TELEMETRY FOR ASALM-PTV MISSILE

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ABSTRACT

The telemetry and instrumentation used during the propulsion technology validation (PTV) flights of the Advanced Strategic Air Launched Missile (ASALM) is described in this paper. ASALM-PTV was a test vehicle that demonstrated the concept of the integral rocket/ramjet engine.

INTRODUCTION

This paper describes the telemetry and instrumentation used during the PTV flights of the ASALM vehicle. ASALM-PTV was a test vehicle that demonstrated the concept of the integral rocket/ramjet engine (Figure 1). This concept was proven through many successful test flights. The propulsion system performance and vehicle maneuverability that was shown is representative of what is expected from a supersonic cruise missile.

One of the ASALM test program flight objectives was to demonstrate supersonic cruise missile performance at high and low level trajectories. Another major objective was to prove structural and component durability, along with subsystem performance, during engine transition and maneuvers. More than two hundred inflight measurements were made through the telemetry system. Measurements were taken of acceleration, acoustics, vibration, temperature, pressure (fuel, combustion, and aerodynamic), strain, angle of attack and sideslip, electrical parameters of inertial guidance, missile voltages, and control signals and commands.

The basic telemetry system used two radio frequency (RF) links. One frequency modulation (FM) link was used for wide-band vibration and acoustic measurements. The second link, a 10-bit pulse code modulation (PCM) FM link was used for the remainder of the measurements. The basic design parameters of the telemetry links and the signal conditioning and sensors used will be discussed. Measurement programs and data correlation and calibration will also be discussed.

RF SYSTEM

The FM multiplex signal was fed to one 5-watt band transmitter, while the PCM multiplex signal was fed to an identical 5-watt band transmitter. Each of the signals was tuned to a different S-band frequency. The outputs from the FM and PCM transmitters were each fed to a frequency diplexer. The diplexer mixed the two separate RF signals onto one coaxial cable. The output of the diplexer was fed to a three-port power divider that separated the two combined RF signals into three equal RF outputs. The divided signals were then routed to three separate S-band antennas placed around the periphery of the nose section. This antenna arrangement provided an omnidirectional antenna array.

The antennas were flush-mounted and cavity-backed. Quartz was used for window elements. Extensive testing at temperature and vibration plus antenna pattern plots were performed to ensure performance at high temperatures. Signal strength levels obtained during the flight tests verified the mechanical integrity and electrical function of the RF system during boost and supersonic cruise.

PCM SYSTEM

The PCM system consisted of two elements, the main PCM encoder located in the avionics section, and the remote multiplexer mounted in the aft control section. Characteristics of the PCM system are described in Table 1.

The PCM encoder consisted of a modular package built up using standard PCM modules to accomplish the desired quantity and format of signals. The encoder design consisted of a power supply, analog-to-digital converter, high-level multiplexers (O to 5 volts), low-level multiplexers (O to 50 millivolts), a flow meter totalizer, discrete or bi-level channels, a serial computer word interface, clock and timing formatter, and programmed read only memory (PROM). The parameters of the PCM were:

1 10 bits per word

2 96 words per minor frame

3 32 minor frames per major frame

4 12.5 major frames per second

5 Bit rate: 384,000 bits per second.

By using PROM, various sample rates were available through a mixture of super commutation and sub-commutation. The basic sample rate of one word per minor frame was 400 samples per second (SPS). Super-commutation provided sample rates of 800 and 1200 SPS. Sub-commutation provided sampling rates of 200, 100, 50, 25, and 12.5 SPS.

The purpose of the remote multiplexer was to sample and condition low-level signals located behind the interstage compartment. The multiplexer also provided low-level signals on one pair of wires, since no space existed to channel the 56 pairs of wires required to send the measurements from devices in the aft section. The remote multiplexer was located in the control ring around the booster nozzle. The remote multiplexer required 10 control wires from the main multiplexer to carry clock signals, address codes and gain change, plus sample rate change commands and two output wires.

