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8th Part of Report No.AAEE/935

MINISTRY OF AVIATION

AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT

BOSCOMBE DOWN

SCOUT A.H. MK.1 XP.165
NIMBUS MK.101 ENGINE

TROPICAL ENGINE HANDLING TRIALS

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PRESENTED BY

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U. S. CONFIDENTIAL
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8th Part of Report No.AAEE/935

14 JUN 1963

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Scout A.H. Mk.1 XP.165
Nimbus Mk.101 Engine

Tropical Engine Handling Trials

Presented by

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Performance Division

Date of Tests: July/October 1962.

Summary

Tests made during the tropical trials on Scout A.H. Mk.1 XP.165 show that this engine/airframe combination is satisfactory for initial release to the Service from an engine handling point of view subject to the recommendations contained in para. 8. It is emphasised that this must be regarded as an interim standard and further engine development as recommended in this report is required to make the aircraft fully suited to its operational role.

This Report is issued with the authority of

[signature]

Air Commodore,
Commandant, A. & A.E.E.

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1. Introduction

Engine handling trials were conducted on Scout A.H. Mk.1 XP.165 as part of the Tropical C.A. Release programme. The trials were commenced at Idris Airport Libya but owing to the seasonal reduction in ambient air temperature in mid-September the test aircraft was moved to Khartoum for completion of the hot weather trials. The aircraft was finally positioned at Wilson Field, Nairobi for high altitude performance and handling trials. During the period of the trials ambient air temperature varied between ISA +10°C and ISA +28°C, and where relevant the prevailing temperatures are referred to in the report.

2. Condition of Aircraft relevant to Trials

The test aircraft was one of the development batch powered with a Nimbus Mk.101 engine. Initially the engine fuel system incorporated a datum resetting cam on the free turbine governor and an acceleration control valve installed downstream of the fuel control unit. At an early stage in the trial the system was changed to the one described below owing to malfunctioning of the A.C.V. which was considered to present a serious flight hazard. All data in this report was obtained with the aircraft in the configuration as described below.

The Nimbus Mk.101 is a turboshaft free turbine engine and consists basically of:-

(a) Gas Generator

This comprises a two stage axial flow and single stage centrifugal compressor driven by a two stage axial flow turbine. The inlet guide vanes are of the variable incidence type operated by a pneumatic actuator which relies on a pressure tapping on the compressor delivery for its working fluid and a signal proportional to compressor speed. The combustion chamber is of the annular type.

(b) Power Turbine

This is a single stage axial flow turbine housed in the exhaust casing and transmits its power to a two stage reduction gearbox mounted on the exhaust casing.

(c) Fuel System

The fuel system comprises the following main components.

(i) Combined fuel control unit and pump

The pump is a gear (constant displacement) type integrally housed with a hydro-mechanical variable datum governor and plunger type throttle control. The datum setting and throttle controls are mechanically linked to a twistgrip on the collective pitch lever. This provides the means for accelerating the gas generator from ground idle to the normal flight condition under the control of the governor. With the throttle (twistgrip) in the fully open position this governor operates as a top speed barrier only and control of the gas generator is transferred to the free turbine governor which responds to power demands from the rotor.

(ii) Free Turbine Governor

This is a simple hydro-mechanical variable datum type sensing free turbine (rotor) speed and meters fuel downstream of the fuel control unit. The datum setting mechanism is operated

/by an ...

by an electrical actuator under the control of a three position switch (spring loaded to the central off position) mounted on the collective pitch lever. This provides the means for selecting the datum rotor speed, about which the governors will control in accordance with the static droop law normally associated with proportional type governors.

(iii) Altitude Compensator

This consists of a double bellows assembly, one evacuated and one open to ambient pressure controlling a bleed from the F.C.U. which spills fuel direct to the aircraft fuel tank proportional to the pressure height.

(iv) Overspeed Trips and Torque Limiter

These items were installed but rendered inoperative at a later stage in the trials and have therefore been omitted in the interests of simplification.

(v) High Pressure Cock

This is a simple mechanically operated two position cock, installed in the line downstream of the free turbine governor.

(vi) Rotary Atomiser

Metered fuel is passed through a flexibox seal on the engine front casing through a tube in the centre of the compressor shaft to a small impellor where the fuel pressure is boosted and the fuel is finally discharged in an atomised state from through 9 equally spaced holes around the periphery of the compressor shaft where it passes through the front of the combustion chamber.

(vii) Torch Ignitor

A single torch ignitor is mounted in the combustion chamber and fed with fuel from a tapping on the fuel control unit under the control of a pressure switch sensing compressor delivery pressure and designed to cut the fuel supply to the torch ignitor above the self sustaining gas generator r.p.m. as part of the automatic starting cycle.

