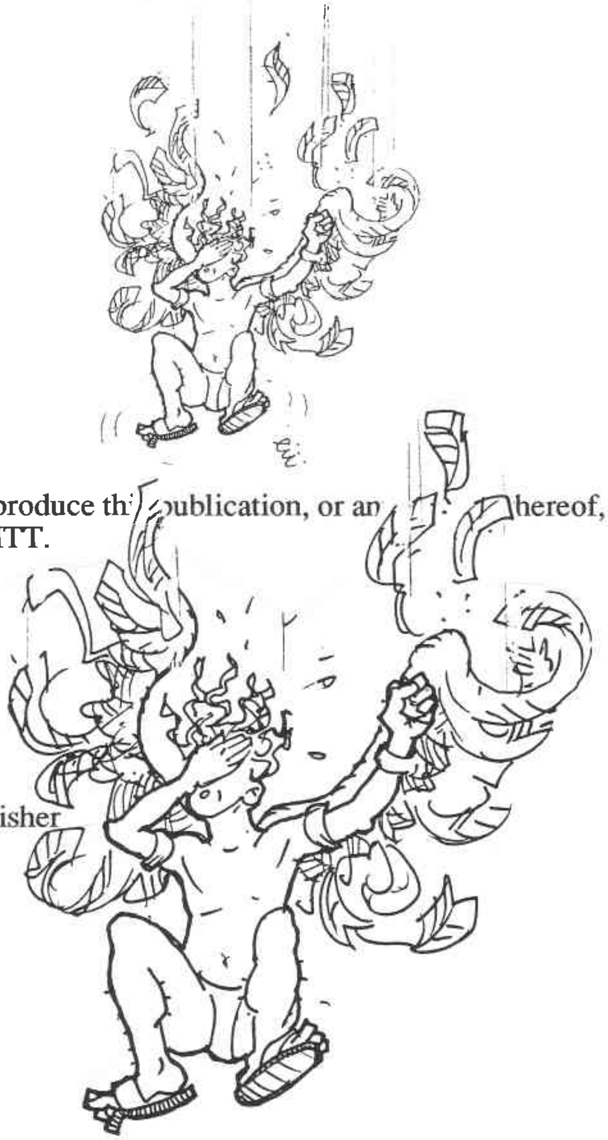
TWITT

Newsletter

Number 20, February 1988



TWITT
(The Wing is the Thing)
PO Box 20430
El Cajon, CA 92021

F. Marc de Piolenc, Editor and Publisher

NEXT MEETING: Saturday, 20 January 1988, 1330 hours, Hangar A-4, Gillespie Field

Telephone: (619) 224-1497 before 10 am or after 10 pm.

MINUTES OF THE JANUARY TWITT MEETING

Bob Fronius called the meeting to order and gave the floor to Jerry Blumenthal, who introduced this month's featured speaker, Norm Cross. It seems that he and Jerry worked together designing and building models for Convair's wind tunnel many moons ago. Jerry recalled that, as soon as the lunch bell would ring, Norm's trimaran drawings would appear on his drafting table and he would work right through the lunch hour. Jerry also noted that the double-Delta planform of the F16XL looks suspiciously like Norm's Delta wing designs, the first of which appeared in the Forties.

Norm Cross introduced himself by saying that he had built his first model airplane in Detroit in 1928. Since his modeling began in the Depression, he could not afford model kits. Instead he bought plans and materials, learning something about design in the process. He particularly enjoyed speed contests and showed an early aptitude for building good propellers for his rubber- band-powered machines. Later he became interested in scale models and designed several models for a model shop in the city, which rewarded him with free modeling supplies. In 1938 he saw a model of the Waterman flying wing, which piqued his interest in the tailless genre. From the beginning, he felt that a flying wing, to be worth the effort of designing and building it, had to have sufficient volume to completely do away with a fuselage; this in turn dictated a low aspect ratio.

By 1940 he was running a model shop in Detroit, which he owned in partnership with two others. This was a part-time project; his "regular" job was on Ford Motor Company's assembly line. It was around this time that he came up with his first all-wing concept, a square planform with two small square extensions at the tips, trailing edges flush with that of the main wing. Mr. Cross was a model builder, not an aerodynamicist, and the idea came to him by analogy with a tripod or a three- point suspension. He reasoned that the wide separation of the centers of pressure of the three wing components, both longitudinal and lateral, ought to confer a high degree of stability on the assembly. Some time later, a few months after having earned a promotion from the assembly line at Ford to the design office, he fell ill with tuberculosis, spending more than a year in the hospital. While he was bedridden, he refined his flying wing idea, sweeping the leading edge of the main wing to join the leading edges of the extensions and sweeping the leading edges of the extensions as well, but not as steeply. The resulting double-Delta planform was much prettier than the three- squares design, which appealed to Mr. Cross' modeling instincts, but there was another reason: he felt that the abrupt change in chord of the original design would cause a vortex to be shed from the main wing onto the extensions, causing interference drag. [Well, yes and no, depending on the relative incidence of the extension and the main wing--he came dangerously close to inventing winglets!--Ed.] When he finally recovered enough to leave the hospital in 1942, he went to work for Flo-Drill Die and Stamping, a company whose main business was building tailfins for bombs. Working hours were flexible--an important consideration considering his weak, convalescent condition, and one of the owners, Sidney Siegel, was a modeler. Of course he resumed his model building, this time building and testing free-flight versions of his double-delta machine. The models flew well from the first, and Norm Cross contacted an office of the Army Material Command in Detroit, proposing a 102-foot span double- Delta transport. The official he contacted objected that the large root chord would mean a very wide center-of-pressure travel, which he felt would be destabilizing; he insisted on seeing a plot of c.p. position versus angle of attack for the proposed flying wing. Mr. Cross didn't know how to do this, so the official showed him. The intrepid inventor eventually came up with a reassuring c.p. curve and a horsepower curve, but nothing came of his proposal. On 5 March 1943 the Department of Commerce politely rejected his idea. Meanwhile, the models continued to out-perform their conventional competitors. Modeler and boss Siegel was sufficiently impressed to persuade his partner, Sam Cohen, that they ought to sponsor a patent application, and a patent search was duly performed. On 15 November 1945 the patent attorney recommended that a patent not be applied for because of possible conflicts with the claims of other patentees.

