Testing and Test Philosophy

The papers in this section are from a session with the same title, chaired by George R. Simpson.

Ground Simulation of Maneuver Forces on Turbine Engines

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Theme

AS advances in aircraft turbine engine design provide lighter and more powerful engines for use in more maneuverable aircraft, verification of engine structural integrity during development and operational use becomes increasingly important. The absence of adequate test facilities and analytical methods to accurately verify turbine engine structural integrity under realistic flying conditions prompted a study to examine the need for, and feasibility of, simulating flight maneuver forces on operating turbine engines. Results of the study include identification of minimum test requirements and selection of a test facility concept.

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As modern technology provides new materials and improved design techniques, aircraft turbine engine performance (thrust-to-weight) continues to increase. The consequence of this continual increase in performance using lighter, but stronger, materials and larger diameter rotors is that engines are more flexible and more susceptible to distortion from internal and external forces. Internal aerodynamic loads, centrifugal forces, gyroscopic moments, pressure loads, thermal stresses, and thermal growth differences together with external loads act simultaneously and nearly independently to bend and distort the engine. One important result of these forces is the changing of gas seals, which further affects engine operation making effective analysis impossible.

The increasing engine thrust-to-weight ratios demanded by future, highly-maneuverable manned and remotely piloted vehicles, with maneuver loads often more than 50% greater than presently experienced, require engine performance and structural integrity far in excess of present flight vehicles. Static engine testing provides adequate data to evaluate engine static performance, but the effects of flight maneuvers remain unknown.

Basing the need for some type of maneuver forces testing on identified trends and extensive discussions with military and industrial engine experts, minimum test requirements were established. Linear accelerations in the fore-aft, vertical, and side directions due to aircraft maneuvers, catapult takeoffs, and arrested landings are extremely important; and a minimum facility design requirement of 15 g linear acceleration capability was selected. Loads due to angular accelerations are considered secondary to those loads due to gyroscopic moments resulting from angular rotation during flight maneuvers. A minimum angular rate design requirement of 3.5 rad/sec was chosen based on flight test data of modern fighter aircraft. The only other major test requirement to be met is to couple linear acceleration and angular rate so they act simultaneously during an aircraft maneuver, such as combined pitch and yaw. It is important to note that the maximum linear acceleration and maximum angular rate normally do not occur simultaneously; in fact, one is more often near a minimum when the other is at a maximum. As a rule of thumb, forces acting on the engine for more than 3 sec arbitrarily were considered steady state and forces acting less than 3 sec as transient. It was determined that the most useful test information will be available from steady-state tests (as defined previously), and the ability to produce steady-state conditions was a primary goal. Table 1a summarizes the test requirements.

Major considerations used to determine how best to create the necessary conditions for meeting test requirements included instrumentation, flight testing, and ground simulation. An important factor in testing an engine under maneuver load conditions is being able to monitor relative movement between rotating and stationary parts of the engine in order to identify changes in gas seals and relate engine performance to the known sealing conditions. Another important consideration is to identify conditions where rub or wear between moving and stationary parts may cause damage or even catastrophic failure of an engine. To realize these intentions, optical devices mounted in the engine and the use of advanced X-ray techniques permit real time viewing of case or component distortion and movement inside an operating engine. Because of the difficulty of adapting optical and X-ray techniques to a flying test bed, in addition to the inability of current aircraft to produce a wide range of the needed test conditions for a highly maneuverable future flight vehicle, a ground test facility is considered essential. The ability to repeatedly produce identical test conditions economically in a ground facility is also an important consideration.

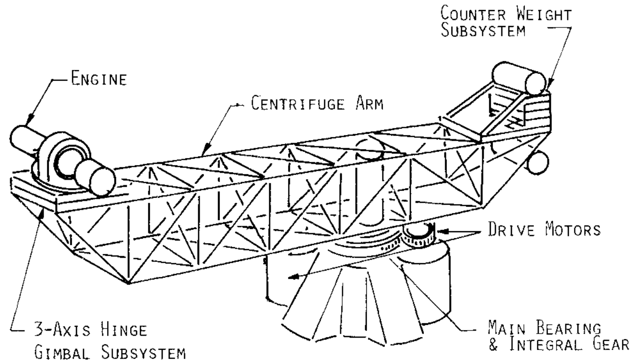

Fig. 1 Turbine engine loads simulator (TELS)