If the remote multiplexer had not been used, 112 wires would have been required. So the space required for running 102 wires was saved. The inputs to the remote multiplexer were all low level differential, with some inputs sampled at 12.5, 25, 50 and 200 SPS. The “O” signals were scaled to provide 5 volts with an input of 25 millivolts. The other signals, “L”, “M”, and “N”, were scaled to provide 5 volts with an input of 50 millivolts. The 25-millivolt signals were obtained from strain gauges. The 50-millivolt signals were generated by pressure transducers and thermocouples located in the aft compartment.

The output signal of the remote multiplexer was a 5-volt pulse-amplitude modulator (PAM) signal at 38.4 kilobytes per second (KBS), the word rate of the main multiplexer. The output of the remote multiplexer was fed to the main multiplexer in a synchronous burst to merge it with the main forebody signals. The PAM output was fed to one of the high-level multiplexer inputs, where it was converted to a 10-bit digital word. Since the ramjet could heat the aft compartment to extremely high temperatures. The entire remote multiplexer was encased in a thermal blanket of min-K insulating material.

The remote multiplexer itself was designed and tested to withstand temperatures of 230°F. The internal printed circuit was soldered, using silver solder with a melting temperature of 596°F. The copper wires entering the remote multiplexer were also insulated.

The basic accuracy of the PCM was 0.2 percent for high-level and 1 percent for low-level channels. The PCM encoder and remote multiplexer proved to work very well during flight, with no failures. Complete electrical testing of the units was performed in conjunction with the RF systems to verify operation. Each unit was 100 percent tested at specification level temperature and vibration.

COMPUTER INTERFACE

An inertial navigation unit (INU) was the basic navigational system used on ASALM. The INU consisted of inertial grade sensors, gyros and accelerometers, and a flight data processor (FDP). By means of a digital computer, the FDP provided continual readouts of flight coordinates in latitude, longtitude and altitude. The FDP was also programmed to issue steering orders to maintain the flight program. Elements of the flight program included various timing commands and sequences such as nozzle deployment, fuel-to-air ratio control, and other functions. The output of the digital computer was fed into a first-in, first-out (FIFO) storage register.

The serial data computer module, a part of the PCM telemetry system, sent PCM clock pulses and an enable pulse when it was ready to accept computer data. The output of the FIFO, which was 30 bits, was then clocked out at the PCM bit rate directly on the PCM serial output bus. This data formed 30 bits, or three consecutive 10-bit words.

Since the computer and the PCM were not synchronized, the data could not be decoded directly with the normal PCM ground station. The 30-bit computer word used actually contained a 6-bit address or designator and three pieces of 8-bit data. A simple ground-based computer program then extracted the data from the apparent random data appearing on the PCM decommutator by means of the 6-bit address. Although the nonsynchronized computer and PCM interface caused a ground reduction problem, the problem was not serious. Obtaining data was not a problem. In order to make the PCM data readout directly, two schemes could have been implemented:

1 Devise a system so that the computer and PCM have a common clock and are synchronous.

2 Devise a random access memory (RAM) array so that the computer can write into memory at one speed, while the PCM can read out the memory locations at another speed.

FM MULTIPLEXER (FM MUX)

The FM-FM system was a standard Inter-Range Instrumentation Group (IRIG) configuration using constant bandwidth and proportional bandwidth subcarrier oscillators. The system consisted of 13 subcarrier oscillators (SCO) and a mixer amplifier. A built-in automatic calibrator was included in the amount to provide a zero, half-scale and full-scale calibration signal on command. Nine of the SCO's provided wide band response by using constant bandwidth channels with 0 to 1000, 0 to 2000, and 0 to 4000 hertz responses. The other four SCO's provided medium response of 0 to 59, 0 to 81, 0 to 110 and 0 to 160 hertz response by using proportional bandwidth channels. The FM multiplexer performance data is summarized in Table 2.

