TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 745

# HIGH-SPEED AIRCRAFT

By M. Schrenk

Zeitschrift des Vereines deutscher Ingenieure
Vol. 78, No. 2, January 13, 1934

Washington
May 1934

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 745

# HIGH-SPEED AIRCRAFT*

By M. Schrenk

It is scarcely 25 years ago that the airplane exceeded a speed of 100 km/h, and many readers will undoubtedly remember the sensation with which this record was received. For many years the top speed remained below that of the automobile, and, in fact, it never reached 200 km/h in level flight, even at the end of the war.

The post-war period then saw its rapid development, as exemplified by the Schneider Trophy Races after 1922 and which ultimately was won in 1931 by the British with the Supermarine S6 (reference 1). This performance was exceeded in 1933 by the Italian Cassinelli in the Macchi-Castoldi MC 72 (reference 2)**(fig. 2), with a speed of nearly 630 km/h (391.5 mi./hr.) over a 100 km course. The airplanes used in these contests were twin-float single seaters specially designed for high-speed flight. The speeds obtained may be looked upon as the limit of that stage of development in airplane design.

Admittedly, these performances are no criterion for the speed of the general purpose airplane. But they did have a great and lasting effect on all other branches of aircraft design. Next to the pursuit airplane which clearly shows the effects of the racing-airplane influence, the transport airplane has experienced an undreamed of increase in speed.

One aviation handbook (reference 3) cites 130 to 160 km/h (80.8 to 99.4 mi./hr.) as the average commercial speed for 1928. Two or three years later commerical airplanes having substantially more than 200 km/h (124.3 mi./hr.) top speed (the commercial speed is about 15 percent lower) were still considered as being very fast. Since then, however, the scales have become totally different (fig. 1).

---

*"Schnellflug." Z.V.D.I., January 13, 1934, pp. 39-47.

** Figures 2 and 3 are taken from this report.

This upswing started in the United States of America. Europe had its first glimpse of it through Frank Hawks in the spring of 1931, when he flew his "Travel Air" from London to Berlin and Paris and back to London in one day at a speed of at least 320 km/h (198.8 mi./hr.). Soon after, the German State commissioned the E. Heinkel Co., at Warnemünde, with the construction of a high-speed commercial airplane, the HE 70, which today is perhaps the fastest commercial airplane used anywhere. Its speed is higher than almost any pursuit airplane of equal engine power.

The simplest and most convenient means for high speed is the use of more powerful engines. The development of aircraft engines within the past decade has anticipated this demand of the airplane designer; the weight per hp. and the dependability of aircraft engines have increased from year to year. The air-cooled engine, a typical development of the United States, leads the field for commercial aircraft with a specific weight of from 0.6 to 0.7 kg/hp (1.3 to 1.5 lb./hp.) whereas the water-cooled engine, especially favored in England, is predominately used in military aviation*. However, this division is not decisive, conditions change from one year to the next, and we are perhaps due again for another change through the introduction of the air-cooled in-line engine with mechanical cooling.

Obviously the racing airplane engine leads all others in the utilization of weight. The 1931 Schneider Trophy winner, a Rolls Royce R type engine with almost 2400 hp. "hour-performance" at approximately 0.3 kg/hp. (165 lb./hp.) performance weight (dry), represents a remarkable point in the advance of the 12-cylinder in-line engine, and is surpassed only by the 12-cylinder Fiat AS 6 engine (fig. 3) in the MC 72 (fig. 2) which develops 2800 hp. (The tandem propeller arrangement, by the way, was already used in the Rumpler-Lutzkoy Taube, before the war, V.D.I., vol. 56, 1912, p. 449.)

One particular problem in racing airplanes concerns the removal of heat without increasing the air resistance. For that reason every available space on wing, fuselage, control surface, struts and floats is utilized as cooling surface.

---

*The operating weight of nearly all engines at the end of the war exceeded 2 kg/hp.

But the performance balance of the airplane is not dependent on the power input but on the output power; the ratio between the two, the propeller efficiency, on the other hand, is little affected. Its limit has been somewhat raised within the past years by using thin metal propeller blades and today ranges at around 86 percent for fast airplanes, with a small percentage off for propeller-body interference. Even the controllable-pitch propeller presents here no progress; its purpose is something else, as pointed out hereinafter.

Another and even more effective way than increasing the power of the engine is by lowering the power required. Since the weight supported by the air in high-speed flight is distributed over a large quantity of air per second the drag induced by the lift is comparatively low; it suffices to analyze the head resistance. This again consists of two parts, wing and residual drag (i.e., of all non-lifting parts), and any attempt at lower air resistance is contingent upon the ratio of these two kinds of drag.

Another fact not sufficiently taken into account is that in the largest majority of airplanes only 1/4 to 1/5 of the head resistance is caused by the wing (reference 4). Here then is the point for effecting improvements. In fact, the profile drag of the American high-speed airplanes quoted in table I, already amounts to 2/5 of the total head resistance; on the Heinkel HE 70 it was even possible to keep the two quotas about even. How was this accomplished?

Among the non-lifting parts the fuselage, of course, predominates. Smooth, streamline design is a matter of self-evidence, it is promoted by a long, narrow in-line engine (fig. 4). Fundamentally the slender body is preferable to the thick body, but for small units this means less space for the passengers. On the other hand, figure 5 shows what actually can be accomplished for passenger comfort even under these circumstances. The categorical demand of a few years back: "head room" had of course, to be abandoned. Indubitably the passenger prefers to spend 4 hours in a comparatively narrow space - which is still better than in a closed automobile - comfortably reclining than to spend twice as long a time in a kind of corridor.

