokhsaz[3], it was found that "for all parameters considered, the conventional configuration had the highest L/D_{trim}." The trisurface was shown to be generally inferior to both canard and conventional arrangements.

Predicting drag is a tricky thing. The best proof lies in the performance of the actual aircraft. A competition like the Oskosh 500 is especially informative since overall efficiency is the basic criterion. With all competitors using engines of virtually identical specific fuel consumptions, and with each allocated the same amount of fuel on a pounds per seat basis, the prize should go to the airplane with the lowest overall drag coefficient. For the past six years, the contest has been won by A. J. Smith's AJ-2, a slick, carefully crafted monoplane with fixed landing gear and a conventional tail. (Figure 1). Competition has included the best and the quickest of the canard configured covey of homebuilts, over which his margins have averaged better than 20%.

In addition, there is the problem of tip vortices off the canard impinging in a disorderly, variable and drag-producing way on that portion of the wing behind the canard tips. Better if those tips are outboard of the wing tips as the Stanford study showed.

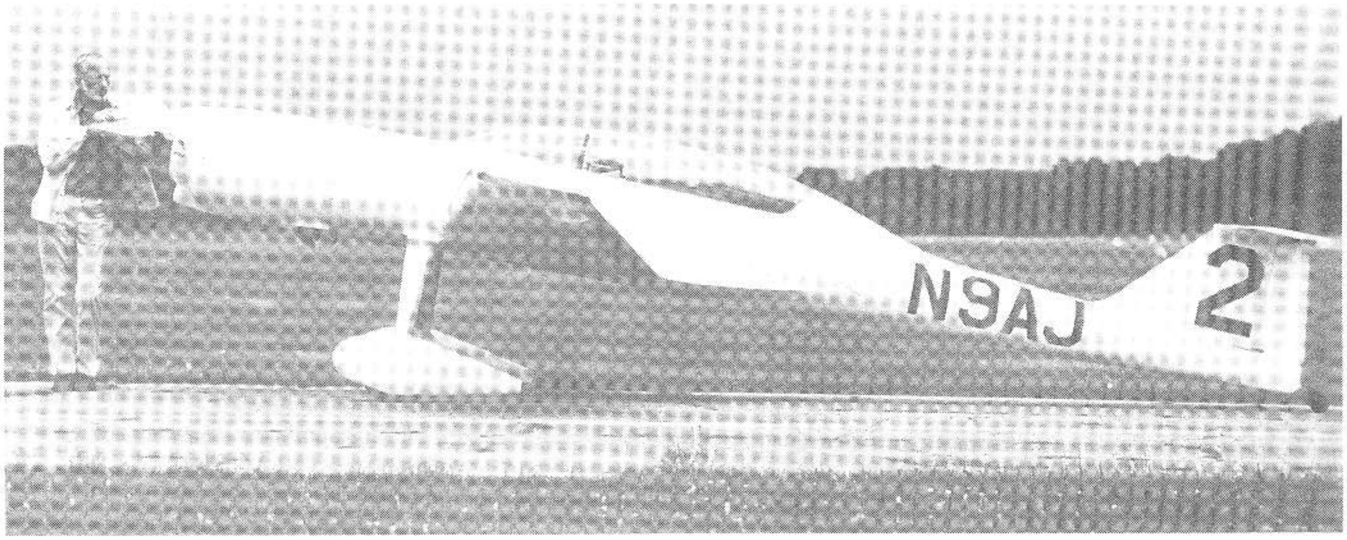


Figure 1. A.J. Smith's AJ-2

Figure 2.

