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USAAVLABS TECHNICAL REPORT 70-46

DESIGN CRITERIA FOR AN INSPECTION AND DIAGNOSTIC SYSTEM FOR THE UH-1D HELICOPTER

By

Joseph C. Leifer
Harold G. Peacock

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November 1970

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-68-C-0004
MELPAR
AN AMERICAN-STANDARD COMPANY
FALLS CHURCH, VIRGINIA

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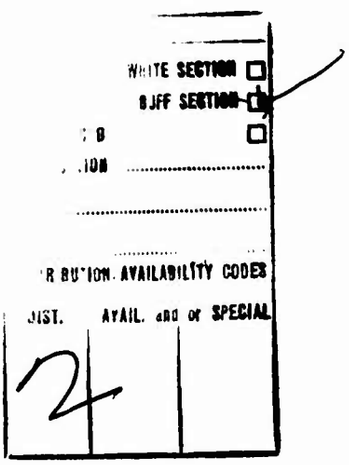

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November 1970

DESIGN CRITERIA FOR AN INSPECTION AND DIAGNOSTIC SYSTEM FOR THE UH-1D HELICOPTER

Final Report

By

Joseph C. Leifer and Harold G. Peacock

Prepared by

MELPAR
An American-Standard Company
Falls Church, Virginia

for

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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ABSTRACT

The objective of this program is to accumulate sufficient vibration and temperature data to establish base-line operating levels and to determine maximum limits for use in the development of an automatic diagnostic and inspection system for the UH-1 series helicopter.

Samples of data were taken from 12 instrumented helicopters at controlled times by three automatic self-calibrating data collection systems which were moved between the aircraft twice each day.

The relevant data were processed by a high-speed digital computer through a number of passes to produce edited calibrated printouts and magnetic tape records of each acceptable data sample.

Maintenance records on the instrumented helicopters were reviewed, summarized, and correlated with measured changes in temperature and acceleration level during the same period.

The conclusions of this report are found on pages 124 and 125.

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INTRODUCTION

The program has as its objective the accumulation of sufficient vibration and temperature data to establish base-line operating levels and to determine maximum limits for use in the development of an automatic diagnostic and inspection system for UH-1 series helicopters. The controlling parameters of the data collection program were specified by the Government and are outlined below.

Three complete data collection systems were supplied, each of which is capable of rapid installation in any one of twelve UH-1D helicopters being used routinely for pilot training at Fort Rucker, Alabama, and which were equipped with six wide-band accelerometers and eight temperature sensors. Also installed on the helicopters were pilot's control consoles, junction boxes, and mounting hardware, enabling rapid, single-cable connection of the data collection systems to the helicopters. Airspeed transducers with electrical output were installed, as well as electrical connections to the aircraft's torque transmitter and attitude gyro. The latter connections permitted the establishment of a data collection "window" indicating straight and level cruising flight, during which data would be collected at intervals extending over a 500-flight-hour period in the life of all twelve helicopters.

Each of the three data collection systems consisted of two major packages, one of which was a 14-channel plus-edge track ruggedized instrumentation recorder having wide-band FM electronics and operating at 60 inches per second. The other package, or Melpack, contained signal conditioners for the 14 data channels and the flight window parameters, DC-to-DC power supplies, and a digital control system and clock that controlled the period between data collections, the duration of data collection, the identification of data taken in the flight window, and a completely automatic calibration system that was activated whenever power was either turned on or turned off.

Field operations consisted of attempting to schedule and install data collection equipment in three helicopters each morning and each evening in a manner that would minimize the interval between data samples on each aircraft. Data consisted of analog recordings taken for 12-second intervals during ground run-up and every 15 minutes while in flight and in the flight window. The tapes made each morning and afternoon were taken to an instrumentation trailer where identification codes were added as they were played back through a multiplexer, 1/3-octave filter bank, analog-to-digital converter, and recorded on standard 1/2-inch digital tape in

computer compatible format. While the tapes were being converted into digital form, a paper chart "quick-look" recorder system generated a record that indicated the general quality of the analog data and indicated which, if any, transducers were malfunctioning.

The preprocessed digital data tape was shipped to Melpar, Falls Church, Virginia, for processing on a Honeywell DDP-224 computer. This processing involved a total of five computer passes with two manual screenings between the first two. Final edited data were sorted by helicopter tail number, by sensor, and by significant frequency, and a master data tape was prepared which contains the results of all the collection activities. A printout of all these data was also prepared, along with recorder and signal processor amplifier gains and drifts, and an analysis of the shift in system gains and offsets between a pre-run calibration and a post-run calibration.

In addition to the above-described data handling procedures, the computer was programmed to present data in a form judged most suitable for correlation with maintenance procedures and the establishment of operating levels for measured parameters. These presentations included a plot on the computer line printer of the value of all significant measured parameters in chronological order. This printout, called the historical record, has been the most useful format for the data in the determination of the effects of maintenance on acceleration and temperature level. The distribution of measured variables for all helicopters and for individual helicopters is presented in the form of histograms. Depending on the shape of the distribution, it has been possible to assign arbitrary "alerting" levels for parameters that were searched out in the historical records and correlated with maintenance actions condensed from aircraft logs. Because each of the 12 instrumented helicopters had its own endemic signature of measured parameters, and because the levels of these parameters varied considerably between helicopters, a highly significant factor was the shape of parameter variation as well as its absolute level. Obvious changes in general level were correlated with maintenance actions.

In order to better identify the sources of certain spectral lines in the acceleration records, a series of high-resolution spectrograms was made from data collected from one helicopter before and after the change of a transmission. This analysis showed that accelerometers at one location can easily detect gear-mesh frequencies generated at other elements in the drive train.

It was possible during the latter phases of the program to collect data on four helicopters while they hovered out of ground effect. Despite the fact that considerably more engine power was required in this flight regime, acceleration levels appeared to be essentially unchanged from the majority of data that were collected during cruising flight.

SYSTEM DESIGN

INTRODUCTION

The function of the system design phase was to implement the required data collection and processing system in an optimum manner. The majority of the parameters of the data collection system were defined in the Statement of Work, with virtually a wide-open area for data processing. The problem, then, was to implement the data collection system in such a manner that it could perform all of the required functions; even more challenging was the development of a data reduction system which could operate on the data as collected and produce the required analysis and go/no-go parameter limits. Figure 1 is a block diagram of the data collection system.

DATA COLLECTION SYSTEM

Accelerometer Band Width

The collection of acceleration data ranging between 4 Hz and 20 KHz for two of the total of the six channels was required. There was also a requirement for velocity pickups ranging between 4 Hz and 2 KHz for three channels, and 4 Hz to 200 Hz for one channel. The two wide-band accelerometer channels established a requirement for an FM wide-band data recorder with no digitization on board the aircraft, and this was explicitly confirmed in the statement of work by the specification of the recorder. It then appeared to be advantageous to record all of the vibration channels as accelerometer outputs because all channels of the recorder were capable of DC to 20 KHz response, and accelerometers should have longer life in adverse environments than velocity pickups, as well as being much smaller in size. Further, there are advantages in recording the data as acceleration rather than velocity, for velocity data can easily be derived from acceleration by electronically or mathematically filtering the latter with the equivalent of a single-section R-C filter having a slope of 6 db per octave above the cutoff frequency, which, in this case, would be 4 Hz. It is evident that, by collecting velocity data, potentially a large amount of information would be irretrievably lost by the filtering process. Therefore, it was determined that the data would be collected as accelerations and that filtering, if necessary, would be performed later. It also seemed likely that extending the bandwidth of all channels to 20 KHz might prove to be useful, and because the only cost penalty would occur in the volume of data processed and analyzed, the advantages of collecting all data as wide-band accelerations appeared to be worthwhile.

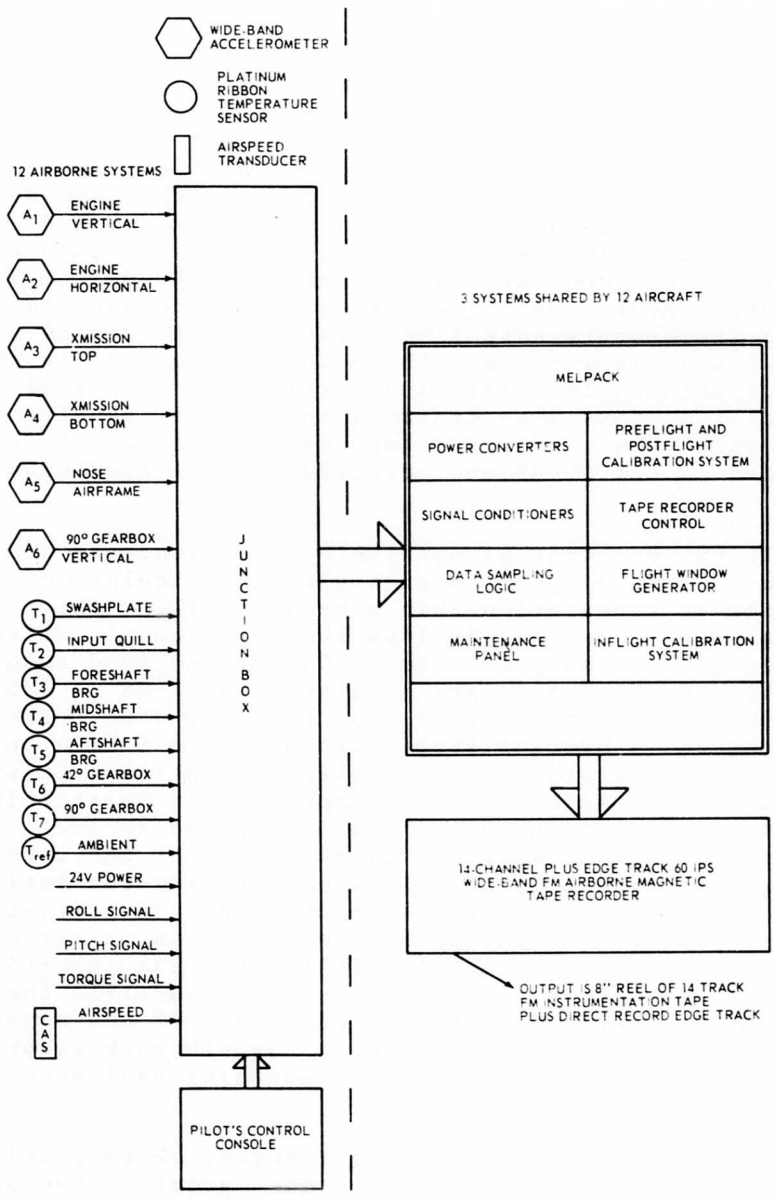


Figure 1. Block Diagram of Data Collection System.

The results of the program showed the great significance of these high-frequency accelerations. Figure 2 shows a block diagram of the acceleration data collection system.

Choice of Accelerometers

Considerable effort went into the selection of the accelerometers which were used in this program. Some of the difficulty was associated with the fact that the National Bureau of Standards does not routinely calibrate accelerometers beyond 10 KHz. There was also some concern that the desired accelerometer, which had a built-in preamplifier, had a temperature limit in the vicinity of 300° F. No data were available on the temperatures that might be prevalent in the engine compartment, and it was necessary to conduct tests employing temperature-sensitive paint in that area as well as to install and fly with four thermocouples mounted in the engine compartment in order to determine the advisability of using accelerometers with preamplifiers. The results of the tests revealed that excessive temperatures would not be experienced in the locations selected for the accelerometer mounts.

The result of the study of available accelerometers was the selection of a low-impedance piezoelectric accelerometer. This device is contained within a hermetically-sealed stainless steel case, weighs less than 1 ounce, is rated flat in frequency response from 4 to 10,000 Hz and good response to 20 KHz, has 30 millivolts per g output, is rated to 100 g's, and has an output impedance of less than 150 ohms. The latter feature is brought about through the use of a built-in field-effect transistor emitter follower amplifier in the accelerometer and is of extreme importance in maintaining low noise level and in assuring adequate response at low frequencies. Another very valuable feature of the accelerometer was its provision for field calibrating the entire system following the piezoelectric material. A precision resistor is built into the transducer which is in series with the signal return to the emitter follower. The insertion of a known voltage across this resistor makes possible the determination of gain through the remainder of the signal conditioners, the airborne recorder, the playback recorder, the amplifiers, and whatever data processing equipment followed.

In addition to the above-listed attributes, these accelerometers had a signal-to-noise ratio much greater than 60 db and were relatively simple to mount. The signal return and the case were well isolated, electrically. Cabling requirements were met by a 4-conductor shielded cable with connectors

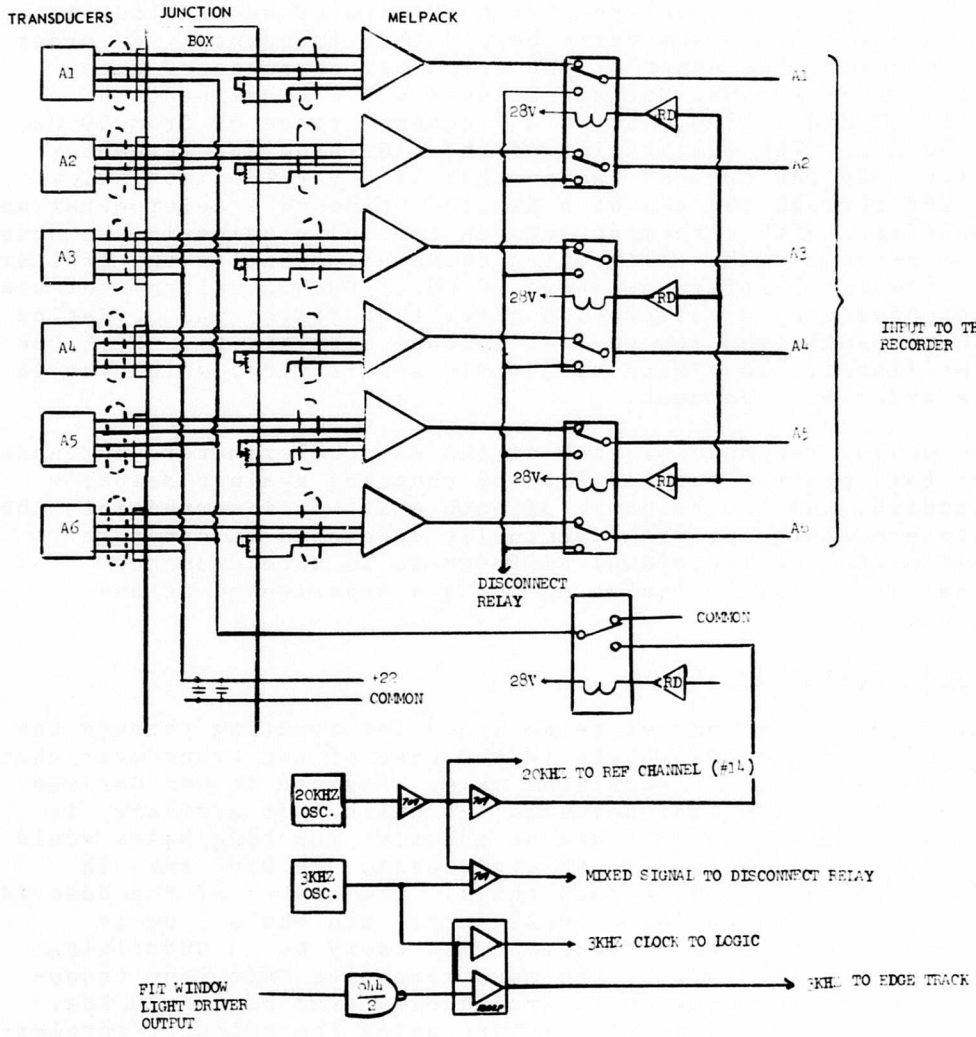


Figure 2. Block Diagram of Acceleration Data Collection System.

at both ends. The shield braid was cut at the accelerometer end of the cable to eliminate ground loops.

Laboratory Calibration of Accelerometers

Because the NBS does not routinely calibrate accelerometers above 10 KHz, no accelerometer manufacturer was willing to provide a calibration curve beyond that frequency. In order to establish the shape of the frequency response of these units above 10 KHz, Melpar employed a B & K calibration Exciter, Model 4290, having a frequency range of from 50 Hz to 30 KHz. The calibration of the wide-band accelerometer built into the exciter was checked at several points below 10 KHz through the use of a Kistler Standard accelerometer and amplifier, with agreement between the units being in the order of 2 percent. The calibration curve accompanying the exciter was used as a reference above 10 KHz. Each accelerometer was accompanied by a calibration chart that listed its deviation (in percent) from its nominal voltage sensitivity, which was also listed, along with cross-axis sensitivity, which was in the order of 2 percent.

The actual response of each of the 72 accelerometers purchased for this program was verified by checking against Melpar's standard, and the response of each unit was inserted into the data processing program eventually developed in order to compensate for individual differences in accelerometer sensitivity when calculating the g's experienced at any location.

Accelerometer Mounting

The 4-281 accelerometer is designed for mounting through the use of a tapped 10-32 hole in the base of the transducer that is coaxial with its sensitive axis. Because it was desired to avoid drilling any holes in the helicopter airframe, it was determined that the use of adhesive mounting bases would be highly desirable. These rigid bases are 0.62 inch in diameter and only 0.14 inch thick. The center of the base is drilled and tapped for a 10-32 screw, and the bottom is ribbed to permit good adhesion with epoxy to an underlying structure. The body of the mount provides excellent transmission of acceleration to frequencies even beyond 20 KHz. The preparation of a test fixture using the selected accelerometer, the adhesive mounting base, and the vibration exciter resulted in the finding that satisfactory operation could be obtained from this type of mount, provided that the usual precautions required for high-frequency accelerometer mounting were observed.

Temperature Sensors

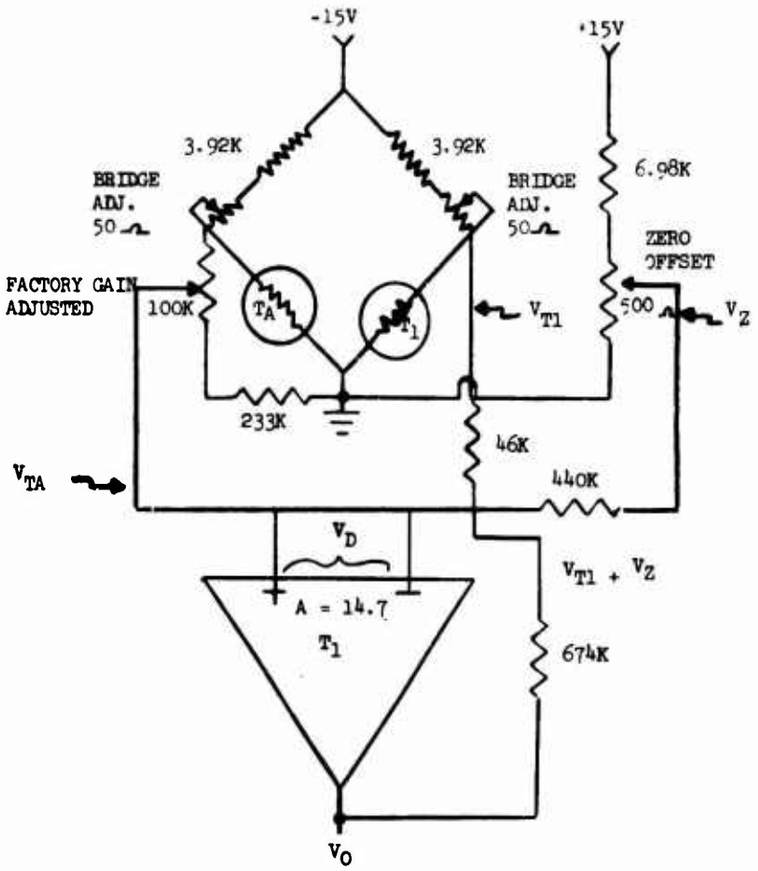
The use of ribbon temperature sensors was specified. RTP-50F-10 type units were selected. Normal specification for these platinum ribbon surface thermometer units is a resistance of 100 ohms +2 and -0 at 70° F. In order to minimize the required manual calibration of these elements, a premium product having the same reference resistance but with a tolerance of -0 and +1 ohm was specified.

The nature of this type of sensor is such that its performance can be adversely affected only by impurities in the platinum element, which is considered highly unlikely, and by the effects of strain on the sensing grid. Of course, the resistance at 70° F must be precisely known, as must the bridge completion resistors, the bridge excitation voltage, and the gain of the signal conditioning amplifiers following it. The effects of the majority of these interfering elements are eliminated by the automatic calibration and drift compensation procedures built into the signal conditioning units and through the use of 0.1% tolerance resistors in the bridge. The initial setup procedures and the automatic calibration and drift compensation circuits will be described later. Figure 3 is a schematic diagram of a single temperature measurement-channel.

One problem that arose following the commitment to use these sensors and their subsequent delivery was the discovery that, despite the tight tolerance on resistance, the platinum leads used for external connection had 4 ohms resistance at room temperature. This necessitated the generation of a procedure for attaching the sensors to strain-relieving terminals which would ensure that all leads were of the same length, and it also necessitated the formulation of a computer-generated calibration chart and installation procedures that compensated for the additional resistance.

Temperature Sensor Mounting

A method of mounting the delicate free filament temperature sensors on curved surfaces under field conditions had to be developed. The technique involved the placement of a thin film of insulating epoxy cement on top of a sheet of aluminum foil. After this coating hardened, a number of sensors with strain-relieving terminal strips soldered to them were placed on the sheet, which had a fresh, tacky coating of epoxy on it. The top of the metal ribbon temperature sensor is cemented to a 1/4-inch-thick foam thermal insulator. The bottom of the foil is covered with a pressure-sensitive adhesive, which is protected by a peel-off strip that is removed when the sensor is applied.



WHEN

$R_{TA} = R_{T1} = 100\Omega$ $V_{T1} \approx -.37V = V_{TA}$

$V_Z \approx +.274V$

$V_D \approx +.096V \therefore V_O \approx -1.414$

WHEN

$R_{TA} = 100\Omega$ $V_{TA} \approx -.37V$

$R_{T1} = 150\Omega$ $V_{T1} \approx -.549V$

$V_Z \approx +.274V$

$V_D \approx -.096V \therefore V_O \approx +1.414$

Figure 3. Schematic Diagram of a Single Temperature Measurement-Channel.

Great care was exercised in designing the system in order to isolate the signal return leads from all sensors in order to reduce noise pickup and crosstalk generated by ground loops. Coaxial cable, type RG-58/U, and crimped TNC connectors were used to further reduce noise pickup in the temperature circuits. The lubricants used in parts of the UH-1D power train dissolved the PVC outer insulation on the RG-58/U cable, causing spurious grounding and chain reactions of noisy, oscillating temperature channels. When this problem was isolated, it became standard procedure to place woven glass tubing over the affected portions of the cable.

Airborne Magnetic Tape Recorder

As described earlier, there was a requirement for an FM magnetic tape instrumentation-type recorder for each of the three data collection systems, and, despite the advantages of digital recording, there was no simple way to provide airborne real-time conversion of the large quantity of analog data being collected. Traditionally, the limiting element in analog data collection systems incorporating magnetic tape recorders is the recorder.

Required Characteristics

It was desired to maintain as high a signal-to-noise ratio as possible in order to provide a wide dynamic range. Wide dynamic range would permit the examination of small signals at some frequencies in the presence of large signals at other frequencies. Wide dynamic range would also reduce the necessity for gain adjustment as the helicopter condition varied. Linearity and distortion specifications were more significant than usual in this application, for data were being examined over a frequency range of 12 octaves, and any harmonic distortion generated in any of the lower octaves would fall within the high-frequency passband of the data reduction equipment. Intermodulation products generated within the recorder could propagate false signals both up and down in the spectrum.

The highest reasonable speed for tape transport that would give acceptable running time and start and stop times is 60 IPS. To obtain 20 KHz response on an FM system at this speed requires the use of extended frequency range heads and electronics, which is quite conventional in the present state of the art. Conventional also is the availability of 14 channels plus edge track for a machine using 1-inch tape. Melpar chose to place the accelerometer data physically at the center of the tape, where it would be less subject to degradation due to wear-induced deterioration of the edge of the tape. Because of the necessity for repeated starting and

stopping of the tape machine when sampling the data, start time to stable speed and, to a lesser extent, stopping time were significant insofar as they represented a loss of recording media that could limit the amount of data taken on a long flight. Also, the time to achieve stable speed had to be consistent, for the control logic of the data collection system had to initiate a record command a fixed time following the command to begin transporting tape. In an attempt to avoid the recording of bad data, the phase error signal of the capstan servo speed control of the airborne recorder was monitored. If the recorder was not up to synchronous speed before recording was initiated, or if phase lock was achieved and broken six times during recording, the control system indicated a malfunction, and no further data were recorded until the system had successfully completed a calibration routine. The airborne recorder also had to be rugged in order not only to survive the hostile environment of the helicopter but also to operate within its specifications.

Recorder Selection

In the selection of the airborne tape recorder to be used on this program, major emphasis was placed on performance and potential reliability rather than on size or weight.

In order to select an airborne recorder that was most suitable for the program, a laboratory demonstration was performed, at which time the significant specifications as listed by the manufacturer were measured. Several machines were evaluated, and although the Genisco Model 10-276 did not meet its own specifications in certain respects during demonstration, the fact that this was the machine described in our proposal, with an assurance that it would meet its specifications, led to its eventual acceptance. These recorders were a continuing problem to the project. Probably the most severe and debilitating defect was the inability of all machines to operate consistently at synchronous speed as the loading on the supply and take-up reels changed. Much data was lost due to asynchronous operation, even after the allowance for time to achieve synchronous speed was doubled to 4 seconds.

Ground-Based Magnetic Tape Reproducer

In addition to the three required airborne recorders, it was necessary to provide a compatible ground-based playback machine for data reduction. An evaluation of available ground-based magnetic tape reproducers that would be compatible with the airborne recorders was conducted. For this application, a number of machines appeared to be satisfactory. An AMPEX model FR-1300 was evaluated, and it met all of its published specifications with ample margins.

An interesting sidelight to the recorder procurement was the result of specifying that an edge track #1 be supplied on both the airborne and ground-based magnetic tape machines. Due to poor planning in the published standards for identifying edge track #1, both machines had the edge track channel on the proper side of the head stack according to the standard, yet they were incompatible until a new head stack was purchased.

Airspeed Sensor

Because the airspeed sensor was to be employed to set one parameter of an adjustable "window" that had to agree with the airspeed transducer already mounted in the UH-1D's, absolute accuracy was not a requirement. However, repeatability, signal level, ruggedness, and reliability were important. The use of a pair of adjustable pressure switches for each helicopter was considered for the system as well as transducers having continuous output and operating threshold determined electronically. The decision was made to purchase the Computer Instruments Corporation Model 6100 i finite resolution differential pressure transducer. These units operated completely satisfactorily and never required any maintenance. This sensor was connected to the existing helicopter pitot-static pressure system through the use of "T" fittings and tubing. Electrical output connections were by cable to the junction box.

Torque Sensor

The flight window parameter of engine or transmission torque was obtained by using signals generated by the aircraft's own torquemeter sending unit. After information was obtained from the manufacturer on the characteristics of the sending and receiving unit, it was possible to design electronic circuitry that could interpret these signals and establish an adjustable go/no-go threshold without interfering with the normal functioning of the indicating instrument. This was accomplished by employing high input impedance circuitry, and by tapping into the aircraft cabling system at a connector through the use of back-to-back connectors, with a cable leading to the junction box. As a result, when the data collecting equipment had to be removed from the instrumented helicopters, either at the end of the program or for maintenance, the aircraft could be restored to its original condition very quickly and easily.

Attitude Sensors

It was determined that the helicopters to be used in the data collection program were instrument-training aircraft. The usual flight profile used for instrument training was the only

one at Fort Rucker in which there would be a good prospect of obtaining the required flight time in straight and level cruising flight. Fortunately, these helicopters were fitted with vertical gyros having electrical output. It was not necessary, then, to provide additional instruments to sense roll and pitch within approximately ±5 degrees if tapping into the existing instrument outputs could be accomplished. The required information was obtained from the manufacturer, and electronic circuitry having high input impedance was designed to accept the gyro output signals and to generate plus and minus threshold values for roll and pitch angles without interfering with existing systems. The tap-in was achieved without modification of aircraft wiring through the expedient of inserting a back-to-back connector between the gyros and the aircraft wiring harness. A cable from the back-to-back connector was run to the junction box.

Power Connection

DC power of 28 volts for the airborne data collection system was obtained by connecting to preexisting outlets in the helicopter ceiling near the transmission tunnel. These outlets were intended for electrically heated blankets that operated from a separate circuit breaker on the nonessential bus. The cable from the blanket heater outlets to the junction box was protected by a 15-ampere circuit breaker in the junction box.

Junction Box

Because of the requirement for there being only a single connector and cable between the airborne data collection systems and each of the 12 instrumented helicopters, a junction box was required. Figure 4 shows a view of the junction box with side plate removed. The junction box not only served as a convenient accessory for terminating all cables, but it also served as a housing for adjustments, controls, and components that were unique to the individual helicopters. Therefore, bridge completion resistors and the precision, 10-turn potentiometers used as reference temperature were included, as well as precision, 10-turn potentiometers used as gain controls for the accelerometer channels. Gain controls were employed in these channels in order that recording levels could be set for each channel of each helicopter, independent of the particular recording system being used. Therefore, the recorder could be operating at a near-optimum signal-to-noise ratio regardless of the magnitude of the signal generated by each accelerometer. Because the automatic calibration system (description begins on page 23) employed in the Melpack measured the actual gain throughout the amplifier and recorder chain and filter bank and computed

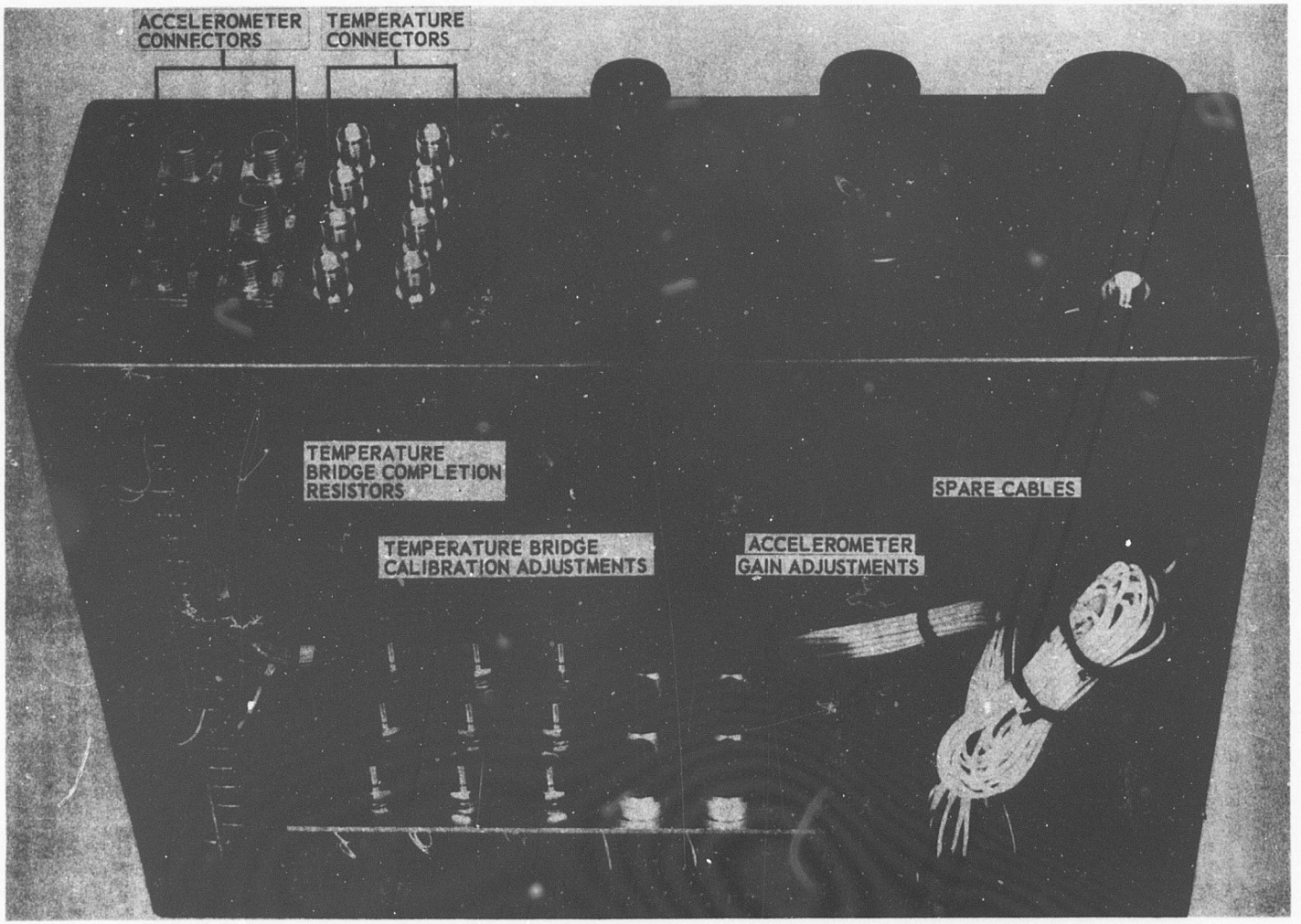


Figure 4. View of Junction Box With Side Plate Removed.

g level from this value, adjustment of gain would have no effect on system accuracy. A precision dial was placed on these gain adjusting pots for reference by the engineer making adjustments, and so that he could change the gain to a value recommended by the data processing computer that would improve the signal-to-noise ratio of the system.

A 120-pin connector and cable were used to link all the helicopter-associated circuitry to the Melpack. Each circuit was provided with its own return signal lead in order to eliminate ground loops. Because only 78 wires were required, there were a number of spare pins and wire pairs to cover possible future requirements. In addition to the spare connector pins and wires between junction box and Melpack, a spare connector was placed on the junction box to accommodate possible future requirements.

To avoid ground loops in the airframe, signal return leads for each transducer were carried separately through all the cables and connectors to the signal ground terminal on each signal conditioning amplifier in the Melpack. The shield braid on the accelerometer cables was broken near the accelerometer so that ground currents would not flow in that lead. Because the body of the coaxial connector (TNC) used for the temperature signals would normally ground the cable shield to the panel upon which the connector is mounted, it was necessary to use an insulating plastic plate to mount all of the sensor connectors.

Pilot's Control Panel

Because of the requirement that data be collected on the ground before and after flight, and because it might occasionally be desirable for the pilot to disable the power bus to the data collection system, it was necessary to provide a pilot's control panel. The console between instructor and student had several blank areas on all the helicopters examined, and this appeared to be a highly satisfactory location for this element. The airborne system was designed to collect data at intervals only when the aircraft was in the desired flight window or during ground run-ups. It was deemed desirable to provide a subtle hint to the pilot when the equipment was waiting for straight and level conditions in order to record. Several other controls and displays were added, and the resulting panel features are outlined below (see Figure 5).

1. An illuminated alternate-action power switch is provided to actuate the recording system. Turning power ON or OFF places the recorder and logic system

Figure 5. Front View of Pilot's Control Panel.

in the CALIBRATE mode for 24 seconds. During final CALIBRATE, before the equipment shuts off, the power switch is illuminated RED rather than the normal WHITE.

2. Calibrate Button -- Depressing this button manually initiates the above-described calibration recording interval. The button is illuminated during all calibration runs.

3. Ready Button -- At the completion of a successful calibration run, the READY button is illuminated. It indicates that the system is operating normally and is idle, awaiting the next recording interval. Depressing this button tests all the lamps in the other push buttons.

4. Malfunction Button -- This button illuminates in the event that the recorder drive system does not establish an on-speed or phase-lock condition within the 4-second interval allowed before data recording begins. If the recorder should achieve phase-lock at the beginning of recording and should drop out instantly six times or continuously for six seconds, the system stops recording, and the malfunction button is illuminated. Because the recording of good data under these conditions would be impossible, the system locks up until a successful calibration run is performed. The latter can be attempted by either depression of the calibration button or malfunction button, or removal and reapplication of power.

5. Waiting Straight and Level Lamp -- After runout of the 15-minute timer, if the aircraft is not within the prescribed torque, attitude, and airspeed window, this yellow lamp indicates that condition.

6. Push Record Button -- Depression of this button initiates a 12-second data recording interval regardless of the condition of the flight window. Whenever the recorder is operating, the record lamp is lit. However, no recording will occur if the malfunction lamp is lit.

Mounting of Sensors and Equipment

In order to eliminate any permanent structural or physical modification to the helicopters, no holes were drilled in any of them, nor was any permanent attachment made. The processes by which attachments were made and the location and dress of

sensors and cables are shown in a separately bound appendix. This appendix is included with the data on file at USAAVLABS.

A summary of the practices used for installation of equipment follows: All sensors were either cemented directly in place or mounted on pads that were cemented in place or attached to the aircraft by using existing bolt holes. Cables either were supported in place by AN-type cable clamps that used existing screw holes or were laced to existing cables. Cables were passed from tail section to junction box and engine compartment and transmission tunnel to junction box through holes (cut and sealed) in aluminum or stainless steel plates used to substitute for existing inspection and handhold covers. The cable from the junction box to the pilot's control panel was run under the floor plates and along existing cable paths.

The junction box itself was mounted on the right-rear cabin bulkhead using existing tapped holes. Because the layout of cargo hooks and fittings on several helicopters appeared to be different, a universal hold-down device for the airborne recorders and Melpacks was designed. The hold-down provides a pair of very shallow boxes that are semipermanently attached to the floor fittings. A matching pair of metal plates holding the shock-mounted Melpack and recorder unit was placed over the box and attached to it by a set of quarter-turn fasteners to permit rapid insertion and removal.

Melpack

The Melpack is the master control for the data collection system, providing power, logic, calibration signals, signal conditioning, and output monitoring functions. The unit is shock mounted, approximately the same size as the airborne magnetic tape recorder, and contains a "service panel" on its upper deck. Figure 6 is a view of the Melpack showing its service panel.

Service Panel

The service panel permits control of the system from the Melpack as well as the pilot's control panel (they are duplicate controls), and, by operating a "master" switch, other controls can be activated which will place the unit into different modes of operation, such as being held in one portion of the calibration procedure, using normal or slow clock, or bypassing the phase-lock signal from the recorder if it is desired to work on the Melpack independently of a recorder. Further, there are provisions for monitoring the condition of all of the elements of the flight window, and for bypassing any or all of them, if it is desired to collect data during special operating conditions.

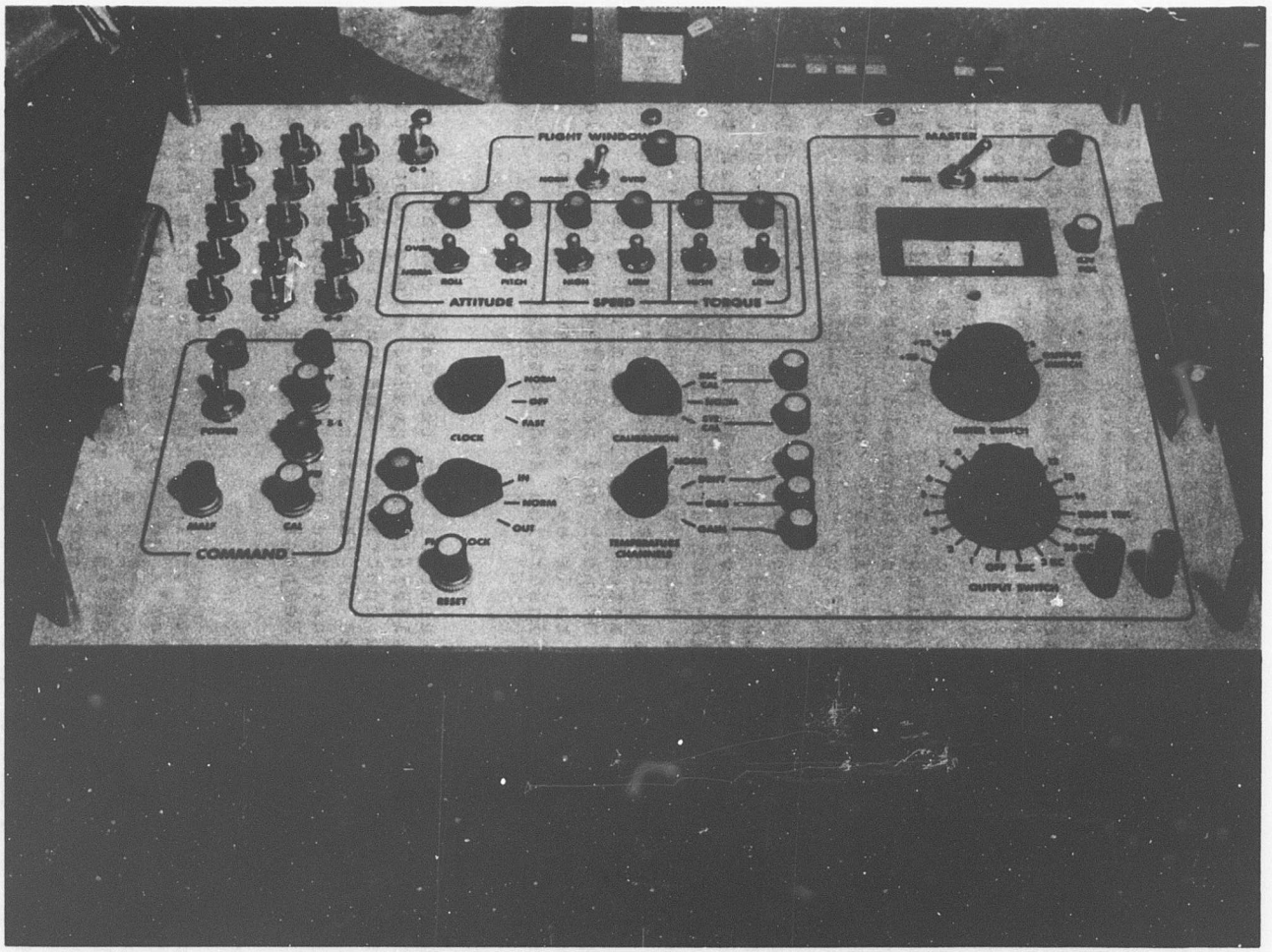


Figure 6. View of Melpack Showing Service Panel.

The Melpack also contains a pair of banana jacks, two rotary selector switches, and a D'Arsonval meter with a high-sensitivity rectifier and indicator. These elements were incorporated into the system in order to provide a convenient means for in-flight monitoring and troubleshooting with a minimum of external equipment and without disassembly of equipment.

The rotary switch nearest the meter permits switching of all seven internal power supply voltages to the meter. Multiplier resistors are of such a value that if voltages are proper, the meter will deflect identically as the switch is rotated through all seven positions. The maximum clockwise position of the meter switches the meter (and rectifier circuit) to the control of the output switch. This switch permits the meter and the banana jacks to monitor each of the 14 input channels to the recorder, as well as the edge track (containing flight window data), the clock frequencies, the calibration signals, and the FM and direct switchable playback channels available on the tape recorder.

Signal Conditioning Amplifiers

Investigation of the availability of signal conditioning amplifiers for the temperature and acceleration channels of these three data collection systems revealed that the cost of purchased, assembled units having the required characteristics would be unreasonably high for this program. Therefore, Melpar developed its own signal conditioners using UA709 integrated circuit operational amplifiers as the primary active elements. Certain less-critical buffer amplifier applications were fulfilled by Type MC1302P integrated circuit dual preamplifiers. The circuit designs were completely satisfactory, having negligible drift over a wide temperature range. Gains of the units were determined by 0.1% precision resistors.

Power Supply

Because of the complexity of the data collection system and of the Melpack, seven different voltage levels were required for all of the elements: +22 volts for the accelerometers, ±8 volts for the MC1302P amplifiers, ±15 volts for the UA709's, +5 volts for the Fairchild integrated circuit LTL micrologic, and 24 volts for the power relays and pilot lamps. All voltages with the exception of the pilot lamps and relays had to have power supply returns isolated from primary power ground in order to control ground loop noise and to offset signals.

A very satisfactory, very compact, and efficient multioutput inverter-type power supply for the three Melpacks was developed for Melpar to its specifications. Figure 7 is an outline drawing and specification for this device.

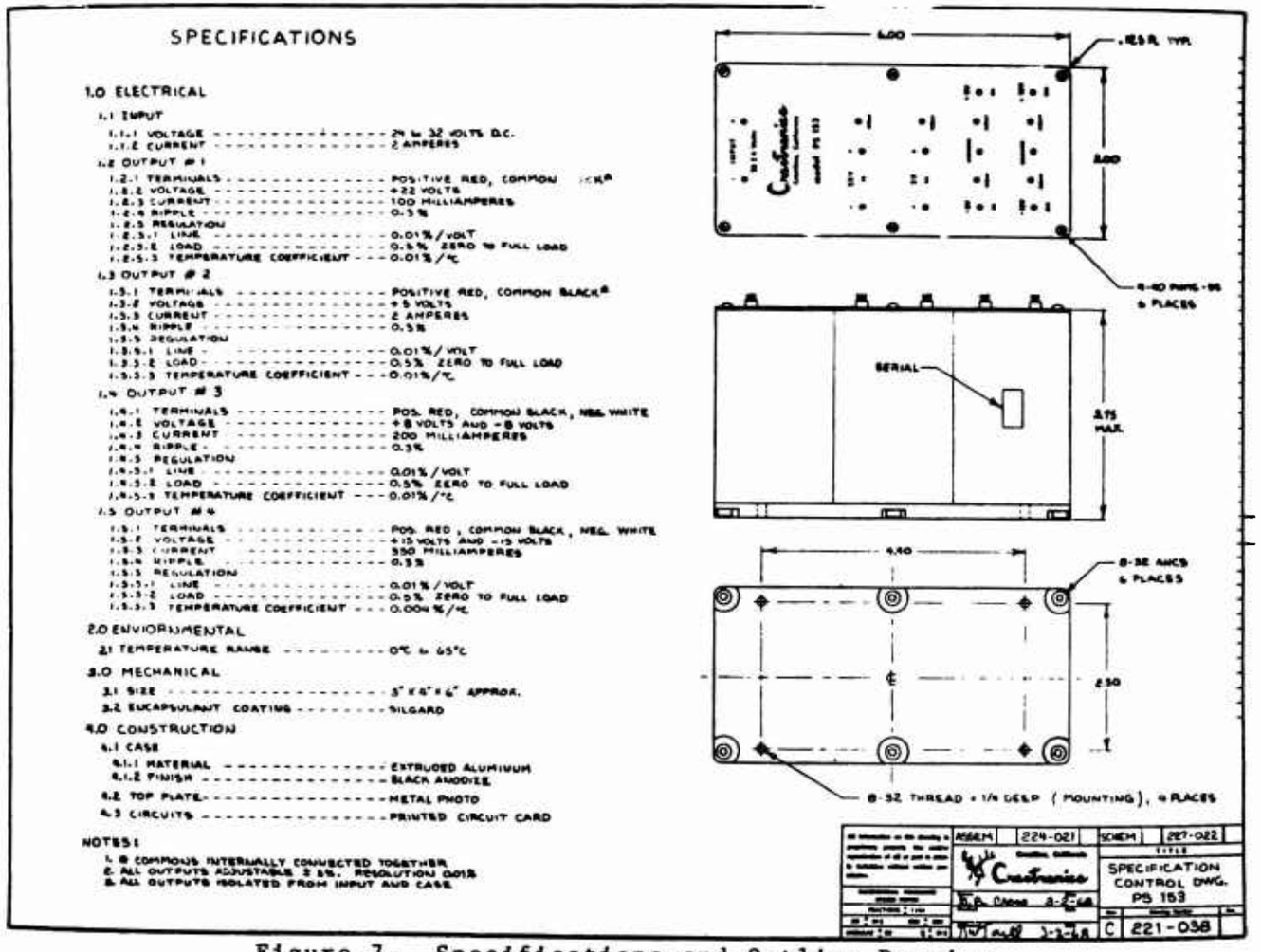


Figure 7. Specifications and Outline Drawing of Multiple Input Power Supply.

INITIATION OF CALIBRATION

As mentioned earlier, it was considered necessary to incorporate an automatic calibration procedure at the beginning and end of each recording period in order to verify proper operation of the tape recorder and the signal processing electronics. In addition to the pre- and postflight calibration, it was deemed advisable to check DC amplifier drift in the temperature circuits and the voltage on the temperature bridge during each measurement.

Calibration is initiated by any one of the following actions:

1. Turning power ON or OFF.
2. Depression of the CALIBRATE button.
3. Depression of the MALFUNCTION button.

Recorder Calibration

The complete procedure occurs in two contiguous phases, each of which is preceded by a 4-second interval, which is provided to assure that the transport is up to speed (phase-lock occurring) at the time recording begins. The first phase is recorder calibration, which lasts 12 seconds. During this time, all recorder channels except T_8, which carries the ambient temperature, are fed equal amplitudes of 3 KHz and 20 KHz signals that together produce a signal of 1 volt RMS. These signals were selected for several reasons. The 20 KHz signal checks recorder operation at the upper end of its frequency response. The use of 1 volt RMS ensures that the recorder is not overloading at rated signal due to electronic failures or change in alignment between record and playback amplifiers. The 3-KHz signal constitutes a midband signal to compare gain with the upper end (20 KHz signal), and any nonlinearities in the recorder will give rise to harmonics of the 3-KHz signal, which will be detected by the filter bank at multiples of 3 KHz. Intermodulation products will result in frequencies which are the differences between 20 KHz and 3 KHz and their harmonics. This calibration signal appears upon oscilloscopic monitoring of channels as a very distinctive pattern that can be used as an instantaneous field check of recorder operation.

Electronics Calibration

Following the 12-second recorder calibration, an electronics calibration is performed. It is clear that in order to maintain 2% accuracy from transducer to output data in a system involving a transducer, signal conditioning amplifiers, a gain adjusting potentiometer, an analog tape recorder (and its amplifiers), an

analog playback recorder, another signal conditioning amplifier, a multiplexer, a filter driver amplifier, 1/3-octave filters, precision rectifiers and ripple filters, an analog-to-digital converter, a digital magnetic tape recorder, and a computer, it is essential that an automatic calibration system be included. The purpose of this calibration is to place known, precision signals into the inputs of the signal conditioning amplifiers in order to measure the overall, end-to-end gain and performance of the signal handling elements. In the Melpack, separate calibration schemes are required for the temperature and accelerometer systems.

