PROPELLER TURBINES
SOME HANDLING AND CONTROL PROBLEMS

BY

LIEUTENANT-COMMANDER (E) COLIN RAWDEN, B.ENG., R.N.

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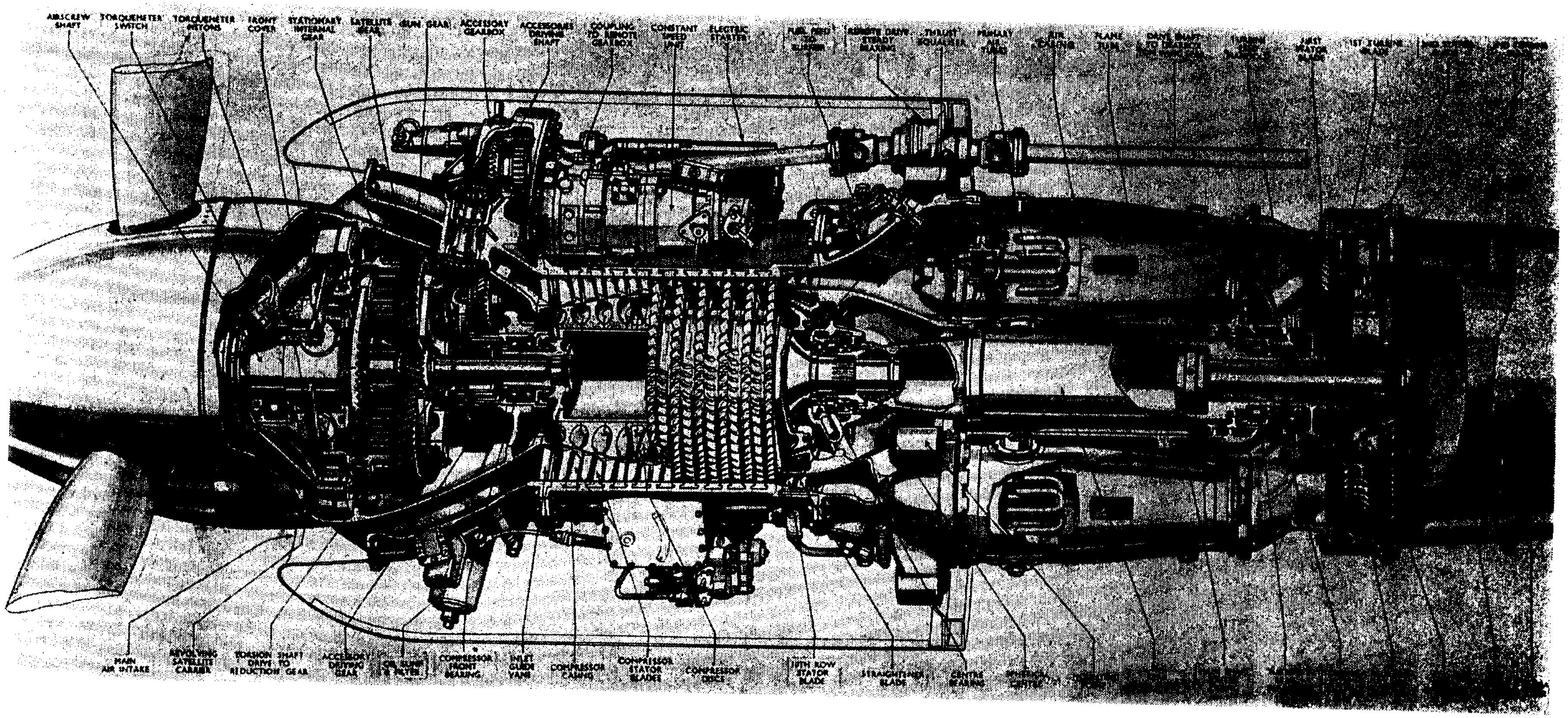
Integral Type Propeller Turbines

