**Hydraulic Diagnostic Monitoring System**

**Final Report**

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**Hydraulic**  |  **Temperature**  |  **Pumps**  |  **Display Panel**
---|---|---|---
**Monitoring**  |  **Fiber Optics**  |  **Displacement**  |  **Analog**
**Flow**  |  **Reservoir**  |  **Accumulators**  |  **Discrete**
**Level**  |  **Desiccant**  |  **Microprocessor**  |  

This report presents a second twelve month summary of a two year effort of a HYCOS hydraulic diagnostic monitoring system. The program was broken down into three tasks:

(See Over)
Task I encompassed the design, development and procurement of hardware, sensors, and microprocessors for two diagnostic monitoring systems. The first system was installed on the F-14 Hydraulic Flight Simulator on Task II of the program.

Task II Installed one system on the F-14A Hydraulic Simulator for System component reliability demonstrations. The task also covered simulated component failures and diagnostic system reaction.

Task III Integrated the Diagnostic System into A6E B/N 155628 Debugged the system and ran a 12 month flight test schedule. This report covers Task III.
SUMMARY

This program was based on the feasibility study of a hydraulic monitoring system described in NADC report number TR75168-30 published in July 1976. The interim report, NADC TR76382-30, was published in May 1979 and covered Tasks I and II.

The purpose of the Hydraulic Diagnostic Monitoring System (HYCOS) is to warn of impending failure of hydraulic system components by onboard sensors continuously monitoring failure-indicating parameters.

The monitoring system consists of three basic types of sensors: analog, discrete, and fiber-optic. These sensors feed information to a self-contained, centrally located display panel through interface circuits that are easily accessible to ground maintenance personnel. The panel has circuit and system test capability which detects malfunctions of electronic equipment, sensor circuits, and display indicators.

The Sensor List includes the following types:

- **Displacement**: (a) Potentiometer - rotary and linear (analog)
  (b) Photo-optic (reflective)
  (c) Hall Effect (magnetic)
- **Temperature**: (a) Pressurized gas (discrete)
  (b) Bimetallic (discrete)
  (c) I/C transducer (analog)
- **Differential Pressure, Filter**: Spring biased piston (discrete)
- **Pressure**: (a) Gas and spring biased switch (discrete)
  (b) Semiconductor strain gage (analog)
- **Liquid Detection**: Fiber-optic probe using refractive index coupling (discrete)
- **Flow**: Orifice with bypass shunt for higher flows (discrete)
- **Desiccant Color Detection**: Fiber-optic color transmission using reflected light. Optical properties of irregular granules (analog - color spectrum)
Displacement sensors of the variable-resistance type were used to measure reservoir piston, accumulator, rudder, and rudder pedal displacements. Two other concepts evolved in the accumulator application, a reflective photo-optic type and a magnetic Hall Effect type. Since they are experimental in nature and require development, they were not used in the prototype system.

Three types of temperature sensors (one analog and two discrete) were chosen and utilized in the pneumatic, fluid, and surface temperature circuits. Their performance was satisfactory during simulator testing. Filter differential pressure indicators were of the spring biased magnetically latching type. Their performance was satisfactory.

Two types of pressure-sensor devices were utilized. In one pneumatic circuit, a temperature-compensated pressure switch performed as predicted over a broad temperature range. In another pneumatic hydraulic circuit, a semiconductor strain-gage type also performed according to specification.

Liquid detection circuits in high-pressure pneumatic bottles proved to be a challenge in the area of pressure sealing and liquid detection using the optical properties of liquids, solids, and gases. All major problems were overcome after extensive development effort.

The use of shunt orifice flow measuring devices proved satisfactory in three hydraulic subcircuits. In two of the three cases, the indicator was immobilized during normal system operation.

Desiccant color detection utilizing color transmission proved difficult due to the irregular desiccant particles. A high-intensity light source was required to achieve sufficient color transmission. An improved sensor was developed for the A-6E installation.

The diagnostic system monitors the hydraulic system during flight as well as on the ground. Any flight discrete failures are displayed when the aircraft is interrogated on the ground. Discrete sensors are manually resettable.

An onboard preprogrammed microprocessor handles all the analog inputs through A/D converters and determines the condition of components with multiple sensors.

Task I defined and procured hardware sensors for two diagnostic monitoring systems. After individual component acceptance testing, the system was interfaced with a F-14A hydraulic simulator.
Task II consisted of installing the system on the F-14A hydraulic simulator in order to demonstrate system/component reliability under simulated conditions. A baseline was established and various failure modes and diagnostic system reactions determined.

The scope of the Interim Report covered only the development and integration of the F-14 hydraulic monitoring system.

Task III of the hydraulic monitoring system contract consisted of procuring, building, installing, and testing in a bailed A-6E flight test vehicle for a duration of at least 6 months.

To accomplish these objectives:

- Bracketry was designed and fabricated to support the system components. The combined hydraulic fluid distribution system was modified to accept pressure, flow, and temperature sensors
- Electrical and fiber-optic cable runs were designed, fabricated, and installed between the HYCOS display panel and sensors
- The HYCOS system was installed only in the combined hydraulic system and did not affect system operation
- Representative system components and parameters were monitored. These included
  - Hydraulic reservoir
  - Filters
  - Accumulator
  - Pneumatic bottles
  - Hydraulic pump
  - Rudder actuator
  - Relief valve
  - System operational hours
- The microprocessor program was written to apply specifically to the A-6E requirements
The vehicle received normal ground tests prior to being cleared for its normally scheduled flight program.

During the flight program (installed January 1979, removed November 15, 1980) the system accumulated over 160 flight hours. First flight occurred on October 31, 1979.

A Navy A-6E bailed aircraft was designated as the official test vehicle in January 1979. By May 1979, the modified hydraulic system was initially pressurized to check for system compatibility. During the latter part of the year, the system was modified to improve reliability and maintainability.

Improvements were made to both the display panel and sensors. In the area of light sensing, transmission of colored light proved difficult since, during installation of the fiber-optic cables, excessive bends were made creating unacceptable light losses. However, the concept was verified.

During the test program, the system continuously detected low pneumatic bottle pressures and low reservoir level during calibration and system operation. No other system abnormalities or malfunctions were detected.

The total time for interrogating the system is 1-1/2 minutes. This significantly reduces turnaround time and increases aircraft availability.
PREFACE

This report was prepared by the Grumman Aerospace Corporation under a Naval Air Development Center, Contract Number N62269-78-C-0041, entitled "Hydraulic Diagnostic Monitoring System".

The program was based on a previous feasibility study conducted by Grumman Aerospace Corporation and reported in NADC TR 75168-30.

Task I of this program covered procured hardware, sensors, and microprocessors for two monitoring systems. One system was installed in a F-14 Flight Simulator and the other scheduled for an A-6 aircraft. The work reported in the report covers the November 1977 to December 1978 timeframe.

Task II covered the results of installing the system in an F-14A hydraulic simulator, integrating and debugging the system, and finally simulating various failure modes in order to demonstrate diagnostic system reaction.

Interim Report NADC TR 76389-30 Hydraulic Diagnostic Monitoring System was published 31 May 1979, covered Tasks I and II.

Task III encompassed the basic integration, debugging, and flight test of the A-6 System.

The sponsoring agency is the Naval Air Systems Command, Washington, D.C.

Mr. Steve Hurst, AIR 340C, was the Program Manager

The work was administered under the technical direction of:

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Program Manager for this effort was Mr. Edwin A. Anderson

Project Engineer for this contract was Mr. John J. Duzich
The author wishes to acknowledge the significant support and contributions made by the following Grumman disciplines:

- Aircraft Programs
- Aircraft Project Office
- Controls and Mechanisms
- Electronic Design and Development
- Equipment Lines
- Flight Development Group
- Fluid Power
- Mechanical Design
- Mechanical/Fluid Systems Test
- Quality Control
- Structural Design.

Daily HYCOS System recording, performed by Mr. Frank Martella, Plane Captain, was invaluable in assessing this phase of the program.
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Section 1

HYDRAULIC DIAGNOSTIC MONITORING SYSTEM

1.1 VEHICLE DESIGNATION

On 31 January 1979, Naval Air Systems Command Selected A-6 Bureau Number 155628 as the vehicle to be used as a flight test bed for the hydraulic monitoring system. The vehicle, which was being modified/updated, arrived at the Grumman facility during the preceding year and started through the modification line in February as MOD 229.

1.2 VEHICLE MODIFICATION

During the time the vehicle was being upgraded to an A-6E configuration, the HYCOS system was installed since all necessary areas were accessible. The HYCOS A-6E block diagram is shown in Figure 1.

Installation was accomplished through the issuance of both Record and Flight Test Engineering Orders (EO) to minimize the impact of the normal buildup. This approach led to an efficient and expeditious system installation. All EOs are listed in Appendix G.

Vehicle modifications included provisions for mounting the HYCOS panel in a ground-accessible area on the port side of the engine duct. Mounting brackets and an access panel door were fabricated and installed. Since the selected surface area is a load-bearing member, Calfax fasteners were used for easy access.

Both wire and fiberoptic line runs were installed in the vehicle at this time in conjunction with the other wiring circuits. New lines were fabricated as required for sensors installed in the pressure system.

All HYCOS sensor line runs terminated at the test panel through the use of three electrical connectors and two fiberoptic connectors. Figure 2 shows the access area with the wire bundles before modification.
Figure 1. A-6E HYCOS block diagram.
Figure 2. Access panel before modification.

1.3 VEHICLE COMPONENT INSTALLATION

As specified in the statement of work, various components were modified to sense variables as determined during the previous program. The parameters included:

- Level
- Temperature
- Air Content
1.3.1 Hydraulic Reservoir

1.3.1.1 Description

The combined system reservoir was designed to meet the requirements of Specification MIL-R-5520A-1 for a "Class II" separated air and oil reservoir. A "Type B" reservoir pressurized with air to a nominal operating value of 40 psi was used. The detail design configuration is that of a welded and machined outer casing with concave hemispherical ends enclosing a cantilevered, pressure-balanced sleeve. This configuration is not subjected to distortions produced by pressure surges and structural deflection. A free-floating piston separates system oil from pressurizing air. Both return and suction ports are located in the side of the outer shell. Returning oil impinging on the outer surface of the piston sleeve provides natural air separation characteristics. The concave ends minimize weight by reducing the volume of non-usable oil. Figure 3 shows the typical construction.

Figure 3. A-6 reservoir typical construction (before modification).
1.3.1.2 Reservoir Sensing Logic

The purpose of the reservoir sensing logic is to:

- Detect the presence of entrained air
- Detect low oil level
- Detect extensive leakage during the previous flight.

Figure 4 shows the A-6E hydraulic reservoir sensing logic. The logic employs variables of fluid temperature and piston displacement. Piston placement during the nonpressurized to pressurized condition gives an indication of entrained air. Fluid thermal expansion is automatically taken into account during microprocessor programming.

1.3.1.3 Displacement Sensor

An external 10-turn potentiometer was driven via a cable attached to the modified piston. Tensioning of the cable was accomplished by a negator spring motor contained in a pressure housing. One pulley on the motor drove an externally mounted potentiometer through a lip type seal. Reservoir pressurization was accomplished through the normal pressure housing port.

This configuration minimized the rework modification required for providing remote reservoir level sensing capability. Figure 5 shows a cross-section of the modification and the adapter ring added to the reservoir piston. Figure 6 shows details and subassembly of the modified reservoir.

The negator motor model number ML-2918, manufactured by the Hunter Spring Division of Ametek, was selected because of its constant-torque characteristics. Pertinent motor assembly details are listed below:

- Physical Dimensions .................. 2-1/2 x 3-3/4 x 1-3/16 in.
- Materials:
  
  Base ................................ Zinc-plated steel
  Drums ................................. Delrin or nylon
  Spring ............................... 301 stainless steel
  Cable ............................... 0.024 in. dia stainless steel
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Figure 4. A-6E reservoir sensing logic.
The motor assembly was mounted in the 1491-901-306 remote sensor housing with the cable terminal modified from a coil to a bead. This cable bead was free to float in the modified piston adapter ring.

A rotary potentiometer was attached to the driving end of the motor assembly as specified in Grumman Specification 209. Some pertinent data includes:

- **Spring Torque**: 1.56 lb-in.
- **Cable Tension**: 2 lb
- **Cable Length**: 72 in.
- **Number of Revolutions**: 15
- **Min Endurance Cycles**: 2500

Figure 5. Modified reservoir (level sensing).
Figure 6. Modified reservoir subassembly and details.

- Element: Wirewound
- Dimensions: 0.875 in. OD
  1.00 in. long
- Resistance: 20,000 Ohms
- Power Rating: 2 W
- Temperature Range: -65 to 255°F
- Torque: 0.60 oz-in. maximum
- Weight: 1 oz
- Resolution: 0.014%
Full travel of the hydraulic reservoir piston is 13.31 in. This piston movement relates to approximately three turns of the potentiometer, which is approximately 6000 Ohms. Figure 7 shows a calibration curve prepared in the Plant 14 Laboratory.

![Hydraulic reservoir calibration curve]

Figure 7. Hydraulic reservoir (laboratory calibration curve).

Considerations of temperature and entrained air variations provide the curves shown in Figures 8 and 9. Since the reservoir pressurization is only 40 psi, significant volumes of entrained air are required to cause measurable piston displacements between the pressurized and nonpressurized state. Hysteresis is limited to 2 psi in either direction.

Another factor considered but not applied in reservoir level sensing is piston movement/depletion time versus leak rate for both the combined and flight system. These curves (Figures 10 and 11) give an indication of reservoir depletion time in minutes versus varying leak rates. The initial datum point is taken at the refill mark of each reservoir. If each respective reservoir is full, the time to depletion is proportionately longer.
Figure 8. Reservoir calibration curve considering fluid temperature variation.
Figure 9. Calibration curve considering entrained air and temperature variation.
1.3.1.4 Temperature Transducer

The temperature sensor utilized a two-terminal I/C temperature transducer manufactured by Analog Devices of Norwood, Massachusetts.

The transducer, part no. AD590.C, produces an output current proportional to absolute temperature. With a supply voltage of 5 VDC, the device acts as a high-impedance, constant-current regulator passing 1μA/°K. Table 1 (extracted from Ref. 1) shows pertinent technical data.

<table>
<thead>
<tr>
<th>TABLE 1. 1C TEMPERATURE TRANSDUCER DATA.</th>
</tr>
</thead>
<tbody>
<tr>
<td>• TYPE: ANALOG DEVICES AD 590.C</td>
</tr>
<tr>
<td>• OUTPUT: 1μA/°K</td>
</tr>
<tr>
<td>• OPERATING TEMP RANGE: -55°C TO 150°C (-67°F TO 302°F)</td>
</tr>
<tr>
<td>• TWO-TERMINAL DEVICE: VOLTAGE IN/CURRENT OUT</td>
</tr>
<tr>
<td>• CALIBRATION ACCURACY: ±1°C</td>
</tr>
<tr>
<td>• LINEARITY: ±0.5°C OVER FULL RANGE</td>
</tr>
<tr>
<td>• POWER SUPPLY RANGE: +4 VDC TO +30 VDC</td>
</tr>
<tr>
<td>• SIZE: TO-52 PACKAGE</td>
</tr>
</tbody>
</table>

Figure 12 (extracted from Ref. 1) shows a voltage-current plot for a typical transducer. Note that the current is essentially flat with an input voltage of 3 to 30 VDC.

The transducer was selected for its small size, performance, and compatibility. Figure 13 shows the actual calibration for the unit.

The final subassembly is shown in Figure 14 before potting and assembly. This sensor is used both in the reservoir-level sensing circuit (Figure 15) and in the accumulator circuit discussed in a later section.

1.3.1.5 Optical Desiccant Sensor

Some hydraulic systems (such as the A-6E) are pneumatically pressurized, utilizing regulated engine compressor bleed air.

A desiccant is used to dry the makeup air used to pressurize the reservoir. The cartridges are replaced on periodic intervals predicated on vehicle system usage. In order to remotely detect a saturated condition, a colored desiccant cartridge is placed in series with the existing unit since the latter could not be readily modified.

The selected sensor was made by Delaval Special Products Division and conforms to Grumman Specification Number 205. The sensor measures approximately 5 in. x 3 in. long, has a transparent housing, and is rated for 100 psi operating pressure. The unit
Figure 11. Flight reservoir depletion rate vs time.
Figure 12. Voltage-current plot for an IC transducer.

Figure 13. Calibration curve for an IC transducer.
Figure 14. Temperature transducer assembly.

Figure 15. Reservoir temperature sensor installation.
contains approximately 2.6 in.\(^3\) of dyed silica gel conforming to Military Specification MIL-D-3716, Type IV. The initial color of the desiccant is deep to pale blue, depending on the desiccant condition. The color changes from pale blue to pink as the unit becomes saturated.

Reading desiccant condition remotely is accomplished by using reflected colored light from the irregular desiccant granules through the transparent housing. Figure 16 shows the concept employed to accomplish this objective.

![Figure 16. Optical desiccant sensor (early approach).](image)

Initial test results revealed that a major portion of the light was being reflected by the transparent housing since the light transmitter and receiver were on the same axis. The light source transmitter-receiver angle was changed from 13\(^\circ\) to 30\(^\circ\). No substantial improvements were noted. Various reflected angles were tested with the transmitter and receiver perpendicular to the desiccant housing axis in order to determine the maximum reflected light. This condition occurred with an included angle of 30 degrees between the transmitter and receiver. A second sensor housing (Figure 17) was originally made to support the grain of wheat light source and the fiber-optic terminal receiver. Subsequent testing revealed that color transmission became apparent but the intensity was not discernable to the viewer at the display panel.

Additional development effort dictated that the light source be brought closer to the transparent housing in order to increase the intensity of reflected light. A light source with a condensing lens was obtained to focus the light rays to one point. This change improved the reflective properties but, due to the irregular shape of the desiccant, the reflected light scatters in many directions and makes reflected colored light
difficult. As a final attempt a condensing lens was used on the reflected light source to intensify the reflected color.

The light source for the sensor was originally a grain-of-wheat bulb, but its intensity after passing through the desiccant was not strong enough to be seen at the display panel. The grain-of-wheat bulb was then replaced by a General Electric No. 2701
A halogen lamp requiring an operating voltage of 3.5 VDC and developing a maximum of 3.5 W, increasing the intensity by a factor of 20. Figure 18 shows plots of voltage, current, and power versus light intensity of the grain-of-wheat bulb; similar plots for the halogen bulb are shown in Figure 19. A comparison of the power versus light intensity of the grain-of-wheat and halogen bulbs is given in Figure 20.

Even with the halogen lamp, the reflected color properties were affected by the irregular angles of the desiccant crystals. Figure 21 shows the interim desiccant sensor installation. A decision was made to eliminate the desiccant and develop a moisture sensor. After several laboratory attempts, a disc was developed.

The desiccant sensor is a mixture of potassium bromide and cobaltous chloride, in a two-to-one ratio by weight, respectively. A description of the two components used in the desiccant is given in Table 2 (extracted from Ref. 2). The mixture is compressed into a half-inch diameter disc under a pressure of 22,000 psi and a vacuum of 25 in. mercury for 2 min. In order to focus the translucent disc color to a narrow point, a condensing lens was used adjacent to the disc support.

