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JT9D Engine Diagnostics: Task II—

Feasibility Study of Measuring In-service Flight Loads

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16. Abstract

The feasibility of measuring JT9D propulsion system flight inertia loads on a 747 airplane is studied. Flight loads background is discussed including the current status of 747/JT9D loads knowledge. An instrumentation and test plan is formulated for an airline-owned in-service airplane and the Boeing-owned RA001 test airplane. Technical and cost comparisons are made between these two options. An overall technical feasibility evaluation is made and a cost summary presented. Conclusions and recommendations are presented in regard to using existing inertia loads data versus conducting a flight test to measure inertia loads.

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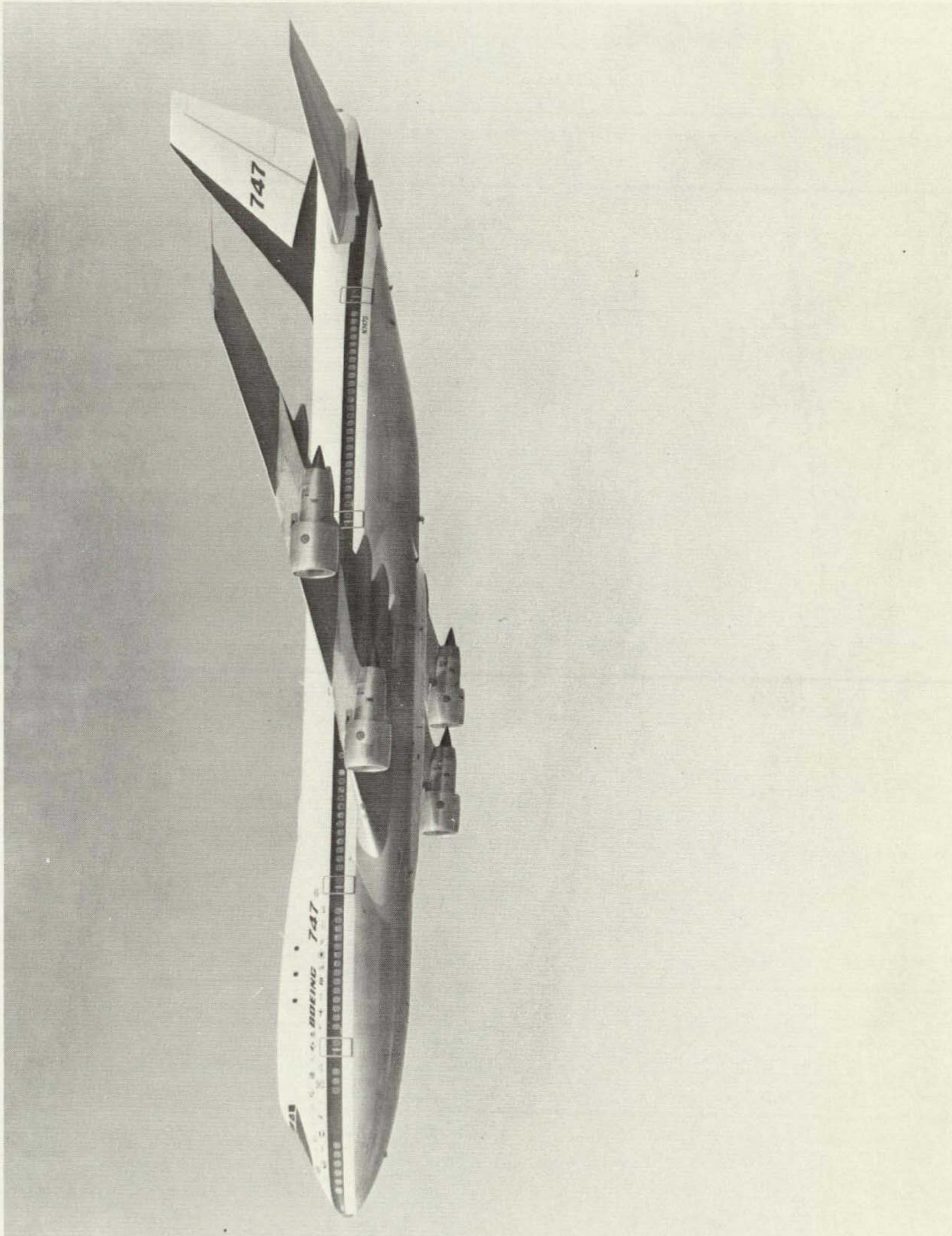

747
BOEING 747

1.0 SUMMARY

This is a report on the feasibility and desirability of measuring in-service flight inertia loads on the 747/JT9D propulsion system. Feasibility is based on technical and economic considerations while desirability is based on the requirement for such data in understanding short-term deterioration of the JT9D engine.

The development of a flight test and instrumentation plan is also included as an objective if this study. Optional measurement of performance data is included. Two test vehicle options are considered in this study: an airline-owned, in-service airplane and the Boeing owned RA001 test airplane.

The propulsion-related flight loads background is discussed and an evaluation of the status of propulsion system loads, aerodynamic and inertia, is given. A flight test and instrumentation plan is described and a comparison of the two test vehicle options is given. Finally a technical evaluation of feasibility and a cost summary for five different options of test vehicle and measured parameters is provided.

It is concluded that the flight test is considered feasible for both the airline-owned in-service and the Boeing-owned RA001 test airplanes, but the Boeing RA001 airplane has decided technical and economic advantages. Current knowledge of nacelle aerodynamic loads are concluded to be adequate for JT9D Diagnostics Studies. The existence of a large amount of test data on inertia loads has been revealed. Its adequacy for the JT9D Diagnostics Study is unknown and may hinge on the relative importance of nacelle aerodynamic and inertia loads on deterioration.

It is recommended that the flight test be postponed until more knowledge of the impact of aero and inertia loads in determined in other activities of the Engine Diagnostics Contract. In conjunction with these activities, an in-depth review of existing inertia loads test data is recommended. Subsequently, if inertia loads are determined to be a large contributor to deterioration and if sufficient existing inertia loads data do not exist, then the flight test should proceed.

A derivation of C.G. acceleration from measured data is given in Appendix A. Appendix B and C is an instrumentation list and a detailed flight plan respectively for the RA001 airplane. Appendix D gives the flight test program schedule.

2.0 INTRODUCTION

The Boeing Commercial Airplane Company, under subcontract to Pratt & Whitney, has conducted a feasibility study of measuring propulsion system flight inertia loads during a typical revenue service flight of the JT9D Propulsion System on a 747 airplane. This is a report of the feasibility study.

This effort is part of Task II of the JT9D Engine Diagnostic Contract. The purpose of Task II is to obtain in-service performance deterioration data.

The reasons for measuring in-service flight loads are:

1. To improve knowledge of propulsion system operating flight loads.
2. To provide data to correlate with engine thermodynamic parameters to determine what events in the flight spectrum contribute to TSFC deterioration.
3. To provide quantitative data for ground test, and analytical studies corroborated by engine teardown inspection results to determine the causes and location in the engine of TSFC deterioration.
4. To provide design data for new propulsion system designs related to the NASA Energy Efficient Engine Program.

The study was limited to inertia type loads, under an assumption that this will be the most cost effective measure of the propulsion system loads. Also, knowledge of aerodynamic loads on the nacelle is tentatively considered to be satisfactory for the purpose of studying TSFC deterioration. Considerable more expense would be required to measure nacelle aerodynamic loads. This could be proposed at some later time if required. Measurement of the temperatures and strains on the engine cases were also considered desirable but is outside the economic scope of this study.

Boeing's role in Task II, "In-Service Performance Deterioration," consists of two tasks:

1. Feasibility Study of measuring In-Service Propulsion System Flight Loads.
2. Engine/Airplane Monitoring Requirements and Plans, referred to hereafter as "Feasibility Study" and "Test Plan" respectively.

The Feasibility Study will determine the requirements and means for acquiring propulsion system loads and optionally the measurement of engine performance data. The Test Plan will provide the design of a flightworthy instrumentation package, installation, and test plan. Two airplane options are considered: 1) an airline-owned in-service airplane, and 2) a Boeing-owned test airplane RA001. This is a six-month duration study, requiring 1200 engineering manhours, four months for feasibility and two months for the test plan.

3.0 STUDY OBJECTIVES

The objectives of this program are to determine the feasibility and desirability of measuring in-service flight inertia loads for a typical in-service revenue flight. Feasibility relates to the technical and economic requirements while desirability relates to the need of collecting the data. The need depends on the relative impact of inertia loads on deterioration and on the amount of already existing test data that might be applicable to diagnostics.

Specifically, feasibility will be based on the following criteria:

1. Accuracy of the data collection system.
2. Reliability of the data collection system.
3. Completeness of the data measured.
4. Use of and requirement for flight test data.
5. Cost of acquiring the data.

Desirability criteria will be based on:

1. The relative impact of inertia loads on deterioration.
2. The completeness and quality of existing flight inertia loads data acquired from previous flight test programs.

4.0 FLIGHT LOADS BACKGROUND

4.1 CLASSIFICATION OF FLIGHT LOADS

Flight loads on the propulsion system can be divided in two categories, engine loads and airplane loads.

1. Engine loads are loads that are independent of the airplane flight environment. Engine loands include:

   - Internal engine pressures.
   - Thermal loads due to temperature differentials.
   - Thrust loads, both forward and reverse.
   - Centrifugal loads.

2. Airplane loads are loads imposed on the propulsion system by the airplane flight environment.

   Airplane loads include:

   - Aerodynamic pressures, both steady state and transient due to gust and maneuvers.
   - Inertia forces due to gust, maneuvers, landing impact and runway roughness.

   It should be noted that the nacelle is affected directly and indirectly by unsteady aerodynamic loads. Thus, a vertical gust will suddenly change the aerodynamic load distribution on the nacelle, setting up nacelle vibrations with respect to the wing, and will also induce wing oscillations that impose additional inertia forces on the nacelle.

4.2 SOURCES OF JT9D LOADS DATA

As a result of the Task IIIA efforts related to airplane flight loads, considerable data were determind to exist which had not been previously examined in relation to engine deterioration. These data consisted of wind tunnel tests, flight pressure tests, flight flutter tests, and flight loads surveys. In addition, theoretical analysis programs were reviewed for their potential for generating nacelle pressure and inertia data. The Task IIIA scope permitted only the investigation of nacelle pressure data, which have been thoroughly analyzed and introduced into the Task IIIA analytical efforts. The existing nacelle inertia loads data are extensive, and are derived from approximately 160 flight flutter tests and 14 flight loads survey tests and 14 flight loads survey tests. Their applicability to engine diagnostics is yet to be determined. Each of the loads data sources are now briefly reviewed.

4.2.1 WIND TUNNEL TESTS

Twelve wind tunnel tests were investigated, seven for force data and five for pressure data. None of these tests provided the combination of correct geometry, mass flow, mach number, angle of attack, and flap deflection that would be needed for direct use of the results. Consequently, these data were used mainly to countercheck flight test data and complement deficiencies in the latter.

4.2.2 FLIGHT PRESSURE TESTS

Nine flight pressure tests were run on the JT9D-7 engine, four with the blow-in-door (BID) inlet and five with the fixed lip inlet. Pressure distributions on cowls and inlets were measured over a wide range of flight conditions by means of pressure taps (up to 200 on the nacelle and strut).

This was the main source of pressure data to introduce into the NASTRAN model. In fact, whenever it was not possible to match exactly the desired combination of Mach number and lift coefficient, loads were inferred from the closest available flight test conditions.

Unfortunately the most heavily instrumented flight tests were run with the BID configuration and no pressure taps inside the inlet, while the fixed lip configuration had taps at only two circumferential stations.

4.2.3 FLIGHT FLUTTER TESTS

Flight flutter test programs were run in which vertical and lateral accelerations were measured at the inlet lip. Only limited information on inertia loads may be obtainable from these tests since it may not be possible to deduce the nacelle's C.G. acceleration and pitch and yaw rates. Furthermore, turbulence conditions were intentionally avoided in these tests, so that the nacelle accelerations may not be typical of in-service experience.

4.2.4 FLIGHT LOADS SURVEY

Two types of flight loads surveys were run, one for maneuver loads and one for gust loads. Again, the instrumentation may not be sufficient for a complete description of nacelle inertia loads.

4.2.5 THEORETICAL METHODS

The theoretical methods described here are of relatively recent origin and were not practical for use during 747/JT9D development. Thus none of these methods have been applied to the JT9D nacelle, but it is deemed appropriate to discuss them for completeness.

There are three principals applications of the theoretical methods as follows:

Three-Dimensional Subsonic Flow

For three-dimensional subsonic flow the Rubbert-Saaris (ref.1) sources and vortex singularities method has been used very successfully on other configurations. This method provides exact solutions of the compressible flow equation without any linearization of the boundary conditions. Compressibility effects are accounted for approximately by the Gothert rule. Very detailed pressure distributions on nacelles, pylons, and inside the inlets have been calculated (using as many as 1800 singularities) and found in excellent agreement with experimental values.

Transonic Potential Flow

For transonic flow a mthod has been developed which solves the potential flow equations by finite differences. Good results have been obtained for axisymmetric inlets at incidence.

Unsteady Flow

Unsteady pressure distributions can be predicted by a doublet lattice method, provided the configuration is sufficiently slender to allow linearization of the boundary conditions.

4.3 STATUS OF JT9D LOADS KNOWLEDGE

The status of JT9D loads is discussed in the context of Task IIIA efforts which have been carried out to date. In that effort, flight loads were evaluated at 14 points of a typical acceptance flight test mission profile for production 747's. (figure 1). Gust intensities and maneuver load factors were taken from the BCAC Fatigue Manual. (See ref.2)

4.3.1 AERODYNAMIC LOADS

In the Task IIIA effort, aerodynamic loads were obtained by running an aeroelastic solution for the Mach number, altitude, gust intensity and maneuver load factor pertaining to each analysis point of the mission profile. The airplane centerline so obtained, as well as the Mach number, were matched as closely as possible with an actual flight test condition to obtain aerodynamic pressure distributions on inlet and core cowl.

A total of 12 axially-positioned pressure taps were installed. Since only two circumferential stations (15° and 180°) were instrumented on the fixed lip inlet, the intermediate pressures were calulated by fitting a distribution law of the type, $p(\Theta) = A + B \cos(\Theta + Y)$, to the experimental data at each axial pressure station.

The phase angle $\emptyset$, which remains indeterminate, was choosen equal to 30° on the basis of a large number of test correlations. This is illustrated in figure 2 which shows that the phase angle is somewhere between 15° and 35°, and in figure 3 which shows that calculated ratios of vertical load to side load agree best with wind tunnel tests when a 30° angle to outboard is selected (black symbols). Aerodynamic forces on the core cowl turned out to be small compared with inlet forces.

In summary, it is felt that an adequate representation has been obtained of the effects of steady state aerodynamic loads as well as the statically equivalent effect at sharp edge gusts.

4.3.2 INERTIA LOADS

In the Task IIIA efforts vertical inertia load factors at the airplane C.G. were obtained from am aeroelastic solution and multiplied by a dynamic magnification factor to obtain nacelle loads. The result is almost certainly conservative because in the aeroelastic solution, gusts and maneuver loads were assumed to occur simltaneously, which is not usually the case.

Lateral inertia load factors on the nacelles were obtained from a fatigue analysis. These inertia load factors are more likely to represent peak envelope loads than actual operating loads. The uncertainties arise from the lack of knowledge of the true dynamic response of the airplane nacelle structural assembly.

Landing impact factors were obtained from flight test data and are considered adequate.

In summary, the transient motion of the nacelle is coupled to the motion of the airframe and cannot be treated as an isolated system for dynamic purposes. A large number of nacelle lineal acceleration measurements are known to exist. Whether these can be made applicable o the engine diagnostic study is unknown at this time. Nacelle pitch and yaw rate measurements apparently do not exist. Design values have been estimated in the past by extrapolation from airplane C.G. measurements.

