NACA

RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF THE CONTROL OF A GAS-TURBINE ENGINE FOR A HELICOPTER

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

A preliminary investigation of the power plant control problem for the helicopter was made. The results obtained from an analog indicated that current turbine-propeller engine controls are suitable for the helicopter. Rotor thrust or propeller torque could be increased from one-half to rated value in less than 4 seconds. Control operation was satisfactory up to an altitude of 15,000 feet.

INTRODUCTION

Success in recent military operations has demonstrated the utility of the helicopter and stimulated interest in new designs for the helicopter. Among these designs are several for a helicopter with higher gross weight than those helicopters now flying and powered by a gas-turbine engine. The gas turbine drives either a lifting rotor or a pair of forward-driving propellers. When the propellers are connected to the engine, the rotor is in autorotation.

Use of a single gas-turbine engine to power a helicopter introduces certain control problems because the rotor and propellers have greatly different characteristics. The question arises as to whether the same type of control is suitable for a power plant, the dynamics of which change with a change in power absorber as well as with a change in altitude.

Accordingly, the NACA Lewis laboratory has made an introductory study of the power plant control problem for the helicopter. The dynamics of a controlled gas-turbine engine with appropriate rotor and propellers were studied with an electronic analog. The dynamic response of the engine and control, which maintained engine speed by regulating the fuel flow, was determined for four different maneuvers. Each of these maneuvers involved power increase from one-half to full-rated power. In one of these maneuvers, the jump take-off, the rotor was

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connected to the engine and the flight altitude was sea level. In the other three maneuvers, power was absorbed by the propellers at sea level, by the rotor at an altitude of 15,000 feet, and by the propellers at 15,000 feet. A second type of control in which the speed was regulated by the variation of the blade angle was investigated for the jump take-off maneuver.

PROCEDURE

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The analog investigation was based on engine and propeller characteristics obtained from manufacturers' data. The engine was assumed to be similar to a T40. Because the manufacturer recommends that this engine be run at rated speed whenever possible, only constant speed controls were considered. The rotor characteristics were scaled from data available on a typical helicopter rotor. Performance data on the engine, rotor, and propellers in the form of partial derivatives among the performance variables evaluated at the rated power operating point were inserted in the electronic analog computer. The dynamic performance of the helicopter power plant was expressed as the response of several of the performance variables to a step change in the power-setting lever.

RESULTS AND DISCUSSION

In the system for which the dynamic response was first determined, the engine speed was kept constant by controlling the fuel flow and the power was determined by the blade angle actuated through the collective pitch control. This system which is representative of current turbine-propeller engine control is shown schematically in figure 1. The engine speed N is compared to the desired set speed N_s, and the difference, or speed error, serves as the input for the control. The nature of the control is such that, except for an assumed lag in the fuel system which has been included as part of the control, the change in fuel flow is proportional to the sum of the speed error and its time integral. The inclusion of the time integral feature in the control assures the absence of any steady-state error in engine speed. A lag was also included between the collective pitch control and the rotor blades.

The response of rotor thrust F, exhaust gas temperature T, engine speed N, rotor blade angle β, and engine fuel flow W_f are shown for a jump take-off in figure 2. The time base for all traces is 20 seconds. For this sea-level maneuver the collective pitch control was raised instantaneously from a position corresponding to 50 percent power to a position corresponding to full power. Pertinent data for the interpretation of figure 2 are as follows:

Altitude	sea level
Power absorber	rotor
Engine-rotor time constant	1.5 seconds
Fuel system lag	0.2 second
Blade system lag	1.0 second
Control integral time constant	2.0 seconds
Loop gain	10.2

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The loop gain is defined as the change in speed for a unit change in speed error when the control loop is open.

The rotor thrust follows the change in blade angle almost perfectly. Because of the lag in the blade actuating mechanism, the rotor blades execute 63 percent of their excursion in 1 second and complete 98 percent of their excursion in 4 seconds. Likewise, the rotor thrust makes 98 percent of its change in 4 seconds.

Neither the exhaust gas temperature nor the fuel flow overshoot their final value. The success of the system and the ability of the rotor thrust to follow the change in blade angle arises from the very nearly constant rotational speed of the power plant. The dip in speed amounts to less than 1 percent of its rated value.

The response of the helicopter power plant at sea level when driving the propellers is shown in figure 3. Again the power change is from one-half to full rated power. The time abscissa for all traces is 20 seconds. Thrust data for the propellers were not available, and so propeller torque Q_p was substituted for the top trace. Pertinent data for figure 3 are:

Altitude	sea level
Power absorber	propellers
Engine-propeller time constant	0.67 second
Fuel system lag	0.2 second
Blade system lag	1.0 second
Control integral time constant	2.0 seconds
Loop gain	9.4

The responses shown in figure 3 are almost identical to those shown in figure 2. The propeller torque follows the change in blade angle and very nearly attains its final value in 4 seconds. Because the loop gain remained practically unchanged, it is possible to compare the results of figures 2 and 3 and observe that a two-to-one change in power plant time constant has little effect on the responses. The engine speed deviated about 0.5 percent from its rated value.