But the name of Bill Stout, designer of the Ford Trimotor, had come up in the patent search. Bill lived in Detroit, and Norm Cross decided to look him up. Stout liked the double Delta enough to write Mr. Cross a letter of recommendation to Colonel Paul H. Kemmer, Air Corps, then Chief of Engineering for the Air Materiel Command. Colonel Kemmer was at that time involved in the Northrop Flying Wing program. He complained to Cross, among other things, about the lack of internal volume afforded by the high aspect-ratio design of the Northrop wings. This was of course what had prompted Cross to come up with his invention in the first place. Things looked hopeful until a new obstacle appeared. A committee was formed to consider all new designs submitted to the Air Corps and Colonel Kemmer felt obliged to insist that Mr. Cross submit his design "through channels." He never did.

In 1953, he took a leave of absence from his employer, the Ball Roller Bearing Company, and from his two model-shop partners, in order to take a "vacation" in California. The real purpose of the trip was to seek employment, and his first stop was in Palo Alto to apply to Hiller. That did not work out, and the Southern California climate beckoned. He marched into Convair and asked to speak to the "Chief Designer." The man he spoke to was Al Lambert in Predesign, who hired him on the spot as an engineer, based solely on his flying wing work. In the course of his work with Convair, he built models of such diverse vehicles as the R3Y flying boat and the Atlas/Centaur booster. He liked boats, having done some boating on the lake while living in Detroit, so he soon bought a 16 foot catamaran. Soon he wanted a bigger boat and began designing his own. Eventually he became known worldwide as a multihull sailboat designer, and quit Convair to devote himself full-time to that pursuit.

He brought with him to the meeting a 40-inch [102 cm] span double-Delta model powered by a Cox .049 cubic inch [.80 cc] engine. Although the model contained obvious provisions for a radio control unit, it had only flown free-flight, the RC conversion having never been completed. Airfoil: NACA 23112. Twist 3 degrees negative. Home movies made in the early Fifties showed similar models flying free and with radio control. The most striking (and un-Delta-like) features of all the models were their willingness to leave the ground after very short takeoff rolls, and their excellent climb rate and forward speed on tiny engines. Some TWITTs noted that the model displayed was not a pure flying wing, having a rudimentary "fuselage" extending forward of the wing leading edge. Mr. Cross replied that some of his early models had shown spiral instability and that the extra side area of the fuselage forward of the c.g. seemed to cure the problem. Bruce Carmichael interjected that spiral instability is the result of an excessive weathercock tendency, so that reducing tail area or adding area forward would indeed cure the problem. A sponge-rubber ball in the nose of the model helped with cars, posts and other obstacles.

Vern Oldershaw displayed and flew the latest of his RC tailless sailplane models. This one has a central fuselage with a very large fin/rudder combination, a set of elevators inboard and ailerons outboard on the wing. The 'plane was rock-steady on tow and actually found some lift, but the flight had to be cut short. It seems that TWITTs in their enthusiasm had obtained permission from the Gillespie tower to fly the model, but had not sought permission from the leaseholder of the field from which the machine was flown. The leaseholder in question made a hurried and angry entrance, followed very closely by a hasty TWITT exit. Back in the Fronius hangar, Vern explained and demonstrated the peculiar control surface kinematics of his model. The ailerons and elevators are connected in such a way that the elevators go down whenever the ailerons are deflected. This is to compensate for a side-effect of the very strong differential aileron deflection needed to prevent adverse yaw, namely a pitch-up tendency. Vern noted that his towline attachment is on the underside of the wing, not on the fuselage; the "classic" towhook location gives tailless models a hard time on tow, as they are generally too short-coupled to overcome the pitch-up moment from towline tension.

MEETING ANNOUNCEMENT

Our next meeting will take place Saturday 20 February 1988 at Hangar A-4, Gillespie Field beginning at 1:30 pm. Our speaker will be Professor Katz of San Diego State University. Professor Katz obtained his doctorate from the Technion in Haifa, Israel, in 1976. Since then he has been first a lecturer in the Aerospace Department at the Technion, then a researcher at NASA-Ames' 40x80 wind tunnel, then head of automotive programs in the Mechanical Engineering Department at the Technion. After another two years' sabbatical at Ames, he joined the faculty of San Diego State. He was responsible for developing the time-dependent extension to the aerodynamic panel code known as VSAERO, which he considers the best available program for low speed aerodynamic analysis. In his talk, entitled "Application of Panel Methods to the Low Speed Aerodynamic Analysis of Complete Vehicle Configurations," he will demonstrate with examples from his own work that it is now possible to compute even unsteady flow fields around complex bodies.

WE ARE NOT ALONE

Other aviation-oriented groups meet in San Diego. Their aims differ from ours a little. Some restore, some fly on minimum aircraft and some save old aircraft.

The largest group is Chapter 14, Experimental Aircraft Association. They meet on the third Thursday of every month at 7:30 pm at the Clairemont Lutheran Church, 4271 Clairemont Mesa Boulevard. They have informal gatherings every Saturday at their hangars on Brown Field. Coffee and donuts are served, and lunch as well. Telephone (619) 292-1888 during the week and (619) 423- 1833 on Saturdays at the hangars.

The San Diego Chapter of the Antique Airplane Association meets on the fourth Tuesday of the month in the auditorium of the San Diego Aerospace Museum in the winter, and at selected hangars and airports in the summer. Their goal is to "Keep the Antiques Flying." Call Jack or Ruth Ebey at (619) 466-1461.

The San Diego Hang Glider Association meets on the first Thursday of the month in Balboa Park at 7:00 pm. This group will celebrate their 15th anniversary with a party and reunion this month. They are financially secure, as are all the other activities listed. They recently changed their name from Ultralite Flyers Organization (UFO) to SDHGA. Their phone number is (619) 449-5888.

TWITT "The Wing is the Thing," the youngest of the groups, also puts out a monthly newsletter that is mailed to Australia, Germany and Switzerland. They have top-notch speakers from the aviation industry, colleges and research groups...plus an occasional pilot. TWITT's aim is to develop and build a high performance flying wing sailplane. Molds for the wing and a plug for the fuselage are being worked on. TWITT meets on the third Saturday of the month in hangar A-4 on Gillespie Field at 1:30 pm. Visitors are welcome. TWITT can be reached at (619) 224- 1497.

LETTERS

Professor Karl Nickel of Freiburg, West Germany writes:

Dear TWITT-family!

I just read TWITT newsletter No 18 and was--as always--very much delighted to hear from you. But there is a thing which puzzles me: I read (on page 1) from Tasso Proppe on the Horten IV flying wing

...that the IV's balance was so critical that the ship had to be rebalanced if the pilot changed his boots.

There must be a mistake somewhere between the lines, only, I do not know where it did occur. I myself had--fortunately--the opportunity to fly many times the Horten IV both in summertime in light sneakers and in harsh winterweather with very heavy clothing and heavy boots. Never ever had the wing to be rebalanced. I also never heard something similar from the other pilots, say Heinz Scheidhauer, Hans Zuebert or Hermann Strebel.