Comparison of Five Homebuilt Aircraft

- Two Canards and Three Conventional -

Model	Rutan Varieze	Rutan Long-EZ	Rand Robinson KR-2	Glasair TD	Glasair RG
Configuration	Canard	Canard	Convent.	Convent.	Convent.
Max. T.O. Wt. (lbs)	1,050	1,325	1,100	1,500	1,800
Wing Area (ft^2)					
Not incl. canard	53.6	82.0	80.0	81.2	81.2
Incl. canard	66.4	94.8	80.0	81.2	81.2
Wing Loading ($\#/ft^2$)					
Not incl. canard	19.6	16.2	13.8	18.5	22.2
Incl. canard	15.8	14.0	13.8	18.5	22.2
Engine Power (hp)	100	115	65	160	160
Power Loading (#/hp)	10.5	11.5	16.9	9.4	11.3
Max. Cruising Speed (mph)	195	183	180*	224	234
Econ. Cruising Speed (mph)	165	144	170	-	-
Take-off Run (ft)	900	830	400	790	630
Landing Run (ft)	900	680	500	550	530
No. of aircraft known to be flying	600	115	350	250	50

* 220 mph for turbocharged version

Source: _Jane's All the World's Aircraft, 1984-1985_

2. Stability, Control and the Stall

One of the highly touted attributed of the canard type airplane is its stall-free flight characteristics. What is meant is that the wing never stalls. The reason, of course, is that the canard stalls well before the wing reaches its stall angle of attack. It had better; otherwise, with the canard still creating lift and the wing stalled, there will be an unpleasant pitchup with potentially catastrophic results. Recovery may be difficult; in some cases it will be impossible.

Thus the angle of incidence of the canard is selected to be sufficiently greater than that of the wing so that the canard always stalls first, not only in one-g flight, but also in a windup turn at maximum load factor and maximum maneuver speed. In addition, for FAA certification, the canard-first stall will undoubtedly have to be demonstrated at conditions of maximum assymetric power in full rudder skids and sideslips. Thus stall-proofing must be an inherent design feature for the canard airplane. It is a condition dictated by the more dangerous pitchup that will otherwise result.

Perhaps for the world of ultralights and homebuilt aircraft, stallproof aircraft are important. But for the world of more complex aircraft, clear definition of their stall characteristics is important for the simple reason that it allows the pilot to optimize the operation of his craft to the maximum limits of its capabilities. As we shall see, this is a must for sailplanes.

Also consider that for a conventional aircraft, one which has passed its certification tests, stalling of the wing means that lift has been lost but not control. In most canard configurations, stalling of the canard means that, at least momentarily, pitch control has been lost.

Now there are a number of reasons for wanting to touch down on an airport at the slowest possible airspeed, to avoid hitting the fence at the far end of a short field, to save tires and brakes, to prevent hydroplaning, to make a nearby turnoff to clear the runway for following traffic, etc.

With good approaches, in the conventional airplane speed can be bled off in final and, taking advantage of ground effect, it's not too much of a trick to plunk it right on the numbers in a fully stalled condition. If a burble is encountered that tends to balloon the airplane just as the runway threshhold is crossed, contact may be made a little more firmly than planned, but the prospect for anything more serious is unlikely.

Now let's try the same maneuver in the canard aircraft. Experience that ballooning action at the runway threshhold with minimum speed while holding the airplane off with back stick a few feet above the runway and stalling the canard. There's nothing to stop the rapid downward rotation of the nose into the runway. Is this why one canard type has busted so many nose struts?

The obvious answer is: in canard type aircraft don't fly near the canard stall speed in the approach; and that's quite a few knots above the wing stall speed for all the reasons noted earlier. But what does that mean to performance, in and out of the airport and at cruise? Let's have a look.