Accelerometer Calibration

The accelerometers selected for this program have built into them precision resistors in the signal return line between the piezoelectric stack and the field-effect transistor (FET) emitter follower amplifier. By inserting a precisely known 20 KHz signal into this resistor, a signal is produced which corresponds to a known acceleration at the sensor (by employing the calibration constant for the sensor). Thus, by applying a known signal to the input of the amplifier chain, measurement of the signal at the output of the chain permits calculation of the gain of the system. This gain value is calculated by the computer and used by it in determining the g levels that must have been present at the sensor to generate values measured during the data runs.

PRECISION RECTIFIER-FILTER

Because the output of the filter bank is a series of AC voltages within the band width of each element of the bank, and because it must be operated on as a DC voltage by the A-D converter, a precision rectifier-filter must be employed to accept these AC voltages over a wide dynamic range and to convert them into a low-ripple DC for conversion. This function is performed by a precision rectifier filter circuit. Because this circuit has DC output, it is subject to drift caused by thermal and other effects. In order that the calibration system be able to isolate DC drift from low-level signals, the DC output of the precision rectifier filters is measured during a period when no signal is applied to the filter bank. This value is subtracted from signal levels obtained during data runs.

Temperature Calibration

The temperature measuring system is calibrated during the electronics calibration period and is checked during each temperature measurement. A schematic diagram of the temperature measuring system is shown in Figure 8. The 12-second calibration

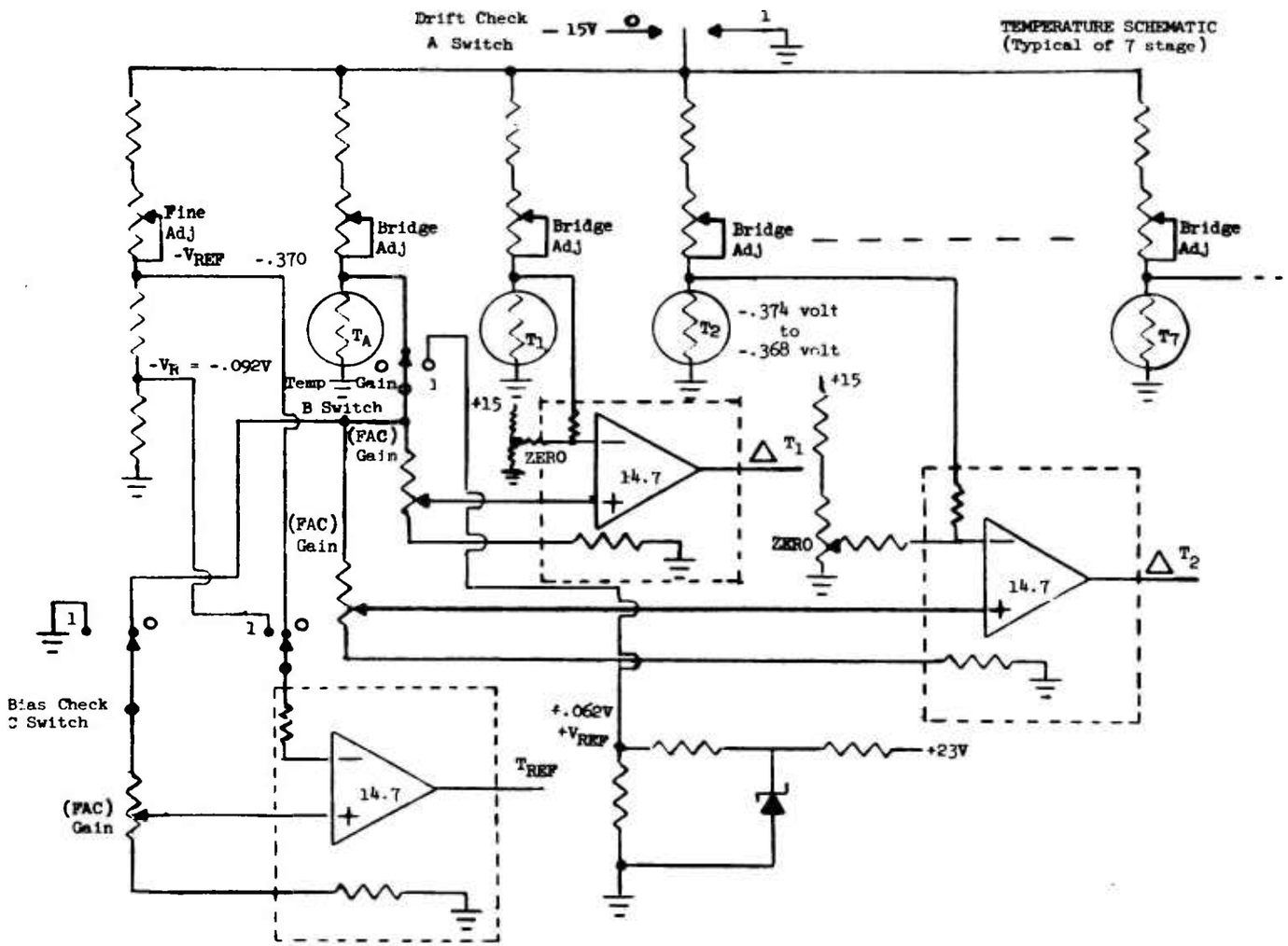


Figure 8. Schematic Diagram of Temperature Measuring System.

period is subdivided into three 4-second intervals. During the electronics calibration, each temperature channel, except that used for ambient reference, has its gain measured during the first interval. This is performed by removing the bridge voltage from the sensors and inserting the voltage from a precision zener diode into the differential inputs of the temperature signal amplifiers. Thus, comparing the output voltage of the temperature amplifiers to known input voltage permits an automatic calculation of gain by the computer used for data processing.

Drift is measured during the second interval by removing the temperature bridge excitation voltage and thereby producing an output voltage that is the result of DC drift only. This process does not modify the input impedances seen by the temperature signal amplifiers; therefore, the drift voltage produced by them should be identical during drift measurement to its value during temperature measurement.

Bridge excitation voltage is measured during the third period through the expedient of removing the ambient sensor from the noninverting input to the ambient channel and substituting a ground-voltage signal. A reference voltage obtained from the -15 volt bridge bus is divided down to a very low value by precision resistors and is inserted into the inverting input of the ambient channel. The remaining sensors are excited normally. Because the output of the ambient sensor is subtracted from the output of the remaining sensors, it is possible to calculate the value of the bridge excitation voltage, if the gain of the temperature channels is known.

During regular data collection operations of the system, the 12-second data collection operation is again broken into three 4-second intervals. Temperature system connections are such that normal temperature measurements are taken during the first period, drift measurements during the second period, and bias measurements during the third period. Figure 9 shows the logic output sequence used in normal recording of temperature data.

Quick-Look Recorder

In order to provide a quick-look record of the performance of the data collection system, a special-purpose system was designed and built. This system operates simultaneously with the operation of the data preprocessor, which converts the analog airborne data to digital data for computer processing. The quick-look has a pair of analog amplifiers that sum separately the outputs of the eight temperature signals and the six accelerometer channels. During the 4 seconds that temperature data are being received, each channel is sequentially removed from the sum for 200 ms and then reconnected. This

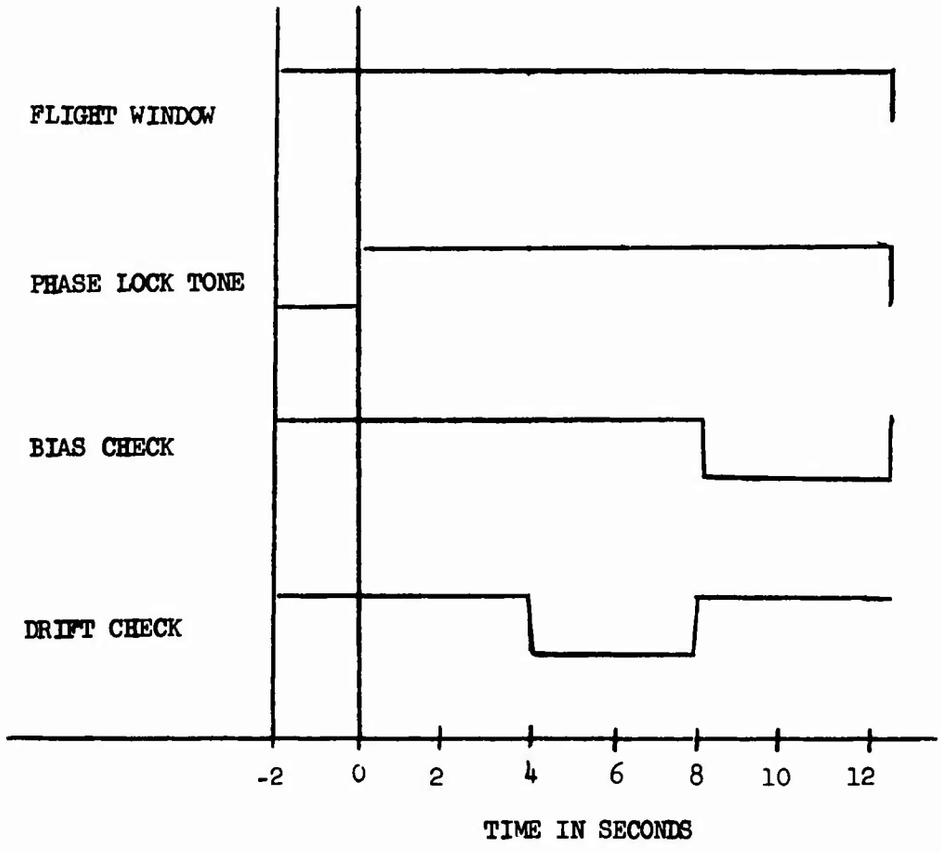


Figure 9. Recording Sequences - Logic Output Normal Recording.

sequence occurs three times during each 12-second run so that each of the eight temperature channels can be observed during each of the data, drift, and bias time slots. The acceleration channels are being observed simultaneously and are switched at one/third the rate of the temperature data since they are present for the full 12-second data period.

The two data channels generated by the quick-look system are recorded simultaneously on a two-channel Brush chart recorder. Figure 10 shows all the elements of the data collection system assembled for laboratory tests.

Data Preprocessor Controller

Commands for controlling the quick-look logic and the data preprocessor are derived from the reference temperature channel of the data, which has superimposed on the DC temperature signal a 20-KHz tone that is initiated by the beginning of the 12-second data recording interval, and which ends with the conclusion of that interval, or in the event of recorder malfunction. The ambient temperature channel is used for the control tone because the dynamic range of that channel should be employed to a lesser extent than that of any of the other measured variables, and it should be less prone to be driven into saturation by high temperatures.

Because the output of the FM playback amplifiers in the ground-based recorder are at maximum in the absence of tape motion or FM carrier (saturated noise), it is not possible to obtain system control simply by detecting the presence of a 20-KHz signal. To accomplish control, a data detector circuit consisting of two comparators is used. During periods of high-amplitude noise (tape not moving, or between data runs), the output of the first comparator, which is connected to any data channel, is used to inhibit the output of the second, which is connected to the reference temperature channel, keeping the quick-look system in a reset condition and preventing start-up of the data preprocessor. During a valid recording run, the noise on all channels is quieted for approximately 3 seconds prior to the appearance of 20 KHz signal on the reference temperature channel. In the data detector circuit, the quiet period causes the noise detection comparator to remove the inhibitive signal from the second comparator, making both comparators inactive, and enabling the second to signal the detection of the 20-KHz command tone when it appears. The attack time of the first comparator is made shorter than the second, while its decay time is longer.

Phase-Lock Detection

As mentioned earlier, if the airborne magnetic tape recorder should fail to maintain phase lock, the Melpack would stop data

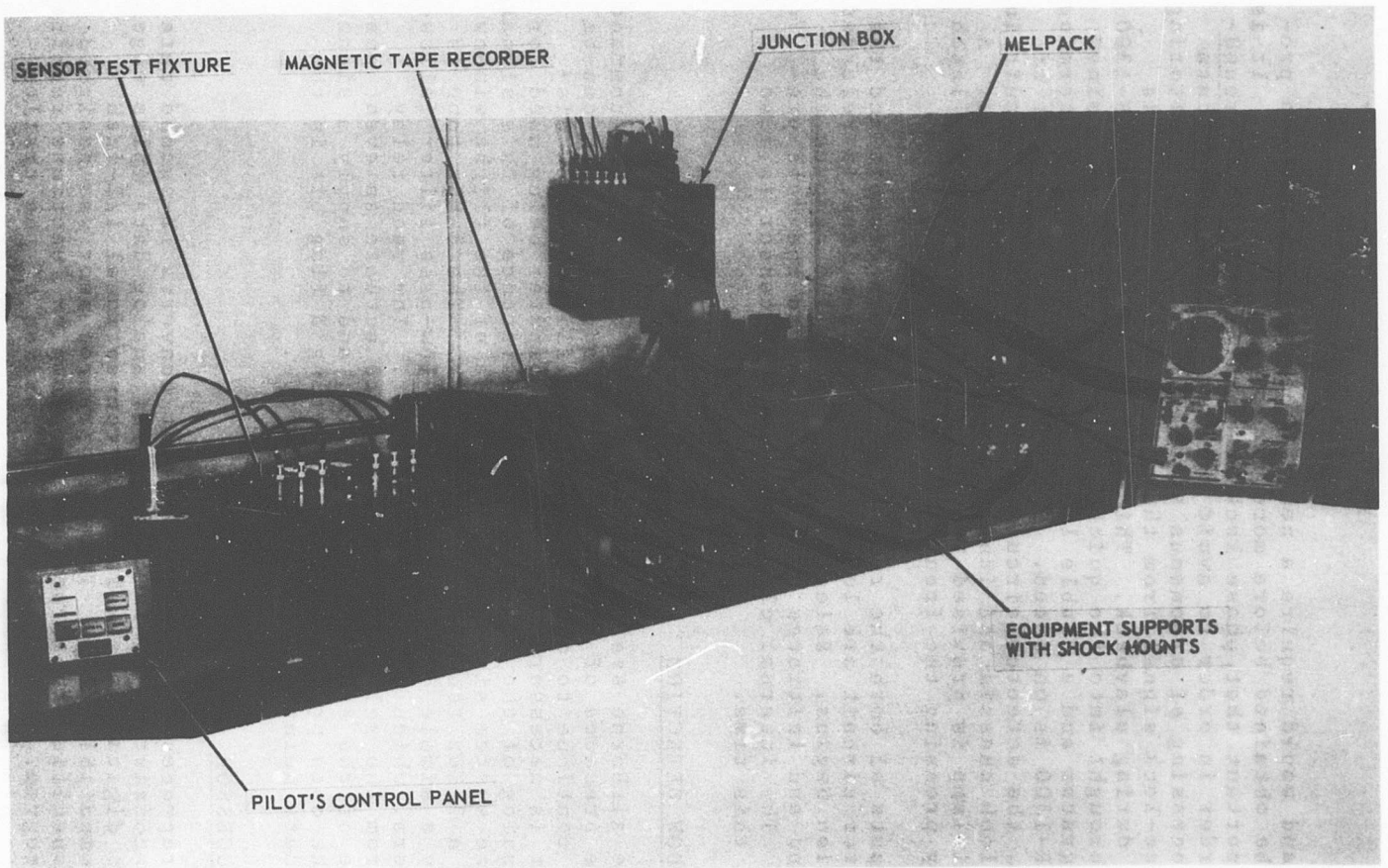


Figure 10. Laboratory Test Setup for One Complete Data Collection System.

recording and would require a new, successful calibration procedure to be obtained before more recording would occur. It is equally important that phase lock be maintained by the ground-based recorder in order to avoid serious degradation of data and the processing of erroneous signals. Therefore, monitoring of the phase-lock signal from the ground-based recorder is maintained during playback. This square-wave from the FR-1300 signal is brought into the quick-look chassis and is examined by an integrator and a double limit comparator, which determines that the FR-1300 is on speed. Should the recorder go out of phase lock, the detector circuit will set a latching circuit in the quick-look chassis and inhibit the processing of data. A front panel lamp is provided to alert the operator. The latch is reset by pressing the front panel switch.

If the outputs of both the recorder phase lock circuit and the data detector circuit are logic "1", the reset line is released and operation begins. Releasing the reset line removes the STOP command and initiates a START command to the data preprocessor. The internal clock of the preprocessor is also started at this time.

FLIGHT WINDOW DETECTION

Because the airborne system is designed to operate upon command without the presence of a flight window, and because it can be allowed to continue to operate after the flight window disappears, it is necessary to inform the computer being used for data processing of the existence or nonexistence of this signal. The airborne system signals the existence of the flight window by placing a 3-KHz tone on the edge track. The 3-KHz tone is detected by a simple diode detector and low-pass filter followed by amplifiers, which feed a relay driver. The reed relay operated from the relay driver is used to actuate an event pen on the edge of the Brush recorder chart, and to supply a signal level to the data preprocessor for setting a flag bit in the digitized data being put on computer tape.

DATA PREPROCESSOR

The data preprocessor is a device that converts 12-second data increments consisting of 14 channels of analog data (plus edge track) into digital data written on conventional 1/2-inch computer-compatible tape. The data preprocessor was designed and built specifically to perform the complex functions required for this program. Figure 11 shows a portion of the trailer-mounted data preprocessor.

The major elements of the data preprocessor are a datalogger and a 1/3-octave filter bank. Ancillary equipment was designed and built by Melpar.

Figure 11. Front View of Portion of Trailer-Mounted Data Preprocessor.

Header Data Insertion

The datalogger is equipped with an array of twelve 10-position thumbwheel switches that permit the manual insertion of identification data onto its digital magnetic tape output device. Data for manual insertion are obtained from the records accompanying the Melpack and recorder and filled out when the equipment is installed and removed from individual helicopters.

The first two digits are assigned to identify the day of the month, and the third digit has four positions for indicating the quarter of the day during which data was collected. Digits 4 and 5 are the coding for the 12 helicopter tail numbers. Digit 6 employs four different codes to indicate combinations of roll and/or pitch that may have been bypassed on the flight window switches. Digit 7 indicates whether or not the airspeed function has been bypassed, either high or low. Digit 8 indicates whether or not the torque function has been bypassed, either high or low. Digits 9 and 10 were reserved to indicate the existence of special flight window limits, if any. Digit 11 was assigned to indicate an equipment code which would uniquely describe a combination of any of the three recorders with any of the three Melpacks. Digit 12 was reserved to indicate the computer program or any special handling that was required for the following data.

The above-described data were read by the computer, which processed all data and formed the input that controlled a "header", which was written at the beginning of each 12-second data record following the header.

Data Preprocessor Operation

The data preprocessor was designed to process data in real time by sampling each channel for a controlled time, and by executing a carefully controlled routine. The settling time of the lowest frequency filter (25 Hz) was calculated and measured, and sufficient time was allowed for it to stabilize. It was determined that filtering in the 1/3-octave bands between 4 Hz and 25 Hz could not be performed efficiently with electric wave filters in real time and that the filtering function would be performed instead by use of a fast Fourier coefficient determining program already used by Melpar's data processing group. Table I shows the time budget allocation for the datalogger.

The system operates as follows: Accelerometer channel 1 is connected to the filter bank for 1.250 seconds, during which 100 samples of the raw acceleration data are placed on magnetic tape. This time is sufficient for the filter bank and the precision rectifier-filters to settle, so then it is feasible to scan the

TABLE I. TIMING FOR DATA LOGGER

	Function	Time Required (sec)		
(1)	A1 Sample	1.250	= 100 steps so each step is .0125 sec = 1/80 sec	
	Filter Scan	.375	= 30 steps so each step is .01333 sec	
(2)	A2 Sample	1.250		
	Filter Scan	.375	3.250	sec after start
	Temp. Scan	.100	3.350	sec finish
(3)	A3 Sample	1.250		
	Filter Scan	.375		
(4)	A4 Sample	1.250		
	Filter Scan	.375	6.600	sec start
	Temp. Scan	.100	6.700	sec finish
(5)	A5 Sample	1.250		
	Filter Scan	.375		
(6)	A6 Sample	1.250		
	Filter Scan	.375	9.950	sec start
	Temp Scan	.100	10.050	sec finish
	Channel 15	1.250 .375 1.625		
			11.675	Total

30 filter outputs, high-frequency channels first, for 0.375 second. This is followed by 100 samples of accelerometer 2, followed by a scan of the 30 filter outputs. The eight temperature amplifier outputs are then scanned for 0.100 second. The above procedures are repeated three times, during which all accelerometer channels have been sampled 100 times, all filter outputs have been scanned six times, and the temperature amplifier output channels have been sampled three times. The temperature channels are considered to be incapable of changing during the 10.050-second procedure described above, but they are sampled three times in order to include data on drift and bias voltage applied to the bridge.

Following sampling of all the data channels, the input to the filter bank is grounded, and the filter is allowed to settle for the standard 1.250 seconds. Following this, the output of the rectifier-filters is scanned and the outputs are recorded. This operation provides information to the computer on the offset voltage from the filter channels. Offset is subtracted from signal voltage in the calculation of acceleration levels. Figure 12 is a block diagram of the on-site ground-based support system.

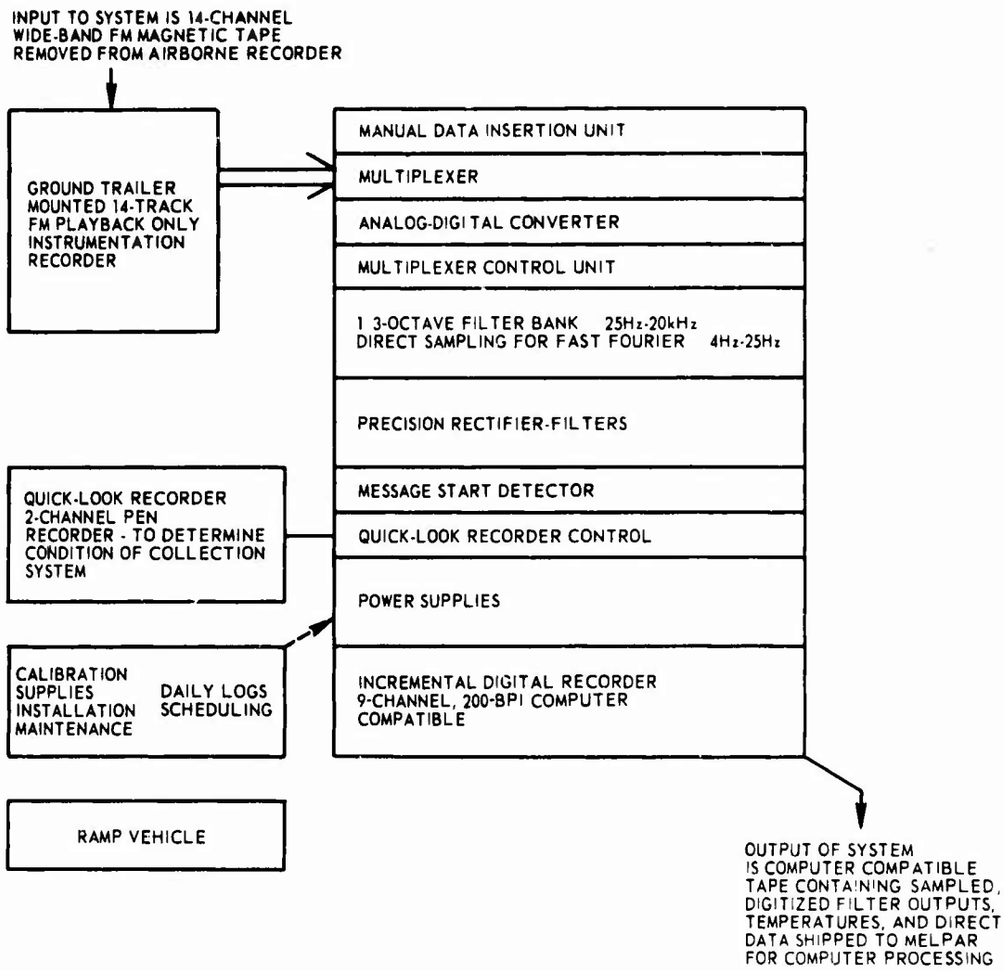


Figure 12. Block Diagram of On-Site Ground-Based Support System.

INSTALLATION OF EQUIPMENT

The plan for installation of equipment required that there be no structural modification, no holes drilled, and no existing components removed. All wiring and securing of equipment had to be approved by designated inspectors, and had to be of the same quality that is typical of aircraft installation. All methods of attachment had to be capable of withstanding 8 g accelerations.

It was observed that considerable potential danger is associated with the location of instrument cables in the vicinity of the tailshaft and its bearings. If the cable stays should allow enough slack, the cable could be wound around the shaft. An alternate routing of the cable through the tail cone appears to be worthy of consideration.

The installation procedure was performed on a noninterference basis, so it was scheduled in steps that could be performed by a crew of three men in three or four consecutive nights. During installation of the equipment, each helicopter was "unbuttoned," worked on, reassembled, inspected, and available for service the next morning.

DATA ACQUISITION

The objective of the data acquisition effort was to sample each of the 12 instrumented aircraft at regular intervals, with each aircraft having, as nearly as possible, the same number of instrumented flight hours. In order to achieve this objective, records were kept of the date and duration of each instrumented flight for each aircraft, and each week a schedule of aircraft requested to be flown with a Melpack and recorder was submitted to the scheduling office at Lowe Field. It should be noted that the scheduling of aircraft for instrumented flight was subject to considerable difficulty because of factors such as weather, unscheduled maintenance, priority assignment of helicopters, and availability of flight crews for instrument training.

Because normal flight activity included both a morning and an afternoon flight, personnel were available from 0530 until 0200 hours. This schedule allowed early daily determination of actual flight schedules and provided time for installation and checkout of equipment for morning and afternoon flights, as well as maintenance, data preprocessing, and availability of Melpar personnel for removal of equipment when helicopter maintenance required it.

A number of briefings were given by Melpar personnel to flight instructors on the purpose and function of the data collection system, and on operational procedure. In addition, written instructions on operational procedure were kept in each of the 12 instrumented helicopters.

After the Melpack and recorder were installed in an aircraft, the system was operated manually on the ground with an external battery to assure proper action. The flight crew's instructions included power turn-on and manual data collection during ground run-up. Following this, data collection was automatic, provided the flight window requirement was met and the airborne equipment did not lock up due to a malfunction. The flight crew was instructed to manually record data during a ground rundown, and to manually turn off the instrumentation system approximately 30 seconds before turning off all auxiliary power.

After the Melpar ground crew determined that an instrumented helicopter had returned from flight, the flight-related elements of the data sheet accompanying the equipment and helicopter were completed, and any comments on the performance of the helicopter or instrumentation equipment were noted.

The Melpack and recorder with fresh tape were then installed in the helicopter next scheduled for instrumented flight. The tape from the just-completed flight was returned to the instrumentation trailer for further processing.

REVIEWING AND PREPROCESSING THE DATA

The instrumentation trailer was equipped with an FR-1300 magnetic tape playback machine, a quick-look recorder, and equipment for scanning the 14 channels of the analog tape, filtering portions of it, and performing analog-to-digital conversion and other functions. As soon as practicable after receipt of an analog tape from a helicopter, it was preprocessed and a digital-computer-compatible magnetic tape was produced. During the preprocessing, the format and the quality of the data were evaluated in order to determine if equipment had been operated properly and if any problems existed with sensors or controls. This evaluation was performed both from oscilloscope presentations and from examination of the quick-look data. The digital magnetic tapes were accumulated for approximately one week and then computer processed and analyzed.

COMPUTER DATA PROCESSING

Early in the program it was thought that cascaded spectrograms would be a suitable way to present, graphically, information generated by the six accelerometer channels mounted on the 12 aircraft. Further consideration of the problem of setting go/no-go limits for accelerations and of correlating maintenance with cyclic and secular trends in the data revealed that a combination of a "historical" or chronological plot of the record of accelerations along with histograms showing the distribution of accelerations would be far more satisfactory. The above data, which are automatically plotted on a high-speed computer line printer, are in addition to computer listings of every item of data collected by every sensor on every helicopter. Temperature data offered no problems in presentation due to their essentially one-dimensional nature. Acceleration data, on the other hand, present problems because, for each accelerometer, it is necessary to present amplitude data for all of the significant 1/3-octave bands between 4 Hz and 20 KHz. Figure 13 shows flow charts of the complete data processing plan.

After some experience with data processing by computer, wherein the computer used predetermined criteria to determine which runs were calibration, ground, flight, and so forth, with all data processed according to the "calibration" run just preceding it, the procedures were modified to permit human auditing of data and editing, where necessary. The problem with the earlier technique was basically that occasionally a perfectly satisfactory calibration run was followed by an imperfect one (caused perhaps by manual depression of the CAL control during recording, or by noise), all data following the imperfect calibration were erroneous because the computer would slavishly assign channel gains and offsets according to its predetermined rules, and these parameters were incorrect for the following data. It was also necessary to provide an editing capability to permit removal of data from the master files in the event that the data were generated by sensors that had been disconnected by maintenance on the helicopter the previous night.

As a result of the above experience, a five-pass reduction process was instituted (see Figure 14). This new procedure required some modification to the program, some additional debugging, and reprocessing of some data. The sequence is as follows:

PASS I

In the first pass, reduce and print out all calibration runs plus the number (only) of full-length (940-word), same-header

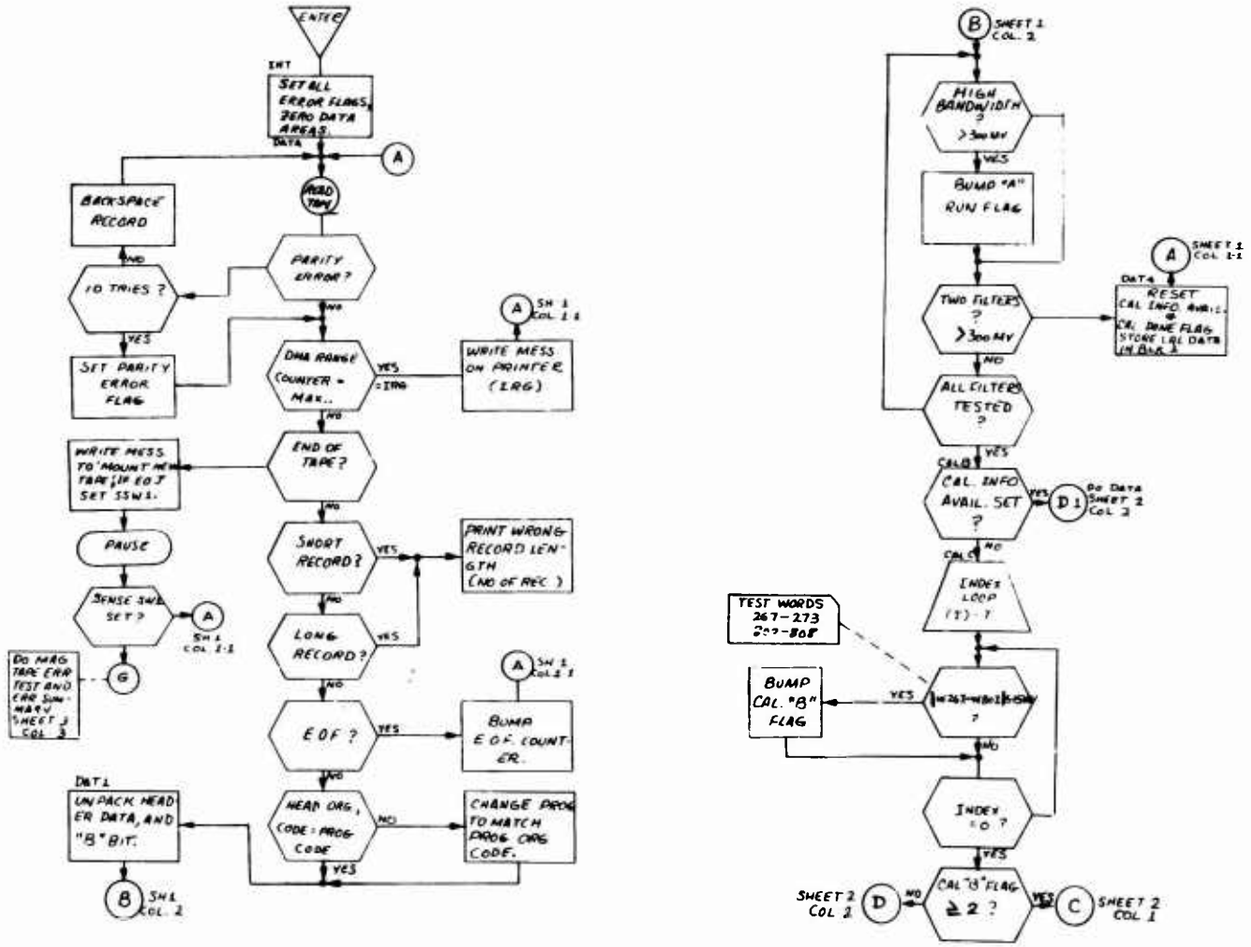


Figure 13. Computer Programming Flow Chart for One of the Intermediate Data Processing Plans (Sheet 1 of 3).

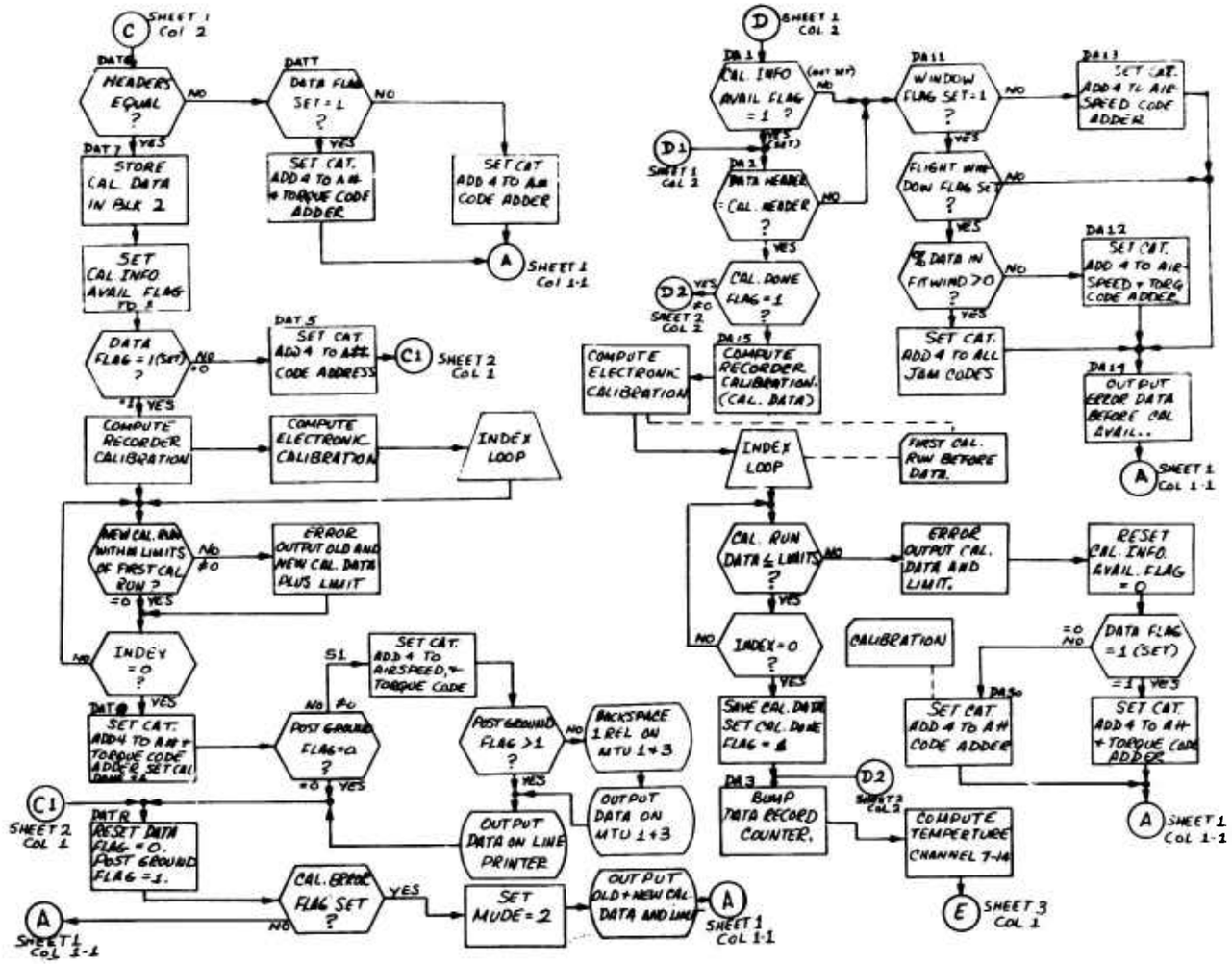


Figure 13 - Continued (Sheet 2 of 3).

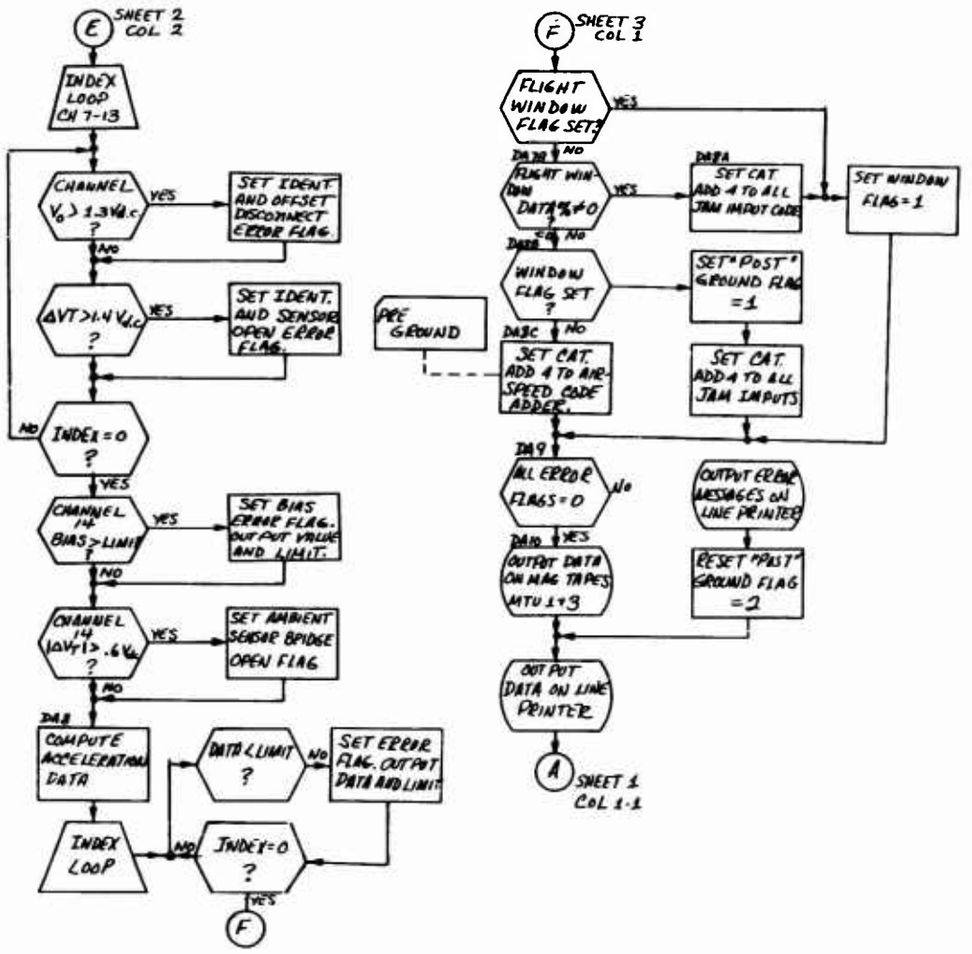


Figure 13 - Continued (Sheet 3 of 3).

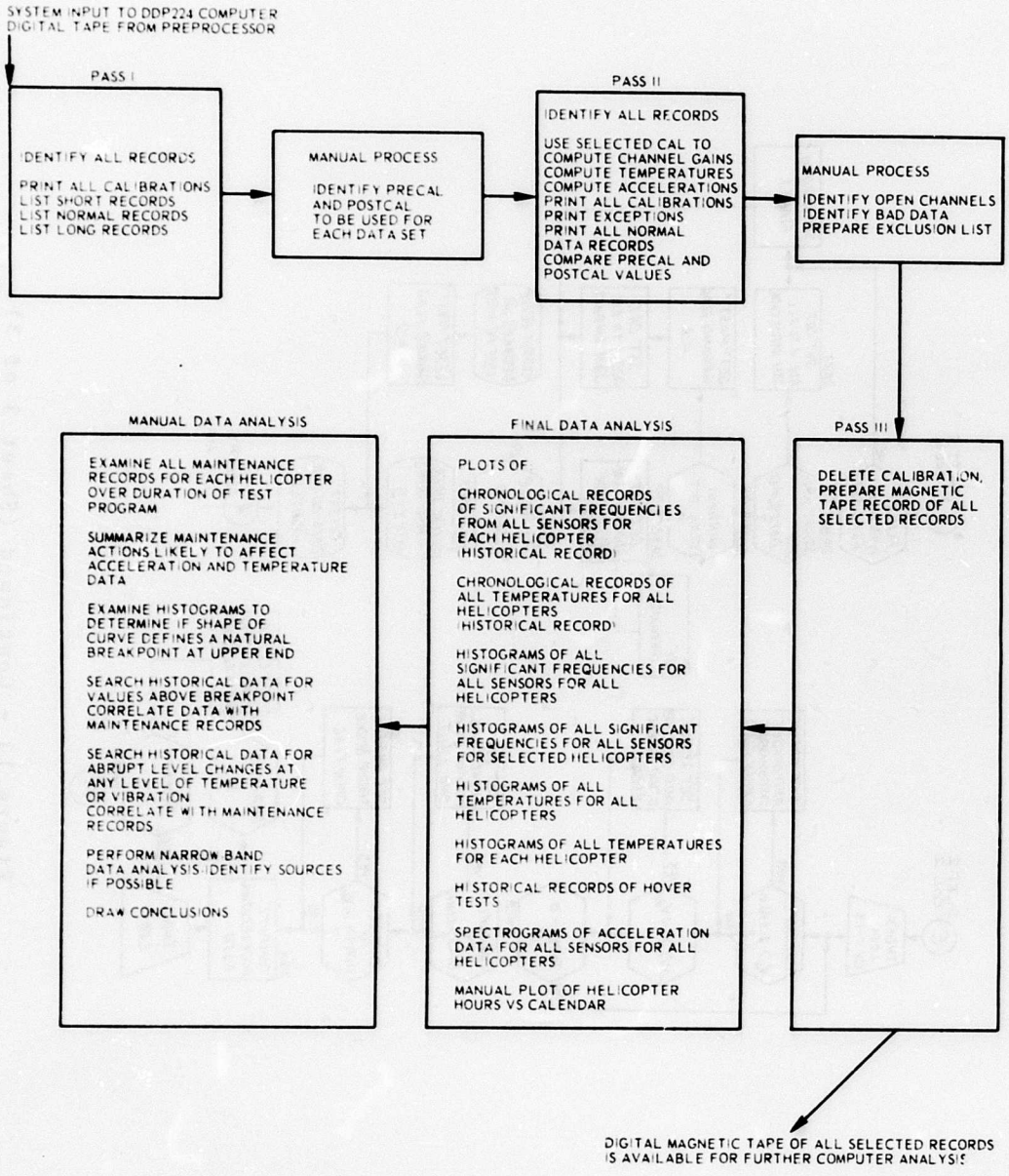


Figure 14. Block Diagram of Data Processing and Analysis Procedure.

records behind these calibrated runs. For information only, print out a list of short records and long records. In those cases where a number of calibration and calibration checks (postcalibration) are available on a header, the most suitable ones were manually selected as the calibration runs to be used in the next data processing pass. Figure 15 is an example of a printout of Pass I.

PASS II

In the second pass (see Figure 16), the selected calibration and calibration check records are printed respectively at the beginning and end of the same header data. From these calibrations, the computer channel gains, temperatures, and accelerations (by 1/3-octave band) are printed, as well as exceptions to predetermined limits for values of noise and gain variation in the calibration data. All normal data records are printed out and labeled in the proper engineering units, i.e., temperature rise in degrees Fahrenheit above reference. The differences between all computed values in the pre- and postcalibrations are computed and printed also.

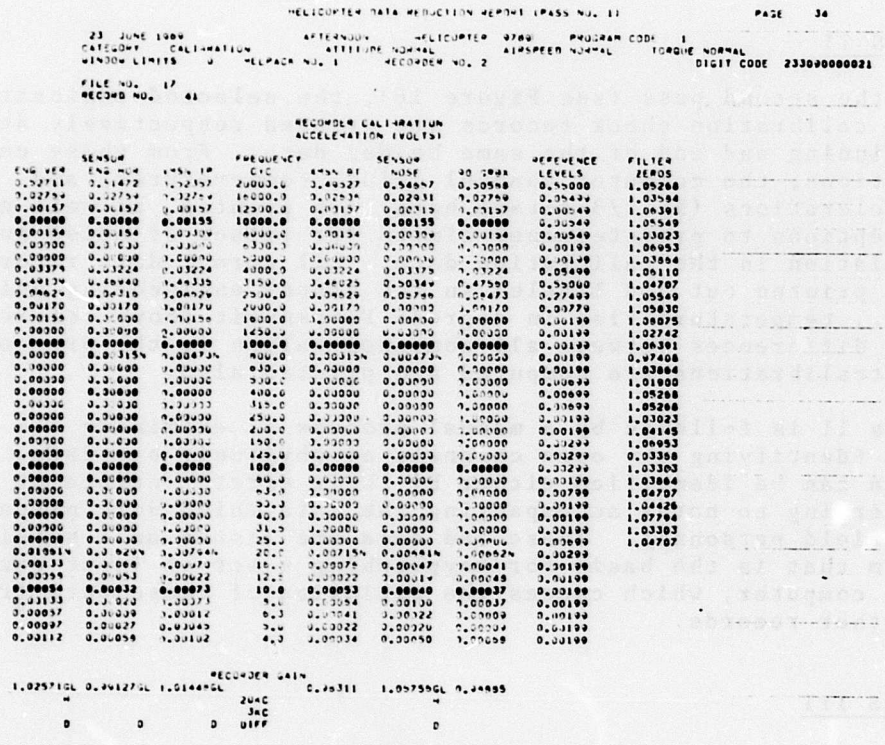
Pass II is followed by a manual process of examining the data and identifying any open channels or obviously bad data. Bad data can be identified either by their erratic nature or by referring to notes accompanying the data which were prepared by field personnel. These bad data are listed on a special form that is the basis for keypunching a set of input cards to the computer, which causes the exclusion of these data from all further records.

PASS III

During the Pass III operation, the computer generates a magnetic tape record containing all the data plus header information. This tape is available at AVLABS for further processing or statistical studies.

PASS IV

The analog tapes generated daily at Fort Rucker were preprocessed into digital tape on an almost daily basis. The resulting digital data tape was shipped to Melpar at approximately weekly intervals. When each weekly tape was processed in Melpar's DDP-224 computer, it was given a particular file number. After all files were processed through Pass III, it was necessary to sort them into chronological sequence by individual helicopter. This involved large amounts of tape



HELICOPTER DATA REDUCTION REPORT (PASS NO. 1) PAGE 36

23 JUNE 1984 AFTERBODY HELICOPTER 0700 PROGRAM CODE 1
CATEGORY CALIBRATION ATTITUDE NORMAL AIRSPEED NORMAL TORQUE NORMAL
WINDOW LIMITS 0 HELPACK NO. 1 RECORDER NO. 2 DIGIT CODE 233000000021

FILE NO. 17
RECORD NO. 41

RECORDER CALIBRATION
ACCELERATION (VOLTS)

ENG VEH	SENSOR ENG HUB	ENG TP	FREQUENCY CYC	SENSOR NOSE	SENSOR RT	REFERENCE LEVELS	FILTER ZEROS
0.52711	0.51472	0.52157	20000.0	0.48527	0.54657	0.50588	0.55000	1.05268
0.02754	0.02754	0.02754	10000.0	0.02634	0.02931	0.02769	0.03449	1.03584
0.00157	0.00157	0.00157	12500.0	0.00157	0.00157	0.00157	0.00549	1.00391
0.00000	**0.00000**	**0.00155**	**10000.0**	**0.00000**	**0.00155**	**0.00000**	0.00549	1.05549
0.00154	0.00154	0.00339	4000.0	0.00154	0.00334	0.00134	0.00549	1.03023
0.00100	0.00100	0.00170	5300.0	0.00099	0.00099	0.00100	0.00199	1.00953
0.00030	0.00030	0.00030	5200.0	0.00030	0.00030	0.00000	0.00149	1.03864
0.03379	0.03224	0.03224	4000.0	0.03224	0.03379	0.03224	0.05499	1.06110
0.49134	0.48440	0.44335	3150.0	0.48025	0.50346	0.47590	0.55000	1.04707
0.04624	0.04315	0.04929	2530.0	0.04628	0.05748	0.04473	0.27499	1.05549
0.00170	0.00170	0.00170	2000.0	0.00175	0.00000	0.00170	0.00779	1.05830
0.00154	0.00000	0.00154	1600.0	0.00000	0.00000	0.00000	0.00199	1.00075
0.00000	0.00000	0.00000	1250.0	0.00000	0.00000	0.00000	0.00199	1.02742
0.00000	**0.00000**	**0.00000**	**1000.0**	**0.00000**	**0.00000**	**0.00000**	0.00199	1.00391
0.00000	0.00315%	0.00473%	800.0	0.00315%	0.00473%	0.00550	0.00199	0.97408
0.00000	0.00000	0.00000	630.0	0.00000	0.00000	0.00000	0.00199	1.03864
0.00000	0.00000	0.00000	500.0	0.00000	0.00000	0.00000	0.00699	1.01000
0.00000	0.00000	0.00000	400.0	0.00000	0.00000	0.00000	0.00699	1.05268
0.00000	0.00000	0.00000	315.0	0.00000	0.00000	0.00000	0.00699	1.05268
0.00000	0.00000	0.00000	250.0	0.00000	0.00000	0.00000	0.00199	1.03023
0.00000	0.00000	0.00000	200.0	0.00000	0.00000	0.00000	0.00199	1.04145
0.00000	0.00000	0.00000	160.0	0.00000	0.00000	0.00000	0.00299	1.00953
0.00000	0.00000	0.00000	125.0	0.00000	0.00000	0.00000	0.00299	0.03368
0.00000	**0.00000**	**0.00000**	**100.0**	**0.00000**	**0.00000**	**0.00000**	0.00299	1.03303
0.00000	0.00000	0.00000	80.0	0.00000	0.00000	0.00000	0.00199	1.03864
0.00000	0.00000	0.00000	63.0	0.00000	0.00000	0.00000	0.00799	1.04707
0.00000	0.00000	0.00000	50.0	0.00000	0.00000	0.00000	0.00199	1.04426
0.00000	0.00000	0.00000	40.0	0.00000	0.00000	0.00000	0.00199	1.07794
0.00000	0.00000	0.00000	31.5	0.00000	0.00000	0.00000	0.00199	1.03303
0.00000	0.00000	0.00000	25.0	0.00000	0.00000	0.00000	0.00699	1.04707
0.01591%	0.01624%	0.00734%	20.0	0.00715%	0.00441%	0.00624%	0.00299	
0.00133	0.00088	0.00273	16.0	0.00075	0.00047	0.00041	0.00199	
0.00359	0.00453	0.00622	12.5	0.00022	0.00014	0.00049	0.00199	
0.00054	**0.00032**	**0.00073**	**10.0**	**0.00053**	**0.00040**	**0.00037**	0.00199	
0.00133	0.00070	0.00373	8.0	0.00054	0.00130	0.00037	0.00199	
0.00057	0.00039	0.00012	6.3	0.00041	0.00122	0.00009	0.00199	
0.00097	0.00027	0.00065	5.0	0.00022	0.00020	0.00004	0.00199	
0.00112	0.00059	0.00102	4.0	0.00034	0.00050	0.00098	0.00199	

RECORDER GAIN

1.02571GL H	0.99127GL	1.01444GL	0.46311	1.05759GL H	0.44885	
D	D	D	2nC 3nC DIFF	D		

(a) Example of Computer Printout of Recorder Calibration.