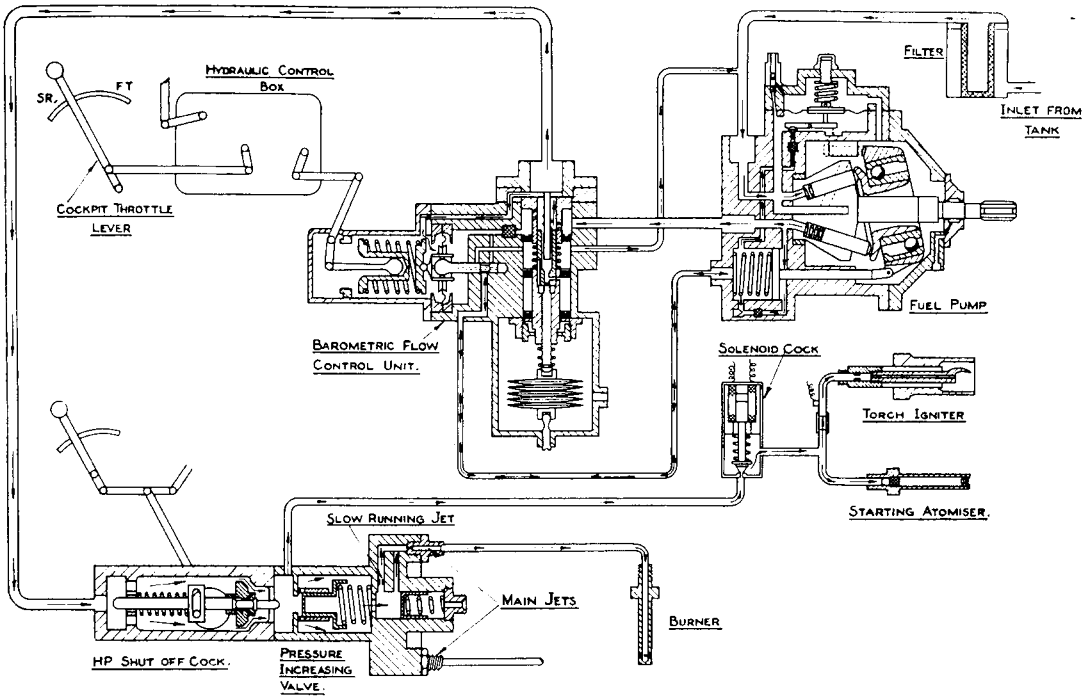
The Python and Mamba propeller turbines coming into the service in the Navy are of the integral type. That is to say the turbine and compressor are mounted on a common shaft, and this is directly coupled through the reduction gear to the propeller. The remarks in the following article, particularly as far as control is concerned, apply only to this type of engine. In the propeller turbine the amount of energy absorbed by the turbine is a very high percentage of the total energy in the jet stream from the combustion chambers, and the residual jet stream thrust is comparatively small. At a given speed the power produced by the turbine can vary within fairly wide limits, since a variable pitch propeller is fitted which can absorb varying power in accordance with blade pitch. Fuel flow varies accordingly and in fact defines the total power available. The proportion of turbine power absorbed by the compressor is very high and generally exceeds half the total, the remainder only being available to produce useful work via the propeller.

Throttle Response

One of the main fundamental differences between the propeller turbine and the piston engine is the greatly increased rotational inertia of the turbine. This is due partly to the greater mass of the moving parts but mainly to the much higher speed of rotation. Cruising revs. for Mamba are 14,500 r.p.m. and 7,800 for Python. The problem of power response to throttle immediately presented itself. In the case of engine acceleration a considerable delay resulted, because as engine revs increased most of the engine power was absorbed in accelerating the engine compressor and turbine rotor, and relatively little power became quickly available as propeller thrust. Conversely on sudden closing of the throttle deceleration of the engine rotor threw up power to be absorbed by the propeller, and in fact response was initially in the opposite sense. It was apparent that unless some new method of engine control were adopted, the degree of throttle response necessary for deck landing approach, and in particular the rapid power response in acceleration for the re-take off or wave off case, could not possibly be met. The important decision was therefore made to run the engine at constant r.p.m. throughout the power range except at the lower end for ground idling, and a small increase at the top end for take off or combat power. Engines of this type are known as " Constant Speeding Engines."