3. Performance

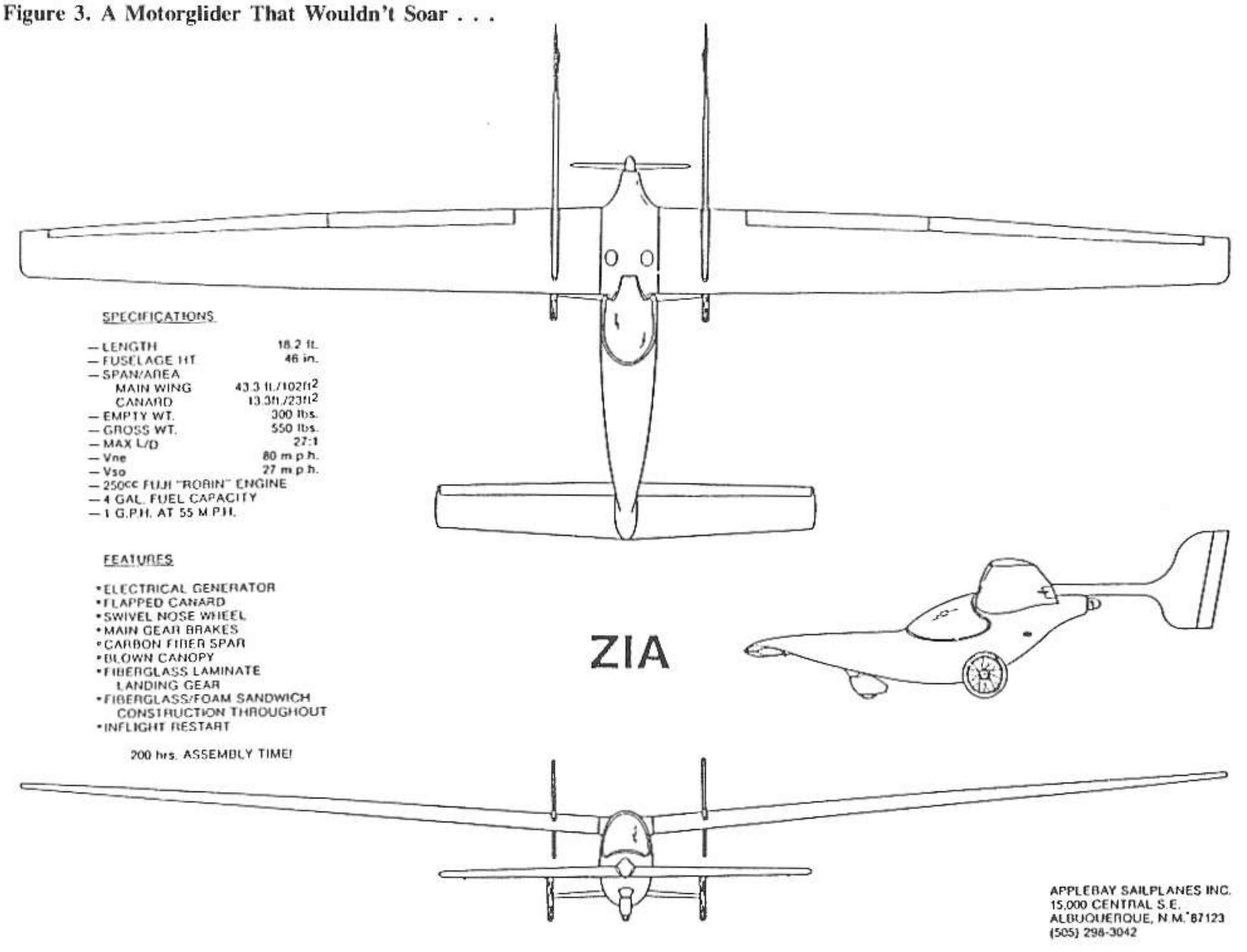
It is apparent from the foregoing that to meet generally accepted stability, control and stall criteria for FAA certification, a canard aircraft will either have a lot more wing than it needs for cruise performance in order to meet desired runway requirements (and therefore will be slower in cruise than its conventional equivalent); or, if optimized for cruise, it is going to need a lot more runway than its competitors with the entire empennage in the back.

Examine the designers' estimates of take-off and landing distances for representative homebuilt aircraft. For models with essentially the same power and wing loading, canard configured aircraft require at least fifty percent more runway (Figure 2). Of course these aren't FAA certified numbers; and besides, 900 feet versus 400 feet isn't that big a deal as long as your airport has runways of 2,000 feet or more. It is understandable and appropriate that enthusiasts do not extol the STOL capabilities of canard designs.