Figure 15. Helicopter Data Reduction Report - Pass I.

HELICOPTER DATA REDUCTION REPORT (PASS NO. 1) PAGE 35

23 JUNE 1989 AFTERNOON HELICOPTER 9789 PROGRAM CODE 1
CATEGORY CALIBRATION ATTITUDE NORMAL AIRSPEED NORMAL TORQUE NORMAL
WINDOW LIMITS 0 HELPACK NO. 1 RECORDER NO. 2 DIGIT CODE 233090000021

FILE NO. 17
RECORD NO. 42

ELECTRONICS CALIBRATION

ACCELERATION (VOLTS)

SENSOR ENG VER	SENSOR ENG HOR	VMAS IP	FREQUENCY CYC	AMSS RT	SENSOR NOSE	90 CRSE
3.11143	0.11497	1.11674	23000.0	0.10966	0.12028	0.10799
0.00000	0.00000	0.00000	16000.0	0.00162	0.00000	0.00000
0.00000	0.00000	0.00000	12500.0	0.00036	0.00157	0.00000
0.00000	**0.00000**	**0.00000**	**10000.0**	**0.00000**	**0.00155**	**0.00000**
0.00154	0.00154	1.00154	8000.0	0.00154	0.00304	0.00154
0.00000	0.00000	0.00000	6300.0	0.00000	0.00156	0.00000
0.00000	0.00000	0.00000	5000.0	0.00000	0.00159	0.00000
0.00000	0.00000	0.00000	4000.0	0.00000	0.00306	0.00000
0.00000	0.00000	0.00000	3150.0	0.00000	0.00000	0.00000
0.00156	0.00156	1.00000	2500.0	0.00156	0.00941	0.00313
0.00170	0.00000	1.00170	2000.0	0.00170	0.00170	0.00170
0.00000	0.00000	1.00000	1600.0	0.00000	0.00634	0.00000
0.00000	0.00000	0.00000	1250.0	0.00000	0.00945	0.00000
0.00000	**0.00000**	**0.00000**	**1000.0**	**0.00000**	**0.02255**	**0.00000**
0.00000	0.00000	1.00000	800.0	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	630.0	0.00000	0.01120	0.00000
0.00000	0.00000	0.00000	500.0	0.00000	0.00485	0.00000
0.00000	0.00000	0.00000	400.0	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	315.0	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	250.0	0.00000	0.00164	0.00000
0.00000	0.00000	1.00000	200.0	0.00000	0.00160	0.00000
0.00000	0.00000	0.00000	160.0	0.00000	0.00000	0.00000
0.00000	0.00000	1.00158	125.0	0.00000	0.00000	0.00158
0.00000	**0.00000**	**0.00000**	**100.0**	**0.00000**	**0.00000**	**0.00000**
0.00000	0.00000	0.00000	80.0	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	63.0	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	50.0	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	40.0	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	31.5	0.00000	0.00000	0.00000
0.00000	0.00000	1.00000	25.0	0.00000	0.00000	0.00000
0.00058	0.00745	0.00766	20.0	0.00735	0.00795	0.00788
0.00091	0.00093	0.00086	16.0	0.00068	0.00236	0.00066
0.00094	0.00020	1.00030	12.5	0.00041	0.00416	0.00030
0.00068	**0.00020**	**0.00030**	**10.0**	**0.00034**	**0.00120**	**0.00061**
0.00058	0.00050	1.00143	8.0	0.00048	0.00246	0.00081
0.00022	0.00081	0.00105	6.3	0.00035	0.00074	0.00060
0.00048	0.00091	0.00073	5.0	0.00032	0.00143	0.00054
0.00104	0.00071	0.00036	4.0	0.00050	0.00210	0.00309

ACCELERATION AMPLIFIER

10.3	10.8	10.4	GAINS	10.7	10.7	10.3
719.0	972.4	672.4	INDEX	670.2	684.3	712.4

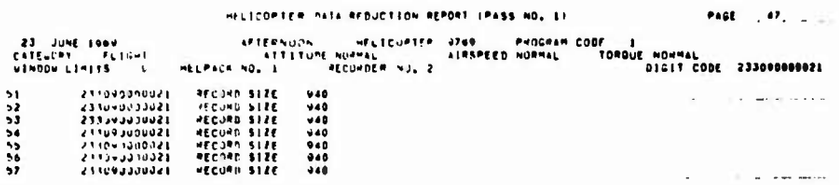
TEMPERATURE (VOLTS)

SENSOR	GAINS	OFFSETS	
SWASHPLATE	13.07	-0.719	0 G
QUILL BRG	0.00	1.434	0SG
FORESHAFT	13.20	-0.803	0 G
MIDSHAFT	13.20	-0.862	0 G
AFTSHAFT	13.07	-0.865	0 G
GEAR 42	13.47	-0.853	0 G
GEAR 90	12.49	-0.738	0 G
AMBIENT	12.40	-0.483	G

BIAS VOLTAGE = -10.89 BL

(b) Example of Computer Printout of Electronics Calibration.

Figure 15 - Continued.



HELICOPTER DATA REDUCTION REPORT (PASS NO. 1) PAGE 47.

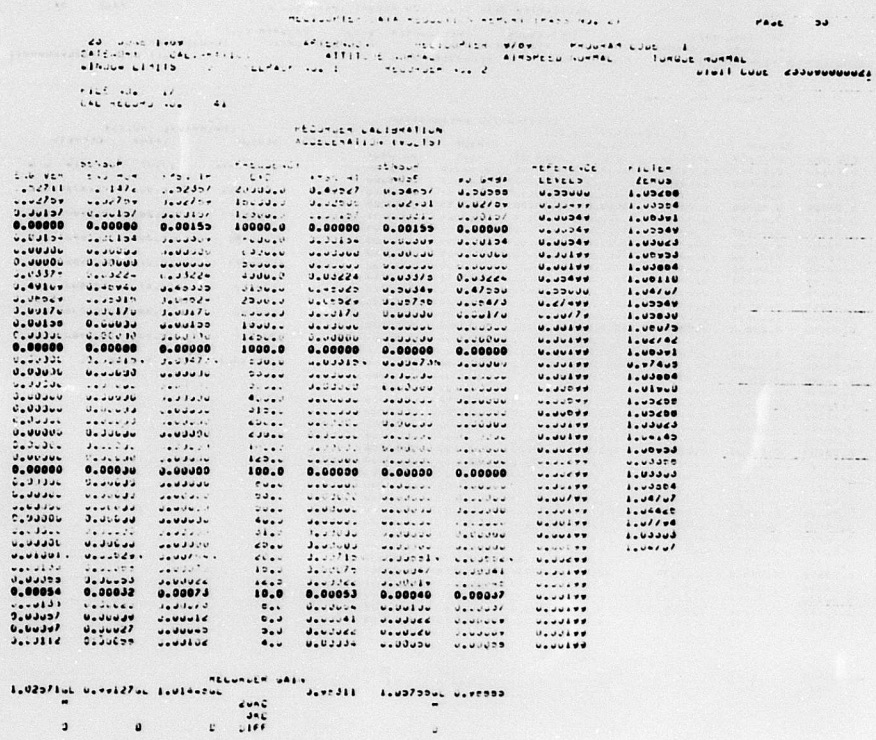
23 JUNE 1969 AFTERNOON HELICOPTER 0769 PROGRAM CODE 1
CATEGORY FLIGHT ATTITUDE NORMAL AIRSPEED NORMAL TORQUE NORMAL
WINDOW LIMITS L HELPACK NO. 1 RECORDER NO. 2 DIGIT CODE 233000000021

51	2310000000021	RECORD SIZE	940
52	2310000033021	RECORD SIZE	940
53	2330000000021	RECORD SIZE	940
54	2310000000021	RECORD SIZE	940
55	2310010000021	RECORD SIZE	940
56	2310000330021	RECORD SIZE	940
57	2310000000021	RECORD SIZE	940

(c) Example of Computer Listing of Normal Length Records Following Calibration.

Figure 15 - Continued.

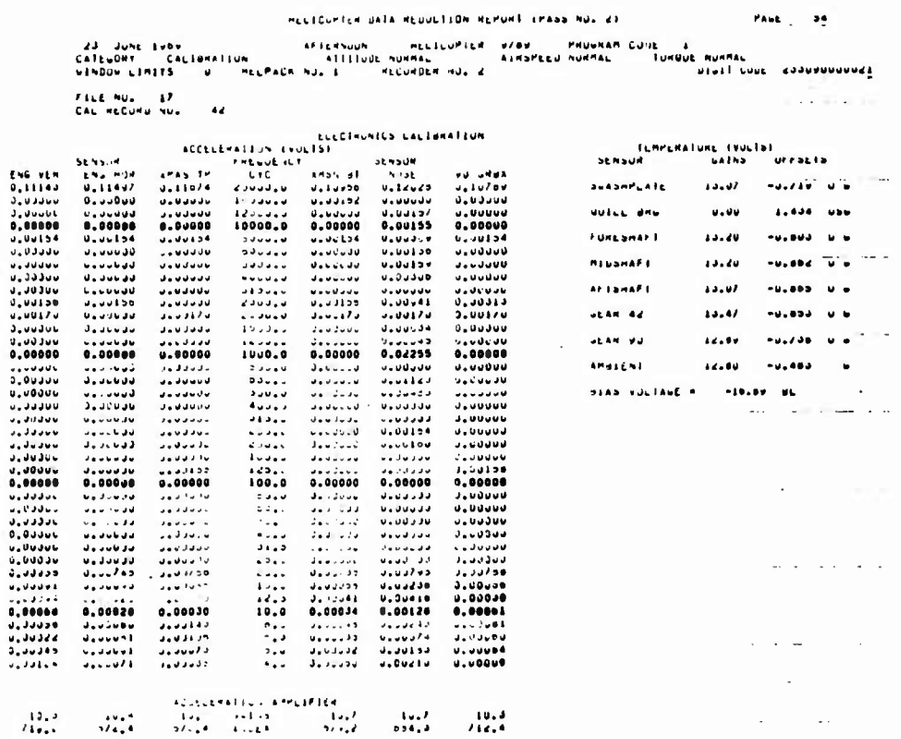
NOT REPRODUCIBLE



(a) Example of Recorder Calibration Printout.

Figure 16. Helicopter Data Reduction Report - Pass II.

NOT REPRODUCIBLE



HELICOPTER DATA REDUCTION REPORT (PASS NO. 2) PAGE 39

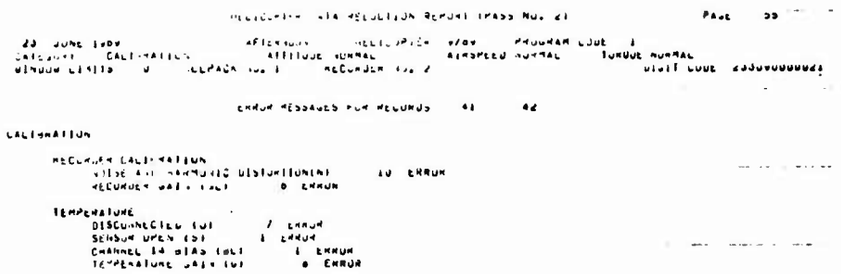
23 JUNE 1980 AFTERNOON HELICOPTER V/80 PROGRAM CODE 1
CATEGORY CALIBRATION ALTITUDE NORMAL AIRSPEED NORMAL TORQUE NORMAL
WINDOW LIMITS 0 HELPACK NO. 1 RECORDER NO. 2 DIGIT CODE 6666666666661

FILE NO. 17
CAL RECORD NO. 42

ELECTRONICS CALIBRATION

ACCELEROMETER (VOLTS)

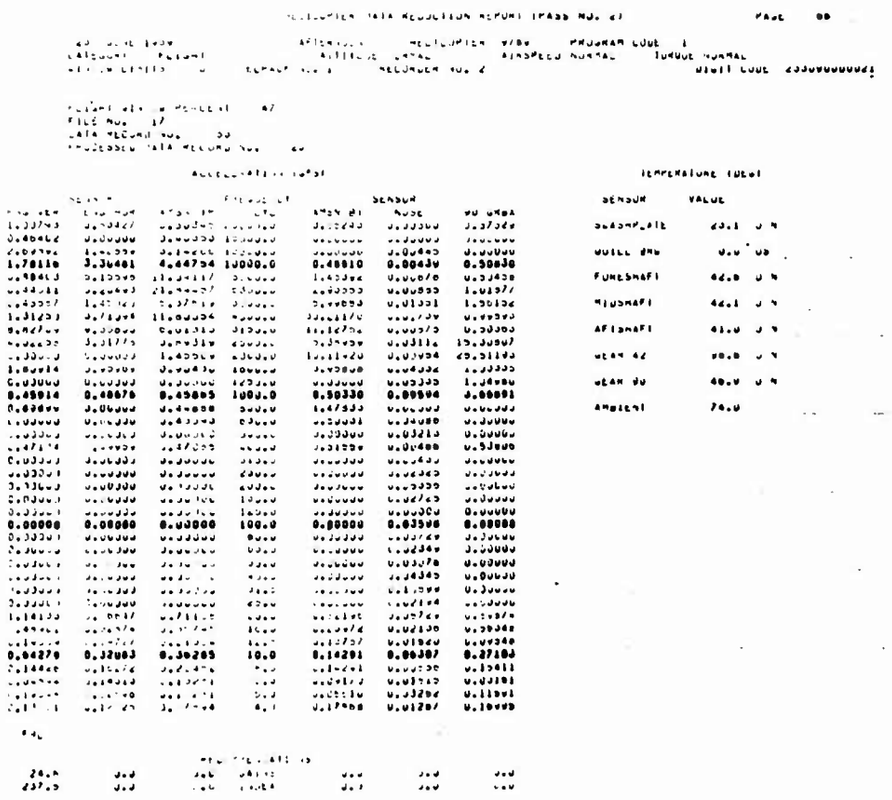
SENSOR			FREQUENCY		SENSOR	
ENG VER	ENG HOR	AFAS TP	LTC	AMSK GI	NOSE	FU AMSK
0.11143	0.11497	0.11074	20000.0	0.10050	0.12629	0.10784
0.00000	0.00000	0.00000	10000.0	0.00192	0.00000	0.00000
0.00001	0.00000	0.00000	12000.0	0.00000	0.00157	0.00000
0.00000	**0.00000**	**0.00000**	**10000.0**	**0.00000**	**0.00155**	**0.00000**
0.00154	0.00154	0.00154	9000.0	0.00154	0.00154	0.00154
0.00000	0.00000	0.00000	8000.0	0.00000	0.00154	0.00000



(c) Example of Computer Printout of Exception Report on Pass II.

Figure 16 - Continued.

NOT REPRODUCIBLE



(d) Example of Computer Printout of Data Processed Using Calibration Data Shown in 16(a) and 16(b).

Figure 16 - Continued.

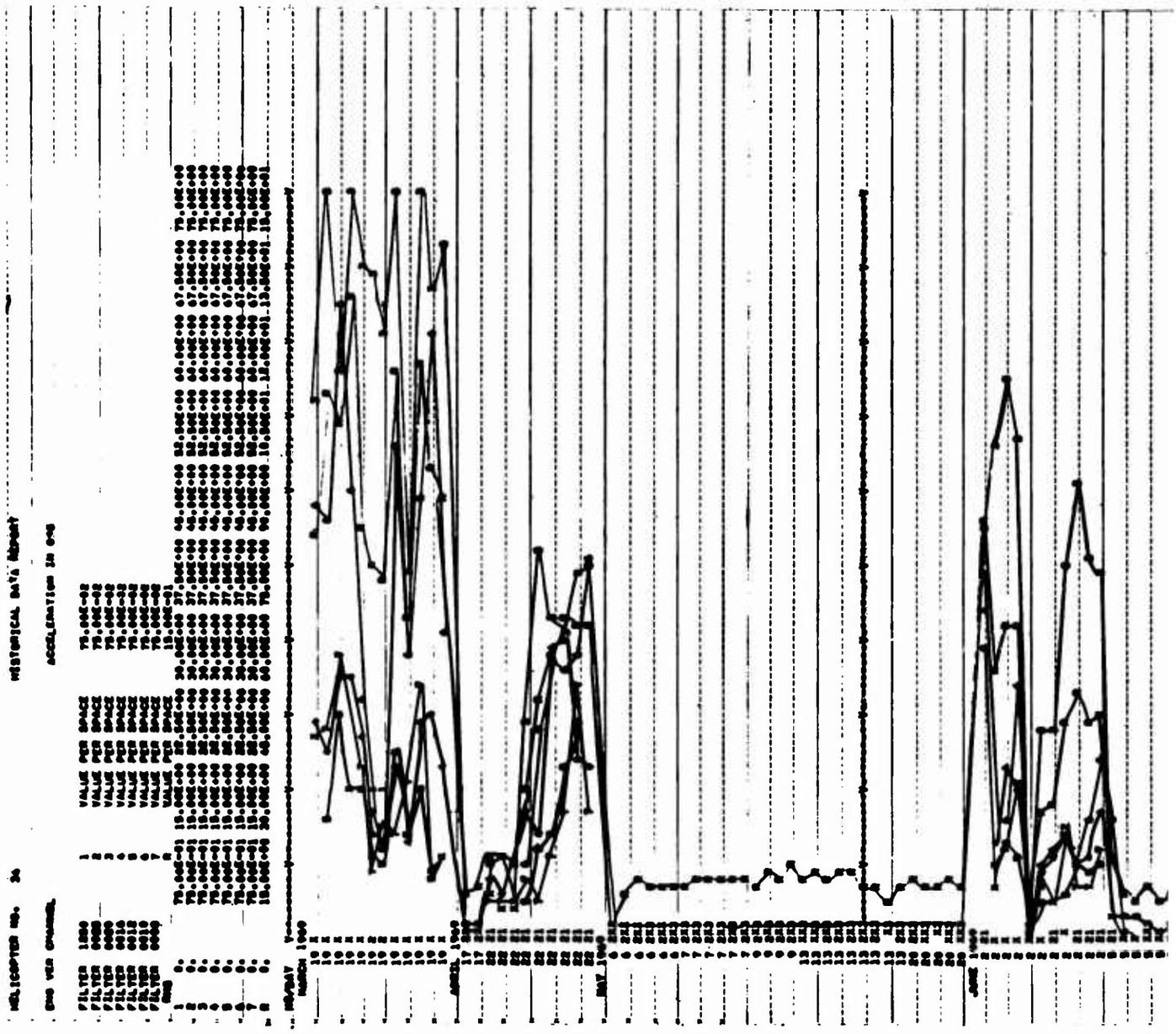
NOT REPRODUCIBLE

handling. The sorted tape then served as source data for the Pass IV operation, which produced plots of historical data by helicopter, by sensor, and by 1/3-octave band (see Figure 17). Different sensors appeared to have different numbers of filters of interest, but, on the average, about 10 filter bands were plotted for each sensor for each helicopter in addition to the RMS acceleration over the entire frequency span of the accelerometer channels. A series of plots was made, one for each helicopter, which revealed the historical record of all temperatures on that helicopter.

PASS V

Following the Pass IV runs, the histogram runs, Pass V, were conducted (Figure 18 shows examples of histograms of acceleration levels measured at the nose of all helicopters through four contiguous filters). Histograms were prepared for the composite of all helicopters by accelerometer location for the most significant frequency bands experienced by that sensor, which were the same ones plotted on the historical records. Histograms were also prepared for composite temperature by sensor location and also for each sensor location for each individual helicopter.

Another feature of the Pass V data processing run is the generation of a spectrogram for all filter channels of all sensors. The spectrogram shows the mean acceleration in g's and the standard deviation (sigma) in plotted form. Tabular values for mean g's and the sigma are also presented.



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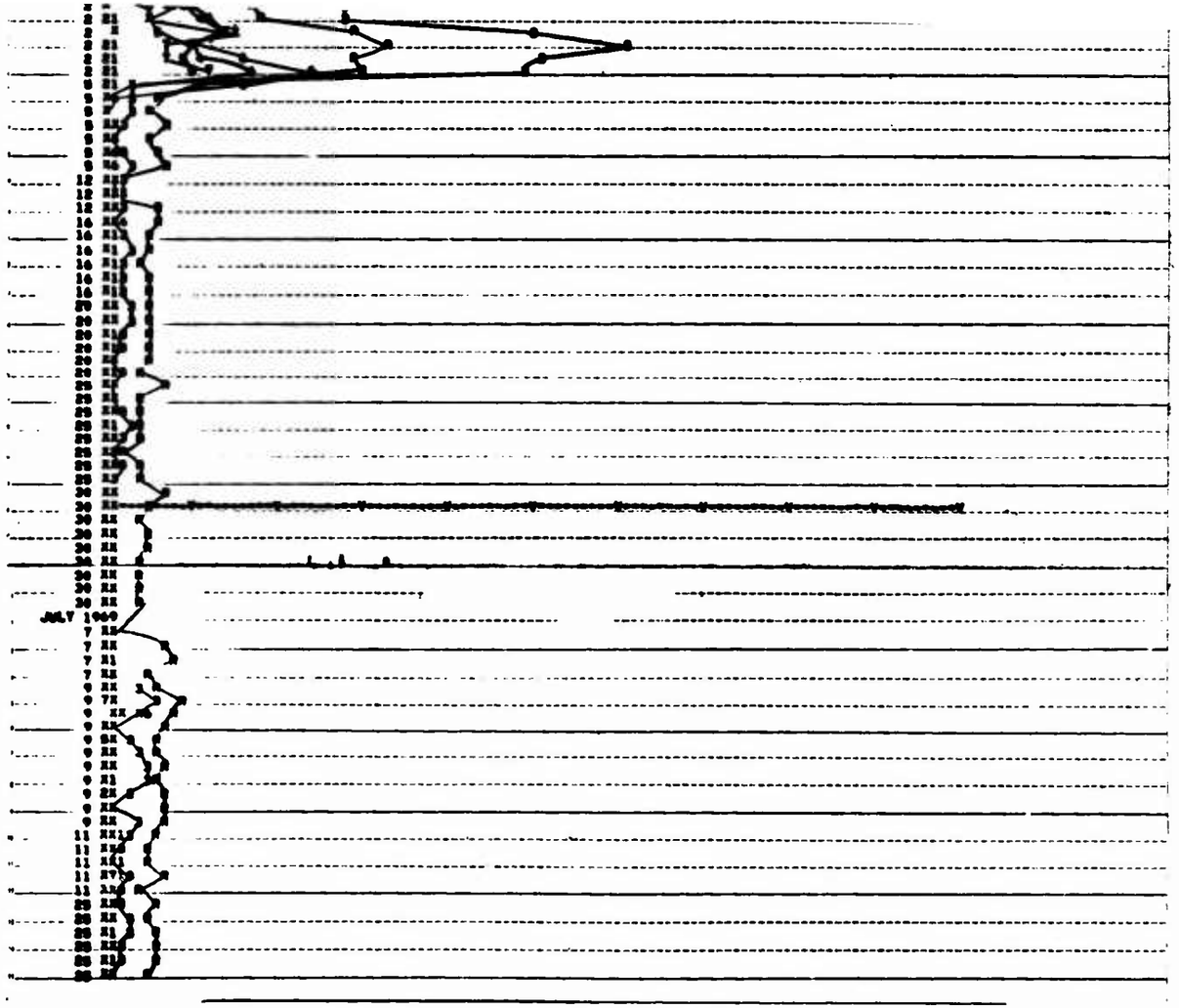

(a) Lower Significant Frequencies.

Figure 17. Historical Record, Engine Vertical Acceleration - Helicopter 65-10034 (Pass IV).

A

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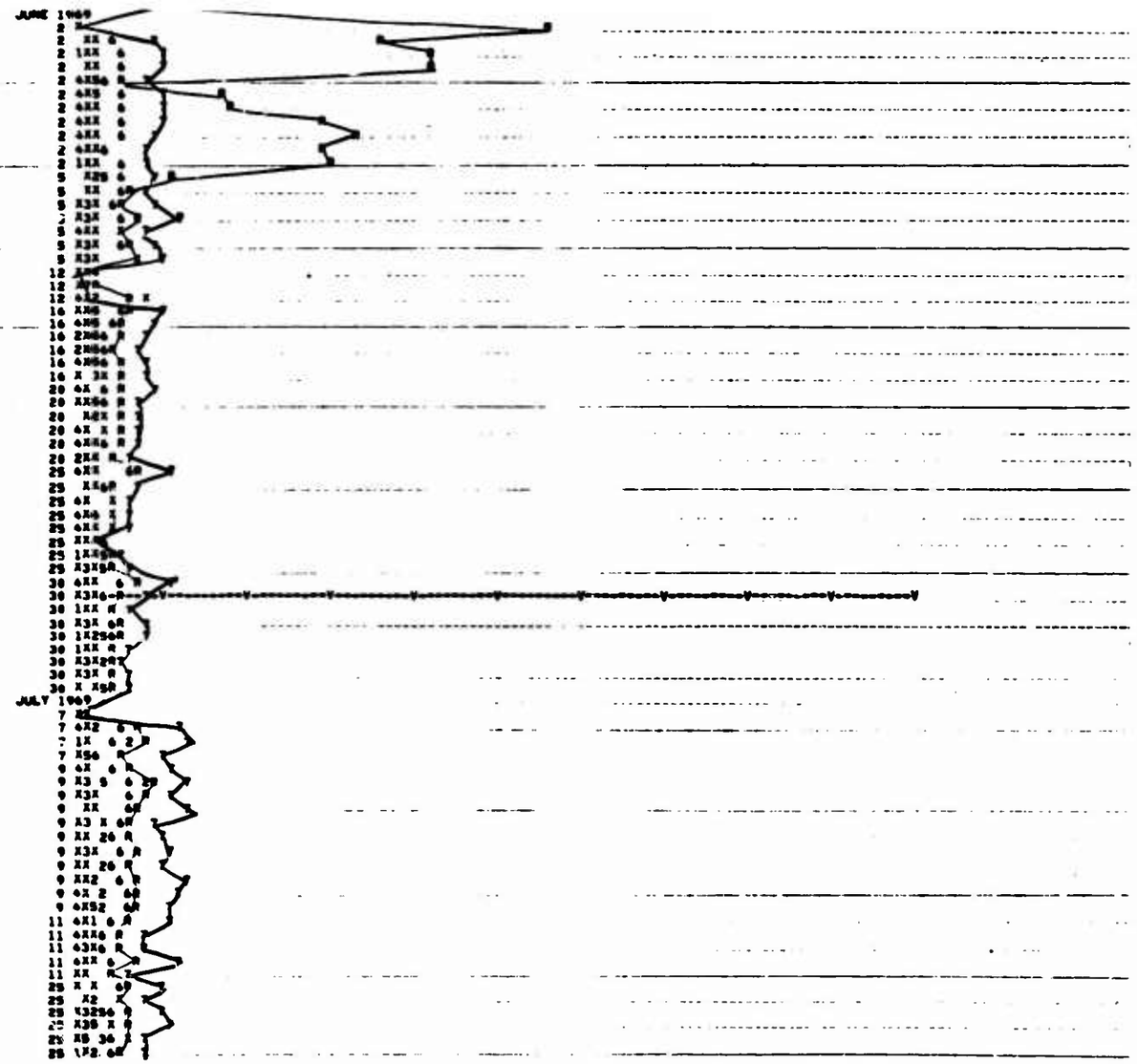

(b) Higher Significant Frequencies.

Figure 17 - Continued.

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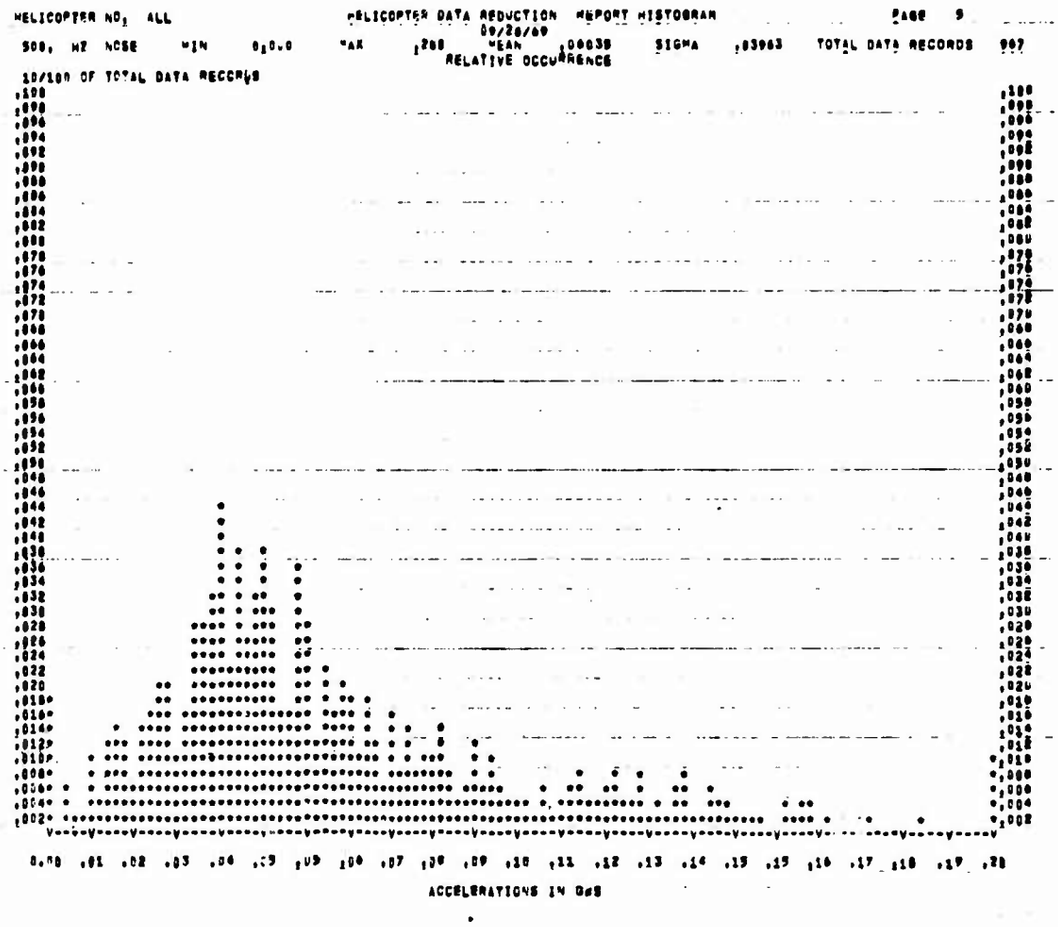

(a) Within 500 Hz Filter Band.

Figure 18. Histogram of Acceleration Levels Measured at Nose of All Helicopters.

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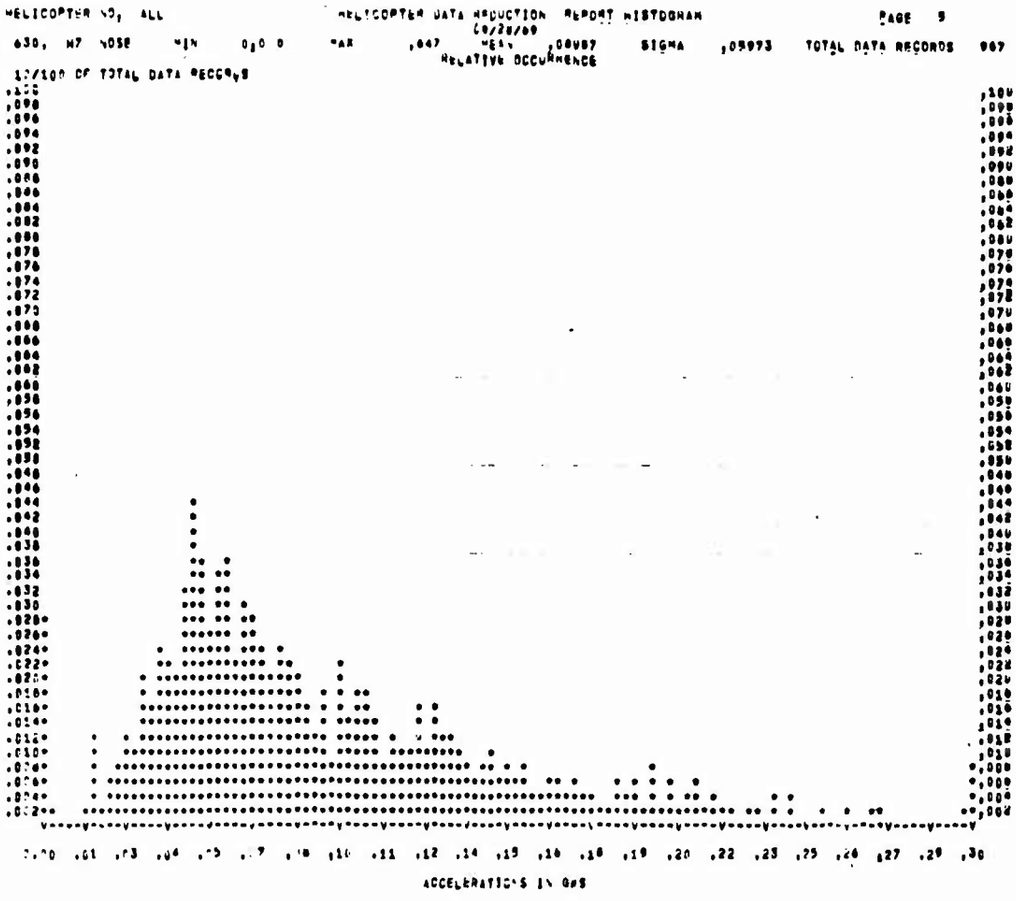
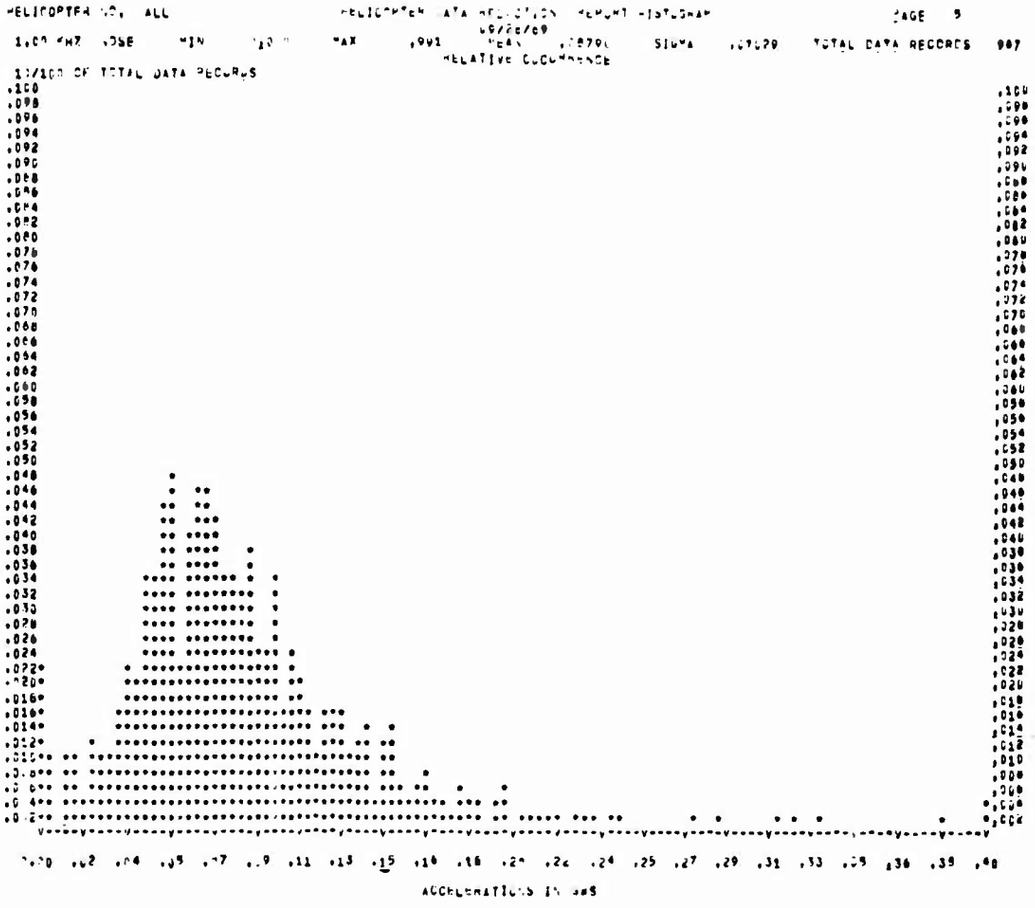


(b) Within 630 Hz Filter Band.

Figure 18 - Continued.



(c) Within 1.00 KHz Filter Band.

Figure 18 - Continued.

NARROW-BAND ANALOG DATA PROCESSING

In addition to the computer processing of data described above, it was considered desirable to perform a small amount of conventional narrow-band analysis of the analog magnetic tapes removed from the airborne recorder. The results of this data processing operation would provide a series of results that could be compared with the digital data reduction and would perhaps emphasize different aspects of the signal.

The data were processed on a 100-channel filter bank. This device, with its auxiliaries, is capable of producing a spectral analysis having 1% resolution within any desired octave. The data that were processed were taken from helicopter 9758 before and after a transmission time change. Narrow-band analyses were made of the entire spectrum of interest for the helicopter from all accelerometer locations except the airframe nose. The results of this study are shown in Appendix III.

DATA ANALYSIS

A major objective was to test the thesis that measurements of temperature and acceleration at certain selected locations near or on critical components of selected UH-1 series helicopters will provide a means for accurately determining the need for component replacement and for indicating questionable operation of the aircraft before an actual failure occurs. The data collection and subsequent analytical procedures were directed toward furnishing answers to the following questions:

1. Do the components of the UH-1D helicopters generate identifiable acceleration and temperature signature patterns?

2. Does aging, wear, or near-failure produce a recognizable alteration of the pattern?

3. Is the variation of signature patterns for each aircraft sufficiently small that a pronounced variation may be considered significant? May operating levels be reasonably established for each test aircraft?

4. Is the variation of signature patterns between aircraft sufficiently small that maximum composite operating levels for the UH-1D helicopter can be recommended?

5. Can these acceleration patterns be adequately defined by the energy level of a small number of frequencies or bands of frequencies?

6. Is the data collected during ground run-up of the aircraft sufficiently similar to the data in-flight or between ground run-ups to be used for establishing reasonable operating levels for the test aircraft?

7. Do any changes in the location or type of sensors seem desirable in order to better detect faulty components?

GROUND RUN-UP DATA

This program called for collection of data during ground run-up. This required manual operation of the data acquisition system by the flight instructor or the student pilot. After a study of the results, it appeared that, although detailed instructions were given to the pilot regarding the time to operate the system, these data were collected at different times in the

ground run-up. This time difference, plus the bouncing of the aircraft on the ground, appeared to cause large variations in the temperature and vibration data. Since these variations would have distorted the histograms and spectrograms and would have made the analysis more difficult and less meaningful, these data were edited out of the inflight data considered in this report.

ACCELERATION DATA ANALYSIS PROCEDURE

The computer-processed data were analyzed generally as described below. Computer plots in historical form have been made of what are judged to be the most significant filter channels for all accelerometer channels for each helicopter. The significant filter channels were selected after examination of spectrograms showing the arithmetic mean and the standard deviation of accelerations for all helicopters in each of the six accelerometer locations. These spectrograms are plots of frequency versus the composite amplitude of accelerations measured on all the test aircraft. The spectrograms show the arithmetic mean as M and the standard deviation, sigma, as S for all thirty-eight 1/3-octave filter channels from 4 Hz to 20 Hz. Large values for mean acceleration indicate that the recording process is occurring well above the noise level, and large values of sigma indicate that the data are highly variable. Large signals and high variability offered a promising opportunity for investigating the causes of the deviation. Also, investigations of these frequencies would determine if the questions in the introduction of this section could be answered. The spectrograms of acceleration signals collected at each sensor are shown in Figure 19.

The spectrograms also showed that each vibration measurement has up to four bands of frequencies which appear to contain significant acceleration data. Therefore, these were investigated for mechanical changes in the aircraft condition which could have produced these changes in the data. The remaining frequencies were very low in acceleration levels and were judged relatively irrelevant.

Historical data printouts for all 8 temperature channels for each of the 12 helicopters were also studied.* Composite histograms for each significant filter channel for all

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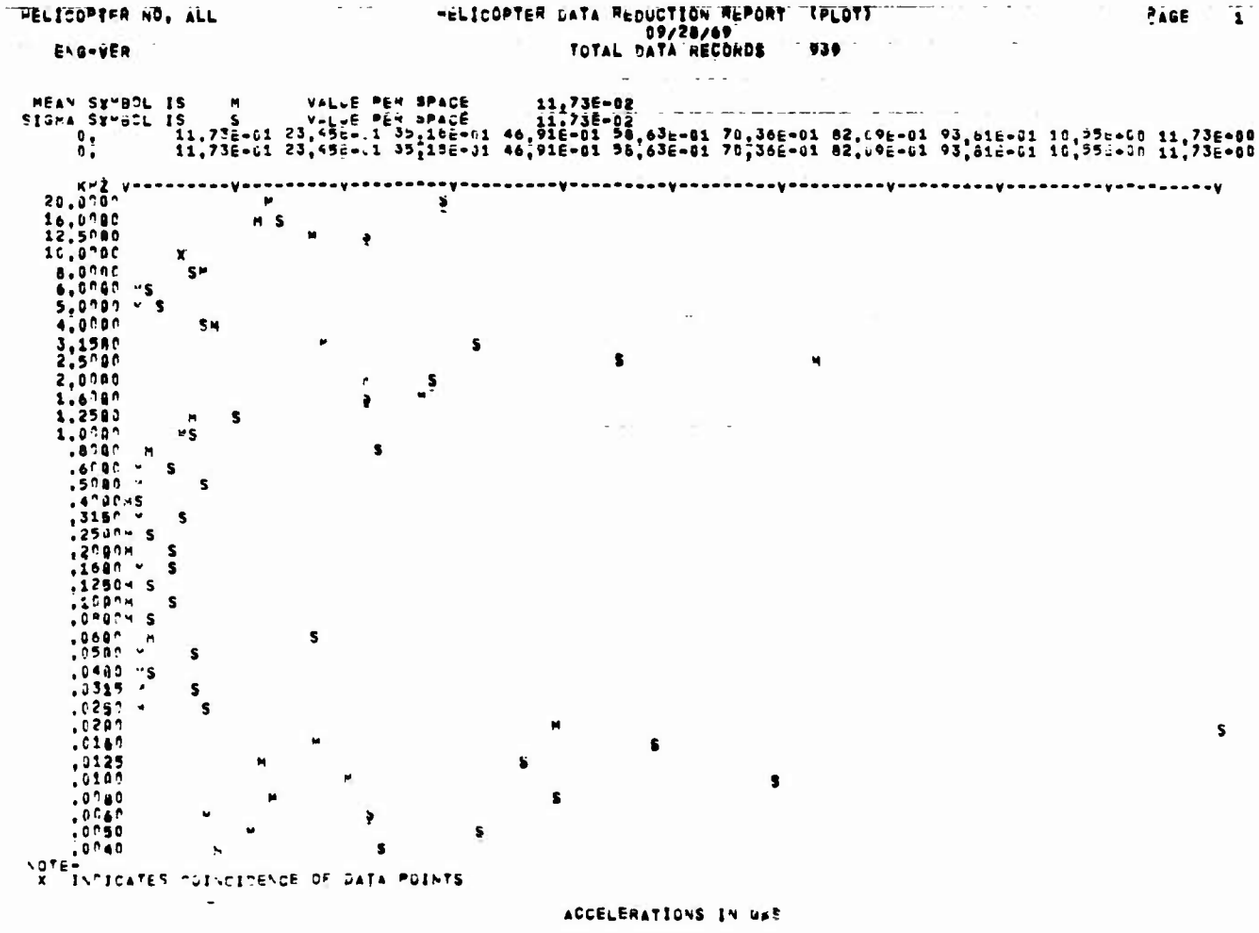
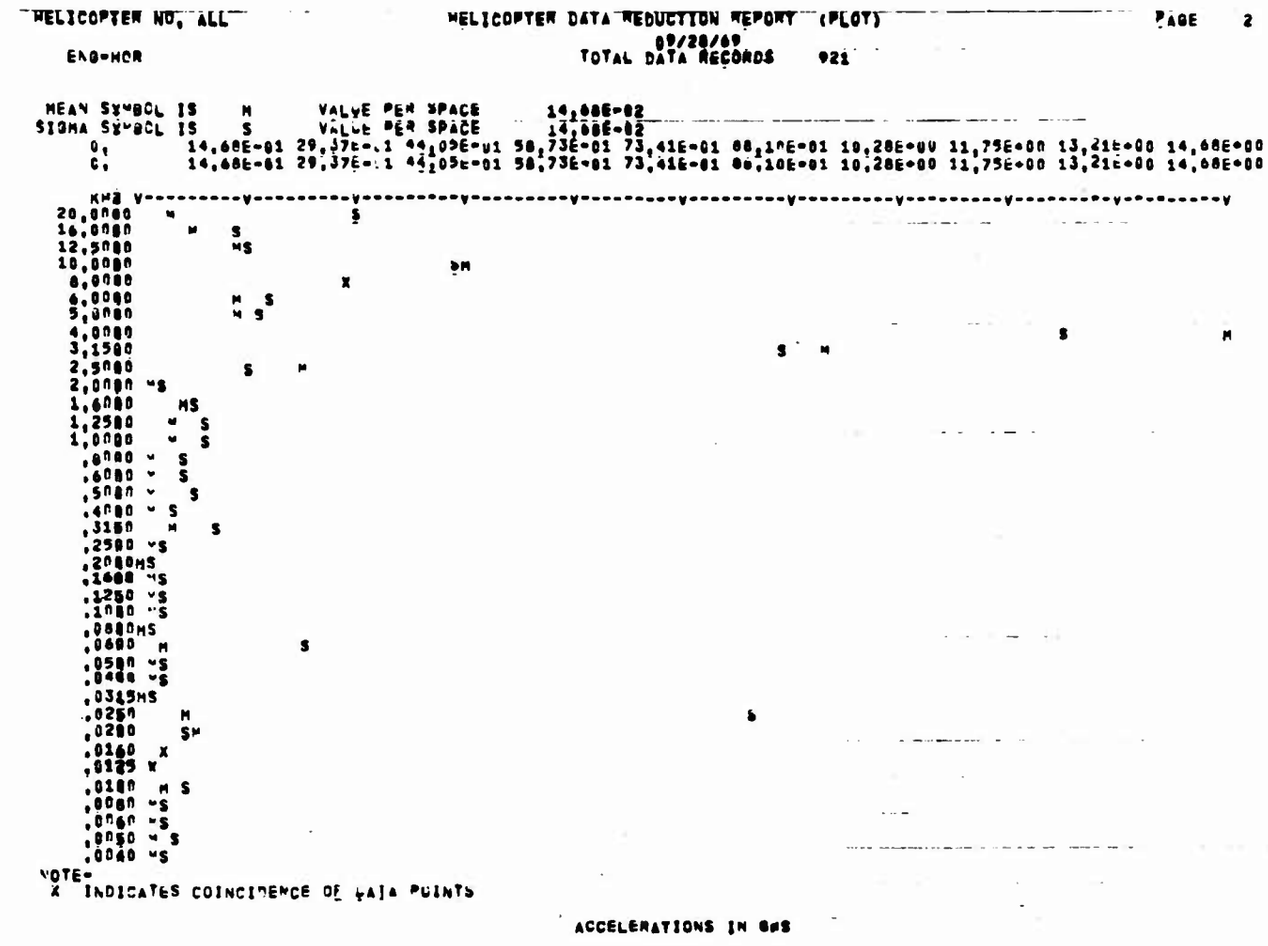
*Because the computer printouts are very voluminous, it was judged impractical to photographically reduce and/or reproduce them for distribution with all copies of this report. However, all these printouts are on file at AVLABS, Fort Eustis.