SECTIONED VIEW OF ARMSTRONG SIDDELEY " MAMBA "



PYTHON FUEL SYSTEM

Single Lever Control

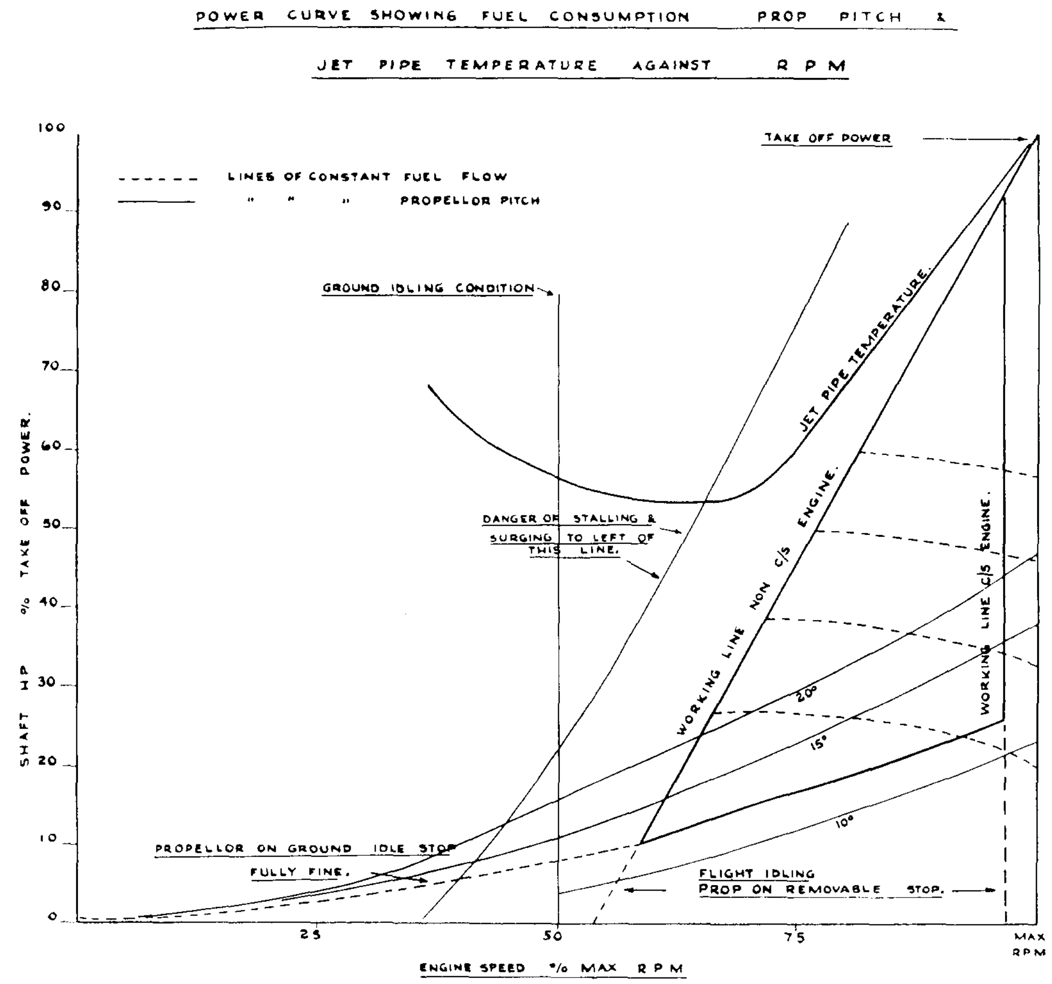
It had previously been decided to utilize the normal piston engine type of constant speed unit for controlling engine speed, in conjunction with the type of altitude compensated fuel control unit normally used on pure jet engines. Both of these units had already been subject to considerable development, and providing they could be made to work satisfactorily together a suitable method of control should result. The remaining major decision was that control should be effected by a single lever only.

Constant Speeding and Fuel Control

Now the term Constant Speeding Engine is something of a misnomer, since variations of power are still absorbed by changes of propeller pitch setting, which in turn are governed by fluctuations of speed of the C.S.U. To increase the power setting by movement of the control lever, it is not sufficient merely to increase the fuel flow. One has to coarsen the propeller pitch at the same time, and this is achieved by increasing the speed setting on the C.S.U., the immediate effect of which is to increase the revs. slightly, which is only permitted by an initial fining off of propeller pitch. Then the C.S.U. takes over and coarsens the pitch until the new increased power setting is absorbed. This cycle of events is unfortunate, since the first response to throttle movement is in the wrong sense, then there is a time lag before any increase of actual thrust is obtained, and a period of hunting takes place before the engine settles down to the new power setting. These undesirable effects are reduced if the throttle is moved very slowly, but this is incompatible with deck landing requirements. The solution to this problem was found as follows. Instead of directly linking the throttle lever both to the F.C.U. and the C.S.U. a device embodying a hydraulically operated delay mechanism was incorporated in the linkage between the two units. This is rather a complex device known as the E.C.U. or Engine Control Unit and hydraulic pressure is supplied from the engine oil feed. The effects of its operation are twofold. Firstly it reduces the C.S.U. setting below the actual speed of the engine, when increased power is demanded, and hence ensures that the immediate response is to coarsen the pitch, followed by a steady coarsening during power increase. Conversely a steady fining off of pitch takes place during shut down. Secondly, during increase of power the E.C.U. ensures that the fuel flow always lags slightly behind the demand, and during shut down, the decrease of fuel flow is slightly ahead of the instantaneous requirement. This ensures that any given instant during change of power, the fuel supply is never sufficiently excessive to cause increase of working temperatures in the turbine above those permissible. As a result of fitting the E.C.U. surging is almost entirely eliminated, rapid throttle movements can be permitted and quick transitions from thrust to drag conditions can be obtained. Tests with this system have shown results compatible with the most favourable piston engines. A slight penalty has been paid in that higher capacity C.S.Us. than normal have been found necessary to provide the high rates and wider ranges of pitch change.