I wish a very successful 1988 to all TWITT-members!

And Tasso Proppe responds:

My involvement with the Horten IV began at the end of World War 2, when I was hired in 1946 as a recreational gliding instructor at Oerlinghausen by the British forces. Because the British encouraged their people to fly captured German gliders, while the Americans forbade theirs to do so, the British were able to obtain a half-completed Ho IV from the US Zone. I contacted Reimar Horten to obtain his help in completing the ship, particularly in designing replacements for the metal wingtips, which were missing from our ship. The ship was still incomplete when I left the employ of the British in 1947, so I never flew it myself. The boots story was told to me by Reimar Horten, who I believe got it from Heinz Scheidhauer. Obviously I cannot verify it from my own experience.

Bill Hannan of Escondido, California writes:

Dear Marc,

Thoroughly enjoyed your most recent newsletter! The A.R. Weyl article on stalling was particularly significant. Interesting that I assume he is the same gentleman who authored the book Fokker, the Creative Years that has been the subject of controversy.

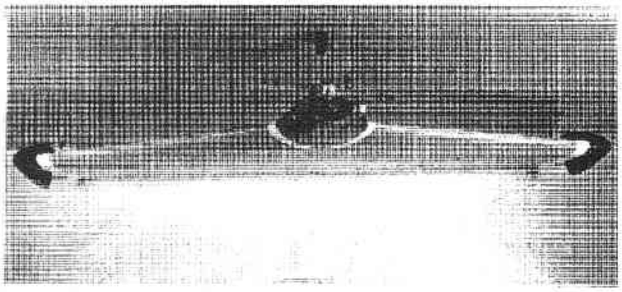
Enclosed are a few more wing model photos. They are the work of Beechcraft engineer Dan Walton,

Apt. 21B
217 West 3rd Street
Andover, KS 67002

He has construction plans available for some of his flying wing models.

Thank you for keeping me on your mailing list, in spite of the fact that I have not sent subscription money! I receive so many club newsletters from various parts of the world that I could scarcely affort to subscribe to them all. Yet all are worthy efforts deserving support, thus I try to contribute useful bits of information plus occasional mentions in my MODEL BUILDER magazine column.

Keep up the fine effort.


Unnamed 3-channel RC Delta wing by Dan Walton. Power is an OS Wankel. Span: 54" [137 cm].


"Flat Cat" 3-channel RC model by Dan Walton. Span: 34 inches [86 cm]. Powered by a G-Mark .061

ICARUS FLIES AGAIN...ALMOST

Many TWITTs probably know that a team from the Massachusetts Institute of Technology, aided by Yale, NASA, the Smithsonian Institution and the National Geographic Society, is planning to fly a man-powered aircraft from Crete to the mainland of Sicily, thus reproducing the tragic flight of Daedalus and Icarus. But TWITT was dismayed when a photograph of the man-powered airplane *Deadalus* was published in the 14 January 1988 issue of the Los Angeles *Times,* San Diego County Edition. You see, the machine has a TAIL! Admittedly a very small one, but still an obvious deviation from the *Homo Sapiens* prototype. Clearly the MIT et al team is cheating on the original specifications. TWITT feels this matter should be brought to the attention of competent authority at the earliest opportunity.

The enlightening article that follows originally appeared in Air BP, a journal of the International Aviation Service of the British Petroleum Group, Britannic House, Moor Lane, London EC2. It is reprinted here from Hang Glider Weekly, Volume 4, Number 34.

ICARUS

MYSTERY SOLVED AT LAST

By Basil Clark

Author's Note: Recent excavations in the Greek Islands have brought to light an interesting collection of tablets. Unofficially attributed to Herodotus, they have been translated by experts of the Dead Languages School at Thule, Greenland, and are reproduced here in full. Although, on the evidence provided, it would seem that the majority finding was more logical, there is an element of doubt as a result of recent observations by astronauts. It may be recalled that several of these remarkable men have reported flying through clouds of what appeared to be bright objects or sparks. Is it possible that Icarus actually went into orbit before falling into the sea? If this was the case, it could surely be that some of the molten sealing wax remained in orbit and is encountered occasionally by space craft. Perhaps Cape Kennedy or Baikhonur would consider a mission to collect some of these sparks for chemical analysis.

Report of enquiry into Icarus accident: Following the fatal accident to the Icarus Mk. I, which fell into the Aegean Sea on the 4th day of the Summer Solstice, AD Minus 2001, a Court of Enquiry was convened on instructions from His Majesty King Minos, to be held as soon as all available witnesses had been contacted. The pilot was killed, but no other crew or passengers were known to be on board during the flight. Chairman of the Court was Diogenes*, assisted by two Technical Assessors, Janus and Tycho Brahe. The hearing took place in a wine shop in Heraklion. Evidence of the identity of the pilot was taken first, a necessary action as the body was not recovered. This was given by his father, Daedalus, and proved to be somewhat circumstantial. It appeared that his son, Icarus, had taken off for an altitude test of the Icarus Mk. I shortly after dawn. (No specific time could be given, owing to the fact that Daedalus' water clock had sprung a leak and was known to be running slow, but the Court was prepared to accept the necessarily vague time estimate).

Daedalus stated that Icarus left the testing ground in a fast climbing turn and settled down on an easterly course at a rate of climb estimated as one foot per second. Against the glare of the sun he was soon lost to sight. He did not return. This was the only positive evidence available, but later witnesses for the Air Traffic Control established to the Court's satisfaction that no other flying had taken place on that date. The Court, therefore, accepted unanimously that the aircraft and pilot concerned in this enquiry were, respectively, Icarus Mk. I and Icarus himself.

Evidence, again from Daedalus, was taken as to the qualifications of the pilot. Daedalus said that he had been in charge of the course on instruction completed by the deceased one month before the fatal accident. This had included two years' ground instruction in the principles of flight and airframe design. A period of three months had been devoted to the study of materials and, in particular, the properties of adhesives.

Daedalus pointed out also that, as no Mark of the Daedalus aircraft was fitted with dual control, flight experience prior to first solo was limited to passenger ascents in the Daedalus Modified Mk. VI. The solo flight in the Icarus Mk. I had been successful and was followed by a period of circuits and bumps prior to the commencement of serious test flying.

Questioned by Hermes, who was briefed to represent the interests of Olympus, Daedalus stated that he considered Icarus had the makings of a first class test pilot but that, like most young men, he was inclined to take chances which a more experienced pilot would have eschewed.