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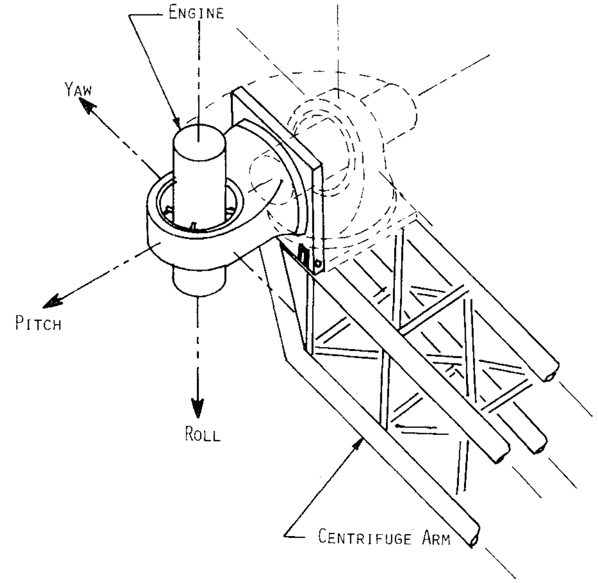

Fig. 2 Hinge-gimbal mechanism

Examination of several facility designs indicates that a centrifuge can produce both the linear accelerations and angular rates at the required magnitudes and in the combinations desired. Figure 1 shows a basic centrifuge design called the Turbine Engine Loads Simulator (TELS) with a 40 ft test arm and 20 ft counterweight arm that rotates at 33.4 rpm (3.5 rad/sec). The engine is mounted in a hinge-gimbal mechanism able to rotate 360° in pitch and roll, and ±90° in yaw as shown in Fig. 2. This unique mechanism permits orientation of the engine in any desired pitch, roll, yaw, or combined position, to accurately duplicate conditions encountered by the engine during flight. The entire hinge-gimbal can be located anywhere along the test arm from the 40 ft radius maximum load position (15 *g* and 3.5 rad/sec) to a zero radius directly over the pedestal that will produce pure gyroscopic loads (at 3.5 rad/sec). Pure linear acceleration loads on the engine are possible by orienting the engine vertically so its longitudinal axis is parallel to the centrifuge axis of rotation as in the final position shown in Fig. 2. To insure proper oil scavenging, engine orientation will take place as

Table 1 Turbine engine loads simulator design requirements

Parameter	Large engine	Intermediate engine
a. Test requirements		
Linear acceleration (g)	4	15
Angular rate (rad/sec)[a]	3.5	3.5
Gyroscopic moment (ft-lb)	200,000	400,000
b. Engine characteristics		
Diameter (ft)	10	5
Length (ft)	30	30[b]
Weight (lb)	10,000	5,000
Thrust (lb)	100,000	30,000

[a] Determined from actual and simulated flight data.
[b] With afterburner.

the arm begins to rotate and provides centrifugal acceleration forces to simulate the normal force of gravity.

Although the TELS centrifuge concept does not include a capability to induce transient load conditions, such as large angular accelerations or rapid onset rates, these are considered in the growth potential of the facility. The TELS will be capable of testing two groups of engines categorized according to engine-aircraft usage: first, high-maneuver-load engines normally in the smaller fighter aircraft, and, second, low-maneuver-load engines in cargo or transport aircraft. Table 1b summarizes the characteristics of these two engine categories. Reference 1 contains similar, but broader, nontechnical coverage of the study described here and is available from the author. Reference 2 is a detailed technical report on all aspects of the study, including data and calculations used in addition to some philosophy behind conclusions reached and decisions made.

References

[1]Mulenburg, G. M., "Ground Simulation of Flight Maneuver Forces on Turbine Engines," presented at the Symposium on Propulsion System Structural Integration and Engine Integrity, Naval Post Graduate School, Monterey, Calif., Sept. 1974.

[2]Andriulli, J., "Turbine Engine Loads Simulator Study," AEDC TR-74-73, TN, AD 923486L, Oct. 1974, Arnold Engineering Development Center, Tullahoma, Tenn.