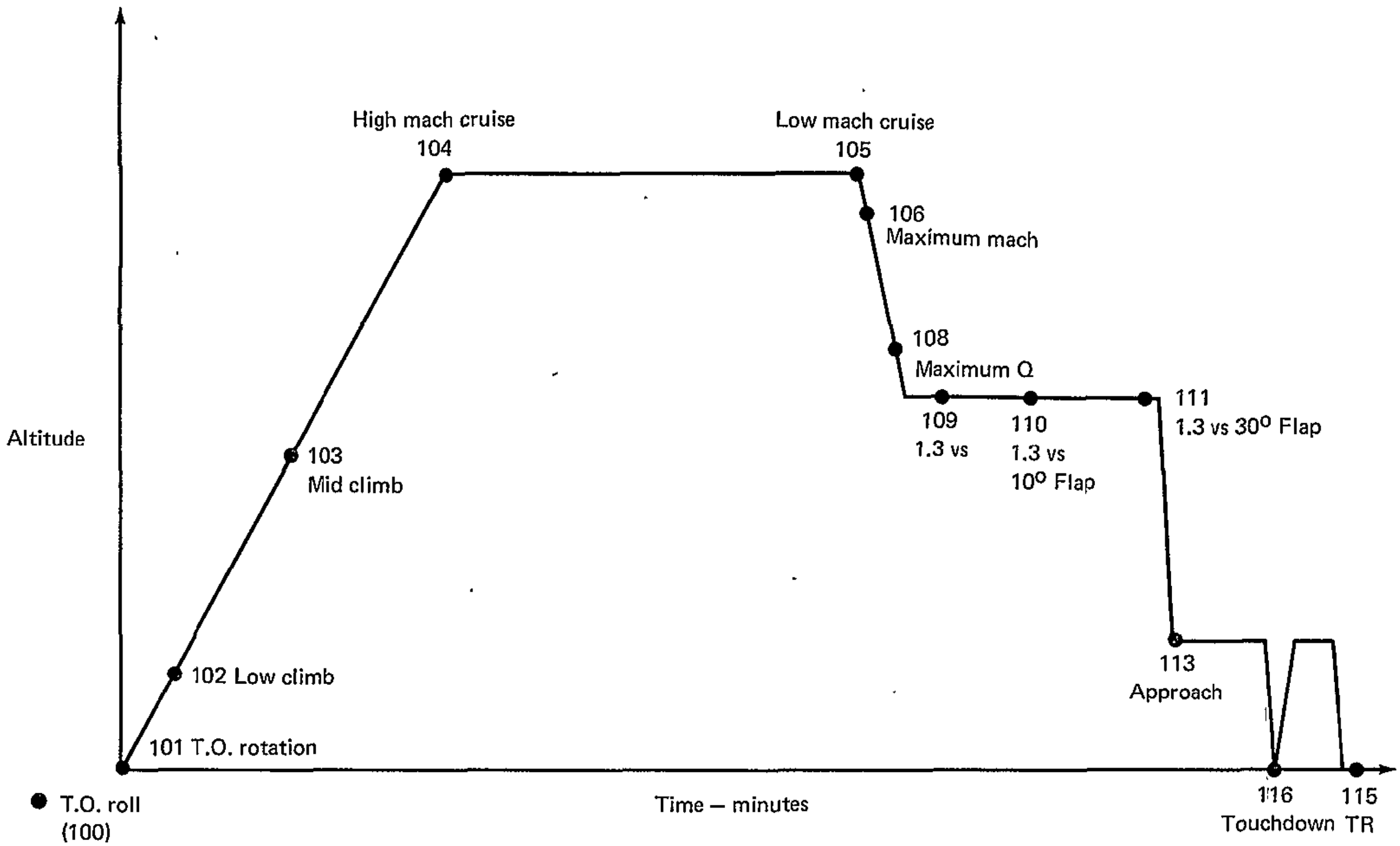


Figure 1.– Acceptance Flight Test Profile

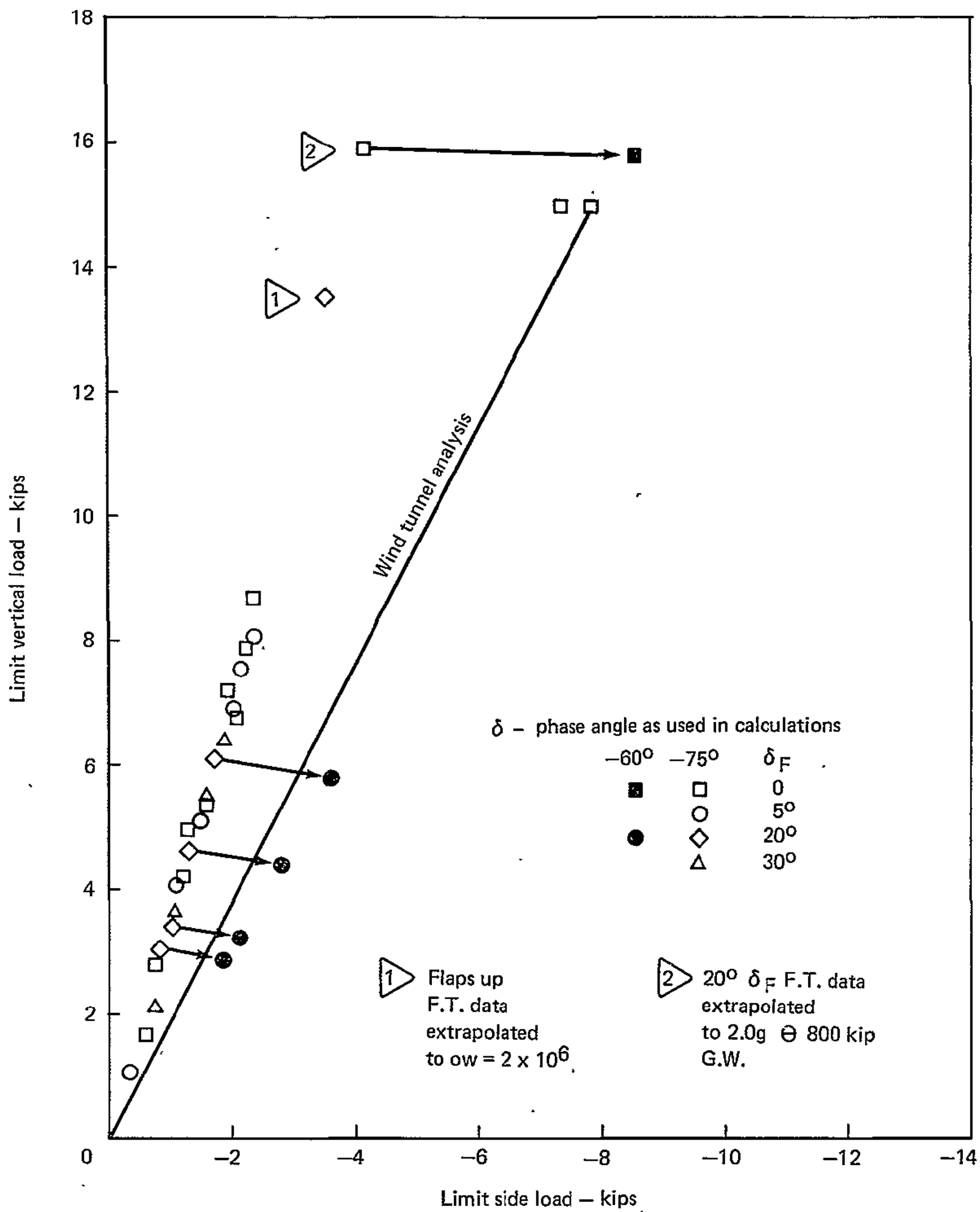


Figure 2.— Fixed Lip Inlet - Fan Cowl Loads NAC STA 100

Wind-up Turns

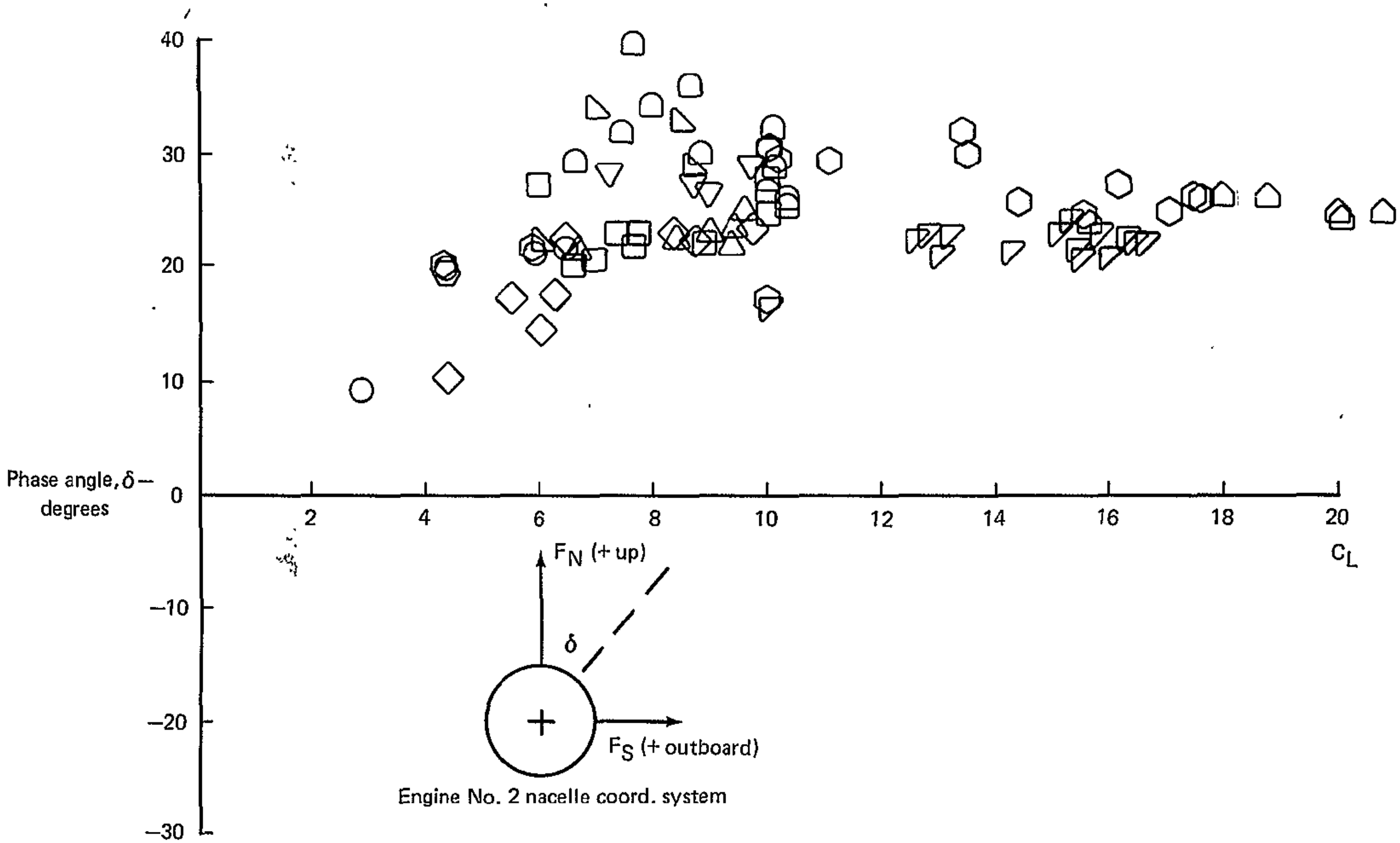


Figure 3.– Blow-In-Door Inlet - Phase Angles

5.0 PROPOSED FLIGHT TEST

This part of the study is to determine the requirements and means for acquiring propulsion system flight inertia loads data on one inboard and one outboard 747/JT9D propulsion system. The study also will determine separately the means for acquiring engine performance data simultaneously with the propulsion system loads and to define the instrumentation and data recording requirements.

Originally the flight test was intended to monitor the loads simultaneously with performance data of a new engine during flight acceptance testing and initial in-service flights, thus providing correlation of deterioration with events in flight. This plan was essentially precluded by the PICS program which, during initial flights, monitored performance data of new engines which were then removed for teardown inspection. The primary need now is to determine the magnitude of acceleration and angular velocities of the propulsion system during initial flights. The option of measuring engine performance data in addition to loads is still included, as well as the option of an in-service airplane or the Boeing 747 test airplane RA001.

Generally, the placement and operation of load measuring devices (accelerometers) on airplane structure is a straight-forward procedure. The peculiar requirements that necessitate this feasibility study is the revenue flight environment, the length of recording time, the type and number of required measurements, in a severe operating environment, and the frequency range. All of these call for more stringent instrumentation requirements than usual, particularly with respect to reliability.

This section will describe the instrumentation selection , the two test vehicle options, data reduction, as well as a comparison of technical requirements, costs, and schedules, for the two options.

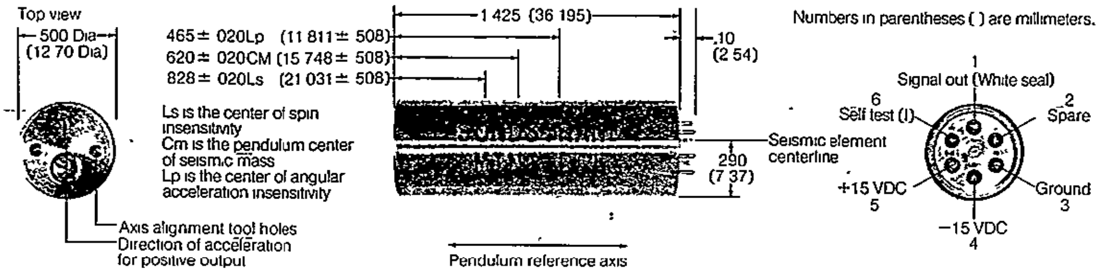
5.1 TRANSDUCER SELECTION

The estimated requirement for measurement accuracy in the range of 1 to 2% of full scale dictated the use of highly accurate linear accelerometers on the powerplant. To obtain angular as well as linear accelerations at the powerplant center-of-gravity, a system of equations based on rigid body motion was derived. This derivation is presented in Appendix A. The installation locations were then determined based on these equations and other requirements such as operating environment, accessibility, and structural rigidity.

5.1.1 POWERPLANT PRIMARY TRANSDUCERS

Most flight test experience with accelerometers designed for D. C. to low frequency response in the past 10 years has been with servo-type accelerometers in temperature environments not exceeding 185° F. A new, highly accurate servo accelerometer, the Sunstrand Mini-pal Model 2180, (figure 4) is now available in ranges to ± 150 g's for operation in environments up to 160° F. It was decided that this instrument would be the primary sensor if a low temperature location could be found for installation.

Sundstrand Data Control, Inc.
Low Temperature Mini-pal Servo Accelerometer
Model 2180



Specifications

Range full scale	±1g to ± 50 g max
Sensitivity, voltage (VG) . . .	5V/g to 0.03 V/g
Output voltage linear range	± 5V max
Sensitivity current (1g)	0.3 ± 1%mA/g
Source impedance.	RL=Vg/1g
Supply voltage.	±15VDC ± 10%, 350 mW max
Natural frequency	150Hz min
Damping	0.3 to 1.0
Linearity	<0.05% of full range or 0.005 g whichever is greater
Hysteresis and repeatability . . .	<0.02% of full range or 0.005 g whichever is greater
Threshold	.005% of full range maximum
Output at zero G	0±0.010 g maximum
Scale factor temperature coefficient	±0.02%/°C maximum
Temperature zero shift	± 0.00005g/°C maximum
Axis alignment error	0.005g/g maximum
Case alignment error	.75° maximum
Vibration rectification coefficient (sine)	$0.00010g/g^2$
Vibration limit 20 to 2000hz	16g RMS
Acceleration limit	250g
Shock limit (5 ms pulse) . . .	200 g peak
Temperature, operating. . . .	−55° C to +71° C
Temperature, storage	−60° C to +100° C
Humidity	Sealed Case
Current self test (pins 1 and 6)	3.33 ± 0.3g/mA
Weight	20 grams

Figure 4.— Low Temperature Accelerometer

Pratt and Whitney engine case temperature data (figure 5) was then reviewed to determine instrumentation locations that were below 160° F. To be conservative, the worst case of 120° F takeoff at sea level with 8th stage bleed was selected, during which the only area cooler than 160° F is forward of Nacelle Station 100, the "A" flange defined in figure 5. To solve the equations for all c.g. acceleration components, at least six accelerometers had to be installed in this area.

Figure 6 shows the selected locations for primary instrumentation which are identified in table 1. These include a vertical and lateral accelerometer on the Hi-lite at NS 40 and two vertical, one lateral and one longitudinal accelerometers, on the "A" flange at NS 100. All of these accelerometers will be ±50 g models to preclude loss of data due to high g levels at frequencies out of the range of interest. Additionally, these unwanted frequencies (above 20 Hz) will be removed from the transducer output before digitization through the use of 4-pole Butterworth low-pass filters. To measure engine angular rates in pitch and yaw, a Northrup 3-axis D.C. gyro (figure 7) will be installed at the 3 o'clock position (looking aft) of NS 100. This gyro has been used extensively on flight test programs in the past seven to eight years and is highly reliable.

5.1.2 POWERPLANT REDUNDANT ACCELEROMETERS

To support the primary instrumentation a total of eleven additional accelerations will be used. These are located in the higher temperature areas of the engine (figure 6) at two locations - the diaphragm at NS 152 and the "P" flange at the aft end of the low pressure turbine, NS 254. These locations will employ a yet-to-be-proven accelerometer, the KAMAN 1901 (figure 8). This transducer uses an eddy current technique to give very high accuracy with low hysteresis in environments up to 1050° F. The transducer will, of course, be subjected to a thorough check-out at the BCAC Flight Test Instrumentation Technology Laboratory prior to inclusion on any test flight. Other redundant powerplant instrumentation includes a vertical and lateral accelerometer at the front mount, NS 125, and vertical accelerometers at the attachment point of the pylon to the wing at the front and rear spar. These installations will employ the KISTLER, Model 303TF20, (figure 9) a low temperature servo accelerometer already exisiting and proven in flight test. Table 2 describes the redundant accelerometers.

A Complete tablulation of all powerplant transducers and their specifications is included as Appendex B.