Details of the Icarus Mk. I were next given by the designer, Daedalus. The aircraft was of the ornithopter type, with high wing configuration. Wing parts were of cedar, specially imported from Lebanon under license, and the skin was composed of goose feathers. Questioned by the Chairman, Daedalus said that these had been obtained from Rome under somewhat dubious conditions owing to the rigid export regulations extant in that region. Control was by a form of elevon, of the same structure as the wings, mounted on the trailing-edge wingtips, and operated by muscular movement of the fingers. The wing skin was secured to the framework by a thermoplastic known as sealing wax.

The wing roots were attached to the fuselage at the pilot's shoulders and, although dynamic test had not been completed at the time of the accident, it was estimated that approximately 1 Man Power could be developed at maximum output. The Court, having consulted, agreed that the estimate could be accepted as accurate.

Hermes intervened to ask whether wings were fitted to the flying helmet and boots. Daedalus replied that they were not, as he considered the system inefficient and outdated. Hermes rose immediately to object that the remarks of the witness were irreverent, inaccurate, and calculated to cast grave doubts on his, Hermes', technical capability. The objection was sustained and the Court ordered that the statement should be chiselled out of the record stone.

Janus asked to see the log of Icarus Mk. I, and some twenty Assyrian slaves were detained to carry it into court. From this it appeared that the aircraft had logged a total of ten hours prior to the final flight. Hermes again intervened to point out that it would therefore have been acceptable in the flying programmes at Essbac, Farnborough, if it had been built in ancient Britain. Maintenance tablets showed that a total of 4,821 goose feathers had been replaced since initial construction.

Only two eye-witnesses of the accident could be located. The first, Acopopopopolis, refused to give evidence on oath on the grounds that he did not believe in Zeus. Hermes again objected, but this time he was over-ruled and the witness was allowed to affirm. He began his evidence by saying that he was skin diving on the east coast of the island on the day that Icarus flew over.

Diogenes interrupted to ask "What is skin diving?", and the witness replied, "Bathing in the nude, Guv." Laughter was suppressed instantly by the Chairman, with a stern warning that any further contempt of Court would be purged by a life sentence at the rowers' benches in a trireme.

Continuing, the witness** said that he next heard a loud bang and, looking up, saw a flash in the sky. He took no action because he thought it was "only Hermes on one of his supersonic message trips." Gratuitously, he added that the sonic boom had aroused a great deal of complaint locally and that the roof of the village temple had fallen down because of it. One of the Technical Assessors remarked observed that this was yet another of the fallacious complaints about sonic booms made in attempts to obtain compensation from the Ministry. In fact, he added, it was well known that this particular temple roof had been lying in ruins for more than a thousand years.

The second witness, Constantinos, said that he was in his boat, having just taken on board a consignment of fifty amphora of Ouzo from a trireme cruising just outside the 12 mile limit. He also heard a bang and saw a glowing object drop into the sea close to him. At the same time a shower of hot, sticky rain fell on the boat. Examining the rain later, he saw that it was now solid, though tacky, and of bright red colour, streaked with black. He submitted a sample which was admitted as His Majesty's Exhibit Alpha.

The witness went on to say that he cruised around for some time while he tested the quality of the Ouzo, and during this period he picked up several scorched feathers, admitted as Exhibit Beta. He produced also a charred strip of wood, identified by Daedalus as cedar, and on which could still be distinguished faintly certain manufacturer's marks, Exhibit Gamma. He had found no other traces and this concluded his evidence. Hermes did not cross-examine.

An Alchemist was then called and he identified Exhibit Alpha as sealing wax, adding a rider that, in his expert opinion, the wax was secondhand and had been used at least once before.

Daedalus was then recalled and stated that he obtained the wax from a dealer named Stepto, who roamed the country in company with Hercules. Stepto had said that the wax was of the same specification as that used in the construction of the Wooden Horse of Troy and that it had proved eminently satisfactory, adding, in an aside to Hercules, "We've got a right one 'ere, Tosh." Daedalus said that he entirely failed to understand the expression but assumed it wassome patois from Dodecanese Islands. He, Daedalus, now suspected that the wax had actually been used in the Wooden Horse and reclaimed by some enterprising scrap merchant.

The Court adjourned while unsuccessful attempts were made to subpoena Stepto and Hercules.

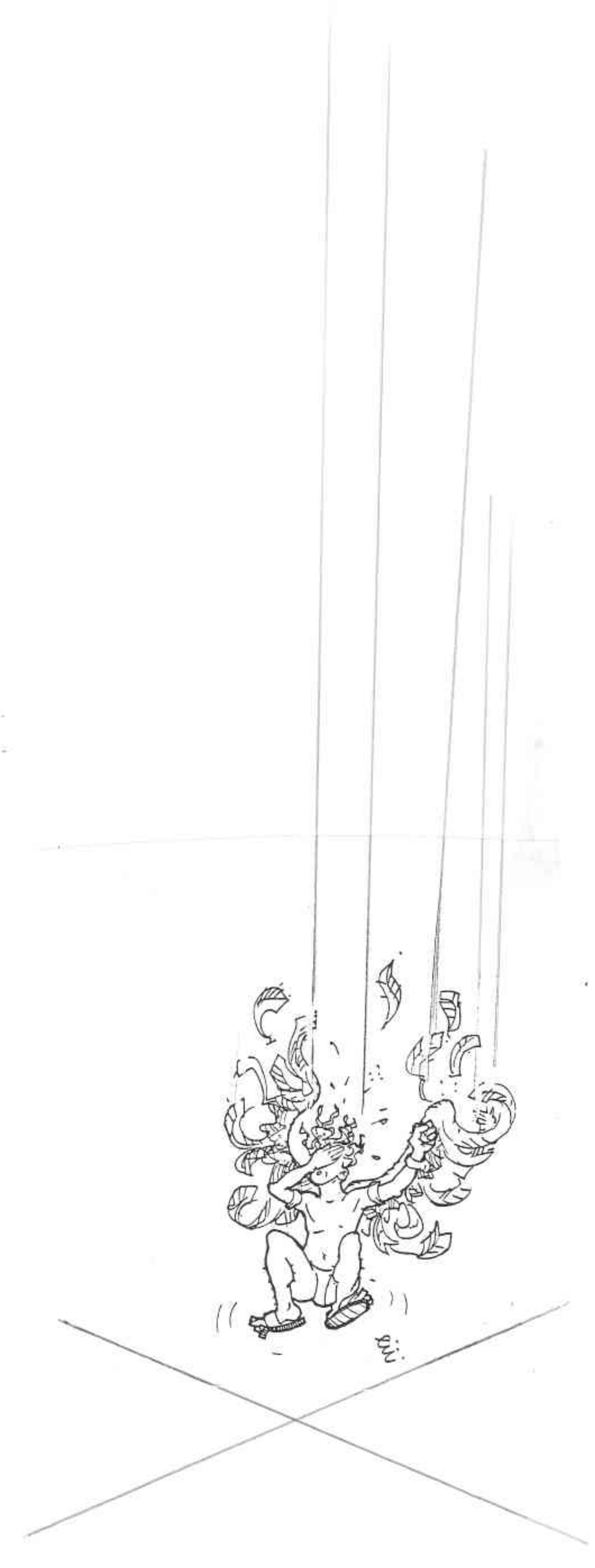
On resumption, the Court considered the evidence and produced both majority and minority findings, as follows: (I) That the accident was due primarily to pilot error in that Icarus, with insufficient flying time, had entered the transonic phase of flight, thus generating heat in excess of that permitted for the structural materials of which Icarus Mk.I was constructed. (II) That the designer had been negligent in that he did not submit the structural materials to the Air Inspection Department for examination and approval. It was recommended that his designer's license be revoked. (III) That the Ouzo illegally imported by the witness, Constantinos, be confiscated by the Court.