The basic accuracy for the constant bandwidth channels varied from 5 to 10 percent, while the proportional bandwidth approached 2 percent with calibration. The FM-MUX performed well on all flights, and the vibration data correlated well with predictions in regard to amplitude and frequency.

INSTRUMENTATION

The telemetry instrumentation used consisted of various transducers located throughout the missile. Over 200 inflight measurements, including acceleration, acoustic, vibration, temperature, pressure (fuel, combustion, and aerodynamic), strain, angle of attack and sideslip, plus electrical parameters of inertial guidance, missile voltage, control signals and commands were made. Table 3 summarizes the number of telemetric measurements taken during seven ASALM test flights.

PRESSURE

The pressure measuring devices were all strain gauge-type transducers. These transducers were low-level signal devices and required low level amplifiers to amplify the signal. The devices were accurate between 0°F and 250°F. The transducers and their associated tubing were mapped in an insulating cocoon to protect the unit from high heat that could be experienced in the ASALM missile. Other units, such as the chamber pressure measurements, were grease-filled to protect the diaphragm from hot burning gases.

TEMPERATURE

Various types of temperature measuring devices were used to monitor temperature throughout the missile. Thermocouple devices were used where temperatures could have reached greater than 700°F. Figure 2 shows the ASALM temperature measuring system, with connections to the pulse code modulator. Platinum temperature sensors were used to monitor temperature where the maximum temperature did not exceed 700°F. Platinum temperature sensors plus electronic signal conditioning provided better accuracy than thermocouples in the 0 to 300°F temperature range. Thermistors were used to provide the temperature readings for the thermocouple reference junctions.

FUEL FLOW TOTALIZER

An impeller-type of flowmeter was used to provide a highly accurate measurement of fuel flow. The output of the flow meter was a series of pulses indicating revolutions of the impeller and the rate of fuel flow. Previously used techniques integrated these pulses to form an analog signal which represented flow. This analog signal would then be digitalized by the telemetry system.

In ASALM, however, these pulses were amplified and conditioned. Then the pulses were applied directly to the totalizer module of the PCM. Figure 3 shows how flow meter information was relayed to the PCM. This module produced an encoded number representing the total number of pulses received. The flowmeter was calibrated to indicate pounds of fuel per pulse. The technique used in ASALM started with a digital signal and was processed digitally all the way to the printout. This technique provided excellent measurement accuracy of fuel flow.

MISCELLANEOUS

Vibration and acoustic measurements were made using piezoelectric transducers and charge amplifiers calibrated by the vendor. Drag acceleration was measured using a sero-controlled accelerometer. Mechanical strain, bending and hinge moments were measured using strain gauges.

VOLTAGE AND TIMING

Various guidance, control, and other electrical parameters, including discrete events such as motor ignition, arming, nozzle release, etc., were also measured.

AERODYNAMIC DATA

An air data probe and matching transducer system were used to monitor angle of attack (α), and angle of sideslip (β). Figure 4 shows the ASALM air data probe system. The air data sensor was attached to the nose of the missile. The sensor contained five ports which fed the air pressure through tubing to a set of transducers located inside the missile. One pair of tubes measured the differential pressure in the yaw plane (which is proportional to angle of sideslip), while another pair measured the differential pressure in the pitch plane (which is proportional to angle of attack). The center hole measured pitot pressure, which is proportional to velocity. The actual angle of attack (α) and angle of sideslip (β) must be calculated from the formula.

$$\text{Angle of attack, } \alpha = \frac{P_1 - P_2}{K}\left[\left(P_5 - P_3\right) + \frac{\left(P_3 - P_4\right)}{2}\right]$$

$$\text{Angle of sideslip, } \beta = \frac{P_3 - P_4}{K}\left[\left(P_5 - P_3\right) + \frac{\left(P_3 - P_4\right)}{2}\right].$$

STRAIN GAUGE

Figure 5 shows the ASALM strain gauge system. Strain gauge measurements were made on the vanes to provide hinge moments and vane panel bending moments. Good data was obtained on the bending moments, but good hinge moment data was not obtained because square cross section vane shafts were used. The torque readings on the strain gauges were quite low in comparison to these obtained with circular cross section vane shafts.