There is another aspect of performance to be considered. Turning capabilities. The ability to realize the full capability of the wing's lifting power can on occasion be important. Two such events come to mind: recovering from the indignities of a downburst on final approach, and in close encounters of the worst kind, avoiding collision with another aircraft.

Recent experiences in the domain of homebuilt motor gliders offer two clear demonstrations of the turning performance limitations of the canard configured airplane. George Applebay of Albuquerque designed and built the *Zuni* in the later 1970's. The *Zuni* is a 15-meter racing sailplane, one of the few of U.S. origin that in its time proved competitive in a field dominated by European (principally German) products. This design was later shelved, but in 1982, when the Soaring Society of America (SSA) sponsored a design competition for a low-cost self-launching sailplane, George went for it. He also went for the mythology of the canard. He built the *Zia* which mounted a canard on the nose, a pusher engine-prop combination behind the cockpit, and fins and rudders on the wingtips. To improve directional characteristics, this configuration was modified to one with twin tail booms mounting rudders but retaining the canard. (Figure 3). The *Zia* flew well enough, but it wouldn't

Figure 3. A Motorglider That Wouldn't Soar . . .



soar and was not entered in the contest. In order for a sailplane to climb, it must circle in rising columns of air called thermals. If the columns are small, as they frequently are, the sailplane must turn tightly to stay in the strongest part of the thermal. Achieving maximum lift coefficient, or in other words flying very near the stall, is essential to good sailplane performance. As we have seen, the canard configuration does not permit this.

The *Zia* canard was later replaced by a conventional horizontal stabilizer and elevator joining the twin tailbooms at the rear of the motor glider. (Figure 4). This proved to be a much better arrangement, but funds for the development were depleted and the new *Zia* was never put into production.

Meanwhile, the Soaring Society's competition was won by another canard configuration, the *Solitaire*, designed and built by Rutan Aircraft. It was a beautifully executed prototype with smooth laminar-flow wings, a long thin canard mounted on the tip of the nose, and an engine on a strut just behind the canard that folded back into the fuselage between the canard and the cockpit. (Figure 5). It could power itself into the air and fly acceptably, but it was neither a good power plane nor a good sailplane. Like the original *Zia*, whenever the *Solitaire* is really racked into a tight turn for the small thermals, it wants to fall out of the sky. (Figure 6)[4].

Another concern is that the *Solitaire's* large canard seriously restricts forward view which gets even worse when the engine is extended.