The minority findings did not support Sections (I) and (II). An alternative finding was that Icarus had flown too near the sun and thus caused the wax to melt. The minority was, however, in full agreement with the majority finding and recommendation 'Section III.'

The enquiry closed, having adopted the majority opinion.

* The original tablets described Diogenes as the Tubman, but the modified translation is considered to be more appropriate.

** The scribe who chiselled the tablets clearly tried to give the witness's name, but it is apparent that he miscounted the number of 'pops' and ran short of stone.



Stalling Phenomena and the Tailless Aeroplane—III

By A. R. Weyl, A.F.R.Ae.S.

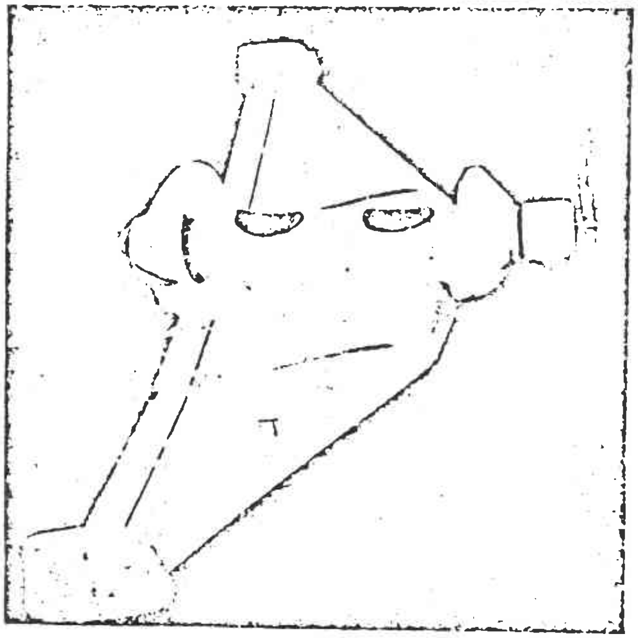
Previous sections of this article appeared in THE AEROPLANE *page 427, April 25, and page 478, May 9.*

FOR any plan shape of a wing, an elliptical lift grading over the span may be achieved by means of wing twist or by appropriate variation of the aerofoil section along the span. In such cases, however, the lift grading will remain strictly elliptical only for one particular incidence. For the condition of simultaneous stall, this incidence should be identical with that of maximum lift. At incidences other than that for which the lift grading is elliptical, there will be an increase in the induced drag although, in practice, these differences are not great. A more serious factor, especially for tailless wing systems, is that all wings with twist or section variation give lower values for the maximum-lift coefficient than the local section lifts would allow. More serious still is the fact that, in practice, the current design methods for such wing systems fail to take into account the mutual interaction of neighbouring span-wise sections with different incidence (due to the twist), and with variations of the aerofoil sections.

At incidences sufficiently below the stall, these influences, due to twist or aerofoil section shape, express themselves only in increases of the wing profile drag (wing interference drag) and in decreases of the slope of the lift curve $(dC_L/d\alpha)$. The interaction most probably forms one of the causes for curvatures of the lift curve at low incidences observed on composite wing systems composed of aerofoil sections which otherwise show a strictly linear dependence of the lift on the incidence.

TWIN PUSHER.—(Right) An early Northrop all-wing design was this little N-1M single-seater of 1940, which had a span of 38.5 ft. and supplied valuable data for the XB-35 programme. Power plants were two 65 h.p. Lycomings, later replaced by two 120 h.p. Franklin engines.

PUSH AND PULL.—(Below) Unlike its prototype, the "Hermann Köhl," which had a triangular wing, the Lippisch Fieseler F.3 "Wespe" of 1932 had a trapezoidal-shape wing. Power plants were two 75-h.p. Pobjoy engines. Slotted control flaps were along the entire trailing edge.



At the stall, the interaction effects along the span tend to be aggravated. They greatly contribute to premature stall, and hence give cause for the origin of the incipient stall.

A similar form of span-wise interference between neighbouring regions of the span is caused by the direction which trailing and leading edges of the wing assume to the direction of flight. This interference differs from the first form of interaction in that it may be detrimental or beneficial. The first form is, as far as experienced, always harmful.

In spite of the failure of present theory to consider the effect of mutual interference between neighbouring span-wise regions, the results of the elaborated "strip" theory are nevertheless valuable as a guide for the designer.

Shih Chang Zien investigated in a thesis (Ref. 8) the possibilities for an elliptical lift grading on trapezoidal wing shapes under the condition that the stall should originate at the centre (root) of the wing. The analysis was based on R. Fuchs's trigonometric solution of Prandtl's integral equation for the circulation along the span. Zien found that the condition for elliptic lift grading (for incidences representing high-speed flight) and for stall inception at the root, could be satisfied for taper ratios up to 3 either by twist, or by section variation, or by a combination of both.

For taper ratios exceeding a value of 3, an elliptical lift distribution was found to be possible only by variation of the aerofoil-section shape (cambered aerofoil sections at the wing-tips), or by a combination of section variation with twist; even in this case, the effectiveness of flap-type controllers at the wing-tips would be impaired. The expedient of cambered aerofoil sections at the wing-tips for the purpose of enforcing a root or mid-span stall with efficient lift grading at small incidences will be considered more fully later.

The interrelation between undisturbed flow and fully separated flow at neighbouring strips of the span has a very important bearing on the inception and the progress of the stall along the span. An investigation by P. Jordan (Ref. 9) has greatly contributed to the information on this subject.

