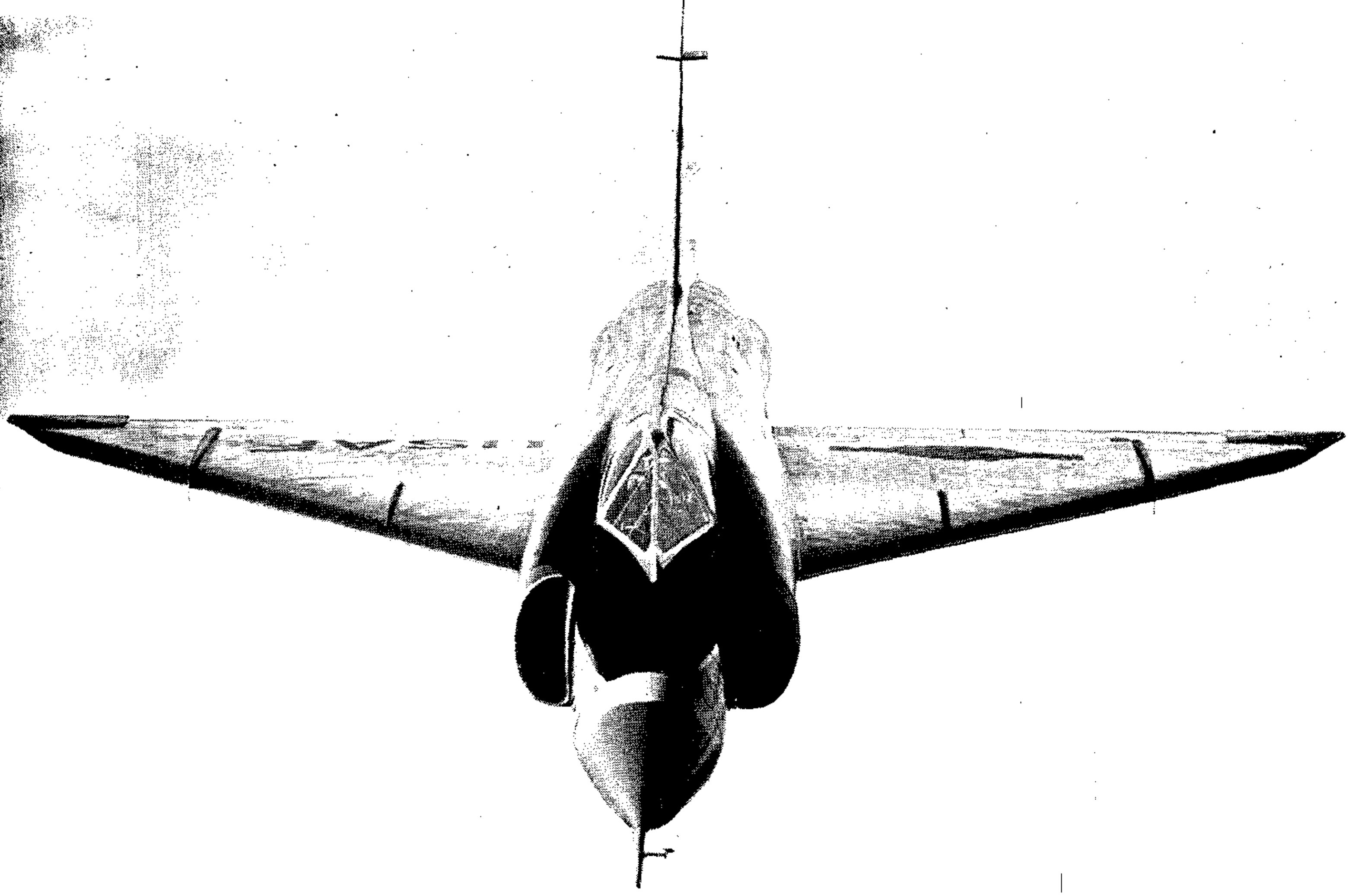


The Day of the Delta

By GROUP CAPTAIN H. R. FOOTTIT

"Men become attached to certain particular sciences and speculations . . ."