5.1.3 AIRPLANE BASIC INSTRMENTATION

To obtain airplane airspeed, altitude, and Mach number the co-pilots' total and static pressure will be recorded along with airplane total temperature. The six components of acceleration at the airplane c.g. will also be recorded. Other engine parameters to be instrumented include low pressure rotor RPM (N1) and engine pressure ratio (PT7/PT1) on both instrumented engines. The airplane basic measured parameters are listed in table 3 and are further identified with all other transducers in Appendix B.

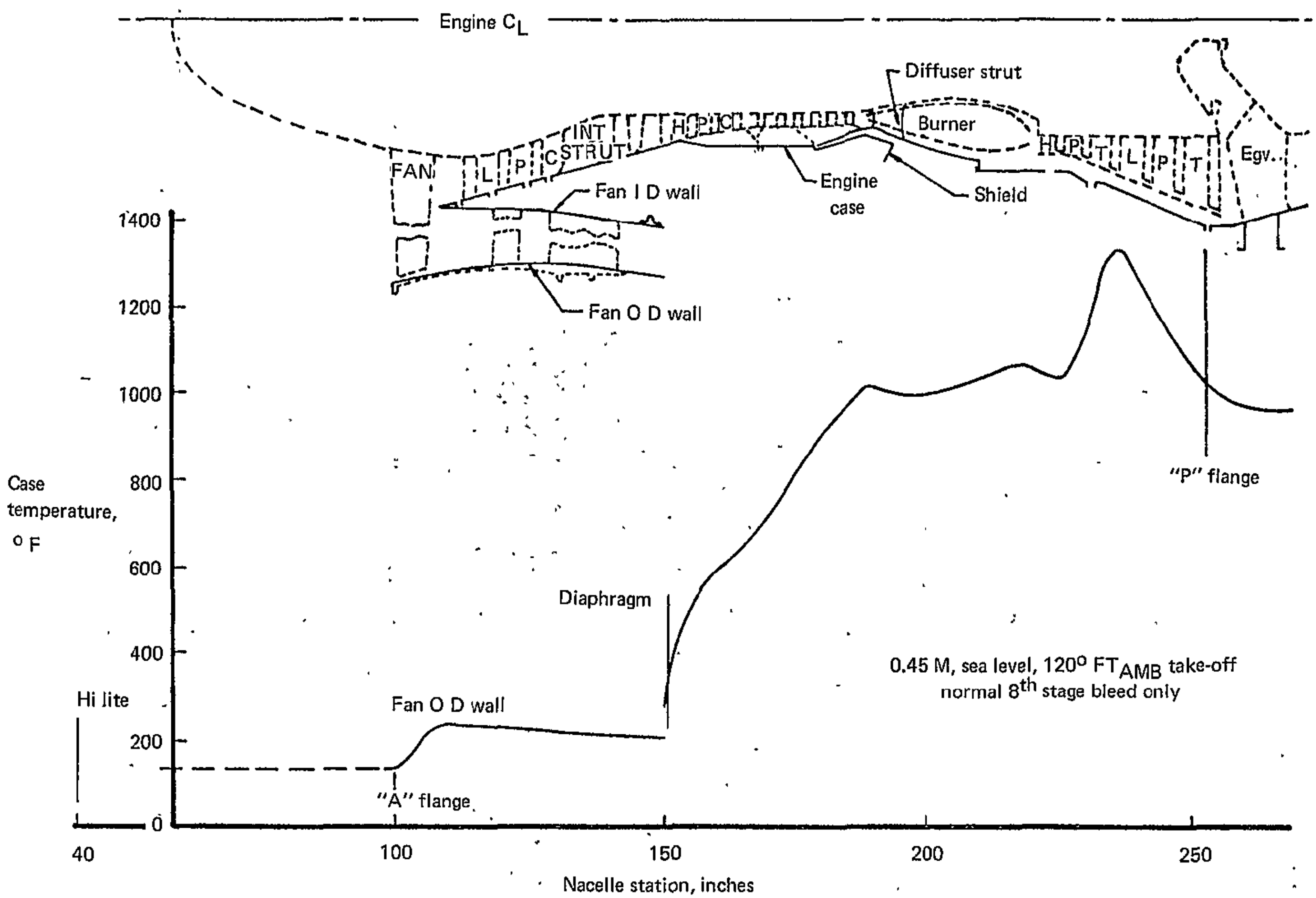


Figure 5.— JT9D Engine Case Temperature

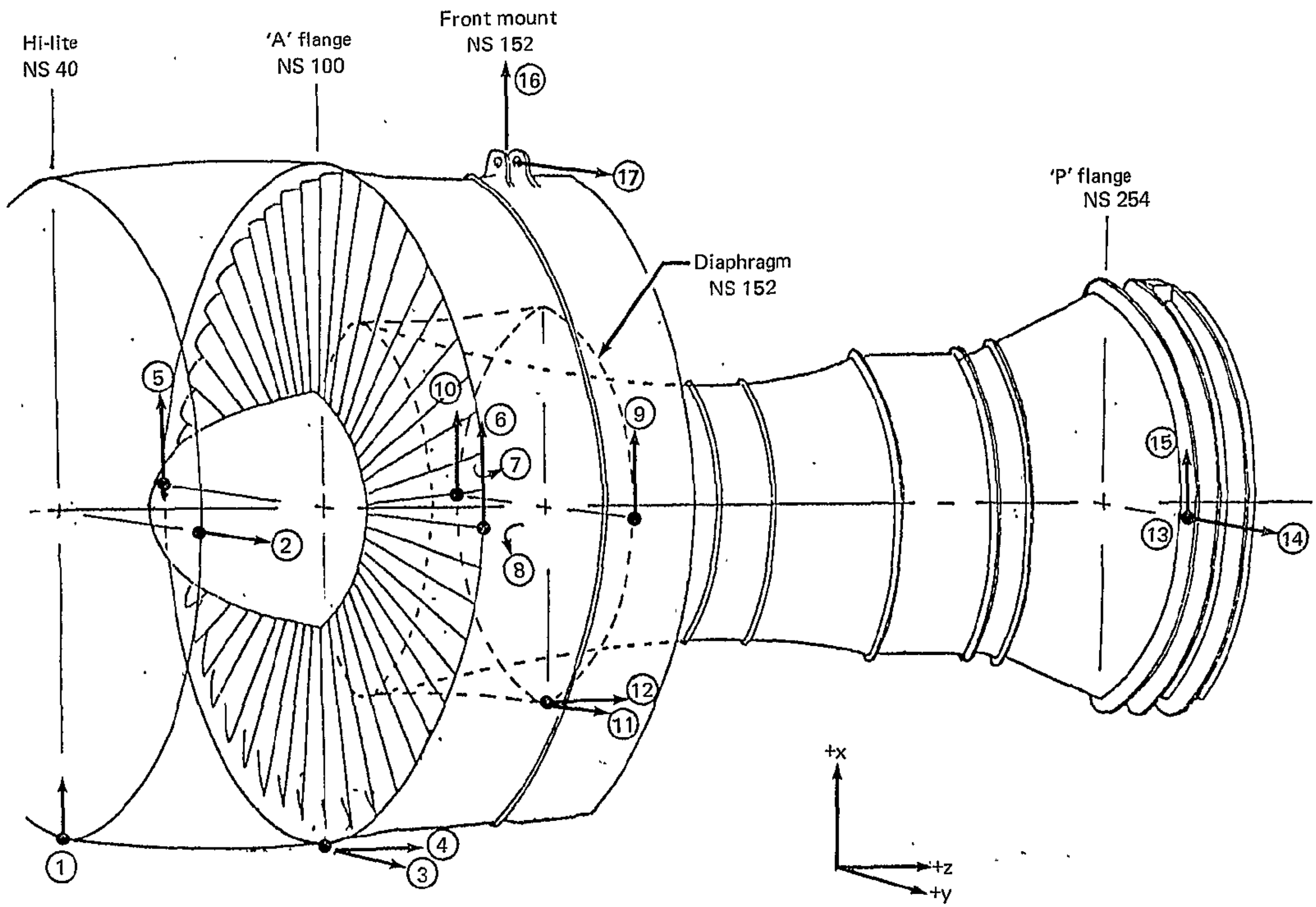
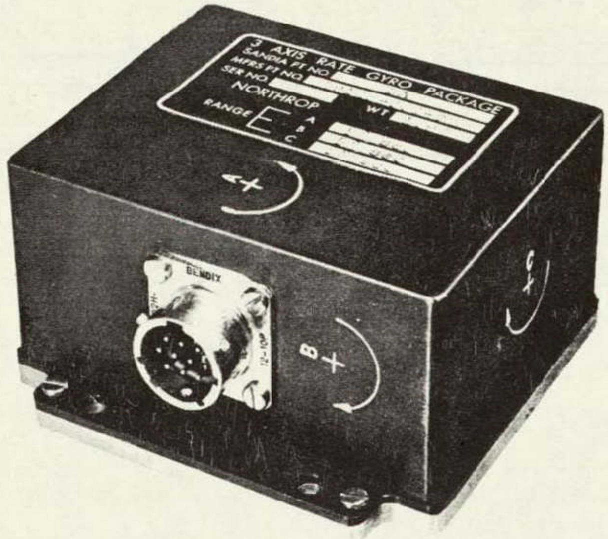


Figure 6.— Powerplant Accelerometer Locations

Table 1.— Powerplant Instrumentation-Primary

					Engine 1 and 2 Instrumentation		
Code	Description	Units	Min	Max	Accuracy	XDCR type.	Maximum operating temp.
1	Vertical acceleration — NS40 —6 o'clock	g	–4	6	0.1	Mini-pal	150° F
2	Lateral acceleration — NS40 —3 o'clock	g	–2	2	0.04	Mini-pal	150° F
3	Lateral acceleration — NS100 —6 o'clock	g	–2	2	0.04	Mini-pal	150° F
4	Longitudinal acceleration — NS100 —6 o'clock	g	–2	2	0.04	Mini-pal	150° F
5	Vertical acceleration — NS100 —9 o'clock	g	–4	6	0.1	Mini-pal	150° F
6	Vertical acceleration — NS100 —3 o'clock	g	–4	6	0.1	Mini-pal	150° F
7	Yaw rate — NS100	deg/sec	–10	10	0.2	Northrup 3–axis	150° F
8	Pitch rate — NS100 —3 o'clock	deg/sec	–15	15	0.3	Northrup 3–axis	150° F

Northrup
Angular Rate Gyro
3 Axis DC/DC

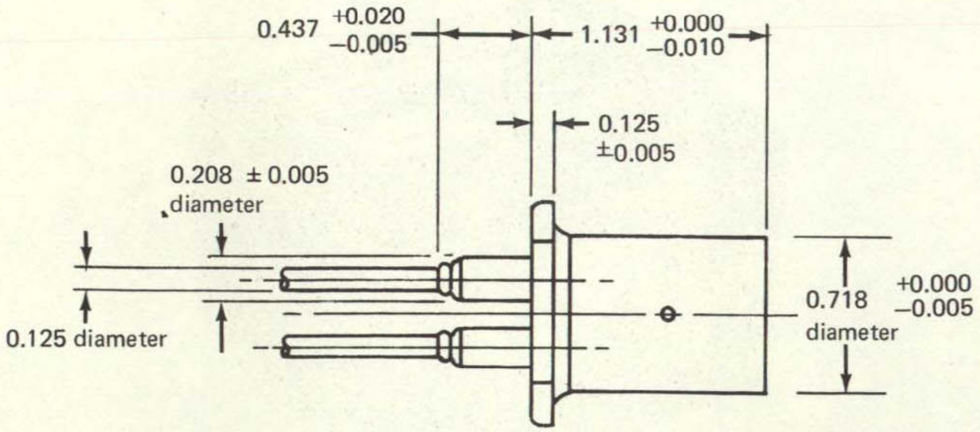


Specifications

Range	Pitch	±15 deg/sec
	Roll	±60 deg/sec
	Yaw	±10 deg/sec
Linearity		±0.5% full scale
Hysteresis		±0.2% full scale
Threshold and resolution		±0.01 deg/sec
Damping ratio		0.7 ±0.07 critical
Frequency response		Flat to 0.5% full scale from 0-15 hz
Phase shift		Output lagging no greater than 18° from 0-5 hz
Acceleration sensitivity	Linear	$<$0.05 deg/sec/g
	Angular	$<$0.04 deg/sec/radian/sec^2
Non-repeatability		$<$0.04% full scale
Thermal zero shift		±0.01% full scale/°F
Thermal sensitivity shift		±0.03% full scale/°F
Output voltage		±2.5V full scale
Output impedence		$<$ 5000 ohms
Output ripple		$<$ 40 MV p-p
Overrange capability		To ± 500 deg/sec in any axis
Operating temperature		20 to 135° F

Figure 7.– Angular Velocity Transducer

Kaman Sciences Corporation
High Temperature Accelerometer
Model KA-1901

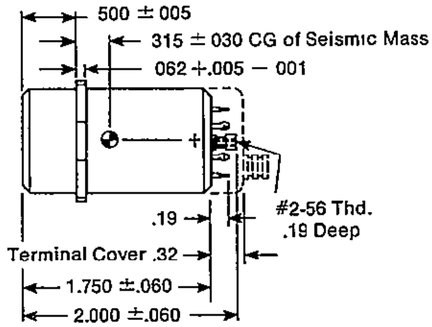


Specifications

Range	±1.0 g to ±100 g
Input	28V DC, 110 VAC, 60~
Output	+5V DC
Dynamic resolution	0.1% full scale
Operating temperature . . .	−100° F to 1050° F continuous
Non-linearity	< ± 1% full scale
Sensitivity shift w/temp . .	< 0.01% full scale/ °F
Zero shift w/temp	< 0.01% full scale/ °F
Frequency response range . .	Dependent on range i.e., for ± 5g the response is DC to 150 hz (down 3dB @ 150 hz)
Overload capability	300% full scale
Humidity effect	None
Operating pressure	500 PSI

Figure 8.– High Temperature Accelerometer

Sundstrand Data Control, Inc.
Low Temperature Servo Accelerometer
Model 303TF20



303T/TF PIN CONFIGURATION

PIN 1. +28 VDC
2. POWER GROUND
3. LOW IMPEDANCE SIGNAL
4. SIGNAL GROUND
5. GAIN
6. SIGNAL
7. +TEST
8. –TEST

Specifications

Range (full scale)	±40g
Voltage sensitivity (adjustable)	0.1 V/g
Current sensitivity (nominal)	0.24 ma/g
Output voltage	to ±5.0 V
Noise: 1 MHZ to 8 MHZ (less than)	5 mV, rms
Below 1 MHz (less than)	1 mV, rms
DC to 1 Hz (resolution)	5 micro-g
Supply voltage and current	±28 VDC ±10%; 40 ma, max
Electrical isolation at 50 VDC, pins to case	50 megohms
input to output at 50 VDC	50 megohms
Linearity (to 50 volts any range)	±0.05% full scale
Hysteresis and repeatability	0.0005 g
Output at 0 g (max)	±500 mg (303TF)
Zero shift with line voltage (max)	0.005 g/V
Sensitivity shift with line voltage (max)	0.05%/V
Temperature range	-65^{o} F to $+185^{o}$ F
Zero shift with temperature variation	0.150 g/100^{o} F
Sensitivity shift with temperature variation	0.01%/^{o} F
Transverse acceleration -DC to 5 HZ	±100 g
-5 HZ to 2000 HZ	40 g peak
Cross coupling coefficient (pendulosity error)	none
Case alignment (to true sensitivity axis)	0.002 g/g
Acceleration limit (non-operating sensitive axis)	200 g
Shock limit (5 msec pulse)	200 g
Weight (with terminal cover)	3.4 oz.