According to the vortex-line theory of lift, the occurrence of high lift and low lift at adjoining strips of the span must necessarily have an effect on the three-dimensional flow pattern, since lift is the result of pressure differences at the aerofoil. Hence adjoining regions of high lift (unstalled wing strip) and low lift (stalled wing strip) must modify the induced incidence of the strips. Moreover, when "dead-air" regions adjoin regions over which high negative pressures (lift) exist, span-wise flow components result which will influence flows that are of an unstable nature. In general, the boundary between strips of smooth flow and those with disturbed flow will travel along the span when the incidence is increased. The rate of this travel and its uniformity are, as pointed out above, of great importance in connection with the character of the incipient stall.

Jordan's tests have established that the differences caused in the induced incidences across such a boundary between stalled and unstalled span-wise regions, are quantitatively of less importance than the span-wise flow.

Moreover, Jordan found, from water-channel tests at effective Reynolds Numbers of 0.15×10^6, that a transition vortex occurs near the leading edge, at the incidence of maximum lift when the laminar boundary layer breaks down into the turbulent state, and that this vortex exerted a major influence on the phenomena of the front stall. He observed that a widening of the vortex under the intake of more stale boundary-layer material, gave rise to the separation of a laminar boundary layer.

This separation is, as already mentioned, not a steady phe-

(*Continued on page 627*)

nomenon: the transition vortex is periodically expanding and contracting, due to the quantity of boundary-layer material rotating in it. Consequently, at a certain constant incidence of the wing, regular changes between smooth flow and flow separation occur at the same strip of the span. This shows how misleading it is to rely on the interpretation of steady force measurements, as far as stalling phenomena are concerned.

When the particular incidence of separation instability was slightly increased (by an amount of only 0.25 degrees in Jordan's tests), a change from the slow periodic fluctuation in the flow pattern to a rather fast and less defined one, was observed. Beyond this incidence, the burbling flow of the separated boundary layer became predominant, and at still larger incidences it persisted.

There is, then, an incidence range of complete instability of the flow pattern at the stall, where periodic fluctuations govern the resulting aerodynamic forces and moment of a wing system. For reasons of safety, the designer of tailless aeroplanes should take care to decrease or to abolish this critical range of stalling incidences, since it does not permit stability or a continuation of a steady flight path.

Jordan's observation would also provide an explanation for the existence of secondary lift maxima (double peaks in the lift curve) to which W. S. Farren referred at an earlier date (Ref. 10). Such secondary lift maxima (which sometimes even exceed in value the first and true lift maximum) have also been observed to occur when a wing was swept back by 30 degrees, keeping the same aspect ratio, aerofoil section and wing twist (Ref. 71).

Secondary lift maxima attained beyond the critical wing incidence, may reach higher values than the steady primary lift maximum. The reason for this lies in their unstable nature: at the instant when the expanding transition vortex extends over the entire chord, it transforms the aerofoil section to virtually one of greater camber, in its effect on the outer potential flow. Higher negative-pressure peaks follow, hence greater lift. But this lift disappears as quickly as it has been formed, leaving only the effect of greater strain on the wing structure.

Application of these observations on the mechanics of laminar boundary-layer separation ("front" stall Form "A") to the problem of the span-wise spreading of the stall, indicates that the periodical stalling and unstalling of a wing strip will cause flow impulses over neighbouring regions of the span. First of all, negative pressure will be exchanged, i.e., equalized, in a span-wise direction, when lift peaks are being reached over the critical region of the span. This will transfer stale boundary-layer material into the transition vortex which subsequently further expands and causes front separation (deep stall), with break-down of the circulation. The same will happen when tired boundary-layer material assumes transverse flow at chord stations nearer to the trailing edge where the boundary layer is already turbulent. But there it will only thicken the turbulent boundary layer and promote a gradual "rear," or shallow, stall. Since the pressure differences are smaller in this chord region, the rear separation is bound to be more gradual and not quite as unsteady.

From this, seemingly, the "rear" stall should give a smaller rate of travel in span-wise spreading than the "front" stall originated by the transition vortex. It might also provide some explanation of the fact that wing twist generally tends to result in a more gradual spreading of the stall over the span, quite distinct from the effect of the incidence difference.

Experimental investigations of the interaction between smooth flow and flow with separation, were also made by W. Fabricius (Ref. 11), another collaborator of the Göttingen circle. The Reynolds Number of these tests was fairly low, at about 0.3 × 10^6. The investigations were made on a rectangular wing with end discs and with a narrow centre-section which had 7 degrees more incidence than the rest of the span, so that the stall became incipient at this narrow-chord centre section. There was, as a result, a definite boundary region between an unstalled wing strip adjoining the centre section and the stalled centre section which lent itself well to the specific observation of interaction phenomena.

Within the boundary between stalled flow and smooth flow, the absence of backward flow in the boundary layer (the first indication of the inception of boundary-layer separation from the surface) was noted as evidence that no flow separation occurred in this critical strip of the span. The thickness of the boundary layer in it, however, was greatly increased. The development of flow patterns was found to depend largely on the shape of the aerofoil section. This is in agreement with N.A.C.A. experiments, which proved how greatly the rate of span-wise spreading of the stall is influenced by the aerofoil section.

Thickening of the Boundary Layer

The enormous thickening of the boundary layer in the region intermediate between a stalled and an unstalled strip of the wing is caused by transverse flow components which deposit stale fluid particles in this region. As a consequence, the circulation over the critical region of the span is decreased, and the lift approximates to that of the stalled wing region. The boundary layer, even near the trailing edge at the critical span region, however, exhibits no backwards flow. Within this boundary layer, a flow component directed inward towards the stalled centre section was found, while, near the leading edge, the flow was towards the tips. The maximum transverse-flow velocity was observed to occur not at the wing but behind the trailing edge. There, flow persisted from the under-surface of the critical region to the upper-surface of the stalled centre.

Such oblique flow around the trailing edge would seem of importance, by reason of the consequences of partial stall on a tailless aeroplane. It will affect the action of reflexed camber on the stability in pitch, and also the effectiveness of controllers mounted with a slot behind portions of the wing which are adjacent to parts of the wing likely to stall first.