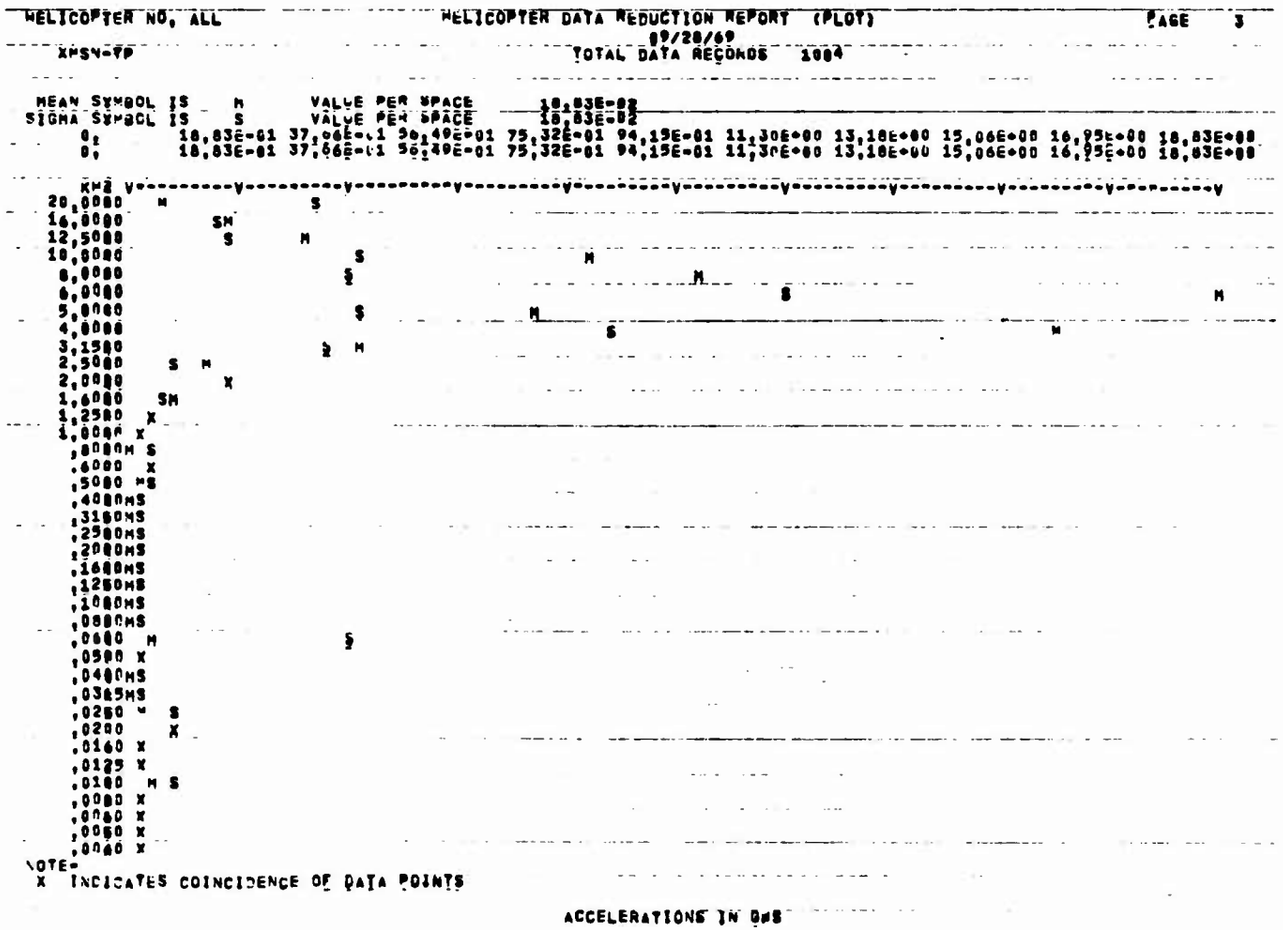
(a) Engine Vertical.

Figure 19. Composite Acceleration Spectrogram.



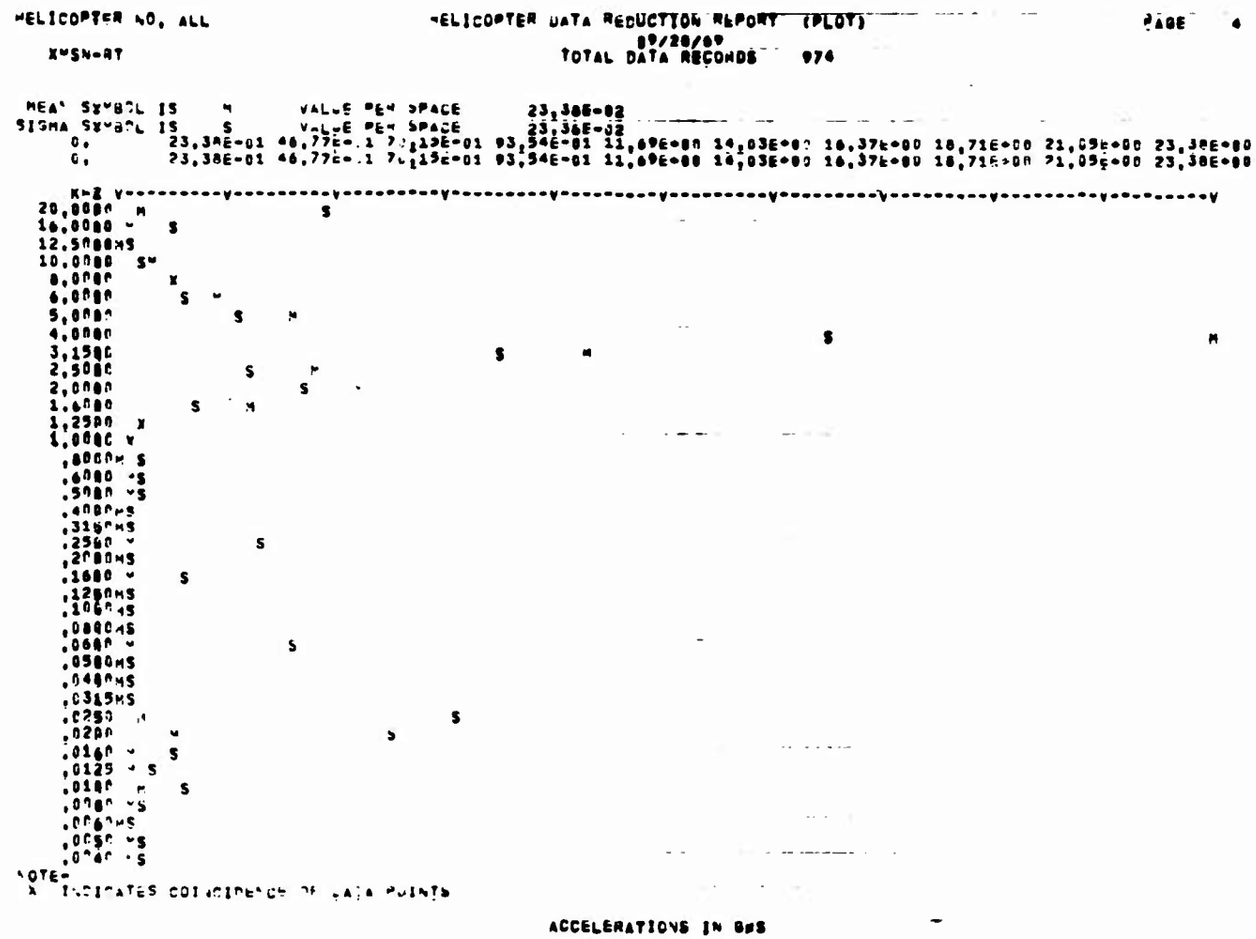
(b) Engine Horizontal

Figure 19 - Continued.



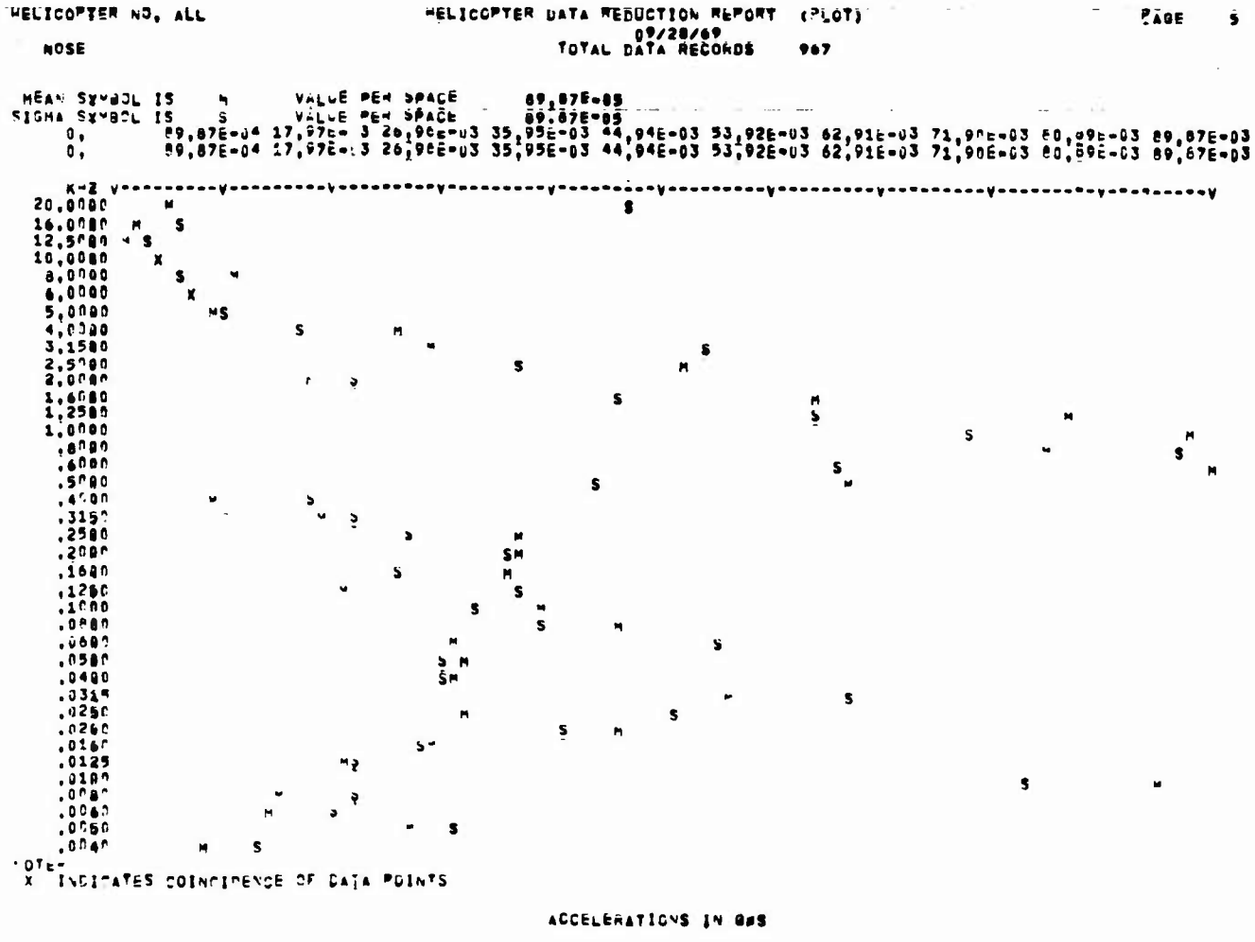
(c) Transmission Top

Figure 19 - Continued.



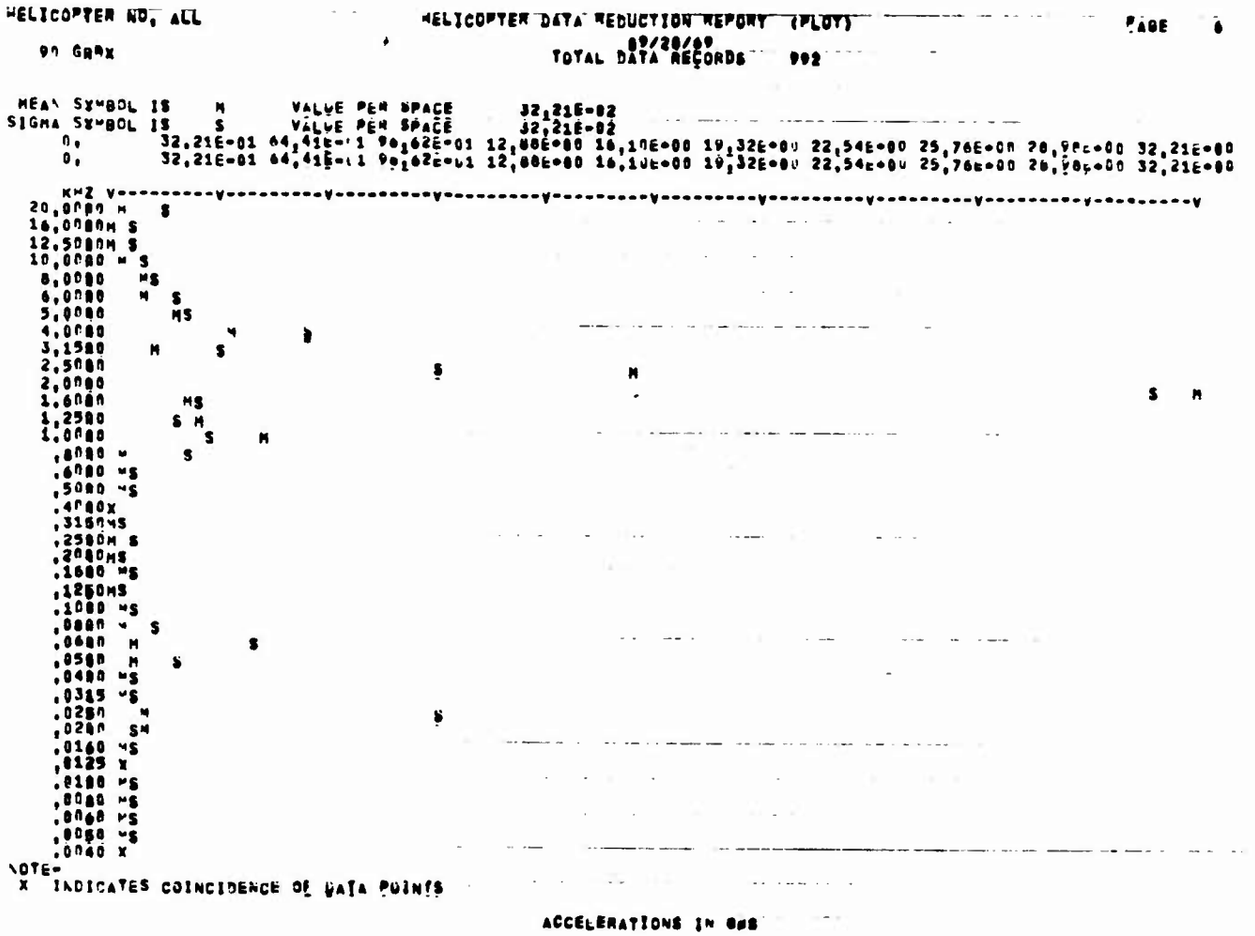
(d) Transmission Bottom.

Figure 19 - Continued.



(e) Nose.

Figure 19 - Continued.



(f) Ninety-Degree Gearbox.

Figure 19 - Continued.

locations were prepared, as were the temperature histograms, which were prepared on a composite and individual basis for each helicopter. These data, in addition to excerpts of power-train-related maintenance actions, were examined. The historical data for each significant parameter was followed from the beginning of data collection to the end. Any discernible shift in the level of that parameter upward or downward was noted, and an attempt was made to correlate such shifts with both the pilot's observation of helicopter performance and the maintenance actions selected from the aircraft logs. Satisfactory correlations were then compiled for presentation on both a parameter and an aircraft basis. There were many cases where maintenance action did not change measured acceleration levels. This is quite reasonable in light of the fact that much maintenance was performed on a scheduled rather than on an as-needed basis. It is possible that extremely detailed studies of the computer-produced reports and the raw tapes would produce other examples of malfunctions or would detect pattern changes caused by scheduled replacement of certain components. However, from a practical operational standpoint, an analysis based on very small changes in measured parameters runs the risk of being too susceptible to noise.

DESCRIPTION OF TABLES II, III, AND IV

The histogram report was reviewed first to establish temporary maximum operating acceleration levels (MOAL). When maintenance actions entered in DA Form 2408-13 resulted in a change in the operating level for an aircraft, as shown in the historical report, the MOAL for that aircraft was adjusted accordingly (usually downward). The maintenance action, significant frequencies, and acceleration levels before and after maintenance are listed in Table II. A summary of the frequencies and the observed operating acceleration level are shown in Table III. After historical reports on all of the test aircraft were reviewed and the observed operating acceleration levels were corrected for maintenance actions, Table IV was generated. Table IV contains the maximum operating level encountered with the 12 instrumented helicopters and represents our judgment of the values above which maintenance should be undertaken. As a check, the historical reports were reviewed to see if maintenance actions always reduced acceleration levels observed on any aircraft to a level below those on Table IV. The check corroborated the observation that no aircraft exceeded this level without requiring maintenance. These levels must, then, be considered acceptable values for airworthy aircraft under the time-between-overhaul schedules maintained for the aircraft studied.

TABLE II. HELICOPTER DIAGNOSTIC REPORT

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
8 to 20 cps	Eng Ver	6/10 & 6/12	The 8-to-20-cps signal increased from near 0 to approximately 25 g's.	6/13	(1) Improper clearance on safety washer on white. Repl. (2) Left & right lat servo turns in mount. Tightened mount nut.	9750
				6/18	(1) Replaced eng N-2 carbon seal.	
		3/19	The 10-to-20-cps signal changed from near 0 to approximately 75 g's.	3/26	(1) Main D/S insp and lub. (2) Fwd & aft p/p tube bearing worn exc. at mixing sect. under floor panel. Replaced. (3) Bipod trunnion bearing worn exc. Replaced. (4) T/R hub assy replaced.	0034
	T2*	3/27	T2 temp increased to approx. 131°F.			
	Eng Ver	4/22	The 10-to-20-cps signal changed from near 0 to approximately 35 g's.	4/28	(1) White mixing lever control tube bearing worn. Replaced. (2) T/R hub assy replaced.	
				4/30	Main D/S insp and lub C/W (A20-3550) changed.	
		6/2	The 20 cps signal changes from near 0 to approximately 45 g's. Pilot's comment: Exc. play in white rotating trunnion.	6/3	Replaced white trunnion bearing.	
		2/4	20 cps slight increase.	2/6	(1) White scissor drive link trunnion brg worn exc. Replaced. (2) Red scissor drive link trunnion brg worn exc. Replaced. (3) Red & white mixing lever pivot brgs worn exc. Replaced.	9789
		2/19	One run shows high 20 cps level change.	2/19	Pilot's comment: Exc. vib. Test-flown and released.	

*Signifies double entry.

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
8 to 20 cps	Eng Ver	5/23	(1) 20 cps increased in level, also slight increase in 8 to 16 cps. (2) Pilot's comment: 1:1 vert at 80 knots and EGT approx. 640°F from 600°F. (3) Test pilot's comment: Leaking collective servo is binding and adds to collective bounce in flt. Req coll servo chg. Heavy vib in airframe very noticeable during landing approach.	5/23	Coll servo removed. Replaced.	9789
				5/25	(1) L & R lat servos loose and turn in mounts. (2) Elev push-pull tube brg rough. Replaced.	
		6/3	The 8-to-20-cps signal changes from near 0 to 35 g's.		The next data run was 6/30 and several maint. actions have taken place.	9898
		4/22	The 8-to-20-cps signals peaked. The g level changed from near 0 to approximately 70 g's for 20 cps, 40 g's for 10 and 16 cps, and between 7.5 and 25 g's for 8 cps.	4/24	(1) Main D/S found to be unserviceable. Replaced. (2) L/H rear mounts sep. exc. on inside & outside mount sleeves.	6990
	Xmsn Bt*	4/22	The 4-kc signal changed from 12 to 20 g's.			
	Eng Hor*	4/22	The 10 kc signal changed from 7.5 to 12 g's variable.			
	Eng Ver	3/10	20 cps signal changed from 7.5 to near 0 g's.	3/12	Input quill seal leaking. Replaced.	0099
	Xmsn Tp*	3/10	6.3-kc signal increased during this test.			

*Signifies double entry

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
31.5 cps	Nose	6/25	31.5-Hz signal changed from above .15 variable to near 0.	7/1	White mixing lever had play. Repaired.	6969
				7/8	Tracked M/R due to pilot reporting 1:1 vert vib.	
				7/8	Pilot reported xmsn oil low. Serviced.	
800 cps	Eng Hor.	5/15	The 800-cps signal decreased from approx. 5 to 1.5 g's. It had been about 5 g's since start of program.	5/28	Changed engine. The nose seal was written up by a pilot as leaking excessively on 5/15.	6990
2 k	90° Gearbox	7/18 thru 7/30	2-kc signal increased in June and a greater increase in July.	8/7	42° gearbox replaced.	9789
2 kc	Eng Ver	3/12	2-kc signal decreases between 3/12 and 3/19 from about 5 to 1 or 2 g's.	3/13	Airline loose at eng deck L/side at bottom of eng tripod leg.	6969
				3/14	Flt #1 - Evidence of oil leak in eng compartment R/side. Tightened oil line.	
	Xmsn Bt	3/12	2-kc signal decreased from approx. 12 to approx. 7.5 g's.	3/13	Prefit - white drive link trunnion brg has exc. wear. Trunnion brg was replaced.	1075
		6/24	The 2-kc signal was near 8.4 g's. It decreased on 6/27 to approx. 7.5 g's, where it remained until near 7/25.	6/30	(1) White drive link trunnion has exc. in and out play. Replaced. (2) Red scissors pivot brg has exc. axial play. Replaced. (3) Trunnion at left lat servo to swashplate horn removed. Replaced.	

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
2 kc	Xmsn Bt	2/10	2-kc signal changed from approx. 15 g's on 2/4 and 2/10 to 8 g's thereafter.	2/20	Excess hyd leak in fitting right side xmsn area of chock valve, down 1/3 rd in 30 min. Repl. hyd line.	9789
2 & 2.5 kc	90° GB	5/1	A large increase in the level of the 2.5-k and 2.0-k signal (from 2 to 4 times normal level). This increase cont. throughout remainder of test period.	4/30	Replace 42° GB. (Minor trouble with this new GB was reported throughout test period.)	1075
2.5 kc	Eng Ver	5/12	The 2.5-kc signal fluctuated.	5/12	(1) Tracked M/R blades. (2) Red scissor arm pivot brg worn, replaced brg.	9898
				5/21	Engine changed.	
		5/28	Pilot's comment: High EGT. 625°F in flt.	5/28	(1) Cleaned engine. (2) Adjusted xmsn oil pressure.	
		5/21	(1) Slight change in the g level of the 2.5-kc signal from a normal of 12 to 15 g's. (2) Pilot's comment: Flt #3, xmsn oil press 74 psi after 1-hr flt. Xmsn temp 70°F.	5/21	Adjusted xmsn oil press relief valve.	6969
				6/18	Replaced pressure relief valve.	
		2/20	The 2.5-kc signal changes from approx. 15 to 35 g's. The 2-kc signal slightly higher also.	2/21	Scissors bearing is loose and rotating on preflight. The nut was retorqued.	9898
				2/27	Engine oil return line leaking at engine oil tank. The nut was tightened.	

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
2.5 kc	Eng Ver	5/12	The 2.5-kc signal varies greatly between 15 and 35 g's. (Normal level is approximately 15 g's.)	5/15	(1) Replaced red scissor arm pivot bearing. (2) Replaced all red mixing lever bearings. (3) Eng D/S insp and lub. (4) Both end mount pillow block brgs worn exc. Replaced.	9898
	Xmsn Tp*	5/12	The 4-kc signal decreased slightly. Change from 35-50 g's to 30 g's.			
	Eng Hor	6/25	Engine smokes on shut-down. Test flt was OK. No maint.	6/30	(1) White drive link trunnion has exc. in and out play. Repl. trunnion. (2) Red scissors pivot brg has exc. axial play. Replaced brg. (3) Trunnion at left lat. servo to swashplate horn removed. Replaced trunnion.	1075
		6/27	A high 4.0-kc above 33 g's signal extended from 3/20 to 7/2.			
		6/5 - 7/9	2.5-kc signal peaking during June. Signal decreased after 6/7 and made further decrease after 7/9.	7/13	(1) Eng D/S replaced. (2) M/R P/C link rod end worn. Replaced.	
2.5 KHz	Eng Ver	3/19	The 2.5-KHz signal varies to 27 g's.	2/20	Compressor blades damage by D.O.D. in exc. of .010" I/A/W 30/1. Some damage near roots of blades.	0034
				2/24	Two blades removed from 1st-stage compressor.	
3.15 kc	Eng Hor	3/20	The 3.15-kc changed from 45 g's on 3/20 to 30 g's until 5/13, and then it decreased in amplitude with more decrease taking place.	3/26	Replaced eng S/S.	1075
				4/4	Eng. used oil exc. Replaced plt seal. Signal dippled a little.	
				5/15	Eng. bipod unibell brg worn exc. Replaced bearing.	
		3/13	Slight increase in 3.15 kc.	3/13	White mixing lever brg worn exc. Both inbrd mixing lever brgs replaced.	0034

*Signifies double entry.

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
3.15 kc & 4 kc	Eng Mor	5/15	The 4-kc and 3.15-kc signals change from about 5 g's for 4 kc to 7.5 g's for 3.15 kc to about 6 g's for 4 kc & 2 g's for 3.15kc.	5/21	Engine changed. The nose seal was written up by a pilot as leaking exc. on 5/14.	6990
		6/3	4-kc and 3.15-kc signals peaked at approx. 35 g's. The 4-kc signal changed from approx. 10 to 18 g's and the 3.15-kc signal changed from 15 to 25 g's.	6/4	Flt #5 Gimbal ring bearing worn exc. The maintenance action taken was to tighten the bolt thru bearing.	0099
		3/21	4 kc and 3.15 kc had high level from 3/7 thru 3/21.	3/28	(1) Play in tripod fwd rod end brg. Replaced. (2) Main D/S lub & insp. (3) T/R hub T/C. (4) R/L lat servo turning in mount. (5) White mixing lever brg exc. outboard front inboard.	9750
		6/16	The 4-kc signal has a slight increase in amplitude from approx. 33 to 40 g's. The 3.15-kc signal changes from 15 to approximately 30 g's.	6/16	Xmsn oil press. fluctuates in flight from 30 to 60 psi. The oil line leaking on the bottom xmsn. Replaced line and serviced xmsn.	0034
4 kc	Xmsn Tp	4/21	Change in level fluctuations of 4-kc and 5-kc signal from 4/9 thru 4/21.	4/16	(1) Rt aft brg plate worn exc. Replaced. (2) White mixing lever brgs worn. Replaced. (3) White scissor arm (inboard) trunnion worn. Replaced. (4) White scissor outbd pivot brg worn. Replaced.	9898
		5/27	Change in 4-kc level. Xmsn oil press. low at flight idle 28 lbs light comes on.	5/27	Replaced press. relief valve	

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
4 kc	Xmsn Bt	6/20	The 4-kc signal decreased in level from 6/6 of approx. 55 g's to approx. 25 g's 6/20 and after that settled at about 15 g's.	6/25	(1) T/C on xmsn. Replaced S/N A12-2021 with A12-1004. (2) Scissors and sleeve S/N Q19-2297 removed for T/C. (3) Rivets loose top of left horseshoe. Repl. with bolts. (4) Lift link beam cracked fwd right side. Repaired. (5) Play in upper lift bearing. Replaced.	9758
	Xmsn Tp	6/25	The 4-kc signal increased from approx. 15 g's to approx. 45 g's. The 6.3-kc signal decreased from approx. 30 g's to approx. 22 g's.			
	Eng Hor	7/31	The 4-kc signal increased in level, peaking on 7/31.	8/9	(1) Changed eng D/S. (2) Eng inlet guide vanes exc. dirty. Washed engine.	6969
	Eng Ver	4/22	The 8-to-20-cps signals peaked. The g level changed from near 0 to approx. 70 g's for 20 cps, 40 g's for 10 and 16 cps, and between 7.5 and 25 g's for 8 cps.	4/24	(1) Main D/S found unserviceable. Replaced. (2) L/H rear mounts sep exc. on inside & outside mount sleeves.	6990
	Xmsn Bt	4/22	The 4-kc signal changed from 12 to 20 g's.			
	Eng Hor*	4/22	The 10 kc signal changed from 7.5 to 12 g's variable.			

*Signifies double entry.

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
4 kc	90° GB	7/3	The 4-kc signal has increased in level.	7/25	90° GB changed.	0099
6.3 kc	Eng Hor	3/20	High 6.3 kc also high 4/5, 4/10 and 6/5.	6/20	Eng D/S insp & lub.	1075
	Xmsn Tp	6/5	The 6.3-kc signal decreased in g level after this date and stayed approximately 30 - 35 g's.	6/6	Hyd failure. Repl line.	0034
				6/8	Xmsn oil drain clogged. Unclogged drain.	
				6/16	Xmsn oil press. fluctuates. Xmsn oil level low. Serviced xmsn.	
				6/16	Oil line bottom xmsn leaking. Replaced.	
8 kc	Eng Hor	3/20	The 8-kc signal changed from near 0 to 12 g's (no low freq. data available). The 3.15-kc signal changed from near 45 to 30 g's.	3/26	Eng to xmsn s/s replaced.	1075
				4/4	Eng using oil, repl. plt seal.	
10 kc	Eng Ver*	4/22	The 8-to-20-cps signals peaked. The g level changed from near 0 to approx. 70 g's for 20 cps, 40 g's for 10 and 16 cps, and between 7.5 and 25 g's for 8 cps.	4/24	(1) Main D/S found unserviceable Replaced. (2) L/H rear mounts sep. exc. on inside & outside mount sleeves.	6990
	Xmsn Bt*	4/22	The 4-kc signal changed from 12 to 20 g's.			
	Eng Hor	4/22	The 10-kc signal changed from 7.5 to 12 g's variable.			
		3/14	The 10-kc signal changed from approx 7.5 to 12 g's.	3/18	Replaced RMI.	1075

*Signifies double entry

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
12.5 kc	Xmsn Tp	6/27-7/8	12.5-kc signal increased to approx. 6.5 g's (slight increase).	7/9	RPM high beep. Adj.	1075
				7/13	(1) Eng D/S SN A20-6540. Replaced A20-11314. (2) Eng aft trunnion brg rt side & single leg removed for use on other A/C.	
16 kc	Xmsn Tp	5/6	16-kc signal increase.	5/7	Oil cooling fan stand broken. Repaired.	9750
T2 Temp	Input Quill	3/10	High input quill temperature.	3/12	Quill seal changed.	0099
		3/20	High input quill temperature.	3/22	Quill seal changed.	0025
		3/21	Temperature increased from about 30° to about 75°F.	3/26	Pilot commented quill leaked exc. Replaced seal.	9898
		4/8	Temperature increased to approx. 100°F and remained there.	5/28	Several comments were made by pilot concerning quill leaking. Replaced seal.	
		5/2	Sensor reads high.	5/12	Changed engine drive shaft.	9789
		7/2	Temperature approx. 100°F.	7/29	Replaced seal.	9898
		7/23	Sensor reads high.	7/30	Engine driveshaft pitted on both ends. Replaced.	6990
		7/25	Xmsn leaking oil at input quill seal. T2 reads high.	7/25	Ckd & found no exc. in A/W ECM 498.	9750
		7/31	Change in temperature rise to about 130°F.	8/9	(1) Pilot commented quill seal leaking. (2) Eng to xmsn shaft insp. and relub.	6969

TABLE II - Continued

Frequency Indicators	Data Channel	Significant Change in Data		Maintenance Action Taken		A/C No.
		Date	Frequency - G Level Change	Date	DA Form 2408-13	
T3 Temp	Foreshaft	3/19	Foreshaft temp changed from approx. 40° to 112°F.	3/22	Changed the #2 hanger bearing.	6990
		4/17-5/12	Temperature varies above 75°F.	5/15	Changed the #2 hanger bearing.	9898
		5/19	Sensor reads high.	5/22	Changed the #2 hanger bearing.	6990
		5/23	T3 reads high.	6/14	A hole found in seal. Replaced seal.	9789
		6/5	T3 reads approx. 100°F above ambient.	6/10	Changed the #2 hanger bearing.	1075
T4 Temp	Midshaft	4/8	Temperature above 85°F.	4/14	Repaired cable grounds.	9898
		3/10-5/12	Temperature reads approximately 84°F during this period.	5/27	Replaced #3 hanger bearing after approx. 230 hours.	0099
		5/12	High T4 reading.	5/15	Repaired grounded instrumentation cable.	9750
		5/29	High T4 reading.	6/5	Replaced bad sensor.	
T5 Temp	Aftshaft	2/27	T5 reads slightly high, approx. 60°F.	2/27	Changed #4 hanger [illegible] - rough and dry.	1050
T6 Temp	42° GB	7/8	Temperature increased to about 90°F from normal of about 75°F.	7/13	Grease seal leaking in coupling of 42° gearbox. Repl seal.	1075
T7 Temp	90° GB	3/19	Temperature increased to approx. 75°F.	3/22	90° gearbox serviced.	6990
		3/25	Temp. started increasing.	4/4	Pilot commented oil turned black. Oil drained and refilled	

TABLE III. OPERATING ACCELERATION LEVELS ABOVE WHICH MAINTENANCE WAS REQUIRED

	ENGINE VERTICAL ACCELERATION (g's)											
	Aircraft Tail Number											
Filter	0025	0034	1050	9750	9758	6960	6969	1075	9789	9898	6990	0099
8	.75	.75	.7	1	5	1	2	1	1.5	2.5	2	1.5
10	.75	.75	3.7	1	6	2.5	2	1.5	1.5	3	3	1.5
12.5	.75	.75	.7	.75	2	1	2	1.5	1.0	.7	3	1.5
16	.75	.75	.7	1.5	2	2	2	2	3.7	5	3	1.5
20	3	5	3.7	5	6	2.5	5	4	6	6	3.5	3
25	1.5	1.5	.8	1.5	2	1.5	1	1		.5	1.5	1
1.00K						1				.5		
1.25K	.75	.75	.7	1			2	2.5	.7		3.5	1.5
1.60K	7.5	10	4	4	5	5	5	8.5	2	3	3	1.5
2.00K	13	7.5	4	3	3	7.5	5	11	0	4.5	0	7.5
2.50K	7.5	3	10	14	15	7.5	12	3	7	13	20	18
3.15K	.75	.75	1	1	7.5	1.5	2	7	8.5	1.5	5	2.5
10.0K	2.5	1.5	1	2	2	1.5	3	.7	2	0	2	1
12.5K	5	.75	1	2	3	3	7.5	4.5	5.5	0	5	1
16.0K	3	2.5	1	3	1	1	4	3	3.5	1	3	1

Notes Applicable to all Parts of Table III:
1. Values corrected for maintenance actions after being estimated from the historical data report.
2. No maintenance data available for helicopter number 65-10025.
3. Only filter bands judged relevant to the applicable parameter are shown in this table.

TABLE III - Continued

ENGINE HORIZONTAL ACCELERATION (g's)

Filter	Aircraft Tail Number											
	0025	0034	1050	9750	9758	6960	6969	1075	9789	9898	6990	0099
800												
1.00K	.75	3	1	1	1.5	1		.5	.7		0	0
1.60K							1.5			.7		
2.00K	.75	1	1	1	1	1	1.5	.75	0	2	0	0
2.50K	3	5	1.5	1	2	1.5	5	4		7	4	3
3.15K	15	20	2.5	12	7 5	6	15	16	9.5	28	12	16
4.00K	30	33	4	22	14	12	30	18	4.5	27	16	16
5.00K	1.5	1.5	5.5	4	3	3	2	4	2	5	1	2
6.30K	.75	1.5	4	5	3	1.5	2	4	5	3	1	.7
8.00K	7.5	3	12	7.5	10	4	4	2.3	5	6.5	10.5	3
10.0K	20	10	1.5	8	10	3	5	2.3	9	2	15	7
12.5K	2	5	3	4	5	1.5	3	./	2	0	7	2
16.0K	.75	3	1	4	1.5	2	1.5	.7	1.5	.7	.5	.5

TABLE III - Continued

TRANSMISSION TOP ACCELERATION (g's)

Filter	Aircraft Tail Number											
	0025	0034	1050	9750	9758	6960	6969	1075	9789	9898	6990	0099
2.50K	4.5	3	2	5	5	2.5	4	3	2	2	3	3
3.15K	4.5	7.5	4	12	7.5	3	6	9	6.5	4.5	7	4.5
4.00K	17	25	22	22	20	15	35	9	15	27	23	21
5.00K	10	16.5	20	14	10	12	10	9	4	7	8	12
6.30K	25	36	32	34	30	35	35	14	30	11.5	25	30
8.00K	15	12	12	15	20	15	20	11	12.5	10.5	17	9
10.0K	12	15	6	10	10	7.5	10	15	6.5	7.5	14	7.5
12.5K	3	7	7	6	6	5	6	4.5	3	4.5	4.5	7
16.0K	3	7	5	7.5	6	7.5	4	3	.7	7.5	1.5	7

TABLE III - Continued

90° GEARBOX ACCELERATION (g's)

Filter	Aircraft Tail Number											
	0025	0034	1050	9750	9758	6960	6969	1075	9789	9898	6990	0099
1.00K	6	16	6	5	7	15	9	7	6	8	2.5	2
1.25K	3	10	5	4	6	8	6	4.5	4.5	5	1.5	2
1.60K	5	10	4	1	3	1.5	1.5	3	2	12	.7	1.5
2.00K	45	75 Max	36	3	22	25	53	57	35	17	25	40
2.50K	30	55	17	15	20	15	26	27	20	5	16.5	15
3.15K	1.5	4	7	6	3	7.5	1.5	1.5	2.5	.7	.7	7.5
4.00K	4.5	40	3	3	3	25	3	6	.7	15	3	5

Notes (90° Gearbox Data):
1. The 90° gearbox on 65-10034 seemed very high in all cases.
2. The 4-kc signal increased during testing. The use of A/C 66-16960 as a gunship made analysis of this problem impossible.

TABLE III - Continued

TRANSMISSION BOTTOM ACCELERATION (g's)

Filter	Aircraft Tail Number											
	0025	0034	1050	9750	9758	6960	6969	1075	9789	9898	6990	0099
1.25K	1.5	4	.5	1	2	1	3	.7	.7	1	.7	.7
2.00K	11	6	8	7	10	4	6	11	12	4.5	8	10
2.50K	10	5	6	7.5	6	7.5	5	7.5	4.5	4	4.5	10
3.15K	30	18	18	23	15	12	10	19	14	10.5	12	20
4.00K	25	60	12	42	20	7.5	30	39	35	40	12	25
5.00K	4.5	7	3	7	7	3	10	10	6	5	2	4
6.30K	3	5	7	4	6	1.5	5	3	2.5	3	2	2.5
8.00K	2	3	1	.7	1.5	1.5	3	.7	.7	2.0	.7	2
10.0K	.75	3	1	.7	1.5	1.5	3	.7	2	.7	.7	1.5

TABLE IV. RECOMMENDED MAXIMUM COMPOSITE OPERATING ACCELERATION LEVELS (g's)

Freq.	Eng Ver		Eng Hor		Xmsn Tp		Xmsn Bt		90° GB	
8	5.0									
10	6.0	*								
12.5	3.0									
16	5.0									
20	6.0	*								
25	2.0									
1.00K			3.0						16	
1.25K	3.5						4		10	
1.60K	10		1.5						12	
2.00K	11	*	2.0				12	*	57	**
2.50K	20	*	7.0	*	5	*	10		27	*
3.15K	8.5		28.0	*	12		23		7.5	
4.00K			33.0	*	35	*	42	*	15	*
5.00K			5.0		16.5		10			
6.30K			9.0	*	36		6			
8.00K			10.5	*	20		3			
10.0K	3.0		15.0	*	15		3			
12.5K	7.5		7.0		7					
16.0K	4.0		4.0		7.5					

Note: These values are g levels and are derived from the histogram report and estimated from the historical report corrected for the maintenance action shown in Table II.

* Seems to be more responsive to needed corrective action.
** Seems to be responsive to condition of the 42° gearbox.

It should be observed that monitoring the accelerations of each aircraft and comparing these periodically to that aircraft's own established operating level (shown in Table III) provides a much more sensitive test of aircraft condition than does the MOAL. Study and evaluation would be necessary to determine if different operating conditions and maintenance schedules would result in a transition of present acceleration levels to higher or lower values.

It was also observed that within each of the acceleration channels there are groupings of 1/3-octave frequency bands that are particularly sensitive to mechanical problems. These selected groupings, seen in Table IV, are likely candidates for evaluation in a low-cost on-board monitoring system.

GENERATION OF TABLE II

Table II was generated by analyzing the data in the following manner. First, histograms of all significant acceleration measurements were made. An example of an acceleration histogram is shown in Figure 18. These graphs show if and how the accelerations of the test aircraft fit a pattern. By comparing the histogram data with the historical data and by checking data level shifts and unusual values with the maintenance records, preliminary examples for investigation were selected. These examples were listed in Table II. Further investigation was conducted to determine applicability to Tables III through VI.

The effort to observe significant variations in parameter values was assisted by reference to histograms of these parameters, where it was easily determined if there were sharp or gradual roll-offs of events at higher levels of temperature and acceleration. Emphasis was placed on an attempt to determine whether RMS acceleration in various channels may correctly lead to a conclusion of malfunction. If this is possible, a successor system might be considerably simplified over one that requires spectral analysis of parameters.

GENERATION OF TABLE III

Table III shows the highest accelerations experienced by these individual aircraft during normal flight at each accelerometer location. The operating levels of the accelerations of the preliminary examples in Table II were screened and values selected that reflect levels at which maintenance was required. These levels were recorded in Table III. One example of how the corrected acceleration levels were generated for Table III

can be seen by considering historical data taken March 19, 1969, for aircraft 0034 (see Figure 17). The 2.5-KHz 1/3-octave filter output for the engine vertical accelerometer shows accelerations of up to 27 g's. On March 20, 1969, this engine was inspected and was found to have foreign-object damage; repairs were made. For the remainder of the test period, the acceleration level from this filter never exceeded 3 g's; therefore, 3 g's was entered in Table III for helicopter 0034. Because the 2.5-KHz channel showed no excursions or patterns other than its 3-g baseline activity, it must be assumed that any further difficulty with the engine was of a nature that did not generate signals having energy in the 2.5-KHz filter. The historical data also shows a rise in the RMS level of acceleration on June 2. The rise in RMS level shown in this historical record was caused by activity in the 20-Hz band. Table II shows that on June 3 the white trunnion bearing was replaced, and acceleration levels returned to baseline levels. It is interesting to note that the trunnion bearing malfunction had no observable effect on the 2.5-KHz acceleration level. The maximum operating acceleration level for the engine vertical sensor within the 2.5-KHz filter bandpass is 20 g's, which was observed on helicopter 6990. If a limit detector had been in use, this 27-g malfunction would have been noted. The maximum acceleration recorded does not indicate the maximum amount that the engine could withstand but only the amount recorded under the test condition.

For another example of how Tables II and III were generated, take the example of aircraft number 0034, page 72, on March 19, 1969: The acceleration on the engine vertical accelerometer changed from near 0-g level to approximately 75 g's for 8 to 20 Hz filters. On March 26, 1969, the maintenance data DA Form 2408-13 showed that four maintenance actions were performed. The time of the maintenance action was seven days after the first data showing this high acceleration level were collected. Since maintenance actions resulted in a reduction in the acceleration level, the g-level in Table III shows the level that was observed when no maintenance was required.

Study of Table III reveals that often there is, between helicopters, a ratio of 5:1 or 10:1 in operating acceleration levels beyond which maintenance activity is required. This indicates that the relevance of absolute accuracy of parameter measurement of 2% is open to serious question in light of the range of 1000% (and more) of variation experienced on safely operating same-model helicopters. It would appear that wide dynamic range of the instrumentation system, along with repeatability of relative measurements would be the desired objective of subsequent data collection systems.

GENERATION OF TABLE IV

Each aircraft has been found to have its own peculiar operating acceleration level. Through use of the histograms and the observation of historical data, it is possible to recommend maximum operating levels applicable to all helicopters. However, more data will be needed to verify whether or not the simplicity of a composite maximum operating level is justifiable in light of its reduced sensitivity. Based on observations of the 12 instrumented helicopters, a composite maximum level can be established by sensor and by frequency band for verification in further test programs. These levels are shown in Table IV.

GENERATION OF TABLE V

The most simple vibration detection system would involve the monitoring of an accelerometer with a wide-band RMS detection circuit. Therefore, the historical report was reviewed to observe RMS operating levels and to determine if limits could be set for RMS levels. The levels for RMS were taken from the historical report and are shown in Table V. The recommended maximum RMS operating level was selected as the highest value found for any tested helicopter.

The maximum levels were used with the historical report and with Table II to see how sensitive the wide-band RMS signal was to maintenance actually performed on the aircraft. There are 48 maintenance actions (more than one item repaired between data acquisition dates counts as one maintenance action) correlated with the accelerations shown in the historical report, and, of this total of 48, only 17 were judged to be correlatable with RMS levels. The 17 maintenance actions correlatable with RMS levels were those actions which were preceded by RMS accelerations judged greater than the average for that parameter over the test period. The RMS levels which were examined are found in the historical data reports. It would be expected that RMS values would be less sensitive than filter outputs because the RMS values would be heavily influenced by nearby components having high accelerations but which are operating normally. However, this detection sensitivity could be increased by adjusting the limit individually for each aircraft.

A judgment of the sensitivity of single filter channel limits compared to the wide-band RMS channel is that the most informative individual filter channels indicated in Table IV are approximately twice as sensitive as the RMS limits. Even better performance might be obtained by monitoring contiguous groups of frequencies as shown in Table IV.

TABLE V. RECOMMENDED MAXIMUM RMS OPERATING ACCELERATION LEVELS AND LIMITS

Data Channels	Aircraft Tail Numbers												Recommended Max. Composite Accel. Levels
	0025	0034	1050	9750	9758	6960	6969	1075	9789	9898	6990	0099	
Eng Ver	18	15	15	16	18	14	18	18	15	15	25	22	25
Eng Hor	33	43	15	30	20	15	30	30	15	43	30	30	43
Xmsn Tp	20	45	30	50	44	44	50	30	50	33	38	44	50
Xmsn Bt	36	54	24	54	54	16	30	44	44	45	30	33	54
90° GB	35	50	38	28	36	50	51	51	40	24	30	45	51

Note: These values are g-levels and are estimated from the historical report, corrected for maintenance actions shown in Table II.

Condition Warning Using Acceleration Data

Involved also in the concept of maximum operating levels is experience in the area of determining which high levels of acceleration or temperature are indicators of immediate hazard to the helicopter and which high levels merely require some noncritical maintenance. Melpar has been unable to isolate these elements because, among other things, we received no feedback of data on the condition of replaced components.

The correlation of maintenance records with acceleration levels has limitations, in that a faulty component may induce excessive loads on other components, thus causing the latter to deteriorate rapidly and to have to be changed despite the fact that it may not have been faulty at the beginning of malfunction of the first component. It is possible also that, in order to return the aircraft to service quickly, components that were not faulty were changed "just to be sure." It is considered likely that different maintenance foremen would differ in their judgment on replacement "just to be sure." Therefore, more consistent results in correlating component replacement with signal levels could be achieved by using a single maintenance group for all instrumented aircraft.

Examination of the maintenance data reveals that a monitoring system might provide better warning of difficulties in the cyclic and collective pitch control assemblies if an accelerometer were installed on the main rotor controls or the cyclic control cylinder assembly. This accelerometer should detect, more clearly and quickly, signals presently detected only by the engine vertical accelerometer between the frequencies of 8 and 20 Hz. An alternative location that should be considered is that of placing an accelerometer on the swashplate assembly. Measurements taken in this location could give positive indication of the condition of the swashplate bearing in addition to the control assembly, whereas the swashplate temperature sensor and vertically mounted accelerometers have proven to be ineffective.

During review of the historical data report, it was observed that increase of an acceleration signal could, at times, be observed before maintenance personnel could recognize the existence of a faulty component. This occurred on April 22, 1969, on aircraft 0034, when the 10-to-20-Hz signal on the engine vertical accelerometer increased from near 0 to 35g's. Six days elapsed before repairs were made to the white mixing lever control tube bearing. On February 10, 1969, on aircraft 9789, it occurred again when there was a lag of between 6 and 10 days between observation of a high level of acceleration (at the beginning of the measurement program) at 2 KHz on the transmission bottom and the initiation of repairs to the hydraulic system. Both of these examples are shown in Table II.

Condition Prediction Using Acceleration Data

The historical report shows that, as the time advanced toward overhaul, there was a tendency for increase in amplitude and variation at the significant frequencies for that component. It must be remembered, however, that this 500-hour program had a duration only one/half to one/third of the time between overhaul intervals of these major components, and the data from this short test, while revealing a trend, cannot be used to set limits at values which will be indicative of wearout and the need for replacement. It is believed that this type of information would be much more strongly indicated on a longer test period, one that lasted an appreciable percentage of the life of these components. The feedback of information on the condition of replaced components, as revealed by disassembly and inspection, would greatly assist in the evaluation of signal levels and fluctuation with component wearout and remaining service life.

By referring to the aircraft flight history charts (Appendix II), one observes that this program monitored aircraft in which each of the major components, engine, transmission, and gearboxes, was in different phases of the time between overhaul.