Figure 9.— Kistler Low Temperature Accelerometer

Table 2.— Powerplant Instrumentation-Redundant

Engine 1 and 2 Instrumentation

Code	Description	Units	Min	Max	Accuracy	XDCR type	Maximum operating temp.
9	Vertical acceleration — NS152 –3 o'clock	g	–4	6	0.3	Kaman 1901	350° F
10	Vertical acceleration — NS152 –9 o'clock	g	–4	6	0.3	Kaman 1901	350° F
11	Lateral acceleration — NS152 –6 o'clock	g	–2	2	0.12	Kaman 1901	350° F
12	Longitudinal acceleration — NS152 –6 o'clock	g	–2	2	0.12	Kaman 1901	350° F
13	Temperature — NS254 –3 o'clock	°F	0	1100	11		1040° F
14	Lateral acceleration — NS254 –3 o'clock	g	–2	2	.12	Kaman 1901	1040° F

Table 2.— (Concluded)

Engine 1 and 2 Instrumentation

Code	Description	Units	Min	Max	Accuracy	XDCR type	Maximum operating temp.
15	Vertical acceleration — NS254 —3 o'clock	g	–4	6	0.3	Kaman 1901	1040° F
16	Vertical acceleration — NS125, front mount	g	–4	6	0.1	Kistler	100° F
17	Lateral acceleration — NS125 front mount	g	–2	2	0.04	Kistler	100° F
18	Vertical acceleration — Front Spar wing/strut intersection	g	–4	6	0.1	Kistler	100° F
19	Vertical acceleration — Rear Spar wing/strut intersection	g	–4	6	0.1	Kistler	100° F
20 → 27	Possible 8 channels — 4 thermocouples and 4 strain gages - to be installed by Pratt & Whitney to measure case bending loads						

Table 3.— Airplane Basic Instrumentation

Description	Units	Min	Max	Accuracy
Co-pilot's total pressure	In. HG	.1	12	.003
Co-pilot's static pressure	In. HG	3	31	.006
Total air temperature	Deg. C	−60	60	0.6
C.G. lateral acceleration	G	−2	2	0.04
C.G. longitudinal acceleration	G	−1	1	0.02
C.G. normal acceleration	G	−1	3	0.04
C.G. pitch acceleration	Deg/sec^2	−35	35	1.4
C.G. roll acceleration	Deg/sec^2	−40	40	1.6
C.G. yaw acceleration	Deg/sec^2	−15	15	0.6
Irig time	Hr:min:sec			0.001 sec

5.2 TEST VEHICLE OPTIONS

Originally, the feasibility study was limited to an in-service, passenger aircraft. The intent was to monitor inertia loads and performance of a new engine over the first few decade hours of flight and correlate performance deterioration with flight events, tear-down inspection results, test stand X-ray measurement and structural analysis results. As the scope narrowed to obtaining only inertia loads data, the requirement for a new engine no longer existed. Consequently, the test vehicle selection was widened to possibly include either a freighter with JT9D's or the Boeing-owned prototype 747, RA001. As far as the Flight Test program was concerned, there would be no difference if either a freighter or passenger airplane was chosen as the in-service vehicle and hereafter they will both be referred to as the "in-service" airplane.

5.2.1 IN-SERVICE AIRPLANE

The in-service airplane program would cover a period of three months during which 50 hours of data would be collected. The 64 channels of basic instrumentation would be installed during the factory cycle and recorded on a tape recorder mounted in the forward electronics bay. The data acquisition system, outlined in figure 10, would include signal conditioning for the 64 channels, and IRIG time display, a bit synch decommutator for maintenance monitoring and checkout, and a Bell and Howell M-14E tape recorder activated from the flight deck by the flight engineer. This system will provide four hours of continuous recording capability, but would only be activated by the crew during takeoff, climb, and a few minutes of cruise, turbulence encounters, approach and landing. Due to the widely dispersed destinations during an average week's flying (see figure 11) flight test personnel would be stationed at key points along the route to maintain the data system, remove the data system, remove the tapes, and send them to Seattle for reduction.

5.2.2 RA001 AIRPLANE

The RA001 test program would be conducted from Boeing Field, Seattle, over a period of 3 months. During this time, 30 hours of data would be collected on the high speed PCM data system and monitored via the Airborne Data Acquisition and Monitor System (ADAMS), (figures 12 and 13).

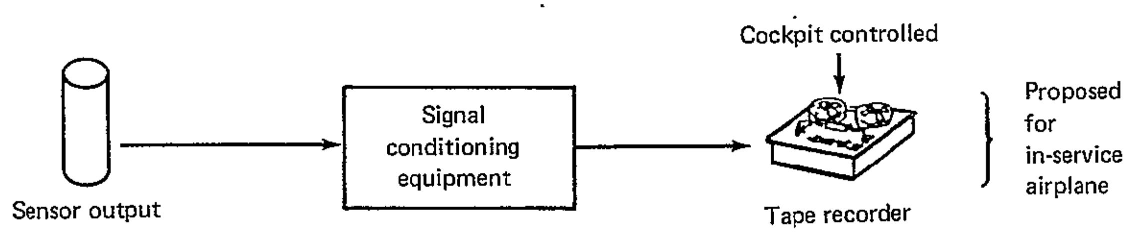


Figure 10.— In-Service On-Board PCM Data System

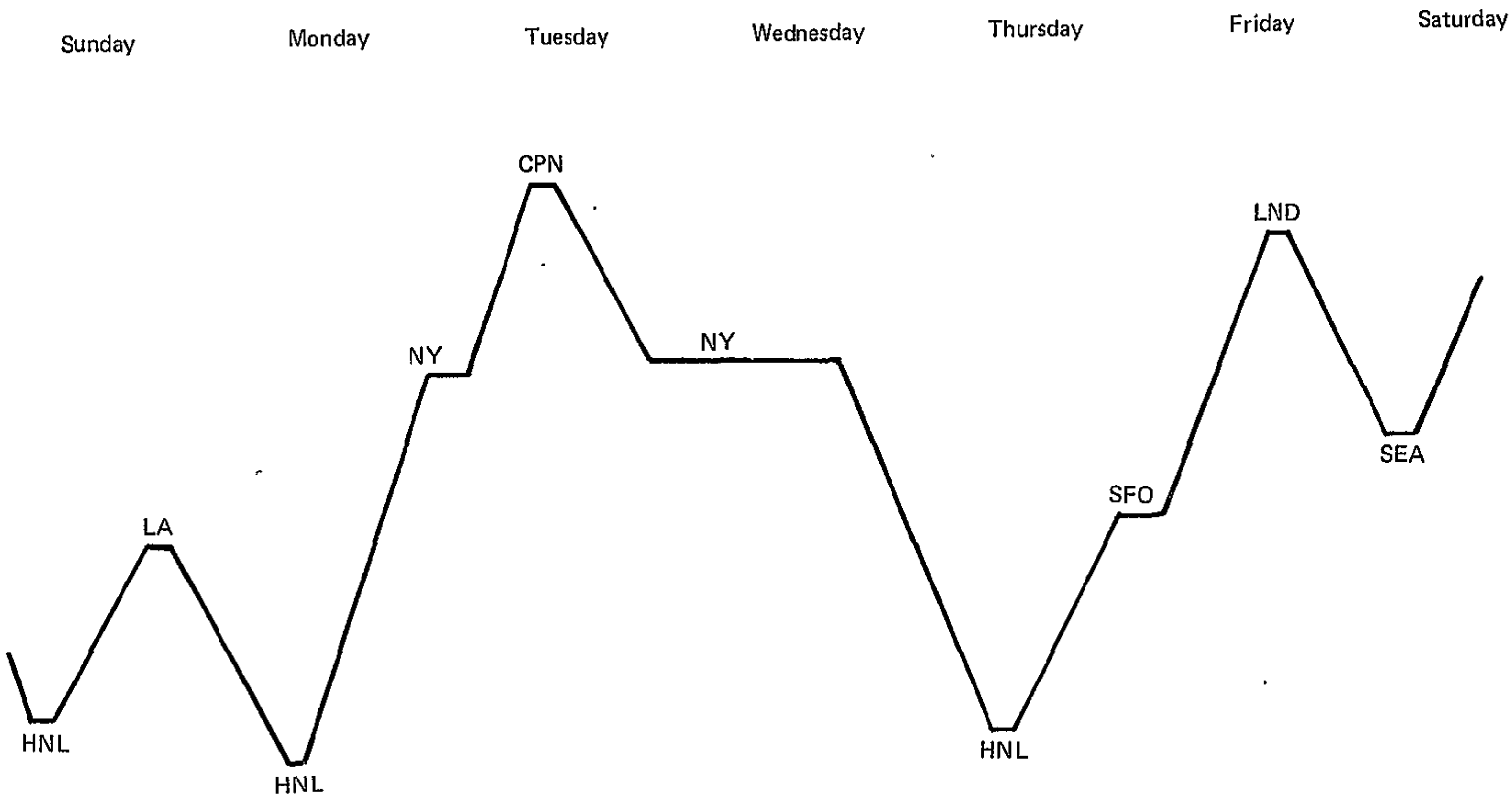


Figure 11.– Typical 747 In-Service Flight Schedule

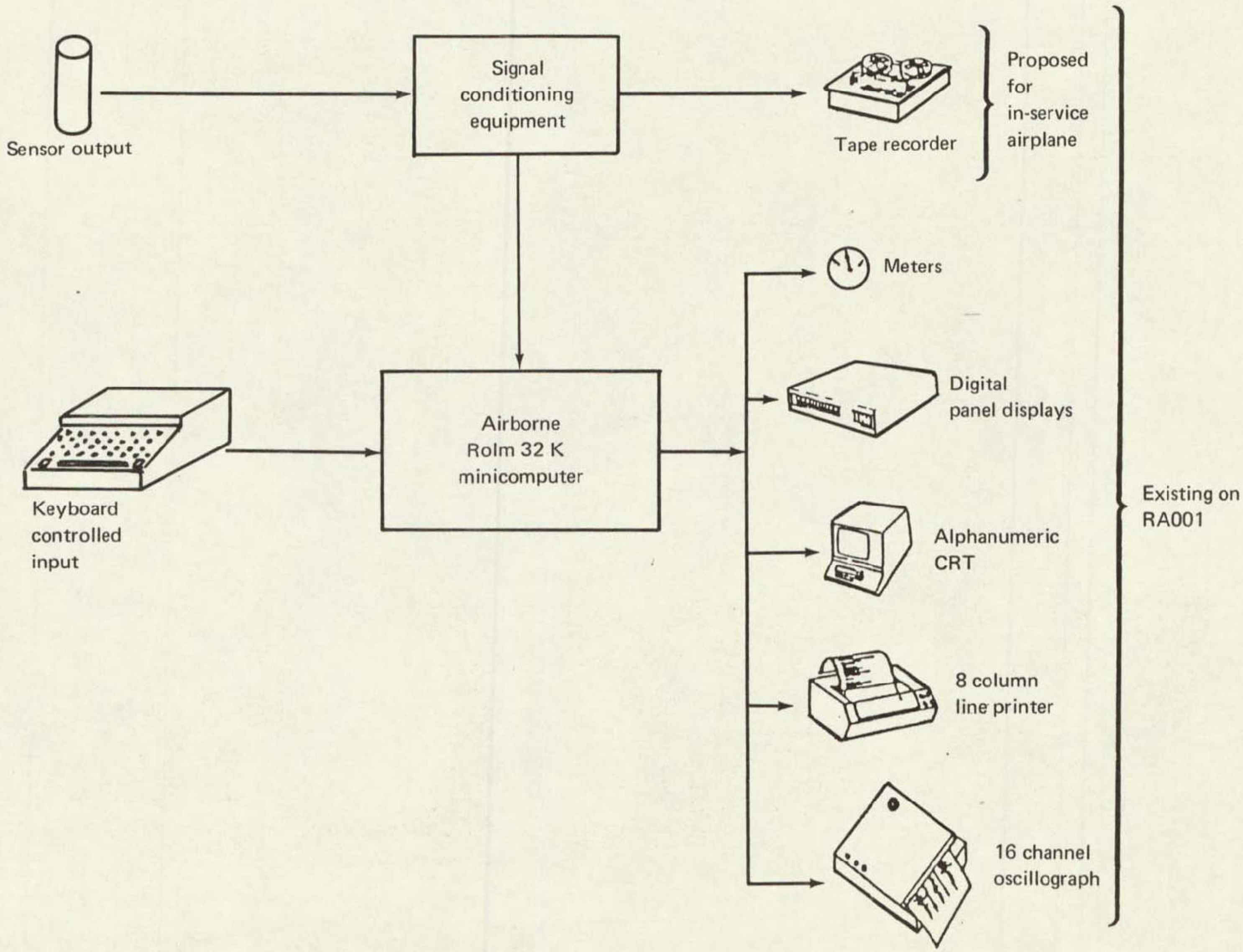


Figure 12.– RA001 On-Board Data System

Figure 13.– 747 RA001 Airborne Data Acquisition and Monitor System (ADAMS)

The high speed pulse code modulation (HSPCM) acquisition system is a programmable, digital system consisting of remote multiplexer/demultiplexer units (RMDU's), a distribution assembly, and a tape recorder. Each data value is contained in a 10 bit word with a resolution of one count in 1023. The data system is operated at 128,000 bits per second and can handle individual sampling rates, depending on the number of measurements required, up to 800 samples per second. At the tape speed of 7 ½ inches per second, the Bell and Howell M-14E tape recorder can record continously for four hours with a 9200-foot tape. The tape can be changed inflight to allow, essentially, non-stop recording from take-off through landing.

The ADAMS provides the capability to accomplish preflight instrumentation checkout, inflight monitoring and real time computation and analysis on any recorded parameter. It can be used to route transducer outputs to an alpha-numeric CRT, an 8-column high-speed printer, digital panel display units, or a 16-channel oscillograph.

The RA001 airplane has reconditioned JT9D-7A's installed at all four positions. These engines have fan pressure rakes and primary nozzle rakes installed along with other temperature, position, and rate transducers, and were calibrated for thrust measurement at the Boeing Tulalip Test Facility. A list of pertinent engine performance parameters available on RA001 are in table 4. The parameters listed in table 5 can be derived from these, using the in-flight computer system.

Table 4.— RA001 Engine Performance Parameters

Fuel quantity consumed
Fuel temperature
Bleed duct pressure and temperatures
Inlet guide vane angular position
Power lever angle at the fuel control
High pressure compressor static pressure (PS4)
Low pressure compressor total pressure (PT3)
High spool rpm (N2)
Low spool rpm (N1)
Low pressure turbine exit total temperature (TT7)
Low pressure turbine exit total pressure (PT7)

Table 5.— RA001 Derivable Engine Parameters

Net and gross thrust — fan, primary, and total
Ram drag
Engine airflow rates — actual and referred
Engine pressure ratio
Turbine pressure ratio
Primary nozzle expansion ratio
Fan nozzle expansion ratio
Inlet temperature ratio
Gas specific heat ratio
Predicted fuel flow
Primary bleed airflow
Engine bypass ratio

A test plan was developed for RA001 that would contain all maneuvers encountered in production flights that contribute to significant powerplant inertia loads. As shown in figure 14 these maneuvers include:

- takeoff roll and rotation
- turbulence encounters
- avoidance maneuvers
- landing impact and roll-out

5.2.3 DATA REDUCTION

All data reduction will be accomplished by the Flight Test Dta Group (Organization B-7955) at Seattle, Washington. The data reduction facility is shown in the photograph of figure 15. As shown in the data flow schematic, figure 16, the flight tapes will be processed in the ground station to change the digital data bitstream to an engineering units format and then passed on to the IBM 360 computer for processing through advanced procedures. Output from the system can be in the form of plots, tabulated data or an output media tape that can be used by Boeing Technology Staff organization on their PDP 11 computers.

5.2.4 TEST VEHICLE COMPARISON

Cost and Schedule

The original cost study presented to NASA-LEWIS on August 23, 1977 did not include 8 channels of strain gages and thermocouples proposed by Pratt and Whitney to measure case bending loads or 5 acceleration channels.

Discussion following this meeting revealed a desire on the part of Pratt and Whitney to have cost and schedule figures for several other RA001 program options including:

- the basic instrumentation package obtained during 10 dedicated flight hours and 20 concurrent hours.
- the basic instrumentation package + 22 engine performance parameters obtained on a 10 dedicated/20 concurrent flight hour basis.
- the basic instrumentation package obtained during 30 hours of dedicated testing.
- the basic instrumentation package + the engine performance package obtained during 30 dedicated hours.

A chart presenting these revised RA001 cost and schedule options as well as the basic package for an in-service airplane is presented in the Cost Summary of Section 7.0 Appendix D gives the overall program schedule.