(d) Starting System

The engine is rotated for starting by a combined starter generator which is controlled by an automatic starting cycle. Initiation of the starting cycle in the cockpit energises the starter and high energy ignition supply to the torch ignitor. With the high pressure cock in the open position fuel is passed to the torch ignitor only during the initial phase of the start. When the fuel pressure has reached a predetermined level a pressurising valve opens admitting fuel to the main burner line. The engine then continues to accelerate under the combined influence of the starter motor and fuel combustion until it reaches its self sustaining r.p.m. At this point a pressure switch operates cutting out the electrical supply to the starter and high energy igniter and operates a solenoid valve to cut off the fuel supply to the torch igniter. In addition the pressure switch operates a field changeover switch which converts the starter to a generator. The engine continues to accelerate under the control of the governor in the fuel control unit until it reaches the stable ground idle condition.

/(e) ...

(e) Engine Adjustments

The fuel system described briefly above employs a constant displacement engine driven pump and consequently control has to be effected by spilling off surplus fuel. This is done by a pressure relief valve on the pump delivery which spills back fuel to the inlet side according to the varying demands of the fuel control unit and the free turbine governor. Alternatively the pump may be regarded as maintaining a substantially constant pressure upstream of the metering units (i.e. F.C.U. and F.T.U.) which in turn effect control by varying their flow numbers and hence the pressure drop across the units.

An adjustable acceleration bleed is provided on the fuel control unit. This is used to modify the flow characteristics of the unit to:-

(i) Control the fuel available for acceleration during the automatic starting cycle up to ground idle.

(ii) Adjust the sensitivity of the system to fuel demands above this condition.

An adjustable by-pass is provided across the governor to prevent flame extinction on rapid reduction of power. Adjustable stops are provided to control the minimum and maximum throttle positions which in turn control the range of authority of the governor.

The Free Turbine Governor has an adjustable by-pass to prevent flame extinction on rapid reduction of power. This can also be used to adjust the gas generator speed and hence the power available at flight idle.

The Altitude Compensator is provided with an adjustment to vary the datum but not the slope of the barometric correction curve.

As some of the adjustments referred to above affect the pressure drop across the units there is a high degree of interaction and adjustment of one control frequently necessitates adjustment to another.

(e.g. Adjustment of the acceleration bleed or altitude compensator can entail adjustment of the ground idle stop).

Adjustment of the free turbine governor by-pass normally entails several flights with inter flight adjustment, as the flight idle gas generator speed can only be checked during a descent at minimum collective pitch.

Adjustment of the altitude compensator or maximum throttle stop requires checking on a ceiling climb.

(f) Engine and Component Change

During the course of the trials, several engines were rejected due to high oil consumption and surge. I.G.V. actuators, fuel control units and free turbine governor were also changed due to malfunctioning. Most of the troubles experienced are basic engine problems not related to high temperature operation and are dealt with in the Engineering report ref 1.

3. Instrumentation

An automatic observer was installed to record engine temperature and pressures and basic flight data and used to obtain steady state conditions. Continuous trace recording of the main engine parameters was also provided and used for transient conditions.

4. ...

4. Flight and engine limitations

Engine and airframe limitations for the trials were given as follows:-

4.1 Weight and Centre of Gravity

The maximum operating weight is 5,000 lb.

The longitudinal c.g. limits are 5.0 in forward to 5.5 in aft of the axis of referance.

The lateral c.g. limits are

(a) 3.0 in port to 3.0 in starboard - normal spider arms.

(b) 3.0 in port to 5.75 in starboard - extended spider arms.

The normal vertical c.g. range is from 43 in. to 51 in. below datum. For test purposes the lower limit is extended to 55.9 in. below datum.

4.2 Airspeed

The maximum permitted airspeed is 120 knots indicated up to 2,500 ft. reducing by 4 knots/1,000 ft. above this altitude. With normal spider arms and aft centre of gravity the airspeed is to be further reduced by 10 knots for each inch of c.g. position aft of a point 2.5 inches aft of datum. With extended spider arms the maximum permitted speed is unaffected by longitudinal c.g. position.

The maximum rearwards speed is 20 knots.

The maximum sideways speed is 20 knots.

The maximum speed in autorotation and flight-idle glide is 90 knots.

With extended spider arms the maximum speed is 115 knots I.A.S.

The airspeeds are to be reduced by 5, 10 knots respectively in ambient temperatures in the ranges 10 to 20 and 20 to 30 degrees above standard.