As easy as it is to design a fusiform body of low drag, just as difficult is it to join the selfsame body to the wing without producing additive drag due to mutual interference. The best aerodynamic conditions call for mounting the wing at about body-axis height; but this is out of the question for reasons of statics and visibility. Airplane design practice has increasingly leaned toward the low-wing design, which particularly favors the landing gear and the safety of the passengers in an accident.

The problem of fairing the wing in the fuselage is amenable to several solutions. The Americans use an ingenious wing fillet (figs. 6, 7, and 8), based upon elaborate wind-tunnel research. Such fillets prevent the premature breakdown of the flow at the wing contiguous to the fuselage at high angle of attack and thus avoid the so-called "buffeting" at the tail surfaces (reference 5). In the Heinkel HE 70 (fig. 4) the wing roots are swept up slightly, and have a negative angle of incidence to improve the air-flow over the tail plane; it resulted in a 15 km/h higher speed.

Another drag-producing part is the landing gear. Its use being limited to landing and take-off, it was natural to make it retractable in flight; although there had not been much progress until the last few years. Now, however, the majority of the high-speed, single-engine, commercial airplanes, such as the Heinkel (fig. 9), Junkers (fig. 10), Lockheed, Airplane Development (fig. 6), etc., are equipped with retractable landing gears, and safety and warning devices to prevent landing with wheels retracted, although several accidental landings with wheels retracted due to some cause, have proved the absence of imminent danger because of the marked ground interference of the low wing. There is no record of personal injury in accidents of this kind. On the other hand, the possibilities with a fixed landing gear have been well illustrated by the Northrop Co. (fig. 11). Here wheels and oleo struts are enclosed in streamlined casings, reminiscent of Klemperer's glider "Blue Mouse" of 1921. The drag of the wholly enclosed landing gear can be lower than with wheel fairing alone, because the exposed struts set up additional drag on account of the inevitable open gaps. In point of fact, the avoidance of all mutual interference is one of the most important factors in high-speed airplane design.

The enclosure of the engine front which is exposed to the propeller slipstream and its fairing into the fuselage is another significant factor. The introduction of radial, air-cooled engines followed after elaborate studies had finally evolved an engine cowling which combines low drag with satisfactory cooling (the N.A.C.A. cowling and the Townend ring (reference 6)).

Fundamentally the in-line engine is the best, but its advantages are nullified by the additive water radiator drag. This radiator drag is reduced to 1/3 by using ethylene-glycol cooling, as first applied successfully in Germany in the HE 70 (reference 7). Partial retraction of the radiator affords a further decrease. Skin radiators as used on racing planes are for the present unsuitable on account of the danger of damage as well as control difficulties. Perhaps a medium course would be successful, that is, to use only the absolutely necessary minimum surface for skin cooling, but to make the rest of the radiator retractable.

As concerns the wing, the old question of thick or thin airfoil still awaits a definite answer. There is a decided leaning toward the cantilever wing, but the question remains how thick the profile may be relative to its span consistent with correct balance between structural weight, load space and profile drag. This problem still awaits final settlement through conclusive full-size profile measurements. However, we do know that with sufficient surface smoothness and without undue thickness, the whole profile drag is practically nothing but air friction, which explains the marked response of the drag coefficient to surface roughness (reference 8).

Recent American experiments (reference 9) in the variable-density wind tunnel, for example, proved a drag increase of 20 percent for a single row of rivets on a metal-covered 6 by 36 foot airfoil. Hence a very smooth surface is imperative; and this holds true for every other airplane part as well, if the desired result is to be actually obtained.

Whereas, the cited racing airplanes have reached a landing speed of around 200 km/h - seaplanes, which, moreover, were flown only by specially trained pilots* - this factor is naturally of the greatest importance in the commercial airplane for reasons of safety. Admittedly, the conceptions of safe landing speeds have changed as we gained in experience and the airplane performances became

---

*Still at the cost of many human lives.

better. But even today it is still considered very hazardous to land a commercial airplane at much more than 100 km/h (62.1 mi./hr.) landing speed. The passenger airplanes cited in tables I and II all fall within this range.

Low landing speed follows from low loading of the "maximum lift area", i.e., the product of wing area times maximum lift coefficient. To hold the wing area small and through it the profile drag, calls for a corresponding increase in maximum lift coefficient. Figure 12 shows a selection of high-lift devices with which this may be obtained. Probably the oldest method, the slotted wing of Lachmann-Handley Page (c) has obtained to a high stage of perfection in the last few years. Among other successful devices there is the split-flap (d) and (e). The operation is seen from figure 13 (reference 10). The positive (negative) pressure forward and aft of the split flap continues over both sides of the profile up to the forward stagnation point.

Even this appliance is not altogether new. The first experiments of this kind were made by the author of this article in 1923 at the suggestion of Dr. Ackeret, who was then the section chief of the Göttingen laboratory. The experiments, in themselves very promising, were, however, discontinued as there was no urgent need for this appliance.

Aileron control problems are amenable to various solutions. The flap is eliminated within range of the very small ailerons (fig. 14) or the latter are mounted above the wing (fig. 18)*. This method is said to be effective. In slotted wings the difficulties have been overcome long ago (reference 11).

The maximum lift figures cited in figure 12 should not be considered as absolute values, as they are markedly affected by the Reynolds Number. In reality they are much higher as proved in the rating of the minimum speed flights of the 1932 Europe flight (reference 12).