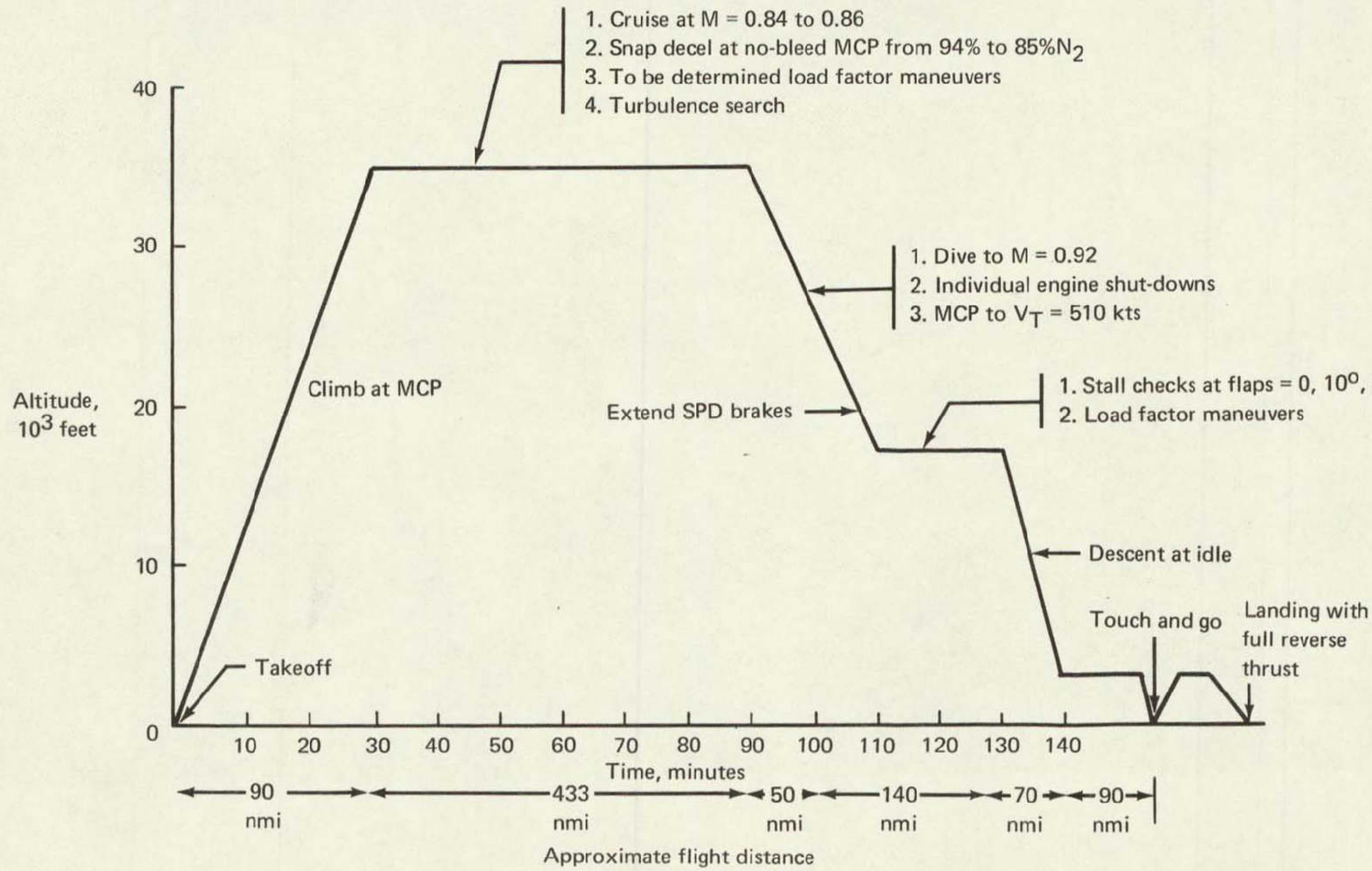


Figure 14.– RA001 Flight Test Profile - Preliminary
(See Appendix C for final plan)

Figure 15.— Data Reduction Ground Facility

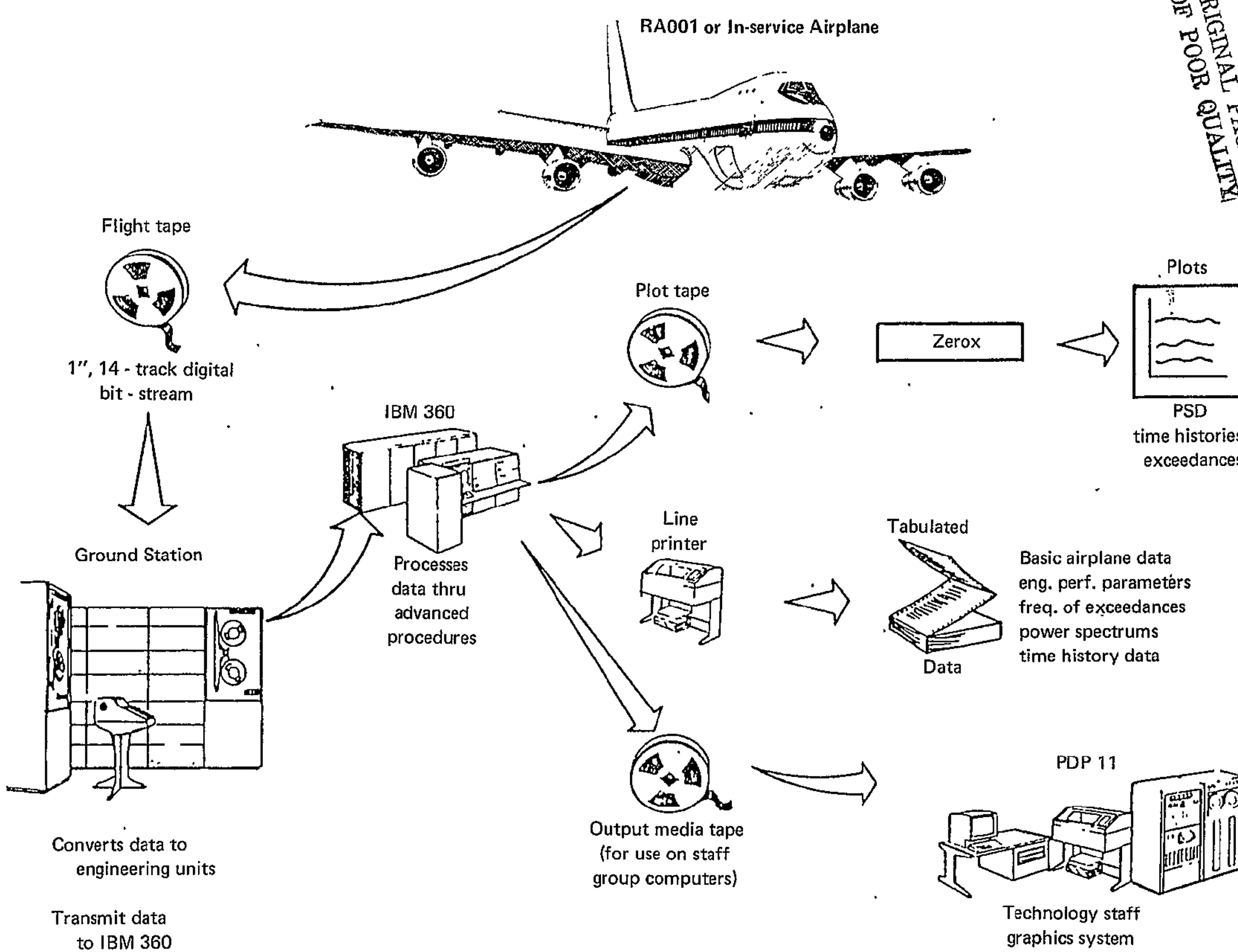


Figure 16.— Post Flight Data Flow

Test Vehicle Pro and Con

Although an in-service test vehicle would probably incur the most realistic flight schedule and would contain a random sampling of different pilot techniques, it is felt there would be too many inherent drawbacks. In addition to higher program costs, the production cycle would have to be interrupted to install the instrumentation, the flight data would be gathered during an inflexible flight profile, and data system maintenance would have to be interfaced with the host airline's operation schedule.

Using a test vehicle with a complete acquisition and monitor system aboard eliminates wasted flight time due to faulty instrumentation. Also, the ability to fly a compressed test profile consisting only of pertinent maneuvers will greatly reduce the toal flow time of the test program. A minor drawback would be that if the program option of 10 dedicated and 20 concurrent flight hours is selected, it may take from one day to six months (a complete unknown at this time) to gather the concurrent data. Based on these factors, Boeing concludes that RA001 is the logical test vehicle for the program.

6.0 TECHNICAL EVALUATION OF FEASIBILITY

The primary technical considerations in evaluating the feasibility of measuring in-service flight loads are:

1. Experience
2. Accuracy
3. Reliability of measuring system
4. Completeness of data
5. Use of and requirement for flight test data

Each of these considerations are addressed in turn.

6.1 EXPERIENCE

Low frequency accelerations have been successfully measured on the nacelle cold sections in numerous flight flutter tests. Since 1966, over 300 hours of testing has been conducted on the 737, 747, AWACS, YC-14 and 747SP airplanes. Generally, the acceleration measurements involved one vertical accelerometer at the three o'clock position looking aft and one lateral accelerometer mounted at the six o'clock position, both attached to the inlet near the hi-lite plane. The typical flutter test procedure is to suddenly actuate an aileron, inducing a step load on the wing, and then observe the accelerometer response to ensure that proper damping exists for stable motion.

Hot-section, high-noise environment acceleration measurements in the low frequency range have not been attempted because adequate transducers were not available. Recently Kaman Sciences Corporation has introduced a high temperature gage, Model KA-1901 (see Section 5.1.2) which appears to meet the requirements. These gages are being evaluated in the Boeing laboratories and will be utilized in the proposed flight test if proven adequate. The confidence level in successful use of these gages is currently seventy percent, i.e., seventy out of 100 minutes of test data would be valid.

It should finally be noted that hot-section, higher frequency range acceleration measurements have been carried out successfully during 100 hours of testing on three major airplane systems. These tests employed piezo-electric type sensors, good for 20 to 2500 Hz.

6.2 ACCURACY

The accuracy of determining nacelle rigid body accelerations and angular velocities about the center of gravity hinges on:

1. correctness of the rigid body motion assumption
2. inherent accuracy of the sensors and data recording system

The rigid body assumption is known to be correct below 10 Hz, based on existing analytical and test experience. Higher frequency elastic components can be eliminated if necessary by data filtering; so, in a sense, one can enforce this assumption by simply choosing the frequency level of the filter. One should be able to identify the transition from rigid to elastic behavior by measuring over a range of 0 to 15 Hz. The lowest known elastic mode (fan case/inlet rocking with respect to the engine core) is around 12 Hz. The indication of transition from rigid to elastic behavior will occur when calculated c.g. accelerations, using different sets of the redundant accelration measurements, no longer coincide.

The inherent accuracy of the sensors and data recording system is well established for low temperature measurements. The probable error is less than 2%. This also applies to the rate gyros which are located in the cold section. As stated earlier, Boeing laboratory tests will verify the accuracy of the high temperature sensors in the flight environment. Manufacturers' specifications indicate more than addquate capability.

6.3 RELIABILITY OF MEASURING SYSTEM

Low temperature measurements are estimated to have an overall reliability of approximately 85 percent including loss due to engine maintenance, i.e., 100 flight hours would result in 85 hours of valid test data for the complete set of cold section measurements.

The Kaman 1901 sensors have already been tested in the Boeing laboratory under a noise environment of 150 decibels at 40 to 11,000 Hz. The zero shift and slope (sensitivity) was negligible. A tentative 70% reliability is estimated. The redundant sensors will further enhance the overall reliability of obtaining valid c.g. data and should provide near 95% reliability on an overall basis.

The rate gyro reliability has been well established for airplane c.g. measurements; approximately 90% reliability. Similar reliability is expected in the engine cold section.

6.4 COMPLETENESS OF FLIGHT TEST DATA

Completeness of data revolves around the question, "Will sufficient loads data be acquired to determine the effect of the flight environment on short term deterioration?" There are three facets to this question:

1. Are rigid body inertias sufficient to characterize the dynamic behavior of the propulsion system due to flight related disturbances?

2. Are the other flight-induced loads data (aerodynamic) which already exist, sufficient in breadth and depth?

3. Are the proposed number of flight hours adequate to characterize short-term inertia loads?

Each of these will be discussed in turn.

6.4.1 SUFFICIENCY OF RIGID BODY INERTIAS

The lowest flexible propulsion system vibratory mode is about 12 Hz which is a rocking motion of the fan case/inlet structure relative to the engine core in a vertical plane. This mode could be significant in causing fan rub strip loss. This mode should be discernible in the flight test data and, coupled with the dynamic analysis of Task IIIA, should be quantified sufficiently to determine its impact on fan rub strip loss.

Any additional effects of dynamic flight loads on engine clearances involving flexible modes will be considered in the Task IIIA analytical dynamics work. It is assumed also that rotor unbalance induced dynamic behavior will be treated sufficiently in Task IIIA.

Another question relates to how the measured pitch and yaw angular velocities would be utilized in calculating gyroscopic moments to be applied to the rotors. Current practice idealizes the airplane as going through steady state angular motion from which the gyroscopic moment can be simply calculated. This is the basis for the gyro moment loads input to the NASTRAN model so far. Neither the twist of the wing nor the lateral elastic deflection and yaw twist of the strut are taken into account other than perhaps estimating upper bound design loads. This area will be given rigorous and detailed treatment in the dynamics analysis of Task IIIA to complement and help understand and utilize the measured flight test data. It is known that the gyro stiffening effects of the rotors do not effect airplane flutter speeds. What the impact is on engine clearances and deterioration is not yet understood.

6.4.2 SUFFICIENCY OF OTHER FLIGHT INDUCED LOADS DATA

Based on the extensive collection and review of existing nacelle pressure data in Task IIIA, it is believed that aerodynamic loads are sufficiently characterized for purposes of engine diagnostics. The only exception to this might be unsteady air loads of which very little is known in regard to transient pressure distributions, primarily because appropriate instrumentation does not exist. It is believed that the primary effect of unsteady air loads is seen in the nacelle accelerations, and that pressures per se are not needed.

6.4.3 ADEQUACY OF FLIGHT TEST HOURS

Since the primary source of nacelle inertia loads is air turbulence, the expected frequency of occurrence and magnitude of turbulence can be used to estimate the flight time required. This would come from airplane gust exceedance data. No absolute index is available since the relation between gust velocity and nacelle acceleration level in unknown.

Typical 747 fleet gust experience provides the following data for typical three hour flight missions:

Flights	Gust velocity exceeded, ft/sec
1	15
10	22
100	31
3000	49

The probability of one airplane encountering a 15 ft/sec gust at least once per flight is .63. A specific in-service airplane flying three months will accumulate about 270 flights, based on nine hours per day usage and a three-hour flight duration. The probability of encountering a 15 ft/sec gust at least once during these 270 flights is approximately 1, i.e., $1-e^{-270} \approx 1$. On the other hand, the probability of encountering a gust in excess of 31 ft/sec during the 270 flights is only .013. Consequently, it can be stated, with a very high level of confidence, that gust intensities experienced in such a test program will lie in the 15 to 31 ft/sec band.

Measured accelerations in excess of two g's in one instrumented in-service airplane flying 270 flights may be rare. However, the measurements below two g's will provide adequate data for conducting short term (less than 100 hours) exceedance curves which can be extended to longer flight times by mathematical extrapolation and existing knowledge of gust load exceedance curves and g levels.

The RA001 test airplane will be flown to deliberately seek out turbulence during the dedicated flight time of ten hours. The 20 hours non-dedicated time will probably involve maneuvers and could also include deliberate search for turbulence. Thus, the flight hours for the RA001 is considered adequate to obtain representative, short-term inertia loads data.

6.5 USE OF AND REQUIREMENT FOR FLIGHT TEST DATA.

This section discusses how the flight inertia loads data would be used and the need for it in evaulating TSFC deterioration.

6.5.1 USE OF FLIGHT TEST DATA

Figure 17 illustrates the form of the reduced acceleration data and its applications in current and future propulsion systems.

From the acceleration time history, the power spectral density of acceleration would be derived which would provide the frequency characteristics of the acceleration and help to identify fundamental vibration modes. The power spectral density of measured acceleration a(t) is:

$$\Phi(\omega) = \underset{T \to \infty}{\text{Limit}} \frac{1}{\pi T} \left| \int_0^T a(t)\, e^{-iwt}\, dt \right|^2$$

where T is the time interval over which a(t) has been observed.

Acceleration exceedance plots will be constructed by counting level crossings on the recorded histograms.