—Francis Bacon (1620)

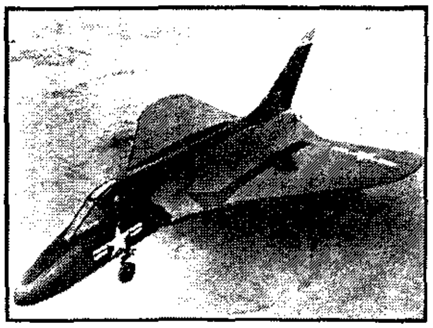
THE DEVELOPMENT of aircraft, like all mechanical developments, will forever be embroiled in debate. We have only to turn the pages of history to know that this is no new thing under the sun. In the early part of the nineteenth century, for example, the American Philosophical Society asked the most eminent engineer in the U.S., Benjamin H. Latrobe, to summarize the situation on steam engines. In his report, published in May, 1803, Latrobe made a scathing attack on the use of steam for ships. "A sort of mania began to prevail," he said, "which indeed has not entirely subsided, for impelling boats by steam engines." He then went on to list six reasons why the steamboat would not be successful. He summed up by saying, "There are indeed general objections to the use of the steam engine for propelling boats, from which no particular application can be free."

Four years later Robert Fulton launched the steamship *Clermont* in New York. This ship had been built, as he said, without "a single encouraging remark, a bright hope, or a warm wish." From this time on the steamship was on its way. And to Latrobe's undying credit, he ultimately became one of its warmest enthusiasts.

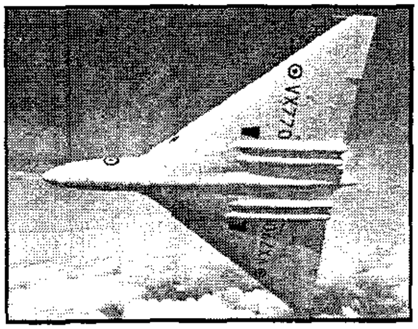
Modern Parallel: In this day of supersonic aeronautical developments almost a similar situation prevails when it comes to wing shapes. Should the fast fighter have a straight wing, such as the Lockheed F-104; or a swept wing, such as the North American F-100; or a triangular, delta wing, such as the Convair F-102? Without too much trouble you can dig up debaters who will throw facts and figures to support some particular stand. Yet, in spite of this, the delta wing has been gaining ground. There is the Avro "Vulcan" bomber, the Douglas "Skyray" fighter, the Gloster "Javelin" interceptor, and others. Is this the day of the delta? "It all depends on the aircraft's specification," says R. N. Lindley, Chief Designer for Avro Aircraft. "One set of requirements, in terms of the aircraft's speed, altitude, role, and other demands, will show the delta wing to be the best. For other requirements, a swept wing may be superior."

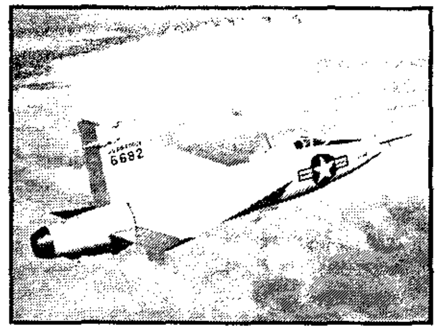
The delta wing, however, has probably precipitated so much discussion since it is only in the last decade that detail design data on deltas started to trickle through. And it is only in the last few years that it has reached any great volume. Like so many of our

1905

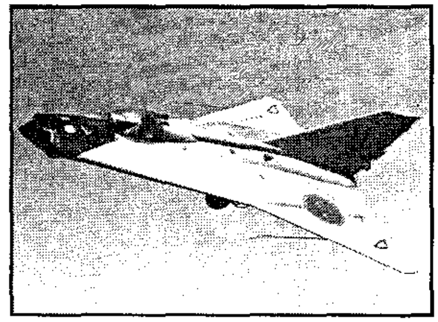


Modern deltas include the Douglas Skyray, the prototype XF4D being shown above, Avro's Vulcan (below) and Gloster's all-weather Javelin (R).





Convair XF-92A (above), precursor of all-weather F-102, was first delta in the world to fly. Below is Sweden's Saab 210 experimental delta.



modern aeronautical developments, the delta had its birthplace in wartime Germany. And it grew up as an offspring of other developments.

There is no question that late in the last war the methodical Germans led the world in basic data on transonic and supersonic airflow and aircraft. Dr. Alexander Lippisch was one of their leading authorities. After completing a job of consulting engineer to Messerschmitt on the design of the Me-163 rocket powered fighter, Dr. Lippisch became president of a research establishment near Vienna. Here he moulded his ideas on supersonic flight.