The performance for the rotor drive and propeller drive at an altitude of 15,000 feet is shown in figures 4 and 5, respectively. At altitude the power plant time constant is increased by a factor of 1.68 and the loop gain is increased by a factor of 1.78 over the respective values at sea level. These changes in system parameters have little apparent effect on the dynamic performance of the system.

The results illustrated in figures 2 to 5 in which the control constants were not changed indicate that a control system similar to the one illustrated in figure 1 is satisfactory for controlling a gas-turbine engine when driving either a lifting rotor or a pair of forward-driving propellers at altitudes up to 15,000 feet. 2222

Should it be possible to increase the speed of response of the blade actuating mechanism, faster thrust response can be obtained. The results illustrated in figure 6 were obtained for a system similar to the one for which results are shown in figure 2 except that the blade system lag has been reduced to 0.5 second. The rotor thrust reaches 98 percent of its final value in 2 seconds, but the speed change has increased to almost 1.9 percent of its rated value. Any further attempts to increase the speed of response of the thrust would probably initiate temperature overshoots.

An investigation was also made of the performance of the helicopter power plant in which constant speed was maintained by regulating the blade angle and power was set by the fuel flow throttle. Such a control is similar to the one recommended by the engine manufacturer for turbine-propeller service. The control system is shown schematically in figure 7. A speed error is determined as in the first control by taking the difference between the engine speed and a set speed. The nature of the control is such that, except for the assumed lag in the blade actuating mechanism which has been included as part of the control, the change in blade angle is proportional to the sum of the speed error and its time integral. The fuel system lag has been included between the throttle and the engine.

Dynamic response of the gas-turbine engine driving a lifting rotor at sea level and being regulated by a blade-angle - speed control is shown in figure 8. Pertinent data for the power plant and control are:

Altitude	sea level
Power absorber	rotor
Engine-rotor time constant	1.5 seconds
Blade system lag	1.0 second
Fuel system lag	0.2 second
Control integral time constant	3.0 seconds
Loop gain	5.2

For an increase in power from 50 percent to rated, the thrust reaches its rated value in 1 second, overshoots by 21 percent of its rated value, returns and remains constant after about 8 seconds. The speed also exceeds its rated value by 5 percent. Although the thrust

overshoot may not be objectionable, the speed overshoot will endanger the engine. It is considered that a speed overshoot accompanying a power increase would be more detrimental to the engine than a speed overshoot accompanying a power decrease. The loop gain and control integral time constant were chosen to give what appeared to be the most satisfactory speed and thrust response. Any further increase in the gain of the control aimed at reducing the speed overshoot would render the thrust even more oscillatory and would introduce overshoots
2222 in the temperature response.

In the blade-angle - speed control system there are two lags of about equal magnitude in the control loop: a lag of 1.5 seconds for the power plant itself, and a lag of 1.0 second for the blade actuating mechanism. The presence of the two nearly equal lags in the system illustrated by figures 7 and 8 makes this system more oscillatory with a loop gain of 5.2 than the system illustrated in figures 1 and 2 with a loop gain of 10.2. The decreased loop gain results in an increased speed error.

A further disadvantage of the blade-angle - speed control system for helicopter service is a mechanical one. When the engine is switched from rotor drive to propeller drive, it would be necessary to open the control loop. Special provision would have to be made during the change-over period to prevent the engine from making any radical change in speed.

SUMMARY OF RESULTS

A preliminary investigation of the control problem of a gas-turbine powered helicopter indicated that currently proposed turbine-propeller engine controls are applicable for either lifting rotor drive or propeller drive. Power could be increased from one-half rated to full power in less than 4 seconds. Satisfactory operation was indicated for altitudes up to 15,000 feet. The results were obtained from an electronic analog computer.