The lens is a condensing plano-convex lens Stock No. 10.0015 made by Rolyn Optics Company, Arcadia, California. The lens is made of spectacle crown glass (B-270) having a diameter of 0.295 ± .02 in. and a focal length of 0.512 in. ± 5%, as shown in Figure 22. The power of this lens is the reciprocal of the focal length, which gives a power of approximately 2 in.\(^{-1}\) or 76.9 diopters.

The lens and desiccant disc are mounted inside the cartridge by a slide type assembly, shown in Figure 23. The slide is secured in position by the gasket, screen filter, and felt rings in the end covers. The complete assembly is coupled with two through bolts.

Since no suitable halogen bulb lamp holders were available, one had to be designed and fabricated to support the bulb and provide the proper mechanical/electrical interface. The resultant design was the 1491-304-21 optical desiccant fitting shown in Figure 24. A modified MS connector supplied power to the lamp. In order to reduce the voltage from 5 VDC to approximately 3.5 V, a 20-Ohm, 5-W resistor was used in the mating connector.

Specifications for the light source are as follows:

- **GE Lamp Number** ............ 2701
- **Voltage** .................... 3.5 V
Figure 19. Halogen bulb characteristic.
Figure 20. Grain-of-wheat bulb/halogen bulb comparison.
Figure 21. Interim desiccant sensor installation.
### TABLE 2. DESICCANT COMPONENTS.

<table>
<thead>
<tr>
<th>POTASSIUM BROMIDE, KBr</th>
<th>COBALTOUS CHLORIDE (COBALT CHLORIDE (A) CoCl₂ (B) CoCl₂ 6H)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROPERTIES:</strong> White, crystalline granules or powder; pungent, strong, bitter saline taste; somewhat hygroscopic. Soluble in water and glycerin; slightly soluble in alcohol and ether; SP GR 2.749; M.P. 730°C; H.P. 1435°C.</td>
<td><strong>PROPERTIES:</strong> (A) Blue (B) ruby-red crystal. Soluble in water and alcohol; also soluble in acetone. SP GR (A) 3.348 (B) 1.924; M.P. (A) sublimes (B) 86.75°C.</td>
</tr>
<tr>
<td><strong>DERIVATION:</strong> Solutions of iron bromide and potassium carbonate are mixed and heated the solution filtered and concentrated and the bromide crystallized out.</td>
<td><strong>DERIVATION:</strong> By the action of hydrochloric acid on cobalt, its oxide, hydroxide or nate. Concentration gives (B) and dehydration (A).</td>
</tr>
<tr>
<td><strong>GRADES:</strong> Technical, C. P. N.F.; reagent; single crystals.</td>
<td><strong>USES:</strong> Absorbent for ammonia; gas masks; electroplating, sympathetic inks, hygrometer in soils and animal feeds; vitamin B₁₂; for magnesium refining; solid lubricant; mordant; catalyst; barometers.</td>
</tr>
<tr>
<td><strong>HAZARD:</strong> Moderately toxic by ingestion and inhalation.</td>
<td><strong>USES:</strong> Medicine; photography (gelatin bromide papers and plates); process engraving and lithography; special soaps, laboratory reagent.</td>
</tr>
</tbody>
</table>

Figure 22. Plano-convex lens.
Figure 23. Moisture detector fiber-optic circuit.

- Power .................... 2.5 W
- Life .................... 20 hr
- Bulb Type .................. TL 1/2
- Dimensions ................ 0.625 x 0.285 in.

Desiccant Fiber-Optic Link. In an effort to improve visibility at the display, power optical measurements were taken using a recently purchased Photodyne Model 22XL optical multimeter. The results indicated that the cable running from the optical sensor to the display unit had an unsatisfactory 32 dB/m optical loss instead of 10 dB/m, which would normally be expected with a properly installed line run. The fact that the cable run was installed during vehicle buildup precluded improvements in this area.

1.3.2 Pneumatic Bottles

1.3.2.1 Description

Pneumatic bottles are energy storage devices which are used as an emergency backup to a principal system. Servicing these bottles requires that the maintenance technician compensate for topping pressure as a function of ambient temperature. A typical nitrogen bottle service card is shown in Figure 25 (Ref. 3).

In this flight test program, two of the eight stored energy sources were modified to accept HYCOS sensors. One landing gear door dump bottle (Figure 27) was modified to accept a temperature-compensated pressure switch and a fiber-optic liquid detection circuit. The second emergency canopy dump bottle (Figure 26) was modified to accept another temperature-compensated pressure switch. Special fittings were manufactured to provide sensor bosses.
Figure 24. No. 1491901-304-21 optical desiccant fitting.
1.3.2.2 Temperature-Compensated Pressure Switch

At the onset of the program, it became evident that temperature-compensated pressure switches were not off-the-shelf hardware. NeoDyn Incorporated of Chatsworth, California, was contracted to develop and build temperature-compensated pressure switches for the hydraulic monitoring system program. An initial Grumman sensor specification (Number 204) was prepared.

**Switch Description.** The switch is an all-welded, hermetically sealed unit which physically conforms to Figure 28. The switch senses applied pressure and compares it to an internal sealed self-contained reference pressure within the probe, which is at the same temperature as the sensed media. A proprietary, welded stainless-steel sensing diaphragm is exposed to the probe reference pressure on one side and to the sensed pressure on the other side. Pressure settings, which vary as a function of sensed and reference pressure, are accomplished through a force balance interaction between a sensing diaphragm and a Belleville spring reference load. Since the reference pressure varies directly with sensed temperature, pressure settings are a function of temperature. Variation of reference pressure with temperature is shown graphically in Figure 29.
Figure 26. Emergency canopy dump bottle installation.
Figure 27. Landing gear door dump bottle installation.
Figure 28. Temperature-compensated pressure switch.
Figure 29. Plot of pressure vs temperature for nitrogen.

A precision snap-action electrical switch exposed to sensed pressure is positioned within the mechanism stroke limits to provide electrical circuit control at predetermined differences between sensed and reference pressure. The complete assembly is housed within an all-welded, high-pressure hermetically sealing housing. Figure 30 shows the diagrammatic circuit.

Figure 30. Temperature-compensated pressure switch: diagrammatic circuit.
Laboratory testing of a pneumatic charge at variable temperatures verified the pressure switch temperature concept. Data for this switch (Grumman specification 204-1) is shown in Figure 31.

The reference temperature compensating gas is dry nitrogen that is hermetically sealed within the unit.

Switch Testing. Switch testing was conducted and found to fall within acceptable limits as defined by source control specification 204-2. The test results are listed in Table 3 and plotted in Figure 32.

1.3.2.3 Fiber-Optic Liquid Detection Circuit

The fiber-optic fluid detection circuit employs the properties of refractive index. If a diagonal gap exists between two fibers, light transmission will not jump the gap and will be absorbed by the core. In the presence of suitable fluid, the light will pass through the fluid and appear at the display panel. Water will be indicated by a white light and hydraulic oil will appear as a red light.

The liquid detector concept uses the optical properties of the light-conducting media. It is necessary to determine not only the properties of the light-conducting cables but also those of the fluids.

One of the important parameters of any fluid or light-conducting medium is its refractive index, defined as the ratio of the velocity of light in air to that in a given

- ACTUATION POINTS (SEE GRAPH)
- INCREASING PRESSURE: BY "A" MAX
- DECREASING PRESSURE: WITHIN BAND "B-C"

Figure 31. Switch actuation points vs temperature (Specification 204-1)
TABLE 3. TEMPERATURE-COMPENSATED PRESSURE SWITCHES (GRUMMAN SPECIFICATION 204-2).

<table>
<thead>
<tr>
<th>P/N 1500 PT89-2, S/N 001</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AMBIENT</strong></td>
</tr>
<tr>
<td>+69°F</td>
</tr>
<tr>
<td>69°F</td>
</tr>
<tr>
<td><strong>HOT</strong></td>
</tr>
<tr>
<td>273°F</td>
</tr>
<tr>
<td>275°F</td>
</tr>
<tr>
<td><strong>COLD</strong></td>
</tr>
<tr>
<td>-48°F</td>
</tr>
<tr>
<td>-55°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P/N 1500 PT89-2, S/N 002</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AMBIENT</strong></td>
</tr>
<tr>
<td>69°F TO 73.5°F</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>COLD</strong></td>
</tr>
<tr>
<td>-64.5°F TO -69°F</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>HOT</strong></td>
</tr>
<tr>
<td>+274.5°F TO +272°F</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

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TRIP POINT RANGE INCREASING PRESSURE

TRIP POINT RANGE DECREASING PRESSURE

A. P/N 1500 PT 89-2, S/N 001

B. P/N 1500 PT 89-2, S/N 002

Figure 32. Switch actuation points vs temperature (Grumman Specification 204-2).
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solid or fluid taking into account the angle at which the light beam travels. Willebrond Snell's Law of Sines states that the index of refraction is a constant, equal to the sine of the angle of incidence divided by the sine of the angle of refraction. Table 4 lists the refractive indices of various materials.

**TABLE 4. REFRACTIVE INDICES OF VARIOUS ELEMENTS.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Refractive Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>1.330</td>
</tr>
<tr>
<td>MIL-H-83282</td>
<td>1.456</td>
</tr>
<tr>
<td>MIL-H-6083</td>
<td>1.468</td>
</tr>
<tr>
<td>AIR</td>
<td>1.003</td>
</tr>
<tr>
<td>CROFON (DUPONT)</td>
<td></td>
</tr>
<tr>
<td>- CORE</td>
<td>1.490</td>
</tr>
<tr>
<td>- CLAD</td>
<td>1.392</td>
</tr>
<tr>
<td>CABLE, FIBER-OPTIC TRANSMISSION</td>
<td></td>
</tr>
<tr>
<td>- CORE</td>
<td>1.62</td>
</tr>
<tr>
<td>- CLAD</td>
<td>1.52</td>
</tr>
<tr>
<td>LUCITE/PLEXIGLASS</td>
<td>1.51</td>
</tr>
<tr>
<td>R80-2036-036(T)</td>
<td></td>
</tr>
</tbody>
</table>

During the course of development, it became apparent that a single large-diameter fiber would be placed within the pneumatic bottle to detect the presence of a liquid, using the properties of the liquid for light coupling. The fiber angle in which a light ray would be lost when traveling through the conduit, unless the presence of water and/or hydraulic oil were available to permit optical coupling, was then derived mathematically. An analysis of the derivation follows:
\[
\sin \theta_c = \frac{n_2}{n_1} \\
\sin \theta_2 = \frac{n_1}{n_2} \sin \theta_c \\
\sin 90^\circ = \frac{n_1}{n_2} \sin \theta_c \\
\sin \frac{90^\circ}{\sin \theta_c} = \frac{n_1}{n_2} \\
\frac{1}{\sin \theta_c} = \frac{1.49}{1.00} \\
\sin \theta_c = \frac{1.00}{1.49} (1) \\
\theta_c = \sin^{-1} \frac{1.00}{1.49} = 42^\circ \\
\theta = 90^\circ - \theta_c \\
\angle A = \phi \\
\angle B = 90^\circ + 21^\circ \\
\theta = 90^\circ - 42^\circ \\
\angle C = \theta \\
\theta = 48^\circ \\
\Delta ABC = \theta + (90^\circ + 21^\circ) + \phi \\
180 = \theta + (90^\circ + 21^\circ) + \phi \\
180 = 48 + 90 + 21 + \phi \\
\phi = 21^\circ \\
\]

Any beveled cut less than 21° will result in having light absorbed by the core.

Definitions

\( \theta_c \) = critical angle  \\
\( \phi \) = angle required (beveled cut angle)  \\
\( n \) = refractive index  \\
\( \theta \) = angle used in solving \( \phi \)

Assume \( n_2 = 1.33 \) (index of refraction for water)

\[
\sin \theta_c = \frac{1.33}{1.49} \\
\theta_c = \sin^{-1} \frac{1.33}{1.49} = 63^\circ \\
\theta = 90^\circ - \theta_c \\
\theta = 90^\circ - 63^\circ \\
\theta = 27^\circ \\
180^\circ = \theta + (90^\circ + 21^\circ) + \phi \\
180^\circ = 27^\circ + 90^\circ + 21^\circ + \phi \\
\phi = 42^\circ; \text{ beveled angle is increased, resulting in light being transmitted.} (1)
\]

Since \( \theta_c \) (63°) exceeds the critical angle (42°), light will be transmitted through the light guide.

\[
\sin \theta_c = \frac{1.4635}{1.49} \\
\theta_c = \sin^{-1} \frac{1.4635}{1.49} = 79.2^\circ \\
\]

(2)

Since \( \theta_c \) (79.2°) exceeds the critical angle (42°), light will be transmitted through light guide with a MIL-H-5606 coupling.
It has been shown in the laboratory that this approach works in the presence of either fluid. However, instead of using one multistrand fiber-optic cable it became necessary to employ two single-fiber cables with an external light source, with the flexible sensing probe at the bottom of the bottle. Figure 33 shows the concept of an early liquid sensor (Ref. dwg 1491901-307). This approach had screw-on terminals attached to the fiber-optic cables at both the sensing probe and a lucite conductor. The lucite conductor provided an optical means of passing light out of the pneumatic bottle while still retaining the pressure seal. This method proved unacceptable as losses through the fittings and connectors were so drastic that no detectable amount of light could be found at the output fiber. Modifications were made and all unnecessary connectors removed. The result was a design which had one continuous fiber carrying inputted light, a gap allowing fluid detection, and another continuous fiber carrying outputted light. This design (Figure 34) combined the sensor with the fiber-optic cables and greatly reduced transmission losses.

Figure 33. Liquid sensor assembly (early version).
Figure 34. Liquid sensor assembly (improved version).
Two types of fiber-optic cables were purchased from Valtec Corporation, West Boylston, Massachusetts. The transmission cables were of the bifurcated and the single cable types. The bifurcated cabled type is used on the pneumatic bottle detection loop, whereas the single cable is used on the desiccant color-detection circuit.

Some of the parameters include:

- Number of fibers: 222-234
- Fiber diameter: 0.0031
- Bundle diameter: 0.045
- Acceptance cone angle: $68^\circ$
- Cone index of refraction: 1.62.

Additional cable information is provided in Appendix B, Specification No. 206. All cables use fiber-optic connectors in accordance with MIL-L-85044/1, developed by the Naval Ocean Systems Laboratory in San Diego, California. MIL-L-85044/1 covers pressurized bulkhead connectors, Type 1, for relatively low-pressure systems. These stainless steel connectors were manufactured and supplied by the Sealectro Corporation in Mamaroneck, New York.

The cable terminal ends were installed in accordance with the procedure specified on Page 6 of MIL-C-85044 using an epoxy bonding agent to fasten the assembly together.

Properties of Crofon Light Guides. Crofon is a DuPont registered trade name for plastic fiber light guides. The data in Table 5 were taken from a DuPont publication on Crofon Fiber Optics (Ref. 4) and a Machine Design article (Ref. 5). Table 5 shows some properties of the Crofon Fibers and their polyethylene jackets. Figure 35 shows a light ray entering the light guide.

Transmission of light through Crofon varies as a function of length. It is also dependent on input light intensity, output light interfaces, and any gap through the optic circuit. Figure 36 shows the transmission efficiency of white light through fully polished light guides.

Single bends are employed in the liquid detection circuit at the sensor end. It is desirable to ascertain the minimum bend radius for the single 1056 light guide. Too severe a bend will cause a significant light loss due to degradation of the cladding fiber itself. Figure 37 shows typical light transmission for several grads of Crofon light.
### TABLE 5. PROPERTIES OF CROFON FIBERS WITH POLYETHYLENE JACKETS.

**A. IDENTIFICATION: CROFON 1056**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Fibers:</td>
<td>1</td>
</tr>
<tr>
<td>OD</td>
<td>0.111 ± 0.006 IN.</td>
</tr>
<tr>
<td>Critical Angle:</td>
<td>69°</td>
</tr>
<tr>
<td>Fiber Diameter:</td>
<td>0.056 IN.</td>
</tr>
<tr>
<td>Jacket Material:</td>
<td>POLYETHYLENE</td>
</tr>
<tr>
<td>Fiber:</td>
<td>POLYMETHYL METHACRYLATE</td>
</tr>
<tr>
<td>Acceptance Angle:</td>
<td>64°</td>
</tr>
<tr>
<td>Critical Angle:</td>
<td>69°</td>
</tr>
<tr>
<td>Index of Refraction:</td>
<td></td>
</tr>
<tr>
<td>- Core n&lt;sub&gt;D&lt;/sub&gt; = 1.490</td>
<td></td>
</tr>
<tr>
<td>- Clad n&lt;sub&gt;D&lt;/sub&gt; = 1.392</td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Limits:</td>
<td>-40°F to 175°F</td>
</tr>
</tbody>
</table>

**B. TYPICAL PROPERTIES OF POLYETHYLENE**

<table>
<thead>
<tr>
<th>ASTM Test</th>
<th>Property Description</th>
<th>Low Density</th>
<th>Medium Density</th>
<th>High Density</th>
<th>Ultra-High Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>D792</td>
<td>Specific Gravity</td>
<td>0.910-0.925</td>
<td>0.926-0.940</td>
<td>0.941-0.965</td>
<td>0.928-0.941</td>
</tr>
<tr>
<td>D570</td>
<td>Specific Volume (in.³/LB)</td>
<td>30.4-29.9</td>
<td>29.9-29.4</td>
<td>29.4-28.7</td>
<td>29.4</td>
</tr>
<tr>
<td></td>
<td>Water Absorption, 24 HR, 1/8-IN. THK (%)</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>D638</td>
<td>Tensile Strength (PSI)</td>
<td>600-2,300</td>
<td>1,200-3,500</td>
<td>3,100-5,500</td>
<td>4,000-6,000</td>
</tr>
<tr>
<td>D683</td>
<td>Elongation (%)</td>
<td>90-800</td>
<td>50-600</td>
<td>60-1,000</td>
<td>200-500</td>
</tr>
<tr>
<td>D638</td>
<td>Tensile Modulus (10⁶ PSI)</td>
<td>0.14-0.18</td>
<td>0.25-0.55</td>
<td>0.7-1.8</td>
<td>0.20-1.10</td>
</tr>
<tr>
<td>D785</td>
<td>Hardness, Rockwell R</td>
<td>0-100</td>
<td>15</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>D790</td>
<td>Flexural Modulus (10⁵ PSI)</td>
<td>0.08-0.60</td>
<td>0.60-1.15</td>
<td>1.0-2.0</td>
<td>1.0-1.7</td>
</tr>
<tr>
<td>D256</td>
<td>Impact Strength, Izod (FT-LB/IN. OF NOTCH)</td>
<td>NO BREAK</td>
<td>0.5-16</td>
<td>0.5-20</td>
<td>NO BREAK</td>
</tr>
</tbody>
</table>

**C. THERMAL**

<table>
<thead>
<tr>
<th>ASTM Test</th>
<th>Property Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>D177</td>
<td>Thermal Conductivity (10⁻⁴ CAL-CM/SEC-CM²-°C)</td>
<td>8.0</td>
</tr>
<tr>
<td>D690</td>
<td>Coef of Thermal Expansion (10⁻⁵ IN./IN. - °C)</td>
<td>10-22</td>
</tr>
<tr>
<td>D648</td>
<td>Deflection Temperature (°F)</td>
<td>90-105</td>
</tr>
<tr>
<td></td>
<td>AT 264 PSI</td>
<td>100-121</td>
</tr>
<tr>
<td></td>
<td>AT 66 PSI</td>
<td>120-165</td>
</tr>
<tr>
<td></td>
<td>Continuous, No-Load Service Temp (°F)</td>
<td>180-212</td>
</tr>
<tr>
<td></td>
<td></td>
<td>220-250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>250</td>
</tr>
</tbody>
</table>

**D. ELECTRICAL**

<table>
<thead>
<tr>
<th>ASTM Test</th>
<th>Property Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>D149</td>
<td>Dielectric Strength (V/MIL)</td>
<td>460-700</td>
</tr>
<tr>
<td>D150</td>
<td>Dielectric Constant</td>
<td>2.25-2.35</td>
</tr>
<tr>
<td></td>
<td>AT 60 Hz</td>
<td>2.25-2.35</td>
</tr>
<tr>
<td></td>
<td>AT 10³ Hz</td>
<td>2.25-2.35</td>
</tr>
<tr>
<td>D150</td>
<td>Dissipation Factor</td>
<td>0.0002</td>
</tr>
<tr>
<td></td>
<td>AT 10³ Hz</td>
<td>0.0003</td>
</tr>
<tr>
<td>D257</td>
<td>Volume Resistivity (Ohm-CM)</td>
<td>10¹⁵</td>
</tr>
<tr>
<td></td>
<td>AT 73°F, 50% RH</td>
<td>10¹⁵</td>
</tr>
<tr>
<td>D495</td>
<td>ARC Resistance (SEC)</td>
<td>135-166</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200-235</td>
</tr>
</tbody>
</table>

**E. OPTICAL**

<table>
<thead>
<tr>
<th>ASTM Test</th>
<th>Property Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>D545</td>
<td>Refractive Index</td>
<td>1.51</td>
</tr>
<tr>
<td>D1000</td>
<td>Transmittance (%)</td>
<td>4.50</td>
</tr>
</tbody>
</table>

*kv/cm
guides. It becomes evident that bend radius should be as large as possible to minimize transmission loss.