Power—R.P.M.—Compressor Stalling and Jet Pipe Temperature

Let us now turn to some general considerations of propeller turbine characteristics based on a typical power curve shown opposite. Neglecting for the moment what has been said previously about constant speeding engines, it will be seen that owing to the fitting of the variable pitch propeller the speed of the engine could be varied independently of fuel supply, and in fact for any given power setting an infinite number of fuel delivery to engine speed relationships could be adopted. Furthermore, the specific fuel consumption remains practically constant at constant power, over a fairly wide range. The full power operating conditions are limited by the maximum turbine temperature, which in turn is defined by the mechanical properties of the blading under load at temperature, and of the turbine disc under heavy centrifugal loads. Turbine temperature is not easily measured under practical running conditions. However the temperature of the jet flow at any given point down stream of the turbine is always in constant relation to the turbine temperature and it has been found more convenient to measure the temperature of the jet stream by thermocouples, and relay this signal to an indicator in the cockpit. Hence the operating conditions of the engine are observed from this jet pipe temperature gauge. At the lower end of the speed range there is a minimum idling speed, below which the engine will not run properly. This speed is approximately half the maximum, and below these r.p.m. not only is the compression ratio of the axial compressor insufficient to produce any appreciable power, but there is danger of the compressor stalling or surging and in general working in an unstable and unsatisfactory fashion. Now the effect of stalling is very important. When the compressor stalls the mass flow of air through the engine is suddenly and drastically reduced. But the same amount of fuel continues to be fed in, temporarily at any rate, and the effect of this is to increase the working temperature very seriously. In extreme cases we are faced with the dismal and expensive prospect of distorted or molten turbine blades issuing from the jet pipe orifice. This phenomenon of stalling is a fundamental characteristic of the axial compressor, and may continue above idling speed some way into the lower end of the operating power range of the engine, especially when power demand is high in relation to r.p.m. Hence for any given shaft horse power developed, an operating speed is chosen which is well in excess of the possible stalling revs. This gives a safe margin for engine handling (or mishandling). Happily in the case of constant speeding engines,