Lastly it is important to note that flaps, especially the split flaps, increase the wing drag considerably and thus lower the fineness ratio of the whole airplane. Aerodynamic refinements on the airplane had made the problem of landing in restricted territory increasingly difficult. Now the flap makes it possible to fly fast with good fineness ratio and to land slowly, with a poor fineness ratio and high lift.

---

*Principally developed by the Zap Development Co. (U.S.).

At take-off there is yet another difficulty. Propellers with high propulsive efficiency which in high speed show satisfactory performance, have a low thrust on the torque stand and at starting. Besides, such propellers are in this condition from 10 to 15 percent below the normal r.p.m., which lowers the engine performance correspondingly. As a result it has happened that fast airplanes had great difficulties in taking off despite a large excess of power.

Here the only remedy lies with the controllable propeller, whose r.p.m. remain constant independent of the speed either automatically or by the pilot. And the demand for such controllable propellers increases with the speed range ratio. The latter amounts to nearly 4 for German high-speed aircraft, which is remarkable when one considers that 2.5 was considered very good indeed, a few years ago.

Because of the added air drag of the wing engines, high-speed, multi-engine aircraft is much inferior to the single-engine type, hence its development has been retarded until quite recently, when the inevitable demand for greater safety in flight brought about their development. (See table II.)

One notable feature at first sight, is the power input per number of passengers, which is substantially higher than in the single-engine type. This condition will continue to exist until it is possible to house everything within the wing, which, however, is impossible below a certain airplane size. In the meanwhile, everything must be done to keep the loss due to the exposed wing engines to a minimum.

As to engine installation, the Fokker F 20 (fig. 15) represents a typical development. It forms the last link in a long and successful attempt of three-engine airplanes (F 7, F 10, F 12, and F 18). While the F 10 was being built, Fokker experimented with a two-engine high-wing monoplane, the F 8, in the attempt of lowering the air drag by mounting the outboard engines ahead of instead of below the wing, on the strength of American investigations (reference 13) (fig. 16).

Fokker's attempt resulted in a 10 percent gain in speed, an experience which led the company to change over to the new arrangement for the designs of the F 36 (fig. 17) and the F 22 (smaller version of F36 with 12.7 ton (28,000 lb.) gross weight. Although these two new types are not rigorously high speed, they still have the outside characteristics. For the rest, figure 18 is reminiscent of the 1919 (reference 14) four-engine all-metal Rohrbach. The three-engine high-speed mail airplane S 4 of the Pander and Zonen Co. which has just been completed also exhibits this central engine arrangement (figs. 18 and 19).

The engine question is the subject of much controversy. Whereas the European countries have finally decided in favor of three engines, the United States favors two (figs. 20 to 22).

This change is substantially due to two factors. The excess power of modern high-speed aircraft has consistently increased with the fineness ratio, and the change to controllable propellers. In multi-engine airplanes the flying speed drops considerably when an engine stops. The other engines run at full r.p.m. and the propellers operate under unfavorable conditions; the r.p.m. and the efficiency drop as at take-off, thus the loss of effective power is much greater than the power quota of the stopped engine. The controllable propeller has produced a decisive change. An idea of the improvements may be obtained from a report on one of the Douglas air liners*. It took off with one engine at full throttle from a point 1450 m (4757 ft.) above sea level**and flew in this condition for 390 km (242 mi.) at 2700 m (8858 ft.) averaging 193 km/h (120 mi./hr.). There surely is no question of lack of excess power. This example is particularly suited to show the advance of modern design practice, especially when reflecting that flight with our three-engine airplanes was quite defective four or five years ago when one engine happened to fail.

Lastly, we may speculate as to the trend of future developments. The air drag of modern high-speed airplanes has reached the point where it approaches the frictional drag. The retraction of the landing gear leaves only the parts necessary for flying and storing the cargo, exposed to the air. Any increase in required space for useful load or fuel capacity entails increased head resistance, which spells increased drag. The most important problem will be

---

*Aeroplane, vol. 45, 1933, pp. 857-858.

**First stages of taxying with two engines.

to find ways and means to house the loads consistent with minimum expenditure of frontal drag.

The power plant promises further improvements. The use of booster compressors, whether as "mixing fans" or moderate superchargers, at take-off is consistently increasing. And it is not at all impossible that within a few years the use of supercharged engines with exhaust turbines may become universal. Such engines hold out promises for markedly improved weight performances (reference 15), their dependability after sufficient trials will probably not be inferior to the engines of today. Another very effective means of raising the speed of supercharged engines is to fly at high altitudes. The maximum speed of an airplane for equal engine power increases approximately as the cube root of air density. At 6 km (19,685 ft.) height this means an increase of around 25 percent. In his interesting speech before the W.G.L., November 6, 1933, (reference 16) on the HE 70, Dr. Heinkel showed a graph (fig. 23) which illustrates the effect of engine power and full pressure height on the maximum speed. Some of the United States air liners already utilize this method. (See table I.)

The effect of this speed increase on the commercial performance is reduced by the wind which at first increases with the altitude, but gradually slackens beyond the boundary of the stratosphere (at 11 km). However, the speed of the airplane increases consistently with altitude, so that no real gain may be anticipated except in the stratosphere (reference 17).

## REFERENCES

1. Schröder, Th.: Z.V.D.I., vol. 76, 1932, p. 620.

2. Giacomelli, R.: Ingegnere, vol. 7, 1933, p. 376.

3. Pollog, C. H.: Der Weltluftverkehr, Leipzig, 1929.

4. Schrenk, M.: Entwicklungsrichtungen im gegenwärtigen Flugzeugbau. Z.F.M., vol. 24, 1933, pp. 273-279.

5. Hood, Manley J., and White, James A.: Full-Scale Wind-Tunnel Research on Tail Buffeting and Wing-Fuselage Interference of a Low-Wing Monoplane. T.N. No. 460, N.A.C.A., 1933.

