MODERN COAL-MINING MACHINERY

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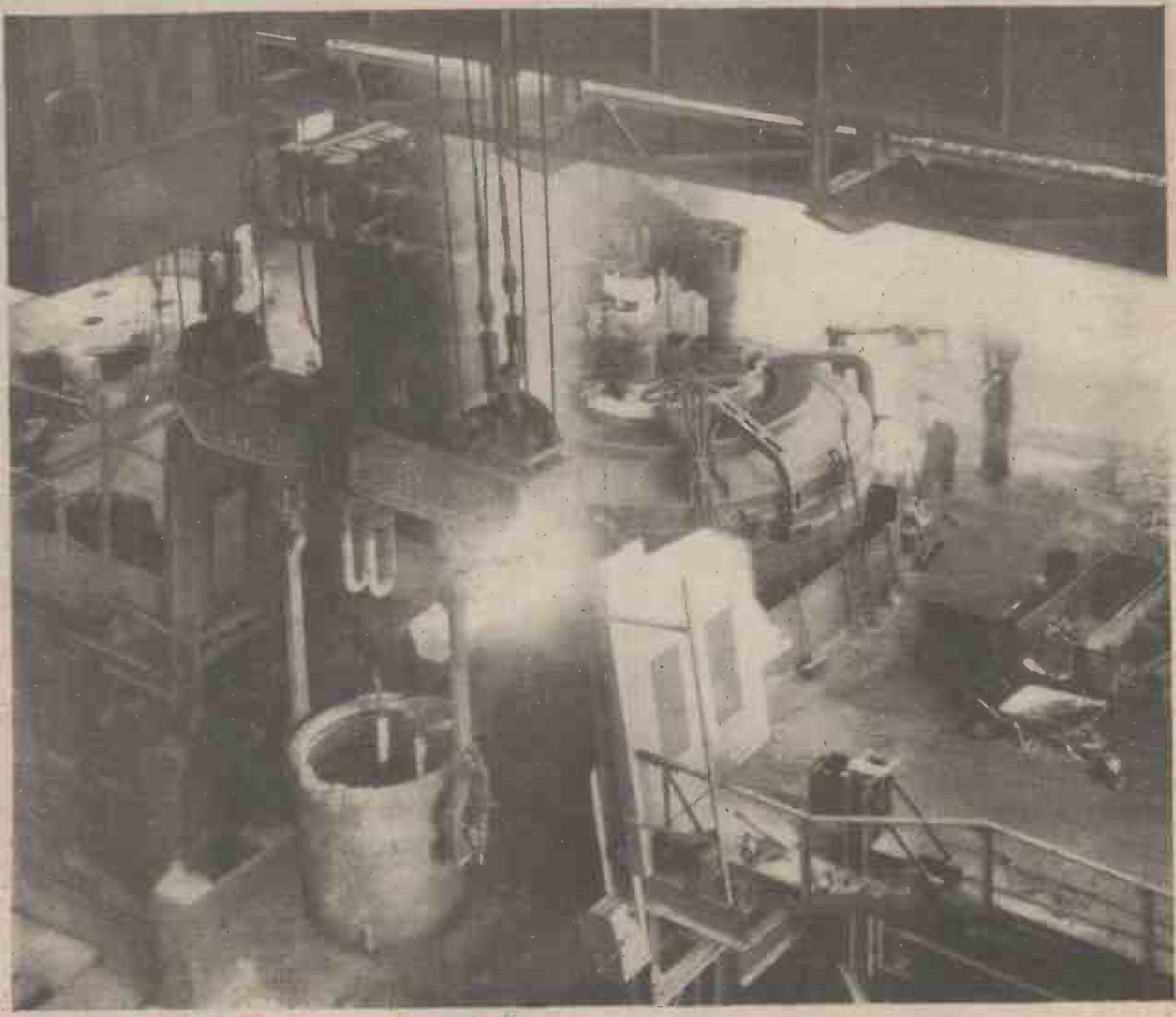


Rocket Propulsion

The Super-sonic Aircraft : Atomic Propulsion

By K. W. GATLAND

(*Continued from page 95, December issue*)

NOT only did the society's investigations cover the practicability of abstracting boundary layer by the suctional effect of the rocket exhaust, but a scheme was also developed by which it was intended to increase the mass delivery to the propulsor by the incorporation of a compressor. The improved induction, of course, would have its result in a more efficient abstraction of the boundary layer.