**Fiber-Optic Connectors.** Numerous types of fiber-optic connectors were considered for use in HYCOS. The major concern was the availability of a high-pressure bulkhead fitting capable of sealing 3000 psi pneumatic pressure. As of February 1978, no bulkhead connectors on the market were capable of resisting this high pneumatic pressure differential without leakage.

![Diagram](image)

**Figure 35.** Crofon light guide properties.

![Graph](image)

**Figure 36.** Transmissivity of Crofon light guides.
Grumman was informed that the proposed MIL-C-85044/1 Connector, Fiber-Optic, Pressurized Bulkhead, Type I, Class I was being manufactured by Sealectro Corporation, Mamaroneck, New York. Sealectro indicated that the connectors were in stock.

Sealectro part numbers and unit weights are:

- Cable Connector: 55-907-0149-89 0.1056 Oz
- In-Line Splice: 55-972-0039-89 0.1746 Oz
- Bulkhead Mounting Connector: 55-975-0049-89 0.3527 Oz

All parts are made of corrosion-resistant stainless steel. Figure 38 shows a typical fiber-optic terminal used in HYCOS. The connector has a fiber terminal diameter of 0.0465 in. (area = 0.001698 in.$^2$). For HYCOS, special connector interfaces were designed to withstand the intended environment. Figure 39 shows a Display Panel fiber-optic terminal.

Pressure Seal. In order to transport light through a pressure seal, it became necessary to design a seal that would satisfy system integrity and provide maximum light transmissivity. Concept Number One, shown in figure 40A, employed a transfer tube containing machined and polished clean acrylic rod for light transmission. Although

Figure 37. Effect of bend radius on light transmissivity.
initial pressure testing at 3000 psi revealed good results, the optical transmission properties were very poor. Almost all of the light generated at the outside source was lost due to the optical properties of the acrylic rod. A revised approach, shown in Figure 40B, eliminated the acrylic rod and utilized the fiber-optic cable up to the external connector interface. Initial testing revealed that the plastic tended to creep and extrude under prolonged exposure to pressure. Additional development effort overcame this problem and considerably improved the overall transmission efficiency. Limited operational cycling and proof testing verified this approach. No problems were encountered during the flight test program.

1.3.3 Hydraulic Pump/System

1.3.3.1 Flow Sensor Description

The flow sensor is a device placed in series with a hydraulic system or component which gives an external indication when a specific flow value has been exceeded under controlled conditions.

1.3.3.2 System Quiescent Flow Sensor

System quiescent flow values for the A-6E system were established at 0.5 to 1.5 gpm. This will vary depending on which system components are on the line during a no-input system demand condition. For the A-6E combined system, quiescent flow limits of 4.5±1 gpm were established as excessive internal flow.
Figure 39. Display panel fiber-optic terminal.
A. PNEUMATIC HIGH-PRESSURE SEAL CONFIGURATION

B. IMPROVED HIGH-PRESSURE SEAL

Figure 40. Pressure seal.
The system flow sensor incorporates an electrically actuated locking device which prevents indicator actuation during normal system flow demands. Under quiescent flow conditions, the flow is measured through a movable orifice. Flows beyond the required measured values are shunted across the movable orifice. Figure 41 shows a typical quiescent flowmeter used in the flight test program. Once the indicator trips due to excessive flow conditions, it must be manually reset.

Figure 41. Quiescent flow sensor.

The flow sensor meters actual quiescent flow through a flow resistor that produces a desired differential pressure. The differential pressure, equated to a specific maximum permissible quiescent flow leakage, generates a signal. During normally higher system flow demand, the calibrated restrictor bypasses through additional flow passages at acceptable additional pressure differentials across the entire sensor.
Plant 14 Hydraulic Laboratory generated calibration data that produced the curve shown in Figure 42. The curve shows a trip point of 4.18 gpm which is within the design limits. It should be noted that the curve flattens out above 8 gpm.

The actual installation on the flight test vehicle is shown in Figure 43.

![Diagram](Image)

Figure 42. Calibration: flow sensor, bypass type, quiescent flow.

1.3.3.3 Pump Case Drain Flow Sensor

The pump case drain flow sensor is similar to the system quiescent flow sensor in design but does not incorporate a lockout device since pump case flow does not significantly vary over the hydraulic pump flow range. A failsafe bypass device is incorporated, however, to preclude high back pressure due to inadvertent momentary block liftoff. Excessive pump case flow was established at 1.25 to 1.75 gpm. Figure 44 shows a typical pump case flow sensor. A case drain flow calibration curve is presented in Fig. 45. Actual switch trip occurred at 1.47 gpm, Figure 46 shows a partially obscured installation in the A-6E test vehicle.

1.3.3.4 Rudder Actuator Quiescent Flow Sensor

Excessive rudder actuator internal leakage is detected by an in-line flow sensor located in the pressure line. The unit is similar in construction to the system quiescent flow sensor, but is sized for a lower flow. Since normal rudder actuator quiescent leakage rates are very low, a value of 0.625 to 0.875 gpm was selected for the A-6E rudder actuator. Figure 47 shows the rudder actuator quiescent flow sensor.
Figure 44. Pump case drain flow sensor.

Figure 45. Calibration: pump case drain flow sensor, bypass type.
Figure 46. Pump case drain flow sensor installation.
Flow versus pressure drop data produced the curve shown in Figure 48. The installation is shown in Figure 49. Note that the sensor was installed in the pressure line.

1.3.3.5 System Pressure Switch

The system pressure switch serves two functions: it indicates low system pressure during system operation and provides panel circuitry to the flow sensors and elements.

The elapsed time meter on the panel is actuated by the pressure switch; the flow sensor circuits are dependent on the pressure circuit being on.

For this purpose, a switch (Figure 50) manufactured by Sigmanetics of Mountain Lakes, New Jersey, was incorporated. The switch weighs less than 0.085 lb and actuates on decreasing pressure of 2300 ± 100 psi. The switch installation is shown in Figure 51.
Figure 48. Calibration: rudder actuator quiescent flow sensor, bypass type.

- P/N AC-A770-83, S/N 1
- OIL TEMPERATURE: 102±2 °F
- SWITCH TRIP POINT: 0.82 GPM
Figure 50. System pressure switch.
1.3.3.6 Case Drain Flow Temperature Switch

Excessive case drain flow indicates hydraulic pump degradation, resulting in system fluid temperature rise. By installing a fluid temperature switch in series with the flow sensor, an excessive temperature limit can be detected.

Type II hydraulic systems operate at a 275°F maximum. A value of 300 ± 20°F was selected as the trip limit on a Texas Instrument Klixon manual reset temperature switch.

The switch was mounted to the case drain line near the pump by using a clamp-on adaptor. This switch must be manually reset after being tripped.

1.3.3.7 Relief Valve Leakage

Relief valve leakage was measured with a probe-type manual reset temperature switch as used to measure pump case drain flow. Trip setting for this switch was 300 ± 20°F.

Type II hydraulic systems operate at 275°F maximum. A value of 300°F was selected as the trip limit on a Neo-Dyne model 1103TR119 manual reset temperature switch.

The switch probe is immersed in the fluid flow and contains n-propyl alcohol as the sensing medium. Temperature sensing is accomplished by exposing a welded corrosion-resistant steel diaphragm to changes in pressure created by expanding fluid in the probe. Figure 52 shows pressure versus temperature slot for this fluid at constant volume. Temperature settings are determined by a force-balance interaction between the sensing diaphragm and a snap-action Belleville spring system. An electrical switch assembly positioned within the mechanism's stroke limit provides electrical circuit control at predetermined temperatures. The manual reset button functions as both a visual indication and a mechanism reset after switch actuation. The temperature switch is illustrated in Figure 53. Installation is shown in Figure 51.

1.3.4 Hydraulic Accumulators

1.3.4.1 Description

Hydraulic accumulators are energy storage devices used in many aircraft hydraulic systems. They usually employ stored gas as the variable energy source. Their applications include hydraulic pump ripple attenuation, momentary system power overdemand conditions, and performance of emergency actuation functions such as deploying a ram air turbine via a hydromechanical actuator.
Figure 52. Pressure versus temperature of n-propyl alcohol at constant volume.
Figure 53. Manual reset temperature switch.
The work output is dependent on initial precharge pressure, precharge temperature, and delta volume change caused by piston movement under constant temperature conditions:

\[ P_1 V_1 = P_2 V_2 \]

and

\[ W = \int_{V_1}^{V_2} P \, dv \]

If we consider an isentropic (no heat flow condition), then

\[ W = K \int_{V_1}^{V_2} \left( \frac{dv}{V^{1.4}} \right) \]

Since the variables are precharge pressure, precharge temperature, and piston displacement, the piston displacement for a final hydraulic system pressure of 3000 psi is a function of initial precharge conditions (Ref. 6, NADC TR 75168-30-Pg 33).

This monitoring effort was initiated to develop a method of determining accumulator precharge irrespective of whether the accumulator is fully or partially discharged. The variables required to determine this condition are charging pressure, temperature, and piston displacement.

Figure 54 shows the variation of piston displacement versus precharge pressure for a 50 in\(^2\) accumulator. Figure 55 shows a plot of piston displacement versus precharge pressure versus temperature at constant 3000 psi pressure. Figure 56 is a nomograph developed to determine precharge pressure.

In order to measure accumulator piston displacement, precharge pressure (accumulator pressure), and precharge temperature, various methods were investigated to ascertain their suitability to accumulator applications. These specific sensing methods will be defined in subsequent paragraphs.
1.3.4.2 Piston Displacement Sensors

Several methods of determining piston displacement within a pressurized accumulator were investigated. They include:

- A direct type in which a rod attached to the piston passes through a dynamic seal
- A reflected energy type which measures reflected IR energy from a movable surface.

The first direct type seemed to offer less development risk than the other method since the output could be processed easier with the microprocessor circuits. This direct type included a linear potentiometer with its axis parallel to the accumulator piston axis. By affixing the movable piston rod to the linear potentiometer, a direct
relationship can be obtained by measuring resistance versus displacement. A 4 k
Bournes potentiometer was chosen for this application. Figure 57 shows this config-
uration installed in the A-6E test vehicle. In order to provide for potentiometer
extension clearances, the mounting bracket was offset.

Normally, it has been necessary to empty the fluid from the accumulator to measure
precharge pressure. However, utilizing a newly developed equation involving system
pressure, volume, temperature, and displacement it is now possible to determine pre-
charge pressure without displacing the fluid. Displacement is expressed as a ratio of
resistances measured by a linear potentiometer. The equation, graphically displayed in
the nomograph of Figure 56, is derived as follows:
Figure 56. Precharge pressure nomograph.
Figure 57. Ram air turbine accumulator installation.
\[ \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \]

\[ P_1 = P_{\text{Precharge}} (P_{pr}), \quad V_1 = 50 \text{ in}^3, \quad T_1 = 70 \, ^{\circ}\text{F} = 530 \, ^{\circ}\text{R} \]

\[ P_2 = P_{\text{system}} (P_{sys}), \quad V_2 = \text{Volumetric Displacement} = 50 \left( \frac{R}{3850} \right) \]

\[ T_2 = (T_2 + 460)^{\circ}\text{R} \]

\[ \frac{(P_{pr}) (50)}{530} = \frac{(P_{sys}) (50) (R/3850)}{(T_2 + 460)^{\circ}\text{R}} \]

\[ (530) (P_{sys}) (50) (R/3850) = (P_{pr}) (50) (T_2 + 460) \]

\[ P_{pr} = \frac{(530) (P_{sys}) (R/3850)}{(T_2 + 460)} \]

Another indirect method of determining piston position using reflected IR energy was investigated. This concept, shown in Figure 58, utilizes an external IR light source whose energy is reflected from the bottom side of the accumulator piston and picked up by an IR photodiode. Preliminary nonpressurized test results are plotted in Figure 59. It should be noted that the curve is relatively flat up to approximately 4 in. of stroke and then changes markedly. The test circuit wiring is shown in Figure 60.

1.3.4.3 Pressure Transducers

The Entran EPS-1032 (Entran Devices, Little Falls, New Jersey) miniature pressure transducer is a thread-mounted semiconductor strain-gage sensor which fits into a 10-32 UNF threaded boss. The transducer employs a face seal and has a full-scale output of 143 mV at 3000 psi pressure with 5 V input (room temperature). There is, however, a temperature shift when tested at -40 and 250°F. Calibration curves for this unit, shown in Figure 61, are very linear over the normal operating range (0-3000 psi). Sensitivity of the transducer is 0.0485 mV/psi. The unit is normally compensated for linearity by using an external compensation module from 80 to 180°F. The wiring diagram is shown in Figure 62.
Figure 58. Photo-optic accumulator piston displacement sensor.

Figure 59. Photo-optic accumulator piston sensor test results.
Figure 60. Photo-optic displacement sensor wiring diagram.
Figure 61. Entran transducer: output voltage versus pressure.

Figure 62. ESP-1032 pressure transducer wiring diagram.
Since the intended application encompassed broader temperature ranges, an extended calibrated temperature range was made. Table 6 shows performance data for the Entran ESP-1032 transducer. Envelope dimensions for a typical unit are shown in Figure 63 (Ref. 7).

**TABLE 6. ENTRAN ESP-1032 TRANSDUCER DATA**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL</td>
<td>EPS-1032-2500 (.33), S/N 10 H8H-C1-1</td>
</tr>
<tr>
<td>TYPE</td>
<td>MINIATURE PRESSURE</td>
</tr>
<tr>
<td>RANGE</td>
<td>2500 PSIG</td>
</tr>
<tr>
<td>EXCITATION</td>
<td>6.0 TO 8.0 V</td>
</tr>
<tr>
<td>OVERPRESSURE</td>
<td>4000 PSIG</td>
</tr>
<tr>
<td>OPERATING TEMPERATURE</td>
<td>-60 TO 250 °F</td>
</tr>
<tr>
<td>TEMPERATURE COMPENSATION</td>
<td>-60 TO 250 °F</td>
</tr>
<tr>
<td>EXCITATION</td>
<td>6 VDC</td>
</tr>
<tr>
<td>SENSITIVITY</td>
<td>0.0469 mV/PSIG AT 77 °F</td>
</tr>
<tr>
<td>THERMAL SENSITIVITY SHIFT</td>
<td>&lt; ± 2%/100 °F</td>
</tr>
<tr>
<td>THERMAL ZERO SHIFT</td>
<td>&lt; ± 1.5% FS/100 °F</td>
</tr>
<tr>
<td>INSTALLATION TORQUE</td>
<td>15 IN.-LB</td>
</tr>
<tr>
<td>IMPEDANCE</td>
<td>INPUT: 430 Ω</td>
</tr>
<tr>
<td></td>
<td>OUTPUT: 239 Ω</td>
</tr>
</tbody>
</table>

**Figure 63. Pressure transducer envelope.**
1.3.4.4 Temperature Sensor

The temperature sensor used in the accumulator circuit is the same as that used in
the hydraulic reservoir circuit. This sensor assembly uses an analog device: the
AD540C integrated circuit temperature transducer. A complete description and test data
can be found in Subsection 1.3.1.4.

1.3.5. Rudder

1.3.5.1 Description

As part of the control logic, the rudder was selected to demonstrate the disconnect
logic. The concept was to measure and compare input-output signals at or close to the
input source rudder pedal and rudder pivot axis.

Since accessibility of the rudder pedal area was not prevalent, the input potentiom-
eter was installed in the turtle deck area.

1.3.5.2 Rudder Differential Displacement Circuit

In some aircraft systems, mechanical disconnects have occurred due to disengage-
ment of a bolt or clevis pin in the mechanical/electromechanical linkage. This would not
be evident in aircraft which do not have flight-control surface display indicators on the
cockpit panel.

System disconnects can be detected by comparing an input signal to a corresponding
output signal. If the output signal does not follow or null out the input signal, micro-
processor circuitry will indicate a disconnect condition until corrective action is taken.

Linear or rotary potentiometers are another type of displacement measuring device.
Rotary or rectilinear movement of the input shaft positions a contactor (wiper) along or
around a continuous resolution resistance element. These devices have practically zero
backlash, are insensitive to vibration, and are compact and lightweight. In addition,
their cost is low. Rotary transducers are made in multiples of 360° rotation; some cover
3600° (10 turns). Figure 64 shows typical transducer wiring diagrams and a represen-
tative plot.

The signal on both transducers are fed to a bridge circuit which detects a variation
or omission of an input signal. When this imbalance occurs, the HYCOS circuit is
energized.
Figure 64. Potentiometer transducers.
Table 7 lists pertinent information on transducers used on the A-6E rudder actuator circuit. Figure 65 shows the turtle-deck potentiometer installation, and Figure 66 shows the rudder position potentiometer installation.

Calibration curves for the installations are shown in Figure 67.