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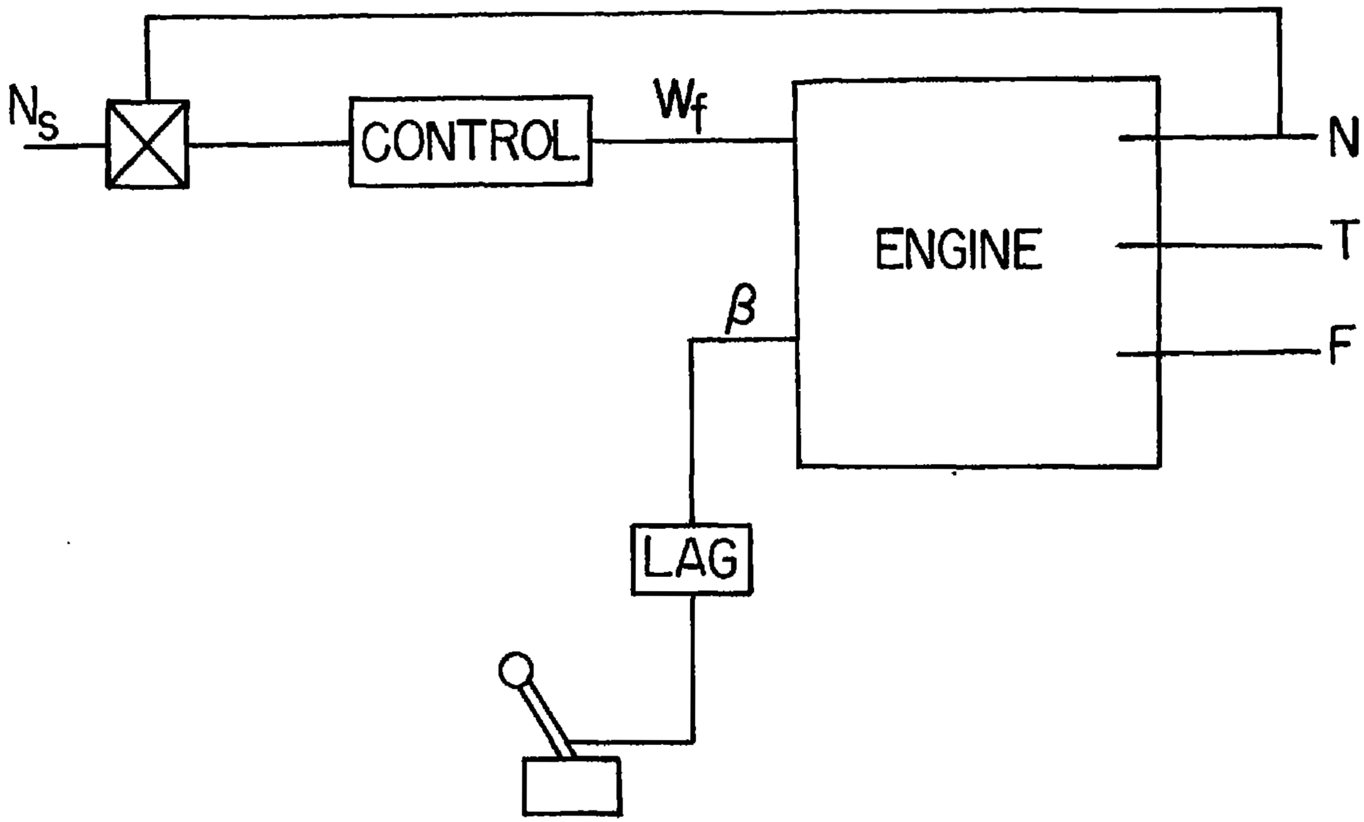

Figure 1. - Schematic diagram of fuel-flow - speed control system.

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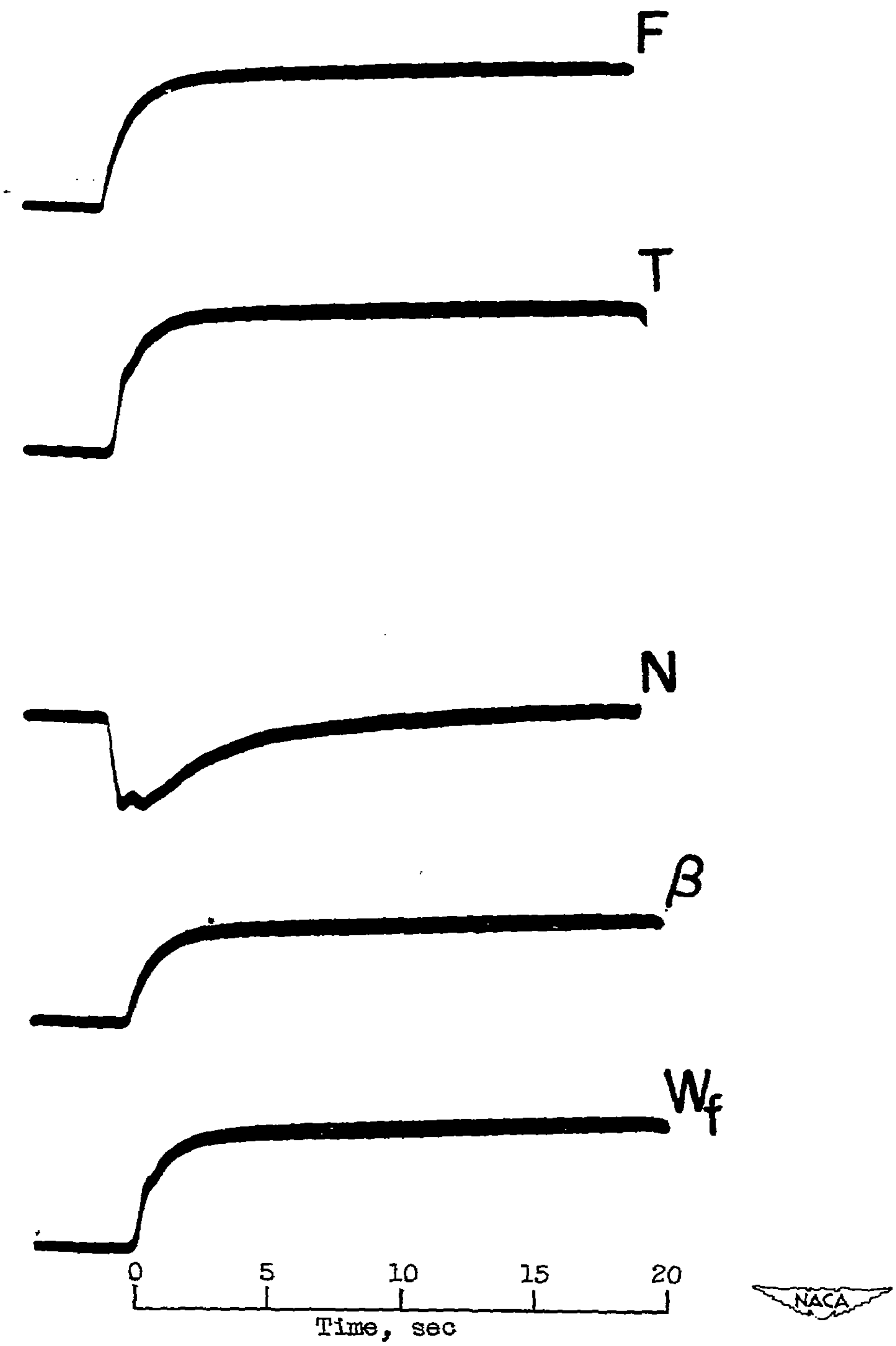