The compressor is driven directly by an internal thrust-turbine, connected on a common shaft, the system being a derivation of the thrust-feed turbine unit (Fig. 44), discussed earlier. In this instance, however, the propellent feed is effected by the incorporation of an auxiliary power motor and pump.

The original layout provided a light petrol reciprocating unit for this purpose, but it is now considered more desirable, in view of the V2 development, to use a light H^2O^2 superheated steam turbine.

The propulsion unit proposed is shown diagrammatically in Fig. 47. The four principal advantages of the "thrust-turbine" power unit over the exhaust-turbine motor can be set down as follows: (a) reduced risk of erosion and "burn-out" of turbine; (b) absence of rotor in gas stream allows improved velocity and conformity of exhaust flow; (c) the injection system provides a true "concentric-feed" arrangement, and facilities a better mixing of the propellent and (d) transmission losses are at a minimum.

The thrust-turbine/compressor unit, besides its use in an augmented rocket system is, too, suitable for adaptation in a light thermal-jet motor. A unit designed on these lines for model research is shown diagrammatically in Fig. 48.

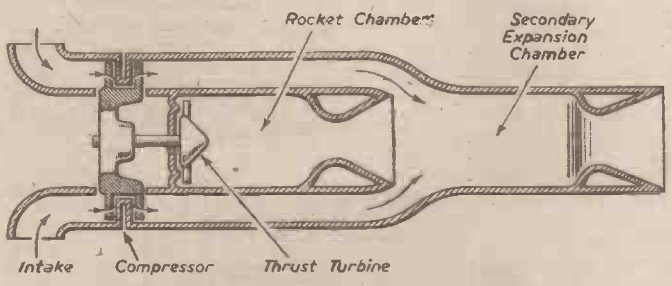


Fig. 47.—Diagrammatic illustration of the thrust-turbine/compressor air-augmented rocket unit.

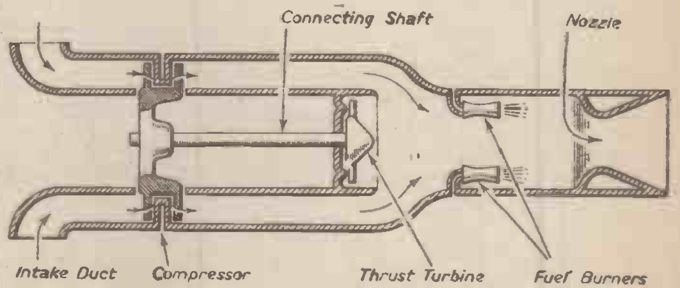


Fig. 48.—Diagram showing the thrust-drive turbine in a thermal-jet propulsor arrangement.

More General Observations

The remaining essential advantages the rocket powered aircraft would appear to hold over all other forms of propulsion are summarised in the accompanying schedule.