**TABLE 7. A-6E RUDDER POTENTIOMETER TRANSUDERS.**

<table>
<thead>
<tr>
<th>TRANSDUCER</th>
<th>MANUFACTURER</th>
<th>SPEC NO.</th>
<th>TYPE</th>
<th>VALUES</th>
<th>LINEARITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUDDER POSITION POTENTIOMETER</td>
<td>ALLEN BRADLY</td>
<td>MIL-R-94</td>
<td>RV45A45D103A</td>
<td>10,000</td>
<td>±10%</td>
</tr>
<tr>
<td>TURTLE DECK BELL CRANK POTENTIOMETER</td>
<td>ALLEN BRADLY</td>
<td>MIL-R-94</td>
<td>RV45A45D103A</td>
<td>10,000</td>
<td>±10%</td>
</tr>
</tbody>
</table>

Figure 65. Turtle deck bell crank potentiometer installation.
Figure 66. Rudder position potentiometer installation.

Figure 67. Rudder differential displacement potentiometer calibration.
Two basic types of systems were originally considered:

- DC-DC displacement transducers
- Linear or rotary potentiometers.

In DC-DC displacement transducers, an oscillator is used to generate an AC signal which then couples a multiple-leg transformer to a moveable core. The coupling efficiency of the core then determines the position of the element being measured. The signal is then demodulated or rectified to a DC output. Figure 68 shows a typical circuit diagram and output curve.

![Circuit Diagram](image)

**Figure 68.** DC-DC displacement transducer.
1.3.6 Display Panel

1.3.6.1 Description

The readout panel is a ground-accessible unit which has clearly labeled lights for indicating component failure conditions. The panel is not accessible to the pilot during normal flight, although certain circuits could be interfaced with a caution-warning panel in the cockpit. Figure 69 shows a typical accessible HYCOS panel location on an operational aircraft. The panel can be interrogated both with and without aircraft or ground-support power.

The primary display panel is a self-contained unit measuring approximately 12 in. by 6.5 in. by 4.5 in. This size was chosen primarily to fit into an available existing space in the proposed flight-test vehicle. When required the size, shape, and weight could be configured to specific vehicle installations. The panel weighs 6.0 lb and contains microelectronic circuits and associated interface elements which are described in detail in subsequent subsections.

Basically, the panel houses:

- Display grain of wheat lamps
- Fiber-optic interface outlets
- Lamp drivers
- Counters
- Shift registers
- Power interface
- Sensor and system test circuits
- Microprocessor
- Analog-to-digital converters
- Memories
- Rechargeable NiCd batteries
- Battery heating and charging circuits.

Figure 70 shows the display panel connector interfaces, while Figure 71 shows the panel installed on the flight test vehicle.
Figure 69. HYCOS panel location on typical aircraft.
Figure 70. HYCOS panel showing bottom connectors.
1.3.6.2 Display Panel Indicators

Several types of display indicators were considered at the beginning of the program. These included LEDs, LCDs, LCDs with backscatter lighting, and subminiature incandescent lamps. Subminiature incandescent lamps are called "grain of wheat" bulbs due to their small size. After careful evaluation, the decision was made to utilize subminiature incandescent lamps since they offer good visibility during daylight and have an acceptable operating temperature range.

LEDs have some advantages but are not readily visible during daylight high-sun conditions. Since the intent of Hycos is to place the display panel in an external ground-accessible area, the subminiature incandescent lamp was selected.

Table 8 compares the indicators considered. Size-for-size, the subminiature incandescent lamps exhibit good visibility under sunlight conditions. Although their current drain is higher than the other types considered, their ability to provide good daylight visibility became an overpowering factor. The use of lamps with a 60 mA rating would provide good service life (5000 hr average) and adequate illumination under sunlight conditions. Figure 72 illustrates the basic types of indicator displays (Ref. 8). Figure 73 is a plot of spectral output for various display types as observed by human eye response.

Since as many as 50 display indicators could light up under circuit test conditions, the NiCd battery momentary current drain could be 3 A or higher, neglecting the power requirements for the microprocessor and associated circuits. This condition occurs when the ship's battery and/or engine electrical power is on. This is a momentary high drain for the NiCd battery and did not significantly affect service life. With ship's power on, adequate monitoring panel and sensor current is available.

Another technique for reducing power drain is to use the microprocessor timer to sequentially test each subsection when the circuit test button is depressed. Under system test conditions, it is highly unlikely that more than five components would indicate failure modes and require power at any one time.

All grain of wheat bulbs are replaceable from the front of the panel by first removing the red plastic cover. Individual and collective circuit and bulb tests can be performed to verify the integrity of each indicator bulb.
<table>
<thead>
<tr>
<th>DISPLAY TYPE</th>
<th>POWER REQUIREMENTS</th>
<th>VISIBILITY</th>
<th>BRIGHTNESS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED (LIGHT-EMITTING DIODES)</td>
<td>VOLTAGE, V 5</td>
<td>CURRENT, mA 20</td>
<td>SUNLIGHT POOR</td>
<td>GOOD 30-300 FOOT-LAMBERTS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NIGHT LIMITED</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LIGHT FILTER</td>
<td></td>
</tr>
<tr>
<td>LCD (LIQUID CRYSTAL DISPLAYS)</td>
<td>VOLTAGE, V 5</td>
<td>CURRENT, mA 30</td>
<td>SUNLIGHT GOOD</td>
<td>POOR PASSIVE DISPLAY REQUIRES AMBIENT OR SEPARATE LIGHT SOURCE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6 SEGMENTS)</td>
<td>NIGHT POOR</td>
<td></td>
</tr>
<tr>
<td>LCD WITH BACK SCATTER LIGHTING</td>
<td>VOLTAGE, V 5</td>
<td>CURRENT, mA 30+</td>
<td>SUNLIGHT GOOD</td>
<td>GOOD TO FAIR SIMILAR TO INCANDESCENT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(15 FOR BACKSCATTER LAMP)</td>
<td>NIGHT GOOD TO FAIR</td>
<td></td>
</tr>
<tr>
<td>SUBMINIATURE INCANDESCENT LAMPS</td>
<td>VOLTAGE, V 5</td>
<td>CURRENT, mA 15 TO 60</td>
<td>SUNLIGHT GOOD</td>
<td>GOOD &gt; 1000 FOOT-LAMBERTS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NIGHT GOOD TO FAIR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NADC 81073-60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- OPERATING TEMPERATURE RANGE: 58 TO 212°F
- LONG LIFE
- LOW OPERATING VOLTAGE
- RUGGED
- SMALL SIZE
- RESPONSE TIME, NANOSECONDS

- OPERATING TEMPERATURE RANGE: 14 TO 140°F (0 TO 60°C)
- BECOMES SLUGGISH AT LOWER TEMPERATURES
- RELIES ON EXTERNAL LIGHT SOURCE FOR VIEWING AT NIGHT

- COMPLEX, BULKY, TEMPERATURE-LIMITED

- LIMITED BY MULTIPLE LAMP CURRENT DRAIN DURING BATTERY OPERATION
- HEAT DISSIPATION A SIGNIFICANT CONSIDERATION
- BRIGHTEST OF ALL DISPLAYS
- LOW VOLTAGE REQUIREMENTS
- RESPONSE TIME IN MILLISECONDS
- VIBRATION-RESISTANT IN SMALL SIZES
Figure 72. Types of display indicators.
HYDRAULIC DIAGNOSTIC MONITORING SYSTEM (U)

MARK 81 J J DUZICH

UNCLASSIFIED

NUCLEAR WEAPONS DESIGN CENTER

MAR 81 J J DUZICH

N62269-78-C-0081

UNCLASSIFIED
1.3.6.3 Microprocessor

The Intel 8748 (Ref. 9) is a single-component, 8-bit microcomputer fabricated on a single silicon chip using the N-channel silicon gate MOS process. Unlike the 8048, the 8748 has an erasable program memory which can be varied for tests and evaluation during the prototype and reproduction stages. The 8748 is easily programmable and has sufficient room for additional programs and/or add-on functions. In particular, it:

- Is an 8-Bit CPU containing ROM, RAM, I/O, and a Timer in a single package
- Is powered by a single 5 VDC power supply
- Responds in a 5.0 μsec cycle. All instructions use one or two cycles
- Has a 1K by 8-bit EPROM, 64 by 8-bit RAM, and 27 I/O lines
- Contains an internal timer/event counter
- Has a single-level interrupt.
A block diagram of the 8748 is shown in Figure 74. Figure 75 shows a typical pin arrangement for this unit.

![Block Diagram of Intel 8748](image)

**Figure 74.** Intel 8748 block diagram.

### 1.3.6.4 Charging Circuit

A charging circuit was designed into the system to keep the twelve nickel-cadmium batteries charged when the vehicle is on ground-support power or on an operational mission.

A transformer is used to step-down the 115 VAC, 400 Hz power supply. Rectification is accomplished by a diode to a DC value slightly higher than the 5 VDC system. Since nickel-cadmium batteries are difficult to charge below 0°C, external heaters are used to maintain battery temperatures above this value.

### 1.3.6.5 Heating Circuit

Since the NiCd batteries must be charged with the vehicle flying at various altitudes, thermostat-controlled battery strip heaters are incorporated. When the temperature drops below 0°, the heating strip functions until the surface temperature reaches 32°F. This thermal cycling enables the batteries to achieve and retain a full charge. Figure 76 shows charging characteristics of NiCd batteries as a function of temperature (Ref. 10). During the flight test programs, modifications were made to the battery charging circuit to reduce the charging rate and provide for an external access connector. This connector was used to check status on battery voltages and provide an external dedicated recharge capability. Both battery analysis and external battery charging circuits are discussed in Appendix I.
<table>
<thead>
<tr>
<th>PIN</th>
<th>TO INPUT PIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>XTAL1 - INTERNAL OSCILLATOR</td>
</tr>
<tr>
<td>3</td>
<td>XTAL2 - OTHER SIDE OF CRYSTAL INPUT</td>
</tr>
<tr>
<td>4</td>
<td>RESET - INPUT USED TO INITIALIZE PROCESSOR</td>
</tr>
<tr>
<td>5</td>
<td>SS - SINGLE STEP INPUT</td>
</tr>
<tr>
<td>6</td>
<td>INT - INTERRUPT INPUT</td>
</tr>
<tr>
<td>7</td>
<td>EA - EXTERNAL ACCESS INPUT</td>
</tr>
<tr>
<td>8</td>
<td>RD - OUTPUT STROBE ACTUATED DURING A BUS READ</td>
</tr>
<tr>
<td>9</td>
<td>PSEN - PROGRAM STORE ENABLE</td>
</tr>
<tr>
<td>10</td>
<td>WR - OUTPUT STROBE DURING BUS WRITE</td>
</tr>
<tr>
<td>11</td>
<td>ALE - ADDRESS LATCH ENABLE OCCURS ONCE DURING EACH CYCLE</td>
</tr>
<tr>
<td>12-19</td>
<td>DB0 -DB7 - DATA BUS BIDIRECTIONAL PORT</td>
</tr>
<tr>
<td>20</td>
<td>VSS CIRCUIT GND POTENTIAL</td>
</tr>
<tr>
<td>21-24</td>
<td>P20-P27 8-BIT QUASI-BIDIRECTIONAL PORT</td>
</tr>
<tr>
<td>25</td>
<td>PROG - PROGRAM PULSE</td>
</tr>
<tr>
<td>26</td>
<td>VDD - PROGRAMMING POWER SUPPLY</td>
</tr>
<tr>
<td>27-34</td>
<td>P10-P17 8-BIT QUASI-DIRECTIONAL PORT</td>
</tr>
<tr>
<td>35-38</td>
<td>PORT 2 - P20-P23 CONTAIN THE FOUR HIGH-ORDER PROGRAM COUNTER BIT DURING AN EXTERNAL PROGRAM MEMORY FETCH</td>
</tr>
<tr>
<td>39</td>
<td>T1 INPUT PIN TESTABLE USING THE JT1 &amp; TNT1 INSTRUCTIONS</td>
</tr>
<tr>
<td>40</td>
<td>VCC - MAIN POWER SUPPLY (+5V) DURING OPERATION &amp; PROGRAMMING</td>
</tr>
</tbody>
</table>

Figure 75. Intel 8748 pin configuration.
Figure 76. Nickel-cadmium battery charge characteristics.
1.3.6.6 Wiring Circuit

The basic wiring circuit is shown in Appendix I. Four removable display cards (Figure 77) comprise the major portion of the circuit and consist of the following:

- Card No. 1: Microprocessor - memory and display drivers
- Card No. 2 & 3: Counters and A/D converters
- Card No. 4: Interface circuits.

Figure 78 shows the HYCOS panel with its cover removed.

Basic card element functions are as follows:

- Microprocessor - unit, controls all calculations
- Lamp Drivers - supplies current to display lamps
- Output expanders - receives three inputs and delivers eight different outputs
- Dual flip-flops - used for data storage
- A/D converters - receives analog data and converts it to a 8-bit digital word
- Hex Buffer - used to drive data bus
- Counter latch; seven-segment driver - counts pulses, stores value, and drives seven-segment display
- Transistors - amplifies pulse input and potentiometer signals
- Schmitt Trigger - used to square waveshapes
- Diodes - used for lamp test isolation and to rectify AC for battery charging
- Batteries - 1 A-hr battery drives high-power circuits and 100 mA-hr battery supplies low-power requirements.

1.3.6.7 HYCOS Flow Diagram and Program Limits

Program limits are established for the particular subsystem in question. A math model was first established which defines the normal operating parameters. When these limits are exceeded either individually or collectively, the program subroutine detects the discrepancy and provides the proper circuit response.
Figure 78. HYCOS panel with cover removed.
The program flow diagram is broken down into six basic routines:

- Executive Routine
- Sequence Routine
- RAM Load Routine
- Rudder Routine
- Reservoir Routine
- RAT Routine.

Additional details of the flow diagram and the microprocessor program are listed in Appendix K.

1.3.7 Hydraulic Filters

1.3.7.1 Filter Differential Pressure Indicators

Filter differential pressure indicators, commonly used in the fluid power industry, are an indirect means of identifying contaminated filter elements which require servicing. The indicator is usually mounted to the filter head or bowl and provides a visual signal when a predetermined element differential pressure has been exceeded. In order to take into account fluid viscosity changes due to thermal conditions, various means are employed to preclude indicator operation before the system reaches normal operating temperature. One method uses a bimetallic sensing unit placed in close proximity to the visual indicator; another employs a temperature-sensitive gas, fluid, or elastomer.

To provide remote indication capability, an electrical switch may be mechanically or otherwise actuated by the primary sensor indicator. Resetting the mechanical indicator also resets the electrical circuit.

A boot or transparent cap is provided over the indicator to improve reliability by making it less susceptible to extrinsic debris and fluid. This cap is physically restrained or bonded to the adjacent element. Figure 79 shows a typical interchangeable differential pressure indicator. An actual installation photograph is shown in Appendix J.

1.3.7.2 System Fluid Sampling

Another version of the delta-p indicator contains a sampling port which permits fluid extraction from the upstream side of the filter element while the system is pres-
Figure 79. Filter differential pressure indicator.

surized. One such type of "Multicator"* is shown in Figure 80. Figure 81 shows an installation in the pump case drain filter.

Figure 80. Filter differential pressure indicator with sampling valve.

* Multicator is an APM Trademark
A special wired plug is used to protect the sampling port when not in use, and also acts as a redundant pressure seal.

Grumman Specification 202 defined the pertinent parameters of each unit used for the HYCOS Program.

It should be noted that most visual and electrical indicators are usually discrete signals (Go/No-Go type). In cases where an analog signal is required, this may be provided by using the approach shown in Figure 82. This concept utilizes a linear output Hall Effect sensor actuated by a movable permanent magnet which is coupled to a spring-biased piston. Movement of the sensing piston magnet affects the magnetic flux density seen by the Hall Effect sensor, reducing the output signal. Since the sensor output varies as a function of ambient temperature, temperature compensation must be provided.
1.3.8 Flight Control Hydraulic Backup Package

A Klixon overtemperature switch was bonded to the flight control backup module to measure system and closed-loop surface overtemperature conditions. The switch conforms to Grumman Specification 201 and has a trip setting of 300 ± 20°F. It is manually resettable through a neoprene overmold. Figure 83 (Ref. 11) shows typical switch characteristics. Actual installation on the flight control backup module is shown in Figure 84. Operation of the hydraulic backup package occurs during preflight check and only if one hydraulic system is lost.

Figure 82. Linear output Hall Effect differential pressure indicator.
SNAP-ACTION SWITCHING
NORMALLY OPEN OR NORMALLY CLOSED
AUTOMATIC OR MANUAL RESET
SPST OR SPDT
OVERMOLD OPTIONAL

PERFORMANCE CHARACTERISTICS

DIELECTRIC STRENGTH:
1250 VAC, RMS, 60 CYCLES FOR ONE MINUTE (1500 VAC RMS AVAILABLE ON SPECIAL REQUEST)

AMBIENT TEMPERATURE RANGE:
NON OVERMOLD – 65°F TO 450°F
NEOPRENE OVERMOLD – 65°F TO 160°F
SILICONE OVERMOLD – 65°F TO 450°F

SWITCH ACTION:
SPST OR SPDT (SNAP-ACTION)

LIFE CYCLE:
SEE ELECTRICAL RATING TABLE

VIBRATION:
STANDARD CONSTRUCTION 5-500 CPS, 3G’s
HIGH VIBRATION CONSTRUCTION 5-500 CPS, 5G’s

WEIGHT:
WITHOUT OVERMOLD 21 GRAMS AVERAGE
WITH OVERMOLD 56 GRAMS AVERAGE

ELECTRICAL RATINGS (RESISTIVE)

<table>
<thead>
<tr>
<th>AMPERES</th>
<th>30 VAC/DC</th>
<th>125 VAC</th>
<th>250 VAC</th>
<th>LIFE CYCLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4</td>
<td>2</td>
<td></td>
<td>100,000</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>3</td>
<td></td>
<td>50,000</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>4</td>
<td></td>
<td>25,000</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>5</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
<td>6</td>
<td></td>
<td>5,000</td>
</tr>
</tbody>
</table>

CROSS-SECTION VIEW OF TYPICAL UNIT WITH OVERMOLD (AUTOMATIC RESET)

Figure 83. Resettable temperature switch characteristics.
Figure 84. Flight control backup module installation.
Section 2
GROUND AND FLIGHT TESTS

2.1 SYSTEM DEBUGGING

During the early part of 1979 all sensors, hard lines and wiring were installed during vehicle buildup. In mid-May, the vehicle with sensors and HYCOS wiring was subjected to and passed the hydraulic ground check and acceptance testing. These tests verified hydraulic system integrity on both the flight system and the combined system on which HYCOS was installed.

Debugging included rerunning hydraulic reservoir displacement calibration to verify the laboratory values. All HYCOS wiring was checked between the sensor interface and display panel for continuity. A rudder differential displacement check was made after calibrating both potentiometers. Continuity checks were also made on the fiber-optic circuits. After the first flight in October 1979 it was found that the elapsed time meter (ELT) was not functioning. Investigation showed that the ELT operated through a relay after the panel switch was energized. A wiring change was made to the ELT circuit. This enabled the ELT to register every time the combined system was monitored or AC power was available on the aircraft. While the panel was being rewired, an IC chip was also replaced. Details of the wiring change is shown in the appendix.