Figure 2. - Controlled engine response for a step increase in power setting. Fuel-flow - speed control. Power absorber, rotor; altitude, sea level; blade system lag, 1.0 second.

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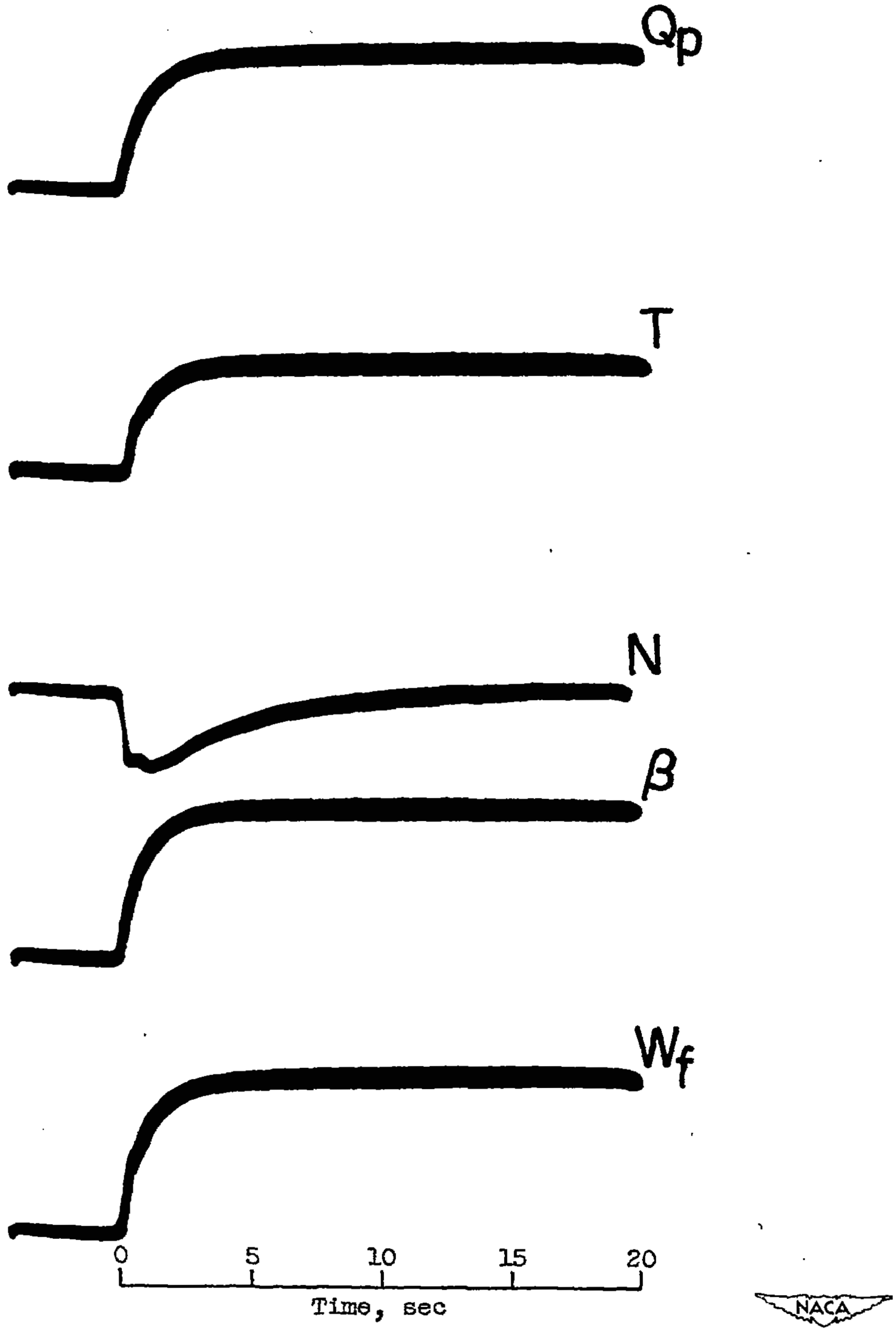

Figure 3. - Controlled engine response for a step increase in power setting. Fuel-flow - speed control. Power absorber, propellers; altitude, sea level; blade system lag, 1.0 second.