(1) The power is applied in "direct reaction," there being no frictional transmission losses. (2) Advantages are presented with respect to altitude. Whereas contemporary power systems require atmospheric air to support combustion, the rocket system functions independent of the atmosphere, and, indeed, operates at maximum efficiency within a vacuum. (3) Owing to the improved thrust/weight ratio, the rocket system lends admirably to complete submergence, and facilitates a reduction in aerodynamic drag. It would, for instance, be ideal in an all-wing layout. (4) The less weight and greater simplicity of the power plant allows reduced installation space for a given thrust H.P. (5) The rocket motor functions without vibration, and torque is virtually eliminated. (6) It is capable of operating at maximum propulsive efficiency almost immediately after ignition. (7) The absence of an airscrew, as with the thermal-jet machine, enables the rocket aircraft to be of low build. (8) Location of the propulsor enables a better position of the pilot. (9) The simplicity of the rocket motor facilitates servicing and maintenance, and (10) it is a possibility to combine the thermal-jet and rocket systems, allowing independent function. A rocket propulsor, for instance, would be most desirable for accelerating a heavily laden aircraft into flight. This would allow a greater wing-loading due to an increased weight of fuel than would normally be possible for take-off. Another scheme might be the operation of the "jet" system up to its maximum effective ceiling, and the use of a rocket component above this region.

The Super-sonic aircraft

The question of aircraft flight in the ballistic speed range involves another limiting factor.

At super-sonic velocities there are not only profile drag and induced drag to be considered, but also a wave resistance which arises from an approach of the air speed to the speed of sound. When this limit is reached the air flow suffers a sudden change in character due to compressibility which has effect in an increase of the pressure and density, with accompanying severe increase of drag, and, in the case of an aerofoil, decrease in lift.

This problem of air compressibility is an aerodynamic phenomenon with which the propeller designer has had to contend for years. It has resulted in a limiting of the tip speed and the development of large area, thin section blades, which permit a low angle of attack. Despite these refinements, however, a compressibility wave is sometimes formed at the tip of the propeller blade, because the tip travels a great deal faster than the aircraft, due to its rotary and forward motion.

Reinhold Tiling during a demonstration of his folding-wing rocket aircraft at Hanover, Germany, in 1931. They were powder fuelled and capable of rising to heights varying from 1,500 to 2,500ft. ("Practical Mechanics," July, 1945, page 343.)

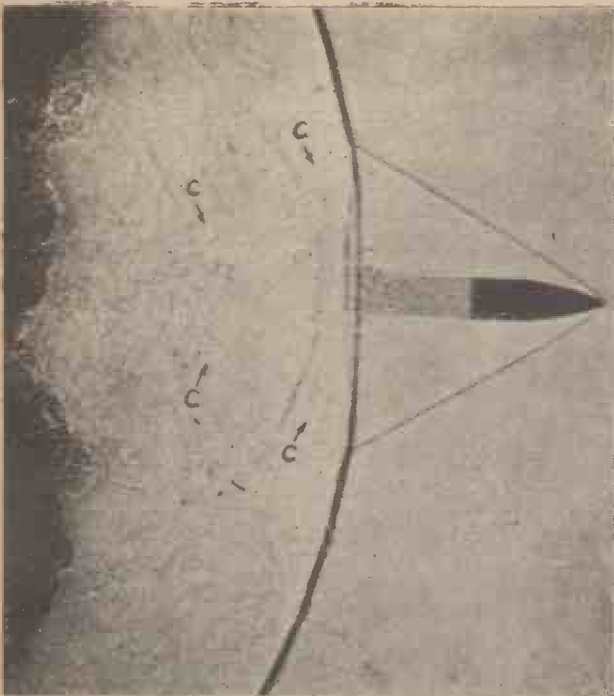
Shortly before the explosion which caused the inventor's death in 1933, Tiling had announced his intention of building similar rockets to span the English Channel.

The designer of fighter aircraft, too, has need to be conscious of compressibility. In present-day machines this takes the form of what we may term "local compressibility," which is common where contour changes occur. The speed at which the air flow changes is termed the "critical speed." This is normally lower than the sonic velocity, because the local air speed relative to the body may have attained this value at some points of the surface.

Ballistic Research

Experiments with shells and bullets have provided valuable empirical data, which, in many ways, is useful in investigating the problems of super-sonic aircraft motion.