6. Everling, E.: Z.V.D.I., vol. 77, 1933, pp. 1197-1200.

7. Weidinger, Hanns: Liquid Cooling of Aircraft Engines. T.M. No. 649, N.A.C.A., 1931.

8. Schrenk, M.: Über den Oberflachenwiderstand bei Flugzeugen. Z.F.M., vol. 19, 1928, p. 208.

9. Dearborn, Clinton H: The Effect of Rivet Heads on the Characteristics of a 6 by 36 Foot Clark Y Metal Airfoil. T.N. No. 461, N.A.C.A., 1933.

10. Gruschwitz, Eugen, and Schrenk, Oskar: A Simple Method for Increasing the Lift of Airplane Wings by Means of Flaps. T.M. No. 714, N.A.C.A., 1933.

11. Pleines, W.: Deutsche Flugzeugmuster für Sport und Reise. Z.V.D.I., vol. 76, 1932, pp. 949-957.

12. Pleines, W.: Die Flugzeugmuster des 3. Internationalen Rundfluges 1932, Z.F.M., vol. 23, 1932, pp. 563-577.

13. Wood, Donald H.: Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. Part I. Thick Wing - N.A.C.A. Cowled Nacelle - Tractor Propeller. T.R. No. 415, N.A.C.A., 1932. Part II. Thick Wing - Various Radial-Engine Cowlings - Tractor Propeller. T.R. No. 436, N.A.C.A., 1932.

14. Rohrbach, K.: Das 1000 PS-Verkehrsflugzeug der Zeppelinwerke in Staaken, Z.V.D.I., vol. 65, 1921, pp. 591-594.

15. Hansen, A.: Thermodynamische Rechnungsgrundlagen der Verbrennungskraftmaschinen und ihre Anwendung auf den Höhenflugmotor, V.D.I.-Forsch. No. 344, Berlin, 1931.

16. Schrenk, M.: Z.V.D.I., vol. 77, 1933, p. 1330.

17. Schrenk, M.: Probleme des Höhenflugs. Z.F.M., vol. 19, 1928, pp. 466-473.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

## TABLE I

Single-Engine High-Speed Transport Airplanes

| Type | Engine, hp. | Total weight kg | Pay-load % | Wing load kg/m² | Seating capacity | Top speed km/h | Source |
|---|---|---|---|---|---|---|---|
| Heinkel HE 70 | BMW VI 670 hp. | 3350 | 31 | 92 | 5 | 377 | DVL* tests |
| Junkers Ju 60 | BMW-Hornet 525 hp. | 3100 | 32.3 | 89 | 6 | 280 | manufacturer |
| Lockheed Orion | Wright-Cyclone 580 hp.(?) | 2450 | 33.5 | 90 | 4 | 360 | Swisse Aero-Revue vol. 7, no. 51, 1932 |
| Northrop Delta | Wright-Cyclone 710 hp. at 2 km height | 3160 | 41.5 | 94 | 8 | 355 at 2.4 km height | manufacturer |
| Northrop Gamma (for Hawks) | Twin-Whirlwind 730 hp. at 2 km height | 3000 | - | - | special purposes | 400 | Interavia no. 62, 1933 |
| Airplane Development Corp. V-1A | Wright-Cyclone 710 hp. | 3850 | 37.5 | 108 | 8 | 375 | manufacturer |

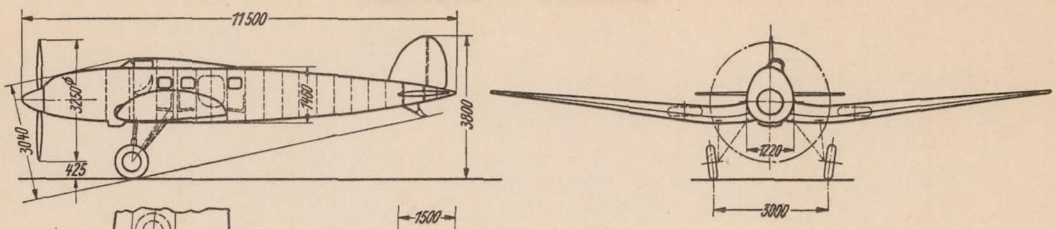
*Deutsche Versuchsanstalt für Luftfahrt, Berlin-Adlershof.

km x 0.62137 = mi.   $kg/m^2$ x 0.204818 = lb./sq.ft.   kg x 2.20462 = lb.

TABLE II

Multi-Engine High-Speed Transport Airplanes

| Type | Engine, hp. | Total weight kg | Useful load % | Wing load $kg/m^2$ | Seating capacity | Top speed km/h | Source |
|---|---|---|---|---|---|---|---|
| Fokker F 20 | 3 Wright-Cyclone<br>3 × 640 hp. | 8850 | 39.5 | 92 | 12 | 300 | manufacturer |
| Dewoitine D 332 | 3 Hispano-Suiza 9 V<br>3 × 575 hp. | 9350 | 42.5 | 97 | 8(?) | 300 | Interavia, 1933, No. 47 |
| Boeing 247 | 2 Pratt & Whitney Wasp<br>2 × 550 hp. | 5950 | 36 | 76 | 10 | 290 | manufacturer |
| Douglas Airliner | 2 Pratt & Whitney Hornet<br>2 × 700 hp.<br>at 2 km height | 7950 | 32 | 91 | 14 | 338<br>at 2 km height | Aeroplane, v. 45, 1933<br>p. 857 |
| Pander S 4 | 3 Wright-Whirlwind<br>3 × 420 hp. | 5500 | - | 125 | crew of 3 & mail | 360 | manufacturer |
| Lockheed "Electra" | 2 Wasp "Junior"<br>2 × 420 hp.<br>at 1.5 km height | 4080 | 39.5 | 96 | 10 | 345<br>at 1.5 km height | manufacturer |