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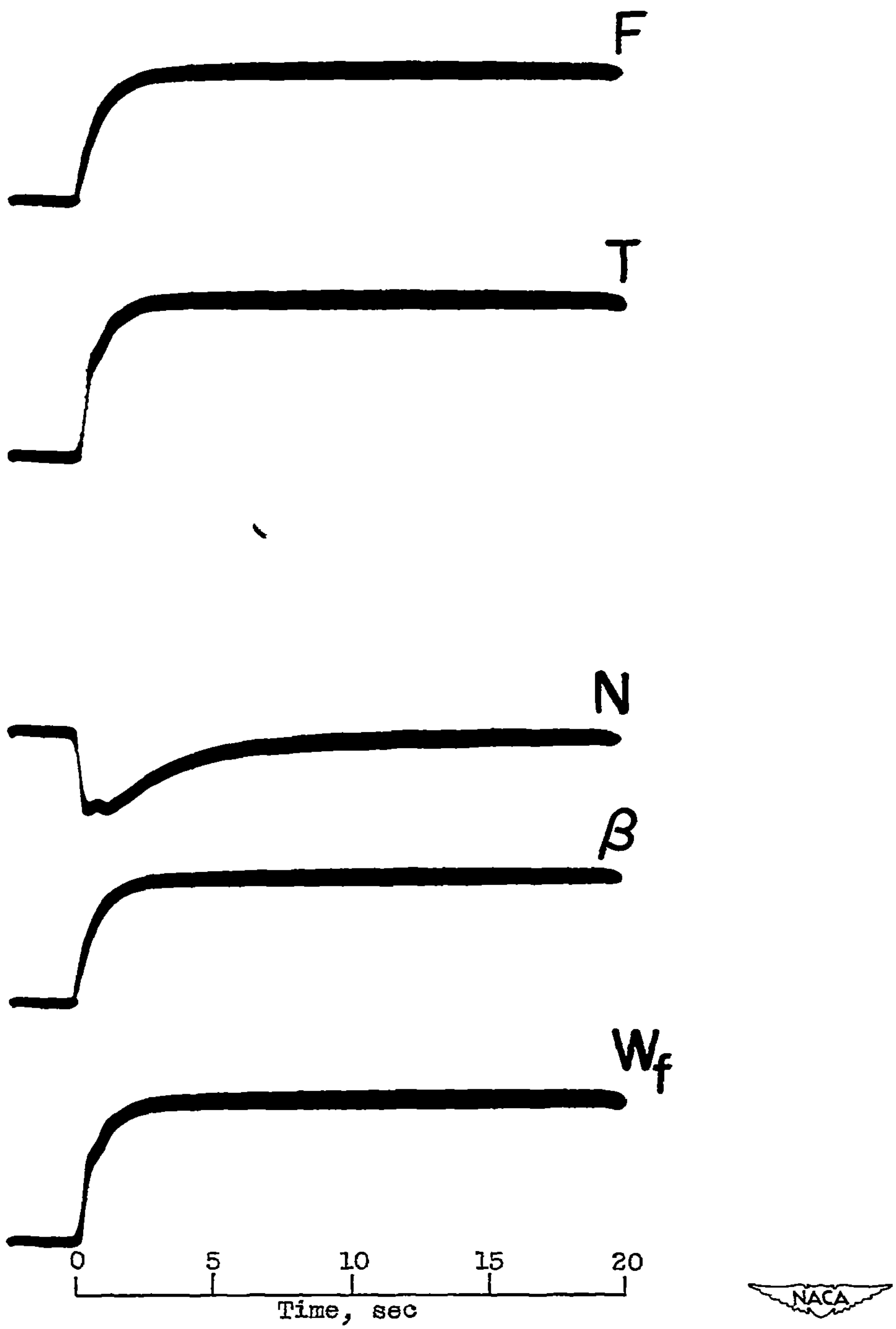

Figure 4. - Controlled engine response for a step increase in power setting. Fuel-flow - speed control. Power absorber, rotor; altitude, 15,000 feet; blade system lag, 1.0 second.