In this research, screens are arranged in the firing path so that, as the projectile passes though, its time at each stage can be recorded. Thus it is possible to obtain



Photograph of a bullet in flight, showing compression waves. The bullet is 11in. from the gun muzzle—a .30 calibre Springfield rifle was used in the experiment—and, travelling in the region of 3,000ft. per second, has outdistanced the discharge waves. Note the deflection of the conical bow waves in the explosion wave area, indicated by the arrows "C"; also the stray powder particles which have created compression waves on their own account. (*Taken by P. P. Quayle, of the American Bureau of Standards*). *Courtesy of Kodak, Ltd.*

the velocity at each section by process of differentiation, and further differentiation, also with respect to time, will yield a figure for the acceleration at each section. This acceleration will, of course, be negative, and after the effects of gravity have been taken into account the final result will be the retardation due to air resistance.

Some interesting points arise from the figures thus obtained. Firstly, it is found that the drag is dependent upon several variables, and in the case of bodies moving with a velocity less than that of sound it is given by the formula of aerodynamics, namely:

$$D = kd.\ p.\ S.\ V^2.$$

where kd is the shape coefficient, p is the specific mass of the air, S is the maximum cross-sectional area of the body, and V is the velocity at which the body is travelling relative to the air.

Since we are taking the case of super-sonic motion, it is necessary to add a further coefficient to the equation. In experiment it has been found that this coefficient is constant at unity until the sonic velocity is approached. Its value then increases rapidly and reaches a maximum value of approximately 3.3 when V/v_s is just greater than unity. Since V/v_s increases beyond unity, the value of the coefficient falls, until it may again be regarded as a constant for velocities of over five or six times that of sound. The value of the coefficient will then be in the region 2.3 to 2.5, and the equation for drag can then be rewritten as:

$$D = kd.\ K.\ p\ S.\ V^2$$

Having shown that the value of the coefficient K is dependent upon the ratio between the velocity of the projectile and that of sound, it now remains to ascertain the values of the other terms of the expression.

When S represents the maximum cross-sectional area of the body, the other coefficient kd is found to depend upon the shape of the body. For a spherical shape it is approximately .106, reducing to .047 for a streamline body. Between these values there are, of course, very many others for diverse shapes, and the exact value for a given body will need to be found by means of wind-channel tests.

The remaining term, p, represents the specific mass of air at the place considered, and for varying heights it is found to follow an exponential law:

$$ps = p_0.e^{-h.s}$$

where p represents the specific mass at zero altitude, s is the height in metres, and h is a variable coefficient dependent upon s.

The form of the air flow about a projectile travelling at super-sonic velocity is shown in the accompanying photograph. It can be seen that a compressibility region is built up at the nose of the body. Because of this the oncoming air has a denser region to traverse, and instead of passing evenly over the body the flow takes the form of hyperbolic sound waves, originating a short distance from the nose. This compression wave initially moves with the speed of the body, and in reducing to normal sub-sonic values produces the "bow wave" which constitutes the main drag. The curvature of the wave is indicative of the compressibility flow, and the velocity is damped exponentially, as shown by the straightening of the compression curve and its gradual dissipation to sub-sonic values.

Fig. 49—Sänger "super-sonic" wing section.

There is, in addition, a sound wave produced by the rear of the body due to rarefaction.

The above, of course, is only the barest outline of the problems involved, and that only in so far as the body shape is concerned. There is yet the effect of compressibility on the aerofoil surfaces to consider.

Compressibility and the Aerofoil

The *wave resistance* is independent of the aspect ratio, and both the induced drag and the wave resistance are proportional to the square of the lift, depending on the Maché number (ratio of flight velocity to sound velocity). As a general observation, the greater proportion of the total drag in super-sonic flow for normal aspect ratio is due to wave resistance, while the induced drag represents only a small proportion of the total.

The aerofoil theory at super-sonic velocities is virtually opposite to that employed in the sub-sonic range. Whereas at sub-sonic speeds a relatively blunt contoured nose secures the most efficient results, the super-sonic aerofoil demands a knife-edge nosing.