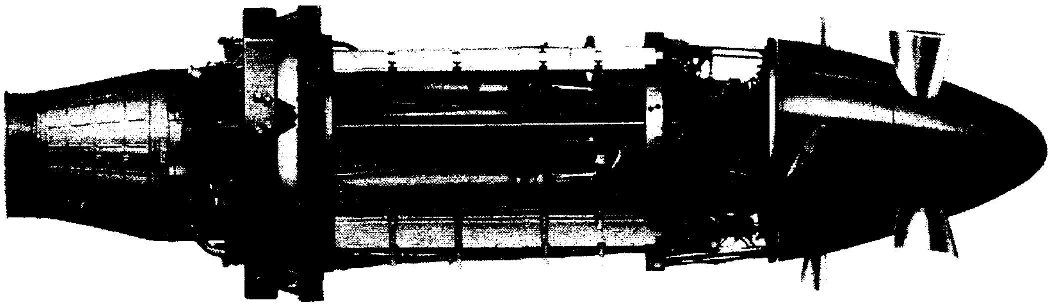


POWER CURVE

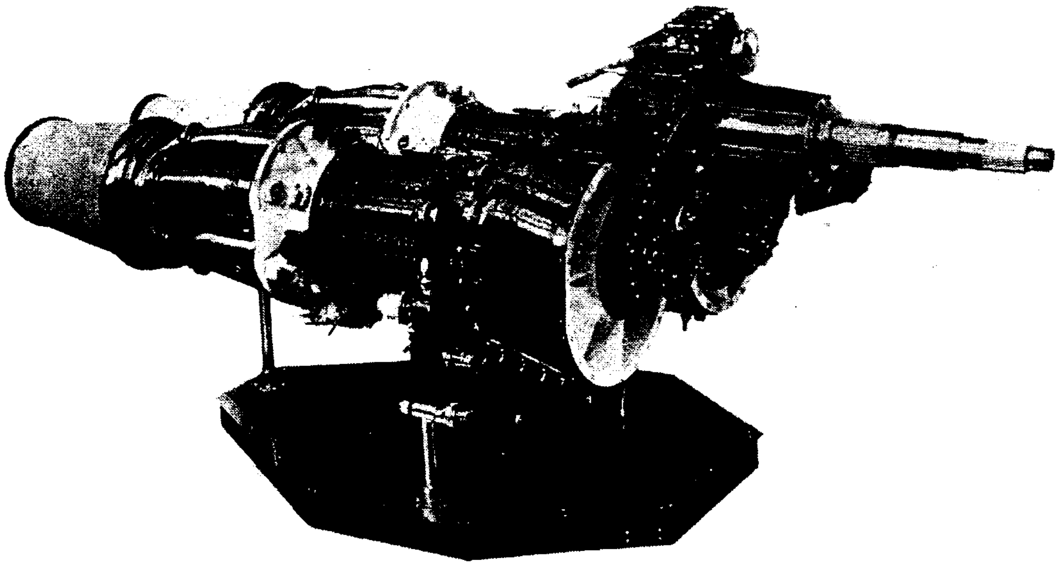
the high revs at the lower end of the power range, with the propeller in very fine pitch, and a low fuel setting, produce a safe condition, from the point of view of stalling and overheating. Before leaving this question, it may be pointed out that the danger of compressor stalling is of course greater at low air speeds, and particularly when starting up on the ground.

Torquemeter Gauge

In a propeller turbine aircraft there is little indication of the precise value of the power output at any moment, especially when the engine is of the constant speeding variety. Jet pipe temperature does give an indication, but this is not very accurate since power varies fairly widely with J.P.T. near the top end of the scale. Hence the torquemeter gauge is provided as a standard fitting instrument. This is operated from oil-filled statimeter cylinders, which actually react the torque in the reduction gear casing. The gauge gives a direct indication of shaft horsepower, and may be calibrated in torquemeter pressure, pounds per square inch, or in actual S.H.P. This is the instrument which corresponds most nearly to the boost gauge for a piston engine.