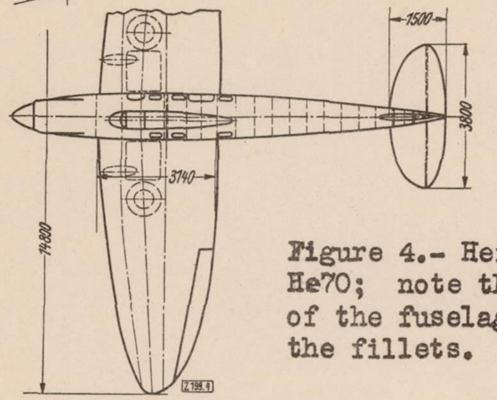




Figure 4.- Heinkel He70; note the lines of the fuselage and the fillets.

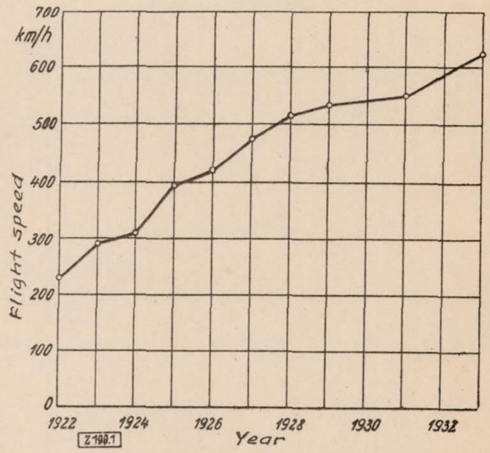



Figure 1.- Record speeds of the Schneider trophy races over a 300 km course. The (1933) figure, while not obtained during the race, was reached with a 1931 entry.

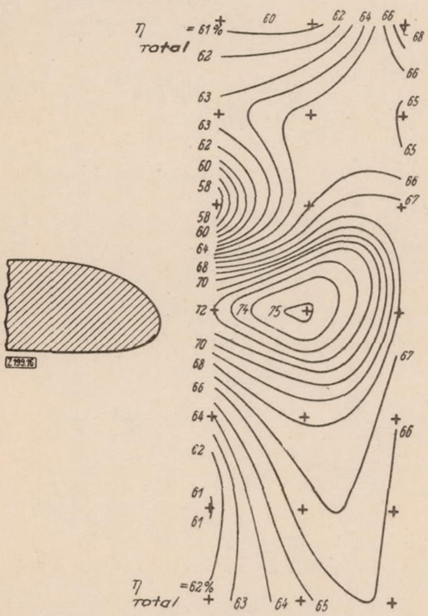



Figure 16.- Propeller efficiency at high speed for different engine installations forward of the wing. The + denote the individually recorded positions of the propeller; the curves represent lines of equal total efficiency (mutual interference included). A radial engine model with N.A.C.A. cowling was mounted aft of the propeller. The best position is: propeller axis at mid-profile heigth.

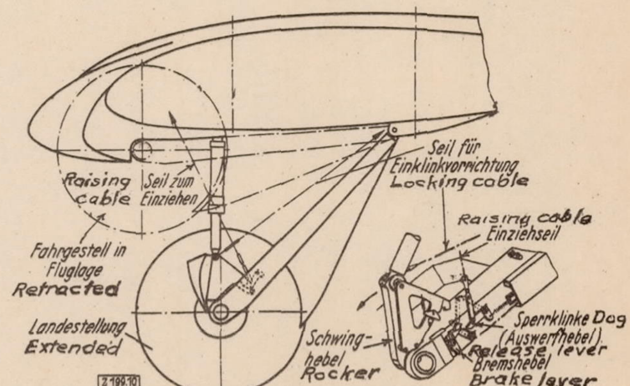



Figure 10.- Retractable landing gear on the Junkers Ju60. The wheels are pulled up forward and retract half in the wing, thus preventing damage to airplane in case the lowering mechanism locks.

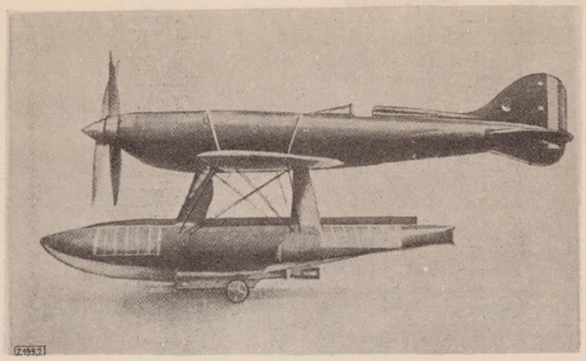


Figure 2.- Italian racer: Macchi-Castoldi MC72 holder of the last record shown in Figure 1.

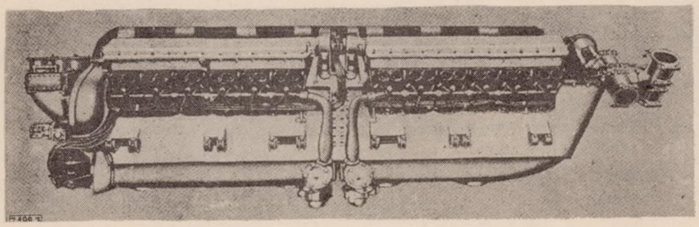


Figure 3.- Power plant: Fiat AS6 of the MC72 of 2800 hp.