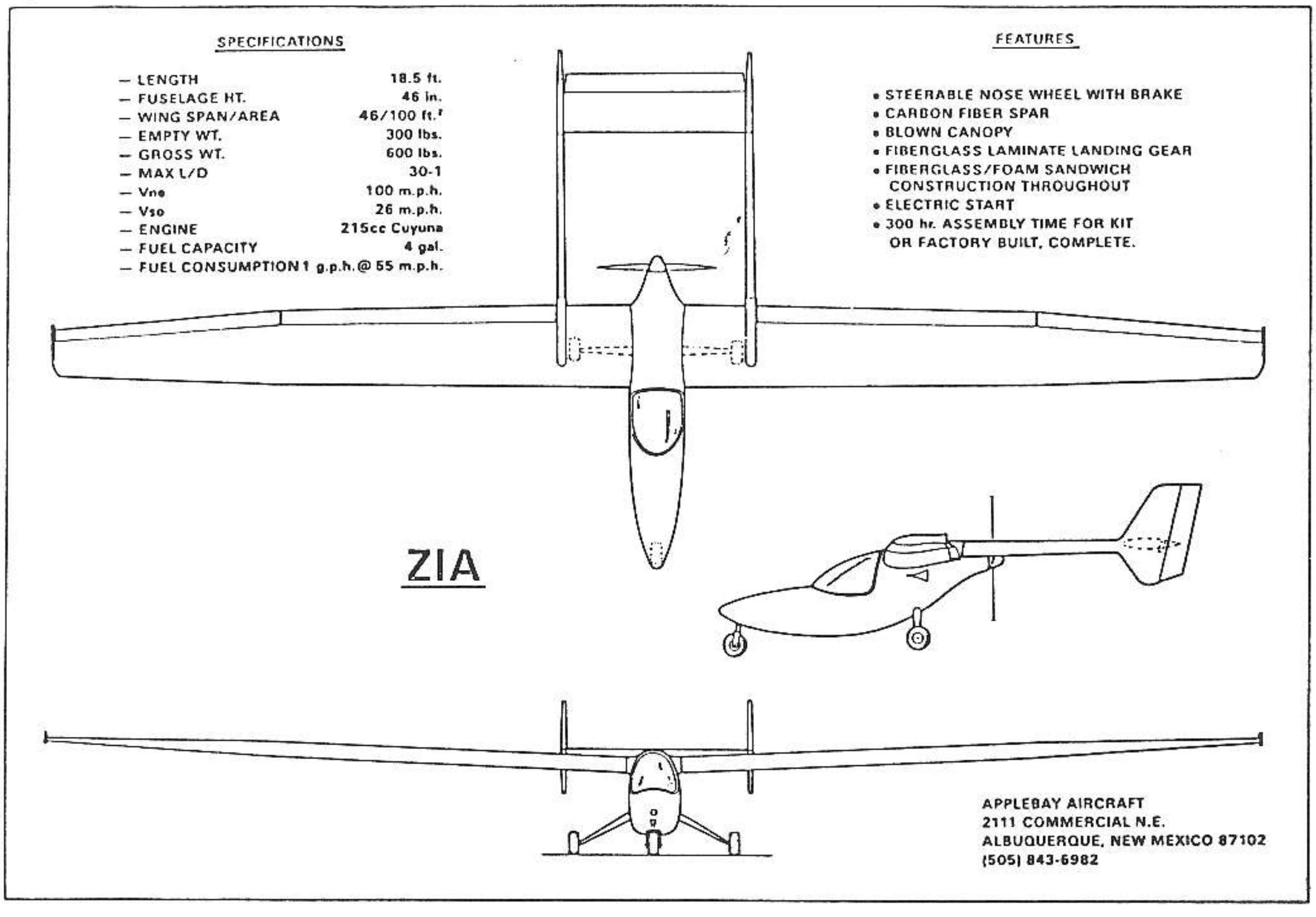
Plans were offered to the homebuilders and later kits. So far only one had been built and flown since the prototype. Rutan Aircraft no longer offers kits or plans. However, an imaginative builder has acquired the original molds for the aircraft. The canard has been removed and replaced with a conventional horizontal stabilizer and elevator. A more powerful engine has been installed in the nose as a fixed, fully cowled substitute for the foldable one. The wings have been fabricated with removable tips to provide two types of performance: a sport plane with somewhat higher speeds and longer runway requirements, or a STOL plane with modest soaring capabilities. In this renascence, the plane has been renamed the *Silhouette*. (Figure 7).[5]

So much for the performance benefits of the canard. There are other concerns.

4. Weight and Balance

For the more conventional designs, the wing has always proved a good place to put fuel. This is because the aircraft center of gravity usually falls in the range of 20 to 40 percent of the wing's mean aerodynamic chord. Consequently with fuel tanks in (or on) the wing, there is little shift in center of gravity with fuel consumption. Also, distributing the weight of the fuel along the wing reduces substantially wing bending moments when airborne with a consequent reduction in the overall weight of the wing structure.

Figure 4. And One That Would.



SPECIFICATIONS

— LENGTH	18.5 ft.
— FUSELAGE HT.	46 in.
— WING SPAN/AREA	46/100 ft.^{2}
— EMPTY WT.	300 lbs.
— GROSS WT.	600 lbs.
— MAX L/D	30-1
— Vne	100 m.p.h.
— Vso	26 m.p.h.
— ENGINE	215cc Cuyuna
— FUEL CAPACITY	4 gal.
— FUEL CONSUMPTION	1 g.p.h. @ 55 m.p.h.