Planting the Seed: Strange as it seems, Lippisch struck on the delta wing as an outgrowth of some work he was supervising on a Lorin ramjet engine. As the engine screeched through its early ground tests, Lippisch decided that he must have a high speed research aircraft to use as a flying test bed. After scouring the available data he initiated the design of a 60 degree swept delta wing airplane. The center section of this aircraft housed the ramjet, which was to be run on refined coal. The airplane was estimated to weigh 5,000 to 6,000 pounds, and be able to fly at speeds over 1,000 m.p.h.

Lippisch selected the delta since he had a firm faith that it held the real key to supersonic flight. He was convinced that the control problems through the turbulent transonic speed range, around Mach 1.0, would be easier with the stability characteristics of the delta. There were also some structural advantages.

When the first layout of the airplane was off the drawing board a model was built and put in the Gottingen high speed wind tunnel. The results were disappointing. The airplane had questionable stability at high speeds, and practically no stability at low speeds. To probe this stability problem Lippisch called in a group of designers and started them to work on a delta wing, wood and fabric glider. Lippisch intended that his glider should be carried aloft by a light transport. At altitudes around 25,000 feet the glider would be cast loose. Small rocket motors would be fitted to boost the glider's speed in dive tests. Towards the end of World War II the glider was nearly finished. The research flights were being scheduled to start. Then the Allies overran Germany and her satellites and captured the delta glider before it left the ground.

delta disciples

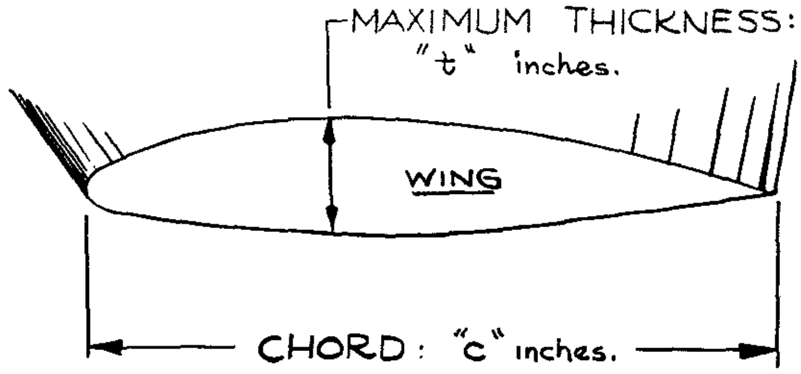
ALTHOUGH Lippisch is generally credited with the delta design, other famous scientists and engineers, such as von Karman and Northrop, have expressed a belief in this type of planform. Numerous German wind tunnels ground out data on deltas before the war ended. And Germany's Horten completed preliminary drawings of a delta research glider that was to be followed by a supersonic delta airplane. The coming of peace put an end to all these delta dreams. But the cease-fire was no sooner signed than the Western research agencies began to sift through the German reports and commence wind tunnel tests of their own. The day of the delta began to dawn. Convair of San Diego, in particular, saw the light. The result was the Convair 7002 (XF-92) airplane. It skimmed over the sands of Muroc Dry Lake in Southern California at a few feet altitude. This was its first flight on June 9, 1948—the first delta to be airborne.

Other deltas, however, were on the drawing boards. The following year A. V. Roe of Manchester, England, flew their first one, the Model 707. As it ultimately came to light, these 707 series airplanes were scaled down versions of the huge, delta winged jet bomber, the Avro Vulcan. By building up design data from these research aircraft, Avros were able to get their big bomber in the air, they believe, in a much shorter time. When the Vulcan finally flew in August, 1952, it caught the imagination of the aeronautical world, even though it had been preceded by the Boulton Paul research aircraft, the P-111, the Douglas Navy fighter, the Skyray, and other small deltas.

A Canadian Delta: In Canada another delta winged airplane is now taking shape in the form of the Avro Aircraft Limited CF-105, supersonic fighter for the RCAF. Although this is a new Canadian design, it is passing through its design birthpains when the general advantages and disadvantages of deltas have been largely sifted out. Broadly speaking, the credits and debits of delta wings can be tabulated under aerodynamic and structural headings. On the aerodynamic side, the slower shifting of the wing center of pressure as the airplane accelerates through the transonic speed range, that Lippisch first brought to light, is still valid. This means slower changes in trim which, since they are slower, are easier to compensate for.