The data acquired during this program have been analyzed to determine if worn components or mechanical malfunctions could be detected by observing changes in the absolute level of acceleration or in fluctuation of the level of the data before and after the malfunction or replacement of a worn component. An example of this is found by reviewing the engine change on May 21 on aircraft 9898. It may be observed from the historical records (see Figure 20) that the RMS level of the vertical accelerations measured on the rear of the engine changed from an average of approximately 16 g's with fluctuations of 13 g's, from February to May 1969, to an average of approximately 13 g's with fluctuations of 7.5 g's during July 1969. The acceleration level, measured from the accelerometer mounted vertically on the rear of the engine for the 2.5-KHz filter, varied from a low of 10 g's to a high of 22.5 g's, with some peaks higher. The fluctuation after replacing the engine was a low of 7.5 to a high of 14 g's. From February to May 1969, there were fluctuations from 7.5 g's to 25 g's at frequencies of 4 KHz and 3.15 KHz, as measured on the engine horizontal accelerometer. After May 21, 1969, these acceleration levels were near 3 g's and displayed little variation in level. There were changes noted in vertical accelerations measured at the transmission top. This example illustrates how the pattern of acceleration levels was modified as a result of engine change. On May 14, 1969, this engine was reported as having an excessive oil leak on the left side seam. Also, on the same date, the engine nose seal was found to be leaking and was replaced. On May 21, 1969, this engine was found to have an

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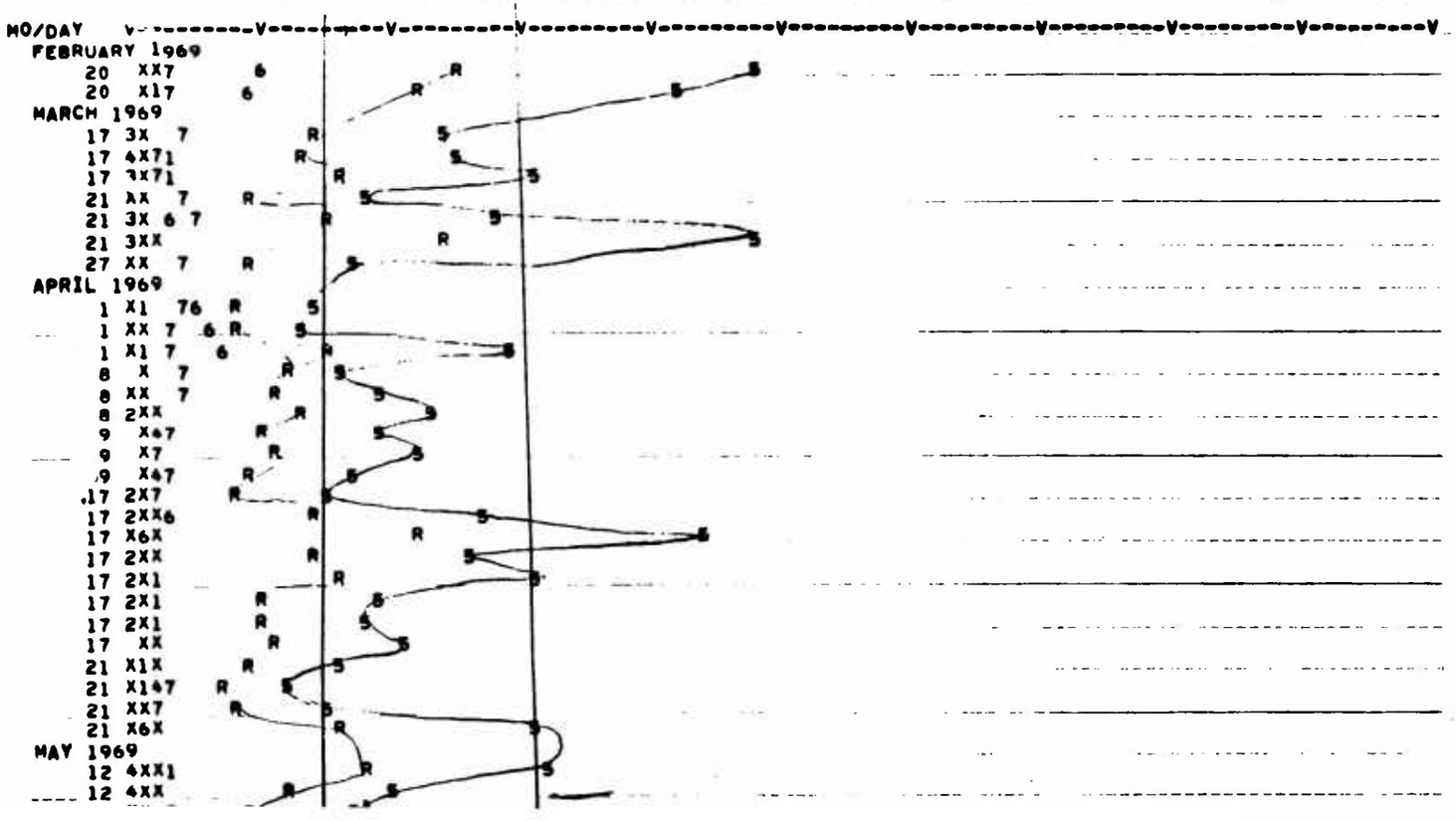
HELICOPTER NO. 9898 HISTORICAL DATA REPORT

ENG VER CHANNEL ACCELERATION IN G#S

FILTER 16000	1	VALUE PER SPACE	75.00E-02	
FILTER 12500	2	VALUE PER SPACE	75.00E-02	
FILTER 10000	3	VALUE PER SPACE	75.00E-02	
FILTER 3100	4	VALUE PER SPACE	75.00E-02	
FILTER 2500	5	VALUE PER SPACE	75.00E-02	
FILTER 2000	6	VALUE PER SPACE	75.00E-02	
FILTER 1600	7	VALUE PER SPACE	75.00E-02	
RMS	R	VALUE PER SPACE	15.00E-01	

1	0.	75.00E-01	15.00E+00	22.50E+00	30.00E+00	37.50E+00	45.00E+00	52.50E+00	60.00E+00	67.50E+00	75.00E+00
2	0.	75.00E-01	15.00E+00	22.50E+00	30.00E+00	37.50E+00	45.00E+00	52.50E+00	60.00E+00	67.50E+00	75.00E+00
3	0.	75.00E-01	15.00E+00	22.50E+00	30.00E+00	37.50E+00	45.00E+00	52.50E+00	60.00E+00	67.50E+00	75.00E+00
4	0.	75.00E-01	15.00E+00	22.50E+00	30.00E+00	37.50E+00	45.00E+00	52.50E+00	60.00E+00	67.50E+00	75.00E+00
5	0.	75.00E-01	15.00E+00	22.50E+00	30.00E+00	37.50E+00	45.00E+00	52.50E+00	60.00E+00	67.50E+00	75.00E+00
6	0.	75.00E-01	15.00E+00	22.50E+00	30.00E+00	37.50E+00	45.00E+00	52.50E+00	60.00E+00	67.50E+00	75.00E+00
7	0.	75.00E-01	15.00E+00	22.50E+00	30.00E+00	37.50E+00	45.00E+00	52.50E+00	60.00E+00	67.50E+00	75.00E+00
R	0.	15.00E+00	30.00E+00	45.00E+00	60.00E+00	75.00E+00	90.00E+00	10.50E+01	12.00E+01	13.50E+01	15.00E+01



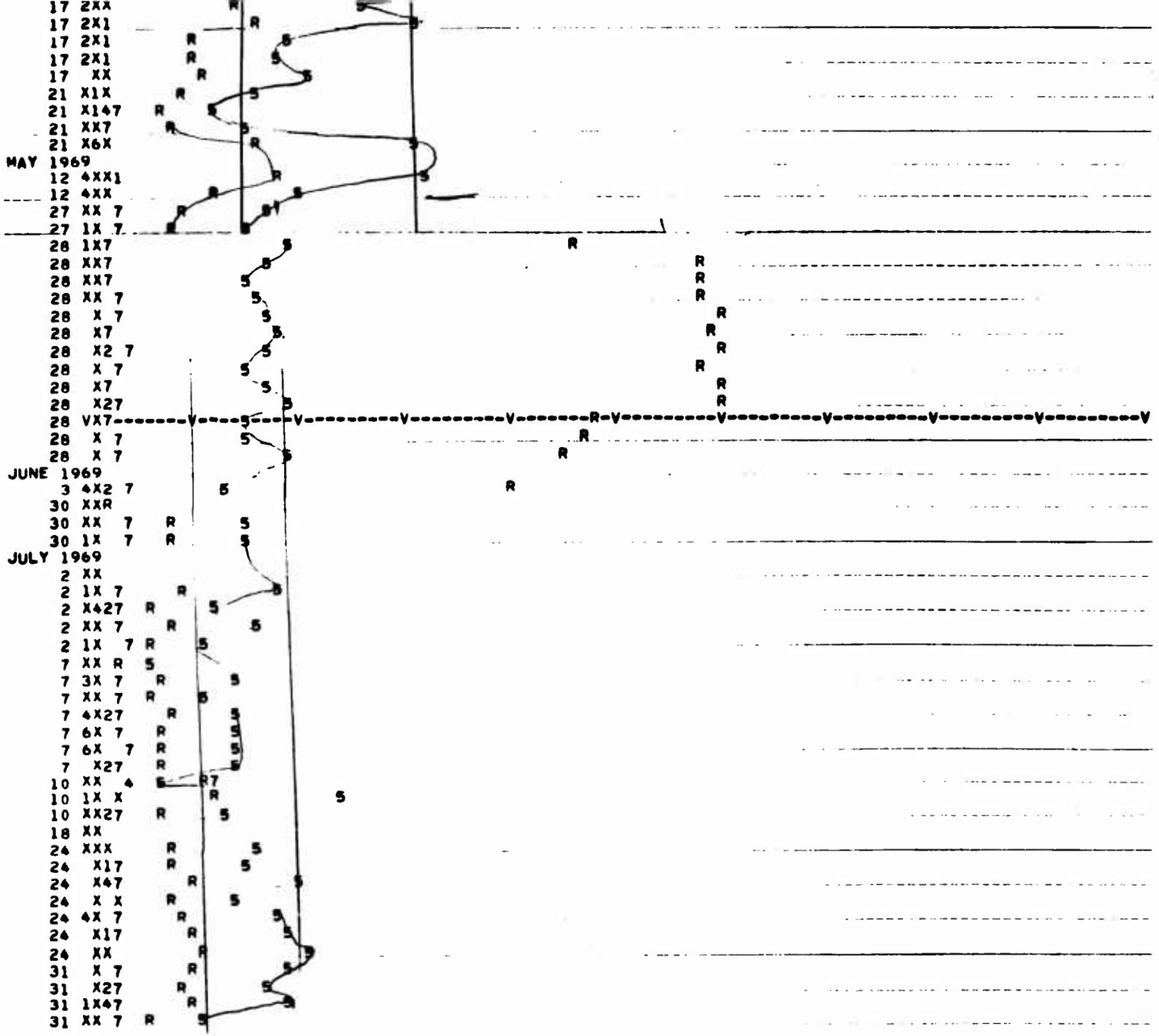


Figure 20. Historical Record, Engine Vertical Acceleration - Helicopter 65-9898.

excessive EGT of 640 degrees at 94% power. The engine was changed on this date.

The question of whether the variation of acceleration patterns is sufficiently small that deviations from normalized data can be interpreted to provide prognostic information also is difficult to determine, due to the previously mentioned limitations of length of testing and no feedback from teardown analysis. However, there is indication that at least occasionally prognosis can be obtained. By continuing to use aircraft number 9898 as an example, it can be observed that the output from the 1,000-Hz filter on the 90-degree gearbox increased from approximately 4.5 g's during March and April to approximately 6.5 g's during July 1969, for a 2-g level shift. The fundamental frequency of the 90-degree gearbox is contained in the passband of this filter. Another example showing a slight increase in acceleration during the test period can be observed by viewing the 6.3-KHz and 4-KHz filter from the vertical-mounted accelerometer on the transmission top of aircraft number 6990. The acceleration level for the 4-KHz filter increased approximately 2 g's, while the 6.3-KHz filter increased to approximately 3 g's.

It is noteworthy that maintenance activity often occurred with no observable effect on measured accelerations. This is as one might expect, for with components being changed on a time basis only, it is inevitable that some of them would be perfectly satisfactory when replaced.

TEMPERATURE DATA ANALYSIS

The temperature measurements gave large changes in levels when indicating mechanical problems. Usually, when a bearing started heating due to the loss of lubricant, the temperature increased rapidly with a likely rapid decrease in bearing life. See Figure 21, which is an example of the historical record of temperatures measured on helicopter number 66-16990.

Temperature sensors were located on the tail rotor drive shaft hanger bearings, input quill, 42° and 90° gearboxes, and swashplate. All of these locations were areas of high maintenance activity. As can be seen in the edited, condensed maintenance action forms that were prepared (examples of which are shown in Figure 22), the input quill was often removed for seal replacement, and this, plus the high frequency of hanger bearing inspections and replacements, resulted in the destruction of many sensors.

Due to the fragile nature of the metal film temperature sensors and the difficulty in installing and calibrating them, it was difficult to collect as much temperature data as was desired.

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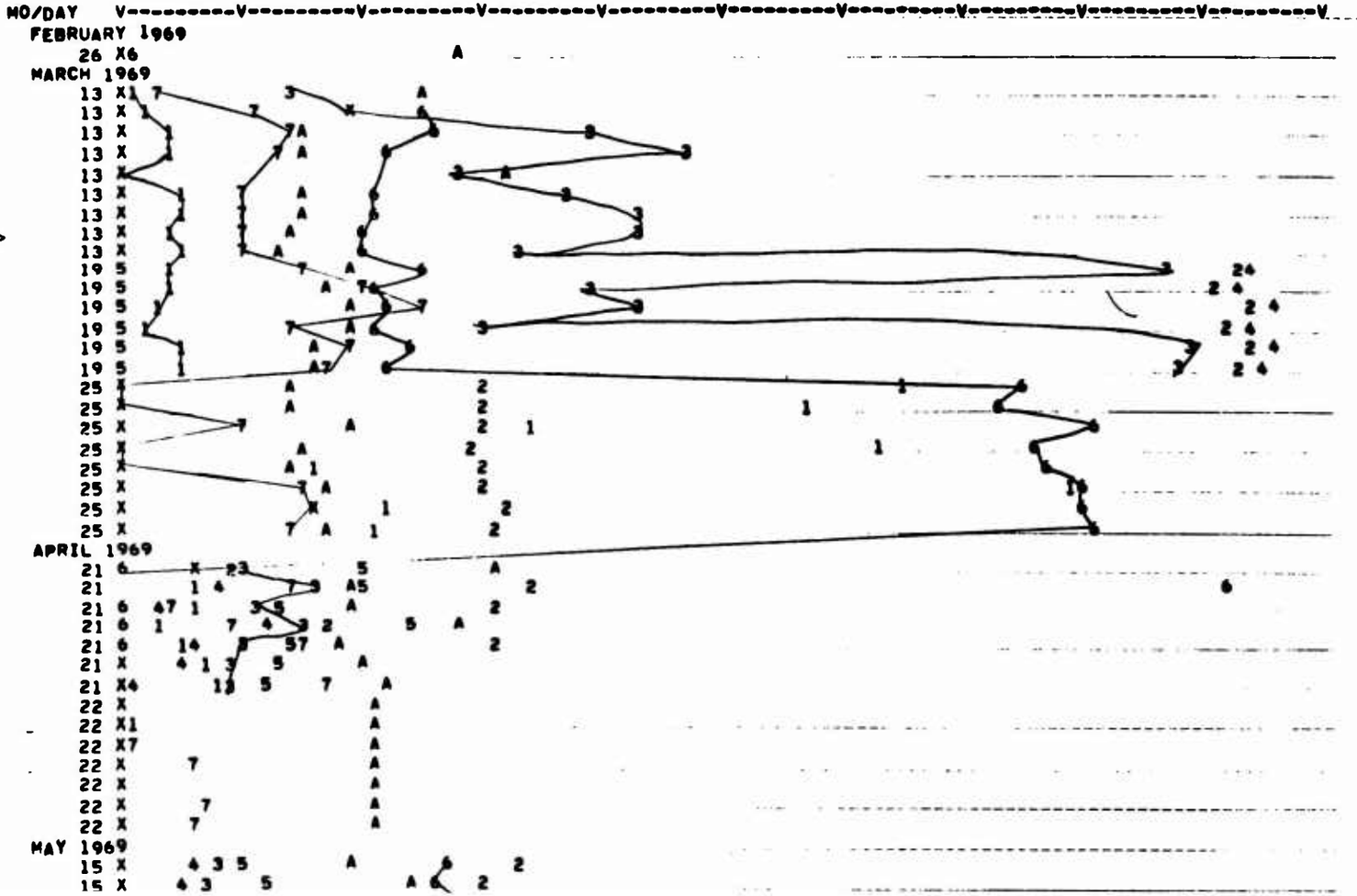
HELICOPTER NO. 6990 HISTORICAL DATA REPORT

TEMPERATURE RISE ABOVE AMBIENT IN DEGREES (F)

SWASHPLATE	1	VALUE PER SPACE	28.00E-01	
QUILL BRG	2	VALUE PER SPACE	28.00E-01	
FORESHAFT	3	VALUE PER SPACE	28.00E-01	
MIDSHAFT	4	VALUE PER SPACE	28.00E-01	
AFTSHAFT	5	VALUE PER SPACE	28.00E-01	
GEAR 42	6	VALUE PER SPACE	28.00E-01	
GEAR 90	7	VALUE PER SPACE	28.00E-01	
AMBIENT	A	VALUE PER SPACE	28.00E-01	

1	0.	28.00E+00	56.00E+00	84.00E+00	11.20E+01	14.00E+01	16.80E+01	19.60E+01	22.40E+01	25.20E+01	28.00E+01
2	0.	28.00E+00	56.00E+00	84.00E+00	11.20E+01	14.00E+01	16.80E+01	19.60E+01	22.40E+01	25.20E+01	28.00E+01
3	0.	28.00E+00	56.00E+00	84.00E+00	11.20E+01	14.00E+01	16.80E+01	19.60E+01	22.40E+01	25.20E+01	28.00E+01
4	0.	28.00E+00	56.00E+00	84.00E+00	11.20E+01	14.00E+01	16.80E+01	19.60E+01	22.40E+01	25.20E+01	28.00E+01
5	0.	28.00E+00	56.00E+00	84.00E+00	11.20E+01	14.00E+01	16.80E+01	19.60E+01	22.40E+01	25.20E+01	28.00E+01
6	0.	28.00E+00	56.00E+00	84.00E+00	11.20E+01	14.00E+01	16.80E+01	19.60E+01	22.40E+01	25.20E+01	28.00E+01
7	0.	28.00E+00	56.00E+00	84.00E+00	11.20E+01	14.00E+01	16.80E+01	19.60E+01	22.40E+01	25.20E+01	28.00E+01
A	0.	28.00E+00	56.00E+00	84.00E+00	11.20E+01	14.00E+01	16.80E+01	19.60E+01	22.40E+01	25.20E+01	28.00E+01

MO/DAY V---------V---------V---------V---------V---------V---------V---------V---------V---------V---------V



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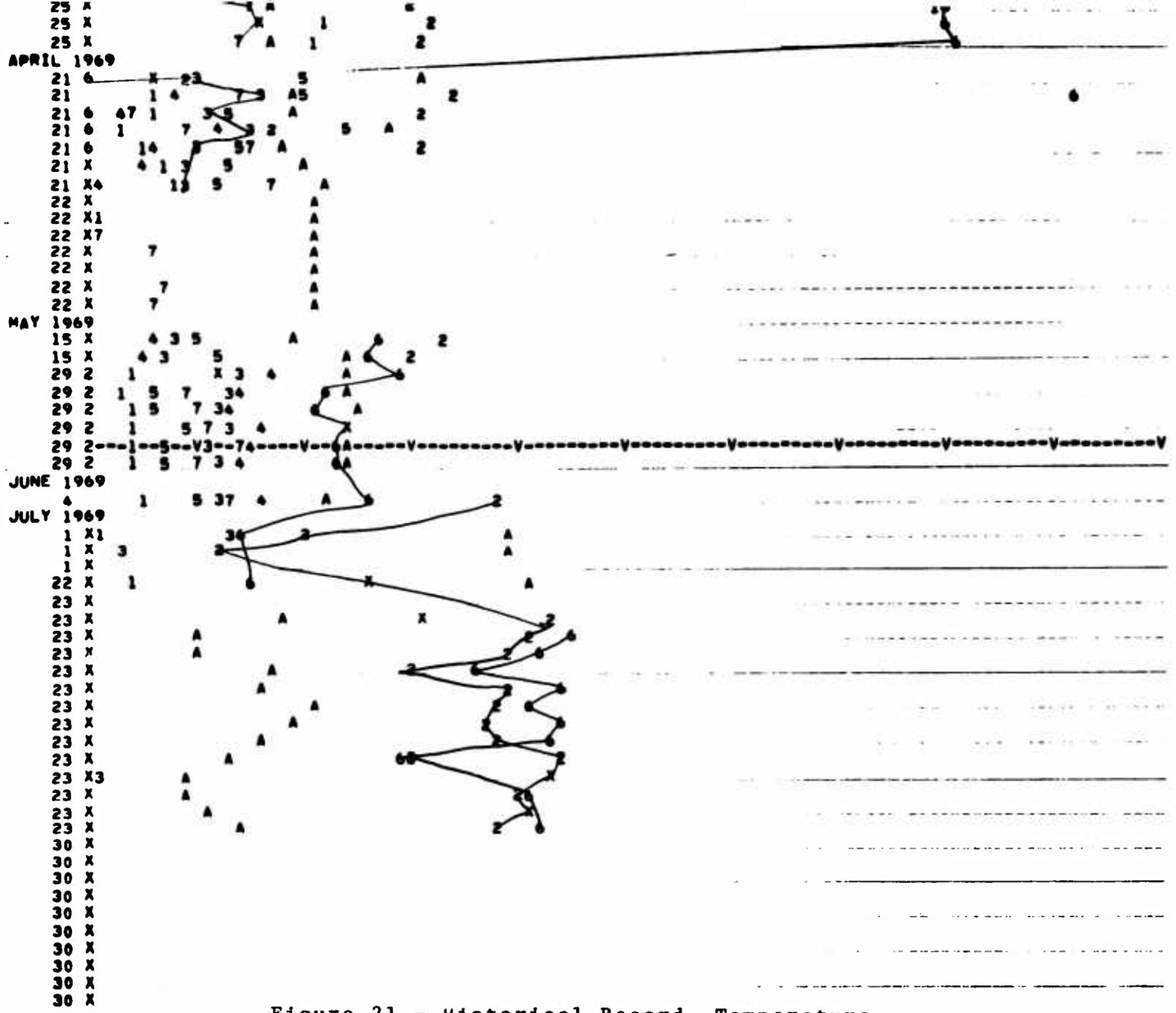

Figure 21 - Historical Record, Temperature - Helicopter 66-16990.

Helicopter Maintenance Record

AIRCRAFT SERIAL NO. 66-16980 DATE February 1969

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
3 Feb	Metal to metal contact push-					
	pull tube and mxing lever	Cleaner around bearing	3:45	1358:45	12	38
5 Feb	Flt #5 engine nose seal leaks					
	rotating beacon inop	Replaced	6:30	1365:15	26	64
7 Feb	Flt #3 input quill seal broken	See quill replacement below	4:45	1374:30	4	71
7 Feb	Main Trans input quill removed	Replaced quill	"	"	"	"
20 Feb	T/R Assy S/N 29-8444, Yoke	Reinstalled HUB SN A3-8923, Yoke				
	SN Q29-8458, GRIP SN Q29-16870 Q29-16869	SN A3-5413 Grips SN A3-6708 A3-6483	1:00	1414:00	7	282
20 Feb	Main driveshaft Insp and Lub due	C/W	"	"	"	"
20 Feb	Eng to xmsn D/S clamp bolts due torque	C/W	"	"	"	"
20 Feb	Lt Aft. xmsn mount separated at center	Checked and found not excessive	"	"	"	"
20 Feb	Red. Mixing lever inboard &					
	outboard bearing worn excessive	Feplaced	"	"	"	"
20 Feb	Red P/c/l ropend excessive	Replaced rod	"	"	"	"
20 Feb	Stablizer bar center frame					
	bearing worn	Replaced bearing	"	"	"	"
20 Feb	White mixing lever in board bearing worn excessive	Replaced bearing	"	"	"	"
20 Feb	Outboard bearing worn excessive in sink elev	Replaced	"	"	"	"
20 Feb	Inboard bearing white sissors worn excessive	Replaced	"	"	"	"
20 Feb	Engine oil drained	Serviced	"	"	"	"

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Figure 22. Examples of Condensed Maintenance Action Form Used to Correlate Downward Changes in Acceleration & Temperature With Aircraft Repairs (Sht 1 of 10).

Helicopter Maintenance Record

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AIRCRAFT SERIAL NO. 66-16990 DATE Feb 1969

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
20 Feb	F.O.D. to several compressional blades	Checked and found serviceable	1:00	1414:00	7	282
20 Feb	90° & 42° G/B drained	Refiled	"	"	"	"
20 Feb	T/R blade tracking due	complted	"	"	"	"
25 Feb	2 to 1 vertical vibration at 80K cruise	Tracked M/R system	7:15	1432:15	11	328

Figure 22 - Continued (Sheet 2 of 10).

Helicopter Maintenance Record

3-1

AIRCRAFT SERIAL NO. 66-16990 DATE March 1969

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
4 Mar	Engine oil low AQAD	Serviced	5:45	1463:00	39	78
4 Mar	Flt 3 EGT reads 600° on cumb out	Within limits	"	"	"	"
5 Mar	Flt 1 EGT stays at 600°C in mor - mal climbs. following indications	Within limits I/A/W tm	2:45	1465:45	2	80
	noted. 30psi torque 91° on 2200'Pressure alt 40°C at 600°EGT					
10 Mar	Xmsn quill seal pouring	See replacement below	2:15	1475:00	4	97
10 Mar	Trans quill seal removed	Replaced	"	"	"	"
17 Mar	Flt #1 sever vib in co-pilots seat	Tracked M/R	3:05	1489:05	12	119
17 Mar	Flt #3 EGT 620° on T/O about 570° cruise	Checked and found to be within limits.	"	"	"	"
22 Mar	EGT exceeds 650°@ 90K 24 lbs torque	Replaced fuel divider	:30	1496:15	4	131
22 Mar	Eng N-1 nozzle worn, burned					
	and cracked excessively	Replaced - see below	"	"	"	"
22 Mar	Nozzle turbine removed SN P5556A	Repl SN 1272	"	"	"	"
22 Mar	Main drive shaft insp & lub due	Relub	"	"	"	"
22 Mar	42° G/B S/N A13-1106 due	Replaced	"	"	"	"
22 Mar	*1 Hanger bearing SN rem	Replaced SN A 20-3641	"	"	"	"
22 Mar	*2 Hanger bearing REm.	Repl SN A20-12090	"	"	"	"
22 Mar	T/R thrust bearing removed	Replaced	"	"	"	"
22 Mr	42° G/B removed	Replaced SN B 13-9876	"	"	"	"
22 Mar	42° G/B oil drained	Serviced	"	"	"	"
22 Mar	90° G. B. mag plug safty cut	Resaftied	"	"	"	"

Figure 22 - Continued (Sheet 3 of 10).

Helicopter Maintenance Record

AIRCRAFT SERIAL NO. 66-16990 DATE March 1969 3:02

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
22 Mar	90° G/B oil drained	refilled	:30	1496:15	4	131
T/R Hub	Assy rem. Hub Assy A3-8923	Replaced HUB SN Q29-5765				
	Yoke A8-5413, GRIPS A 3-6483 and A3-6708 T/R blade SN I3-5205	Yoke SN Q 296201, GRIPS SN Q2912332 and SN Q 29-12333 REpl blds SN				
	SN I3-8052	A3-43860 and A344076	"	"	"	"
22 Mar	Transmission input quill vibration					
	pick up pulled loose	CF	"	"	"	"
22 Mar	Xmsn oil drained	Serviced	"	"	"	"
22 Mar	Bottom red end bearing wornon					
	white damper P/P tube	Replaced	"	"	"	"
22 Mar	Bottom rod fuel bearing worn on					
	red damper p/p tube	Replaced	"	"	"	"
22 Mar	White scissor arm pivot bearing worn	Replaced	"	"	"	"
22 Mar	Red scissor arm pivot bearing worn	Replaced	"	"	"	"
22 Mar	Engine oil drained	Refilled	"	"	"	"
22 Mar	Eng in take filter water logged	cleaned	"	"	"	"
22 Mar	T/R tracking due to complete 300	test flown	"	"	"	"
	hr. insp & component changes					
25 Mar	Xsmn input quill vibration					
	pick up pulled loose	Rewired sensor Insp.	3:45	1504:15	22	172
26 Mar	Inter medium vertical vibration	Adj m/r trim tab & tracked	"	"	"	"

Figure 22 - Continued (Sheet 4 of 10).

Helicopter Maintenance Record

AIRCRAFT SERIAL NO. 66-16990 DATE April 1969

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
4 apr	oil in 90° G/B is turned black	Oil drained and refilled	4:40	1537:10	24	74
9 Apr	Preflight Eng oil leak in vicinity of governor	Not excessive	7:15	1556:25	7	110
24 Apr	Main drive shaft insp & Lub	Comp. insp on A20-33084 & found unser.	4:00	1601:00	15	246
24 Apr	Red Draglink Trunion worn exc.	Replaced trunion	"	"	"	"
24 Apr	L/H rear trans mount sep exc ~~on inside and outside mount sleeves~~	Replaced	"	"	"	"
24 Apr	Eng D/S SN A2033084 Pitted on					
	female and male splines	Replaced	"	"	"	"
24 Apr	Hyd reservoir needs to be svcd	serviced	"	"	"	"
24 Apr	Both M/R dampers low	Serviced	"	"	"	"
24 Apr	Engine oil drained	REfilled	"	"	"	"
24 Apr	T/R Hub Removed SN Q29-5765 ~~Yoke Q29-6261, Grip Q29-12333~~	Replaced A3-12651 Replaced A37917, Repl A3-14736	"	"	"	"
	Grip Q29-12332	A3-14691				
24 Apr	T/R Blade & tracking due	comp	"	"	"	"

Figure 22 - Continued (Sheet 5 of 10).

Helicopter Maintenance Record

AIRCRAFT SERIAL NO. 66-16990 DATE May 1969

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
8 May	Flt 2 oil leak L/Side xmsn from	Tightened plate	:30	1631:05	3	68
	plate on same level as eng D/X					
12 May	White rotating trunnion bearing					
	loose and worn	Replaced	5:45	1641:50	7	38
14 May	Engine leaking excessive oil on	See nose seal repl below	:20	1642:10	2	80
	left side of engine					
14 May	Excessive oil leak on upper	See nose seal repl below	"	"	"	"
	right side of engine at seam					
14 May	Eng. Nose seal leaking exc	Repl. Seal	"	"	"	"
21 May	No buxx	C/F	:30	1663:10	4	102
21 May	Exc EGT 640° at 94%	See engine change	"	"	"	"
21 May	Eng C A removed	Repl Eng C				
	ENG SN LE 10377HFuel Cont AL 30C1 SN 562	SN LE 11342 Fuel Con SN 652AL2092	"	"	"	"
	Oil pump SN Cov, Nozzle turpin SN Cov	Oil Pump SN B4694, nozzle Tur SNP26207A				
	O/S Gov SN642AM1300	O/S Gov SN632AM223				
	G/B assy sn cov	G/B assy X1223				

Figure 22 - Continued (Sheet 6 of 10).

Helicopter Maintenance Record

AIRCRAFT SERIAL NO. 66-16990 DATE June 1969 305

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
2 Jun	Flt 2 engine High side 6600 RPM	RPM adj	7:15	1692:00		
3 Jun	Thrust washer worn excessively	Insp & retorqued red scissor to	4:45	1696:45	17	23
	on red blade	drive link				
6 Jun	T/R Hanger A20-35595) coupling		:45	1707:35	10	45
	inspec & relub due I/A/W ECM#708	C/W				
6 May	Main D/Shaft insp of internal	Insp. ok Completed on SN A20-5080	"	"	"	"
	splines & lub of coupline due					
	I/A/W ECM #708					
6 May	Engire oil drain	Refilled	"	"	"	"
6 Jun	TR Hub Removed SN A3-12651	Repl. Hub with SN Q29-10315				
	Yoke A3-7817, GRIP A3-1457,A3-14736	Yoke SN Q29-12103 Q SN29-20601				
	A 3-14736	Q29-26000	"	"	"	"
6 Jun	T/R blades removed SN A3-43860,	Repl. With SN A3-51737, A3-52238	"	"	"	"
	A3-44076					
6 Jun	Hanger bearing rmvd A20-35595	Replaced SN A20-22821	"	"	"	"
6 Jun	Oil drained in 42° G/B	Refilled	"	"	"	"
6 Jun	oil drained in 90° G/B	Refilled	"	"	"	"
11 Jun	Flt #1 Vert Vib at 80K in flight	Tracked Blds	4:00	1719:15	30	110
12 Jun	Hyd fluid reservoir level low	Reserviced Res	3:25	1728:35	40	181

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Figure 22 - Continued (Sheet 7 of 10).

Helicopter Maintenance Record

AIRCRAFT SERIAL NO. 66-16990 DATE July 1969 3.6

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
1 Jul	Tail Rotor blades tracking out	Comp	:30	1709:10	7	7
1 Jul	Eng D/S A20-5080 Female coupling	replaced D/S SN A20-6655	"	"	"	"
	pitted excessive on forward end					
	Red drive link trunnion worn exc.	Replaced				
	Both M/R Grips drained	Serviced				
1 Jul	Eng . drive removed	Replaced SN A20-6655	"	"	"	"
	Xmsn Scupper drain stopped up	Cleaned	"	"	"	"
1 Jul	Main D/S insp of int. splines	Completed C/W A20-5080	"	"	"	"
	and Lub of Supling in A/W ECM#1C8					
1 Jul	ECM 996, change the lubricant of the transmission 42° G/B 90° G/B & M/R Hub from m il-17808 to Mil-123699 oil	C/W	"	"	"	"
1 Jul	ECM 996 chg the lubricant on 42° G.B & 90° G/B from Mil L7809 to Mil L23699	C/w Mil-L 23699	"	"	"	
1 Jul	Trans oil drained	Serviced with Mil-123699A	"	"	"	"
1 Jul	Eng oil drained	Refilled				
1 Jul	42° G/B oil drained	Refilled				
1 Jul	90° G/B drained	Filled				
1 Jul	T/R Hub REmoved SN Q29-10315 Yoke SN Q29-12103 Grip Q29-26600	//Repl. Assy Hub SN A3-10953 Yoke A3-1701 Grips SN A3-13870				
	and Q29-26601 Tr blades remd	and A3-13852, Repl T/R blades SN A3-43860 A3-44076	"	"	"	"

Figure 22 - Continued (Sheet 8 of 10).

Helicopter Maintenance Record

AIRCRAFT SERIAL NO. 66-16990 DATE July 1969

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
1Jul	Tail rotor retaining nut due retorque at first daily insp	Retorqued	1;45	1800:55	1	8
1 Jul	All rotating bolts due retorque at 1823:40 a/c hours	Retorqued	"	"	"	"
1 Jul	Tailpipe clamps due retorque at 1800:45 a/c hours	Retorques	"	"	"	"
3 Jul	Pre flight 90° G/B oil discolored and bulky	Drained and flushed G/B	6:30	1814:10	56	104
12 Jul	Flt #1. It appears to me that if oil is dirty in 90° G/B which it is, it should have been changed since it take very little longer than making entry in book Please show this since they don't have time to check such.	Changed oil	2:30	1837:25	21	232
15 Jul	Oil in 90° G/B dirty	Flushed and refilled	5:00	1846:55	33	296
15 Jul	Red damper removed SN R 191540	Replaced A20594	"	"	"	"
15 Jul	White damper removed SN A4936	Replaced SN A20514	"	"	"	"
19 Jul	No. 2 hanger assy T/R drive shaft slinging grease	See replacement belwo	2:30	1864:40	19	417
19 Jul	No. 2 hanger assy T/R driveshaft removed SN A20-22826	Replaced SN A20-1866	"	"	"	"
20 Jul	Vert Vib in 60K climb at 80K cruise	Tracked M/R	:30	1865:10	4	421

Figure 22 - Continued (Sheet 9 of 10).

Helicopter Maintenance Record

AIRCRAFT SERIAL NO. 66-16990 DATE July 1969

DATE	FAULTS AND/OR REMARKS	ACTION TAKEN	A/C TIME TODAY	A/C TIME TOTAL	LANDINGS TODAY	LANDINGS TOTAL
Jul 30	T/R Assy REmoved Hub SN A3-10953	Replaced Hub Assy Hub Q29 8332	:30	~~1899:10~~	~~3~~	~~669~~
	Yoke SN A3-6701 Grips SN A3-13870 and SN A3-13852	Yoke Q29-8346 Grips				
30 Jul	90° G/B drained	Refilled	"	"	"	"
30 Jul	42° G/B drained	Refilled	"	"	"	"
30 Jul	Engine oil drained	Refilled	"	"	"	"
30 Jul	Xmsn oil drained	Refilled	"	"	"	"
30 Jul	Eng S/S removed SN A 20-6655	Replaced SN A 20-3589	"	"	"	"
30 Jul	M/Rotor damper splines rusty	Cleaned splines	"	"	"	"
30 Jul	Engine S/Shaft male splines pitted exc. on both ends	See replacement above	"	"	"	"
30 Jul	Request engine alignment due to engine D/Shaft worn exc.	Ck alignment	"	"	"	"
30 Jul	Main D/shaft insp of internal splines & Lub of coupling due	C/W	"	"	"	"

Figure 22 - Continued (Sheet 10 of 10).

OPERATING TEMPERATURE LEVELS

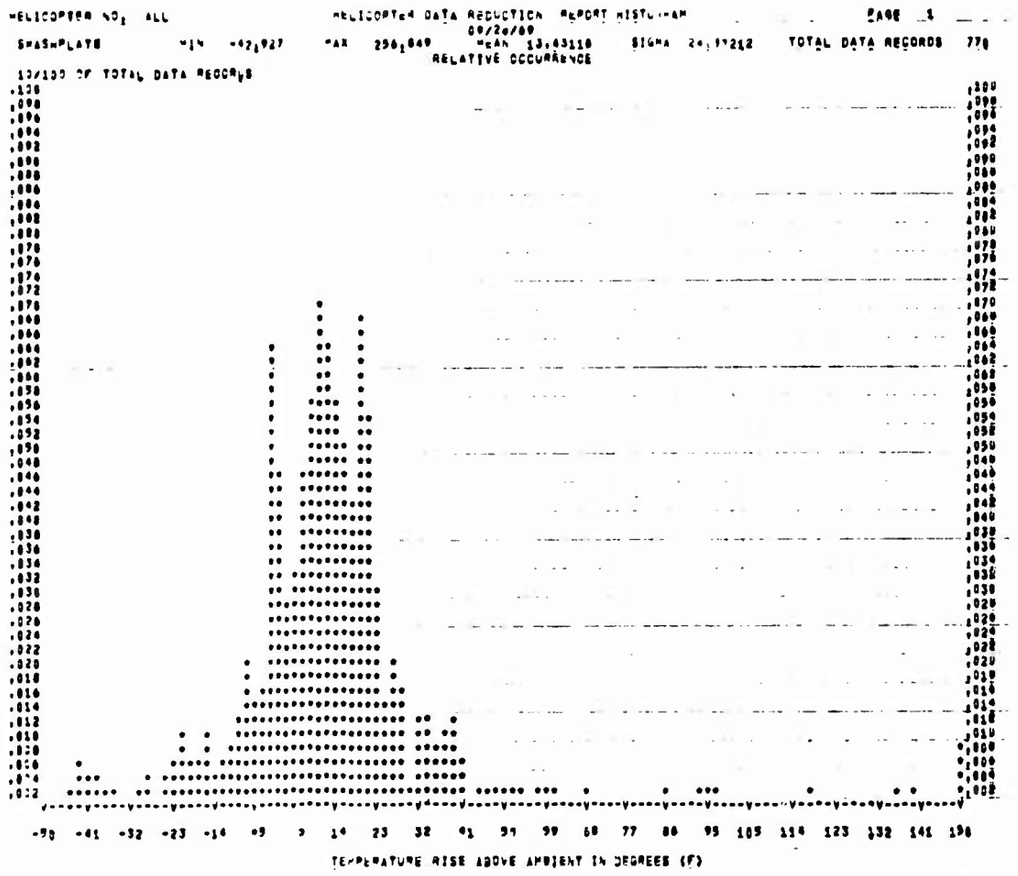
The behavior of the operating temperature levels as a rise above ambient is best determined by reference to the histogram report. The individual aircraft histograms are included in that report as well as are the composite histograms (see Figure 23). The means for the individual aircraft serve as convenient reference levels. The large sigma indicates a large variation about the mean. Inspection of the individual aircraft histograms shows that there is a tendency for the temperature readings to form into discrete groupings.

TEMPERATURE DATA ANALYSIS PROCEDURE

Table VI shows both the histogram report (see Figure 23) mean rise above ambient and the estimated maximum rise above ambient observed from the historical data report. Figure 24 is an example of a historical data report on temperature for one helicopter. The histogram composite mean for each location is given in order to orient the observer when he examines the individual means. It can be seen from Table VI that a much closer maximum operating temperature limit is possible for a particular aircraft if it is tailored to that aircraft rather than when it is set to a limit that is satisfactory for all aircraft.

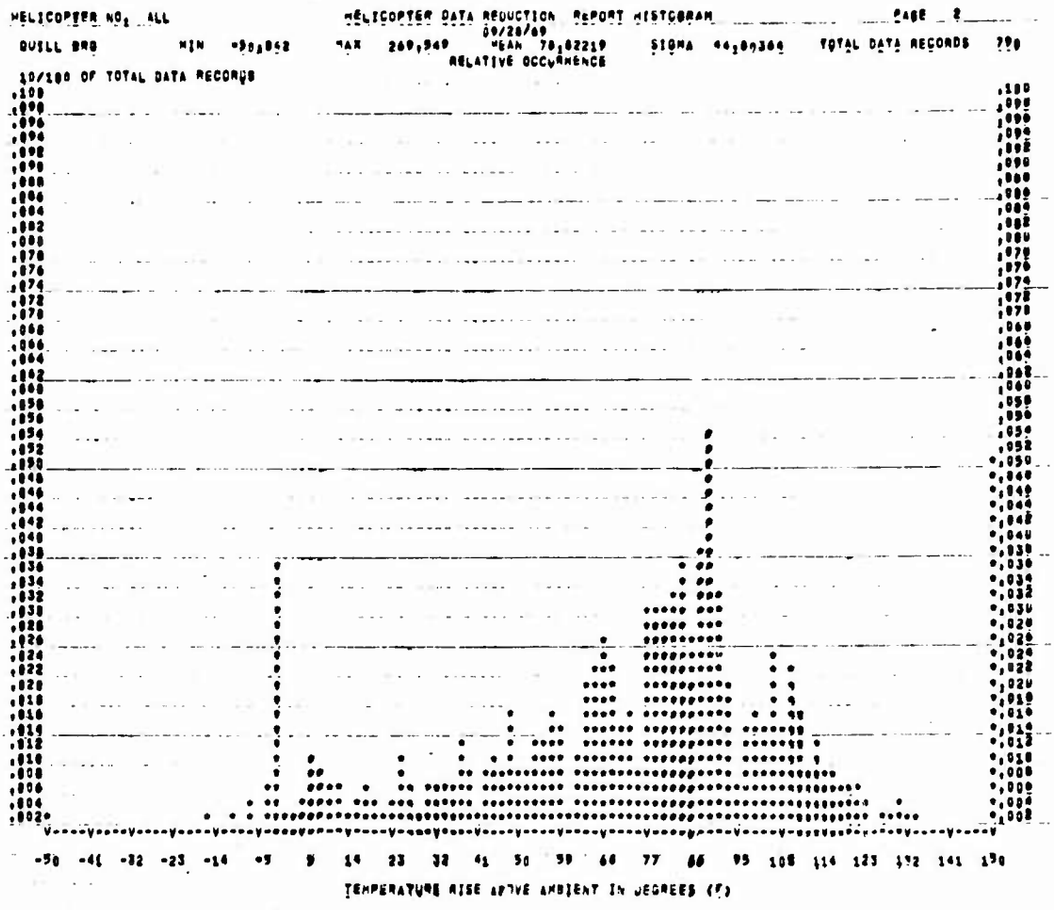
The historical data on temperature for each aircraft were analyzed in the same manner as were the historical data on acceleration. Each deviation from the normal operating level was investigated, and reference was made to the maintenance record, DA Form 2408-13. The results of this analysis are given in Table II. It should be noted that deviations requiring maintenance actions to return the temperature excursions to their normal operating levels were omitted when generating Table VI. The temperature increase due to required maintenance appeared as a sudden and discrete increase, and this increase often came within three to five days prior to ameliorative maintenance actions.

Examples of rises in temperature indicating required maintenance actions within three to five days can be seen by observing the foreshaft temperature on aircraft number 6990. On March 13, 1969, the foreshaft temperature increased from approximately 40°F to approximately 112°F above ambient; then on March 19, it increased to 230°F above ambient. On March 22, the numbers 1 and 2 tail rotor hanger bearings were replaced. It can be seen that the historical data show a return to normal operating level of 56°F rise above ambient following the maintenance. This normal operating level is shown in Table VI.



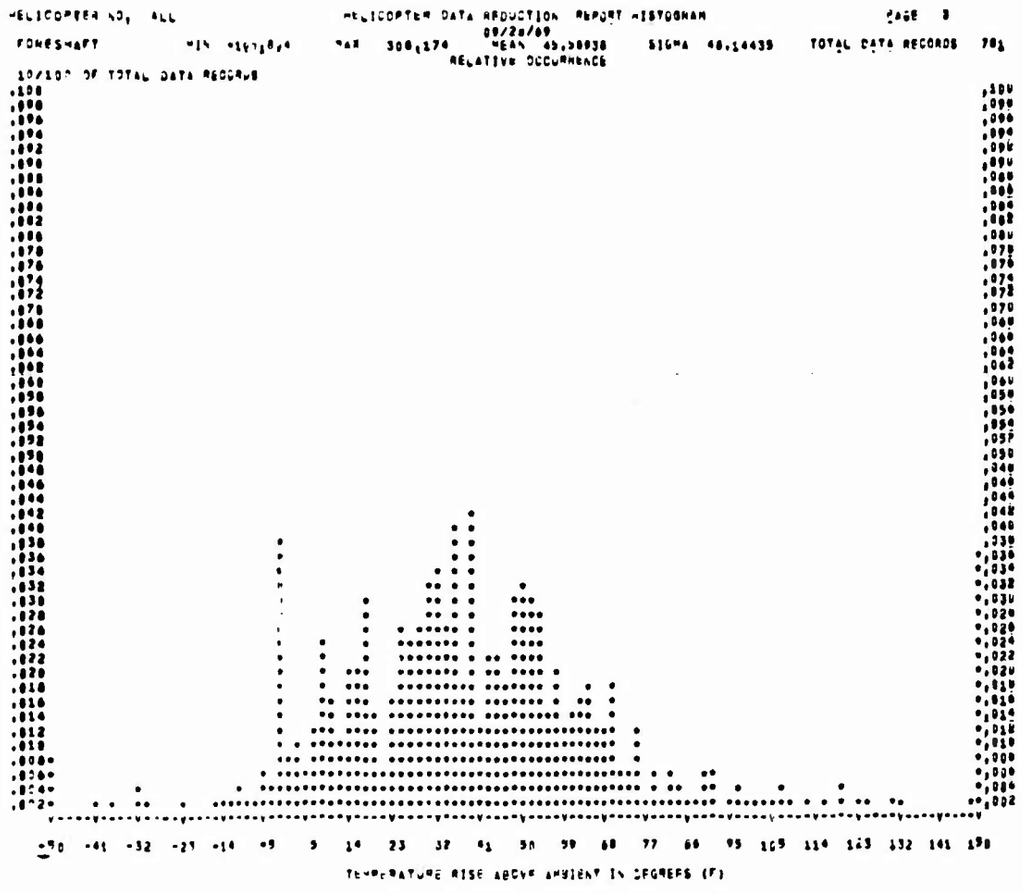
(a) Swashplate Bearing.

Figure 23. Computer-Generated Histograms of Composite Temperature Rises.



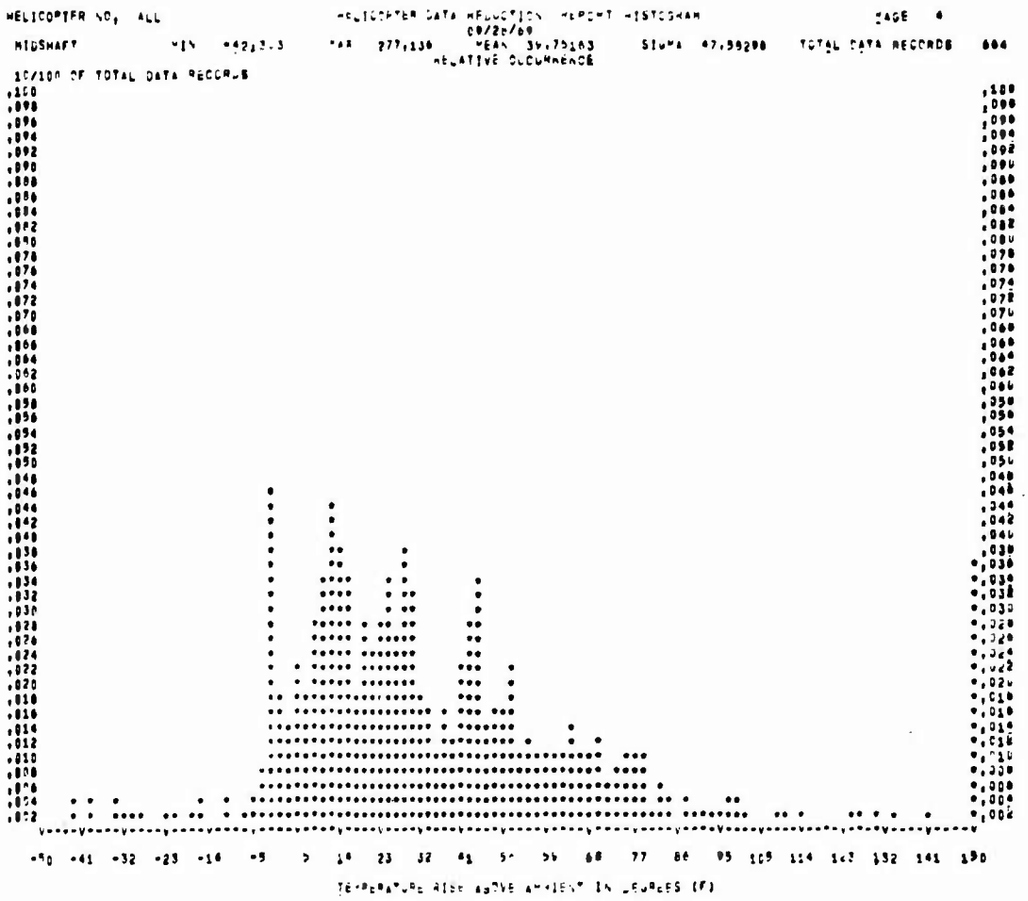
(b) Quill Bearing.

Figure 23 - Continued.