At ballistic speeds, the body with the greatest penetration from the aerodynamic point of view is the flat plate of infinitely small thickness. The hyperthetic case for two dimensional frictionless flow can be expressed:

$$\text{Lift Coefficient} = C_L = \frac{4}{\sqrt{\left(\frac{V}{a}\right)^2 - 1}}\,\alpha$$

where V is the flow velocity; a, the sound velocity; V/a, the Maché number in the undisturbed field, and α, the angle of incidence, assumed small.

The resistance coefficient, under these same conditions, is given by:

$$C_D = C_L\,\alpha$$

and in the case of frictionless flow, the gliding coefficient is thus independent of the Maché number, as:

$$C_G = \frac{C_D}{C_L} = \alpha$$

These simple equations are adequate to illustrate the case, but the actual calculations involved in super-sonic *aerofoil* theory, as might be expected, are considerably more involved. This subject is naturally beyond the scope of the present writing, and the reader desiring further information is referred to the specialised papers and books which have become generally available in recent years.

The super-sonic flow thus demands an entirely original aerofoil shape, and the most practical form has been found in the development of a conical section, the drag of which decreases as the apex angle is reduced. A super-sonic section accorded on these lines is shown in Fig. 49. It will be seen that whereas in the sub-sonic aerofoil every effort is made to reduce turbulence by maintaining a sharp trailing edge, the opposite is the case for super-sonic flow. A necessary quality at high speed is that the wing should be thin with the maximum thickness well aft. This is because the compressibility flow will always break away from the surface shortly behind the mid-section of the aerofoil, involving the trailing edge in pronounced rarefaction.

The outline form of a super-sonic rocket aircraft as envisaged by Dr. Eugen Sänger, the reputed Austrian engineer, is some indication of the practical application of these principles. The illustration (Fig. 50) is taken from an investigation of super-sonic 'plane motion, which Sänger carried out during the early 1930's, and included in this are detailed calculations relating to the proposed trajectory for such a machine. Because of the need for gaining maximum distance and

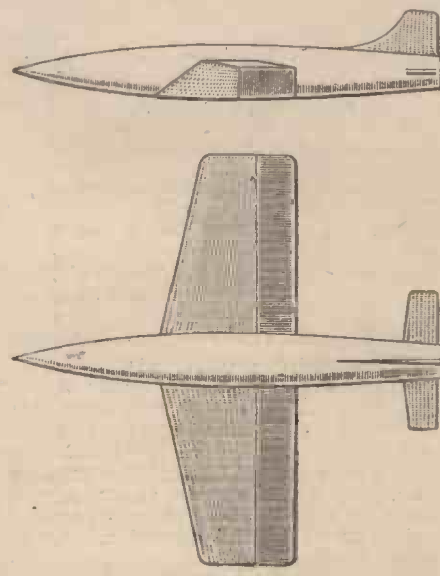


Fig. 50.—An impression of the super-sonic rocket aircraft suggested by Dr. Eugen Sänger, Austria (1933).

height within the shortest space of time, an ascent angle of 30 deg. is maintained until the desired height is reached. The machine is then levelled out and the motors "cut," allowing the balance of the journey to be made under momentum, the 'plane gradually losing speed and altitude until the destination is reached.

The conclusions arrived at provide a firing time of about 20 minutes, and a flight duration of approximately 70 minutes at an average speed of 1,600 miles per hour.

From the foregoing it is clear that no reasonably efficient aircraft can operate both below the ballistic velocity as well as above. The super-sonic aircraft must therefore be designed essentially for flight at ballistic velocities, and no account given to its operation at lower speeds.

It is obvious, therefore, that the engine/propeller combination is immediately precluded from operation in the true ballistic speed range. A substantial problem would be the provisioning of sufficient thrust to operate an aircraft against the drag at such speeds, and as we have already observed, the conventional propeller is the first to be influenced by compressibility. It is obvious that the super-sonic propeller blade section is not a practical solution for a variety of reasons.