4.3 Rotor Speed

Power-On

The maximum power-on rotor speed depends upon the torque and is defined by the following table:-

Max. rotor speed (r.p.m.)	up to torque (%)
440	zero
430	5
420	15
410	97
400	100

/The minimum ...

The minimum continuous power-on rotor speed is 380 r.p.m. In transient conditions a minimum power-on rotor speed of 360 r.p.m. is permitted at torques up to 80%.

Note:- Subsequent to the trials limitations were changed slightly to the following:-

Maximum Rotor r.p.m.	% Torque
440	up to 60
400	up to 100

5. Tests Made

The various engine parameters were recorded under the following conditions:-

(i) Engine Starting and Acceleration to Ground Idle.

(ii) Acceleration from Ground Idle.

(iii) Flight idle descent and Autorotation.

(iv) Ground run, hover and vertical climb.

(v) Step inputs of collective pitch from minimum pitch on ground condition.

(vi) Quick Stops.

(vii) Recoveries from Autorotation.

(viii) Step inputs of collective and cyclic pitch during climb, cruise and flight idle descent.

6. Test Results

6.1 Engine starting and ground idle

In general the aircraft internal batteries were used for starting throughout the trials. This did not give rise to any problems.

The light up occurred at approximately 5 seconds and 12% compressor speed, ignition off at 15 seconds. The time to stable ground idle conditions varied with the acceleration bleed adjustment. This was fairly critical necessitating a compromise between high transient J.P.T. (jet pipe temperature) during starting and sufficient fuel to accelerate beyond the self sustaining engine speed. (22% Ng). An overall time of 30-35 seconds to ground idle was found to be satisfactory and gave an acceptable degree of sensitivity for the subsequent acceleration to the fully governed condition.

On hot restart it was found that the pre-start J.P.T. must not exceed 150°C in order to keep within the transient J.P.T. limits of 630°C. In this connection pre-start ventilating runs were found to have little effect and initially caused a rise in indicated J.P.T. It was found that cutting the H.P. cock at the minimum pitch on ground condition (Where the stable J.P.T. is lower than ground idle) followed by a 20 second ventilating run enabled a restart to be made after four minutes.

6.2 Acceleration from ground idle

In the absence of any surge protection it was necessary to handle the twist grip with caution. In the event of an inadvertent overfuelling surge however it was found that the engine responded immediately to a slight reduction in throttle and there was no need to close the H.P. cock to avoid damage.

/6.3 ...

6.3 Flight Idling Condition and Autorotative Rotor Speed

With the present surge characteristic of the Nimbus engine it is necessary to accept a power contribution to the rotor at flight idle in order to ensure that the gas generator speed is maintained at a level from which it can be accelerated at an acceptable rate. It is also necessary to maintain the true autorotative rotor speed at minimum collected pitch within acceptable limits in order to meet the engine failure case. In order to reduce the number of variables it has been generally agreed that basic settings shall be related to the following datum condition which apply throughout this report unless otherwise stated.

Aircraft A.U.W.	-	5,000 lb.
Aircraft fwd. speed	-	50 knots
I.S.A. ht.	-	2,000 ft.

It can be shown that at constant pitch for any given aircraft weight, forward speed and pressure height the true autorotative rotor speed varies approximately as the square root of the absolute temperature. It was therefore necessary to increase the basic pitch on the main rotor in the prevailing high air temperatures to reduce the autorotation r.p.m. to an acceptable level. It was also necessary to increase the flight idle gas generator r.p.m. in order to obtain an acceptable engine response from this condition and hence an acceptable transient droop (see para. 6.5). A satisfactory compromise was arrived at and test results in this report relate to this condition. In order to avoid frequent adjustment whilst still maintaining these parameters within acceptable limits having regard to the day to day variations in ambient temperatures within the normal seasonal or geographical pattern, it is considered that the basic settings should be related to the following datum temperature conditions:-

		Datum
(a)	Temperatue climate (ISA -20°C to ISA $+10^\circ$C)	ISA -5°C
(b)	Tropical climate (ISA $+5^\circ$C to ISA $+30^\circ$C)	ISA $+20^\circ$C
(c)	Subarctic climate (ISA -40°C to ISA -10°C)	ISA -25°C

Fig. 1 shows the variation of rotor speed with ambient air temperatures for these datum conditions and can be used to obtain the corrected true autorotation rotor speed appropriate to the ambient air temperatures prevailing during the test run.

Fig. 2 shows the variation of gas generator speed with ambient air temperature to maintain a constant $\frac{NG}{\sqrt{T}}$ at flight idle condition which was found during the trials to provide a reasonable compromise between response, surge margin and power contributing.