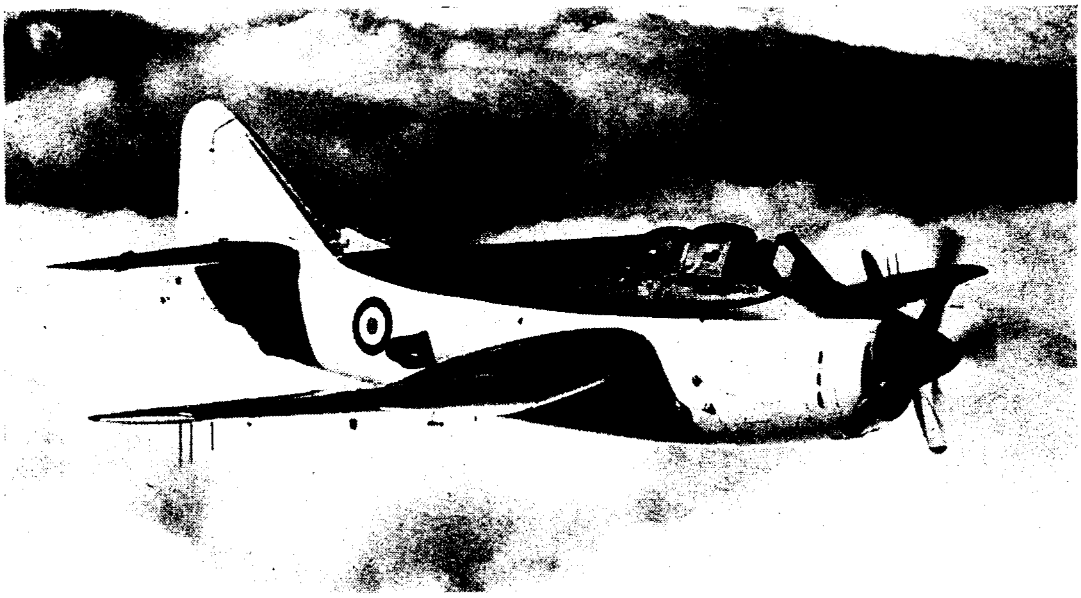
" PYTHON "—EXTERNAL VIEW



" DOUBLE MAMBA "—EXTERNAL VIEW

Starting

Starting is at present achieved by a displacement motor driven by compressed air, though in production aircraft the energy will be produced by an explosive cartridge. The amount of energy involved in starting is very considerable, and in order to keep the size of the motor and the period of accleration within reasonable bounds, the engine speed is not taken up to the full stable ground idling r.p.m. by external source of power. Hence after lighting up there is a period of acceleration of the engine to the idling speed, and this is obviously a period of danger from compressor stalling, especially if the throttle is opened too quickly, or if starting power is on the low side giving too low initial revs. The jet pipe temperature must be watched carefully at this stage and fuel supply cut off if the temperature shows signs of going too high. The problem of re-lighting in the air is less critical owing to the forward speed of the aircraft.



Fairey Gannet in flight, with one engine stopped. Tail of Jet Pipe can be seen aft of wing root

Jet Pipe Temperature Control

It may be asked why, in view of the danger of stalling, and the disastrous effects of turbine overheating, no safety device has been evolved. A system could be produced, interconnected with fuel flow so that whenever the temperature showed signs of exceeding safe limits, the fuel delivery would be reduced sufficiently to prevent damage. Development of such a device has been attempted, the principle adopted being the electrical amplification of a signal from the jet pipe thermocouple operating a servo in the fuel system. However, to date this method has proved somewhat unreliable, and in practice the apparatus evolved has been too heavy to be readily acceptable by the aircraft designers. A palliative measure has been the fitting of a very readily-recognized warning device, in the shape of a loudly ringing bell or flashing light operated by a signal relayed from the thermocouple.

Stopping

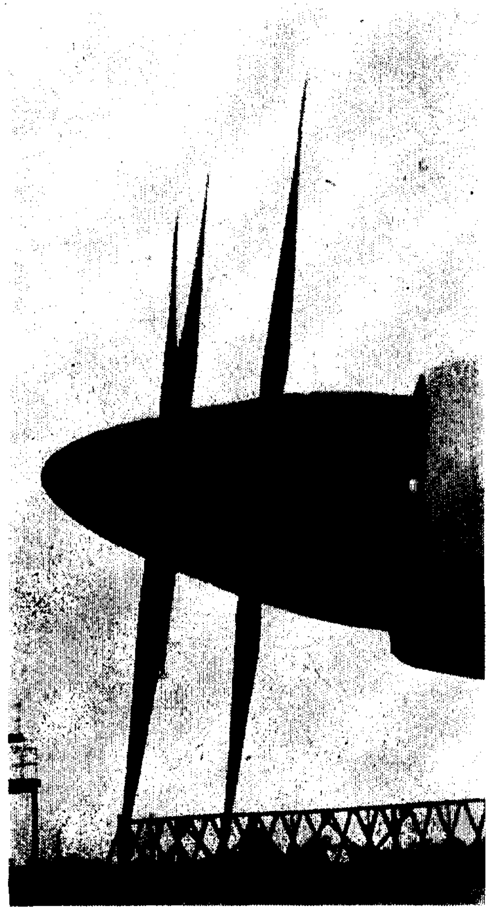
Stopping the engine presents a slight problem since the friction forces are negligible, and the inertia of the moving parts is high. Furthermore, even the lightest of breezes is sufficient to windmill the propeller quite fast. This is unacceptable for the carrier operations of ranging and striking down, hence to avoid decapitation of members of the flight deck party, propeller brakes will be fitted and housed in the reduction gear. The brake will also be used to keep one engine stationary when single engine cruising with the Double-Mamba.