MEASUREMENT CONTROL

The measurement program was computer-controlled and printed. An IBM card system was used. Two cards were required for each measurement. A complete deck could then be fed into the computer for printout. Cards could be added or deleted either manually or by a special program. The printout was reduced to an 8 by 11 format and released directly as a controlled drawing. As additions or deletions were made, a new card was added to the deck with the appropriate revision number.

DATA REDUCTION AND CALIBRATION

All transducers were individually calibrated at the incoming inspection, and calibration curves were prepared by serial and flight number. This data was then programmed into the computer so that the raw magnetic tapes could be fed into a PCM decommutator. The output binary count was read by the computer. Corrections and conversion to engineering units were made, and data printed out at one second intervals. The reference temperature was added to give the corrected reading for temperature data involving thermocouples.

CONCLUSIONS

The telemetry and instrumentation system used on the ASALM-PTV flight program was considered very successful. A data recovery of over 95 percent was obtained on the seven flight tests. Although all of the flights were considered successful, based on the flight missions planned, certain problems in flight control did occur. The telemetry system was instrumental in pinpointing the failure modes. Examples of problems were high missile spin rates which safed the safe-and-armed device, dirt in the fuel system which caused an early shutdown, premature loss of hydraulic pressure on one flight, and others. The computer interface provided excellent data on the INU and its output. The fuel flow totalizer provided a very good correlation on fuel expended and rates of consumption. The remote multiplexer had no problems in flight and returned good data on all flights. The use of the PCM, which permitted the use of computerized printouts, made rapid data reduction possible. Typically, a flight was made in the morning at White Sands Missile Range. The following morning, two sets of oscillograph data (35 records each) were available to the design engineers.

SUMMARY

The telemetry and instrumentation system for ASALM-PTV was used to provide monitor data on the state of the ASALM missile subsystem throughout captive carry and free flight. The telemetry and instrumentation was also used as a monitor system for providing an in-plant acceptance test and final verification of various missile systems. The systems were used in this fashion during factory build-up and final acceptance tests prior to shipment to White Sands Missile Range.

The telemetry system consisted of two S-band RF links, one PCM and the other FM. The PCM system provided over 250 channels of data with varying sample rates. The FM system provided 13 channels of wide-band data, such as vibration and acoustic sound levels.

The PCM and FM systems used individual RF carriers combined into one set of S-band antennas. The instrumentation consisted of transducers to measure pressure, temperature, fuel flow, vibration, acoustic sound pressure, linear acceleration, aerodynamic angles, mechanical strain, and timing events.

Additionally, voltage monitors from the various subsystems, such as battery voltages, guidance commands and responses, autopilot signals, status of one-shot devices, voltage regulator outputs and launch sequence status were encoded and displayed. The 30-bit word from the in-flight data processor computer was also monitored. Five complete sets of digital data in engineering units also were made available. The FM vibration data was displayed on high frequency oscillographs using conventional techniques. Power spectral density plots were made from the original magnetic tapes and were computer printed one day later. The rapid presentation of final data permitted two sequential flights to be made within nine days of each other.