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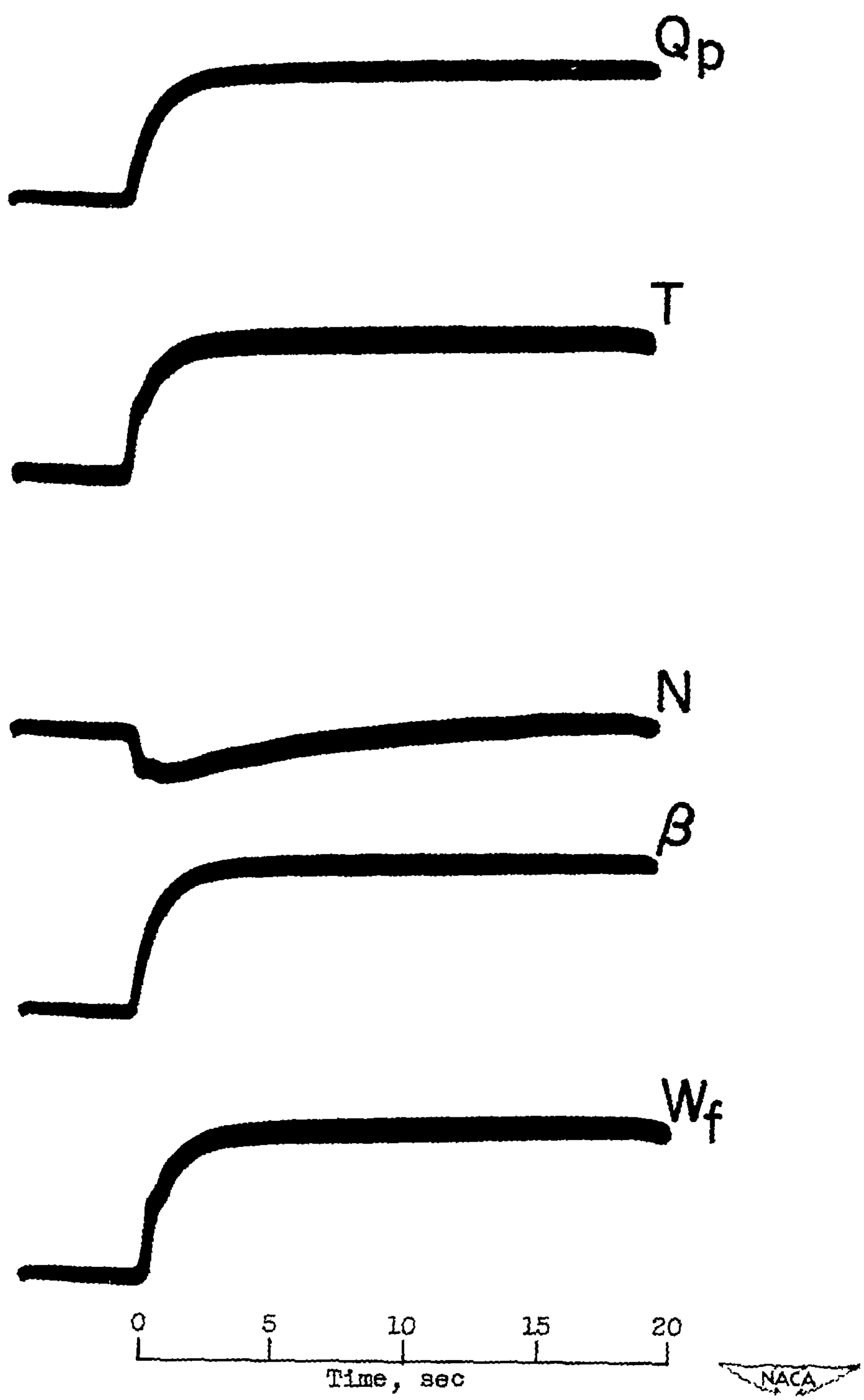

Figure 5. - Controlled engine response for a step increase in power setting. Fuel-flow - speed control. Power absorber, propellers; altitude, 15,000 feet; blade system lag, 1.0 second.