2.2 DEVELOPMENTAL MODIFICATIONS AND IMPROVEMENTS

2.2.1 HYCOS Display Panel

Modifications were made at the onset of the program to the battery charging circuits to improve NI-CAD battery reliability. During the early phases of the program the NI-CAD batteries discharged when the aircraft was stored in the hangar over the weekend. A HYCOS battery analysis was conducted (See Appendix K) which indicated that the batteries were adequately sized and that the charging rates should be reduced from 100 mA-hr to 50 mA-hr for the 5-volt battery. The charging rates for the 3.6V and -6V batteries was reduced from 10 mA-hr to 5 mA-hr.
The analysis also indicated that the panel should be equipped with an external accessible connector to provide direct connections to the battery plus and minus terminals. The connector would then allow external monitoring of battery voltages without removing the panel from the vehicle, and it would also provide charging access to the Ni-CAD batteries using a dedicated ground support charger.

Both improvements were incorporated. A dedicated battery charger was fabricated but seldom used since, after subsequent initial charging, the ship's electrical buss maintained the batteries in a usable state.

Another improvement area was in modifying the internal power circuit to the elapsed time meter. This was done so that power to the elapsed time meter would occur when both AC and hydraulic system power was available. When the system is interrogated on the ground in the static condition no power reaches the elapsed time meter. In the same circuit, the relay was replaced with a heavy duty Leach DM 2-5.

In order to reduce the number of sequential operations, the system test switch was modified by replacing the ON, center OFF, ON configuration to an ON momentary at the panel. This reduced the system test functions to only 1:

- With the system test switch in its ON position, power is supplied to the elapsed time indicator if hydraulic power is on
- System test "ON 2" without hydraulic power checks air in the reservoir and discrete circuits
- System test "ON 2" with hydraulic power checks the reservoir, ram air turbine accumulator, and rudder differential circuit.

The addition of a top hat to the desiccant color detector terminal improved color transmission visibility at the panel.

2.2.2 Panel Support Structure

During the early part of the program, a doubler plate was added to the access plate to provide additional clearance for the load bearing fasteners. This improvement corrected the fastener retention problem caused by marginal material thickness.
2.2.3 Sensor Light Sources

As the flight test program evolved, it was determined that a more intense light source was needed at the desiccant color detector and pneumatic liquid bottle detection circuits. Three halogen lamps were added with specially designed housings for this purpose. There was a significant improvement in available light intensity.

2.2.4 Flow Sensor Indicators

Environmental vibration during a normal flight schedule caused two of the flow sensors to indicate incorrectly. After investigation and vibration testing, it was found that the resonant frequencies of the lockout solenoid armature/spring occurred. The armature/spring mass was redesigned to move the resonant frequency out of the operational envelope.

2.2.5 Desiccant Color Detector

Several improvements were made to this sensor. These included increasing the light intensity at the surface, optimizing the reflected transmitter, receiver angle, and finally developing a new desiccant color disc mounted internally in the air stream. Color transmission from irregular granular surfaces proved difficult because of the irregular granular surfaces.

Fiber-optic cable junctions should be minimized and cable runs must be carefully laid to avoid sharp bends.

Crazing of the transparent plastic tube developed later in the program. This tube was replaced with another unit of the same type. Examination of the part indicated that crazing was caused by over torquing the sensor body to its outside diameter.
3.1 PROCEDURES AND METHODS

3.1.1 Objective

The purpose of the Flight Test Program is to evaluate the HYCOS System under actual operating conditions and to determine its effectiveness in detecting system and component malfunctions. It in no way replaces the normal maintenance schedules, but may be used in conjunction with such maintenance actions.

3.1.2 Procedure

This procedure defines a systematic method of conducting a "HYCOS" Interrogation. All data is to be recorded on the provided HYCOS Log Sheet and HYCOS Check-out Logic Sheet.

Three (3) checks are required:

- "A" Preflight static check is conducted with the flight vehicle in the hangar prior to towing to flight line. This provided the initial condition prior to flight. Any abnormalities or malfunctions would be corrected at this time.

- "B" Postflight dynamic check is required to measure internal system and pump leakage with no mechanical input into the control surfaces. During the time the system is pressurized, power is supplied to the elapsed time meter which keeps track of system operational time.

- "C" Postflight static check is conducted after the vehicle was moved to the hangar. This approach was used to detect any changes that may have occurred since the preflight static check.
3.1.3 Log Sheet Description

Using the HYCOS LOG SHEET:

- **Enter DATE** System is integrated
- **Enter FLIGHT NUMBER**
- **Enter FLIGHT DURATION** in hours
- **Enter Elapsed Time Meter reading**
- **Enter CHECK** in applicable Flight Interrogation column
- **MALFUNCTION** - List ANY Hydraulic System Malfunction that occurs on the combined or Flight Hydraulic System.
- **MAINTENANCE ACTIONS** - List any maintenance actions taken on either Combined or Flight Hydraulic Systems.
- Check if malfunction or maintenance action was indicated by or on HYCOS Panel.
- Plane Captain/Technician - Write name of plane captain conducting interrogation and technician performing maintenance action.

3.1.4 HYCOS Interrogation Procedure

This sheet is used in conjunction with the Log Sheet but presents more detailed information. The switch positions are broken down into three categories:

- **Category "A"** designates a pre-flight static check.
- **Category "B"** designates a post-flight dynamic check (right engine running - no power control input).
- **Category "C"** designates a post-flight static check.

In conducting the **preflight static check**, select **CIRCUIT TEST ON 1** and hold. Record by code those display lights that do and do not illuminate, in column "A".

Release switch.

Select and hold **Circuit Test On 2**. All red lights should sequence in a sub-block order. Record. This check verifies that the microprocessor timer is functioning.

Release switch.
Select and hold Systems Test On 2. Record illuminated lights. This step illuminates those sensors that are out of tolerance and require visual verification. Upon visual verification conduct necessary repair or maintenance action. Record all information in Log Sheets.

3.1.5 HYCOS Display Criteria

- **PUMP** (Sub-Category)
  - **PRESS** - Illuminates when system pressure drops below approximately 2,200 psi in the combined Hydraulic System. The light extinguishes when the system is pressurized
  - **CASE** - Illuminates when pump case flow is excessive and may require pump removal. Excessive pump case flow is an indication of a worn or degraded pump
  - **FILT** - Illuminates when case drain flow filter button pops indicating required maintenance action. After performing maintenance action, reset the visual filter delta "P" button. This rests the electrical circuit
  - **TEMP** - Illuminates when the pump case drain fluid temperature is excessive (caused by high bypass). This is used in conjunction with pump case flow circuit

- **RESERVOIR** (Sub-Category)
  - **LEAK** - Illuminates when level drops two inches or more during flight. Also, illuminates if reservoir is not filled to specification
  - **AIR** - Illuminates if reservoir piston moves greater than one inch from unpressurized to pressurized
  - **TEMP** - Illuminates if reservoir level temperature is excessive. Indicates possible fault in system and requires additional troubleshooting
  - **DRIER** - When pale blue desiccant is still serviceable, when color changes to pink or pale pink, replace desiccant cartridge in system and desiccant in sensor
FILTER (Sub-Category)

- PRESS - Illuminates when pressure filter is clogged and requires replacement. When filter is serviced and indicator button is reset, light will extinguish.

- RET - Illuminates when return filter is clogged and requires replacement. When filter is serviced and indicator button is reset, light will extinguish.

QUISCENT FLOW (Sub-Category)

- SYSTEM - Indicates excessive internal system leakage. This is taken during dynamic check with no control input. Flow sensor must be manually reset after taking corrective action.

- RUDDER - Indicates excessive rudder actuator internal leakage. Also taken during dynamic check with not control input. Flow sensor must be manually reset after taking corrective action. Note: Flow sensors will not indicate properly unless system is pressurized.

ACCUM PRECHARGE (Sub-Category)

- RAT - Indicates low accumulator precharge irrespective of accumulator piston position. If light illuminates with system test "ON 2", service accumulator.

DIFF DISP (Sub-Category)

- RUDDER - Indicates disconnect between push pull rods on and rudder actuator. Combined system must be pressurized. Rudder position follow rudder pedal inputs.

PNEU PRESS (Sub-Category)

- CANOPY - Illuminates when canopy bottle (15 in. $^3$) pressure is low and requires servicing.

- GEAR - Indicates when gear door bottle (30 in. $^3$) pressure is low and requires servicing.

RELIEF VALVE (Sub-Category)

- COMBINED - Indicates when main system relief valve is leaking (failure or improper seating).
- SYSTEM (Sub-Category)

  - CIRCUIT TEST ON 1 - Checks discrete circuits to sensors thru common and on leg
  - CIRCUIT TEST ON 2 - Checks microprocessor and lights in sub-block sequence
  - SYSTEM TEST ON 1 - Programs the microprocessor when system is pressurized
  - SYSTEM TEST ON 2 - Interrogates entire combined system (red lights only). When red lights illuminates this indicates a malfunction or requires maintenance action
  - ELAPSED TIME METER - Runs when combined system is pressurized.

3.2 OVERALL EVALUATION OF HYCOS SYSTEM

As a preventative maintenance tool, the HYCOS System performed exceedingly well in determining the condition of the system. During the course of its program, it consistently detected:

- Low canopy and door gear dump pressures
- Low reservoir level during initial calibration
- Low system pressure during start up conditions
- Continuous elapsed time on system components.

There were no indications of hydraulic pump excessive case flow or case flow oil temperatures since the sensor limits were not exceeded.

Fiber-optic desiccant color detection proved difficult, even with the addition of more intense light sources. This was attributed to the improper installation of fiber-optic runs in which the bend radius were exceeded, causing excessive light loss. Another area requiring improvement is in optical terminal coupling, where losses can be considerable. Color transmission of red and pink is excellent; however, pale blue is not readily detectable.

The filter subsection gave no indication of tripped delta "p" indicators. This may be due to the fact that the vehicle flew over 150 hours and did not experience any hydraulic subsystem failures. Quiescent and rudder actuator flow sensors, when
interrogated under dynamic conditions, did not indicate excessive flows as originally established. There were, however, developmental problems caused by vibration which were subsequently solved.

The ram air turbine (RAT) accumulator functioned flawlessly with no indication of precharge loss. Pressure, temperature, and displacement sensors functioned as advertised. This component is used as an energy storage device and retains this capability even when the system is shut down.

Except for initial calibration, the differential displacement sensors operated satisfactorily since the rudder output follows the mechanical input. This portion of the circuit is not activated until the combined system is pressurized.

Indications of low pneumatic system pressure worked effectively and repeatedly within limits. Minor system leakage was detected after the vehicle remained in an inactive flight status for several days. Topping the bottles corrected this condition.

Since the relief valve did not malfunction, no indication was apparent on the display. Relief valves are usually passive devices until excessive pressures are exceeded. If this occurs and instability prevails, seat or poppet damage can occur. This results in leakage with subsequent system fluid temperature rise.

The circuit and system test switches functioned satisfactorily, but the system test switch was modified to a continuous ON 1 when the battery charging circuit was modified. Future procedures would eliminate the need for first selecting ON 1 followed by ON 2.

The lay-over time between flights determines the condition of the NI-CAD storage batteries. Although the battery charging circuit is adequate, infrequent ground charges may be necessary. This was readily accomplished by using the ground battery changer through the added electrical panel interface. This connector also provided test points to determine battery condition without removing power from the vehicle.
Section 4

RESTORATION OF THE AIRCRAFT

The flight test program terminated on November 15, 1980 when the aircraft was subjected to a debailment inspection before being turned over to Navy inventory as an updated A-6E. The inspection involved the following activities:

- The following special components were removed from the vehicle:
  - HYCOS Display Panel
  - Quiescent, rudder actuator, and pump case drain flow sensors
  - Pressure, filter, and temperature switches on the combined system pump

- The combined system reservoir was replaced with the original unit kept in storage

- Remote reading delta "P" indicators were replaced with original units

- The ram air turbine accumulator and supporting bracket was replaced with a standard unit.

- Potentiometers located on the turtle deck and rudder were removed in the differential displacement circuit

- Both the pneumatic pressure canopy and emergency gear door pump bottles were replaced with standard units

- The fluid thermal switch was removed downstream of the combined system relief valve

- All wire leads and fiber-optic cables peculiar to the HYCOS system were capped and lagged at both the panel and sensor interface

- The surface temperature switch was removed from the flight control backup module.
The power supply cable (110V 400 ~ AC) from the circuit breaker to the HYCOS panel was disconnected. The HYCOS access cover was permanently attached to the structure in accordance to an EO issued by the Structural Design Group.

After installation of standard production components, lines, and fittings, the vehicle was subjected to a hydraulic ground check to substantiate system integrity in accordance with the ATP. No problems were encountered during this refurbishment.

In addition, an engine ground run was successfully accomplished to verify flight worthiness since the port engine was removed to provide access to the keel where most of the HYCOS sensor components were located.
Section 5
CONCLUSIONS

- The flight test program met all the requirements of the work statement
- The HYCOS accumulated over 150 hours flight time during a 1-year flight test program
- Preflight checkout time takes only 1-1/2 minutes using the HYCOS, as compared to 20 - 30 minutes for a manual checkout
- The HYCOS consistently identified:
  - Low pneumatic bottle pressure
  - Low reservoir level
  - Low system pressure
  - System operating hours
  - Malfunctioned components on a post-flight check
- All other sensors operated normally and did not indicate malfunctions
- The microprocessor functioned flawlessly after final programming and integration. It also has capacity for additional fault-detection via changes in microprocessor programming
- The system is capable of detecting the health or malfunctions of components located in hazardous areas, such as when engines are operating
- The HYCOS did not impair or restrict the normal function or the combined hydraulic system
- HYCOS has demonstrated its capability as a preventative, failure, and maintenance tool
- HYCOS sensors were of the prototype configuration and were not optimized for size or weight
As a result of the test program, it was found that the system can be further improved by:

- Relocating the panel away from the inlet duct area
- Reducing fiber-optic coupling & terminations and optimizing bend radii
- Utilizing a dedicated disc detector and selecting fiber-optic cable having wider bandwidth to provide more efficient color transmission

Since prime contractor service and maintenance is excellent, few hydraulic system malfunctions occurred during the test program. In actual squadron use, the benefits of such a system would be realized in:

- Reduced preflight checkout time
- Increased availability
- Reduced turnaround time
- Extended service intervals
- Radio component fault indication
- Utilization of less-skilled personnel
- Ability to readily check inaccessible components on a preflight basis.
Section 6
RECOMMENDATIONS

- Continue developmental effort on alphanumeric (smart) terminal displays to provide quantitative information on status or malfunction in terms of order of magnitude
- Continue sensor development specifically adapted for lightweight hydraulic system vehicles with continuous monitoring
- Incorporate sensors or make provisions for adaptation/inclusion of sensors in selected components within redundant and dedicated power systems
- Expand the use of fiber-optic circuits in conjunction with digital sensors
- Determine the feasibility of a universal microprocessor display capable of multiple vehicle use
- Incorporate several advanced systems in a training squadron in order to obtain a more representative evaluation (larger statistical sample)
- Update current military component specifications to provide for optional (dedicated) sensors in major flight-critical components.
Section 7

REFERENCES

3. NAVAIR 01-85 ADA-6-4 Landing Gear Emergency Operational Check.
4. Designing with Dupont "Croron" Fiber Optics (11/76)
APPENDIX A

HYCOS LOG SHEET FORMAT AND
TYPICAL FLIGHT LOG SHEET
**HYCOS CHECKOUT LOGIC**

**FLIGHT NO.** A6E MOD 229 B/N 155628

**REVISION "A"**

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**NOTES:**

1. DRIER LIGHT TRANSMITS COLOR LIGHT BLUE TO PINK
2. "A" DESIGNATES PREFLIGHT CHECK (STATIC)
   "B" DESIGNATES POSTFLIGHT CHECK (DYNAMIC)
   "C" DESIGNATES POSTFLIGHT CHECK (STATIC)
3. MARK "X" IN BOX TO INDICATE LIGHT ON.

---

Figure A-1. HYCOS log sheet format used during program.
### HYCOS CHECKOUT LOGIC

**DATE:** 08/06/80  
**FLIGHT NO.:** 77 A6E MOD 229 B/N 155628  
**FLT TIME:** 1.8 HR

#### REVISION "A"

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#### NOTES:

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---

Figure A-2. Typical HYCOS flight log sheet.
APPENDIX B

FLIGHT-HOUR ACCUMULATED LOG
## FLIGHT-HOUR ACCUMULATED LOG

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*HYCOS REMOVED FOR REPAIR
PROGRAM STATUS

FIRST FLIGHT .................. OCTOBER 31, 1979
PROGRAM TERMINATED ............ OCTOBER 31, 1980
TOTAL FLIGHT TIME ON SYSTEM .... 156.7 HR.
NUMBER OF FLIGHTS ............. 96
APPENDIX C

ABBREVIATED CHRONOLOGICAL LOG

Dec. '77
- Kickoff meeting
- Display panel daylight visibility
- Started specifications

Jan. '78
- Generated specifications for sensor
  - Thermal switch
  - Delta p indicators
  - Flow sensors
  - Pressure switch

Feb. '78
- Continue sensor specification generation
- Start RLS layout defining panel block diagram
- Proceed with panel layout

May '78
- Review flow sensor; develop pressure probes
- Established display panel size and configuration

April '78
- Reservoir sensor development continues
- Mockup model of panel fabrication
May '78
- Installed sensors in F-14 reservoir
- Started A-6 reservoir layout
- Desiccant color detector
- Pressure transducer investigations
- Started installation of F-14 simulator

June '78
- Calibrated F-14 reservoir, issued P/O for A-6 reservoir parts
- Started testing pressure transducers at high and low temperatures
- Flow sensor manufacturing is in progress
- E.E.D. manufactured panel test set

July '78
- Started modification of A-6 reservoir
- Installed panel on F-14A hydraulic simulator

August '78
- Received flow sensors
- Received optical sensors
- Acceptance-tested thermal switches
- Completed F-14 simulator wiring

September '78
- Develop desiccant color detector
- Develop liquid detector
- Started programming microprocessor for F-14 system

October '78
- Completed A-6 reservoir modifications
- A-6 flow sensors at vendors test
Nov. '78
- Ran displacement calibration on A-6 reservoir
- Ran F-14A HYCOS simulator demo

Dec. '78
- Flight-test vehicle tentatively established Mod 229
- Continue sensor development

Jan. '79
- Authorization received from NAVAIR to install HYCOS on Mod 229
- Vehicle is in second stage of buildup
- Issued Engineering Orders for
  - Brackets
  - Lines
  - Component modification
  - Sensor installation in keel area

Feb. '79
- Installation continues on wiring and hardware installation
- Continue sensor development and integration
- Conducted pressure seal tests

March '79
- Start hydraulic hard lines mockup
- Wiring runs for sensor installation begun
- Start sensor installations on port keel

April '79
- All hydraulic hard lines fabricated
- All wiring before sensor and display panel completed
- System pressurized
• Start electrical run line check
• Submitted interim report

May '79
• Completed hydraulic ground check and acceptance testing
• Instrumentation lines with exception of F/O circuit installed
• Vehicle passed through paint shop
• Vehicle ground run tested

June '79
• Vehicle delayed 5 weeks due to structural bulkhead repairs
• Continue fiber-optic color detection development; investigate halogen lamp