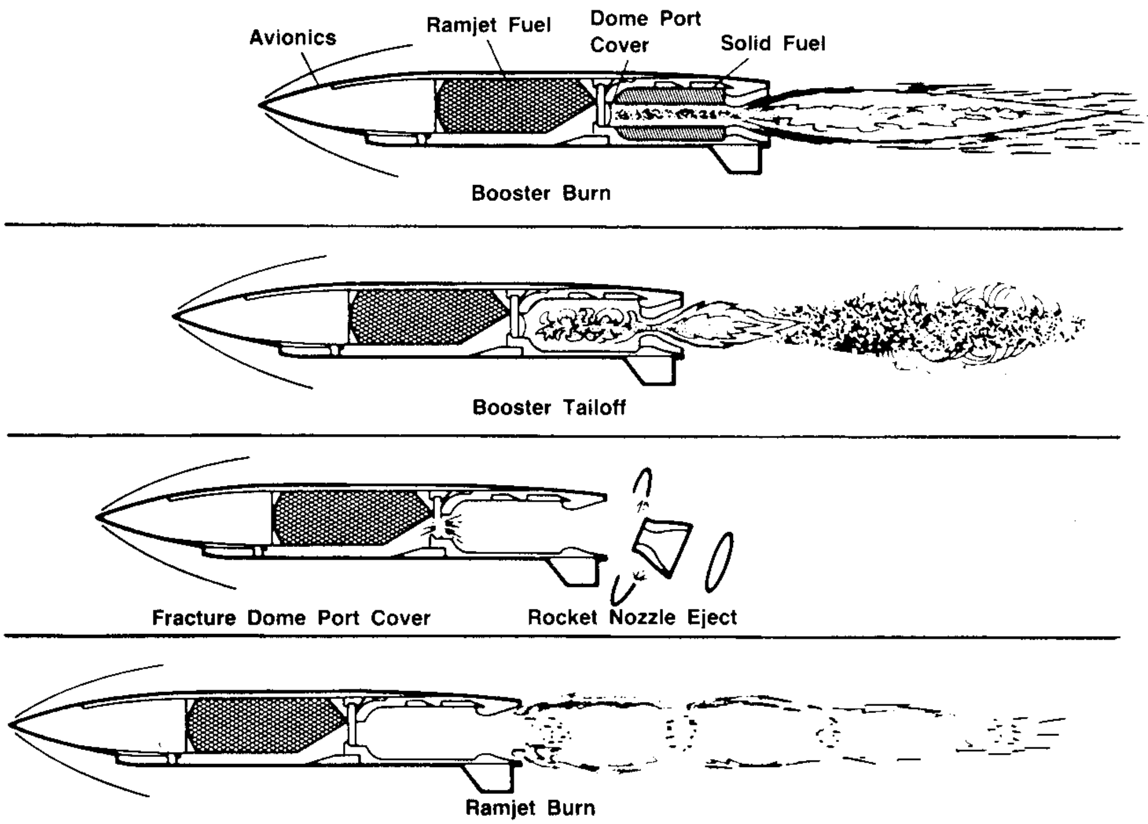

Figure 1. The Advanced Strategic Air Launched Missile (ASALM) Rocket/Ramjet Concept

TABLE 1
Pulse Code Modulation (PCM) System Characteristics

	Code	Words	Samples per Se cond	Input Level	Type
Main Pulse Code Modulation	A	6	1200	0-5V	Analog
	B	18	800	0-5V	Analog
	C	8	400	0-5V	Analog
	D	16	200	0-5V	Analog
	E	8	100	0-5V	Analog
	F	16	50	50-mV	Analog
	G	20	25	0-5V	Analog
	H	64	12.5	50-mV	Analog
	I	2 (20 bits)	100	0-5V	Digital Totalizer
	J	3 (30 ch)	100	35-V	Bi-Level
	K	3 (30 bits)	400	0-5V	Digital Computer
Remote Multiplexer	L	32	12.5	50-mV	Analog
	M	8	25	50-mV	Analog
	N	4	200	50-mV	Analog
	O	12	200	50-mV	Analog
	Sync	3	400	0.5V	
	Frame ID	1	400	0.5V	
	PCM Bit Rate;		384,000 bits per second		
	PCM Output:		NRZ-L		
	Word Length:		10 bits		
	Major Frame Length:		32 minor frames		
	Minor Frame Length:		96 words		
	Minor Frame Rate:		400 words per second		
	Major Frame Rate:		12.5 per second		