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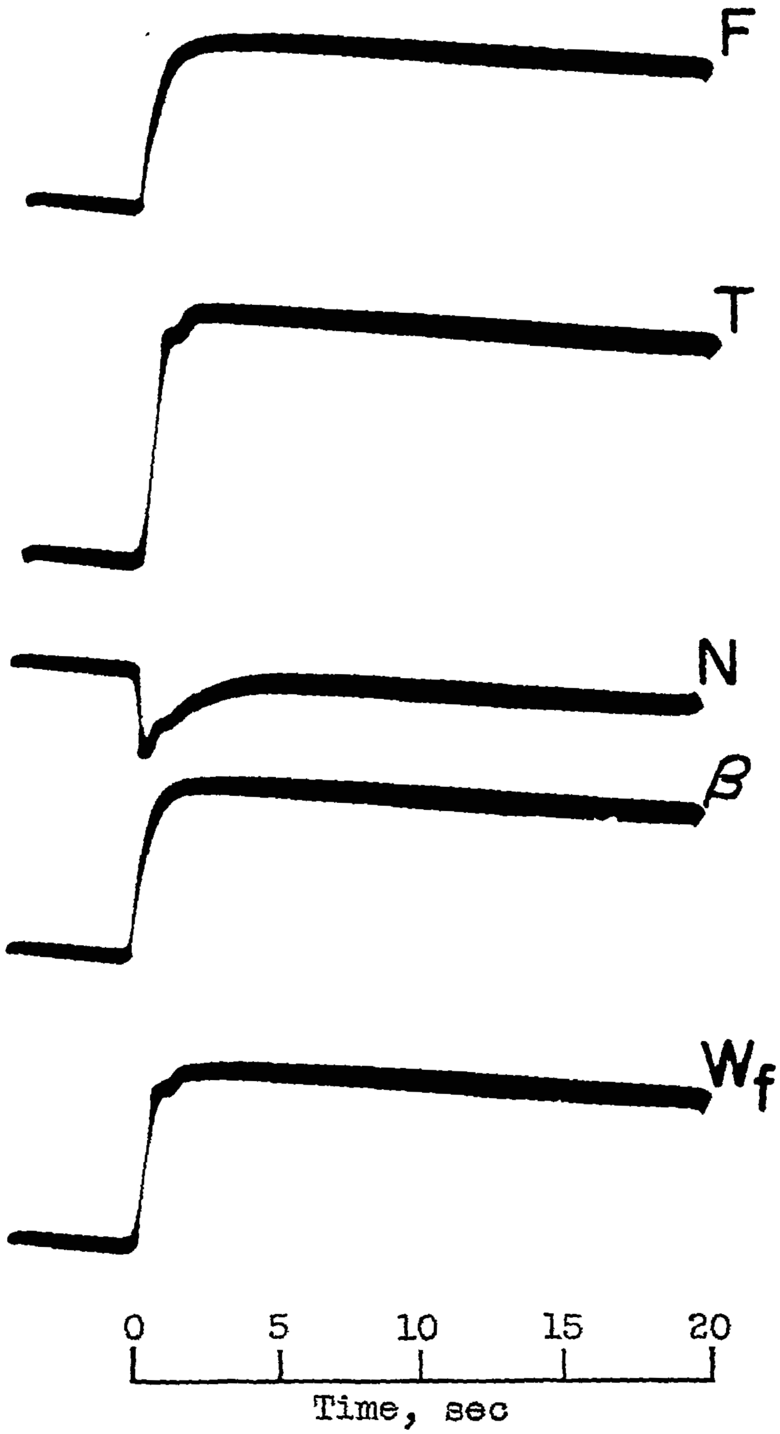

Figure 6. - Controlled engine response for a step increase in power setting. Fuel-flow - speed control. Power absorber, rotor; altitude, sea level; blade system lag, 0.5 second.