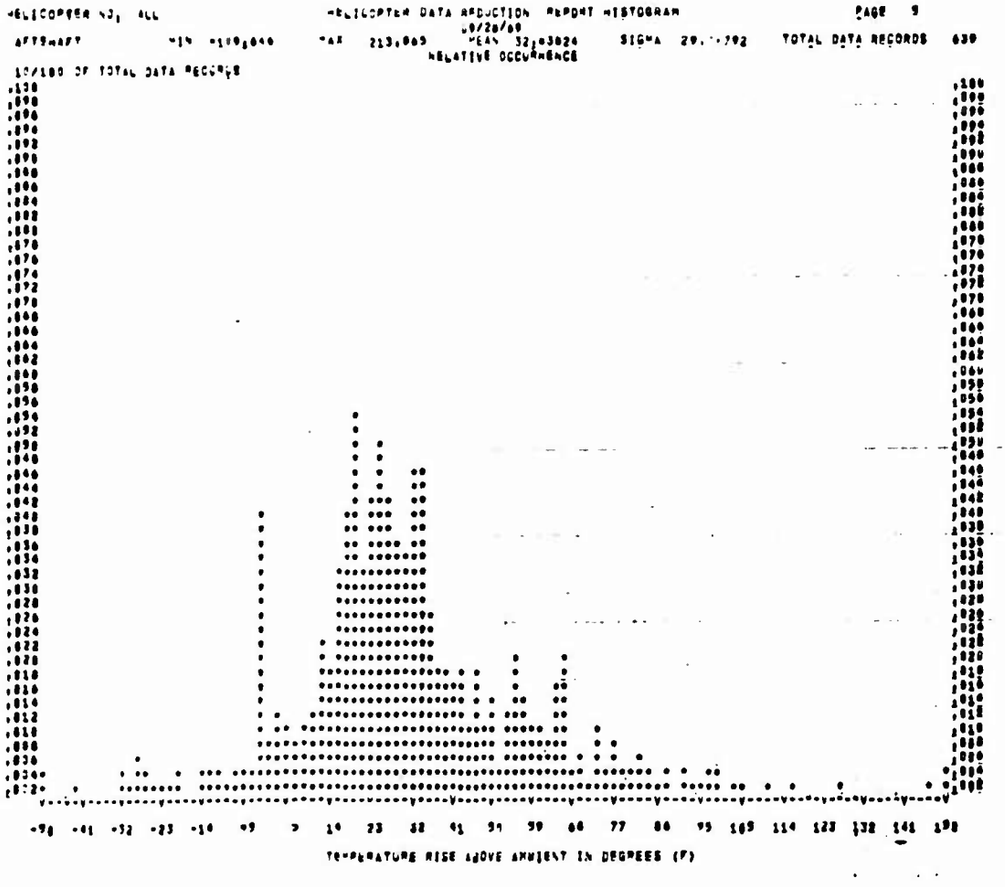
(c) Foreshaft Bearing.

Figure 23 - Continued.



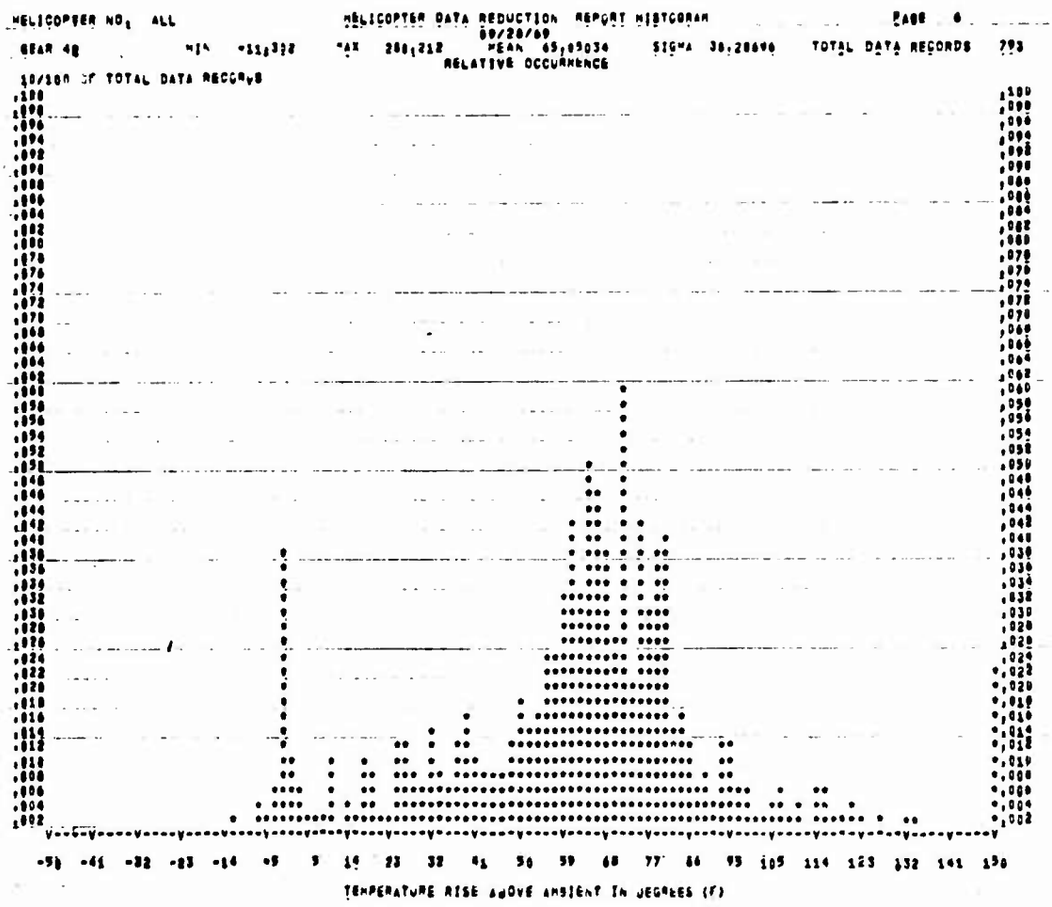
(d) Midshaft Bearing.

Figure 23 - Continued.



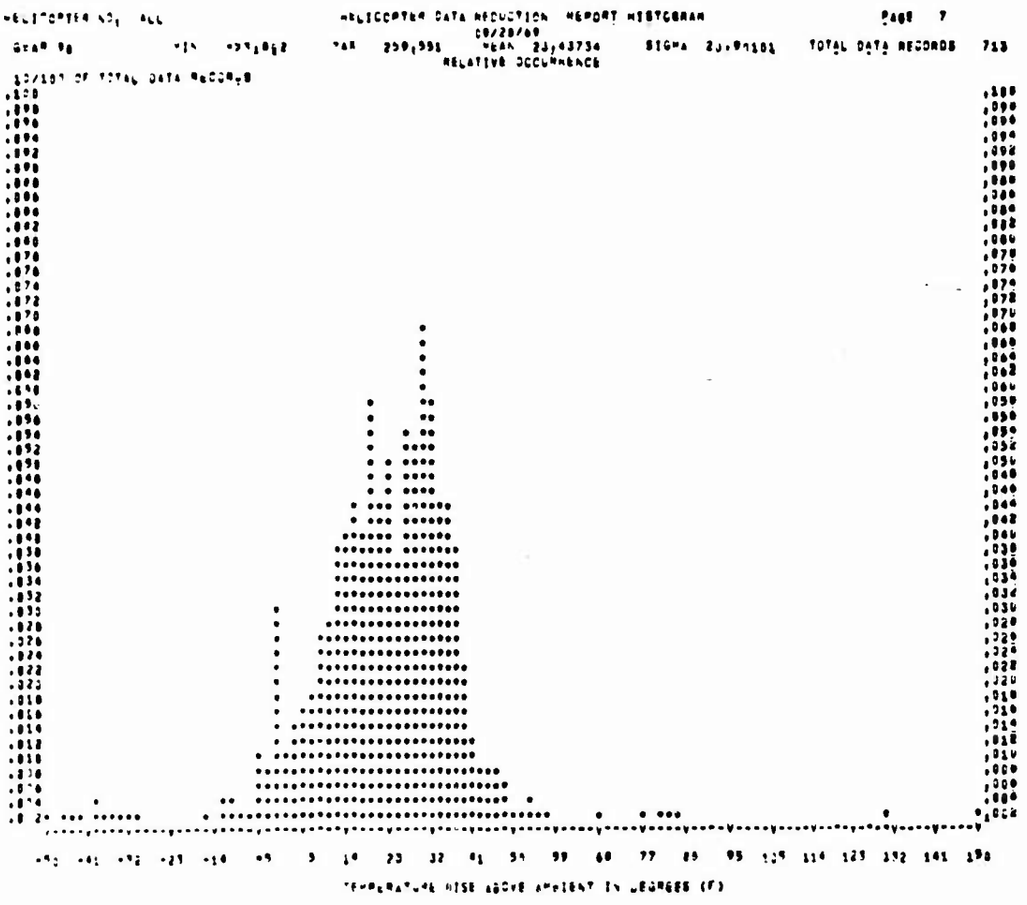
(e) Aftshaft Bearing.

Figure 23 - Continued.



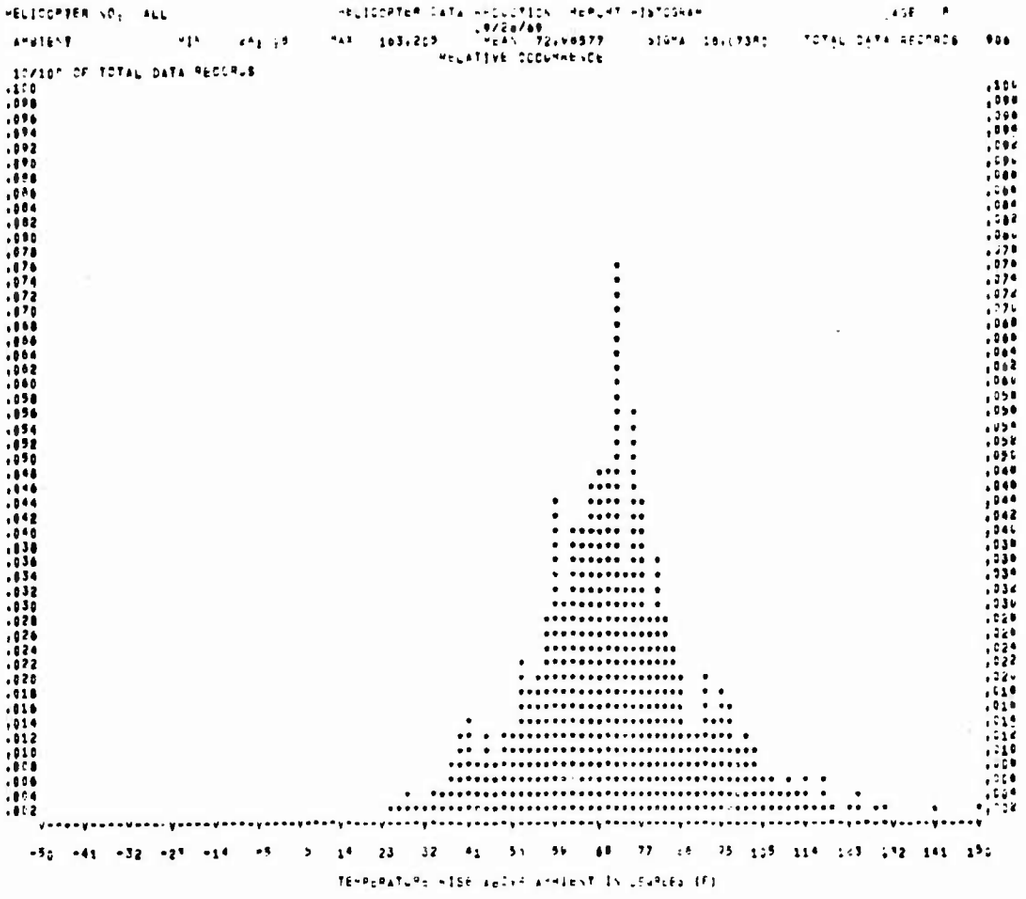
(f) Gear 42 Bearing.

Figure 23 - Continued.



(g) Gear 90 Bearing.

Figure 23 - Continued.



(h) Ambient Bearing.

Figure 23 - Continued.

TABLE VI. MEAN AND MAXIMUM OBSERVED TEMPERATURE RISE IN DEGREES F ABOVE AMBIENT

		Aircraft Tail Numbers											Composite Mean[6]	Temp Max Limits[7]
		0025[1]	0034	1050[2]	9750	9758	6960[3]	6969	1075	9789	6990	9898	0099	
T1 Swashplate	HGM[4]	15.6	22.2	42.9	9.1	13.2	7.8	-2.0	0.6	19.1	13.5	19.1	13.4	13.4	45
	HCAL[5]	40	42	20	28	22	20	16	8	42	26	28	36		
T2 Input Quill	HGM	162.6	93.4	29.1	62.8	94.2	68.8	80.1	59.5	79.9	99.0	74.5	71.7	78.8	100
	HCAL	87	84	84	90	70	87	93	84	100	92	80	84		
T3 Foreshaft Hanger Brg	HGM	16.8	52.1	52.7	19.2	47.7	22.5	34.2	66.3	58.2	48.6	37.2	40.7	45.6	80
	HCAL	30	80	70	60	50	56	70	65	64	56	73	67		
T4 Midshaft Hanger Brg	HGM	61.5	27.7	19.2	38.1	43.4	12.2	36.7	45.1	52.4	70.1	32.1	51.3	39.8	84
	HCAL	45	40	54	60	84	84	50	81	84	42	73	67		
T5 Aftshaft Hanger Brg	HGM	32.7	25.1	34.6	21.0	34.7	12.8	28.3	35.4	44.4	32.1	45.9	35.1	32.8	84
	HCAL	70	40	45	62	78	84	84	80	84	67	73	78		
T6 42° Gearbox	HGM	57.3	61.4	57.3	48.8	75.9	68.8	67.8	54.6	76.5	87.4	64.3	48.2	65.1	90
	HCAL	70	74	62	80	90	84	87	81	84	84	84	64		
T7 90° Gearbox	HGM	25.2	23.2	24.9	10.1	36.0	22.3	10.4	22.4	30.7	28.9	22.6	24.4	23.4	50
	HCAL	20	30	20	28	47	42	34	42	50	43	34	34		

Notes:
1. Due to the early crash of 65-10025, very little data was obtained.
2. The crash and then use of 66-1050 as a gunship limited data acquisition.
3. Due to the limited use of 66-16960, limited amount of data was obtained.
4. HGM = Mean temperature as calculated and printed on histogram plot.
5. HCAL = Maximum temperature observed on historical records below which maintenance action was required.
6. Calculated mean temperature rise for all measurements of each parameter.
7. Highest value of (5) above observed for all helicopters.

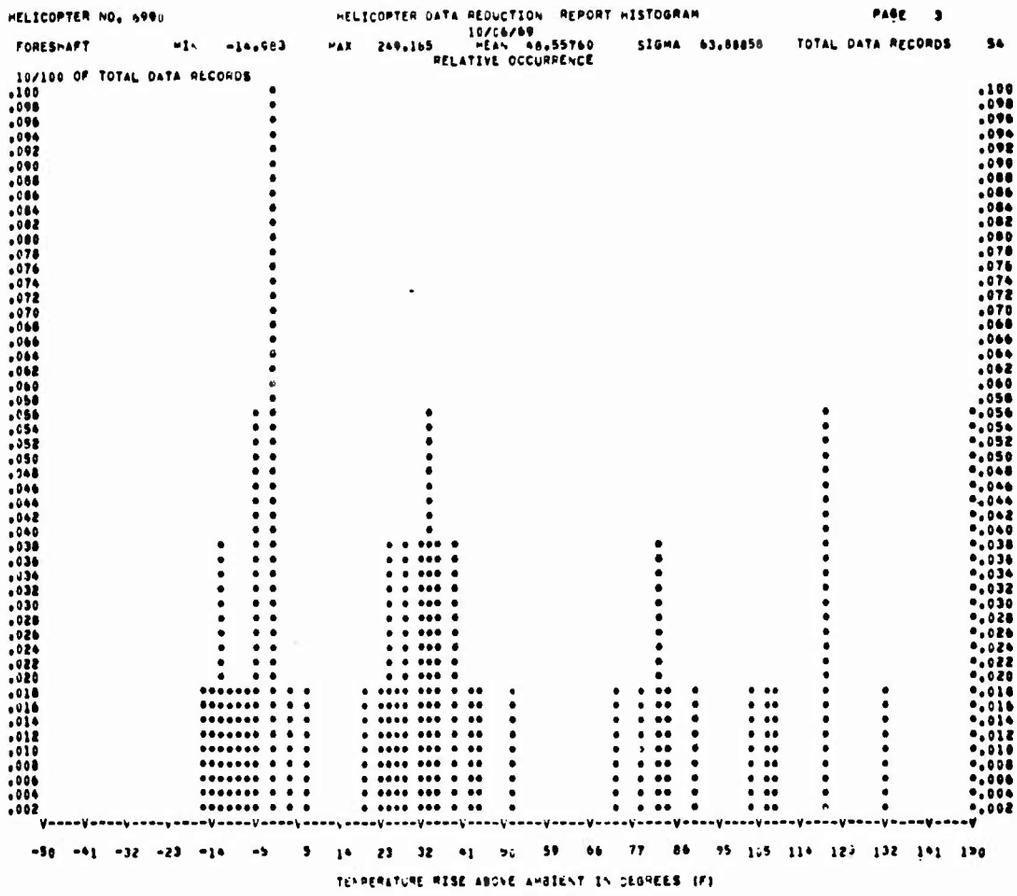


Figure 24. Example of Temperature Histogram for an Individual Aircraft.

By referring to Table VI, one can see that there was a large difference between the normal operating levels of the various instrumented aircraft. For example, excluding the aircraft that crashed and those that were used as gunships, the swash-plate mean rise above ambient ranged from -2° to 22.2°F. Other examples are the mean of the input quill ranging from 59.5° to 99°F. The mean of the foreshaft bearing temperature rise ranges from 19.2° to 58.2°F, the midshaft ranges from 27.7° to 70.1°F, the aftshaft ranges from 21.0° to 45.9°F, the 42-degree gearbox ranges from 28.8° to 76.5°F, and the 90-degree gearbox ranges from 10.1° to 36.0°F. Observations of this general nature indicate that repeatability of a measurement, rather than absolute accuracy, is necessary.

Condition Warning Using Temperature Data

Typical times between detection of increased temperatures and the change of components ranged from about three to five days. This lead in detection-to-maintenance allows time to provide scheduling for aircraft maintenance on a basis that interferes minimally with operations, provided that all helicopters are instrumented continuously. If a warning light came on during flight, an immediate landing and inspection would result in the determination of repair requirements. Thus, immediate indication of overheating components can eliminate major hazards to the aircraft and also possibly permit repair to the component before it is completely destroyed. In Table II are listed approximately 20 maintenance actions that were detected by the temperature sensors. One example of a substantial increase in temperature existing for a long period of time before it was detected by maintenance personnel occurred on May 23, 1969. The number 2 hanger bearing on aircraft 9789 developed a hole in its seal. This time lag, from May 23, when temperature started to increase, until June 14, when it was repaired, might possibly have presented a hazard to the aircraft.

Condition Prediction Using Temperature Data

The temperature measuring array was judged to be not as satisfactory for indicating aircraft condition as the acceleration measurements. The sensors were installed in areas of high maintenance activity, and due to their size, construction, and mounting, they were often destroyed when an associated component was changed and many times when the component was merely inspected. Due to the delays encountered in aircraft availability for the lengthy installation and calibration period, gaps exist in the temperature data that interfere somewhat with data analysis. The historical data report indicates that temperature was a very useful warning device but was only marginally useful in providing indication of component wear-out.

By referring to Table II, it can be seen that the temperature sensors gave a large level change that was useful for indicating the need for corrective maintenance action, but little warning time. One exception is the input quill sensor, which was indicative of seal leaking; therefore, it could possibly be used as a warning of engine-to-transmission drive shaft problems. An example of this may be found in Table II, March 27, 1969, on aircraft number 0034. Here, T2, the input quill sensor, indicated a rise of 131°F. The maintenance action for this effect was the inspection and lubrication of the main drive shaft. This change in T2 for worn drive shafts was also indicated on April 2, 1969, for aircraft number 9789 and on July 23, 1969, for aircraft number 6990.

CONCLUSIONS

ACCELERATION

All of the UH-1D aircraft tested appeared to have similar patterns of acceleration versus frequency, although the operating levels of individual aircraft differed. The particular shape of the general pattern appeared to characterize individual helicopters.

The amplitude of the signal present at the various frequencies tended to increase as time and wear accumulated on the component.

Although the amplitude, or g-level, of the various signals for dangerous flight conditions was not investigated during this study, considerable time between onset of high g-levels and the performance of corrective maintenance seemed evident. More conclusive results on measured accelerations versus wear-out would require instrumentation during a larger segment of the major component lifetime. Assisting in achieving this objective would also be feedback of the results of teardown analysis.

Often, maintenance adjustments and component changes resulted in a change in baseline acceleration. Further, it was possible to recommend individual and composite maximum operating levels for the helicopters at five of the six accelerometer locations. When the measured level exceeded this value, maintenance was performed and always reduced the levels to a value below this recommended maximum operating level. However, the establishment of maximum operating acceleration levels for each helicopter provides a much more sensitive condition indicator than does a maximum operating level for all helicopters.

All of the acceleration channels contained between one and three frequency bands that contained the majority of significant information (refer to Table IV). These frequency bands are not the same on all channels.

Maintenance activity occurred often with no observable effect on measured accelerations.

Ground run-up data appeared to be of a different character and less reliable than in-flight data for assessment of helicopter condition. Hover tests out of ground effect (and of limited scope) did not appear to provide augmented sensitivity to worn components.

The nose channel accelerometer did not reflect any aircraft malfunctions that could be detected by limits that would be applicable to all 12 helicopters.

TEMPERATURE

The temperature sensors usually indicate large level changes in the presence of faulty components. However, these changes occur in advance of imminent component failure, rather than provide an indication of wear-out. T perature sensors do not, therefore, appear to be as useful as elerometers for determining the condition of, or the amou of life remaining in, a component.

Large differences existed between the normal operating temperatures of the various instrumented aircraft. As a result, subtle increases in temperature (when they exist) could not easily be interpreted as impending malfunctions by a single limit system. Further, our experience reveals that even following obvious and suspicious increases in temperature on the historical records of a helicopter, parameter values may not be above those normally existing on another machine. This leads to the conclusion that individual maximum operating temperature limits for helicopters, rather than composite maximum operating temperature limits, should be established. See Table VI.

The swashplate temperature sensor did not provide any indication of wear-out or impending failure. The only temperature sensor that provided some useful diagnostic data was that mounted on the input quill. High temperatures here were indicative of misalignment of the short shaft and/or leakage of the input quill seal.

RECOMMENDATIONS

ACCELERATION

It is recommended that further effort be expended in establishing the relationship between measured accelerations (and temperatures) on UH-1D helicopters and their requirements for maintenance.

Additional wide-band data that are analyzed through 1/3-octave filters, as was done during this program, should be collected if funding is available for an extensive test program.

If a small, relatively economical test program is to be undertaken, the data should be collected from each accelerometer location in groups of broad bands as indicated in Table IV.

Because of the wide variation in acceleration levels between helicopters and the fluctuation in level of an individual helicopter, absolute accuracy of parameter measurement within a diagnostic system can be greatly reduced, with minimum loss in system capability. However, wide dynamic range and repeatability should be maintained at present levels.

Future data collection and analysis programs, large or small, should be designed to last over a period of time that is long compared to the lifetime of the components whose condition is being determined.

Future data collection programs should provide for close coordination between the data collection and processing group and the maintenance crew for selected helicopters. It is preferred that each helicopter in the program be serviced continuously by the same crew, and that feedback on the results of teardown analysis of replaced components be made available on a basis that will permit its use in analysis of the data.

Future programs should include the collection of acceleration data over a range of at least 8 Hz to 16 KHz, as indicated in Table IV.

It is recommended that if a six-accelerometer system is maintained, the nose sensor be relocated on the structural member supporting the cyclic control system. This would likely allow the detection of worn components in the control system sooner than if these accelerations had to be measured from the engine vertical accelerometer (A1), and possible corrective action could be taken to reduce the wear-out of some control system elements due to excessive wear in others.

It is recommended that an accelerometer be located on the swashplate forward horn assembly, where it would be responsive to accelerations in the cyclic control system and in the collective pitch control system. This sensor would simultaneously monitor the condition of the swashplate, which was not effectively monitored by the swashplate temperature sensor.

It is recommended that acceleration measurements be made on isolated components of the UH-1D power train in test stands both before they enter service and after they are replaced for time change or suspected malfunction. The resulting library of data could be very helpful in diagnosing the source of out-of-limit accelerations.

TEMPERATURE

It is recommended that temperature sensors be considered and used more for the purpose of pilot warning than component wear-out.

The fragile metal foil sensors used in the present program were difficult to install and calibrate and should be replaced by small, rugged, high-level precision thermistors.

Temperature sensing on the swashplate should be abandoned, as it is ineffectual in warning or alerting of the condition of that component.

Absolute accuracy of the temperature monitoring system can be reduced considerably from that required of the system used in this program. Repeatability should be maintained.

The cables for sensors on the tail rotor drive system should be insulated by a material that would not be affected by cleaning solvents or by the lubricants used on the helicopters.

In order to reduce a potential hazard to the helicopter, it is recommended that cabling to the tail section be routed through the tail cone rather than alongside the tail drive shaft.

APPENDIX I
HOVER TESTS

DISCUSSION

A special test program was conducted on four aircraft to determine the effect of hovering out of ground effect (at a height of more than 50 feet above the ground). The tests were conducted, and a comparison was made between the individual limits obtained from normal cruising flight as shown in Table III. The objective of the test was to determine the effect on aircraft accelerations and temperatures resulting from the approximately 33% increase in engine torque required for this type of flight.

The normal procedure was to check out the aircraft the night before the tests were run and to make any necessary repairs to the instrumentation system that were needed to ensure good data collection during this one-time test. However, examination of the data reveals that the temperature channels were malfunctioning during the data run, despite the checkout.

TEST SEQUENCE

The hover test sequence required a person on board to operate the data acquisition system. The general procedure was to collect data during straight and level flight 15 minutes after takeoff and to record again just going into hover. This was followed by three recordings taken 3 minutes apart. Another recording was conducted during straight and level flight after completion of the hover tests. In order that the proper identification can be made of various data points, the sequence is listed in Table VII. The temperature data were erratic and undependable despite the fact that the cruise data on these same test aircraft using the same acquisition system were satisfactory.

RESULTS AND CONCLUSIONS

During these tests, engine torque increased from 21 to 22 psi in normal cruise to 31 to 32 psi in hover. The torque rose as soon as a stable hover was maintained and did not increase during the 12-to-15-minute hover period. The EGT showed an increase of approximately 35°F. The engine and transmission oil did not show any discernible change in temperature. Ambient temperature varied from 24° to 26°C during these tests.

TABLE VII. HOVER TEST SEQUENCE

Aircraft Tail No.	Run Sequence	Altitude in Ft. Above N.R	Remarks
9750	Ground Run	--	July 3, 1969
	Ground Run	--	8:15 a.m.
	JGH	20	
	Hover 1	20	
	Hover 2	20	
	Hover 3	20	
	Hover 4	40	
	Takeoff		After 5 min. rest period
	S/L		End
1075	Ground Run		
	S/L		July 14, 1969
	JGH		8:45 a.m.
	Hover 1	50	
	Hover 2	50	T4 open during test
	Hover 3	50	
	Hover 4	50	
	S/L		End
0034	Ground Run		July 15, 1969
	S/L		10:30 a.m.
	JGH		No vibration on T3
			No T3, 4, 5, or 7
	Hover 1	50	No T3, 5, or 7
	Hover 2	50	No T3, 5, or 7
	Hover 3	50	No T3 or 7
	Hover 4	50	No T3
	Ground Run		No temperature
	Takeoff		No T3 or 7
	S/L		No T1, 3 or 7
			End
9789	Ground Run	No T1	July 23, 1969
	S/L	No T1	9:00 a.m.
	S/L		No T1, 4 or 5
	Hover 1	2800	No T1, 4 or 5
	Hover 2	2900	No T1, 4 or 5
	Hover 3	2900	No T1, 4 or 5
	Hover 4	30	No T1, 4, 5 or 7
	Hover 5	45	No T1, 4 or 7
	Hover 6	45	No T1
	Ground Run		No T1, 4 or 7
			End

The values shown in Table III are the operating acceleration levels above which maintenance was required for each aircraft. The historical data report of the hover tests was compared to these levels for the aircraft tested, and it was found that the levels obtained during hover did not vary beyond those for cruising flight. Further, it was noted that very little change took place in the acceleration levels as a result of the considerable increase in power expended (refer to data on aircraft 9750 and 9789). The results of the hover tests appear to show that hover out of ground effect will not set off pilot warnings, and also that this type of flight cannot "sensitize" the monitoring equipment to malfunctions or wear-out.

APPENDIX II
AIRCRAFT FLIGHT HISTORY

Figures 25 through 36 illustrate the rough flight history of all 12 instrumented aircraft. These figures show aircraft flight hours by calendar month along with indication of when changes in major components were made. The figures provide a rapid reference to helicopter condition versus date and show periods of extended maintenance as horizontal lines.

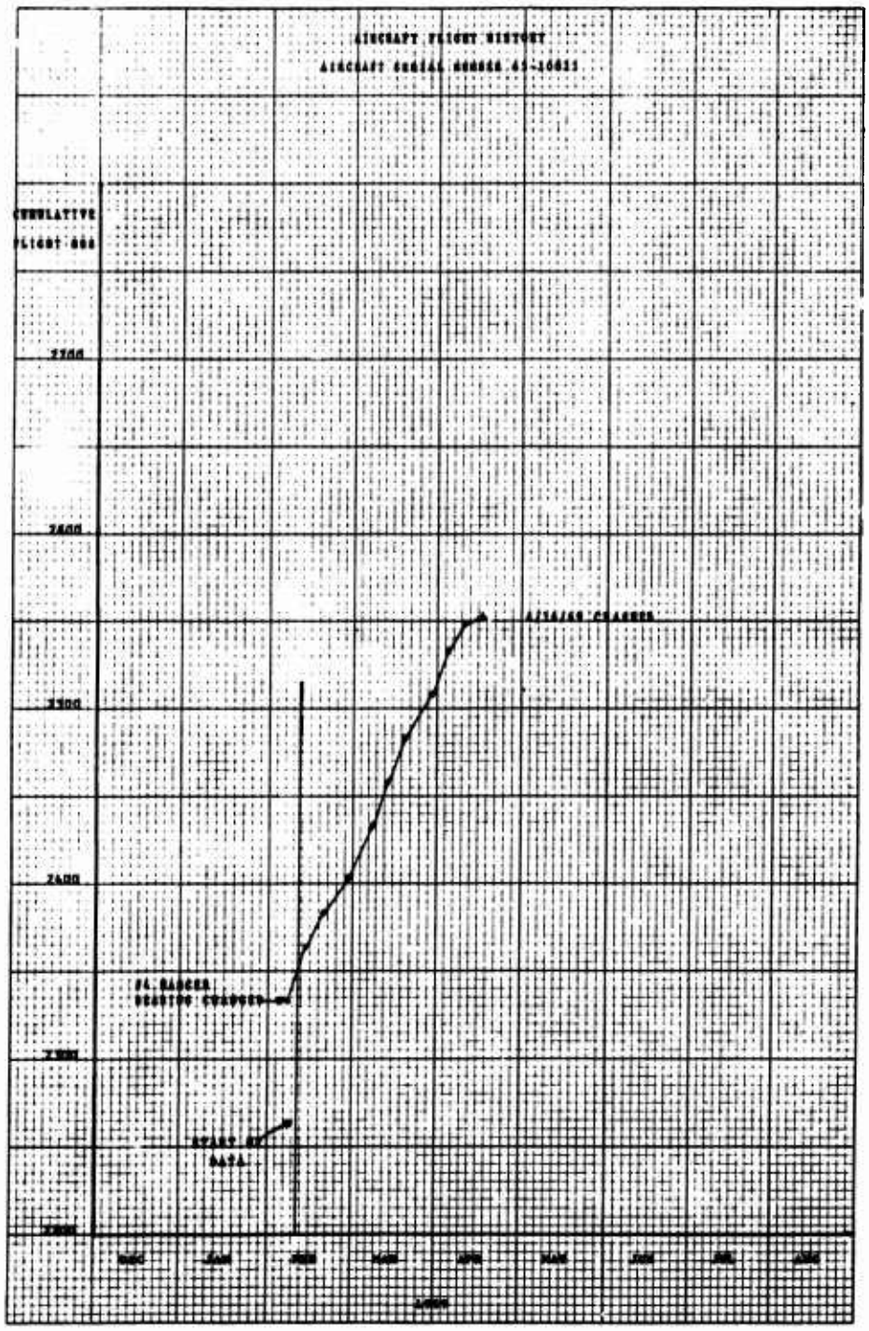


Figure 25. Aircraft Flight History - Helicopter 65-10025.

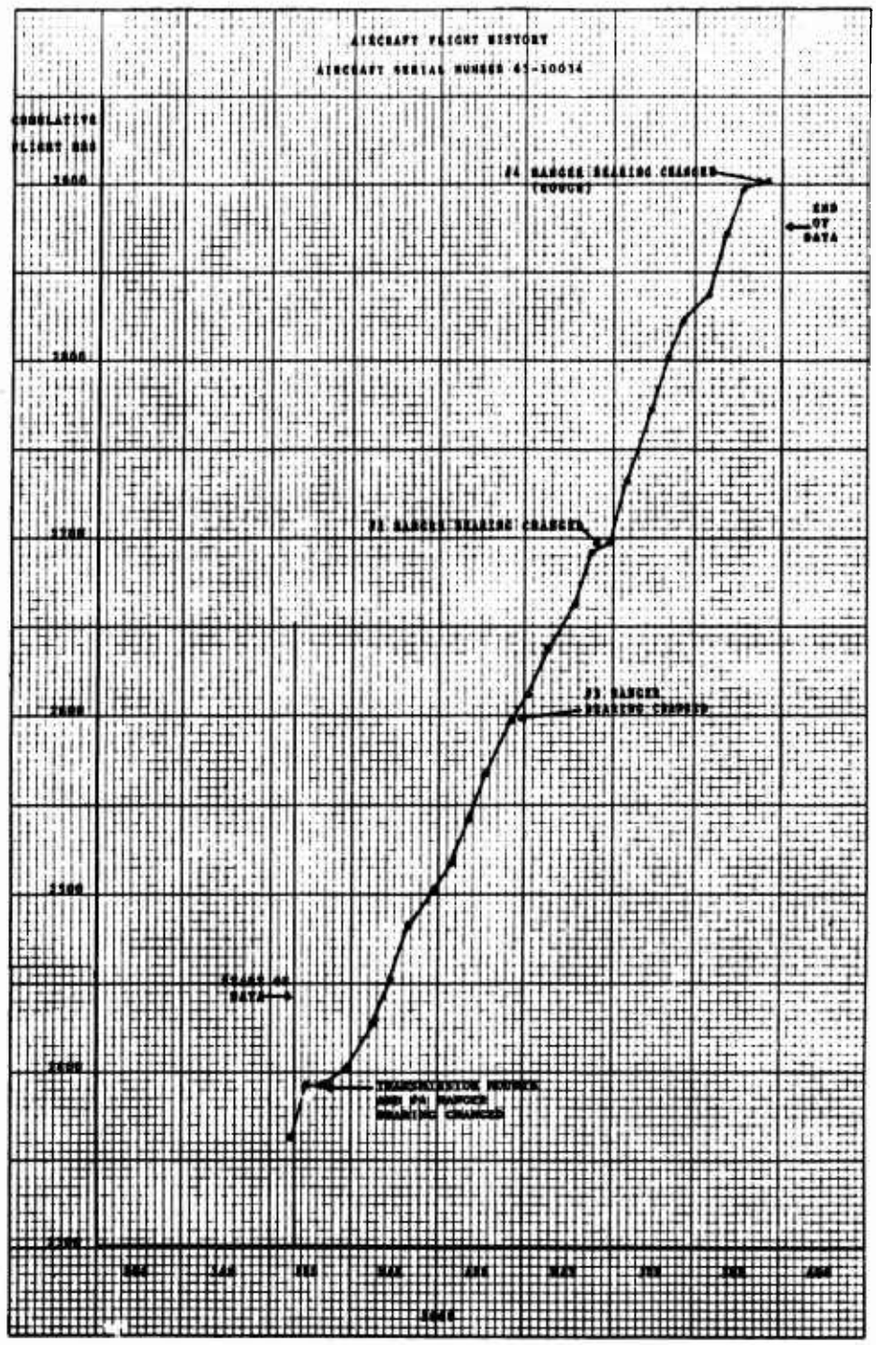


Figure 26. Aircraft Flight History - Helicopter 65-10034.

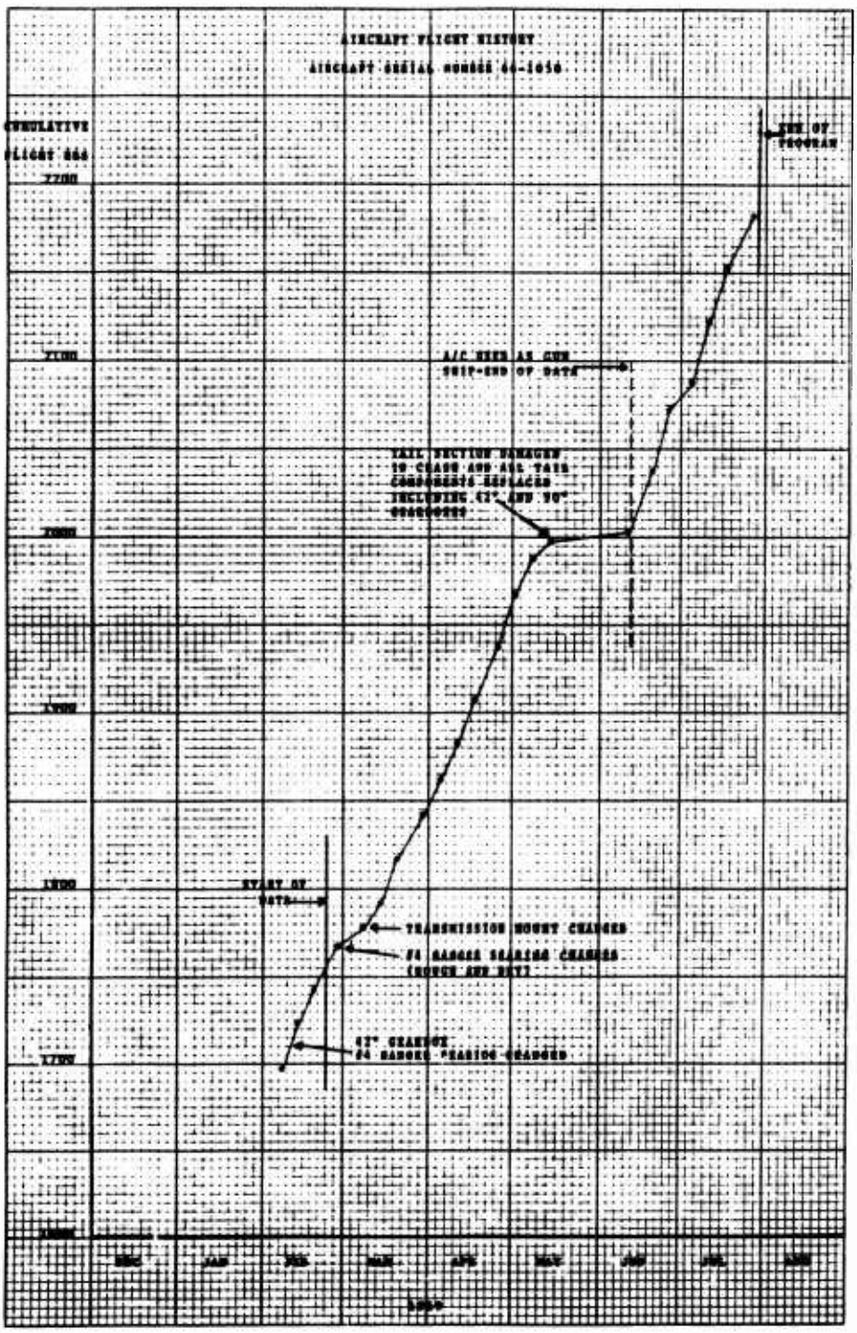


Figure 27. Aircraft Flight History - Helicopter 66-1050.

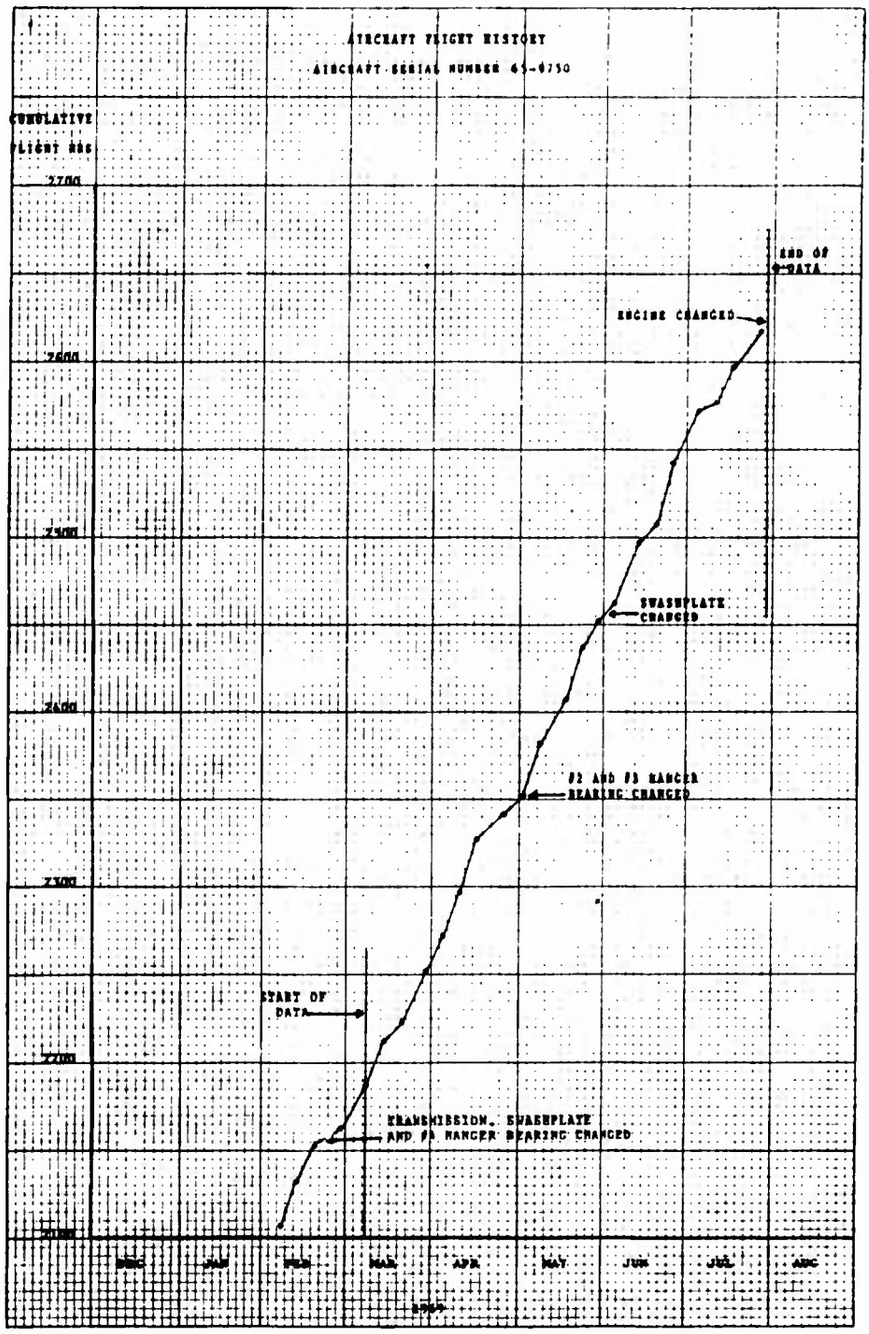


Figure 28. Aircraft Flight History - Helicopter 65-9750.

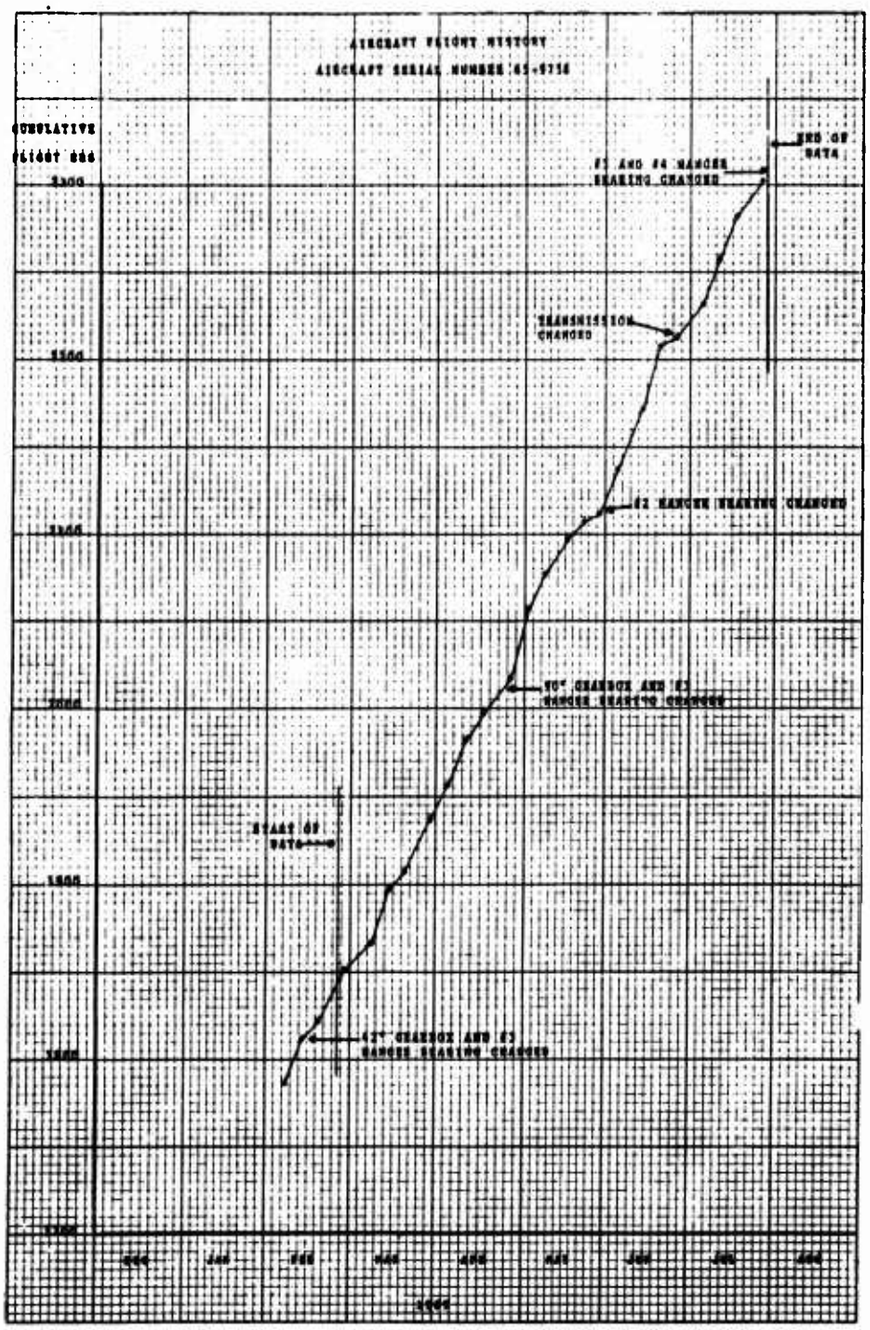


Figure 29. Aircraft Flight History - Helicopter 65-9758.

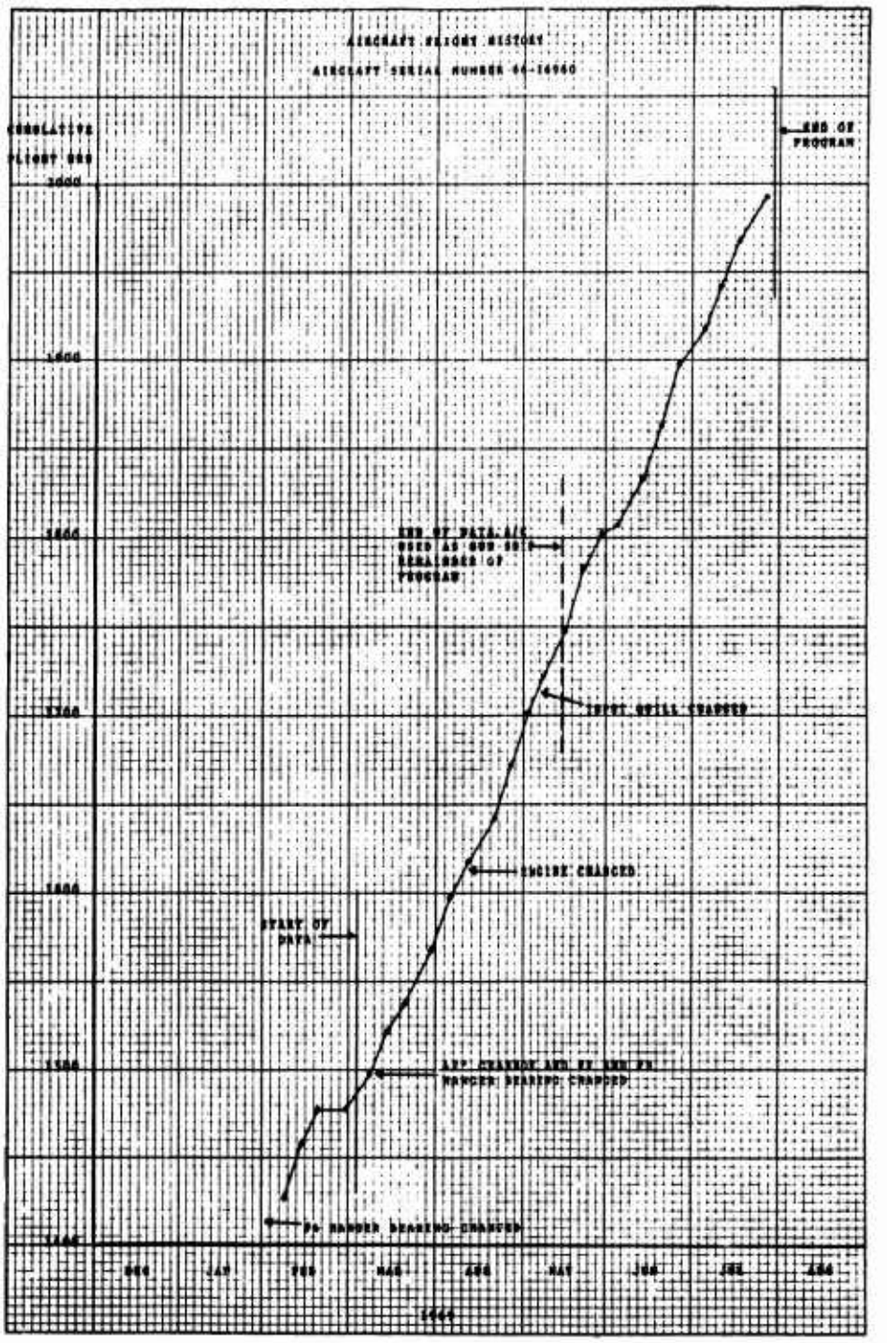


Figure 30. Aircraft Flight History - Helicopter 66-16960.