It was found important that the power contribution at the datum temperature condition should not give more than 8 r.p.m. increase in rotor speed, the actual values being:-

412 r.p.m. True autorotative rotor speed and

420 r.p.m. Flight idle rotor speed.

To facilitate setting up at ambient temperatures above or below the datum condition, a flight idle rotor speed of 420 r.p.m. may be assumed and the free turbine governor by-pass may be adjusted if necessary to give this. This may be exceeded slightly at the upper end of the temperate/bracket by virtue of the increase in true autorotation rotor r.p.m. but there should be no power contribution at temperatures of $+17^\circ$C and above.

/6.4 ...

6.4 Static Rotor Droop

The free turbine governors tested varied in their basic rates (i.e. the variation of decrease in rotor speed with power on for steady conditions) and generally deteriorated within the first few hours of flight. Whilst this deterioration was undesirable it was considered that the following was acceptable as an interim standard.

Basic static droop between minimum pitch on ground condition and 100% torque:- 20 plus 0 minus 5 rotor r.p.m. with a permissible deterioration in service to 25 r.p.m.

The flight idle condition is defined in para. 6.3.

The operating technique adopted consisted of setting 410 r.p.m. rotor speed at minimum pitch on ground and accepting the static droop for all normal flying. This gave 390 r.p.m. at the maximum permissible torque condition and 400 ± 4 r.p.m. in level flight. In order to achieve the maximum climb performance permitted by the engine and rotor limitation the speed select trimmer was operated to give 400 r.p.m. at 100 Torque. Initially the speed select actuator had a range of authority of approximately 70 r.p.m. but at a later stage in the trial this was reduced to 15 r.p.m. by a simple modification and rigged to give 410Rr.p.m. on the lower limit of travel. This was done to provide:-

(a) Limited authority to prevent downward runaway

(b) Sufficient upward authority to permit trimming to 400Rr.p.m. at 100% Torque plus 5 r.p.m. to cater for governor deterioration.

(c) Limited authority to contain an upward runaway or inadvertant selection of minimum collective pitch by the pilot with the rotor speed trimmed up.

(d) An easy means of reverting to the datum condition after trimming in flight.

6.5 Engine Response and Transient Rotor Droop

Fig. 3 shows the governor response to collective pitch demands. The gas generator lag is the elapsed time between initiation of the collective pitch movement and the response of the gas generator. Collective pitch lever rates up to 11°/second were obtained from trace records of quick stops and autorotation recoveries.. The higher rates were obtained from trace records of small step inputs of collective pitch from the minimum pitch on ground condition. Although collective pitch rates in excess of 11°/second cannot be used with the present standard of engine it is considered that Fig. 3 can be used as a guide to future development. It will be noted that the time constant for the system is approximately .15 secs., and the overall lag appropriate to 18° per second collective pitch rate (i.e. application of collective pitch from flight idle to 95% one hour power in one second) is .3 seconds. It is therefore considered that an anticipat would reduce the overall lag by .15 seconds during a one second recovery and is therefore not worth the complication.

Fig. 4 shows the gas generator acceleration in response to collective pitch demands during recoveries from autorotation. The accelerations plotted are maximum obtained from the steepest part of the curve above flight idle. As the acceleration of the engine is at present limited by surge and the curve in Fig. 4 remains quite steep up to the limits tested it is concluded that an improvement in surge margin at flight idle would also show a marked improvement in engine acceleration at the higher powers.

Fig. 5 shows the variation of transient droop with collective pitch lever rates during quick stop manoeuvres. (i.e. reduction of collective

/pitch to ...

pitch to minimum followed by rearward movement of cyclic stick to reduce forward speed to approximately 20 kts., forward movement of cyclic stick to level the aircraft and reapplication of collective pitch at the onset of sink). In view of the performance margin on this aircraft this manoeuvre can be made by recovering to 80% torque. This figure was used for the assessment shown in Fig. 5. It will be noted that with a two second application of collective pitch the transient rotor droop does not exceed the lower power on limitation. In general engine surge should and can be avoided by limiting the rate of application of collective pitch from flight idle to 7°/second on collective pitch lever (i.e. approx 3° pitch/second on main rotor blades.) (Check also on pilots' pitch indicator). Nevertheless experience has shown that the engine is unlikely to sustain damage during surge and will be immediately restored to normal running conditions by a momentary small reduction in collective pitch. It was also demonstrated during this trial that continued application of collective pitch after the onset of surge produced a transient rotor speed of approximately 378 r.p.m., but there was a negligible loss of height and the engine accelerated through this condition to stable running at the higher power.

6.6 System Stability

The system was subjected to step inputs of collective pitch and cyclic pitch under conditions of climb, cruise and flight idle descent. The induced oscillations in gas generation r.p.m. were well damped.