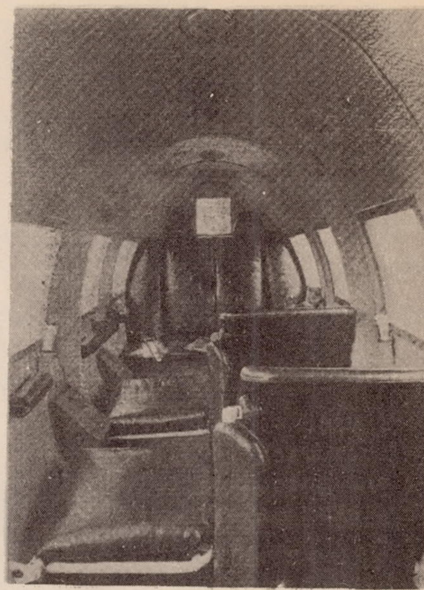


Figure 5.- Passenger cabin of Junkers Ju60, which is comfortable and quite roomy despite the narrow space.

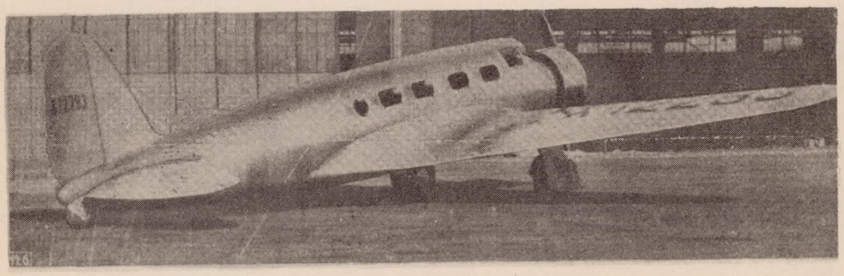


Figure 6.- Eight seat high speed transport V-1R of the Airplane Development Co.;note the wing fillet and the retractable landing gear.

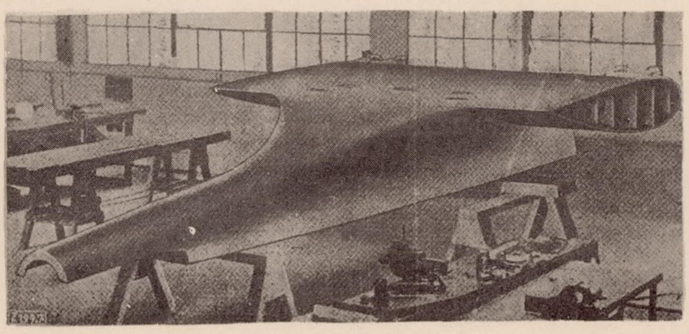


Figure 7.- Wing fillet of Northrop Delta.

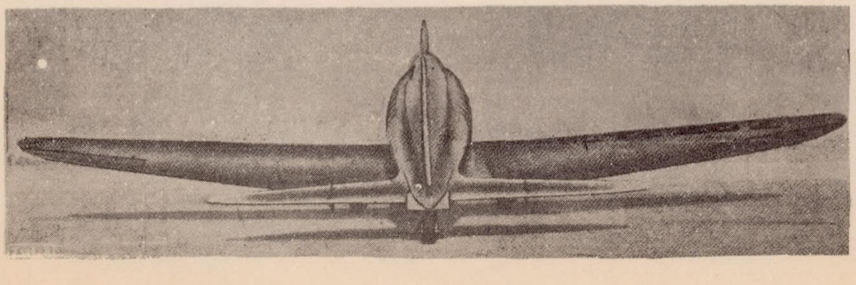


Figure 8.- Rear view of Northrop Delta showing the remarkable fuselage design.

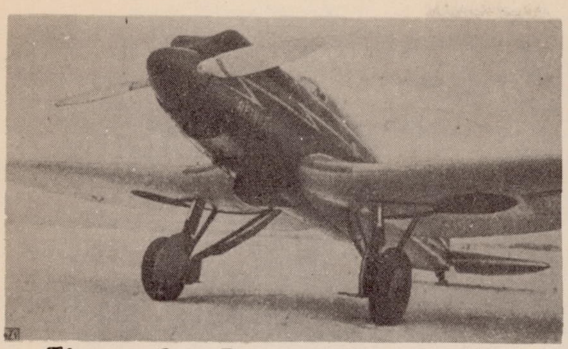


Figure 9.- Retractable landing gear of the He70; note the fairing plates.

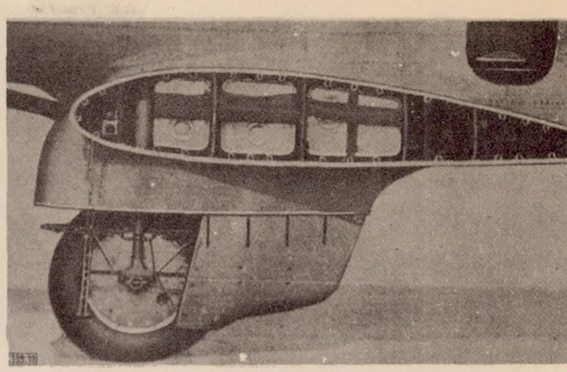


Figure 11.- Landing gear and wing stubs of Northrop Delta. Wheel and struts are streamlined. The wing design and the fuel tanks are clearly visible.