Thermal-jet Aircraft

The prospect is much improved by the thermal-jet aircraft, as we have already seen in the record-breaking trials of the Gloster Meteor. With further developments in jet-propulsion we may confidently expect still closer approaches to sonic values, and it is not unlikely that the jet-compressor will ultimately allow speeds in excess of sound. The powers that will be required to overcome the vast increases in drag, however, will be out of all proportion to those required to gain a few extra m.p.h., at more moderate speeds, with fuel consumed at profuse rate. It is possible, in fact, that the true rocket aircraft may be a more reasonable comparison at ballistic velocities.

Whatever its means of power, however, the super-sonic aircraft will involve several further design headaches; principally, the investigation of the stresses subject to the wings and airframe, but perhaps, more particularly, the attainment of adequate flight control.

In travel above this speed region the rocket aircraft—even if designed along the correct principles of ballistic motion—would nevertheless operate far below a practical working efficiency. Clearly, the atmosphere is the chief barrier to further substantial progress in this direction, and remembering that the rocket engine is at highest efficiency when functioning in vacuum and at high speed, an alternative worthy of serious investigation is the true projectile craft.

Atomic Possibilities

The harnessing of atomic energy, however, can be expected to alter this picture completely. With atomic reaction motors, the flight of large aircraft near the velocity of sound, and capable of travelling to any part of the earth without need for refuelling, would be commonplace.

The size of present aircraft is limited by the engine powers available and the arrangement of the airframe. Larger and more powerful aircraft are already well advanced in design as the result of the recent great strides in thermal-jet propulsion, but the largest aircraft that is ultimately possible using jet-power would obviously be small, and its performance far less effective than the machine powered by atomic reaction.

The "All Wing" Layout

The conventional fuselage and cantilever arrangement of wings and tail assembly are not suitable for dimensions above a certain practical limit which is approached in present designs.

In very large aircraft it becomes increasingly more necessary to spread the weight uniformly over the span.

It is therefore obvious that the "all-wing" shape is the ideal to be aimed at, not only because it is structurally more stable, but due to its improved aerodynamic efficiency. Estimates indicate that the flying-wing has from 33⅓ to 50 per cent. less drag than the conventional type, and this has its result in that considerably less power is needed to attain a given speed.

There seems no particular structural limit to aircraft which take this form, and it is likely that a further half-century's development will witness the accommodation of passengers and freight entirely within the wing section, and in numbers and weights to rival those of the smaller ocean liner.

This is an encouraging prospect, but we must not lose the perspective. It is possible that many years will elapse before the atomic reaction engine becomes reality, and as has already been stressed, there are likely to be many difficulties requiring solution between the experimental engine and its commercial counterpart. True, an "atomic engine" of sorts has already given promise of early development, but it is extremely crude and certainly not of great significance for use in aircraft.

This "atomic generator" employs the radio-active U-235 with admixture of graphite, which serves as a moderant and controls the rate of energy released. It is contained in a tank which is fed with water, and upon its bombardment with "slow neutrons," the substance becomes incandescent, the water acting to slow down the fast neutrons released and returning them to carry on the process. The atomic fission can hence be made to continue as a self-propagating reaction until the fission of all the substance has taken place. The water is rapidly condensed into steam energy, which is used either in driving a turbine or reciprocating engine.

Apart from the use of moderants, it is further possible to control the energy by sleeving the active substance with certain metals that the neutrons cannot penetrate, allowing only a small section to be exposed at a time.

This form of "atomic power" would be most suitable for electricity generating stations, ships, and perhaps even locomotives. It would require an entirely different arrangement to drive aircraft and road vehicles.

In these latter instances it is assumed that *direct reaction* arising from the fission of ultra-high-speed particles would provide the propelling force. This is a far less simple scheme than the atomic steam generator, and introduces problems of control and construction that may take many years to overcome.

(To be continued)

The Gloster Meteor

The Gloster Meteor jet-propelled aircraft which Mr. Eric Greenwood flew at 603 m.p.h. over the Herne Bay course recently.