Peak acceleration values are used directly in the NASTRAN static model as inertia load factors. The pitch and yaw rates are substituted into the equation of motion for a rigid rotor spinning in a rigid housing which is undergoing the motion described by the measured test data. This would then provide the gyroscopic moments which would be applied to the NASTRAN static model (non-rigid system) to calculate clearance changes. Figure 18 is an example of the change of clearance output data from the NASTRAN analysis. The equations to be used for calculating gyroscopic moments are as follows:

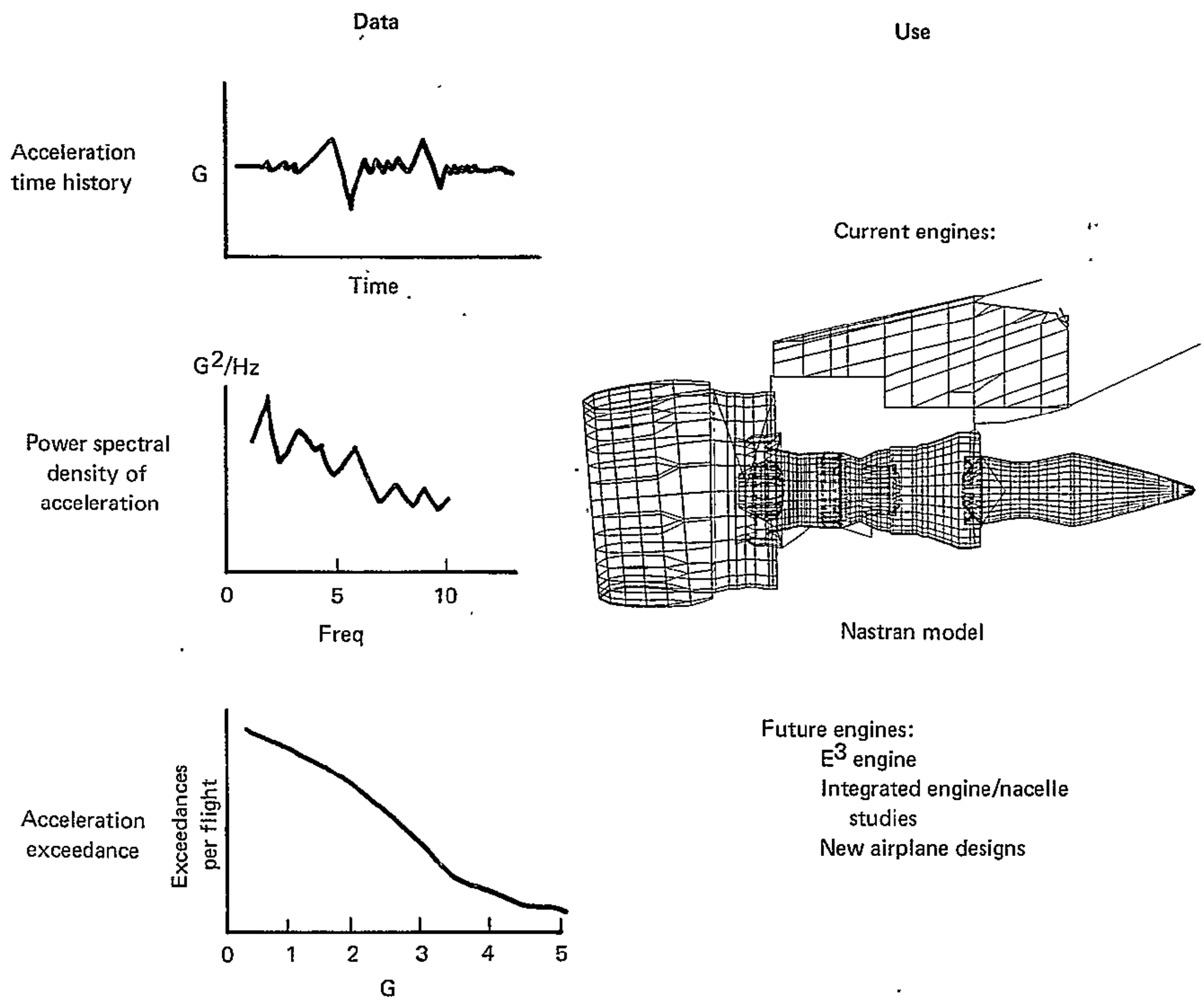
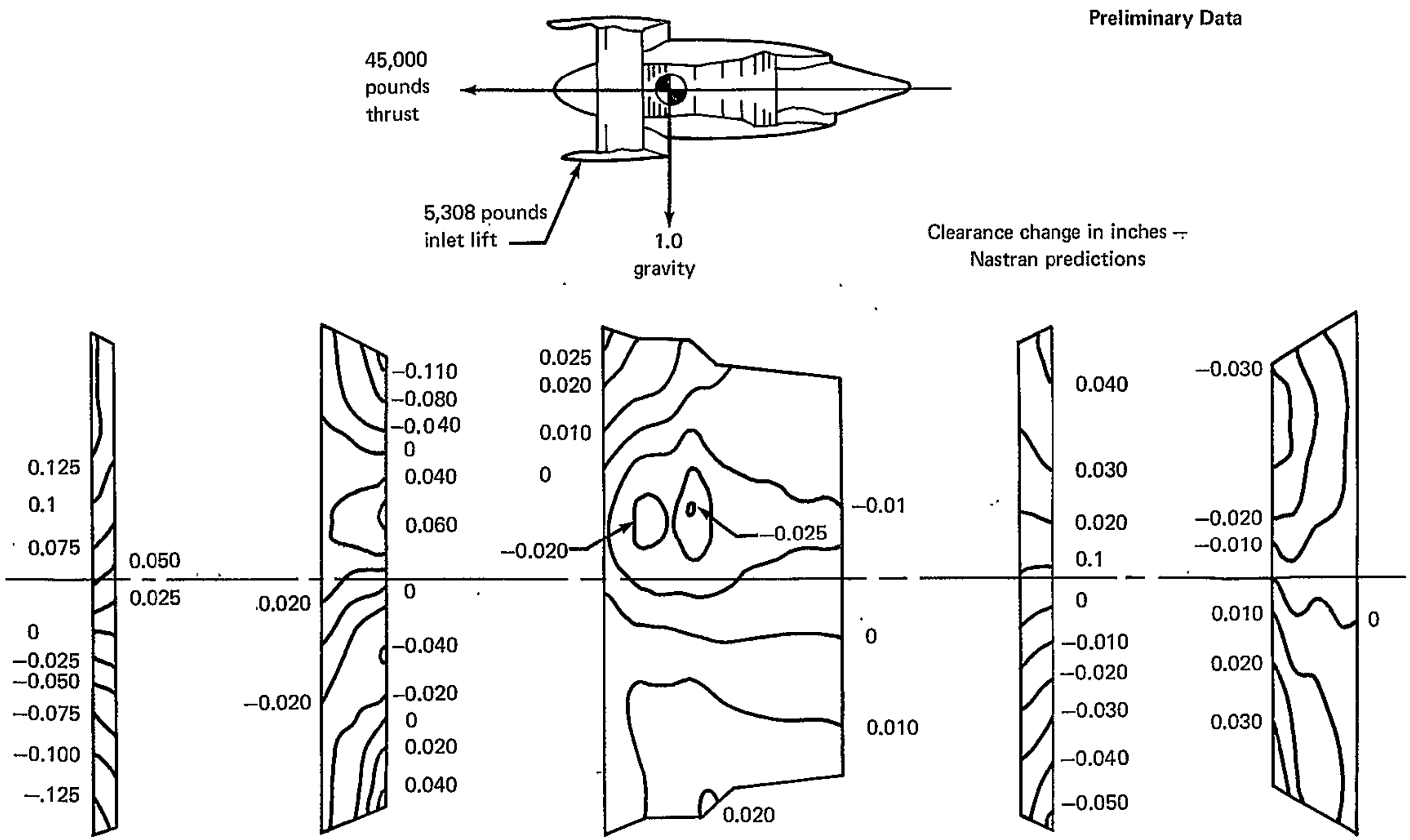


Figure 17.— Use of Flight Data



Flight condition 100 — Takeoff rotation (outer half)

Figure 18.— JT9D-7 Clearance Changes

$M_y = I \Omega \dot{\Theta}$

$M_x = I \Omega \dot{\Psi}$

where I = polar moment of inertia of the rotor
Ω = rotor spin velocity
$\dot{\Theta}, \dot{\Psi}$ = pitch and yaw rates respectively

The.exceedance data would be used to help characterize the deterioration rate and to optimize maintenance cycles.

Finally, the measured acceleration and angular velocities would be used in helping to understand and calibrate the dynamic analyses being conducted under Task IIIA.

In addition to the current engine diagnostics study, the flight inertia loads data could be important in future engine designs where close clearance control becomes extremely critical, particularly in the E^3, 1985-90 generation of engines currently under study by NASA. More rational design criteria for the E^3 engines, for integrated engine nacelle designs, and new airplane designs could be formulated by expanding the knowledge of the in-service nacelle inertia loads.

6.5.2 REQUIREMENT FOR FLIGHT TEST DATA.

The previous section assumed that inertia loads make a significant contribution to engine TSFC deterioration. The question under consideration here is whether the inertia loads do in fact contribute significantly to TSFC deterioration of the JT9D and how the extent to which they contribute might be determined, thus helping evaluate the need for conducting a 747/JT9D flight test.

The NASTRAN tool provides a practical and accurate method of evaluating the effect of different loads on engine clearance changes. The real problem, however, is to determine what are accurate magnitudes of nacelle accelerations and gyroscopic forces. Based on preliminary results of Task IIIA, a comparison of clearance changes due to different loads was made as shown in figure 19. The loads are once-per-flight type loads for the standard production acceptance flight test profile. The lineal accelerations are believed to be conservative. They appear to have minimal impact on clearance change. The pitch and yaw velocities may not be conservative. They have significant impact on clearance change. The ultimate design values for acceleration and angular velocities are:

- Vertical G = 6.5 Inb'd nacelle, 7.2 Outb'd nacelle
- Lateral G = 3 Inb'd nacelle, 3.2 Outb'd nacelle
- Pitch velocity = 2.25 rad/sec
- Yaw velocity = 2.25 rad/sec

Preliminary Data

Flight condition	Load [2]		Maximum clearance reduction, mils [1] Fan	LPC	HPC	HPT	LPT
101	Thrust	36,000 pounds	45	86	15	27	10
Takeoff	Inlet lift	5,308 pounds	98	18	9	19	32
rotation	Vertical G	1	1	7	2	4	2
	Lateral G	0	0	0	0	0	0
	Pitch velocity	0.052 rad/sec	22	3	1	2	2
108	Thrust	15,600 pounds	20	37	7	12	5
Maximum	Inlet lift	3,500 pounds	65	12	6	12	21
dynamic	Vertical G	1.56	2	11	3	6	3
pressure	Lateral G	0.16	7	3	1	2	2
Q	Pitch velocity	0.008 rad/sec	4	1	0	1	1

[1] Maximums occur at different locations in each component and are not additive

[2] Vertical and lateral G's are approximated for propulsion system center of gravity

Pitch velocity assumed same as airplane center of gravity

Figure 19.— Influence of Different Loads on Clearance-NASTRAN Analysis

The clearance change values are ratioed up in direct proportion to these increased values. In this case both the lineal acceleration and angular velocity effects are significant. Unfortunately there is not generally a prescribed relationship between ultimate design loads and operating loads, so it is not known how conservative the above values are.

In summary, the requirement for flight inertia loads depends on their relative impact on deterioration. One approach to determining this, as an alternative to a flight test, would be to review existing inertia loads data and try to establish more reliable estimates of operating loads, and then calculate the relative effect on clearance change via the NASTRAN model.

7.0 COST SUMMARY

A total of five options were considered for the flight test program. A description of the options and the associated cost are as follows:

Option	Description	Cost thousands of dollars
A.	In-service airplane, 64 channels of data, 50 flight hours over 3 month period. New HSPCM data system.	(This information will be supplied under separate cover from Boeing Contracts Organization.)
B.	RA001, 64 channels of data, 30 flight hours - 10 dedicated, 20 concurrent-over a period of one to seven months.	
C.	RA001, 86 channels of data, 30 flight hours - 10 dedicated, 20 concurrent - over a period of one to seven months, (includes 22 channels of engine performance instrumentation).	
D.	RA001, 64 channels of data, 30 dedicated flight hours - over a period of 3 months	
E.	RA001, 86 channels of data, 30 dedicated flight hours - over a period of 3 months (includes 22 channels of engine performance instrumentation).	

8.0 CONCLUSIONS

The conclusions will be discussed under the headings of "feasibility" and "desirability". Under feasibility the conclusions are:

1. Nacelle aerodynamic loads are satisfactorily defined for purposes of JT9D Engine Diagnostics.

2. It is technically feasible to measure flight inertia loads on both an in-service airplane and on the Boeing-owned RA001 airplane.

3. The Boeing-owned airplane has technical and economic advantages which make it the appropriate choice for obtaining inertia loads data.

Under desirability the conclusions are:

1. The existence of a large amount of flight flutter and flight loads survey test data has become evident during the course of this feasibility study. Its applicability to JT9D Engine Diagnostics is unknown.

2. The relative impact of nacelle aerodynamic and inertia loads on 747/JT9D performance deterioration is yet to be determined and must await results of Task IIIA parallel efforts. Thus the need for inertia loads data is not known yet.

9.0 RECOMMENDATIONS

As a result of this feasibility study it is recommended that:

1. A decision on a flight test program be postponed until the following tasks are completed.

   a. Establish the relative importance of aerodynamic and inertia loads on short-term TSFC deterioration (Task IIIA).

   b. Compare structural analyses and TSFC estimates (Task IIIA) with analytical teardown and engine calibrations of engine 695743 (Tasks II and IIIA).

   c. Conduct an intensive review of existing inertia loads data from flight flutter and flight loads survey tests which have been conducted by Boeing in conjunction with 747 development.

2. Proceed with the flight test when it is established that:

   a. Inertia loads are significant contributors to performance deterioration and,

   b. Additional data are required after an intensive review of existing inertia loads data.

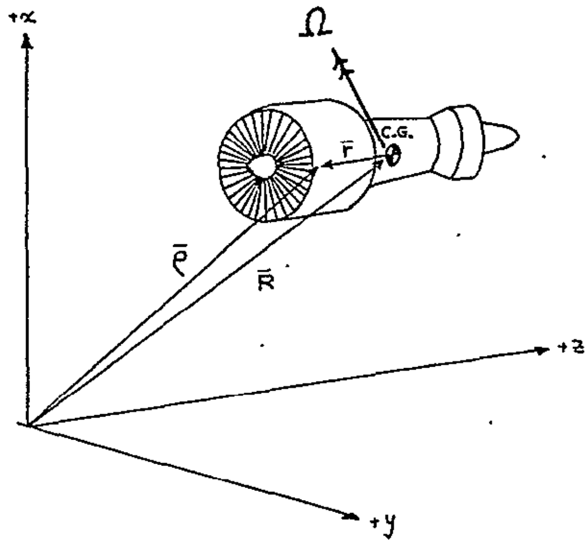
3. If and when the flight test program is carried out, the Boeing test airplane RA001, be used as the test vehicle.

10.0 REFERENCES

1. AIAA Paper 72-188, January 1972.

2. *"Fatigue.Design Methods and Allowables,"* BCAC Document D6-24957 (Proprietary).

APPENDIX A: CALCULATION OF C.G. ACCELERATIONS FROM MEASURED DATA



$$\bar{\rho} = \bar{R} + \bar{r} \tag{1}$$

Differentiating:

$$\frac{d\bar{\rho}}{dt} = \frac{d\bar{R}}{dt} + \frac{d\bar{r}}{dt} = \dot{\bar{R}} + \bar{\Omega} \times \bar{r} \tag{2}$$

Where: Ω = Rigid body rotational velocity of engine.

Differentiating Once Again:

$$\frac{d^2\bar{\rho}}{dt^2} = \ddot{\bar{\rho}} = \ddot{\bar{R}} + \dot{\bar{\Omega}} \times \bar{r} + \bar{\Omega} \times \bar{\Omega} \times \bar{r} \tag{3}$$

Since centrifugal effects can be proven negligible

$$\bar{\Omega} \times \bar{\Omega} \times \bar{r} \longrightarrow 0$$

Equation (3) then reduces to:

$$\ddot{\bar{\rho}} = \ddot{\bar{R}} + \dot{\bar{\Omega}} \times \bar{r} \qquad (4)$$

Equation (4) may be re-written as:

$$\bar{a}_x = A_{x_{C.G.}} + \ddot{\theta} r_z - \ddot{\phi} r_y \qquad (5)$$

$$\bar{a}_y = A_{y_{C.G.}} + \ddot{\phi} r_x - \ddot{\psi} r_z \qquad (6)$$

$$\bar{a}_z = A_{z_{C.G.}} + \ddot{\psi} r_y - \ddot{\theta} r_x \qquad (7)$$

Employing the primary instrumentation package, it can be shown that the 6 components of powerplant c.g. acceleration can be solved as:

$$\ddot{\theta} = (\bar{a}_{x_1} - \bar{a}_{x_5}) \quad [r_{z_1} - r_{z_5} + \frac{r_{y_5}}{r_{y_6}}(r_{z_6} - r_{z_1})] \tag{8}$$

$$\ddot{\phi} = [(\bar{a}_{x_1} - \bar{a}_{x_6}) + \ddot{\theta}(r_{z_6} - r_{z_1})] / r_{y_6} \tag{9}$$

$$\ddot{\psi} = [(\bar{a}_{y_2} - \bar{a}_{y_3}) + \ddot{\phi}(r_{x_3} - r_{x_2})] / (r_{z_3} - r_{z_2}) \tag{10}$$

$$A_{x_{C.G.}} = \bar{a}_{x_6} - \ddot{\theta} r_{z_6} + \ddot{\phi} r_{y_6} \tag{11}$$

$$A_{y_{C.G.}} = \bar{a}_{y_2} - \ddot{\phi} r_{x_2} + \ddot{\psi} r_{z_2} \tag{12}$$

$$A_{z_{C.G.}} = \bar{a}_{z_4} + \ddot{\theta} r_{x_4} \tag{13}$$

TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL JT9DIAG
AIRPLANE NUMBER 747-70
FTIR NUMBER 001

PRINTED DATE 08/30/77
ENTERED DATE 07/01/77 0710
REVISED DATE 08/30/77 1546

TEST ITEM 4.00.001 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC INSTRUMENTATION -B
EWA — REQUESTED BY MAS — GROUP L