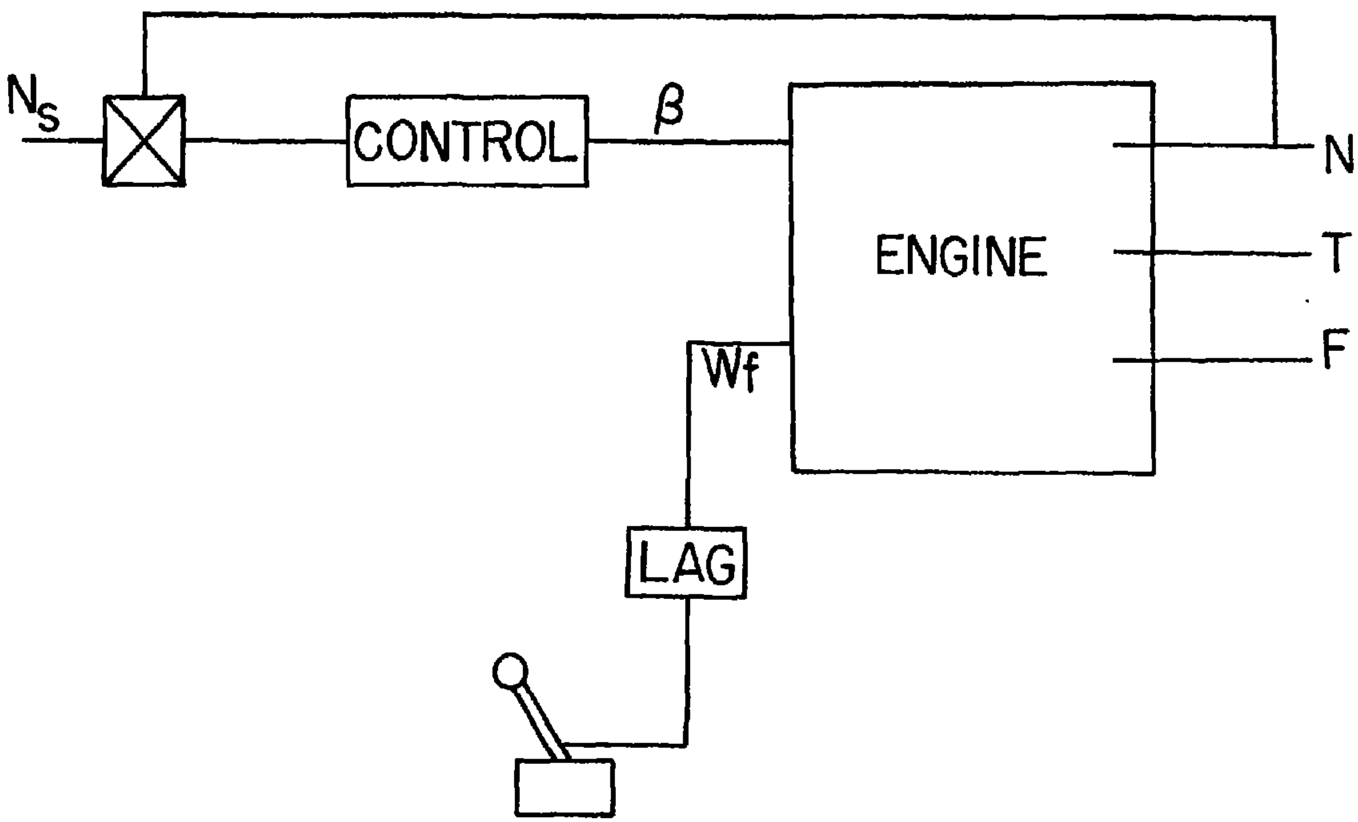

Figure 7. - Schematic diagram of blade-angle - speed control system.

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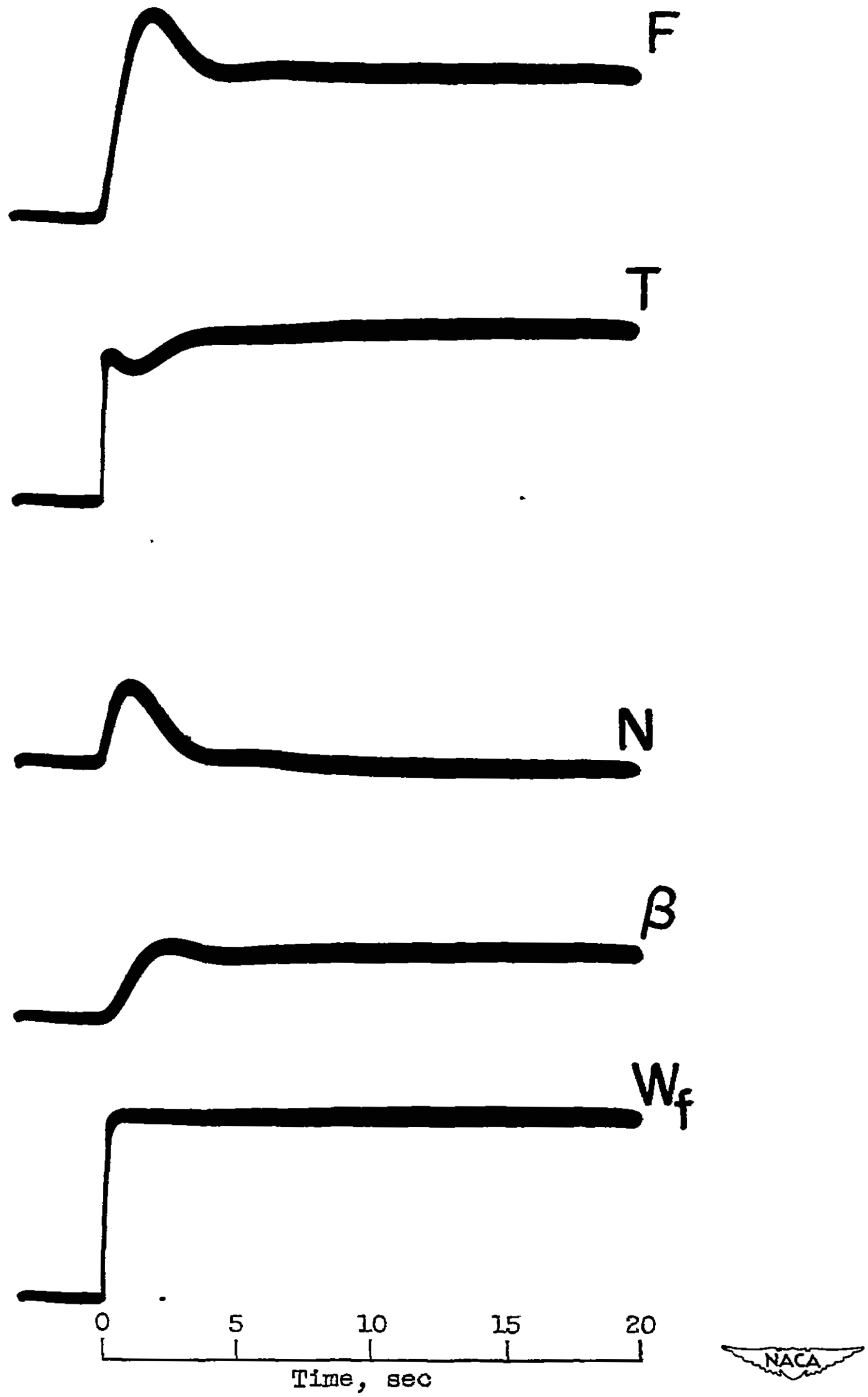

Figure 8. - Controlled engine response for a step increase in power setting. Blade-angle - speed control. Power absorber, rotor; altitude, sea level; blade system lag, 1.0 second.

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