6.7 General

Several engine and component changes were made without recourse to subsequent power checking on the tie down. The various parameters were checked during the ground run and hover in the ground cushion on the basis of previous operating experience and a full power check made in normal flight. The setting of the I.G.V. actuator was greatly facilitated by use of the cockpit indicator installed as part of the instrumentation.

7. Conclusions

From the tests done on XP.165 it is considered that the Scout A.H. Mk.1 is satisfactory for interim release to the Service in Temperate and Tropical conditions from an engine handling point of view subject to the recommendations contained in para. 8.

8. Recommendations

(i) The acceleration bleed on the fuel control unit should be adjusted to give an overall starting time to ground idle of 30-35 seconds.

(ii) If for operational reasons it is desired to restart as soon as possible after shut down, the H.P. cock should be closed with the engine at maximum throttle minimum collective pitch followed by a twenty second ventilating run.

(iii) Caution should be exercised when advancing the throttle above ground idle to avoid surge. If inadvertent surge is encountered the throttle should be reduced immediately. This should be demonstrated as part of pilot conversion.

(iv) The recommended rotor and gas generator settings of para. 6.3 should be promulgated in the production Flight Test Schedule and appropriate aircraft publications.

(v) The rotor governor speed select actuator should be modified to limit its authority to 15Rr.p.m. and the aircraft rigged in accordance with para. 6.4.

(vi) Application of collective pitch from the flight idle condition should be limited to 7° per second lever rate to avoid surge. Unless operational conditions dictate otherwise, immediate recovery action by

/reduction of ...

reduction of collective pitch should be taken in the event of inadvertent surge. This should be demonstrated as part of pilot conversion.

(vii) Some form of cockpit indication should be provided to indicate the two extreme positions of the I.G.V. actuator.

(viii) Information regarding rotor r.p.m., gas generator r.p.m. torque and J.P.T. for ground idle, minimum pitch on ground and hover conditions, showing variation with temperature should be included in the aircraft publications to enable reference checks to be made after engine and component changes. This should enable aircraft to be cleared for flight without the use of a tie down.

(ix) The torque limiter should be permanently deleted and audio warning substituted.

(x) The free turbine overspeed trip should be absolutely reliable and consistent in operation otherwise this could be considered to present a more serious hazard than the one which it is intended to guard against.

(xi) Further development of the engine and fuel system is required to provide:-

(a) A flight idle gas generator speed of at least 28,000 r.p.m. with zero power contribution to the rotor under I.S.A. the datum temperature conditions.

(b) An improved governor with a reduced rate and/or static droop cancelling to give a rotor speed of 400 r.p.m. and 100% torque without the necessity of trimming on the rotor speed select control.

(xii) Adjustable stops should be provided at a convenient position in the collective pitch linkage to permit adjustment of the basic pitch independent of the rotor track rods.

Reference	Title
1	9th Part of Report No. AAEE/935. Engineering Tropical Trials.