Engine or C.S.U. Failure

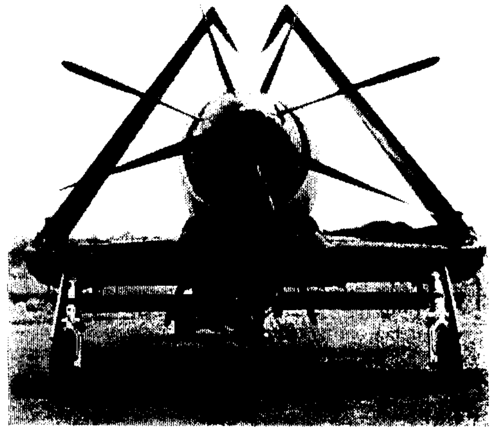
Propeller Discing and Feathering Reverse Torque Switch

Owing to the very high ground idling speed which is forced upon us by the characteristics of the engine, obviously a corresponding fine propeller pitch is required to keep the power output sufficiently low when ground running and taxi-ing, and in fact this pitch needs to be as low as 8 to 12 degrees. Now this is all very well on the ground, but consider the case of an engine or C.S.U.

WYVERN PROPELLER IN FINE PITCH SHOWING LARGE BLADE FRONTAL AREA



WYVERN PROPELLER SHOWING VERY FINE BASIC PITCH SETTING



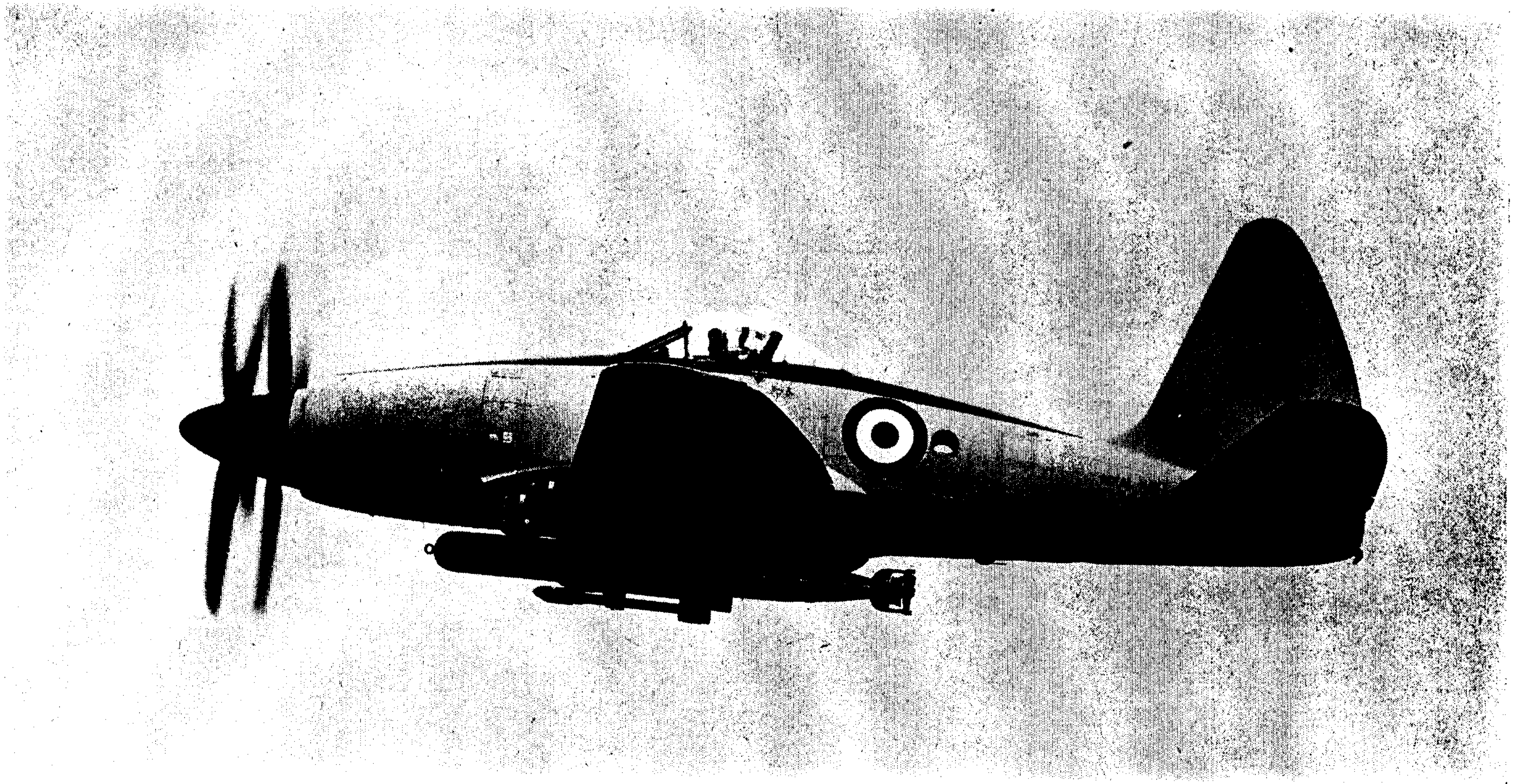
WYVERN PROPELLER "FEATHERED" SHOWING REDUCED FRONTAL AREA AND CONSEQUENT DRAG REDUCTION failure in flight. The centrifugal twisting moments on the propeller blades, caused by their shape, forces them into the finest pitch they can assume. This is a condition known as discing and the associated dangers are all too apparent. Firstly, if it happens to take place at high speed the drag is very high and sufficiently serious to cause a grave handling problem owing to change of trim and deceleration of the aircraft. There is also a danger of drag torque seriously overspeeding the engine. The answer to this part of the problem is fairly simple, and comprises the fitting of an electric switch in the reduction gear which overrides the C.S.U. selecting positive coarse, and at the same time operating the feathering pump, which coarsens the propeller pitch, and if necessary doing so to the fully feathered position. This switch is known as the " reverse " torque switch, and operates automatically whenever a condition of reverse torque exists, i.e., when the propeller is creating back torque on the engine. There is an important exception to this, however, during starting, when the reverse torque switch is automatically isolated to prevent the propeller coarsening off during the starting cycle.