20 June '79
• Investigate halogen lamps
• Added resistor to reduce voltage from 5 VDC to 3.5 VDC

30 July '79
• Ordered incandescent lamps
• Started interface and ground checkout on bailed A/C

August '79
• Structural mods made to vehicle to accept panel
• Started debugging system

Sept. '79
• Started rudder differential displacement calibration
• Reservoir calibration information supplied to E.E.D. for burn-in

Oct. '79
• Calibration rudder differential displacement
• Run circuit check using panel jumper
• Flew A/C for 1-1/2 hr
• ELT not operational
Nov. '79
- Removed panel
- Replaced I/C chip for ELT problem
- NICAD batteries nearly discharged. Changed battery charging rate from 0.100 A to 0.200 - 0.300 A

Dec. '79
- Rudder and quiescent flow sensor found tripped after flight
- Modified optical viewing port at panel terminal
- Conducted lab tests on halogen lamp; 20 to 1 improvement verified
- Received solenoid rework to negate armature resonance on flow sensors

Jan. '80
- Reduced NICAD battery charging rate (50 MAH for 5 V batteries and 5 MAH for +3.6 and 6 V batteries)
- Added regulated power supply to ELT circuit
- Modified system test switch from 2 momentary ON (ON center of ON) to ON - ON (ON momentary ON)
- Added battery test plug on panel face for external charging and battery checking
- Reprogramed M/P to eliminate erroneous over temp light (Rev. 18, Jan. 80)
- EO 128FT80001 installs improved light source on reservoir pressurization circuit
- 128FT80002 installs wiring to light sources
- 128FT80003 changes flow sensor locking solenoids
- 128FT80005 supplies BATT power instead of transformer power to both light sources
- Conducted resonance vibration test on flow sensors - 18-25 Hz resonance occurred. Made improvements. Modified solenoid has no resonance points at 5-2000 Hz @ 5, 10, 15 G ranges

Feb. '80
- High intensity of F/O pneumatic circuit improved at display panel
- Color intensity transmission requires additional development
NADC 81073-60

- External battery charger completed at Plant 14
- ELT stops functioning - suspected relay
- Generated EO 128FT80006 which installs second high-intensity light at pneumatic bottle test circuit
- Issued EO 128B1636 to add spacer on access door

March '80
- Dessicant sensor approach using internal fiber investigation not successful
- Fabricated third high-intensity source for pneumatic bottle circuit; EO 128FT8006 will install unit in vehicle
- Procured high-capacity ELT relay

April '80
- Developed new dessicant sensor (cobalt chloride/potassium bromide disc)
- Installed access door spacer

May '80
- Improved optical dessicant sensor with plastic spacer for isolation due to chemical reaction

June '80
- Added short fiber cable link between modified dessicant optic receiver and junction
- Increased light loss

July '80
- Detected poor F/O cable runs with 32 dbm losses instead of 10 dbm, which might be expected
- Investigate F/O improvements

August '80
- Continue flight test program
Sept. '80
  • Continue system interrogation and assessment

Oct. '80
  • Continue system flight test and assessment

Nov. '80
  • Issue system debailment EO for HYCOS

Dec. '80
  • Return test vehicle to U.S. Navy
  • Complete final report
### NADC 81073-60

#### Filter Display Panel

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<td>3</td>
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<td>Filter Delta P Return</td>
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<td>7</td>
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<td>8</td>
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<td>Relief Valve Main Temp</td>
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<tr>
<td>3</td>
<td>Level 2A1.44 Primary</td>
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#### Diagram

- **Location:** L. H. Bonding Ladder
- **Diagram:** D-3/4
## APPENDIX E

### PARTICIPATING FIRMS

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<thead>
<tr>
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<tbody>
<tr>
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<td>Walter Kidde &amp; Company</td>
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<tr>
<td>Valtec</td>
<td>West Boyleston, Mass.</td>
</tr>
<tr>
<td>Sigma-Netics</td>
<td>Mountain Lakes, N.J.</td>
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<tr>
<td>Sprague Engineering Corporation</td>
<td>Garden, California</td>
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<tr>
<td>Bourns Incorporated</td>
<td>Riverside, California</td>
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<tr>
<td>Neo-Dyn Inc.</td>
<td>Chatsworth, California</td>
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<tr>
<td>De Laval Special Products Division</td>
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<td>Entran Devices</td>
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<td>Frisby Airborne Hydraulics</td>
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<td>E.I. du Pont de Nemours</td>
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<td>Photodyne Incorporated</td>
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<td>Roylan Optics Company</td>
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## APPENDIX F

### ESTIMATED WEIGHT OF PROTOTYPE FULL-BLOWN SYSTEM

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<td>2</td>
<td>RESERVOIR</td>
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<tr>
<td></td>
<td>• PISTON DISPLACEMENT</td>
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<tr>
<td></td>
<td>– POTENTIOMETER</td>
<td>0.08</td>
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<td></td>
<td>– BRACKETS, ADAPTORS, &amp; HOUSING</td>
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<td></td>
<td>• TEMPERATURE TRANSDUCER</td>
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<td>3</td>
<td>FILTER DIFFERENTIAL PRESSURE</td>
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<td>• INDICATORS</td>
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<td>• MULTICATORS</td>
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<td>0.36 (1)</td>
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<td>• RUDDER ACTUATOR</td>
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<td>MODULE, TEMPERATURE SWITCH</td>
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<td>8</td>
<td>POTENTIOMETER ROTARY</td>
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<td>• RUDDER PEDALS</td>
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<td>• RUDDER ACTUATOR</td>
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R80-2036-096(T)

F-1/2
# APPEX G

## ENGINEERING ORDERS

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## GRUMMAN AEROSPACE CORPORATION

**ACTION**  
**QTY**  
**RM NO**  
**PART NO**  
**MFG PART NO**  
**SPEC NO**  

### INSTALLATION Dwg. FUSELAGE

**ACTION**  
**QTY**  
**RM NO**  
**PART NO**  
**MFG PART NO**  
**SPEC NO**  

### PNEUMATIC BOTTLE

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### RATIONALE FOR CHANGE

**TO IMPROVE THE INTENSITY OF THE LIGHT SOURCE.**

**DESCRIPTION OF CHANGE**

**NOTED**
FLIGHT TESTED - NOT TO BE INCORPORATED OR DELETED PRIOR TO 19 MAY 80.
FLIGHT TEST INFO

NOT TO BE INCORPORATED ON DRAWING

TO BE REMOVED AT TIME OF HYDOS REMOVAL PRIOR TO MAY 1980 OR AS EXTENDED BY REVISION TO THIS ED

WHILE AIR CHANGES

("TO BE REMOVED AT TIME OF HYDOS"

REMOVE WIRE * CONNECT WIRE *

E694 6697222
E694 6690822
E696 6695422
g750622
E696 6698622
E697 6695422
E697 6698622
E700 6698622
E700 6697222
E702 6750822
E702 6698622
E702 6690822

DESCRIPTION OF CHANGE

TO SUPPLY BATTERY POWER TO HALOGEN LAMPS INSTEAD OF TRANSFORMER-CHARGED POWER

PREPARED BY JOHN DUTCH

APPROVED BY

GROUP LRN

NOTE

COMMERCIAL SPECIFICATION

MATERIAL SPECIFICATION

PROC

NOTE

REASON FOR CHANGE

NOTE
GRUMMAN AEROSPACE CORPORATION

NEW 1287080007

CATEG REPORT 28512

IN...

1287080007

REPLACE PART NO.

APPLICATION

U

U

U

O

GRUMMAN AEROSPACE CORPORATION

NEW 1287080007

CATEG REPORT 28512

IN...

1287080007

REPLACE PART NO.

APPLICATION

U

U

U

O

EARTHTEST INFO:

NOT TO BE INTEGRATED ON DRAWING

TO BE REMOVED AT TIME

OF AIRCRAFT REMOVAL PRIOR TO

SEPTEMBER 1980 OR AS STATED

BY REVISED TO THIS GO.

ADD

1 1141-901-901

SENSOR OPTICAL

EARTHTEST INFO:

NOT TO BE INTEGRATED ON DRAWING

TO BE REMOVED AT TIME

OF AIRCRAFT REMOVAL PRIOR TO

SEPTEMBER 1980 OR AS STATED

BY REVISED TO THIS GO.

ADD

1 1141-901-901

SENSOR OPTICAL

EARTHTEST INFO:

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OF AIRCRAFT REMOVAL PRIOR TO

SEPTEMBER 1980 OR AS STATED

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ADD

1 1141-901-901

SENSOR OPTICAL

EARTHTEST INFO:

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ADD

1 1141-901-901

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EARTHTEST INFO:

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ADD

1 1141-901-901

SENSOR OPTICAL

EARTHTEST INFO:

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ADD

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ADD

1 1141-901-901

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EARTHTEST INFO:

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ADD

1 1141-901-901

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EARTHTEST INFO:

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ADD

1 1141-901-901

SENSOR OPTICAL

EARTHTEST INFO:

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ADD

1 1141-901-901

SENSOR OPTICAL

EARTHTEST INFO:

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BY REVISED TO THIS GO.

ADD

1 1141-901-901

SENSOR OPTICAL

EARTHTEST INFO:

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TO BE REMOVED AT TIME

OF AIRCRAFT REMOVAL PRIOR TO

SEPTEMBER 1980 OR AS STATED

BY REVISED TO THIS GO.

ADD

1 1141-901-901

SENSOR OPTICAL

EARTHTEST INFO:

NOT TO BE INTEGRATED ON DRAWING

TO BE REMOVED AT TIME

OF AIRCRAFT REMOVAL PRIOR TO

SEPTEMBER 1980 OR AS STATED

BY REVISED TO THIS GO.
GRUMMAN AEROSPACE CORPORATION

ACTION

I hereby certify that the following changes have been authorized and approved for:

1. WAA 10001 A
2. WAA 10002 A
3. WAA 10003 A
4. WAA 10004 A
5. WAA 10005 A

This work has been performed and authorized by:

[Signature]

[Date]

[Employee ID]

[Department]

[Company]

[Location]

[Office]

[Phone]

[Email]

[Contact Info]

[Notes]

[Action]

[Eff Date]

[Revision]

[File]

[Document Info]

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[File]

[Document Info]

[Utilities]

[Notes]
**THIS IS A RELEASE EO.**

**ADDED**

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<tr>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY</th>
<th>REMARKS</th>
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**REASON FOR CHANGE**

HYDRAULIC CHECK OUT SYSTEM (HYCOS)

**DESCRIPTION OF CHANGE**

ADDED I28EL1041-901, I28EL1041-91546 TUBE ASSY

REMOVED VB106401-904A, -2367, -2372, -2376, -2380, -2380A, -2382, -2297-1676, -1769, -2298-975 TUBE ASSY.
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**REPLACE**

- 128EL010401-970 R-4
- 128H1001-976 R-4
- 25750-4
- 29736-4
- 17034-4
- 29736-4
- 26719-4

**TUBE ASSY**

- 25750-4
- 29736-4
- 17034-4
- 29736-4
- 26719-4

**LINES INSTL.**

- 128H1001-976 R-4

**ENGINEERING ORDERS**

- 128EL010401-975 R-4

**MANUFACTURING CHANGE ORDER**

- 128H1001-976 R-4

**NOMENCLATURE**

- 128H1001-976 R-4

**DESCRIPTION**

- 128H1001-976 R-4

**NOTE**

- 128H1001-976 R-4

**COMMENTS**

- 128H1001-976 R-4

**REFERENCE**

- 128H1001-976 R-4

**ACTION**

- 128H1001-976 R-4

**DATE**

- 128H1001-976 R-4

**SPECIFICATION**

- 128H1001-976 R-4

**NOMENCLATURE**

- 128H1001-976 R-4

**NOTE**

- 128H1001-976 R-4

**COMMENTS**

- 128H1001-976 R-4

**REFERENCE**

- 128H1001-976 R-4

**ACTION**

- 128H1001-976 R-4

**DATE**

- 128H1001-976 R-4

**SPECIFICATION**

- 128H1001-976 R-4

**NOMENCLATURE**

- 128H1001-976 R-4

**NOTE**

- 128H1001-976 R-4

**COMMENTS**

- 128H1001-976 R-4

**REFERENCE**

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**Notes:**
- **COMMISSION SPECIFICATION**: Code (O-1) - Code (O-1)
- **MATERIAL SPECIFICATION**: Code (O-1)
- **PROD. FIN. ZONE**: Code (O-1)

**Engineering Order/Manufacturing Change Order**
This is a Record B-0
**This is a record of**
**This E.O. re installs the original PDEK hydrant lines in this aircraft**

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**REASON FOR CHANGE:**
DECREASE AIR PRESS TO PDEK HYDRANT CONFIGURATION

**DESCRIPTION OF CHANGE:**
REPLACES PDEK HYDRANT LINES IN THIS AIRCRAFT

**PREPARED BY:**
[Signature]

**APPROVED BY:**
[Signature]

**GROUP/CRD:**
[Group/CRD]

**SUPPORT:**
[Support]

**RELIABILITY:**
[Reliability]

**STRESS:**
[Stress]

**PROD ENG:**
[Product Engineering]

**PROD ENG SPC:**
[Product Engineering SPC]

**INS: M: D: A:**
[Inspection, Manufacturing, Assembly]

**DATE:**
1/20/56

**QTY:**
1

**PLANT GROUP:**
[Plant Group]

**MANUFACTURING CHANGE ORDER NO.:**
[Manufacturing Change Order No.]

**MANUFACTURING CHANGE ORDER:**
[Manufacturing Change Order]

---

**GRUMMAN AEROSPACE CORPORATION**

**ACCOUNT NO.:**
[Account No.]

**PART NO.:**
[Part No.]

**DESCRIPTION:**
[Description]

**UNIT: DOES:**
[Units]

**ITEM:**
[Item]

**ITEM NO.:**
[Item No.]

**SPEC:**
[Specification]

**MFR:**
[Manufacturer]
|--------|-----|----------|----------|-------------|------|----------------|-----|------|------------|-------|----------|----------------|
THIS IS A RECODE E.C.

THIS E.C. REINSTALLS THE ORIGINAL PRODUCTION HYD LINE IN THIS AIRCRAFT.
GRUMMAN AEROSPACE CORPORATION

LINE 1 INSTL-HYD-FUS AFT SECT - STA 451 - AFT

THIS IS A
RECORD E.O.

HYDRAULIC CHECK-OUT SYS.

DESCRIPTION OF CHANGE: ON-1 INSTL.
ADDED FLOW SENSOR BY-PASS AS SHN.

PREPARED BY: J. BROWN

EFFECTIVE DATE: 3/27/79

PLANT-DROP: 40-092

ENGINEERING ORDER
MANUFACTURING CHANGE ORDER
NADC 81073-60

**THIS IS A RECORD E.O.**

**THIS E.O CANCELS**

- 128EL6600 L1
- 128EL6603 L4
- 128EL6607 L9
- 128EL6606 L1

**ENGINEERING ORDER**

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**PREPARED BY:** [Signature]

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<th>BILLING</th>
<th>CUST</th>
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**REMARKS:**

- CANCELED EO 128EL66010 L1, 128EL66013 L4
- 128EL66047 L9 & 128EL66060 L1
THIS IS A RECORD E.D.

THIS EO CANCELS

128EL66010 L1
128EL66013 L4
128EL66037 L9
128EL66060 L1
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**EQUIP INSIDE AREA**

- Case drain flow sensor - LH keel - 128690-P1
- Case drain- temp SW - LH keel - 128691-P1
- Pump quiescent flow - LH keel - 128692-P1
- L.H.T.A.T.O.R. pump temp sensor - LH keel - 128693-P1
- P.W.M.P.O.M. pump sw. sensor - LH keel - 128694-P1
- P.W.M.P.O.M. pump feedback - LH keel - 128695-P1
- Hydraulic reservoir temp sensor - LH keel - 128697-P1
- Filter Delta P. Preheat - LH keel - 128699-P1
- Filter Delta p. Dump - LH filter - 128700-P1
- Filter Delta p. Return - LH keel - 128701-P1
- B.V. Temp sensor - LH keel - 128702-P1
- P.W.M.P.O.M. SW & pressure sensor - LH keel - 128703-P1
- P.H.E. desiccant dryer - LH filter - 128704-P1

**EQUIP OUTSIDE AREA**

- P.W.M.P.O.M. pump - Tail set - 128706-P1
- P.W.M.P.O.M. pump temp SW - Tail set - 128708-P1
- Pump press switch SW - LH keel - 128709-P1
- STA 139 Blk/hd - LH filter - P6045
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- 30
- 31
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- 35
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- 41
- 42
- 43

**EFFECTIVITY:**
- B

**HARDWARE REQUIREMENTS:**
- MANUFACTURING CHANGE ORDER
- SUPPLEMENT
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**CABLE ASSEMBLY AND ROUTING CODE**

- All cables are prefixed by **128KV**

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**ACTION**

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**EFFECTIVE**

- 9
- 30
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- 32
- 33
- 34

**REFERENCE DESIGNATOR**

- 128KV

**EFFECTIVE**

- B

**ENGINEERING ORDER MANUFACTURING CHANGE ORDER SUPPLEMENT**
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CABLE ASSEMBLY AND ROUTING CODE ALL CABLES ARE PREVIEWED BY I28 AV

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EFFECTIVE
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**REFERENCE DESIGNATOR/ROUTE LETTERS**

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**CABLE ASSEMBLY AND ROUTING CODE**

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**REFERENCE DESIGNATOR/ROUTE LETTERS**

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**ENGINEERING ORDER/ MANUFACTURING CHANGE ORDER**

**SUPPLEMENT**
**GRUMMAN AEROSPACE CORPORATION**

**E0 NOTED** 128 EL 6609

**DRAWING** SEE DWGS

**THIS IS A RECORD E.O.**

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**REASON FOR CHANGE**

INSTR OF HYDRAULIC CHECK-OUT SYSTEM (HYCOS) IN MC FOR INSTRUMENTATION PURPOSES.

**DESCRIPTION OF CHANGE**

ON DWGS 1073 ADDED WIRING RUNS.

**PREPARED BY** 3/31/79

**APPROVED BY** 4/3/79

**DATE** 4/3/79

**INSTRUCTION** NO ACTION

**REMARKS** NO ACTION
THIS IS A RECORD E.O.

THIS EO CANCELS
128EL66010 L1
128EL66013 L4
128EL66047 L9
128EL66060 L1

ENGINEERING ORDER

DRAWING NUMBER REV SEQ NUMBER DWG DOC REF. NO. 51
EO 128EL66010 L4 47 71
EO 128EL66047 L4 34 71
EO 128EL66047 M2 69 71
EO 128EL66040 L4 41 71
THIS IS A RECORD E.O.

DRAWING NUMBER\nREVIEWED\nREVIEW WITH\n\n0.12BEL66041-1
0.12BEL66039-1
0.12BEL66024-1
0.12BEL66019-1
0.12BEL66053-1
**GRUMMAN AEROSPACE CORPORATION**

**ENGINEERING ORDER**

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**ACTION**

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**REASON FOR CHANGE**

**INSTR OF HYDRAULIC CHECKOUT SYS (HYCOS) 
INSTR FOR INSTRUMENTATION PURPOSES**

**DESCRIPTION OF CHANGE**

ON DWG NOTE AOPVL

**DRAWING NOTED AOPVL**

**ADDED WIRING RUNS**

**PREPARED BY**

**APPROVED BY**

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**ENGINEERING ORDER**

**MANUFACTURING CHANGE ORDER**
**THIS IS A RECORD E.O.**

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GRUMMAN AEROSPACE CORPORATION

THIS IS A RECORD E.O.