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA	MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00035	A	PRESSURE, IMPACT < AIRSPEED > COPILOT PT - COPILOT PI AIRPLANES 747-70-001	IN HG	HS	.1	12	.003	1 SPS
00036	A	PRESSURE, STATIC < ALTITUDE > COPILOT PI AIRPLANES 747-70-001	IN HG	HS	3	31	.006	1 SPS
00037	A	TEMPERATURE, TOTAL < AIR > PRODUCTION PROBE AIRPLANES 747-70-001	DEG C	HS	-60	60	.6	1 SPS
00026	R	ACCELERATION, LATERAL < AIRPLANE C.G. > AIRPLANES 747-70-001	G	HS	-2	2	.04	160 SPS
00011	R	ACCELERATION, LATERAL < ENG NO. 1 > NS 152 ON DIAPHRAGM AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.12	400 SPS
00003	R	ACCELERATION, LATERAL < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00017	R	ACCELERATION, LATERAL < ENG. NO. 1 > NS 125 ON FRONT MOUNT AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00014	R	ACCELERATION, LATERAL < ENG. NO. 1 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-2	2	.12	400 SPS
00001	R	ACCELERATION, LATERAL < ENG. NO. 1 > NS 40 ON HI-LITE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00022	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00047	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 125 ON FRONT MOUNT AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00041	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 152 ON DIAPHRAGM AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.12	400 SPS
00044	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-2	2	.12	400 SPS
00020	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 40 ON HI-LITE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00027	R	ACCELERATION, LONGITUDINAL < AIRPLANE C.G. > AIRPLANES 747-70-001	G	HS	-1	1	.02	160 SPS
00012	R	ACCELERATION, LONGITUDINAL < ENG NO. 1 > NS 152 ON DIAPHRAGM AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.12	400 SPS
00004	R	ACCELERATION, LONGITUDINAL < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00023	R	ACCELERATION, LONGITUDINAL < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00042	R	ACCELERATION, LONGITUDINAL < ENG. NO. 2 > NS 152 ON DIAPHRAGM AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.12	400 SPS

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TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL - JT9D7AG
AIRPLANE NUMBER "747-70
FTIR NUMBER 001

PRINTED DATE 08/30/77
ENTERED DATE 07/01/77 0710
REVISED DATE 08/30/77 1546

TEST ITEM 4.00.001 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC INSTRUMENTATION -B
EWA
REQUESTED BY MAS
GROUP L

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA	MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00025	R	ACCELERATION, NORMAL < AIRPLANE C.G. > AIRPLANES 747-70-001	G	HS	-1	3	.04	160 SPS
00028	R	ACCELERATION, PITCH < AIRPLANE C.G. > ANGULAR ACCELEROMETER AIRPLANES 747-70-001	DEG/SS	HS	-35	35	1.4	160 SPS
00029	R	ACCELERATION, ROLL < AIRPLANE C.G. > ANGULAR ACCELEROMETER AIRPLANES 747-70-001	DEG/SS	HS	-40	40	1.6	160 SPS
00009	R	ACCELERATION, VERTICAL < ENG NO. 1 > NS 152 ON DIAPHRAGM AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.3	400 SPS
00010	R	ACCELERATION, VERTICAL < ENG NO. 1 > NS 152 ON DIAPHRAGM AT 9 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.3	400 SPS
00006	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.1	400 SPS
00005	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 9 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.1	400 SPS
00016	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 125 ON FRONT MOUNT AIRPLANES 747-70-001	G	HS	-4	6	.1	400 SPS
00015	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.3	400 SPS
00002	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 40 ON HI-LITE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-4	6	.1	400 SPS
00018	R	ACCELERATION, VERTICAL < ENG. NO. 1 > ON PYLON AT WING FRONT SPAR ATTACH POINT AIRPLANES 747-70-001	G	HS	-4	6	.1	200 SPS
00019	R	ACCELERATION, VERTICAL < ENG. NO. 1 > ON PYLON AT WING REAR SPAR ATTACH POINT AIRPLANES 747-70-001	G	HS	-4	6	.1	200 SPS
00033	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.1	400 SPS
00024	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 9 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.1	400 SPS
00046	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 125 ON FRONT MOUNT AIRPLANES 747-70-001	G	HS	-4	6	.1	400 SPS
00039	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 152 ON DIAPHRAGM AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.3	400 SPS

TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL JT9DIAG
AIRPLANE NUMBER 747-70
FTIR NUMBER 001

PRINTED DATE 08/30/77
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TEST ITEM 4.00.001 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC INSTRUMENTATION -B
EWA REQUESTED BY MAS . GROUP L

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA	MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00040	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 152 ON DIAPHRAGM AT 9 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.3	400 SPS
00045	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-4	6	.3	400 SPS
00021	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 40 ON HI-LITE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-4	6	.1	400 SPS
00048	R	ACCELERATION, VERTICAL < ENG. NO. 2 > ON PYLON AT WING FRONT SPAR ATTACH POINT AIRPLANES 747-70-001	G	HS	-4	6	.1	200 SPS
00049	R	ACCELERATION, VERTICAL < ENG. NO. 2 > ON PYLON AT WING REAR SPAR ATTACH POINT AIRPLANES 747-70-001	G	HS	-4	6	.1	200 SPS
00030	R	ACCELERATION, YAW < AIRPLANE C.G. > ANGULAR ACCELEROMETER AIRPLANES 747-70-001	DEG/SS	HS	-15	15	.6	160 SPS
00050	R	LOAD < ENG. NO. 1 > CASE BENDING AT LOCATION TO BE DETERMINED AIRPLANES 747-70-001	K INLB	HS				200 SPS
00051	R	LOAD < ENG. NO. 1 > CASE BENDING AT LOCATION TO BE DETERMINED AIRPLANES 747-70-001	K INLB	HS				200 SPS
00052	R	LOAD < ENG. NO. 2 > CASE BENDING AT LOCATION TO BE DETERMINED AIRPLANES 747-70-001	K INLB	HS				200 SPS
00053	R	LOAD < ENG. NO. 2 > CASE BENDING AT LOCATION TO BE DETERMINED AIRPLANES 747-70-001	K INLB	HS				200 SPS
00038	R	RATE, PITCH < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG/S	HS	-15	15	.3	400 SPS
00038	R	RATE, PITCH < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG/S	HS	-15	15	.3	400 SPS
00037	R	RATE, YAW < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG/S	HS	-10	10	.2	400 SPS
00034	R	RATE, YAW < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG/S	HS	-10	10	.2	400 SPS
00054	R	TEMPERATURE < ENG. NO. 1 > CASE TEMPERATURE AT LOCATION OF MEAS NO AIRPLANES 747-70-001	DEG F	HS	0	1500	15	1 SPS
00055	R	TEMPERATURE < ENG. NO. 1 > CASE TEMPERATURE AT LOCATION OF MEAS NO AIRPLANES 747-70-001	DEG F	HS	0	1500	15	1 SPS
00013	R	TEMPERATURE < ENG. NO. 1 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG F	HS	0	1100	11	1 SPS
00056	R	TEMPERATURE < ENG. NO. 2 > CASE TEMPERATURE AT LOCATION OF MEAS NO AIRPLANES 747-70-001	DEG F	HS	0	1500	15	1 SPS
00057	R	TEMPERATURE < ENG. NO. 2 > CASE TEMPERATURE AT LOCATION OF MEAS NO AIRPLANES 747-70-001	DEG F	HS	0	1500	15	1 SPS

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TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL JT9DIAG
AIRPLANE NUMBER 747-70
ETIR NUMBER 001

PRINTED DATE 08/30/77
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REVISED DATE 08/30/77 1546

TEST ITEM 4.00.001 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC INSTRUMENTATION -B
EWA REQUESTED BY MAS GROUP L

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA	MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00043	R	TEMPERATURE < ENG. NO. 2 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG F	HS	0	1100	11	1 SPS
01004	S	TIME, IRIG < MONITOR > HOURS AIRPLANES 747-70-001	HOURS	HS	0	23		5 SPS
01000	S	TIME, IRIG < MONITOR > MINUTES AIRPLANES 747-70-001	MIN	HS	0	59		5 SPS
01003	S	TIME, IRIG < MONITOR > SECONDS AIRPLANES 747-70-001	SEC	HS	0	59		5 SPS
01002	S	TIME, IRIG < MONITOR > SECONDS AIRPLANES 747-70-001	SEC	HS	0	.99		5 SPS
01001	S	TIME, IRIG < MONITOR > SECONDS AIRPLANES 747-70-001	SEC	HS	0	.0099		5 SPS
05724	T	PRESSURE, TOTAL < TURBINE EXIT PT7 > ENGINE 1, JT9D-70 AIRPLANES 747-70-001	IN HG	HS	4	65	.03	1 SPS
05725	T	PRESSURE, TOTAL < TURBINE EXIT PT7 > ENGINE 2, JT9D-70 AIRPLANES 747-70-001	IN HG	HS	4	65	.03	1 SPS
05732	T	RATE, RPM < LOW PRESSURE COMPRESSOR -N1 > ENGINE 1, JT9D-70 AIRPLANES 747-70-001	RPM	HS	0	4000	5	1 SPS
05733	T	RATE, RPM < LOW PRESSURE COMPRESSOR -N1 > ENGINE 2, JT9D-70 AIRPLANES 747-70-001	RPM	HS	0	4000	5	1 SPS

THE FOLLOWING HAVE BEEN DELETED FROM THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA	MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00031	R	RATE, PITCH < ENG. NO. 1 > AFT END OF INLET (FLANGE A) AT 9 O'CLOCK POSITION	RD/SEC	HS				160 SPS
00032	R	RATE, YAW < ENG. NO. 1 > AFT END OF INLET (FLANGE A) AT 9 O'CLOCK POSITION	RD/SEC	HS				160 SPS

TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL JT9DIAG
AIRPLANE NUMBER 747-70
FTIR NUMBER 001

PRINTED DATE 08/30/77
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TEST ITEM 4.00.002 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC PLUS ENGINE PERFORMANCE INSTR.
EWA REQUESTED BY MAS GROUP 1

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA	MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00035	A	PRESSURE, IMPACT < AIRSPEED > COPILOT PT - COPILOT PI AIRPLANES 747-70-001	IN HG	HS	.1	12	.003	1 SPS
00036	A	PRESSURE, STATIC < ALTITUDE > COPILOT PI AIRPLANES 747-70-001	IN HG	HS	3	31	.006	1 SPS
00037	A	TEMPERATURE, TOTAL < AIR > PRODUCTION PROBE AIRPLANES 747-70-001	DEG C	HS	-60	60	.6	1 SPS
2023	K	QUANTITY, TOTALIZER < ENGINE NO. 1 > FUEL IN AIRPLANES 747-70-001	GAL	HS	0	10000	95*	1 SPS
2024	K	QUANTITY, TOTALIZER < ENGINE NO. 2 > FUEL IN AIRPLANES 747-70-001	GAL	HS	0	10000	95*	1 SPS
02031	K	TEMPERATURE, FUEL < ENGINE NO. 1 > FUEL TOTALIZER IN AIRPLANES 747-70-001	DEG C	HS	0	160	3	1 SPS
02032	K	TEMPERATURE, FUEL < ENGINE NO. 2 > FUEL TOTALIZER IN AIRPLANES 747-70-001	DEG C	HS	0	160	3	1 SPS
2661	P	PRESSURE, DIFFERENTIAL < DUCT 21, WING MANIFOLD > LH INBD, PS-FTPS AIRPLANES 747-70-001	IN HG	HS	0	100	1	1 SPS
2662	P	PRESSURE, DIFFERENTIAL < DUCT 21, WING MANIFOLD > LH INBD, PT-PS AIRPLANES 747-70-001	IN HG	HS	0	2	.02	1 SPS
03783	P	PRESSURE, DIFFERENTIAL < DUCT 50, WING MANIFOLD > LH OUTBD, PS-FTPS AIRPLANES 747-70-001	IN HG	HS	0	100	2	1 SPS
03781	P	PRESSURE, DIFFERENTIAL < DUCT 50, WING MANIFOLD > LH OUTBD, PT-PS AIRPLANES 747-70-001	IN HG	HS	0	2	.02	1 SPS
2663	P	TEMPERATURE, TOTAL < DUCT 21, WING MANIFOLD > LH INBD, TT AIRPLANES 747-70-001	DEG C	HS	0	260	5	1 SPS
03779	P	TEMPERATURE, TOTAL < DUCT 50, WING MANIFOLD > LH OUTBD, TT AIRPLANES 747-70-001	DEG C	HS	0	260	5	1 SPS
00026	R	ACCELERATION, LATERAL < AIRPLANE C.G. > AIRPLANES 747-70-001	G	HS	-2	2	.04	160 SPS
00011	R	ACCELERATION, LATERAL < ENG NO. 1 > NS 152 ON DIAPHRAGM AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.12	400 SPS
00003	R	ACCELERATION, LATERAL < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00017	R	ACCELERATION, LATERAL < ENG. NO. 1 > NS 125 ON FRONT MOUNT AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00014	R	ACCELERATION, LATERAL < ENG. NO. 1 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-2	2	.12	400 SPS
00001	R	ACCELERATION, LATERAL < ENG. NO. 1 > NS 40 ON HI-LITE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS
00022	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	-2	2	.04	400 SPS

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TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL JT9D1AG
AIRPLANE NUMBER 747-70
ETIR NUMBER 001

PRINTED DATE 08/30/77
ENTERED DATE 07/01/77 0710
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TEST ITEM 4.00.002 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC PLUS ENGINE PERFORMANCE INSTR.
EWA REQUESTED BY MAS GROUP L

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA		MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00047	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 125 ON FRONT MOUNT AIRPLANES 747-70-001	G	HS	NEW	-2	2	.04	400 SPS
00041	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 152 ON DIAPHRAGM AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	NEW	-2	2	.12	400 SPS
00044	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	NEW	-2	2	.12	400 SPS
00020	R	ACCELERATION, LATERAL < ENG. NO. 2 > NS 40 ON HI-LITE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS		-2	2	.04	400 SPS
00027	R	ACCELERATION, LONGITUDINAL < AIRPLANE C.G. > AIRPLANES 747-70-001	G	HS		-1	1	.02	160 SPS
00012	R	ACCELERATION, LONGITUDINAL < ENG NO. 1 > NS 152 ON DIAPHRAGM AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS		-2	2	.12	400 SPS
00004	R	ACCELERATION, LONGITUDINAL < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS		-2	2	.04	400 SPS
00023	R	ACCELERATION, LONGITUDINAL < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS		-2	2	.04	400 SPS
00042	R	ACCELERATION, LONGITUDINAL < ENG. NO. 2 > NS 152 ON DIAPHRAGM AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS	NEW	-2	2	.12	400 SPS
00025	R	ACCELERATION, NORMAL < AIRPLANE C.G. > AIRPLANES 747-70-001	G	HS		-1	3	.04	160 SPS
00028	R	ACCELERATION, PITCH < AIRPLANE C.G. > ANGULAR ACCELEROMETER AIRPLANES 747-70-001	DEG/SS	HS		-35	35	1.4	160 SPS
00029	R	ACCELERATION, ROLL < AIRPLANE C.G. > ANGULAR ACCELEROMETER AIRPLANES 747-70-001	DEG/SS	HS		-40	40	1.6	160 SPS
00009	R	ACCELERATION, VERTICAL < ENG NO. 1 > NS 152 ON DIAPHRAGM AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS		-4	6	.3	400 SPS
00010	R	ACCELERATION, VERTICAL < ENG NO. 1 > NS 152 ON DIAPHRAGM AT 9 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS		-4	6	.3	400 SPS
00006	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS		-4	6	.1	400 SPS
00005	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 9 O'CLOCK (LOCKING AFT) AIRPLANES 747-70-001	G	HS		-4	6	.1	400 SPS
00016	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 125 ON FRONT MOUNT AIRPLANES 747-70-001	G	HS		-4	6	.1	400 SPS

TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL	JT9DIAG	PRINTED DATE	08/30/77
AIRPLANE NUMBER	747-70	ENTERED DATE	07/01/77 0710
FTIR NUMBER 001		REVISED DATE	08/30/77 1546

TEST ITEM 4.00.002 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC PLUS ENGINE PERFORMANCE INSTR.
EWA REQUESTED BY MAS GROUP L

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA		MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00015	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS		-4	6	.3	400 SPS
00002	R	ACCELERATION, VERTICAL < ENG. NO. 1 > NS 40 ON HI-LITE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS		-4	6	.1	400 SPS
00018	R	ACCELERATION, VERTICAL < ENG. NO. 1 > ON PYLON AT WING FRONT SPAR ATTACH POINT AIRPLANES 747-70-001	G	HS		-4	6	.1	200 SPS
00019	R	ACCELERATION, VERTICAL < ENG. NO. 1 > ON PYLON AT WING REAR SPAR ATTACH POINT AIRPLANES 747-70-001	G	HS		-4	6	.1	200 SPS
00033	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS		-4	6	.1	400 SPS
00024	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 9 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS		-4	6	.1	400 SPS
00046	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 125 ON FRONT MOUNT AIRPLANES 747-70-001	G	HS	NEW	-4	6	.1	400 SPS
00039	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 152 ON DIAPHRAGM AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	NEW	-4	6	.3	400 SPS
00040	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 152 ON DIAPHRAGM AT 9 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	NEW	-4	6	.3	400 SPS
00045	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	G	HS	NEW	-4	6	.3	400 SPS
00021	R	ACCELERATION, VERTICAL < ENG. NO. 2 > NS 40 ON HI-LITE AT 6 O'CLOCK AIRPLANES 747-70-001	G	HS		-4	6	.1	400 SPS
00048	R	ACCELERATION, VERTICAL < ENG. NO. 2 > ON PYLON AT WING FRONT SPAR ATTACH POINT AIRPLANES 747-70-001	G	HS	NEW	-4	6	.1	200 SPS
00049	R	ACCELERATION, VERTICAL < ENG. NO. 2 > ON PYLON AT WING REAR SPAR ATTACH POINT AIRPLANES 747-70-001	G	HS	NEW	-4	6	.1	200 SPS
00030	R	ACCELERATION, YAW < AIRPLANE C.G. > ANGULAR ACCELEROMETER AIRPLANES 747-70-001	DEG/SS	HS		-15	15	.6	160 SPS
00050	R	LOAD < ENG. NO. 1 > CASE BENDING AT LOCATION TO BE DETERMINED AIRPLANES 747-70-001	K INLB	HS	NEW				200 SPS
00051	R	LOAD < ENG. NO. 1 > CASE BENDING AT LOCATION TO BE DETERMINED AIRPLANES 747-70-001	K INLB	HS	NEW				200 SPS
00052	R	LOAD < ENG. NO. 2 > CASE BENDING AT LOCATION TO BE DETERMINED AIRPLANES 747-70-001	K INLB	HS	NEW				200 SPS

TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL · JT9D1AG — PRINTED DATE 08/30/77
AIRPLANE NUMBER · 747-70 — ENTERED DATE 07/01/77 0710
FTIR NUMBER 001 — REVISED DATE 08/30/77 1546

TEST ITEM 4.00.002 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC PLUS ENGINE PERFORMANCE INSTR.
EWA — REQUESTED BY MAS — GROUP L

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA		MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00053	R	LOAD < ENG. NO. 2 > CASE BENDING AT LOCATION TO BE DETERMINED AIRPLANES 747-70-001	K INLB	HS	NEW				200 SPS
00008	R	RATE, PITCH < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG/S	HS		-15	15	.3	400 SPS
00038	R	RATE, PITCH < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG/S	HS	NEW	-15	15	.3	400 SPS
00007	R	RATE, YAW < ENG. NO. 1 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG/S	HS		-10	10	.2	400 SPS
00034	R	RATE, YAW < ENG. NO. 2 > NS 100 ON "A" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG/S	HS		-10	10	.2	400 SPS
00054	R	TEMPERATURE < ENG. NO. 1 > CASE TEMPERATURE AT LOCATION OF MEAS NO AIRPLANES 747-70-001	DEG F	HS	NEW	0	1500	15	1 SPS
00055	R	TEMPERATURE < ENG. NO. 1 > CASE TEMPERATURE AT LOCATION OF MEAS NO AIRPLANES 747-70-001	DEG F	HS	NEW	0	1500	15	1 SPS
00013	R	TEMPERATURE < ENG. NO. 1 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG F	HS		0	1100	11	1 SPS
00056	R	TEMPERATURE < ENG. NO. 2 > CASE TEMPERATURE AT LOCATION OF MEAS NO AIRPLANES 747-70-001	DEG F	HS	NEW	0	1500	15	1 SPS
00057	R	TEMPERATURE < ENG. NO. 2 > CASE TEMPERATURE AT LOCATION OF MEAS NO AIRPLANES 747-70-001	DEG F	HS	NEW	0	1500	15	1 SPS
00043	R	TEMPERATURE < ENG. NO. 2 > NS 254 ON "P" FLANGE AT 3 O'CLOCK (LOOKING AFT) AIRPLANES 747-70-001	DEG F	HS	NEW	0	1100	11	1 SPS
01004	S	TIME, IRIG < MONITOR > HOURS AIRPLANES 747-70-001	HOURS	HS		0	23		5 SPS
01000	S	TIME, IRIG < MONITOR > MINUTES AIRPLANES 747-70-001	MIN	HS		0	59		5 SPS
01001	S	TIME, IRIG < MONITOR > SECONDS AIRPLANES 747-70-001	SEC	HS		0	.0099		5 SPS
01003	S	TIME, IRIG ≤ MONITOR ≥ SECONDS AIRPLANES 747-70-001	SEC	HS		0	59		5 SPS
01002	S	TIME, IRIG < MONITOR > SECONDS AIRPLANES 747-70-001	SEC	HS		0	.99		5 SPS
05700	T	POSITION, ANGULAR < INLET GUIDE VANE > HPC, ENGINE NO. 1, JT9D-70 AIRPLANES 747-70-001	DEG	HS		-34	7	.5	1 SPS
05701	T	POSITION, ANGULAR < INLET GUIDE VANE > HPC, ENGINE NO. 2, JT9D-70 AIRPLANES 747-70-001	DEG	HS		-34	7	.5	1 SPS
05704	T	POSITION, ANGULAR < POWER LEVER > FUEL CONTROL, ENGINE 1, JT9D-70 AIRPLANES 747-70-001	DEG	HS		0	130	2	1 SPS
05705	T	POSITION, ANGULAR < POWER LEVER > FUEL CONTROL, ENGINE 2, JT9D-70 AIRPLANES 747-70-001	DEG	HS		0	130	2	1 SPS
05712	T	PRESSURE, STATIC < HIGH PRESSURE COMPRESSOR PS4 > ENGINE 1, JT9D-70 AIRPLANES 747-70-001	IN HG	HS		0	750	.7	1 SPS
05713	T	PRESSURE, STATIC ≤ HIGH PRESSURE COMPRESSOR PS4 ≥ ENGINE 2, JT9D-70 AIRPLANES 747-70-001	IN HG	HS		0	750	.7	1 SPS
05750	T	PRESSURE, TOTAL < LOW PRESSURE COMPRESSOR PT3 > ENGINE 1, JT9D-70 AIRPLANES 747-70-001	PSIA	HS		0	60	.6	1 SPS

TEST ITEM MEASUREMENT REQUIREMENTS (TIMR)

AIRPLANE MODEL JT9DIAG — PRINTED DATE 08/30/77
AIRPLANE NUMBER 747-70 — ENTERED DATE 07/01/77 0710
ETIR NUMBER 001 — REVISED DATE 08/30/77 1546

TEST ITEM 4.00.002 JT9D ENGINE DIAGNOSTICS PROGRAM - BASIC PLUS ENGINE PERFORMANCE INSTR.
EWA — REQUESTED BY MAS — GROUP 1

MEASUREMENTS REQUIRED FOR THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA	MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
05951	T	PRESSURE, TOTAL < LOW PRESSURE COMPRESSOR PT3 > ENGINE 2, JT9D-70 AIRPLANES 747-70-001	PSIA	HS	0	60	.6	1 SPS
05724	T	PRESSURE, TOTAL < TURBINE EXIT PT7 > ENGINE 1, JT9D-70 AIRPLANES 747-70-001	IN HG	HS	4	65	.03	1 SPS
05725	T	PRESSURE, TOTAL < TURBINE EXIT PT7 > ENGINE 2, JT9D-70 AIRPLANES 747-70-001	IN HG	HS	4	65	.03	1 SPS
05728	T	RATE, RPM < HIGH PRESSURE COMPRESSOR -N2 > ENGINE 1, JT9D-70 AIRPLANES 747-70-001	RPM	HS	0	9000	10	1 SPS
05729	T	RATE, RPM < HIGH PRESSURE COMPRESSOR -N2 > ENGINE 2, JT9D-70 AIRPLANES 747-70-001	RPM	HS	0	9000	10	1 SPS
05732	T	RATE, RPM < LOW PRESSURE COMPRESSOR -N1 > ENGINE 1, JT9D-70 AIRPLANES 747-70-001	RPM	HS	0	4000	5	1 SPS
05733	T	RATE, RPM < LOW PRESSURE COMPRESSOR -N1 > ENGINE 2, JT9D-70 AIRPLANES 747-70-001	RPM	HS	0	4000	5	1 SPS
05736	T	TEMPERATURE, TOTAL < LP TURBINE EXIT - TT7 > ENGINE 1, JT9D-70 AIRPLANES 747-70-001	DEG C	HS	0	550	5	1 SPS
05737	T	TEMPERATURE, TOTAL < LP TURBINE EXIT - TT7 > ENGINE 2, JT9D-70 AIRPLANES 747-70-001	DEG C	HS	0	550	5	1 SPS

THE FOLLOWING HAVE BEEN DELETED FROM THIS TEST ITEM

MEAS NO	SECT	MEASUREMENT DESCRIPTION	UNITS	RECORD MEDIA	MIN VALUE	MAX VALUE	ACC	TIME BETWEEN SAMPLES OR FREQ
00031	R	RATE, PITCH < ENG. NO. 1 > AFT END OF INLET (FLANGE A) AT 9 O'CLOCK POSITION	RD/SEC	HS				160 SPS
00032	R	RATE, YAW < ENG. NO. 1 > AFT END OF INLET (FLANGE A) AT 9 O'CLOCK POSITION	RD/SEC	HS				160 SPS

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APPENDIX C – DETAILED PLAN OF FLIGHT TEST

JT9 ENGINE DIAGNOSITCS PROGRAM - B

PURPOSE OF TEST

The purpose of this test is to gather powerplant inertia loads data as would be encountered in commercial service. These data will be used in conjunction with analytical methods on a NASTRAN model to ascertain causes of short term deterioration on JT9D-series engines and associated increases in specific fuel consumption.

REFERENCES

(a) EWA 669700, "Engine Component Improvement - Diagnostics JT9D".
(b) Boeing Document D6-22120, "Configuration and Status, Airplane RA001".
(c) TIMR 4.00.001, "JT9D Engine Diagnostics Program - Basic Instrumentation - B".

CONFIGURATION

The test vehicle will be a Model 747-100, the Boeing-owned airplane RA001, as described in Reference (b). JT9D-7A engines are installed in all four positions.

SPECIAL INSTRUMENTATION

The powerplants will be instrumented with 25 channels on both engine No. 1 and No. 2 to measure inertia loads at the powerplant center-of-gravity. Fourteen additional measurements to obtain basic airplane parameters, engine N1 RPM and EPR as well as the 6 components of acceleration at the airplane c.g. will also be recorded. All required measurements are delineated in Reference (c).

DATA REQUIRED

HSPCM	- On
ADAMS	- Active
Direct Write Oscillograph	- Active

CREW RESPONSIBILITIES

Pilot	- Call out airspeed, altitude, Mach No., load factor, pertinent observations.
Test Director	- Conduct test and record condition no., IRIG time, condition parameters, etc.
Weights Engr.	- Compute gross weight, c.g. for each test condition
Analysis Engr.	- Monitor direct-write to insure condition quality and communicate results to Test Director.
Instrumentation Engr.	- Monitor instrumentation accuracy and inform Test Director should any failures occur.

TEST PARAMETERS

Gross Weight	- As specified ±10%
Fuel Config.	- As specified
C.G.	- Optional
Airspeed/Mach	- As specified
Altitude	- As specified

GROSS WT/FUEL CONFIGURATIONS

	QUANTITY ~ Lbs.		
	CONFIG. A	CONFIG. B.	CONFIG. C.
Center Wing	As Req'd	As Req'd	As Req'd
Inboard Mains	82,000 (100%)	82,000 (100%)	Min. Allowable
Outboard Mains	28,500 (100%)	28,500 (100%)	Min. Allowable
Reserves	3300 (100%)	3300 (100%)	0
Airplane G.W.	Max. Payload	Max. Landing (564,000)	Max. Payload

TEST CONDITIONS

Take-Off

Record data from brake release through 10 seconds after lift-off during a normal take-off with 3 packs on in a tank-to-engine burn configuration.

Condition No.	Fuel Config.	Runway	Rotation Rate	No. of Take-offs
4.00.001.001	A	BFI	Normal	5
.002	A	BFI	High	5
.003	A	MOSES	Normal	1
.004	A	MOSES	High	1
.005	C	BFI	Normal	5
.006	C	MOSES	Normal	1
.007	C	BFI	High	5
.008	C	MOSES	High	1

TEST CONDITIONS (Continued)

Turbulence

Record 3 minutes of data in turbulence for as many of the conditions listed below as encountered during the test program.

Condition No.	Fuel Config.	Alt. ~Ft.	Airspeed KIAS	Mach No.	RMS c.g. Norm Accel ~ g	Remarks
4.00.001.009	C	35,000	As Req'd	.77	1.0 - 1.2	Baseline
.010	↓	35,000	↓	.84	↓	↓
.011	↓	15,000	290	As Req'd	↓	↓
.012	↓	35,000	As Req'd	.77	1.3 - .15	Moderate Turb.
.013	↓	35,000	↓	.84*	↓	↓
.014	↓	15,000	290*	As Req'd	↓	↓
.015	↓	35,000	As Req'd	.77	1.6 - 2.0	Heavy Turb.
.016	↓	35,000	↓	.84*	↓	↓
.017	↓	15,000	290*	As Req'd	↓	↓

*Maximum turbulence penetration speed.

Abrupt Wind-Up Turn

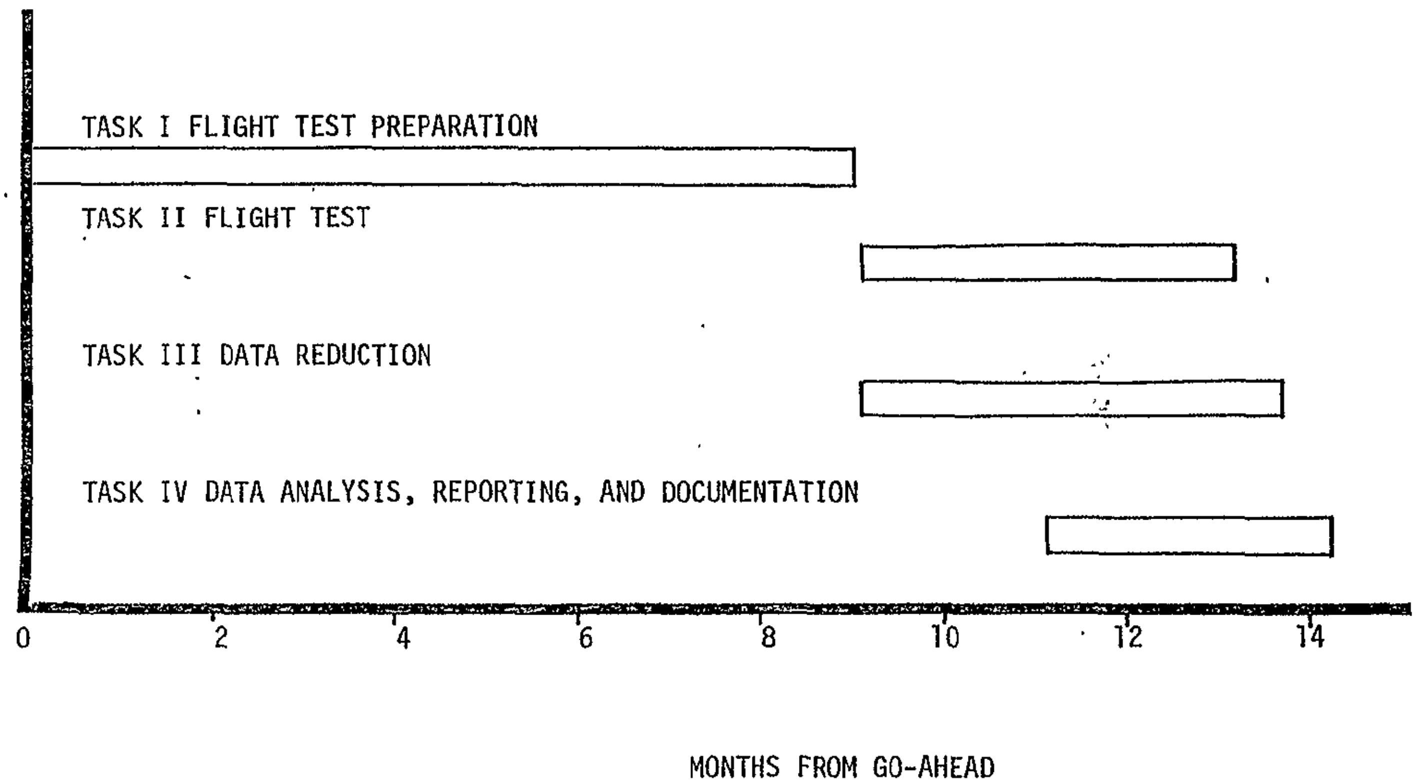
Condition No.	Operation
4.00.001.018	With the airplane trimmed for level flight at V_{REF}+80, 15,000 feet, perform an abrupt left wind-up turn from 1.0 to 1.6 g. Hold for 5 seconds and execute a normal recovery. Fuel Configuration is "C".

Landings

Record data from 50 feet prior to landing impact through a complete stop using thrust reversers and moderate braking. Runway is optional

Condition No.	Fuel Config.	Gross Wt. ~Lbs.	C.G. %MAC	Flap Posn.	Sink Rate ~FPS	Approximate AC.G. Normal Accel ~ g's	No. of Ldgs.
4.00.001.019	B	Max. Ldg. (564,000)	Opt.	Normal	1-4	.4	12
.020	B		↓	↓	5-8	.5-.10	12

APPENDIX D - SCHEDULE*



*Task II Flight Test Period May Require From 1 to 7 Months for RA001 due to Concurrent Testing.