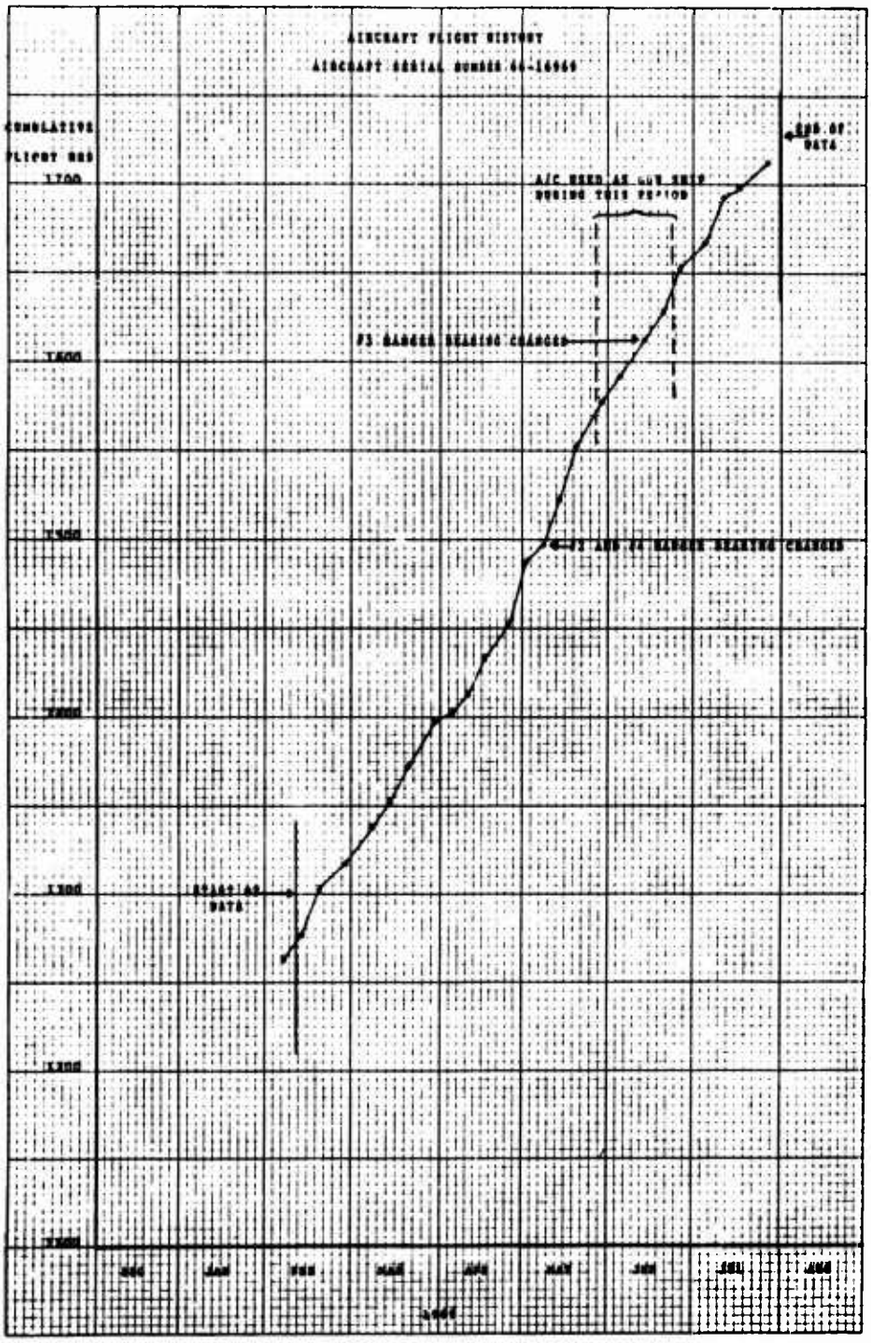


Figure 31. Aircraft Flight History - Helicopter 66-16969.

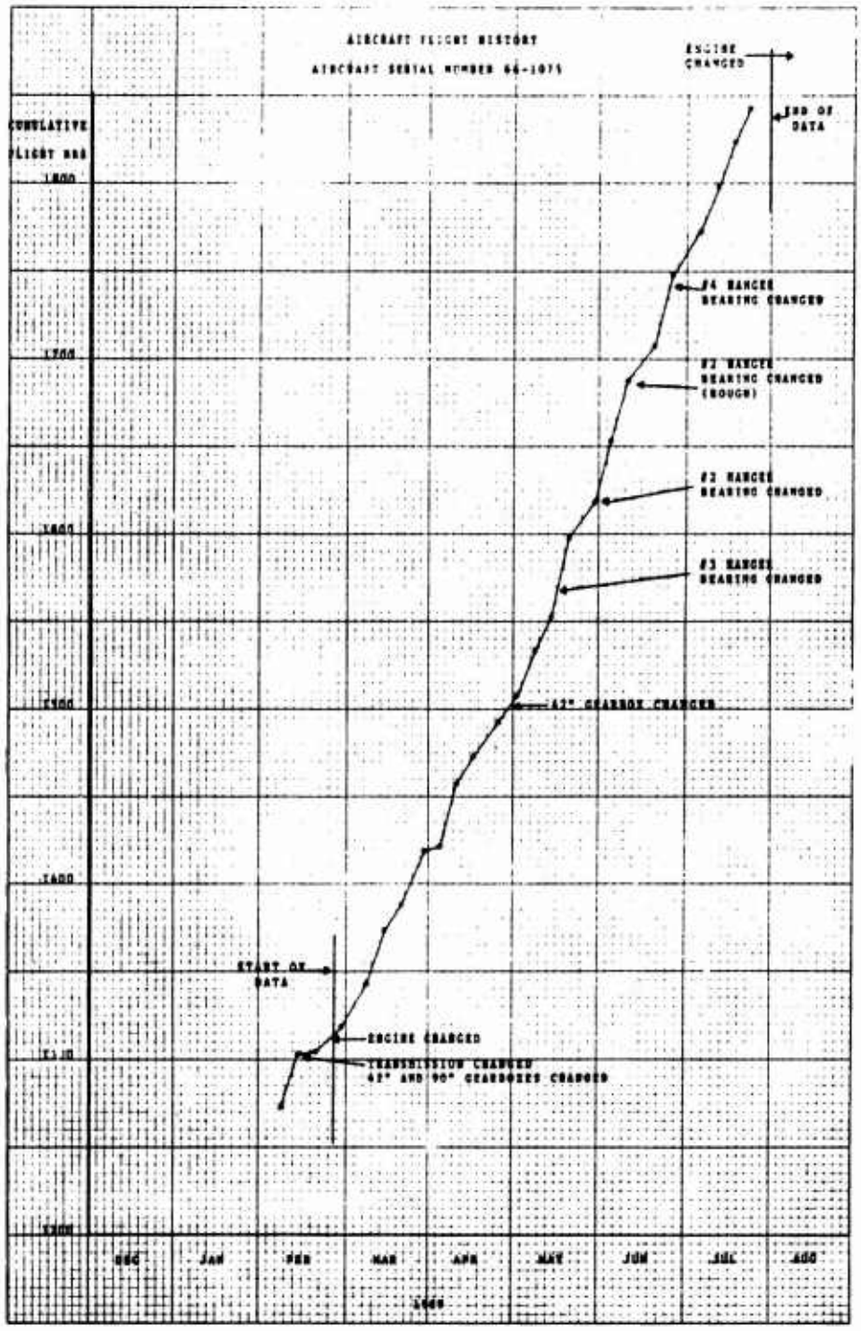


Figure 32. Aircraft Flight History - Helicopter 66-1075.

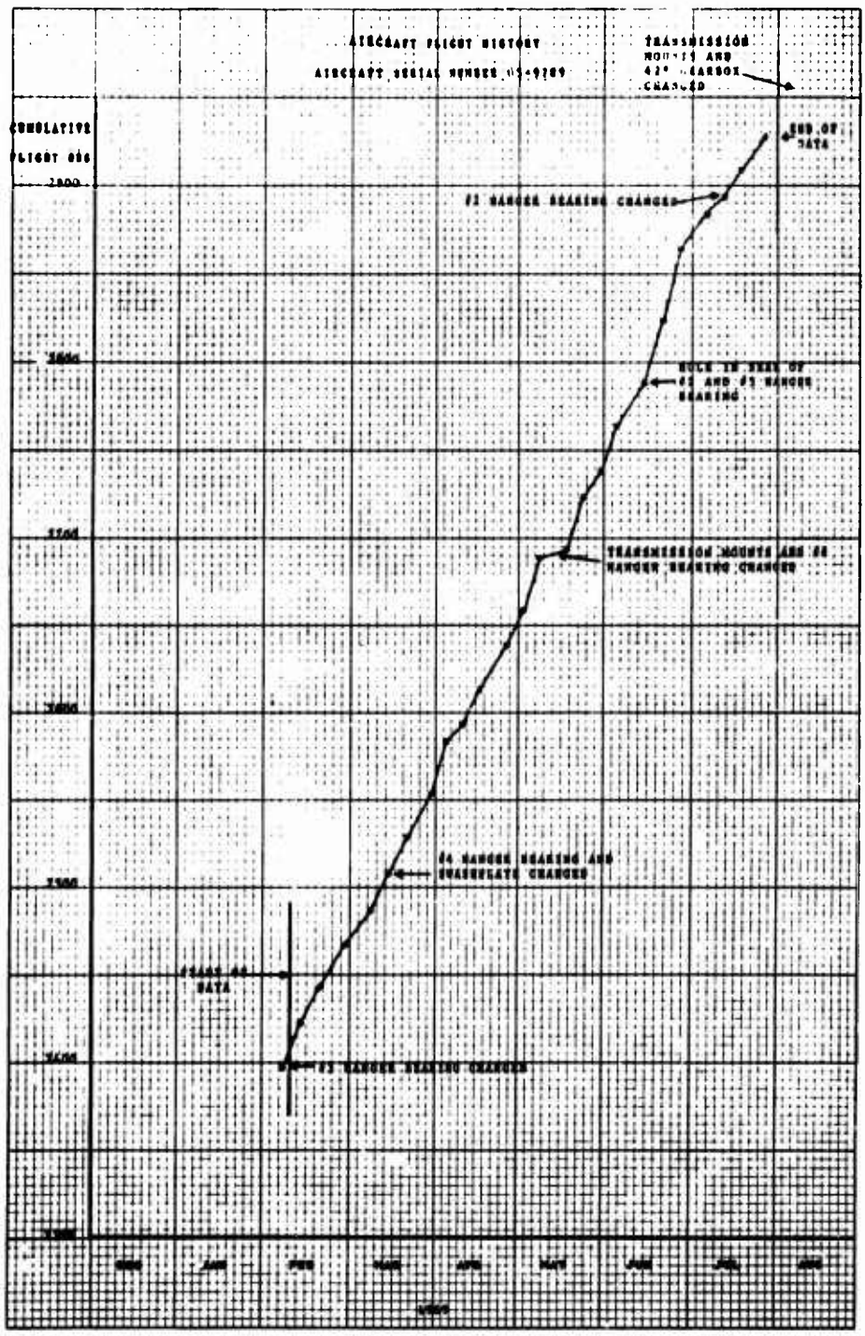


Figure 33. Aircraft Flight History - Helicopter 65-9789.

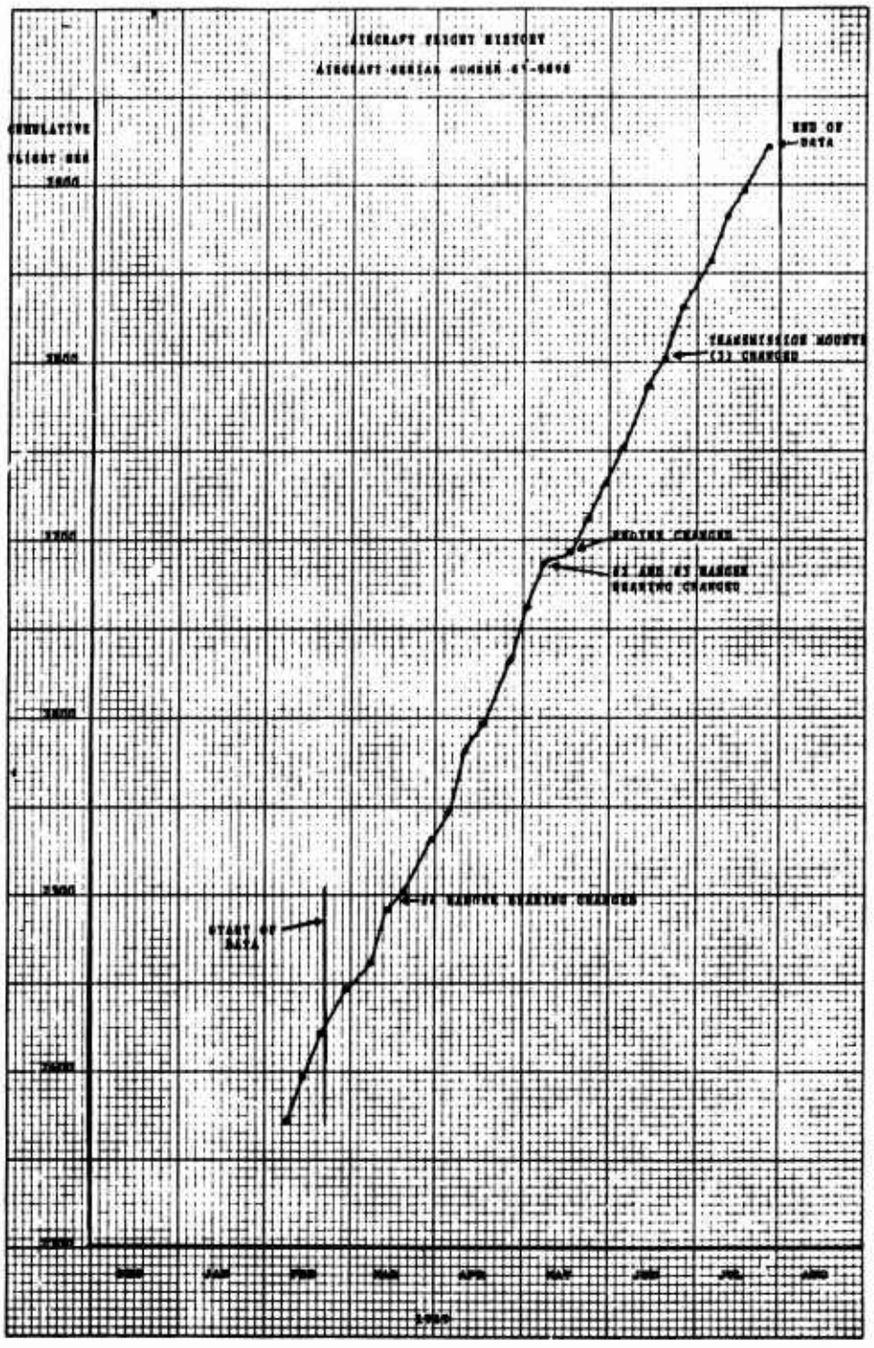


Figure 34. Aircraft Flight History - Helicopter 65-9898.

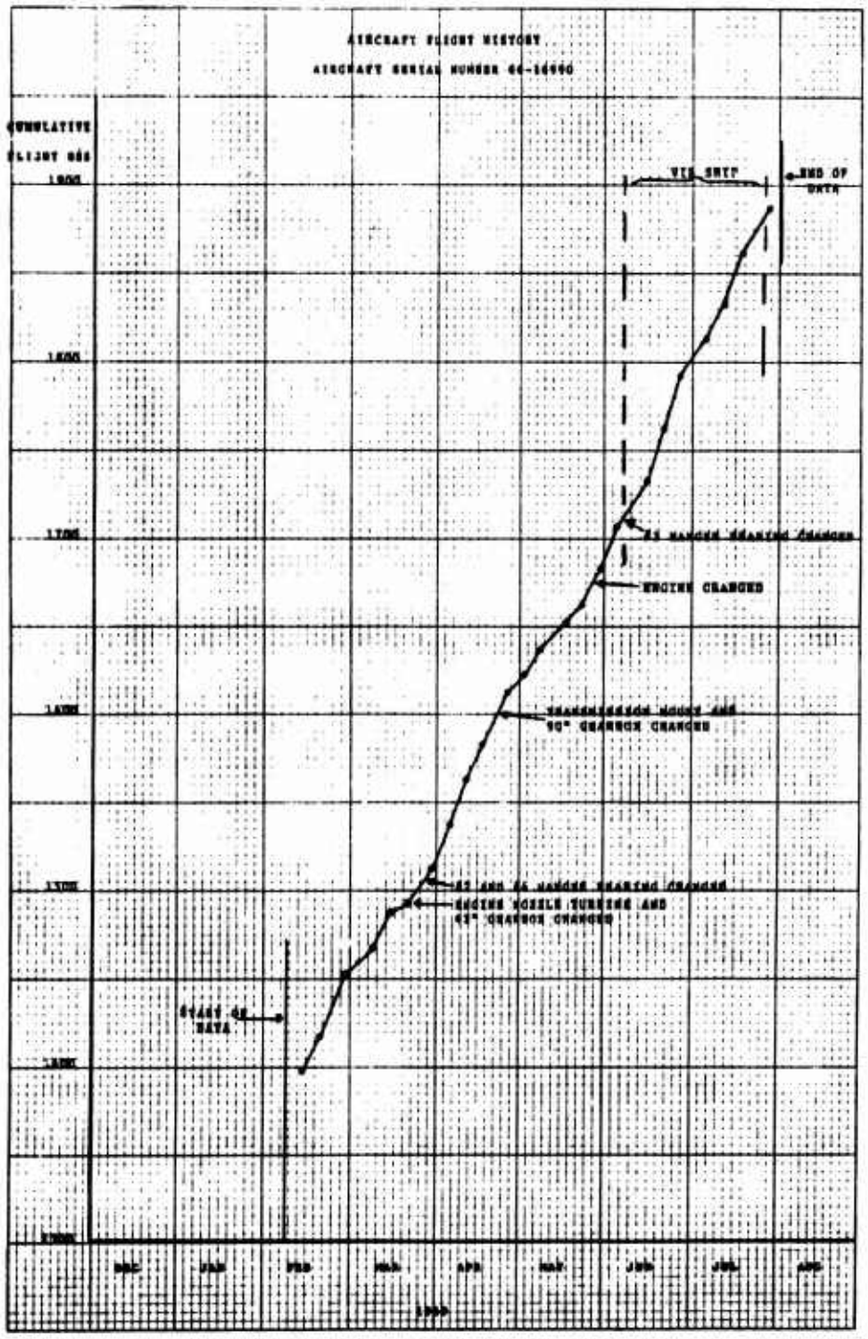


Figure 35. Aircraft Flight History - Helicopter 66-16990.

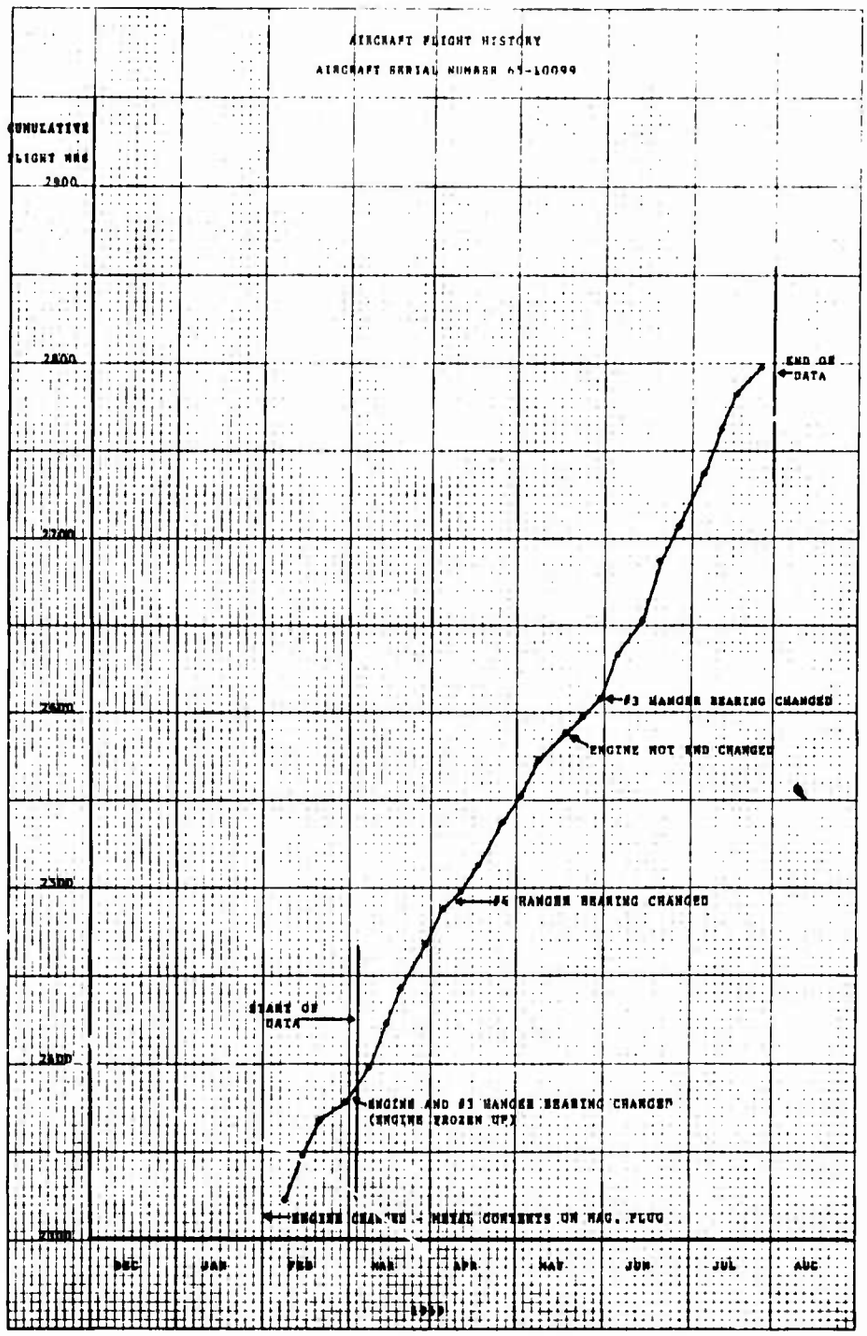


Figure 36. Aircraft Flight History - Helicopter 65-10099.

APPENDIX III
NARROW-BAND ANALOG DATA PROCESSING

Acceleration data from helicopter 9758 were processed on Melpar's 100-channel filter bank. This device contains 100 filter channels spaced at 10-Hz intervals between 1 KHz and 2 KHz. By conventional techniques of dubbing tapes at multiples of the speed at which recording takes place, and by heterodyning the signals with properly chosen reference frequencies and using filters, it is possible to effectively move this filter bank to the desired location within the range of 4 Hz to 20 KHz. At higher frequencies, the fundamental resolution of 10 Hz is not maintained, but when compared with the much coarser 1/3-octave-band filter bank used for the computer analysis, the results may still be considered narrow-band analysis. The 100-channel filter bank is driven in parallel at its input, and the rectified outputs are scanned sequentially by a mercury-jet commutating switch and a filter that effectively removes the fundamental scanning frequency.

The data that were processed were taken from helicopter 9758 before and after a transmission time change. Because the results of this processing procedure are limited to only a single helicopter, and because no subsequent information was available on the condition of the old transmission, it is not possible to arrive at any universally applicable conclusion as to the difference in signature between new and old transmissions as detected at different locations on the helicopter.

NARROW-BAND ACCELERATION ANALYSIS

A narrow-band analysis was performed on one aircraft, number 9758, before and after a scheduled transmission change. There are three significant features to a narrow-band analysis:

1. It identifies discrete bearing and gear-mesh accelerations.

2. It permits identification and observation of behavior of components remote from a sensor (for example, maintenance actions taken on the 42-degree gearbox were identifiable from an accelerometer mounted on the 90-degree gearbox).

3. It does not permit judgment of the efficacy of maintenance actions based on the amplitude of any particular spectral "line" as does wide-band analysis.

Reproductions of Polaroid photographs taken of the filter output when excited from a loop of tape are shown in Figures 37 through 42. Although the gain of the oscilloscope amplifier was varied over different segments of the frequency range displayed, in order to show the structure of the spectrum, the "new" and "old" transmission spectrum photos covering similar frequency bands have identical gains. The responses of the 1/3-octave filters that cover the same frequencies are printed in the historical data report and were used for reference.

Transmission Top - Vertical

The gear-mesh frequencies of the transmission upper section when the input shaft is 6578 RPM have been calculated and are as follows:

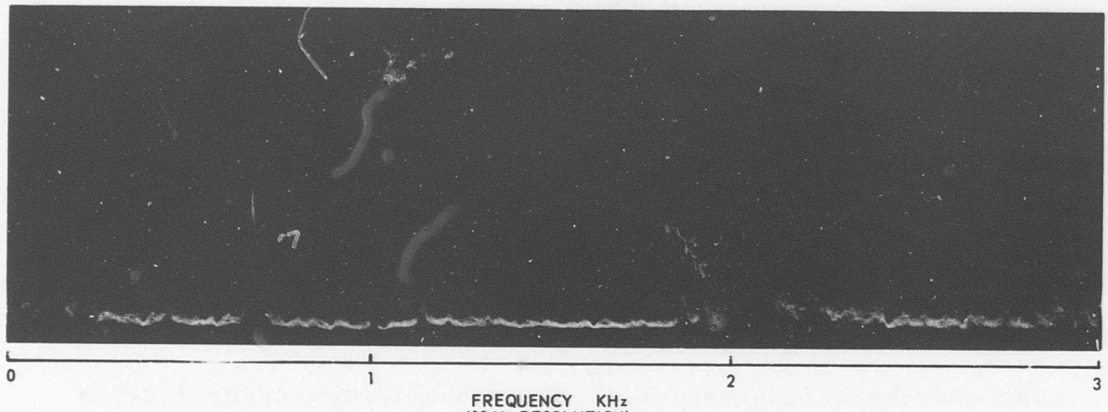
1.	Drive bevel gear (2)	3180 Hz
2.	Generator bevel gear	3180 Hz
3.	Generator spur gear	4496 Hz
4.	Upper section first-stage (sun, planet, and fixed ring gears)	1977 Hz
5.	Upper section second-stage (sun, planet, and fixed ring gears)	640 Hz

The important components of frequencies of the upper section first and second stages include harmonics as well as fundamental frequencies. Within allowable tolerances, the frequency of 667 Hz could be the upper section second-stage sun, planet, and fixed ring gear-mesh frequency. The 1977-Hz signal is that of the upper section first-stage gears. The 2200-Hz signal could have been generated by some of the 15 bearings in the upper section. This frequency is very near that which would be generated by a rough spot on the ball of a generator-driven gear bearing. The higher frequencies show some peaks also, which could be caused by bearing roughness.

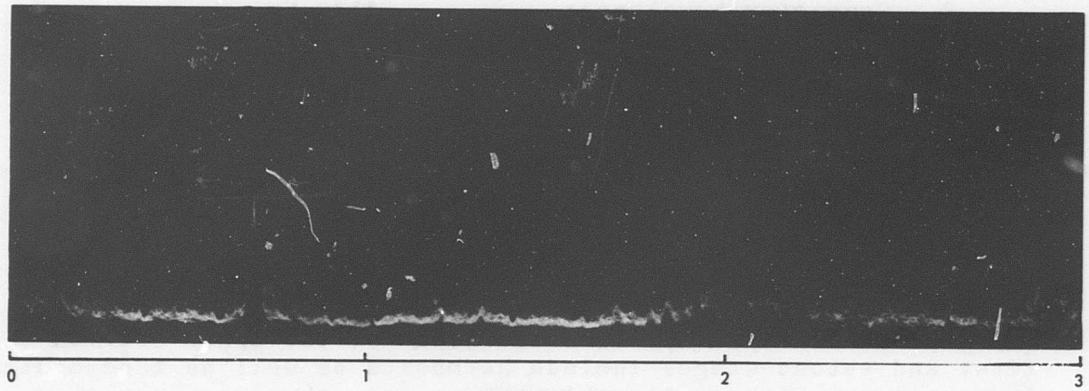
Transmission Bottom - Vertical

The gear-mesh frequencies of the transmission lower section, when the input shaft is driven at 6578 RPM, have been calculated and are as follows:

1.	Drive and driven spur gears	2820 Hz
2.	Drive bevel gear	1857 Hz

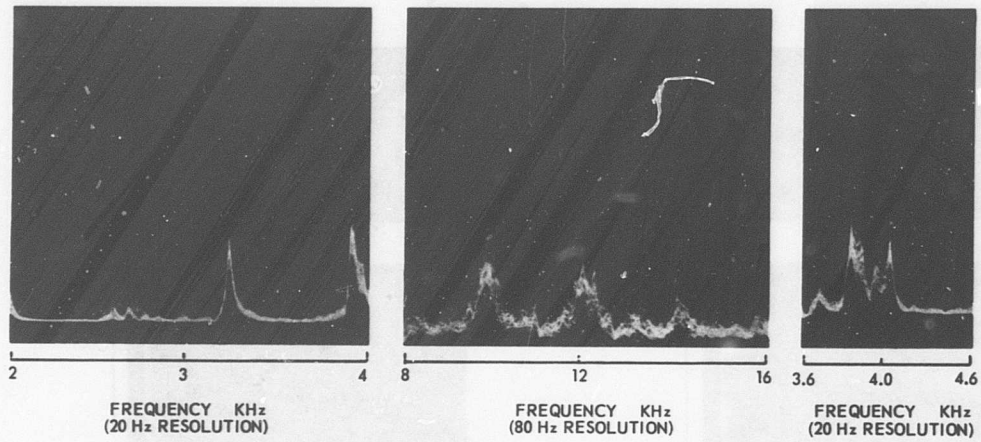


HIGH TIME TRANSMISSION–TRANSMISSION TOP



ZERO TIME TRANSMISSION–TRANSMISSION TOP

Figure 37. Comparison of Narrow-band Spectra - New and High Time Transmission - Transmission Top Sensor 4 Hz to 3 KHz.



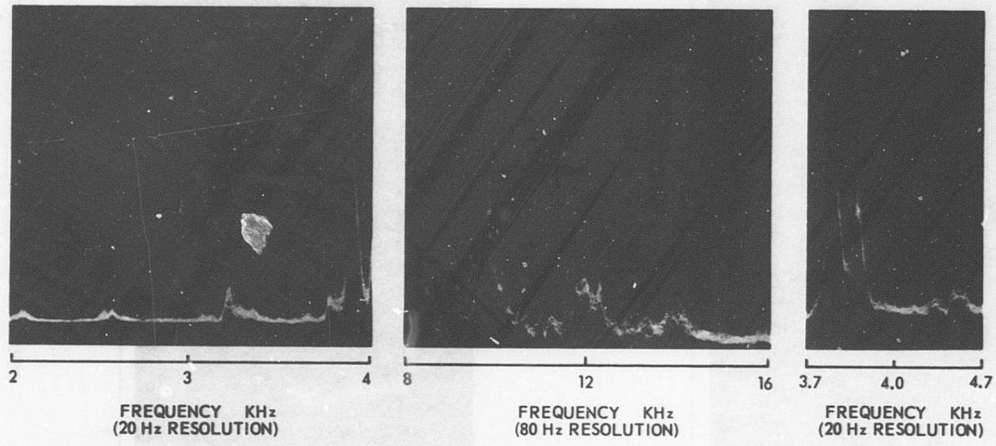
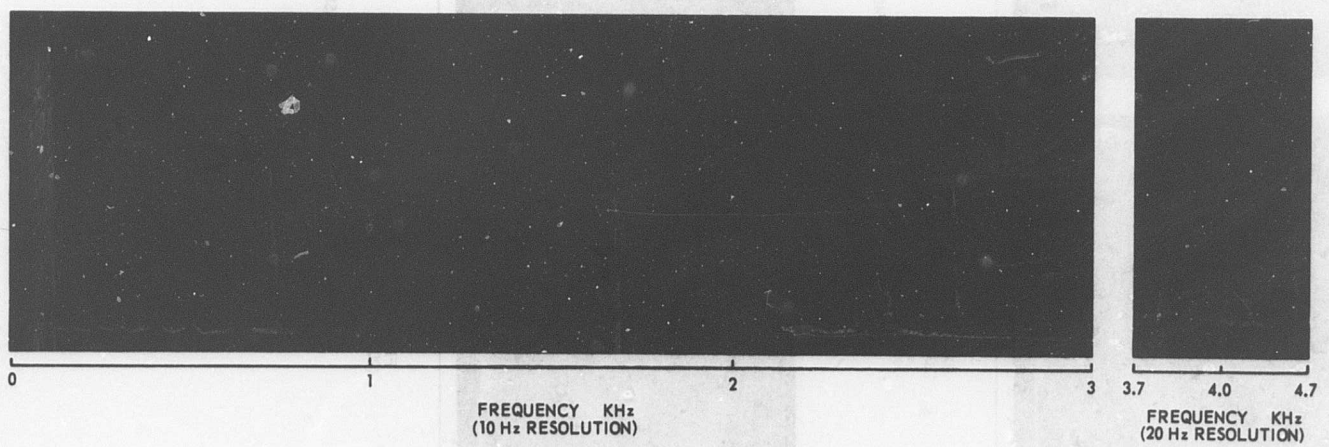


Figure 38. Comparison of Narrow-band Spectra - New and High Time Transmission - Transmission Top Sensor in Segments From 2 KHz to 16 KHz.

HIGH TIME TRANSMISSION–TRANSMISSION BOTTOM



ZERO TIME TRANSMISSION–TRANSMISSION BOTTOM

Figure 39. Comparison of Narrow-band Spectra - New and High Time Transmission - Transmission Bottom Sensor in Segments From 4 Hz to 4.7 KHz.

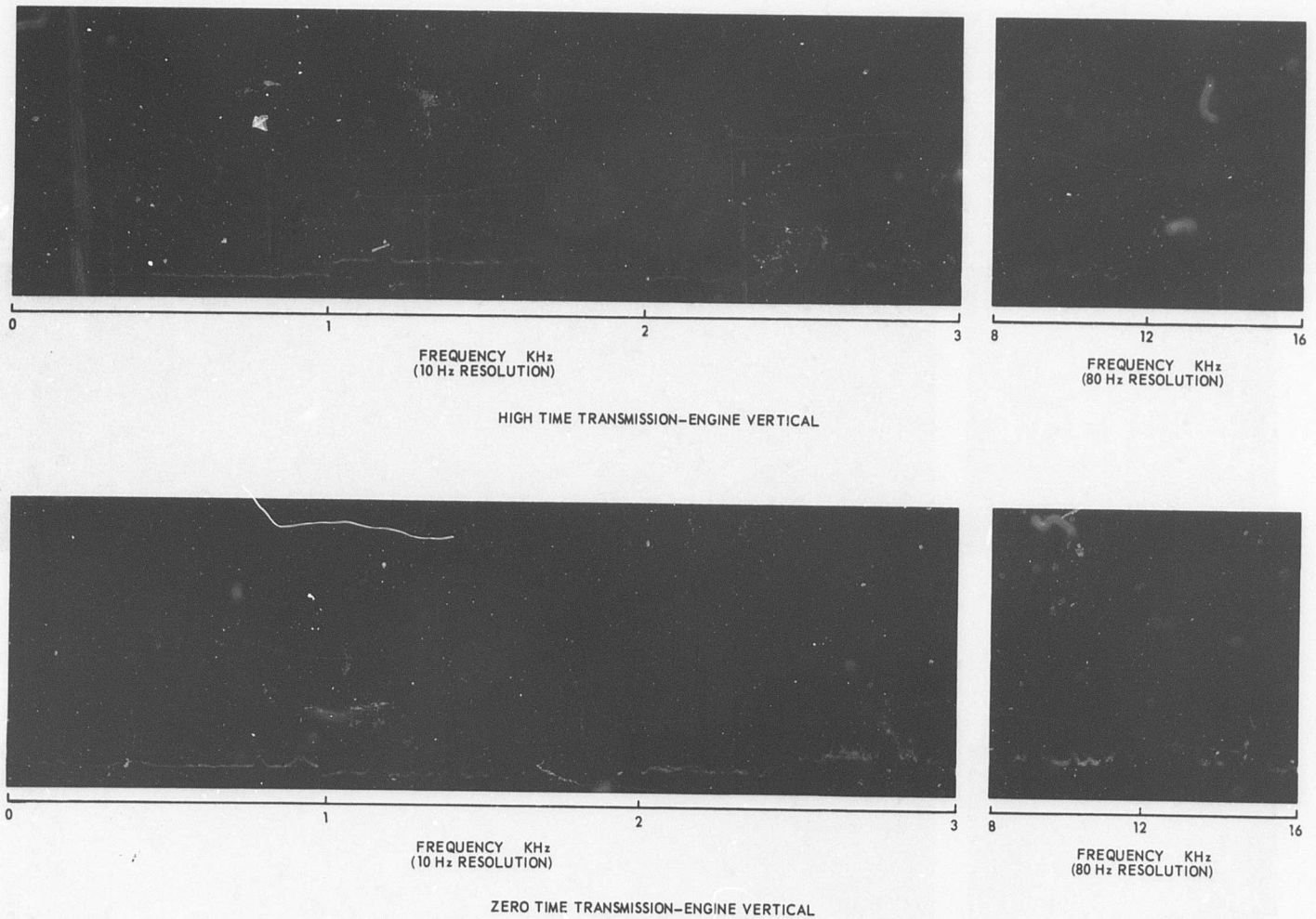


Figure 40. Comparison of Narrow-band Spectra - New and High Time Transmission - Engine Vertical Sensor in Segments From 4 Hz to 16 KHz.

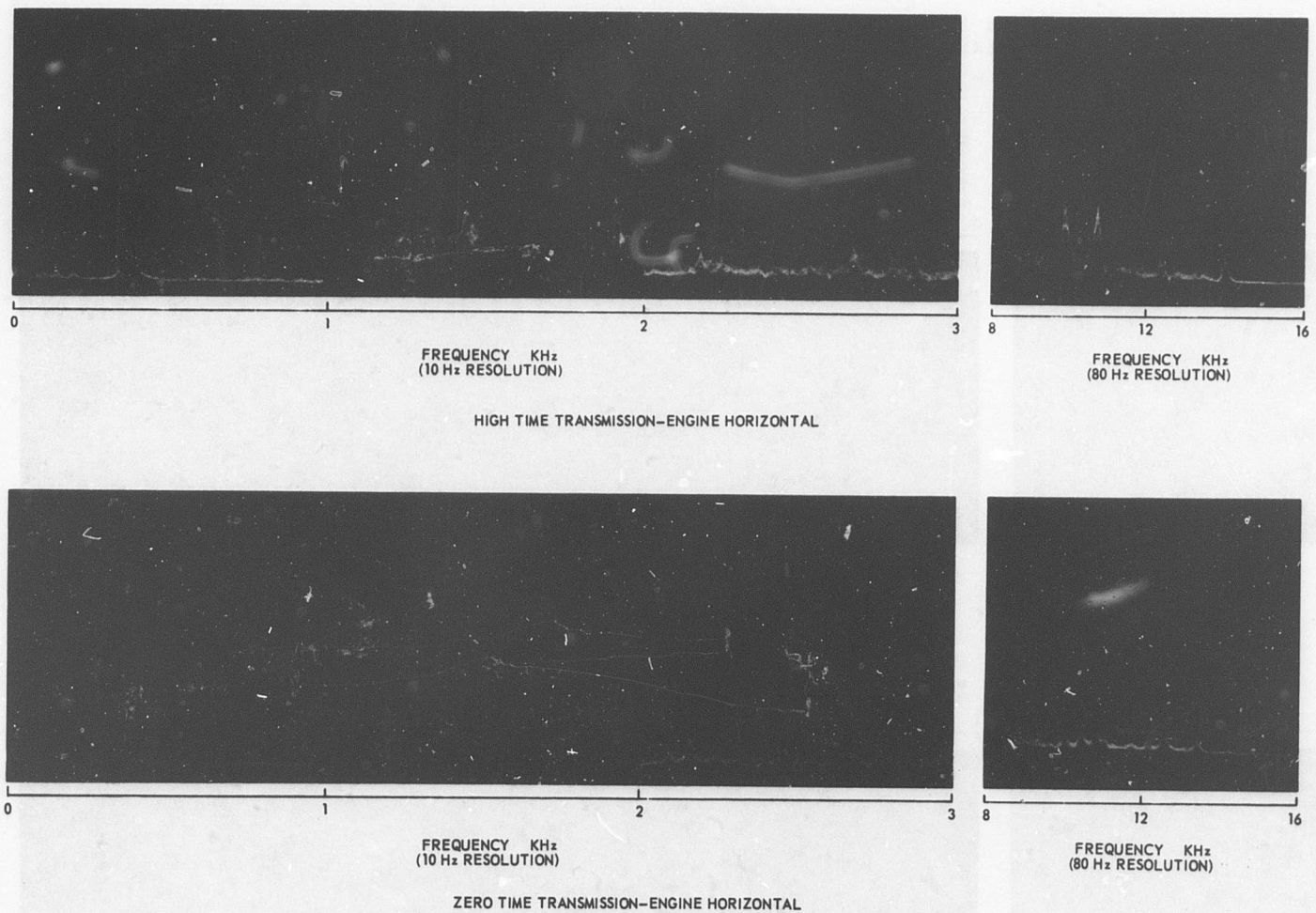
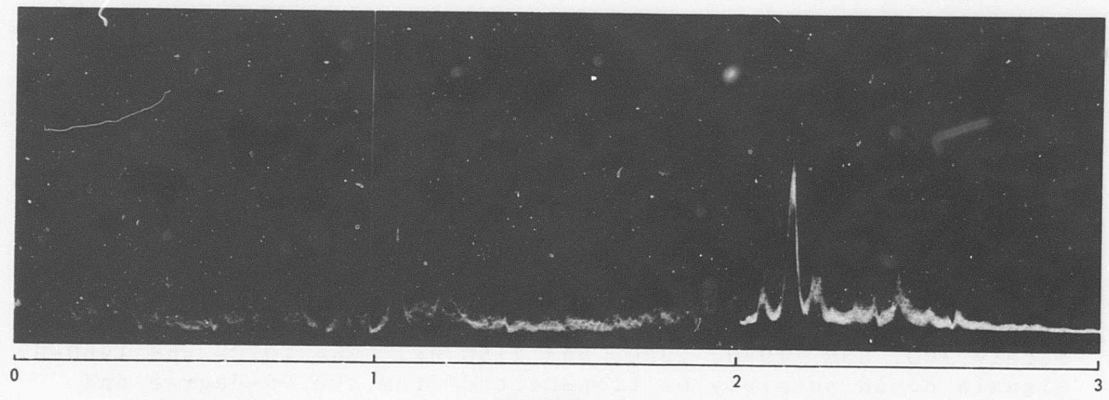


Figure 41. Comparison of Narrow-band Spectra - New and High Time Transmission - Engine Horizontal Sensor in Segments From 4 Hz to 16 KHz.



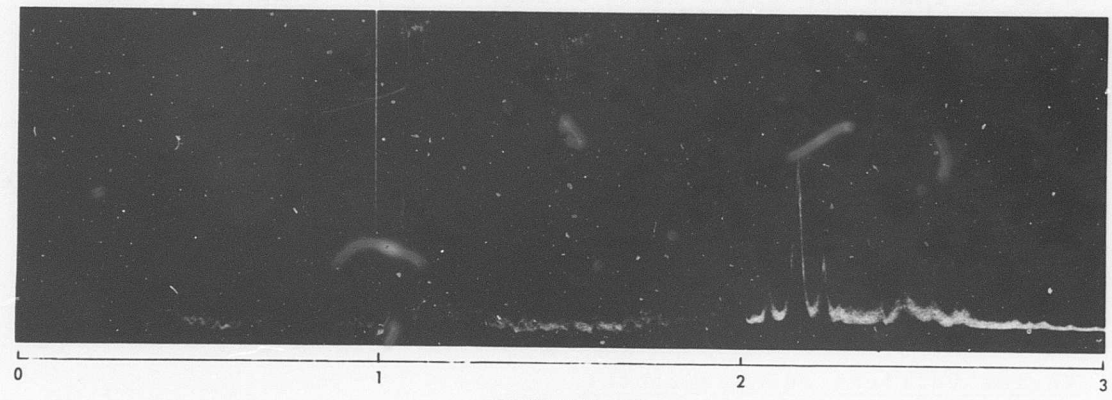


Figure 42. Comparison of Narrow-band Spectra - New and High Time Transmission - 90° Gearbox Sensor From 4 Hz to 3 KHz.

3.	Driven bevel gear - tail rotor	1857 Hz
4.	Driven bevel gear - accessories	1857 Hz
5.	Drive and driven spur gears	1354 Hz
6.	Oil pump	274 Hz
7.	Hydraulic pump	643 Hz

Frequencies observed in the narrow-band analysis are approximately 700, 850, 1070, 1960, and 2150 Hz. The 1070- and 1960-Hz signals could possibly be transmitted from the 90-degree and 42-degree gearbox or may be the harmonic of some bearing frequency.

The particular bearing frequencies generated depend upon the size of inner and outer race, diameter of the balls, and the location of a rough spot, if any. Frequencies between 80 Hz and 1300 Hz are generated by rough spots in the inner race of bearings located in the area of the transmission. If the rough spot is on the outer race, the frequency ranges from approximately 70 Hz to 1200 Hz. If the rough spot is on the balls of the bearing, the frequency ranges from 60 Hz to 1000 Hz. With approximately 11 bearings located in the lower section of the transmission, it can be seen that locating the individual frequency generating component can be difficult and complex. The accelerometer located on the transmission bottom picked up signals in the range from 1 KHz to 3.15 KHz which were significant in indicating necessary corrective maintenance actions.

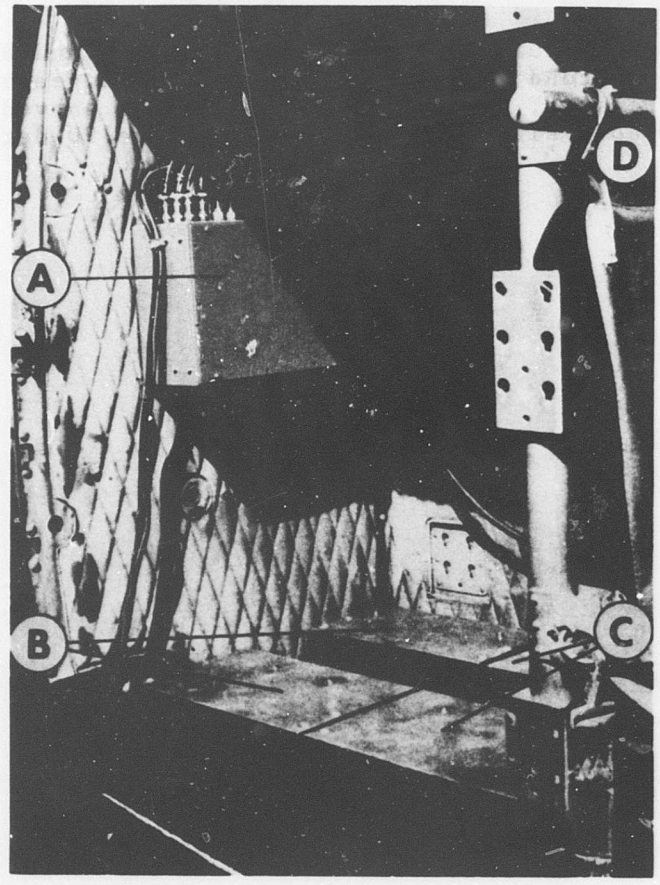
Engine Vertical and Horizontal

The calculated frequencies of the engine compressor rotor stages one through five at 100% RPM for N_1 and N_2 are 10,900, 11,739, 14,255, 15,083, and 15,932 Hz respectively. The fundamental frequency of the centrifugal impeller is 15,093 Hz, the turbine rotor stage one is 27,671 Hz, and stage two is 21,910 Hz. Some of the above-listed spectral lines detected by the engine sensor are shown in Figures 38 and 39.

90-Degree Gearbox

When the input shaft to the transmission is rotating at 6578 RPM, the gear-mesh frequency of the 90-degree gearbox is 1072 Hz. The waveforms detected at this sensor location are shown in Figure 40. It was observed that the 90-degree gearbox accelerometer was sensitive also to meshes in the 42-degree gearbox, which have a fundamental frequency of 1930 Hz. This particular

fect was difficult to determine with wide-band analysis, cause the second harmonic of the 90-degree gearbox is 044 Hz. However, the narrow-band analysis showed, emphatically, that both signals were present at the 90-degree gearbox.



(A) Junction Box

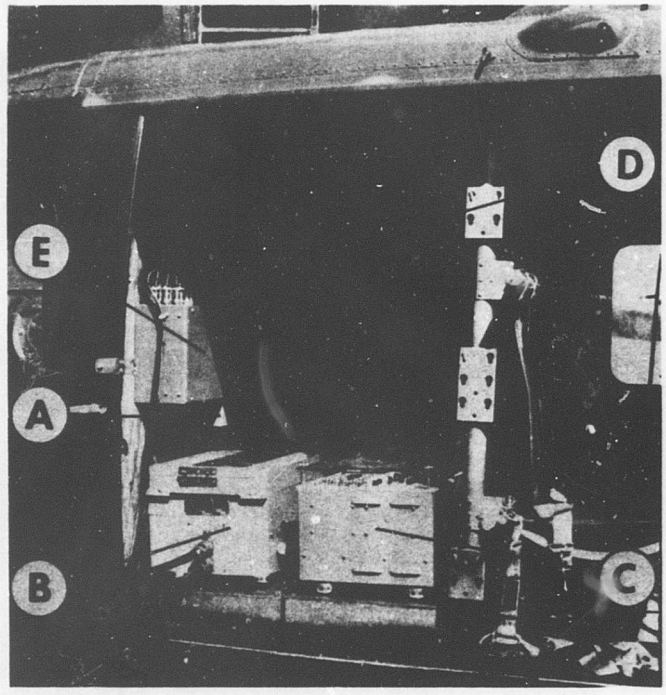
(B) Hold-Down Brackets for the Recorder

(C) Hold-Down Brackets for the Melpack

(D) Instrumentation Cables

The hold-down brackets provide quick installation of the airborne data-acquisition system. The recorder is mounted on the left with eight quarter-turn fasteners. The Melpack is mounted on the right and held by four quarter-turn fasteners.