Flight Fine Pitch Stop

Now supposing the engine is still running but the C.S.U. has failed. We can continue to fly, but only with the propeller at very fine fixed pitch. In the case of a heavily loaded aircraft the power developed will almost certainly be insufficient to maintain flying speed and altitude, and in any case reduction of range due to increased specific fuel consumption would make it impossible to return any distance to base. Clearly a safety device must be provided to prevent the propeller blades assuming this very fine pitch angle, and this has been achieved by fitting a removable stop known as the " flight fine pitch stop." This was electrically operated on earlier engines and is now operated from the engine oil feed. The stop is set at some 25 degrees, which figure has been worked out as a compromise, giving reasonable range, yet fine enough to allow emergency handling at low speeds and landing. The stop must be withdrawn, of course, for satisfactory engine handling, preventing compressor stalling and turbine overheating during normal landing, and particularly for deck landing. This is done by fitting an extra catch on the throttle lever to control the stop, so that it is automatically tripped at a position near throttle full closure. Alternatively the stop may be interconnected with the undercarriage retraction so that the stop is withdrawn on lowering the undercarriage. In this case the interconnection is over-ridden when take-off power is selected, in order to give protection against C.S.U. failure during take-off.

Influence of Ambient Air Temperature

There is a characteristic of the propeller-turbine which should be mentioned although it is a performance feature rather than one of control, and that is the reduction of power output with increase of ambient air temperature. Fuel settings are made on individual engines to give a definite power output at both take off and cruising r.p.m. Neglecting the effect of altitude, speed and intake ram effect on mass flow, the fuel flow settings will determine the steady operating conditions and jet-pipe temperatures at the two powers setting. As we have seen previously at take off power the turbine will be operating at the maximum safe temperature for a short period. Consider now an increase of ambient air temperature. The effect in increasing jet-pipe temperature is more drastic than appears at first sight, since the fuel flow and its thermal content remain unchanged, and absolute temperatures are to be considered in the relationship between the increments of ambient and jet-pipe temperatures. Both experiments and calculation show that an increase of one degree centigrade of the ambient air temperature will cause a rise of approximately three degrees



WYVERN IN FLIGHT WITH WAR LOAD OF ROCKETS AND TORPEDO of jet-pipe temperature. This could be disastrous to the turbine in the case of fuel setting in a cold climate, then moving to a hot climate and continuing to operate there without reduction of maximum fuel flow. Conversely, maximum fuel flow can be set down to prevent jet-pipe temperatures exceeding the safe limits. When this is done the loss of take-off power is in the order of seven per cent per ten degrees centigrade of ambient air temperature. This loss of take-off power must be accepted in tropical climates.

Future of the Propeller Turbine

The propeller jet is going to be with us for a long time in the Navy, certainly in the case of the anti-submarine aircraft, and probably in the case of a strike or escort fighter aircraft in which the specification calls for long range. New techniques will have to be learned, both of engine handling by pilots, and of maintenance by technical personnel. So perhaps it is as well if we try and understand the first principles of operation.