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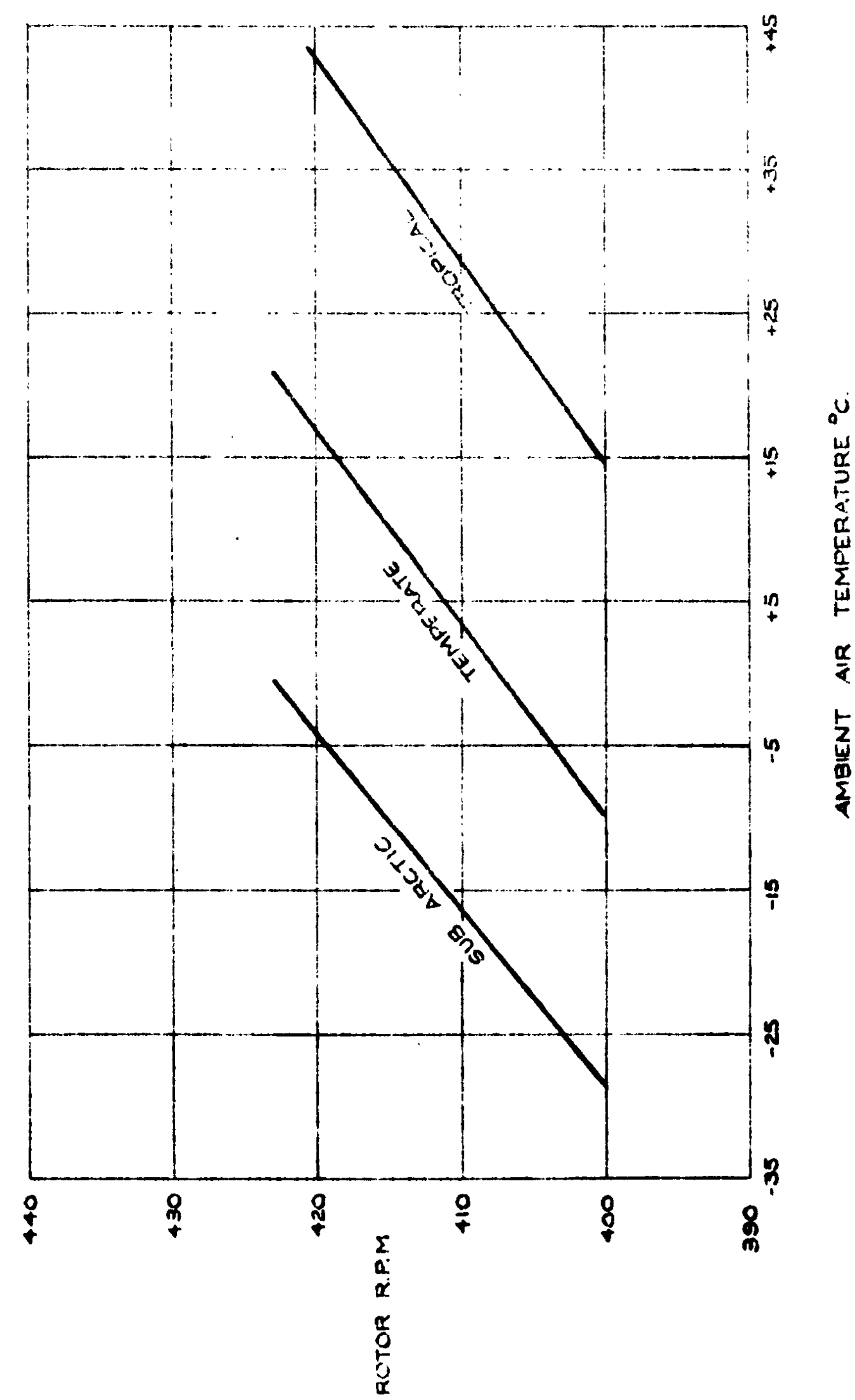
FIG. 1.



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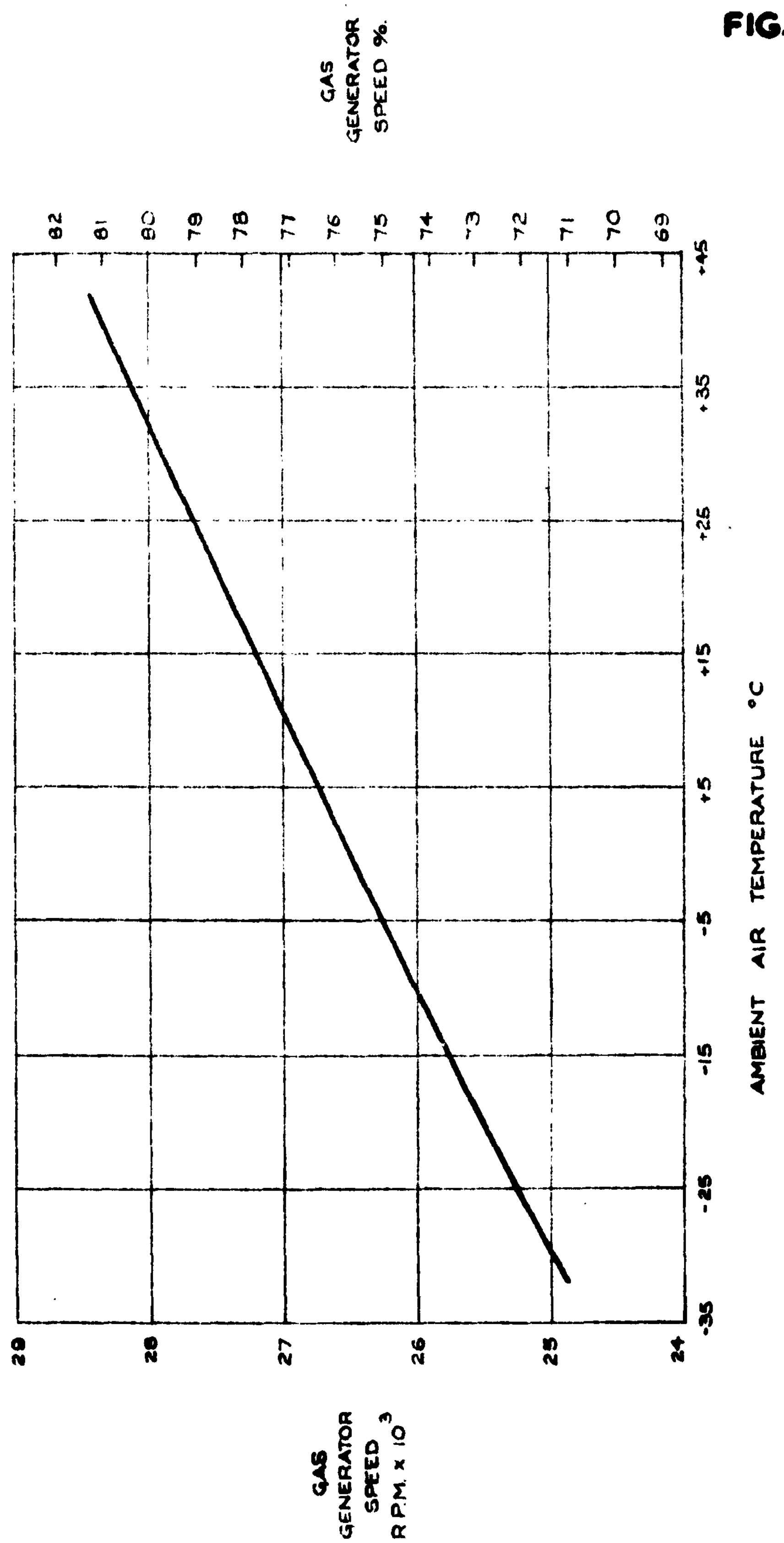
SCOUT AH MK1