FEATURES

- STEERABLE NOSE WHEEL WITH BRAKE
- CARBON FIBER SPAR
- BLOWN CANOPY
- FIBERGLASS LAMINATE LANDING GEAR
- FIBERGLASS/FOAM SANDWICH CONSTRUCTION THROUGHOUT
- ELECTRIC START
- 300 hr. ASSEMBLY TIME FOR KIT OR FACTORY BUILT, COMPLETE.

APPLEBAY AIRCRAFT
2111 COMMERCIAL N.E.
ALBUQUERQUE, NEW MEXICO 87102
(505) 843-6982

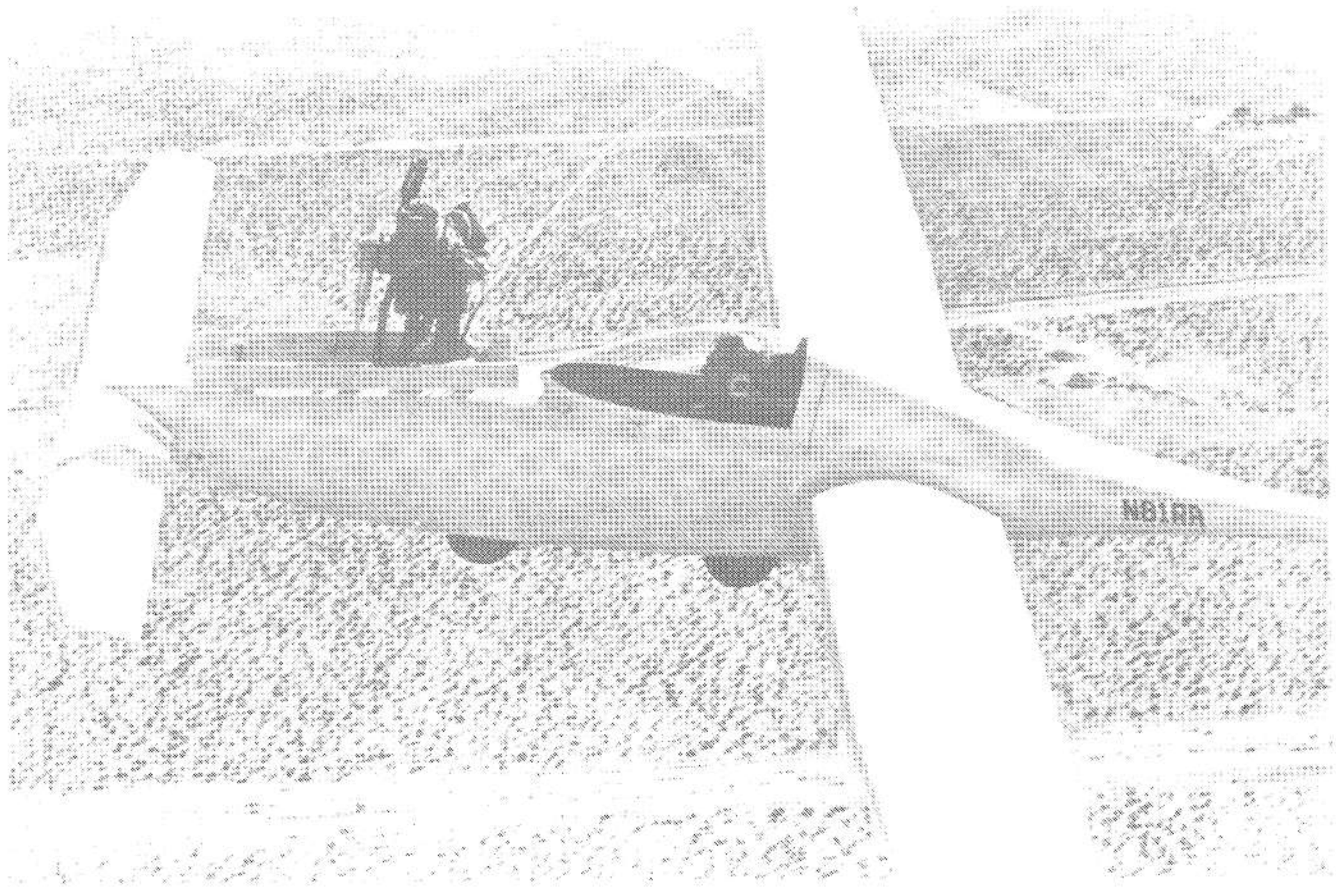


Figure 5. The Solitaire

With a lifting surface out front, the center of gravity of a canard aircraft is going to end up somewhere forward of the wing. If fuel is distributed along the wing span, consumption of that fuel will be accompanied by a large forward shift in c.g. Compensation for that shift can be achieved by placing fuel in a nose tank that is consumed proportionately with the wing fuel, but this adds to the complexity of the fuel system. Besides, the idea of fuel in the nose and fuel lines running the length of the fuselage is not appealing from a crashworthiness point of view.

Another design approach is to add strakes as a highly swept forward extension of the inboard wing section to serve as fuel tanks. This solves the balance problem, since the fuel in these tanks can be centered on the c.g., but it creates some others. With fuel concentrated close to the center of the fuselage, airborne wing bending moments will be greater than with fuel more evenly distributed along the span. The result will be increased structural weight. Also there is more wetted area with the strakes, hence more parasite drag.

These concerns are quite obviously applicable to the location of water ballast in canard-configured racing sailplanes.

Are there any plusses for canards? In the world of corporate turboprops, they tend to sold the problem of the wing spar going through the center of the cabin, and the pusher props should make for a quieter cabin. But for sailplanes and motor gliders, there appear to be none at all.