TABLE 2
FM Multiplexer Performance Data

Channel (IRIG)	Frequency (kHz)	Deviation	Modulator Index	Frequency Response (Hz)
9	3.9	±7.5%	5	59
10	5.4	±7.5%	5	81
111	7.35	±7.5%	5	110
12	10.5	±7.5%	5	160
1A	16	±2 kHz	1	2000
2A	24	±2 kHz	1	2000
3A	32	±2 kHz	1	2000
5B	48	±4 kHz	1	4000
7B	64	±4 kHz	1	4000
9B	80	±4 kHz	1	4000
11B	96	±4 kHz	1	4000
15C	128	±8 kHz	1	8000
19C	160	±8 kHz	1	8000

TABLE 3
Summary of Measurements Taken During
Seven ASALM Test Flights

Measurement	Number of Measurements Per Missile Tested (Seven Missiles)							
	1	2	3	4	5	6	7	Total
Pressure	48	48	48	48	48	48	48	336
Temperature	90	92	88	92	88	88	88	625
Strain	8	14	2	14	2	2	2	44
Vibration	8	8	6	6	6	6	8	48
Acoustic	1	1	2	2	2	2	1	11
Other (end)	6	6	6	6	6	6	6	42
Guidance	61	61	61	61	61	61	61	427
Discrete	29	29	29	29	29	29	29	203
Telemetry Cal	7	7	7	7	7	7	7	49
Total	258	266	249	265	249	249	250	1786

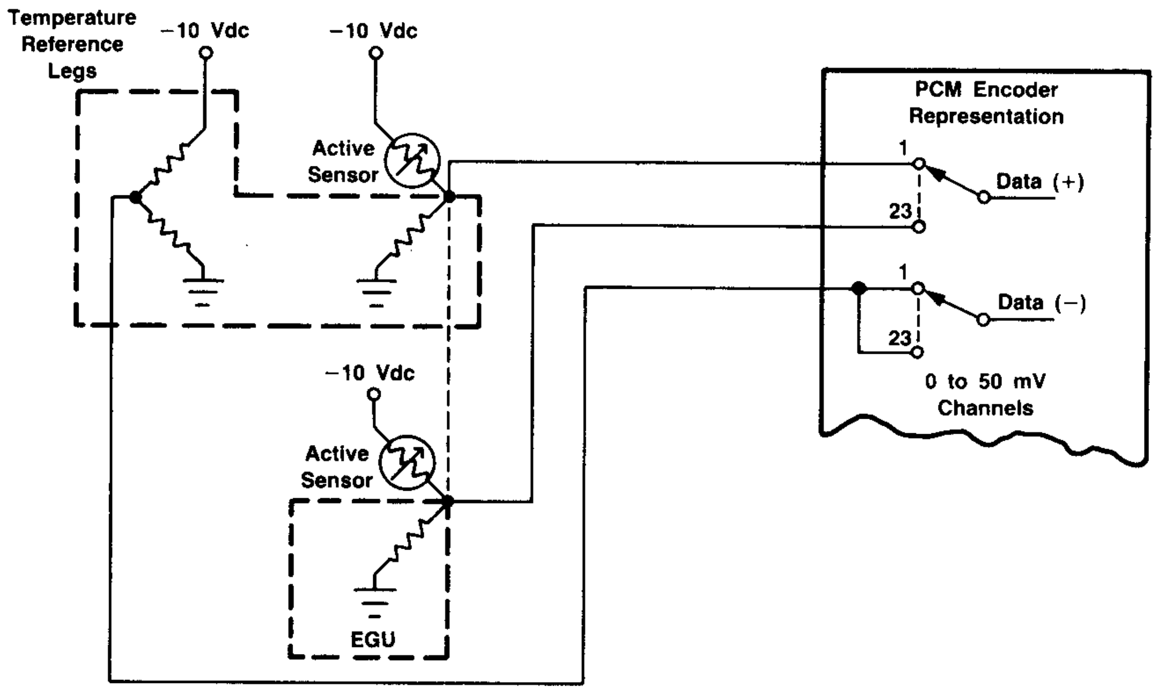

Figure 2. ASALM Temperature Measuring System, Showing Connections to the Pulse Code Modulator (PCM) Encoder.