VARIATION OF ROTOR AUTOROTATIVE R.P.M. WITH AMBIENT AIR TEMPERATURE AT MINIMUM PITCH.

FIG. 2.



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VARIATION OF GAS GENERATOR FLIGHT IDLE R.P.M. WITH AMBIENT AIR TEMPERATURE.

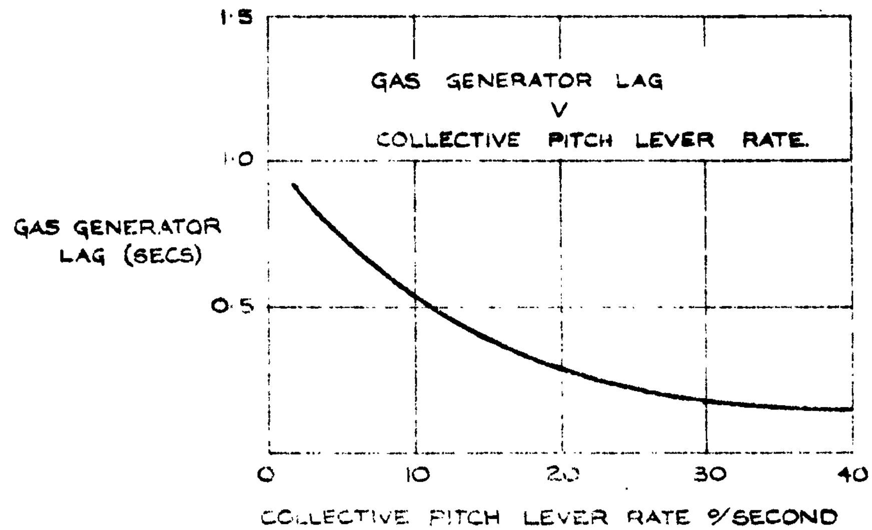

FIG 3. GOVERNOR RESPONSE.