Another advantage of the delta, for supersonic aircraft, can be classed under both aerodynamic and structural headings. Razor thin wings are a "must" for really fast airplanes to keep the drag down. The aerodynamic criterion for defining such wings is the thickness-chord ratio expressed as a percentage (Figure 1): the lower the thickness chord ratio, the lower the drag. With a delta wing the long root chord means that the maximum thickness can be a reasonable figure in inches, while still meeting a supersonic requirement for a thickness-chord ratio of, say, 3 to 4%.

For example, suppose the project engineer decided that a 3% wing was necessary on the airplane to meet its supersonic mission profile. The root chord of a delta design is 500 inches. Thus the maximum wing thickness at the center section would be 3% of 500, or 15 inches. This is a reasonable depth to house spars and ribs of relatively low weight, and is also spacious enough to stow some equipment. A straight wing designed for the same airplane has only a 150 inch root chord. For 3% thickness-chord, the maximum depth at the center section would be 4½ inches. Designing a light structure to fit into this small dimension is very difficult, and space to store equipment is almost nonexistent.



THICKNESS-CHORD RATIO = $t/c \times 100\ \%$

FIGURE 1

Inside Job: J. C. Floyd, Vice-President of Engineering for Avro Aircraft, considers this structural efficiency of the delta one of its more important features. "You have to keep in mind," he points out, "that your design has to house the retractable landing gear. ment. The wing is a good place to fit these things, and the delta wing root gives you more space than any other wing configuration, for a given wing area. Moreover, it is also important to house the control surface actuators within the wing contour. Again, the delta wing gives you more space towards the trailing edge for these components. All in all, we believe that you get the best capacity from the delta for the lightest structural weight."

He goes on to say that, "For supersonic airplanes the deformation of the structure under high air loads is one of the difficult problems to be dealt with. However, these aero elastic effects are minimized with the deeper and stiffer delta structure."

There are disadvantages, too, to the delta. The wing stalls at a very high angle of attack. If the designer attempted to use this for the landing angle, the pilot's view over the fuselage nose would be negligible. Aerodynamically this essentially means that more wing area is required to meet a specified landing speed, than, say, a straight winged aircraft. There are also stability problems at high speeds, though this is a matter of degree, since all supersonic airplanes have these to some extent. Low speed stability can also be critical.

Difference of Opinion: There is certainly no complete agreement on all aspects of the delta wing, particularly for Mach 1.0 to 2.0 airplanes. C. L. Johnson, Chief Engineer for Lockheed, and the key man in the design of their straight winged fighter the F-104, told the Society of Automotive Engineers recently about Lockheed's wing studies. From engineering investigations of different aircraft to the same specification, but with various wing shapes, they arrived at the conclusion that the straight wing was superior for landing and take-off, and had stability advantages over the delta at high angles of attack. Johnson did recognize the structural advantage of the delta, particularly the rigidity and the space available in the wing. He believes, however, that these gains can be nullified in a straight wing design.

Reading between the lines, the point that Johnson really raises is the fact that the delta wing, or any other wing, cannot be considered in a vacuum—it must be assessed on an airplane. The airplane, in turn, arrives at its configuration from the specification requirements. For this is the document that translates the job to be done—whether it be transporting passengers

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the front floor-level hold being intended for freight.

Key factors in high utilization are quick turn-round and quick maintenance—both of which depend to a large degree upon accessibility. The integral rear passenger stair and the front crew/freight doors are as widely separated as could be. The forward door is jeep-size and hydraulically operated, with an inserted manual door for normal use. The under-floor baggage hatches can be used without interfering with the refuelling under the wing. The engines are far removed from the airframe parts requiring between-flights inspection and are accessible from low platforms. The rear stair also supplies the ground tail support. The 7 ft. high main floor level gives easy loading through the freight door from trucks. All these points suggest thought and if routine maintenance has been similarly studied, the overnight progressive servicing should make the target utilization of 3,000 hours a year easily attainable.