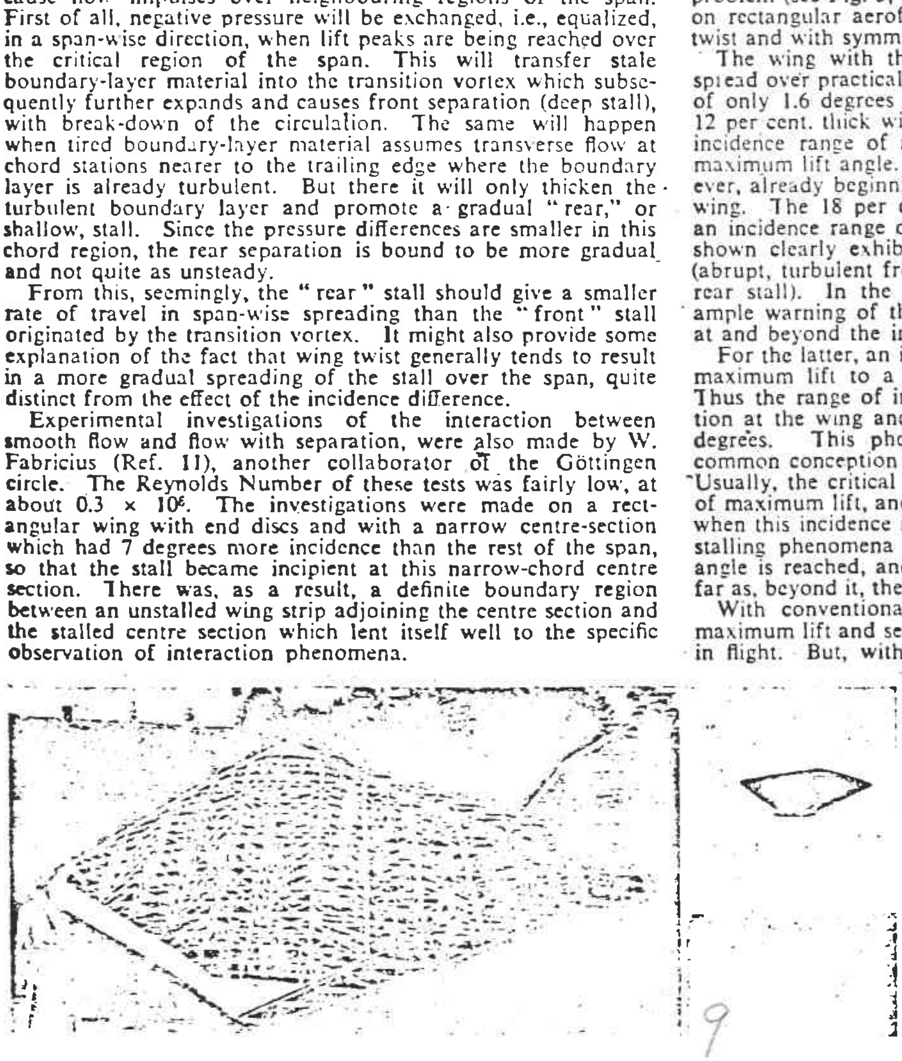
The oblique flow velocities around the trailing edge reach, according to Fabricius, values which are higher than that of the undisturbed outer air flow. It is thus conceivable that trim changes observed with "stable" aerofoil sections near the incipient stall are connected with this phenomenon. The rate at which the stall spreads over the span depends on the various factors mentioned above. Of these, the aerofoil section shape (and its variation along the span) appears to be dominant.

Full-scale wind-tunnel tests made by H. J. Goett and W. K. Bullivant (Ref. 12) seem to shed some light on this part of the problem (see Fig. 5, p. 478, May 9 issue). The tests were made on rectangular aerofoils, slightly rounded at the tips, with no twist and with symmetrical sections of different thickness.

The wing with the 9 per cent. thick section had the stall spread over practically the entire span within an incidence range of only 1.6 degrees exceeding that of maximum lift. For the 12 per cent. thick wing, the span-wise spreading extended to an incidence range of more than 2.5 degrees measured from the maximum lift angle. A rear break-away of the flow was, however, already beginning at the trailing edge in the centre of the wing. The 18 per cent. thick wing developed the stall within an incidence range of not less than 9 degrees. The lift curves shown clearly exhibit the difference between stall form "B" (abrupt, turbulent front stall) and form "C" (gentle, turbulent rear stall). In the latter case, the pilot will obviously have ample warning of the incipient stall. In addition, the lift-loss at and beyond the incipient stall is least with the thickest wing.

For the latter, an initial break-away preceded the incidence of maximum lift to a greater extent than for the thinner ones. Thus the range of incidence between the incipient flow separation at the wing and the complete stall was actually about 12 degrees. This phenomenon, incidentally, indicates that the common conception of a "critical incidence" needs a revision. Usually, the critical incidence is associated with the occurrence of maximum lift, and it is at the same time tacitly assumed that when this incidence is exceeded, the stall is incipient. Actually, stalling phenomena may set in long before the maximum-lift angle is reached, and this angle becomes "critical" only in so far as, beyond it, the lift becomes smaller.

With conventional aeroplanes, this differentiation between maximum lift and separation inception is hardly, if ever, noticed in flight. But, with tailless aeroplanes, it may become worth



AERODYNAMIC DINNER-PLATE.—This is the Canova Rhomboidal Wing, built and flown in Italy during 1935. The pilot sat on a skid slung under the wing, which had a fin and rudder attached to the upper surface; elevators and ailerons were provided. The aspect ratio was about 2. Stability longitudinally was satisfactory but laterally was deficient consideration for investigation in flight. It also may have a bearing on the ability to reach the incidence of maximum lift in flight.

Another result from the N.A.C.A. full-scale tests is that the 18 per cent. thick aerofoil exhibited no "hysteresis loop" in the lift curve, i.e., no double lift values for the same incidence in the stalling region. How far this really means that there is no critical range of incidences with periodically fluctuating lift at fixed incidence, is difficult to judge. Obviously, however, if this is so, then there is no extended incidence range with gross instability in the flow pattern; i.e. one and the same lift value is associated with an incidence value, regardless if this incidence is reached from a higher one or from a lower one. Seemingly, on this aerofoil, the smooth flow pattern is more readily re-established than on the thinner aerofoils. Perhaps this is a result of the greater tendency of the boundary layer to become turbulent.

Stalling observations made by M. Kohler at Göttingen (Ref. 13) with a rectangular wing of Göttingen 420 section at effective Reynolds Numbers of 0.22 × 10^6, gave an incidence range of about 5 degrees for the span-wise spreading of the stall, with a typical "rear" stall. From the maximum value of 1.35 at 15 degrees incidence, the lift coefficient dropped to about half this (0.72) at an incidence of 35 degrees. Beyond this, it decreased slowly to smaller values, without an apparent discontinuity. The span-wise lift grading of this aerofoil had at maximum lift already assumed a saddle-like shape (incipient root stall). The depth of this central saddle deepened with increasing incidence, but became less marked when the stall spread along the span; yet it was still noticeable in the lift distribution curve when the incidence grew to a value of 30 degrees. This would indicate that the stall at the wing centre was deeper, i.e., more extensive in a chord-wise direction, than farther outboard.