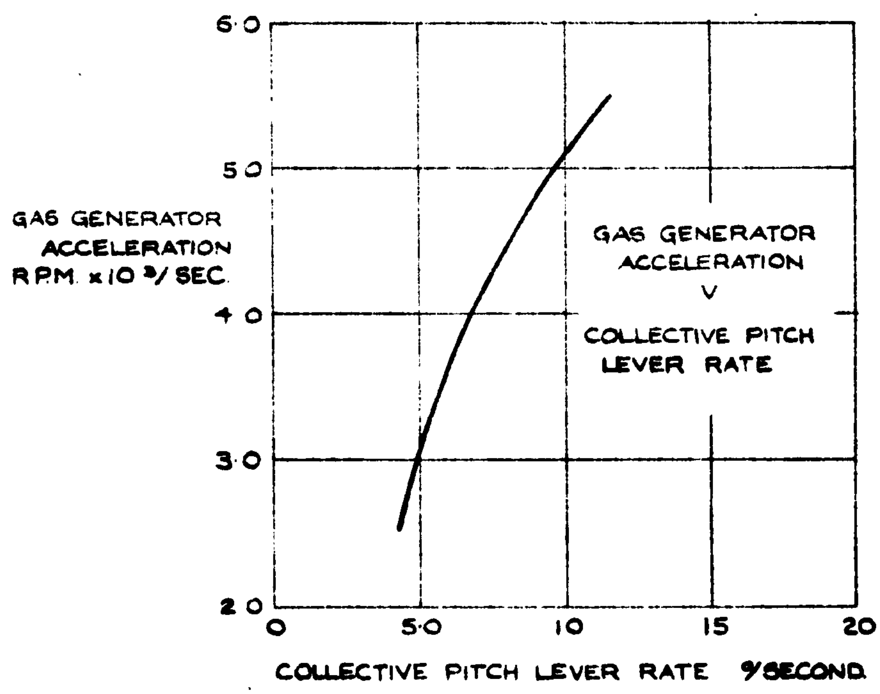

FIG. 4. ENGINE RESPONSE.

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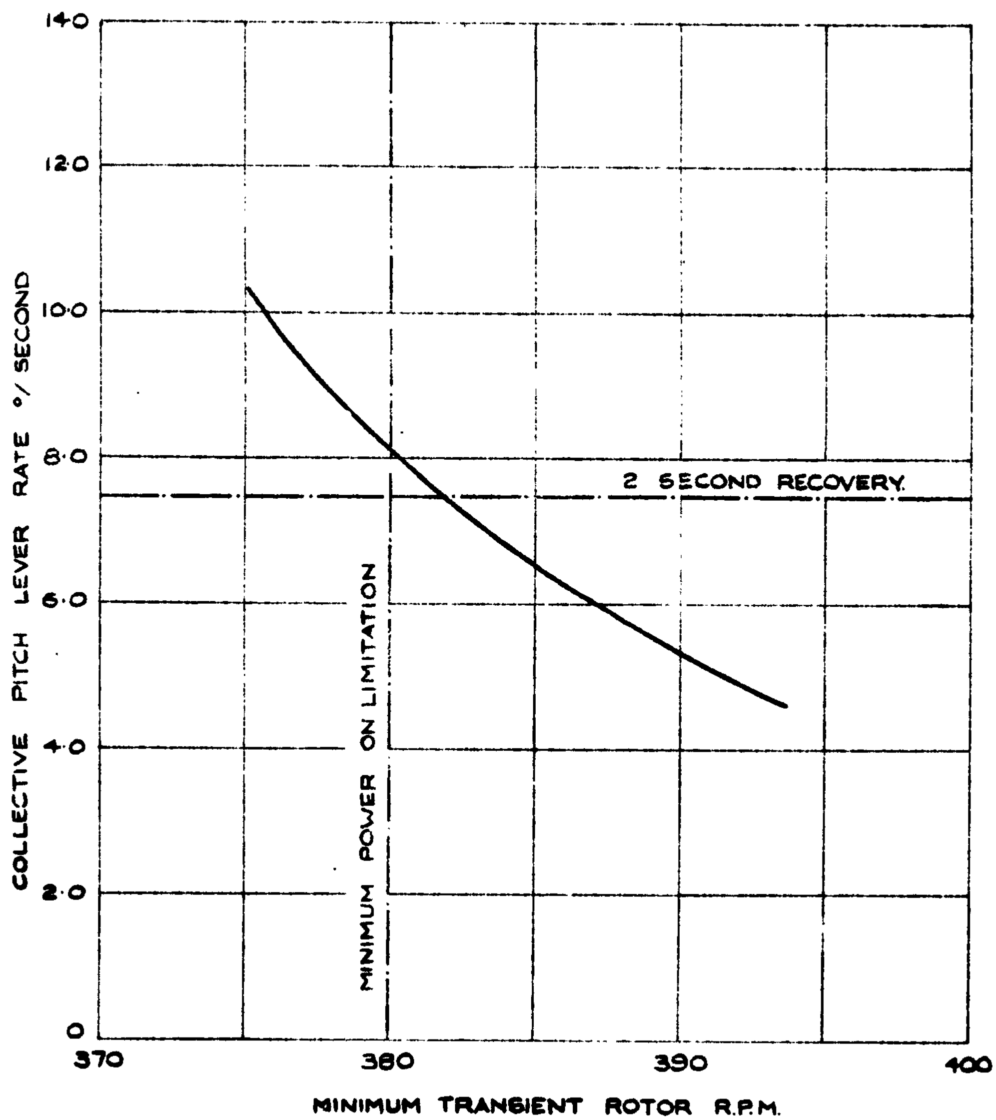
FIG. 5.



TRANSIENT ROTOR DROOP.

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