Figure 43. Floor, Right-Side Passenger Compartment - Mounting Provisions.



(A) Quick-Connect Disconnect Cable

(B) 14-Channel Magnetic Tape Recorder

(C) Melpack—Signal Conditioners, Tape Drive Amplifiers, and Program Logic

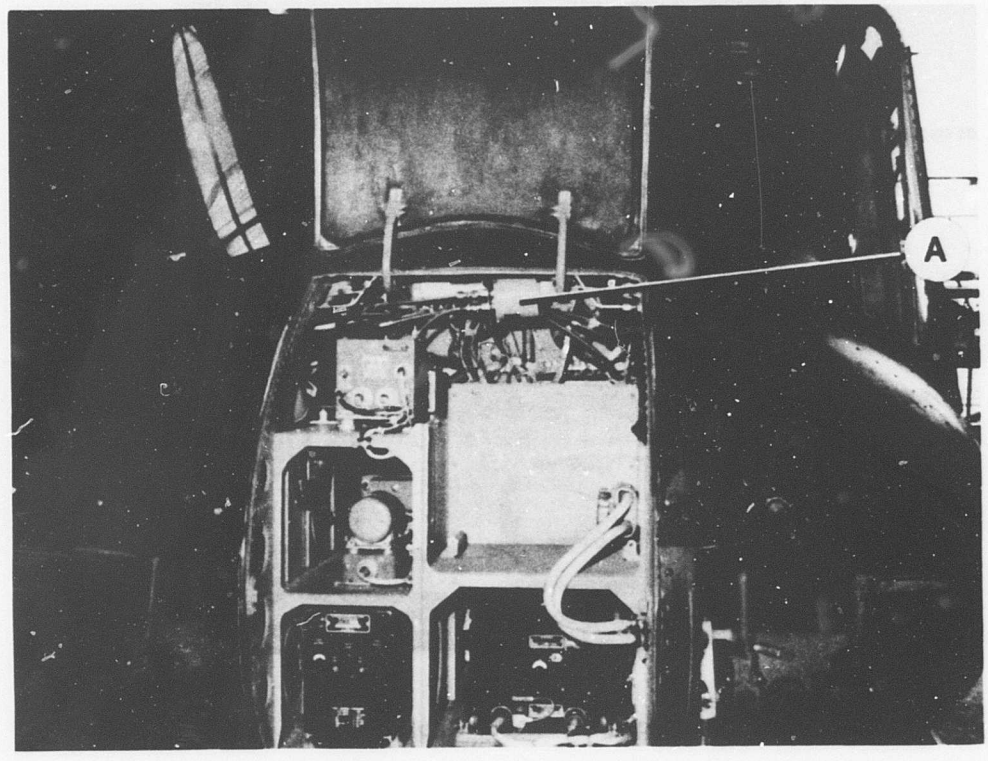
(D) Transmission Access Panel—Pylon Structural Panel Replacement

(E) Junction Box—System Cable Termination Box, Gain Controls, and Bridge Completion Networks

The recorder is attached to the Melpack by a single connector. The Melpack is connected to the instrumentation system installed on the helicopter through the quick-connect disconnect cable connected to the junction box.

The airborne data-acquisition system can be mounted on the helicopter in approximately 10 minutes.

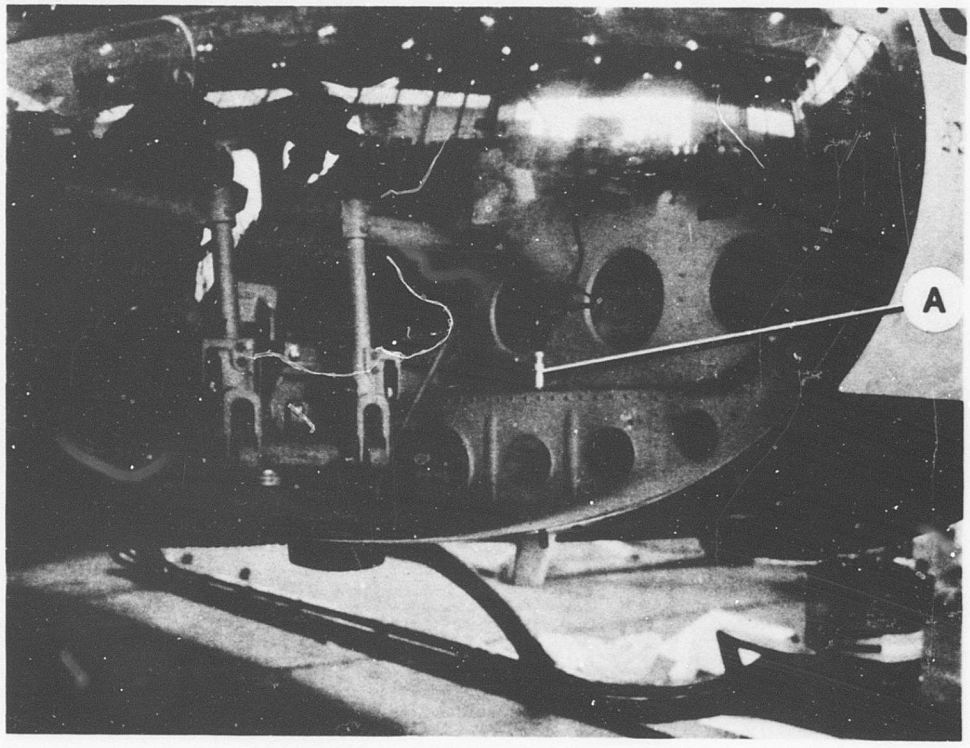
Figure 44. Floor, Right-Side Passenger Compartment - Equipment Installed.



Ⓐ Airspeed Transducer

The airspeed transducer is a pressure transducer connected to the pitot system. The torque and gyroscope are monitored to provide attitude and torque information.

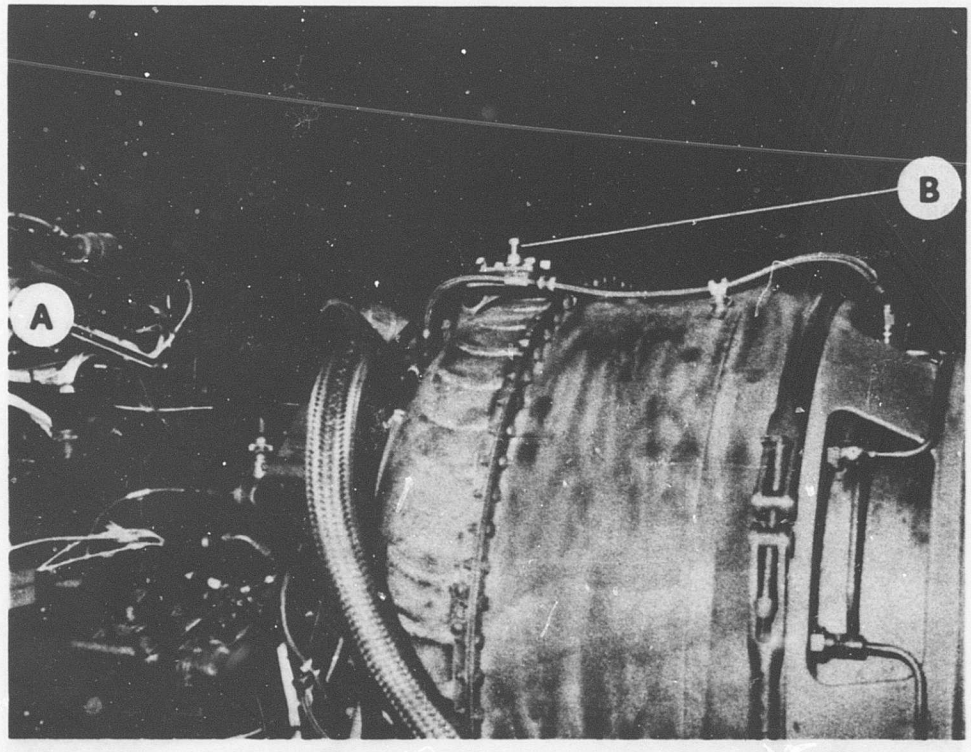
Figure 45. Helicopter - Front - Nose Open.



Ⓐ A5 Air Frame Nose Accelerometer

The cable is routed with existing cable through the center of the helicopter to the transmission area.

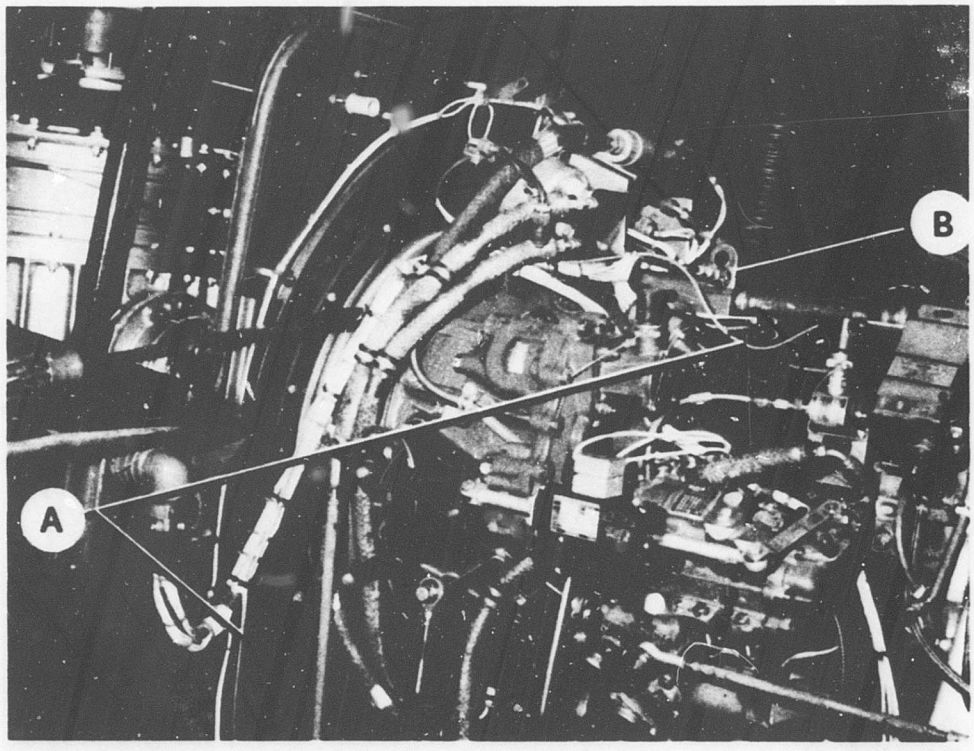
Figure 46. Helicopter - Front Lower Right.



Ⓐ A2 Horizontal Engine Accelerometer

Ⓑ A1 Vertical Engine Accelerometer

Figure 47. Engine - Rear.

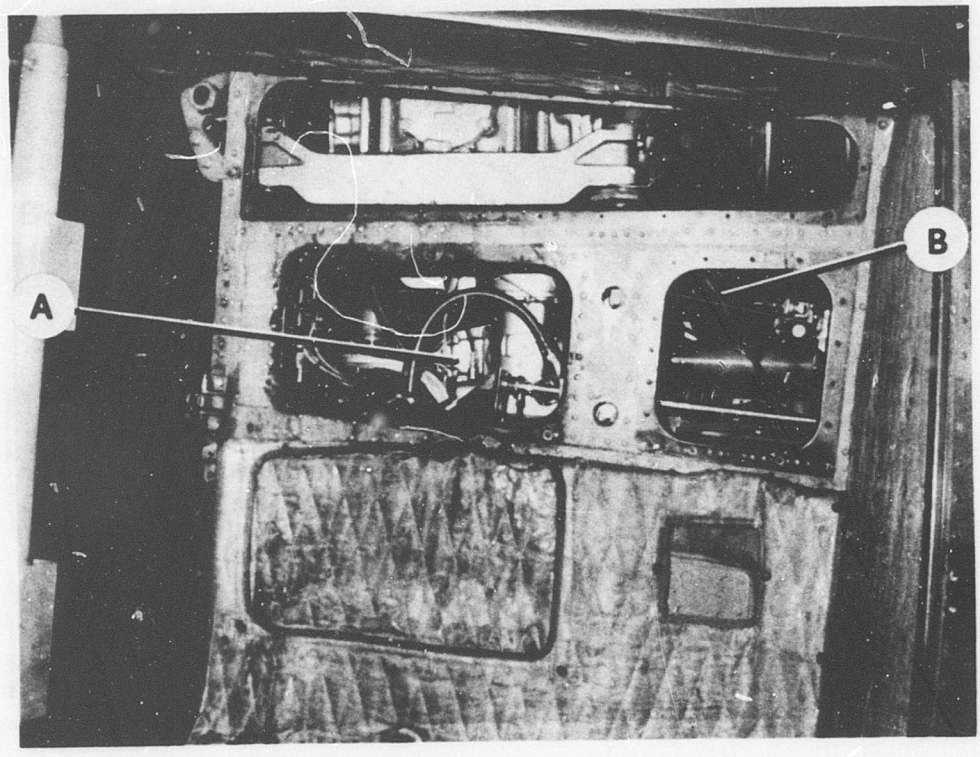


Ⓐ Engine Accelerometer Cables

Ⓑ A2 Horizontal Engine Accelerometer

The accelerometer cables follow existing cable where possible. These cables enter the transmission area through two holes under the engine and in the forward wall.

Figure 48. Engine - Forward.

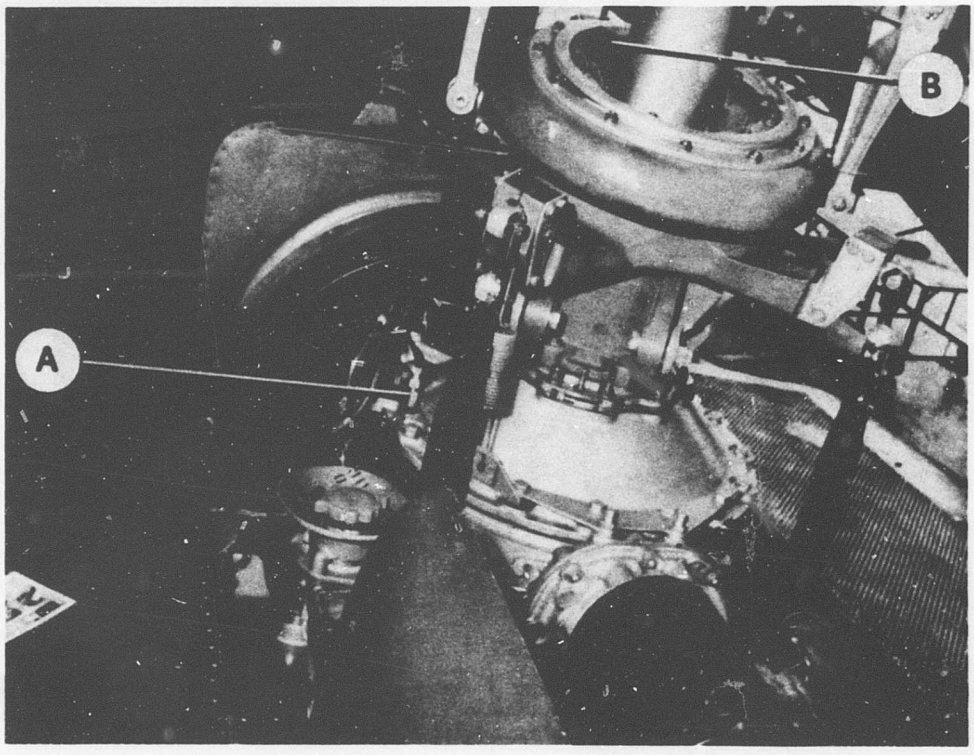


Ⓐ A4 Transmission Bottom Accelerometer

Ⓑ Engine Accelerometer Cables (2)

The engine accelerometer cables come through two holes in the wall. The transmission and engine cables follow existing cables where possible.

Figure 49. Passenger Compartment - Left Side.

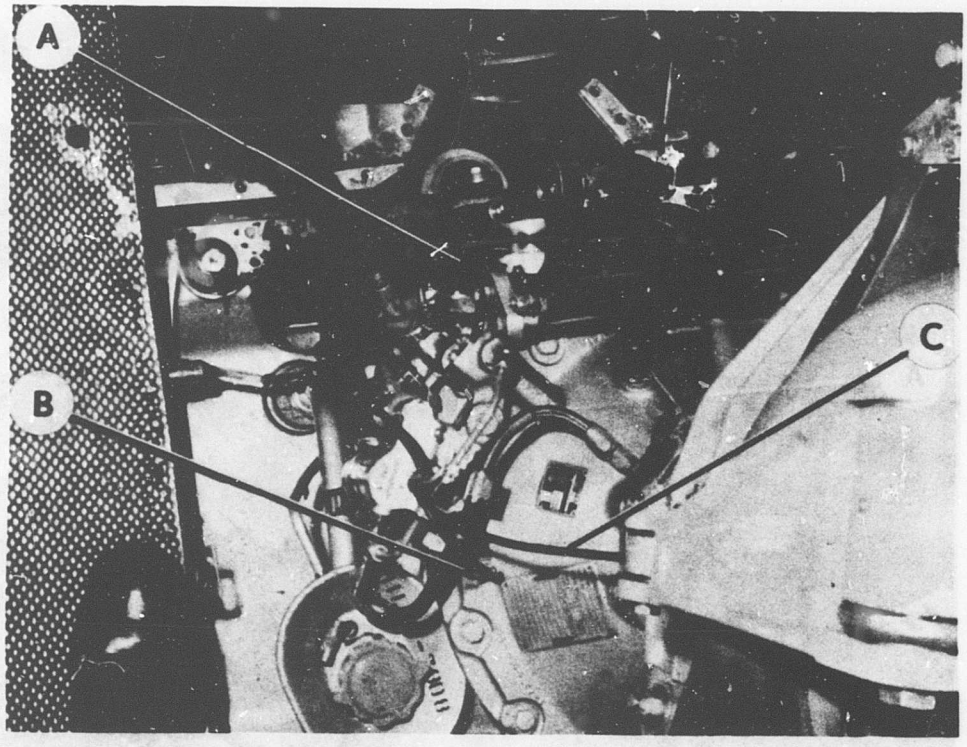


Ⓐ A3 Top Transmission Accelerometer

Ⓑ Swashplate Temperature Sensor

These sensors are in this same position on all 12 helicopters

Figure 50. Transmission Top - Side View.



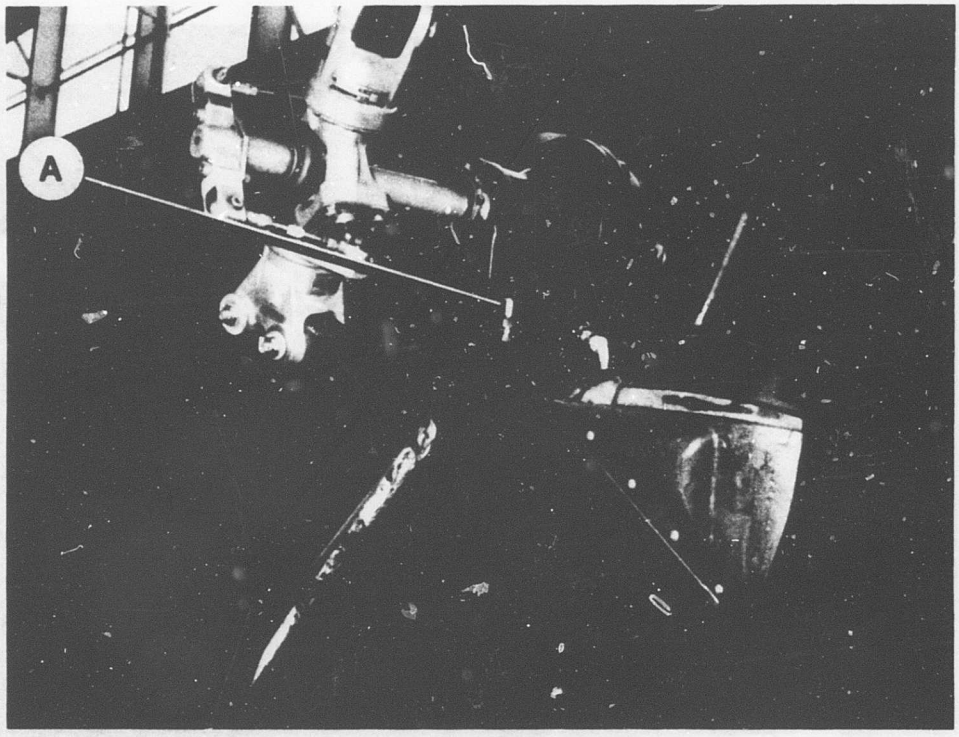
Ⓐ Input Quill Temperature

Ⓑ A3 Top Transmission Accelerometer

Ⓒ Swashplate Temperature Cable

The transmission was sanded to remove the paint and cleaned with "MEK" before the mount and sensors were epoxyed on. The cable follows existing cable.

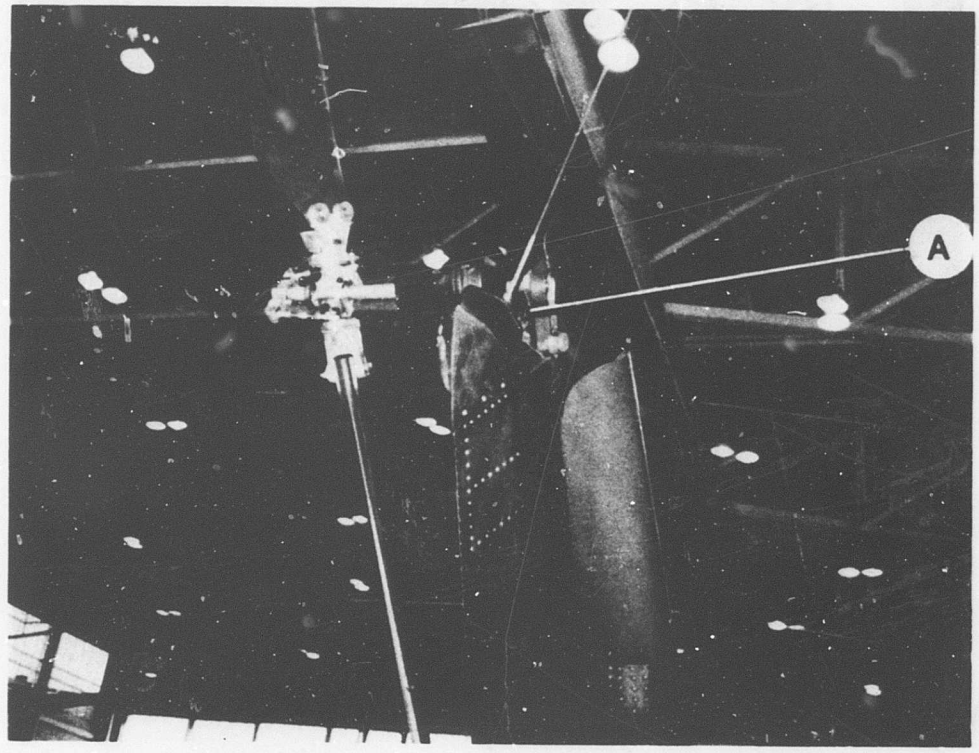
Figure 51. Transmission Top - Top View.



Ⓐ Accelerometer (A6)

The cables for the sensors on the 90° gearbox are routed into the tail boom through existing holes between the skin panels and structure members. No holes are cut.

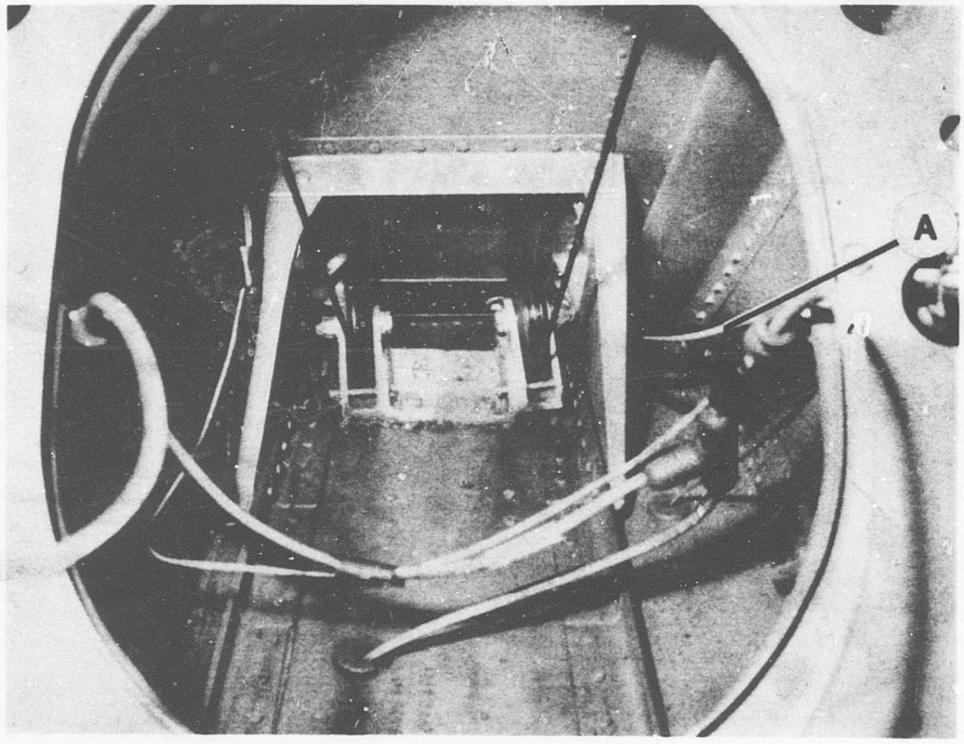
Figure 52. 90° Gearbox Showing Accelerometer.



Ⓐ Temperature Sensor (T7)

The sensor locations are the same on all helicopters.

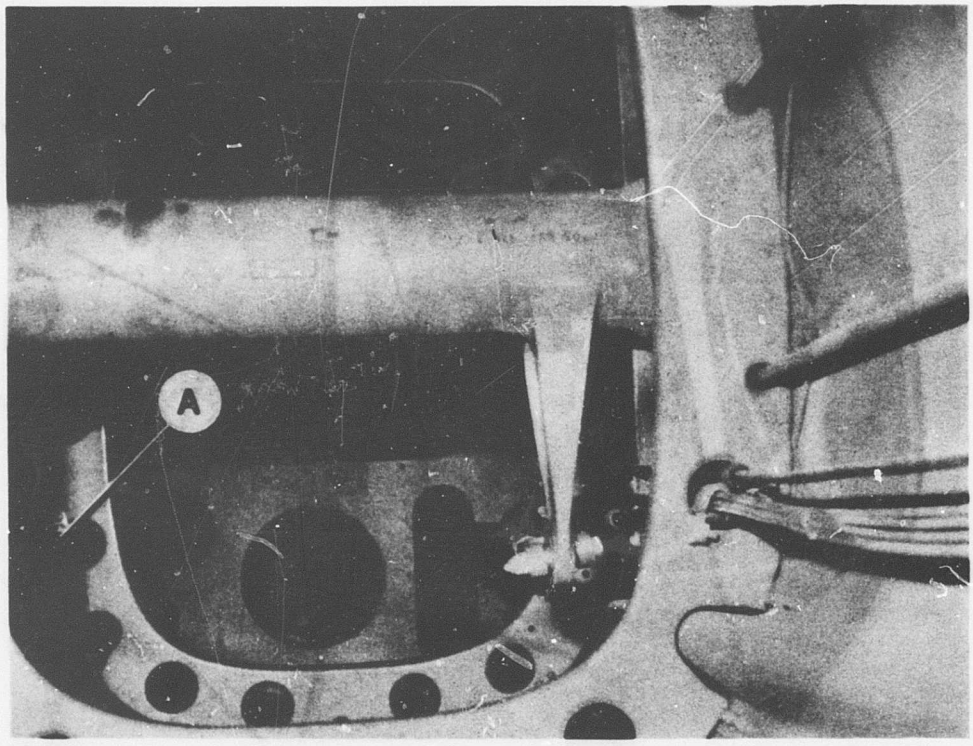
Figure 53. 90° Gearbox Showing Temperature Sensor.



Ⓐ Cable for T7 90° Gearbox Temperature, T6 42° Gearbox Temperature, and A6 90° Gearbox Accelerometer

The cables are routed with existing cable. These cables are routed to the tail fin through holes between structure and skin material. Some cable had to be routed on the inside of the bracket near the pulley.

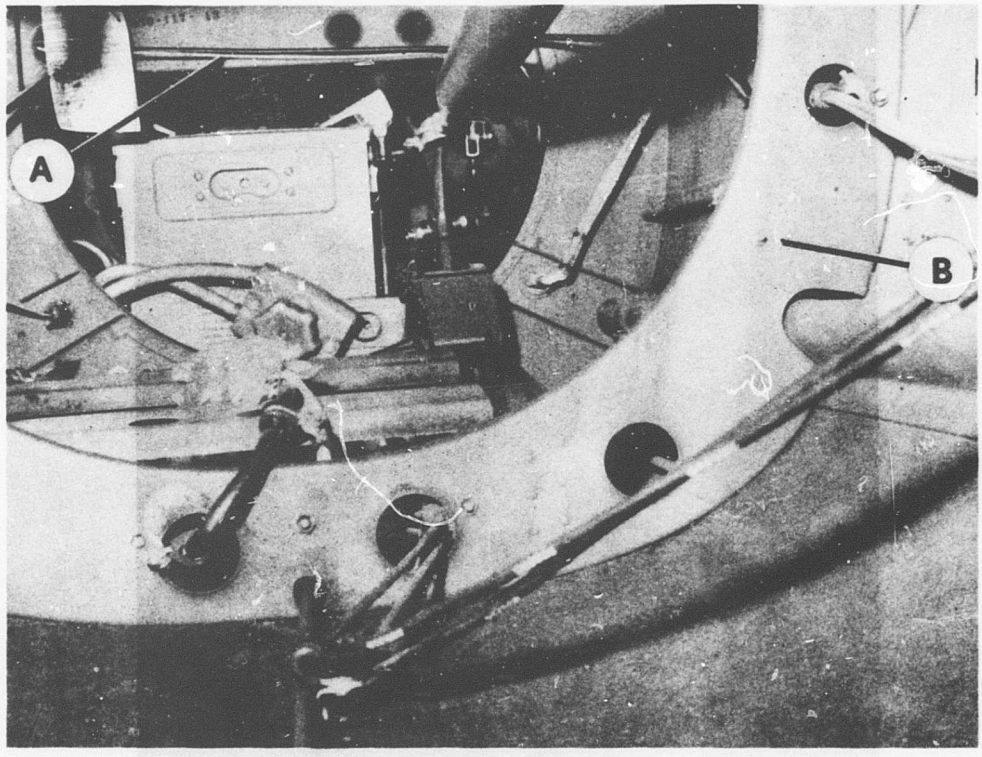
Figure 54. Inside Tail Boom - Aft View.



Ⓐ Sensor Cable

These cables are for sensors on the 90° and 42° gearboxes. They are routed with existing cable and fastened by four Adel clamps.

Figure 55. Inside Tail Boom at Aft End - Forward View.

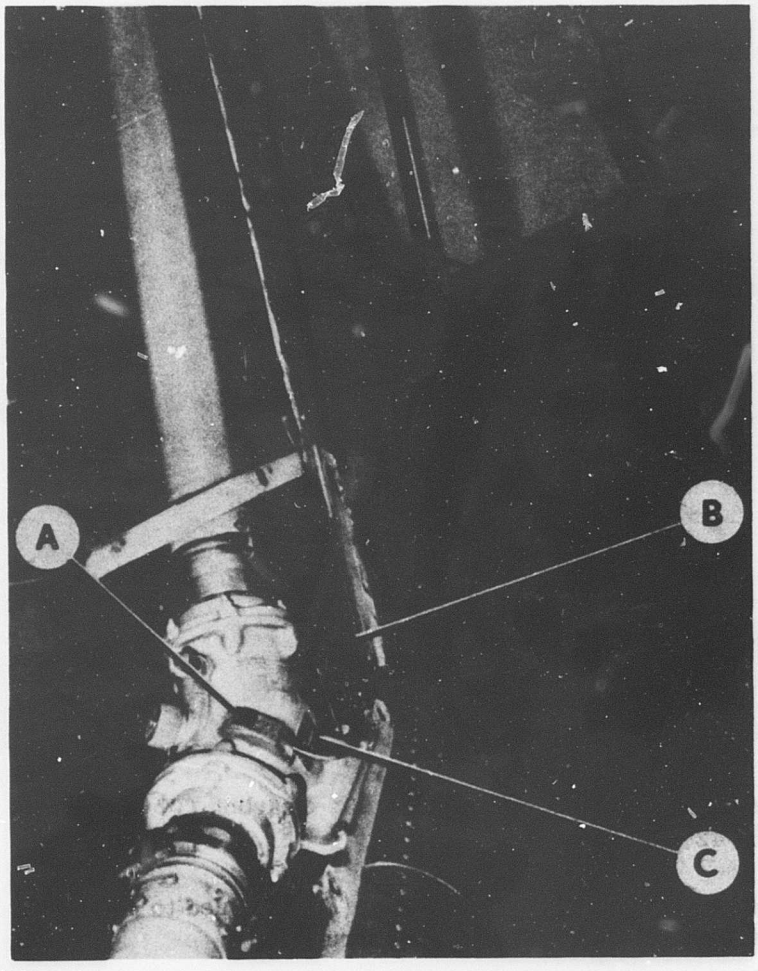


Ⓐ Cables for Sensors Mounted on the 90° Gearbox (T7 and A6) and the 42° Gearbox (T6)

Ⓑ The Reference Temperature Sensor (T8) Is Glued to a Bracket Mounted on the Other Side of This Structure.

The cables in the tail boom are fastened with four Adel clamps and tied to existing cables.

Figure 56. Inside Tail Boom - Forward View Showing Reference Temperature Sensor.



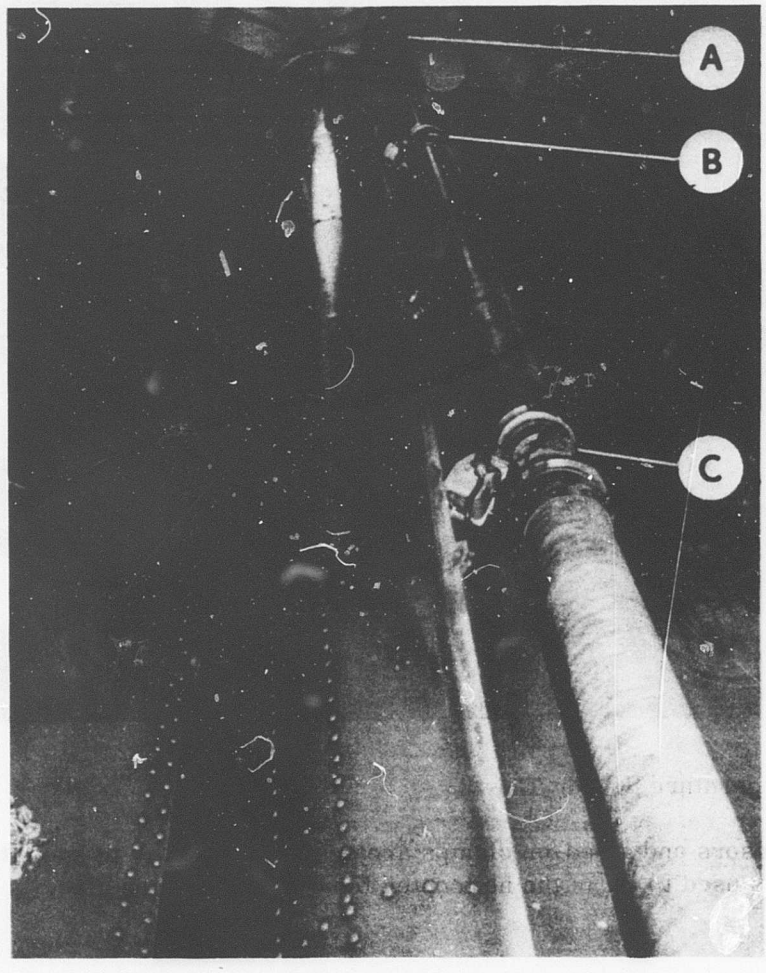
Ⓐ Temperature Sensor (T6)

Ⓑ Cables for the Sensor on the 90° Gearbox

Ⓒ Identification plate

The cables are routed through existing holes. Temperature sensor (T6) is located as shown. If there is no identification plate, the sensor is in that location.

Figure 57. 42° Gearbox.



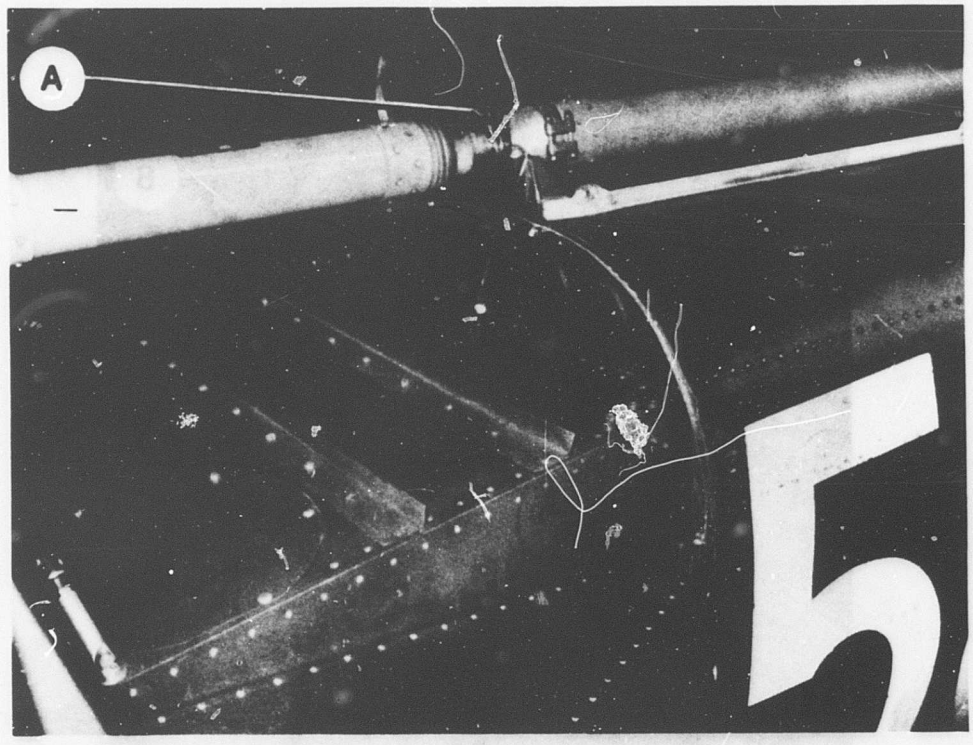
Ⓐ Temperature Sensor T3 No. 2 Hanger Bearing

Ⓑ Temperature Sensor T4 No. 3 Hanger Bearing

Ⓒ Temperature Sensor T5 No. 4 Hanger Bearing

Location of these temperature sensors is on the hanger bearing identification plate. A cushioned, loop-type support clamp at the end of each cable and four glued-on plastic clamps hold the cables.

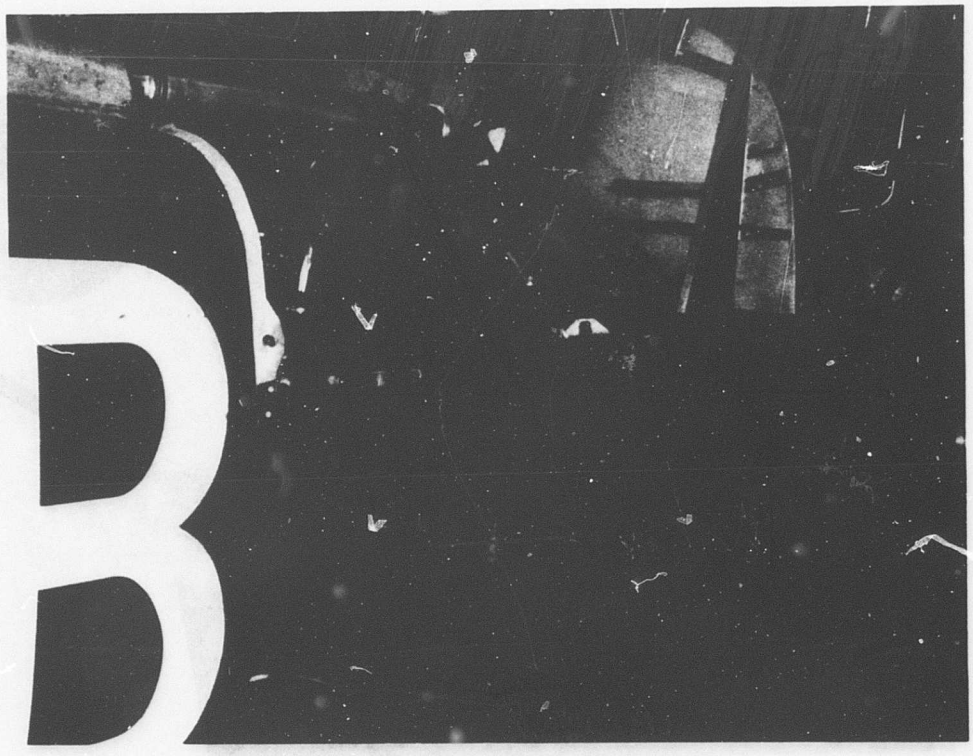
Figure 58. Tail Rotor Drive Shaft Showing Hanger Bearings Nos. 2, 3 and 4.



Ⓐ Temperature Sensor T3

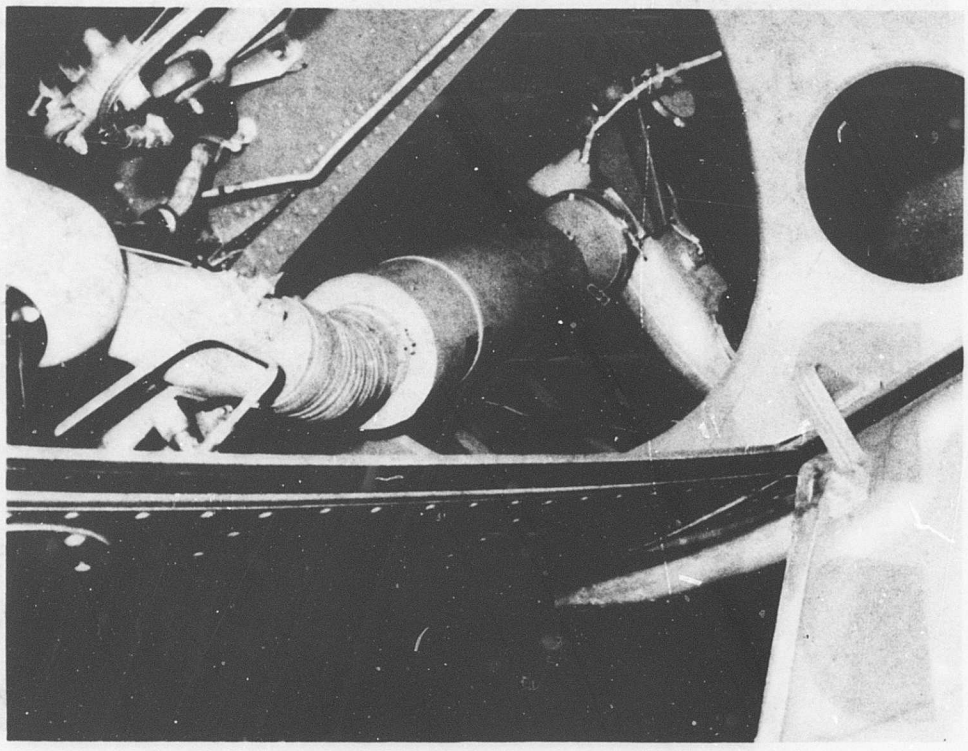
The sensors and glued-on clamps are sealed with epoxy to keep the solvents used to clean the helicopter from dissolving the glue.

Figure 59. Tail Rotor Drive Shaft - Left Side.



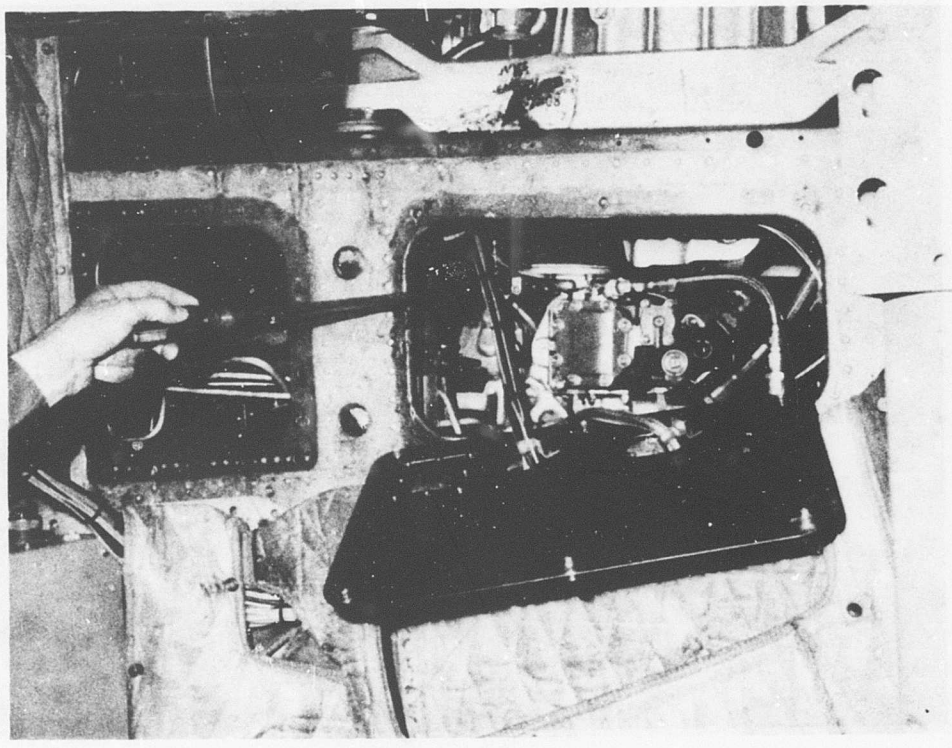
The cables from the drive shaft are routed into the lower compartment through a replacement steel panel made by Melpar. These cables join the cable from the tail boom.

Figure 60. Tail Rotor Drive Shaft - Forward End.



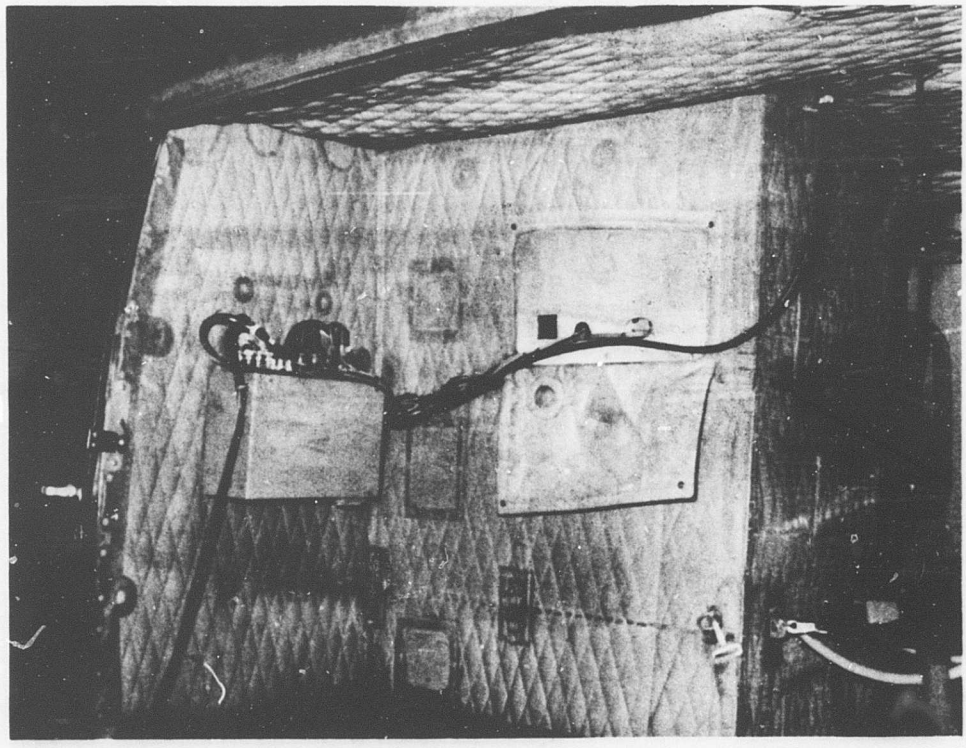
The cables from the tail boom (A6, T7, and T6) and the tail rotor drive shaft (T3, T4, and T5) join and are routed through the heater duct to the right side passenger compartment. The cables were factory-made, and any loose slack was taken up here.

Figure 61. Heater Compartment.



Transmission and Engine Acceclerometer and Temperature Cables

Figure 62. Right-Side Passenger Compartment.



The junction box shown on the rear wall terminates all wiring on the helicopter. The transmission pylon panel is Al 5052 H32 0.063" replacement. The brackets at the bottom of the photograph hold the recorder (≈75 lb with tape) with 8 quarter-turn fittings and the Melpack with 4 quarter-turn fittings. The connector at the bottom of the junction box connects the helicopter to the Melpack.

Figure 63. Right-Side Passenger Compartment Showing Junction Box.

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13. ABSTRACT

The objective of this program is to accumulate sufficient vibration and temperature data to establish base-line operating levels and to determine maximum limits for use in the development of an automatic diagnostic and inspection system for the UH-1 series helicopter.

Samples of data were taken from 12 instrumented helicopters at controlled times by three automatic self-calibrating data collection systems which were moved between the aircraft twice each day.

The relevant data were processed by a high-speed digital computer through a number of passes to produce edited calibrated printouts and magnetic tape records of each acceptable data sample.

Maintenance records on the instrumented helicopters were reviewed, summarized, and correlated with measured changes in temperature and acceleration level during the same period.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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