The influence of the Reynolds Number on stalling phenomena is quite marked. Pressure-distribution measurements made by the N.A.C.A. by R. M. Pinkerton (Ref. 1) on a N.A.C.A. 4412 aerofoil, proved that the shape of the chord-wise loading varies greatly with the Reynolds Number at incidences at which stalling phenomena occur. At greater Reynolds Numbers, for example, about 1.8 × 10^6, the shape of the chord-wise pressure-distribution curve retains, beyond the stall, some similarity with that at sub-critical incidences. This being so, at the complete stall, apparently, the longitudinal trim of a tailless aeroplane need not be gravely upset, while model tests at low Reynolds Numbers tend to indicate a different behaviour.

However, beyond the stall, the flow loses, as mentioned, its steady character. No uniform flow pattern and lift may thus be expected, and it would seem precipitate to arrive at such conclusions on the basis of pressure-distribution tests. On the other hand, experience has shown that tailless aeroplanes may be flown and controlled when completely stalled. G. T. R. Hill has reached with one of his earlier Pterodactyls, controlled flight at an incidence of 45 degrees, and there were reports of Lippisch indicating similar experiences.

Characteristics of the Plan Shape of the Wing

With tailless aeroplanes in the flying-plank category, i.e., without any aerodynamic sweep, the problem of the incipient stall is most easily understood. In this case, taper of the wing in chord will exert the greatest influence.

With symmetrical taper, the stall would tend to set in at the tips and spread from there over the span. The higher the taper ratio (root chord/tip chord), the more pronounced the tendency to tip stall will be. A triangular wing plan should, in theory, be the worst, as the tip will be stalled at all incidences. This quality, however, is greatly modified by the aspect ratio of the wing, when it is small. Small-aspect ratio wings, therefore, do not obey the general rule given above, and will be discussed later.

In the case of a rectangular plan form, the stall sets in near the wing root and spreads from there to the tips (Ref. 5). This quality of the plain, rectangular wing may be seen as the result of the pressure-equalizing flow around the wing tips (wing-tip vortices) which promotes an inward-directed flow component along the upper wing surface. In the region of the tips, this flow component adds energetic flow material to the boundary layer near the tips, and hence delays flow-separation in that region. As a consequence, stalling will set in first near the wing root, towards which stale boundary layer material is directed along the span. The root stall of the rectangular wing is therefore the immediate outcome of the higher induced drag (as compared with an elliptic aerofoil). Theoretically, it is the greater effective incidence of the classic aerofoil theory which makes the wing stall at the centre first.

When controllers are located near the wing tip and at the wing root, as often found practical with tailless aeroplanes in the flying-plank category, a desirable feature would be to have the stall beginning half-way between wing root and wing tip, with the tip stalling simultaneously with the wing root. Wash-out will remedy the premature stall of the wing tips; the application of cambered wing-tip sections would, however, seem preferable to neutralize the effect of moderate taper.

As already pointed out, the main, though not the only, reason for the different behaviour of rectangular wings and symmetrically tapered wings is the existence of span-wise flow components which affect the boundary layer. With the tapered planform, it is the sweep-back of the leading-edge which gives cause to a flow-deflection towards the tips on the upper wing surface. Near the tips, the tip vortices counteract this flow movement with the result that de-energized boundary layer material accumulates in this region. The boundary layer, therefore, thickens and is liable to separate from the wing surface. To a certain extent, sweep-forward of the trailing-edge is neutralizing the effect of the swept-back leading-edge. A tapered wing with a straight leading-edge and a swept-forward trailing-edge is less likely to exhibit tip stall.

"Aeroplane" drawing

FIRST WAR-TIME HORTEN.—We gather, from German test-flight reports, that this Hortell IV tailless sailplane had fair handling characteristics, but the main drawback was over-sensitivity in the controls and insufficient directional control. A small number of Horten IVs was built, and many hours flown in them—conclusions drawn being that the type was not suitable for inexperienced pilots. A later version, with a laminar-flow wing, was designated the Horten IVb.

H. A. Soulé and R. F. Anderson have worked out design charts relating to the stall of unswept tapered wing systems (Ref. 14). These charts, however, take into account only the point along the span at which flow separation will occur first when the incidence of the wing is slowly increased. It has been rightly argued that the charts are inconclusive, since they fail to consider the rate at which the stall is spreading along the span and the loss of lift associated with it (shallow or deep stall). Both factors determine the rate of wing dropping for a conventional aeroplane. With a tailless aeroplane, they are even more important, since longitudinal stability and control are also affected.

Nevertheless, the N.A.C.A. charts are of some value as they permit of a quantitative comparison of the influence exerted by the various design factors, for unswept tapered wings with aerofoils of the N.A.C.A. 230 class, upon the span-wise origin of the stall. The charts also include the remedy of tip stall by the incorporation of various devices. These will be referred to later when discussing swept wing systems.

Clearly, wing taper is the predominant characteristic. Quite apart from the effect of leading- and trailing-edge sweep which impress span-wise flow components upon the boundary layer, taper directly affects the lift-grading over the span at the incidence of maximum lift by its influence on the local aerofoil thickness and on the local Reynolds Number. Since the minimum flying speeds, and hence the landing speeds, are confined to practical limits, the Reynolds Numbers near the wing tips tend to decrease the values of the maximum section lifts in that region when the taper increases.

For wings having thin aerofoil sections at the root, the maximum section lifts tend to decrease from root to tip. The reverse is the case when the root sections are thick. This is valid for all taper ratios, including those commonly found in sailplanes. Root thicknesses exceeding 15 per cent. of the local chord cause the origin of the stall to move inwards, except when the Reynolds Number is below 4 × 10^6.

Aerodynamically and structurally, the flying-plank type would seem superior to all tailless systems which rely on effective sweep. An elliptic lift-grading over the span, i.e., minimum induced drag, can be achieved for lift coefficients of practical flight. Structurally, taper would allow the bending moment to be kept low; the torsional load on the wing structure may be reduced to a minimum.

Ch. Fauvel, who preferred the triangular wing shape, seems to have retained control in pitch by locating the elevator flaps in the wing root, and the rather long ailerons had their greatest chord inboards. Theoretically, the tips of a pointed wing should be always stalled. The flying qualities of the Fauvel tailless have, however, not given the French authorities the impression that the behaviour was unsatisfactory when the stall was approached.