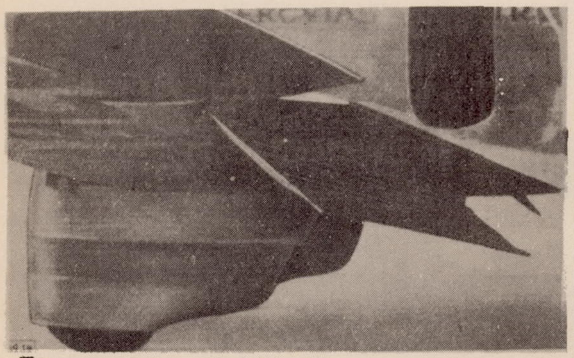


Figure 14.- Split-flap arrangement on the Northrop Delta. The flap extends only as far as the very small aileron, so as not to affect its efficiency.

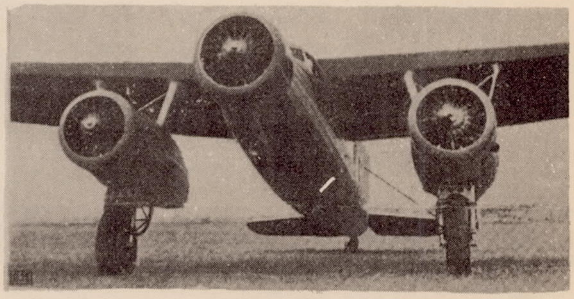
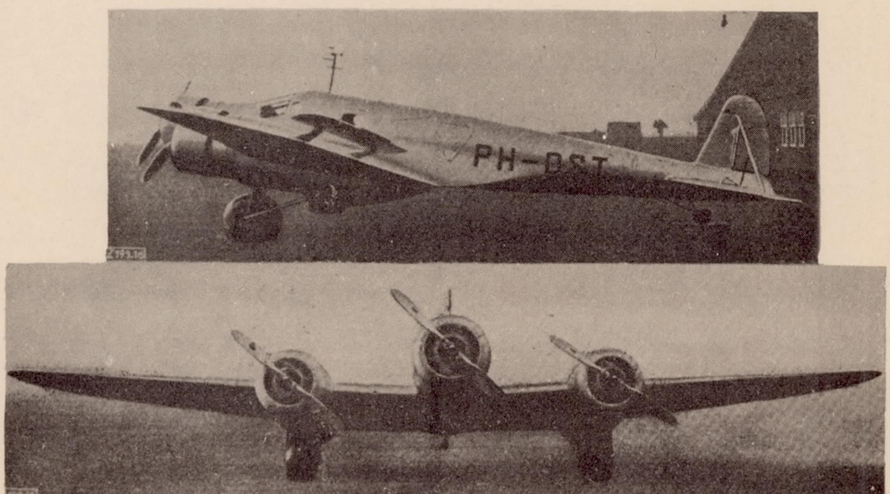


Figure 15.- 3-engine Fokker F 20. The wheels retract in the engine nacelles.



Figures 18,19.- 3-engine mailplane Pander S 4. Wheels retract in engine nacelles, trailing edge flaps with upper-surface ailerons. With a crew of 3 it is to fly the 14,000 km (8,699 mi.) at 8,700 m (28,543 ft.) between Holland and Holland-India in 3½ days.

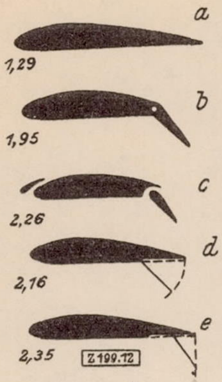



Figure 12.- High-lift devices. The normal profile (a) is fitted with a flap (b), whose effect is amplified by slots (c). Another form is the split flap (d), and in particular the "Zap" flap (e). The maximum lift coefficients given are only comparative on account of the low Reynolds Numbers of the tests (R = 600,000). From Flight, vol.25, 1933, p. 870.

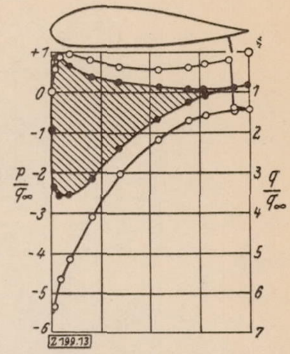



Figure 13.- Pressure distribution on a split-flap wing; the dots denote the pressure distribution for the normal wing, the circles that of a wing with split flap, hinged at 10% chord from the trailing edge of the wing. The pressures are converted to dynamic pressure 1.