THEME: INSTR OF HYDRAULIC CHECKOUT SYS (HYCOS) IN AC FOR INSTRUMENTATION PURPOSES

DESCRIPTION OF CHANGES:

ON DWGS NOTED ABOVE
ADDED WIRING RUNS

PREPARED BY J. Bo. (J)
APPROVED BY (S)

SECTION 2/4 WIRINGS
PLANT GROUP 40 327

DATE: 2/20-79 (W70)

ENGINEERING ORDER
MANUFACTURING CHANGE ORDER

DNC 81075-60
**GRUMMAN AEROSPACE CORPORATION**

**DATE**: 01/04/78

**Dwg Title**: INSTALLATION Dwg: Fuselage

**Contract No.**: N6269-78-C-0084

**Action**: Create -901 as shown

**Note**: Revised wiring changes are shown on the following sheets 3, 4, 5, 6, 7

**Description of Change**

**Installation of hydraulic check out system (hyco)**

**Section**: E00

**Plant Group**: 40 - 543

**Date**: 4-27-78

**Prepared by**: Mr. Miller

**Approved by**: Mr. Jones

**Date of Change**: 4-27-78

**Description**: Add hyco wiring

**Reference**: EO 128AV66014

---

**Additional Information**

- **Wiring Diagram**: View L.G.1 M.D.1 L.H. Inlet duct

---

**Record EO 128AV66014**
NOTE: ALL WIRES TO BE GW805BS22-9 UNLESS OTHER WISE NOTED.

1. ADD PUMP CASE
   12AG90PI
   MS316610SL95
   IDENT SLEEVE STAMPED 12AG90PI ON G8830CV25-9
   FLOW SENSOR
   L.H. KEEL
   B
   G720A22 ---- 12 24
   C
   G690A22 ---- E694 223
   A
   G691A22 ---- 1 24

2. ADD PUMP CASE
   DRAIN TEMP SWICH
   ET09
   12AG92PI
   MB3723-13 R006SN
   IDENT SLEEVE STAMPED 12AG92PI ON G8830CV25-9
   L.H. KEEL
   A
   G694A22 ---- G 24
   B
   G693A22 ---- E695 23
   C
   G693N22 ---- 24 24
   D
   G695A22 ---- E696 25
   E
   G695A22 ---- E696 25

3. ADD RAM AIR TURBINE
   ACCUMULATOR
   DISPLACEMENT TRANSUDER
   R1
   12AG93PI
   G698A22 ---- 20 24
   G699A22 ---- E700 23
   L.H. KEEL

4. ADD RAM AIR TURBINE
   ACCUMULATOR
   TEMP TRANSUDER
   L.H. KEEL
   A
   G697A22 ---- E701 23
   B
   G696A22 ---- 20 24
   C
   G8930A21
   GC16F1223
NOTE: IT IS POSSIBLE TO SPURGE TO GET ADDITIONAL LENGTH IT IS REQUIRED.

GRUMMAN AEROSPACE CORPORATION

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BAD ENDS

(ADD) Rudder

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(ADD) Rudder ACTUATOR POSITION

| 1               | G693D22 | E695 | 23 |
| 2               | G714A22 | 34   | 24 |
| 3               | G713B22 | E697 | 23 |
| TAIL            |         |      |    |

(ADD) HYDRAULIC

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(ADD) PUMP PRESSURE

| HYDRAULIC SWITCH | G717A22 | 2 | 24 |
|                  | G697G22 | E701 | 23 |
|                  | G711A22 | 34 | 24 |

(REF) BALLISTIC PNJ

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L.H. FUSELAGE DUCT 30AB

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ENGINEERING ORDER
MANUFACTURING CHANGE ORDER
**GRUMMAN AEROSPACE CORPORATION**

**NADC 81073-60**

### INSTALLATION Dwg. HUSELAGE

**ACTION**

- Qty. No: 801
- Qty. 2: 801

**PART NUMBER**

- NEXT ASSEMBLY Dwg.

**NOTE**

- NEXT ASSEMBLY Dwg.

**REV**

- V2

**PART NO.**

- 26512

**EO**

- 12B660614

**GRCH NO.**

- 801

**MFG**

- 46E

**MFG**

- M229

---

THIS EO REVISES: AEO 10/15 (control No. 128LAV1678)

---

**ADAP END CAP**

- G24422 - 21 B24
- G69022 - 694 B23
- G70422 - 8 B24

**ADAP END CAP**

- G72422 - 19 B24
- G69022 - 16B24
- G70442 - 3 B24

---

**PREPARED BY:**

- John O'Call

**APPROVED BY:**

- Group: IA
- Support: SP
- Reliability: RE
- Stress: ST
- Proc./Eng.: UN
- END NO.
- All NO.
- All NO.

**DATE**

- V2-79

---

**ENGINEERING DATA**

**MANUFACTURING CHANGE ORDER**

---

**INDEX**

- Part 1:
  - 128LAV1678
  - 128LAV1678

---

**DESCRIPTION OF CHANGES**

- Note:
  - Single-Multi Switches WERE INSTALL
  - Instead of Reversing IN ALL Dwg.
  - Sensitivity of END ASSEMBLY LEVEL REVISION

---

**MATERIAL SPECIFICATION**

- Code 051
- Code 051

---

**REASON FOR CHANGE**

- Note:
  - Single-Multi Switches WERE INSTALL
  - Instead of Reversing IN ALL Dwg.
  - Sensitivity of END ASSEMBLY LEVEL REVISION

---

**NOTES**

- Single-Multi Switches WERE INSTALL
- Instead of Reversing IN ALL Dwg.
- Sensitivity of END ASSEMBLY LEVEL REVISION

---

**DATE OF CHANGE**

- V2-79

---

**MFG**

- 46E

---

**END NO.**

- M229
ADD DOUBLE RING 128B1/380 - 911 RING TO HAVE SAME CONTOUR AS 128B1/380 AAI - 915

FASITE 911 to 915 WITH NAS1097 DD4 CSK BOTH SIDES NKG HAOD FAR EDGE

REMOVE GS520BF GR540CA & GR520BP (11H)
ADD GS520 CK4-02
GR520 CA1, GR540CN1 & GP525 CK1
USE INSTL TOOL CA2104-T12

128B1/380 - 901 INSTL (VIEW LKG INBD LH SIDE)
### GRUMMAN AEROSPACE CORPORATION

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**REASONS FOR CHANGE:**
- TO PROVIDE IMPROVED PANEL FIXTURE FOR longer service life, (HYCOS INSTL)

**DESCRIPTION OF CHANGE:**
- ADD - 711 DOUBL DR GS520BE, GS540CA, GS520CK4, ADD GS515CK1, GS520CA

**PREPARED BY:** G BARES

**SECTOR:** STRUCT SYS

**PLANT GROUP:** 40 - 375

**DATE:** 2/1/80 - 6/73

---

**NADC 81073-60**

**REPLACE PART NO:** NG2267 B6C-0041

**DATE:** 7/1/88

**MODEL:** MA29

**MATERIAL SP ECIFICATION:**

**PROC FOR:**
- A - ACCEPT
- B - REJECT AND TRAVERSE

---

**RECORD EO:**
**GRUMMAN AEROSPACE CORPORATION**

**COMPONENTS INSTL, HYDRAULICS - COMBINED SYSTEM L H AEL**

**ACTION**

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**PREPARED BY** WALTER MOORE

**APPENDED BY**

**GROUP**

**FLUID POWER**

**SIGNATURE**

**DATE** 23/79

**EO** 6189

**MANUFACTURING CHANGE ORDER**
ON RECORD B.O. 128H10009-901, REV V1 (B.O. CONTROL NUMBER 1284755), REVISE AS FOLLOWS:

1. ON SH1, IDENTIFICATION OF BRACKET ASSEMBLY SHOULD READ "ADD 128H10009-911 BRACKET ASSEMBLY." WAS "ADD 128H10009-901 BRACKET ASSEMBLY."

2. ON SH2, IDENTIFICATION OF FILTER SHOULD READ "1289SC/H133-16 COMBINED SYS PRESS FILTER (REF)." WAS "1289SC/H136-16 COMBINED SYS PRESS FILTER (REF)."

3. ON SH3, IDENTIFICATION OF FILTER SHOULD READ "1289SC/H133-16 COMBINED SYS RETURN FILTER (REF)." WAS "1289SC/H136-16 COMBINED SYS RETURN FILTER (REF)."
## Configuration Verification

### Part No: 81073-60

**Action:** OPERATIONS  
**Note:** OPERATIONS

### Contract No:

**NADC 81073-60**

**NADC 81073-60**  
**NADC 81073-60**

### Reservoir Instal, Hydraulic - Combined System

**Model:** M287  
**Part Name:** M287

### Hydraulics Check Out System Installation

**Prepared By:** WALTER MOORE
**Approved By:** J. MOORE
**Date:** 1/20/57

### Section: Fluid Power

**Date:** 1/20/57

### Description of Change

**NOTED ON SHEET 2**

### Engineering Order

**Manufacturing Change Order**
REMOVING BEND AN-528-58
AN-515-60
M-528-78-6

90° PNEUMATIC LINE BEND REPLACED 90° ELBOW

REMOVED FITTINGS FROM 90IRP-6 LINE

VIEW LOOKING INBOARD

THIS IS A RECORD EO.
FASTEN WITH SM 4004-12I
EPOXY - ADHESIVE

HELION TEMPERATURE SWITCH
Model C48H/13 MFA 13049A310

ZONE B7.

VIEW LOOKING FORWARD

ATTCHMENT 1: COMPONENTS LIST

PREPARED BY: WALTER MOORE
APPROVED BY: [Signature]
GROUP: [Group]
SUPPORT: [Support]
RELIABILITY: [Reliability]
DATE: 2-8-70
SD: 100960.30
DISPOS OF: 6
REDRAW: 0
INCREASE: 0
CREATE: 0
USE & GUIDE: 0
ACTION: 0
ACCEPT: 0
KEY AND TRACIBILITY: [Key and Tracibility]

ENGINEERING ORDER:
MANUFACTURING CHANGE ORDER
### GRC1M3-8073-60

#### Configuration/Modification and Traceability Record

**Manufacturer:** GRUMMAN AEROSPACE CORPORATION  
**Order:** 26512  
**EONOTED:** 02/04/2009  
**EONOTED:** 26512  
**SASH NO.:** 26512  
**REV:** W2

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### Action

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1. **GCR Assy - 9000: twin engineacker 1285-2, H, I, 37, 3**

   - **REMOVE 9000 Assy (10-000-1-11) & HARDWARES**
     - AN4-80, AN4-80
   - **REMOVE 9000 Assy (10-000-1-11) & HARDWARES**
     - AN4-80, AN4-80
   - **REMOVE 9000 Assy (10-000-1-11) & HARDWARES**
     - AN4-80, AN4-80, AN4-80
   - **REMOVE 9000 Assy (10-000-1-11) & HARDWARES**
     - AN4-80, AN4-80, AN4-80
   - **REMOVE 9000 Assy (10-000-1-11) & HARDWARES**
     - AN4-80, AN4-80, AN4-80

2. **GCR Assy - combined system pressure filter 1285-1, H, 33, 3**

   - **REMOVE 902 Assy**
   - **REMOVE 907 Assy**
   - **REMOVE 905 Assy**
   - **REMOVE 902 Assy**
   - **REMOVE 901 Assy**

### Reason for Change

- **DESCRIPTION OF CHANGE:**
  - **REMARKS:**
  - **DATE:**
  - **SHEET:**
  - **PREPARED BY:**
  - **APPROVED BY:**
  - **GROUPHashCode:**
  - **SUPPORT:**
  - **RELIABILITY:**
  - **STRESS:**
  - **PROD ENG:**
  - **PROD ENG:**
  - **RELEASE:**
  - **CUSTOMER:**

**ENGINEERING ORDER/ MANUFACTURING CHANGE ORDER**
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*3: NOT ASNY = COMBINED SYSTEM RETURN PUMP C/I-CH-149.

*4: RCV-SRV DIFFERENT PUMP, NON-FAST COMBINATION.

INSTL. THE 3000 EMER SYM A/B ATTLE 0204/04/05/06/07/08 ACCORD. INSTM. PER 12/04/05/06/07 INS.
### GRUMMAN AEROSPACE CORPORATION

**REPLACE** RESERVOIR INSL - HYDRAULIC - COMBINED SYSTEM

**ACTION**
- REMOVE RESERVOIR ASSY, 1284/10/25-1
- REMOVE LEVEL SENSOR ASSY, AR90-306
- REMOVE TEMPERATURE TRANSUCER, DEV0001, AR90-304
- REMOVE ALL ASSOCIATED HARDWARE
  - AN99-D0
  - AN832-D0
  - AN6789-D0
  - AR99-86
  - MS26712-06(2)
  - MS26718-4
  - MS26718-6(2)
  - MS26718-6(2)
  - MS28713-6(2)

**REPLACE** RESERVOIR ASSY, 1284/10/25-1, PER 1284/10/27-1 INSL

**PREPARED BY**
- APPROVED BY
- SUPPORT
- RELIABILITY
- STRESS
- PROD ENGINEERING
- PROD ENGINEERING

**ENGINEERING ORDER/ MANUFACTURING CHANGE ORDER**
APPENDIX H

HYCOS PROGRAM FLOW DIAGRAM
EXECUTIVE ROUTINE

1. START
   - HAS SWITCH BEEN THROWN?
     - NO
       - IS IT CIRCUIT TEST ON-1?
         - NO
           - IS IT SYSTEM TEST ON-2?
             - NO
               - GO TO LOAD ROUTINE
             - YES
               - GO TO SEQUENCE ROUTINE
         - YES
           - LIGHT ALL LAMPS
     - YES
       - GO TO RAM LOAD ROUTINE

2. (No flow label)

3. (No flow label)
SEQUENCE ROUTINE

1. IS POWER OFF
   - NO
   - YES

2. INITIALIZE BUS
   - INITIALIZE STARTING POSITION
   - LIGHT LAMPS FOR 1/2 SECOND
RESERVOIR ROUTINE

1. IS RESULT NEGATIVE?
   - NO: LIGHT LEVEL LAMP
   - YES: GO TO RARE ROUTINE

2. LIGHT LEVEL LAMP
   - NO: SUBTRACT CORRECTED VALUE FROM KNOWN LEAK VALUE
   - YES: LIGHT LEAK LAMP

3. SUBTRACT CORRECTED VALUE FROM KNOWN LEAK VALUE
   - NO: GO TO LOOK-UP TABLE FOR CORRECTION FACTOR
   - YES: ADD CORRECTION FACTOR TO THIS VALUE

4. GO TO LOOK-UP TABLE FOR CORRECTION FACTOR
   - NO: STORE DISPLACEMENT VALUE FROM A/D
   - YES: STORE VALUE IN MEMORY LOCATIONS 'Z', 'Z', AND 'Z'

5. STORE DISPLACEMENT VALUE FROM A/D
   - NO: STORE VALUE IN MEMORY LOCATIONS '0', '1', AND '1'
   - YES: COMPARER TEMPERATURE VALUE TO 1260 F

6. COMPARE TEMPERATURE VALUE TO 1260 F
   - NO: LIGHT TEMPERATURE LAMP
   - YES: TEMPERATURE TOO HIGH?
RAT ROUTINE

1. RETURN TO START
2. LIGHT RAT LAMP
3. IS RESULT NEGATIVE?
4. SUBTRACT 450 FROM RESULT
5. MULTIPLY BY $\Delta \left( \frac{R}{3650} \right)$
6. GET PRESSURE FROM A/D
7. GET TEMPERATURE FROM A/D
8. ADD FACTOR TO PRESSURE GET SYS
9. ADD TEMPERATURE TO 460° RANK IN
10. DIVIDE 530 BY
11. MULTIPLY BY $P_{SYS} \left( \frac{530 - (460 + T)}{460 + T} \right)$
12. GET DISPLACEMENT FROM A/D
13. DIVIDE BY 3650
14. GO TO LOOK-UP TABLE GET PRESSURE CORRECTION FACTOR
15. GET TEMPERATURE FROM A/D
16. ADD TEMPERATURE TO 460° RANK IN
17. DIVIDE INTO 530
18. MULTIPLY BY $\Delta \left( \frac{R}{3650} \right)$

H-8
The Hydraulic Checkout/Diagnostic Monitoring System (HYCOS) includes the following nickel-cadmium batteries:

- **+5V Battery**: 4 Series-connected, 1 A-H, G.E. cells (Gold Top type X GCR 1.0ST)
- **+3.6V Battery**: 3 Series-connected, 100 mA Hr GE cells (Gold Top type X GCR 100ST)
- **-6V/-4.8V Battery**: 5 Series-connected (-6.0V) cells with a 4-cell tap for -4.8V. Cells are the same as the +3.6V battery cells.

These batteries are located within the HYCOS panel (box) and are not readily accessible.

1.1 GENERAL HYCOS POWER UTILIZATION

When installed in an aircraft, HYCOS uses 115 VAC, 400 Hz ship's power (when "on") to support HYCOS functional requirements and to recharge the batteries. When ship's power is "off" or otherwise not available, HYCOS power is supplied by the batteries.

A typical checkout test will last about 1/2 to 1 minute. It is estimated that up to six of these tests could be performed over a period of up to 6 weeks where no battery charging takes place.

1.2 BATTERY DISCHARGE

1.2.1 **+5V Battery**

This battery (now) only supplies power during the actual test period. Loads on this battery include:

- All power to logic circuits which, based on H. Dreksler's analysis, is approximately 500 mA
• Power for a maximum of five 'grain-of-wheat' lamps/test at approximately 50 mA each, or 250 mA total
• Power for two fiber optic light source lamps at approximately 750 mA each, or 1500 mA total.

The total current drain on the +5 battery during the test period is approximately 2.25 A. Assuming a realistic maximum test period of one (1) minute, the energy output per test is approximately 3.75% of the nameplate capacity of the battery.

1.2.2 +3.6V Battery

This battery is used to sustain the CMOS RAM (M5101). It supplies current of between 2-200 μA essentially all the time. Assuming a nominal current of 100 μA, the battery energy output would be approximately 2.4 mA-hr per day. At this rate the 100 mA-hr battery, if initially fully charged, could operate up to about 6 weeks without charging.

1.2.3 -6V/-4.8V Battery

This battery supplies power only during the actual test period to seven (7) 8703 A/D converters. The -6V output supplies approximately 7 x 20 μA or 140 μA, while the -4.8V output, obtained by tapping into the -6V battery, supplies 7 x 5 mA or 35 mA. Thus, the cells that form the -4.8V battery have a total current drain of 35 mA + 140 μA, or essentially 35 mA. On the basis of a one-minute test period, this -4.8V battery supplies about 0.6% of the nameplate capacity per test, while the additional cell used to obtain the -6V output supplies negligible energy/test (0.0023%/test).