* * *

A brief look at the splendid achievement of *Voyager* is certainly called for at this point. The design and the nature of the mission made the canard limitations moot. The fuel booms

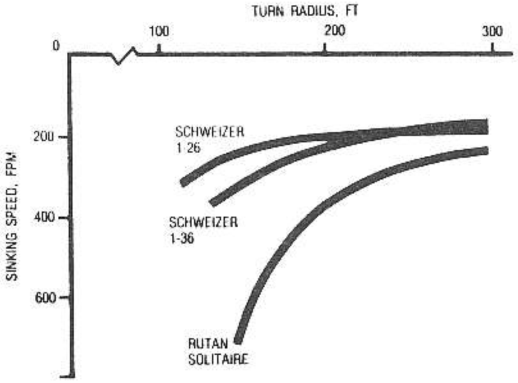


Figure 6. Turning Performance for Solitaire, 1-26 and 1-36.

and large fuselage tanks forward of the cockpit made c.g. control relatively easy. There was even fuel in the canard. The fuel booms also acted as end plates which when combined with the forward sweep of the canard made for a virtually constant downwash angle inpinging on the inboard wing sections during a flight that was flown at a nearly constant angle of attack. This left the outboard wing sections in clean air undisturbed by wake from the canard. There was no need or inclination to make steep turns, indeed the pilot said he was uncomfortable at bank angles of more than fifteen degrees. Pilot view from the cockpit was not important.

Depending on what the average winds were and how greatly the actual flight path diverged from the course claimed, the L/D of the *Voyager* averaged between 23 and 30 for the flight. One could probably join a couple of *Nimbus 3s* with a twenty-foot wing section, mount an engine with pusher propeller on top of the wing at the centerline and have an L/D at 60 knots IAS in the order of 45. Flying the jetstream at 30 to 35 thousand feet, that would give a true air speed of 100 knots and a potential ground speed in the order of 200. This would mean a flight in half the time of the *Voyager* and one requiring only about one third the fuel. And no one has yet done an unrefuelled flight around the world solo.