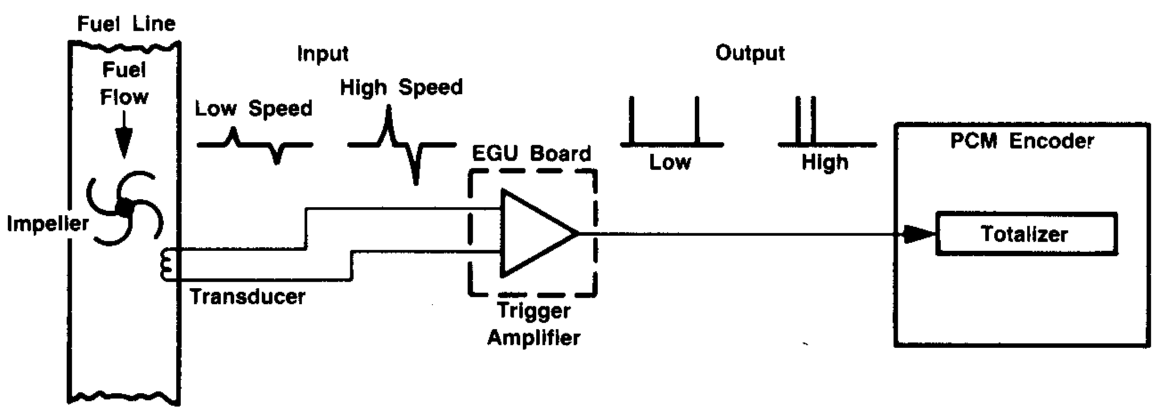

Figure 3. ASALM Impeller-Type Flowmeter System

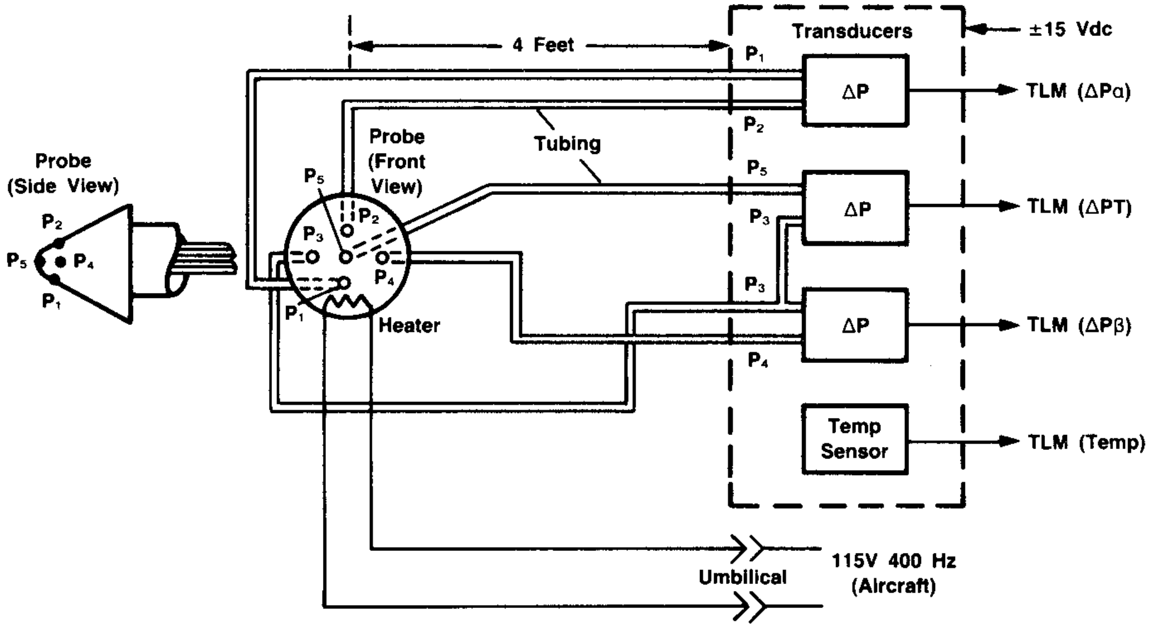