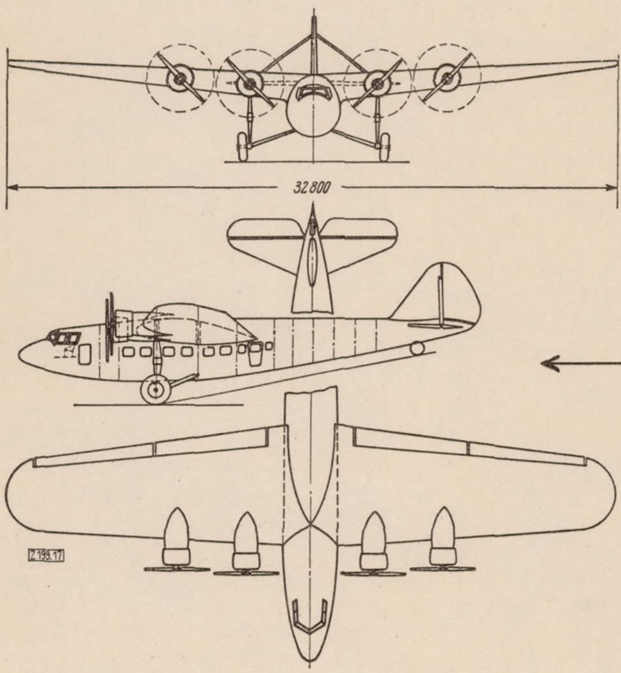
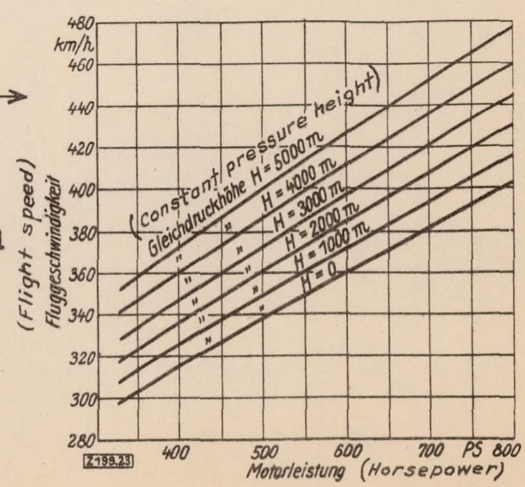



Figure 17.- 4-engine Fokker F 36 (design). Full load: 15.3 t (33,730 lb.) maximum 16 t, (35,274 lb.), useful load 40%. Power plant: 4 x 650 hp., maximum speed 260 km/h (161.6 m.p.h.), 32 passengers; wing loading 89 kg/m$^2$ (18.23 lb./sq.ft.) trailing-edge flaps. (Manufacturers data).

Figure 23.- Speed of Heinkel He70 compared with different engine performances at different altitudes with suitable supercharged engines the performance of the He70 could be raised considerably. The figures are converted according to the ground performances during the D.V.L. test flights. (gross weight a = 3,350 kg)(7,386 lb.). (m x 3.28083 = ft.)



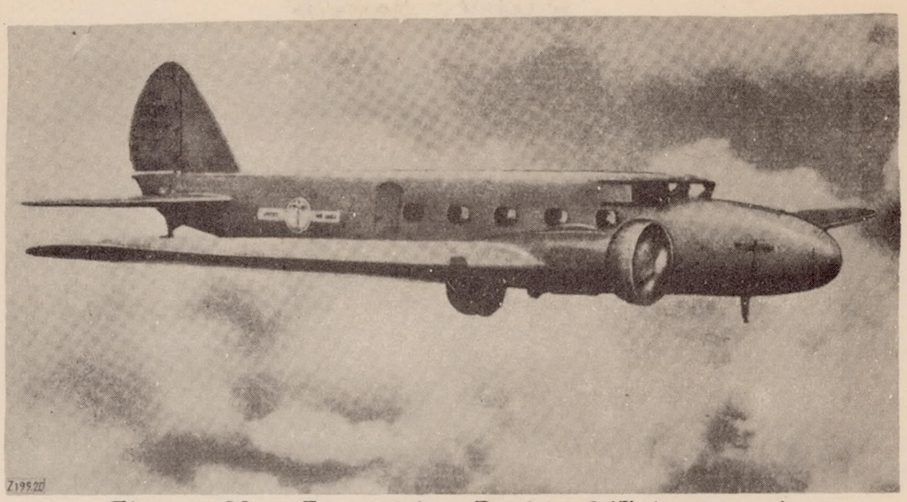


Figure 20.- Two-engine Boeing-247 transport plane. Note the clean engine installation; the wheels retract partways in the wing.

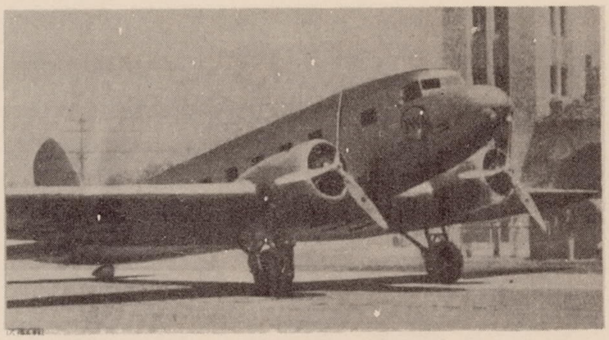


Figure 21.- Two-engine Douglas "Airliner"; largest twin-engine transport plane. The wheels are fully retracted.

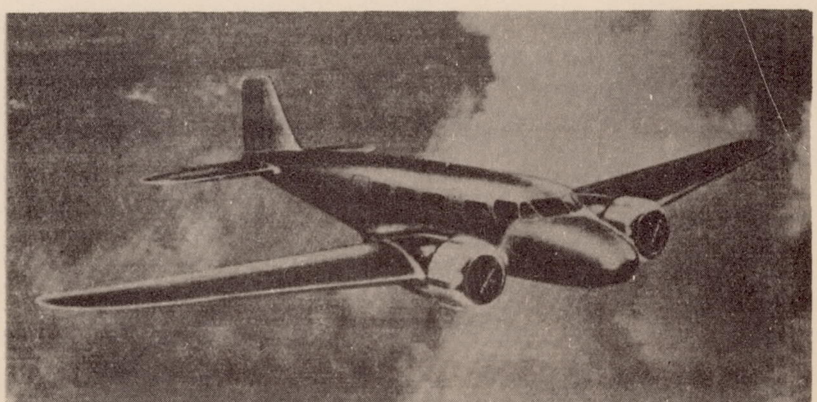


Figure 22.- Lockheed "Electra", the fastest airplane of its type.