Still the *Voyager* has done it and all involved deserve enduring acclaim for a singularly exciting achievement.

Returning to the basic thesis of this paper, it is of some interest that those companies with the best track records for solid aerodynamic advancements in the field of subsonic commercial aircraft over the past several decades, those with the most powerful, computer-based design optimization programs — Boeing, Douglas, Lockheed, Dassault, British Aerospace and Airbus — have been content to let the horizontal tail remain in the rear of the aircraft. The same can be said for Schempp-Hirth, Schleicher, Schweizer, Rolladen-Schneider and the rest.

Burt, Dick and Jeanna — warm applause.

Orville and Wilbur — rest in peace.

7. References

[1] Keith, Michael W. and Selberg, Bruce P. *Aerodynamic Canard/Wing Parametric Analysis for General-Aviation Applications,* AIAA JOURNAL OF AIRCRAFT, Vol. 22, No. 5, May 1985.

[2] Kroo, Ilan. *Trim Drag, Tail Sizing, and Soaring Performance,* TECHNICAL SOARING, Vol. VIII, No. 4, July 1984.

[3] Selberg, Bruce P. and Rokhsaz, Kamran. *Aerodynamic Tradeoff Study of Conventional, Canard, and Trisurface Aircraft Systems,* AIAA JOURNAL OF AIRCRAFT, Vol. 23, No. 10, October 1986.

[4] Enevoldson, Einar and Bohn-Meyer, Marta. *The Rutan Solitaire,* SOARING, Vol. 48, No. 3, March 1984.

[5] Garrison, Peter. *Silhouette,* FLYING, March 1986.

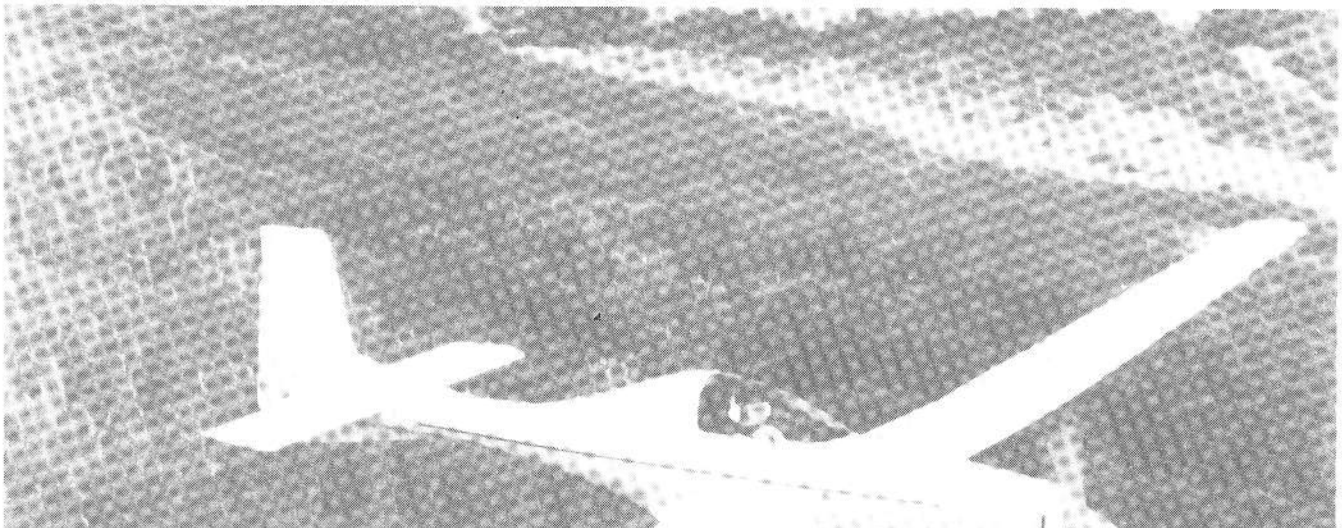


Figure 7. The Silhouette (née Solitaire)