Figure 4. The ASALM Air Data Measurement Probe System

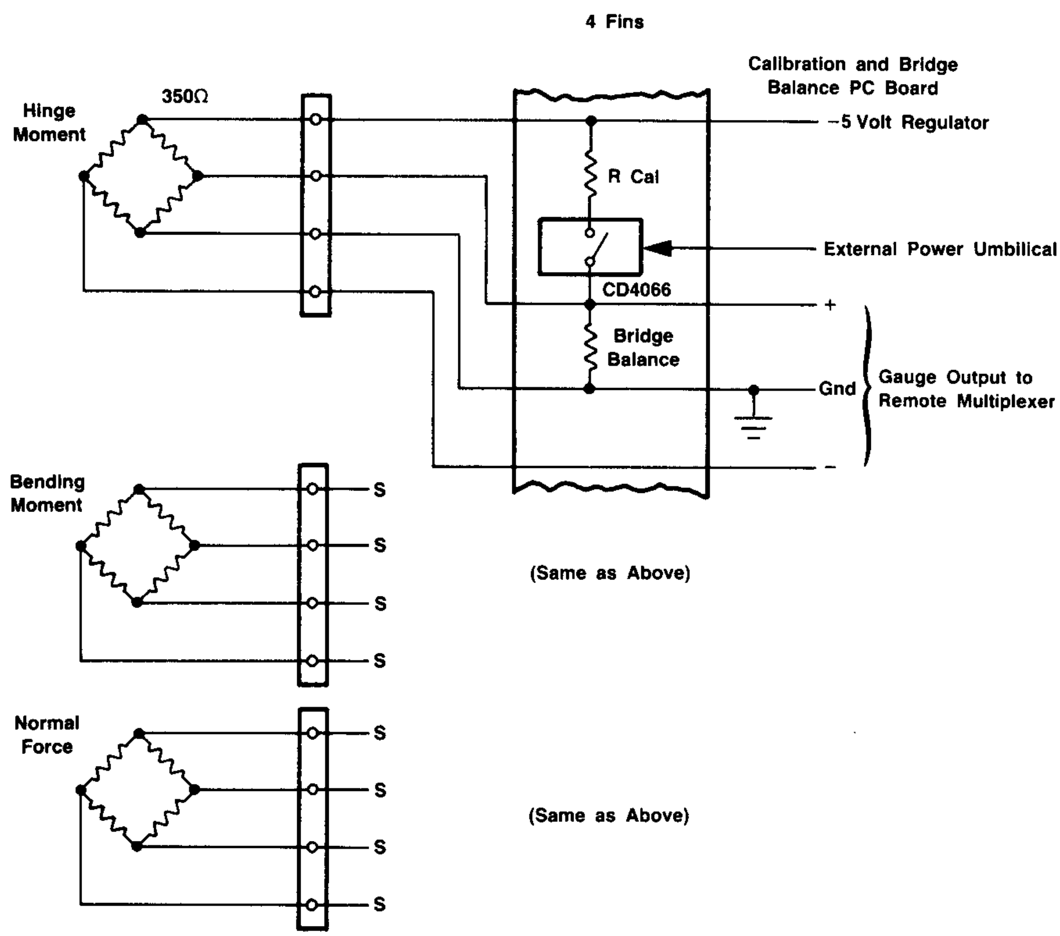

Figure 5. ASALM Strain Gauge Measurement System