Table I shows how the SNCASE calculated utilization on the Paris-North Africa route with the original 9,000 pst Avon RA.16 turbojets. In fact, the engines fitted in the prototype give 10,000 pst, which raises the maximum gross weight to 90,200 lb., with water/methanol to restore power up to I.S.A. +30°C and to 6,000 ft. airfield altitude. Now it seems certain that the RA.29s for production airplanes will be giving 11,000 pst for take-off. All this makes it difficult to be very precise about the money earning possibilities of the Caravelle.

One has a personal theory that reliability of airframe and engine are more significant factors in making an airliner pay than is usually realized. These factors are not easily included in paper cost analysis — save by the artificial means of altering the annual utilization. For instance, a few unscheduled engine changes can counteract the advantages of a raised engine overhaul life. The Caravelle looks like an unusually carefully designed, sound piece of engineering and the makers of its engines have an outstanding reputation for reliability—ask TCA its opinion of the Merlin or the Dart from the same stable as the Avon.

The Caravelle has certainly put in a remarkable number of hours in its first half year of flying. The latest figure at the time of writing was 150 hrs. 30 mins. between the first take-off on May 27 and November 2—72 flights in all.

Twelve airplanes have been ordered by Air France and there are possibilities of a further Armée de l'Air contract. The rear stairway has, in fact, been studied as a parachute exit and it could be used at 135 mph, which is 1.3 Vs at mean weight. The large freight door has obvious military attractions. There is also a tanker scheme in which a total of 4,400 Imp. gals. would be available.

Tailpiece: The rear engine position has given rise to some doubts about c.g. considerations among those who do not know the airplane. The c.g. range is actually 14% of the aerodynamic mean chord, which the SNCASE says represents a ten foot fore-and-aft movement of the normal 15,400 lb. payload.

The fuel, too, is closely grouped round the c.g so that it causes a shift of under 3% AMC between full and empty tanks.

The engine zone of the fuselage has been ingeniously designed to allow considerable fore-and-aft adjustment of the engine mounting to accommodate different weights. The design limits were set to take any turbojet—or by-pass—between 2,950 lb. and 5,060 lb. bare weight. The structural limits for the location of the engine c.g. allows an adjustment of 11 ft. 6 in.

DAY OF THE DELTA

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from Vancouver to Winnipeg, or battling bombers over the Canadian Arctic —into terms of speed, climb, range, and other performance parameters.

design to requirement

R. N. LINDLEY of Avro Aircraft Limited echoes similar sentiments. When I talked to him the other day he pulled from his filing cabinet a paper he had written when he worked with A. V. Roe of England on the delta winged Vulcan. In this report he assumes that the speed, altitude, range, and load carrying requirements are pinned down in the specification. The problem then is to find the best airplane configuration to fit the requirements.

After starting with a selection of various gross weights, he makes different assumptions for such items as the wing span and chord, the thickness-chord ratio, and the taper of the wing. He follows this with a complete weight breakdown. This, in effect, designs a whole series of paper airplanes to meet one specification. By estimating the performance of each one, he is able to pick out the airplane that does the most for the least cost in weight.

"When you go through this procedure for certain specific performance requirements," says Lindley, "the optimum airplane may turn out to be one with a small wing span and a large sweep back angle to the wing leading edge. When you draw up this configuration, keeping an eye on the practical aspects of space for fuel, equipment, and similar items, you may well find that it automatically comes out to be a delta. For other performance requirements, of course, it may not."

Best Judge: The Douglas Aircraft Company's engineers, having designed and test flown a straight wing research airplane as well as their Skyray fighter, are probably the best judges in this delta debate. Last year E. H. Heinemann, their Chief Engineer, made it quite clear that there was "no simple answer" to the question of the "best" wing planform. The best, he stated, depends on the aircraft specification, and the ingenuity of the designers in meeting the requirements efficiently.

While it is too early to predict any sweeping conclusions on the shape of wings to come, the day of the delta has dawned for certain types of airplanes. As more and more full scale flight data are stockpiled from today's deltas—and there is really very little in the supersonic speed ranges—the flying triangle may well fulfil the role that Lippisch originally sketched out for it. At least I am sure that the delta has some specific place to fill in the future aerodynamic scheme of things. But it probably will not be the final answer for every design.

So, as time passes, we should not become inexorably wedded to this configuration. We must take heed of Bacon's dictum: "Men become attached to certain particular sciences and speculations, either because they fancy themselves the authors and inventors thereof, or because they have bestowed the greatest pains upon them, and become most habituated to them."