On the basis of energy output requirements, each HYCOS battery would appear to be adequately sized. Even accounting for self-discharge of the batteries, which could range up to a loss of perhaps 50% capacity over a 6-week period (at normal storage temperatures of about 20°C), the batteries should have adequate capacity.

Note: The +3.6V battery, which is supplying memory-sustaining power while the other batteries are idle, should be marginally acceptable for a 6-week storage.

1.3 BATTERY CHARGING

The circuit used for battery charging is shown in Fig. 1-1. Figure 1-2 depicts the HYCOS Battery Charger. The recommended (by G.E.) constant current charge rate for the Gold Top batteries is between C/10 and C/20. These batteries can supposedly safely handle continuous overcharge at these rates.
Figure 1-1. Battery charging circuit.
A fully depleted battery, in order to be fully charged at C/10, will require 14-18 hr of charge time and 30-35 hr of charge time at C/20. It is unlikely that HYCOS batteries will be provided this much time if charging is to be accomplished during aircraft flight.

Based on the questionable time available for recharge, it is recommended that the HYCOS panel be equipped with an externally accessible connector (Fig. 1-3) that provides direct connection to battery + and - terminals, or connections to the input of the HYCOS battery charging circuit (i.e., 115 VAC, 400 Hz to transformer primary). The preferred approach is direct connection to the battery terminals. This connector would then allow:

- Monitoring or a status check on battery voltages
- Battery charging using a dedicated ground support charger.
Figure I-3. Battery Test Panel Connector Interface.
### PHOTO NO. DESCRIPTION

<p>| J-1 | View showing temperature-compensated pressure switch mounted to 15 cubic inch pneumatic bottle. |
| J-2 | Port keel area showing quiescent flow sensor, system pressure switch, and pressure filter remote reading Delta P indicator. |
| J-3 | View showing temperature transducer in return line to reservoir. |
| J-4 | Combined system reservoir showing remote reading potentiometer and desiccant saturation detection unit. |
| J-5 | Port keel area showing probe-type temperature switch in pump case drain line. Also shown is system pressure switch. |
| J-6 | Port keel area showing probe-type temperature switch in pump case drain line. Also shown is system pressure switch. (Same as J-5.) |
| J-7 | Case drain filter showing APM multicator installation (provisions for fluid sampling case drain line). |
| J-8 | View looking forward at 30-cubic inch gear door dump bottle with temperature-compensated pressure switch on pedestal. |
| J-9 | View showing duct access area where HYCOS panel is to be mounted. Wire bundles are shown in area. |
| J-10 | View showing bottom of Ram Air Turbine Accumulator with temperature and pressure transducer. |
| J-11 | Forward port keel area showing Ram Air Turbine Accumulator with linear displacement transducer. |
| J-12 | View showing bottom of Ram Air Turbine Accumulator with temperature and pressure transducer. (Same as J-10.) |
| J-13 | Closeup of displacement rod on Ram Air Turbine Accumulator. |
| J-14 | Closeup of displacement rod on Ram Air Turbine Accumulator (Same as J-13.) |</p>
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<td>J-15</td>
<td>View looking forward at RAT accumulator mounting.</td>
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<tr>
<td>J-16</td>
<td>Surface temperature switch mounted on flight control backup module.</td>
</tr>
<tr>
<td>J-17</td>
<td>Surface temperature switch mounted on flight control backup module (Same as J-16.)</td>
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<td>J-18</td>
<td>Rudder actuator flow sensor on pressure line.</td>
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<tr>
<td>J-19</td>
<td>Rudder actuator flow sensor on pressure line. (Same as J-18.)</td>
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<td>J-20</td>
<td>Pump case drain flow sensor installation.</td>
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<td>J-21</td>
<td>A-6E Mod 229 flight test vehicle.</td>
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<tr>
<td>J-22</td>
<td>Plane Captain interrogating HYCOS system.</td>
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<tr>
<td>J-23</td>
<td>Closeup on HYCOS Display panel in flight test vehicle.</td>
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APPENDIX K

MICROPROCESSOR PROGRAM
EXECUTIVE ROUTINE
ROUTINE TO BE FOLLOWED EVERY TIME POWER IS
APPLIED. WE CHECK TO SEE IF CIRCUIT TEST
SWITCH IS IN THE DOWN POSITION WHICH GENERATES
A LOOP: THIS SENDS THE PROCESSOR TO THE SEQUENCE
REPEAT TO CHECK IF ALL THE RED LAMPS ARE
WORKING AND IF THE MICROPROCESSOR IS FUNCTIONAL.
IF SYSTEM TEST SWITCH IS IN THE DOWN POSITION WE DO
A SYSTEM TEST IF THE PRESSURE SWITCH IS ON WE DO A
RUGGED CHECK FOLLOWED BY AN OVER TEMPERATURE TEST.
A RESERVOIR LEVEL AND LEAK TEST AND FINALLY A RAT
TEST IF THE PRESSURE SWITCH IS OFF WE DO A RESERVOIR
AIR TEST.

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<td>FIRST THE PUMPS (5 LAMPS), THEN RESERVOIR (4 LAMPS),</td>
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<td>START BUS AT BEGINNING</td>
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<td>021C 3FfP</td>
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<td>OUTPUT TO BUS TO LIGHT LAMPS</td>
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<td>PRELOAD P2 FOR 1/2 SECOND TIMING</td>
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<td>CALL MSBR</td>
<td>GET 1/2 SECOND TIMING SUBROUTINE</td>
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<td>RESTORE ACCUMULATOR</td>
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<td>JMP TSTUT</td>
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<td>0222 0418</td>
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<td>RAM LOAD SUBROUTINE</td>
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K-3
LOC OBJ  SEQ  SOURCE STATEMENT

53  .IF HYDRAULIC SWITCH IS AT A "0" WE GO TO THE AIR ROUTINE
54  .IF AT A "1" WE DO RESERVOIR ROUTINE
55  (FOLLOWING THE RUDDER ROUTINE)
56

8025 2382  57  RAILD:  MOV A, A02  ; ENABLE STATE OF HYDRAULIC SWITCH
8027 29  58  OUTL P1, A:  ; TO BUS
8028 08  59  INS A BUS  ; AND INPUT TO ACCUMULATOR
8029 1250  60  JBR RUDDER  ; IF A "1" DO RUDDER ROUTINE
8029 730  61  AIR ROUTINE:
8029 797  62  THE SYSTEM IS UNPRESSURIZED, THE SYSTEM TEST SWITCH IS
8029 775  63  UP OR DOWN. TEMPERATURE T1 AND DISPLACEMENT R1 ARE IN
8029 753  64  MEMORY LOCATIONS 0 & 1 AND 2 & 3 RESPECTIVELY. THE PRESENT
8029 731  65  TEMPERATURE T2 IS INPUTTED FROM THE TRANSDUCER THROUGH ITS A/D
8029 709  66  CONVERTER AND CHECKED FOR OVERTEMP. THEN T1 IS SUBTRACTED FROM
8029 687  67  T2 TO GIVE DELTA T (CT). CT = T2 - T1. IT IS MULTIPLIED BY
8029 665  68  CONSTANT 3.78 TO GET TEMPERATURE CORRECTION FACTOR. THE RESULT
8029 643  69  IS ADDED TO OR SUBTRACTED FROM R1 DEPENDING ON THE SIGN OF CT
8029 621  70  NEXT ADD 488 TO RL TO ALLOW FOR A 1 INCH DISPLACEMENT AND GET
8029 600  71  (1/"R") DISPLACEMENT R2 IS INPUTTED FROM THE RESERVOIR POCKET AND ITS
8029 578  72  A/D RL1 IS SUBTRACTED FROM R2. IF RESULT IS POSITIVE DISPLACE-
8029 556  73 MENT WAS MORE THAN 1 INCH AND WE LIGHT THE AIR LAMP.
8029 534  74
8029 512  75  EXAMPLE
8029 490  76  ASSUME  T1=135 C  T2=21 C
8029 468  77  R1=5580  R2=5608
8029 446  78
8029 424  79  AIR=R2 - (R1 + 488 + (T2 - T1) X 3.78)
8029 402  80
8029 380  81  R1 + 488 + (T2 - T1) X 3.78 = RL1
8029 358  82
8029 336  83  T2 - T1 = 21 - 135 = -114
8029 314  84
8029 292  85  -114 X 3.78 = -438
8029 270  86
8029 248  87  AIR = 5600 - ( 5588 + 400 - 438 )
8029 226  88
8029 204  89  = 5688 - 5478
8029 182  90  = + 130
8029 160  91
8029 138  92  ANSWER IS POSITIVE SO AIR LAMP LIGHTS
8029 116  93
8029 944  94  START WITH EQUATION ( T2-T1 ) X 3.78
8029 922  95  CALL TMPCX  ; GET T2 FROM TEMP A/D CONVERTER
8029 900  96  ; INPUT TO ACCUM AND R2
8029 878  97  ; CHECK FOR OVERTEMP
8029 856  98  CLR A  ; INITIAL CONDITION
8029 834  99  MOV R5, A  ; R5 SETS MEMORY ADDRESS
8029 812 100  MOV R6, 138H  ; R6 OUTPUT FOR READ
8029 790 101  OUTL P1, A  ; CLEAR PORT 1 FROM BUS
8029 768 102  CALL LSD:  ; GET T1 FROM MEMORY
8029 746 103  CALL SETCT  ; CT = T2 - T1
8029 724 104  MOV P2, 00H  ; SETTING UP SIGN OF SUBTRACTION
8029 702 105  T78 NEG  ; IF NEGATIVE PEG 1 = 1

K-4
NADC 81073-60

LOC OBJ SEX START STATEMENT

0050 C9 188 DEC R1 ELSE REG 1 = 0
0050 543A 189 NEGA CALL LXUP1 GET BINARY VALUE FOR 3 X 3.78
0100 110 BINARY RESULT STORE IN REGISTER 4 RESISTOR R1 IS IN MEMORY
0111 PA 1 AND WE WILL ADD IT TO 400 ( = 000D ) AND ST VALUE
0050 345C 112 CALL LSO GET R1 FROM MEMORY
0050 0388 113 ADD A,130H .RI + 424 COULD NOT GET 400 EXACT.
0050 29 114 XOR A, R1 EXCHANGE SUM WITH SIGN OF IT
0050 253F 115 ANL A,10FH AND TO SEE IF 0
0050 064C 116 JZ POS1 IF 0 IT WAS POSITIVE
0050 117 ELSE NEGATIVE
0050 0646 FC 118 MOV A, R4 GET 3T
0050 07 FC 119 CPL A ONES COMPLEMENT
0050 0648 117 INC A 2'S COMPLEMENT
0050 0649 FC 117 ADD A, RI SUM + ST
0050 0644 FC 112 JMP SUM SUBTRACTION COMPLETE
0050 064C FC 111 POS1 MOV A, R4 GET 3T
0050 064D 114 ADD A, RI SUM + ST
0050 064E AA 115 SUM1 MOV R2.A .RI INTO REG 2
0050 0420 116 MOV A,160H .R2.A/0
0051 0480 117 CALL GONOGO INTO ACCUM
0051 0689 118 XCH A, R2 SWAP R2 AND RI
0051 0483 119 CALL SBTCT R2 = RI
0051 0682 118 JFB START IF NEGATIVE NO ERROR
0051 0487 117 MOV A.1607 ELSE WHOLE OPERATION
0051 03F9 118 OUTL P1.A AIR LAMP
0051 0482 114 JMP START REPEAT WHOLE OPERATION
0051 135
0051 136
0051 137
0051 138
0051 139
0051 140
0051 141
0051 142
0051 143
0051 144
0051 145
0051 146
0051 147
0051 148
0051 149
0051 150
0051 151
0051 152
0051 153
0051 154
0051 155
0051 156
0051 157
0051 158
0051 159
0051 160
0051 161
0051 162

Rudder circuitry

Take analog outputs of 2 pots . R/0 complement.

Subtract from each other then subtract difference

From a given tolerance if difference is

Too high light rudder lamp

Rudder: MOV A,1018H Rudder pot data

Call gonogo from R/0

MOV R2.A PUT INTO R2

MOV A,108H Rudder pedal data

Call gonogo from R/0

MOV A,168H .R2.A/0

Call sbtct .R2 = RI

JFB START; IF NEGATIVE NO ERROR

MOV A,1607 ELSE WHOLE OPERATION

Outl p1.a air lamp

Jmp start repeat whole operation

Rudder:

Due to setting of pot the following constants are used

Each bit is 51 ohms 6780/127

Slope for normal displacement is 1.25 ohms Degree f =

.22 ohms 

Degree c = deg c / Bit

Reservoir routine

K-5
LOC 080  SEQ  SOURCE STATEMENT
163  15420 OHMS AT -54 C = LEVEL MINIMUM
164  15870 OHMS AT -54 C = LEAK MINIMUM
165  
166  TEMPERATURE TRANSUER READS IN DEG C AND IS SET SO THAT
167  
168  -54C IS EQUAL TO 8 EQUATIONS ARE
169  LEVEL = 5420 + 3.33 X T + R (IF POSITIVE WE LIGHT LAMP)
170  LEAK = 5070 + 3.33 X T - R (IF POSITIVE WE LIGHT LAMP)

171 RSVR:
0878 B000  172  MOV R5, 00H  ; INITIAL ADDRESS OF MEMORY
0878 B018  173  MOV R6, 00H  ; INITIAL CONDITION
0878 B408  174  CALL TRAPC  ; GET TEMPERATURE. CHECK FOR
0878 B447  175  CALL BYST  ; OVERTEMPERATURE STORE IN R2 & A
0878 B847  176  CALL BYST  ; PUT IN MEMORY LOCATIONS 'A' & '1'
0878 B847  177  MOV R.A, 00H  ; TEMP BACK TO ACCUM
0878 B84F  178  CALL LKUP2  ; GET BINARY EQUIVALENT OF TEMP
0878 B84F  179  AND STORE IN R4
0878 B84F  180  MOV R.A, 0020H  ; DISPLACEMENT VALUE
0878 B84F  181  CALL GONOGO  ; INTO ACCUM
0878 B84F  182  MOV R5, 00H  ; INITIAL CONDITION
0878 B858  183  MOV R.A, R2  ; STORE DISPLACEMENT IN R2
0878 B850  184  CALL BYST  ; PUT DISPLACEMENT IN MEMORY
0878 B850  185  LOCATIONS "2" & "3"
0878 B84F  186  MOV R.A, 00H  ; GET T
0878 B867  187  CALL GONOGO  ; DISPLACEMENT - 3T = 3P
0878 B870  188  MOV R4, R2  ; STORE X R IN R4
0878 B866  189  MOV R2, 066H  ; 5420 OHMS
0878 B868  190  CALL GONOGO  ; INTO ACCUM
0878 B866  191  JFB RAT  ; IF F8 0R > 5420
0878 B83F  192  MOV R.A, 00H  ; ELSE LIGHT RESERVOIR
0878 B83F  193  OUTL P.I, 00  ; LEVEL LAMP
0878 B84F  194  MOV R2, 0068H  ; 5070 OHMS
0878 B84F  195  MOV R.A, R4  ; GET T
0878 B84F  196  CALL GONOGO  ; 5070 - 3T
0878 B84F  197  JFB RAT  ; IF F8 0R > 5070
0878 B83F  198  MOV R.A, 00H  ; ELSE LIGHT RESERVOIR
0878 B83F  199  OUTL P.I, 00  ; LEAK LAMP
0878 B84F  200  
201 RAT ROUTINE
202 THIS ROUTINE SOLVES THE EQUATION
203
204 PPR = (R/3850) X (538/(T + 468)) X PSYS
205
206 PSYS = PRESSURE READING + TEMPERATURE CORRECTION FACTOR
207 R = RESISTANCE IN OHMS
208 3850 = RESISTANCE AT STP
209 538 = 70 DEGREES F + 468 TO MAKE DEGREES RANKIN
210 T = MEASURED TEMPERATURE IN DEGREES F
211
212 FIRST WE SOLVE FOR PSYS AND STORE RESULT IN MEMORY THEN WE
213 PERFORM 2 DIVISIONS THEN 2 MULTIPLICATIONS WE THEN SUBTRACT
214 458 PSI FROM THE RESULT TO TEST IF OUR PRECHARGE PRESSURE IS ADEQUATE
215 FOR THE SYSTEM - IF NOT WE LIGHT THE RAT LAMP

K-6
NADC 81073-60

ISIS - NC-48/UPJ-41 (MC6800) ASSEMBLER. V2.0
NADC - R6 REV 1/19/74

LOC OBJ SEQ SOURCE STATEMENT

218
219
009B 3400 220 ROL CALL PRSCLC RESOLVE FOR PSYS
009D 2395 221 MOV A, 000H PUT 480 INTO ACCUM
009F 66 222 ADD A, R6 ADD TO GET RANKIN
00A0 E544 223 INC MODR IF NO CARRY NO OVERFLOW
00A2 23FF 224 MOV A, 0AFFH ELSE PUT FF INTO CARRY
00A4 BR 2401 225 MOD R2, 0000H PUT 538 R IN R2
00A6 BR 2402 226 MOV R8, 021H INITIALIZE TO ADDRESS 33
00A8 5400 227 CALL DIVIDE PERFORM 538/(T+460)
00AA 2328 228 BRZ 181/19103 STORE T IN 34 & 35
00AC 3400 229 MOV A, 028H GET DISPLACEMENT FROM
00AE 66 230 CALL GONMOD R/D CONVERTER
00B0 AC 231 MOV R2, A AND PUT IN R2
00B4 2378 232 MOV A, 078H PUT 385B INTO ACCUM
00B8 5400 233 CALL DIVIDE PERFORM R/385B
00BC 2334 234 BRZ 98 ADD STORE IN 36 & 37
00BD 23B7 235 CLR A WANT 0 IN
00BE 4C 236 MOV R4, A R4 AND
00BF AD 237 MOV R5, A R5
00C0 2328 238 MOV R8, 208H ADDRESS 32
00C4 F0 239 MOV A, 008H LBYTE OF PRESSURE
00C8 E6 240 MOV R6, A INTO R6
00CA 3400 241 INC R8 ADDRESS 33
00CB F0 242 MOV A, 008H LBYTE OF PRESSURE
00DC AC 243 MOV R7, A TO R7
00EC 66 244 INC R8 ADDRESS 34
00ED F0 245 MOV A, 008H LBYTE OF TEMP
00EE 0C25 246 JZ HIN T IF 0 NO MULTIPLY
00F0 CE 247 MOV A, R6 LBYTE OF PRESS
00F2 AC 248 MOV R4, A TO R4
00F4 F7 249 MOV A, R7 LBYTE OF PRESSURE
00F8 AD 250 MOV R5, A TO R5
00FA 2335 251 HIN T: INC R8 ADDRESS 35
00FB 68 252 MOV A, 008H LBYTE OF TEMP
00FD 5466 253 CALL QIHM MULTIPLY TEMP A PRESS
00F9 19 254 INC R8 ADDRESS 36
00FC F0 255 MOV A, 008H LBYTE
00FD C608 256 JZ HIN T2 IF 0 CONTINUE
00FE C6 257 MOV A, R6 LBYTE TO A
00FF 0404 258 JMP HIN T2 NO MULTIPLY
0000 18 259 HIN T2: INC R8 ADDRESS 37
0001 F8 260 MOV A, 008H LBYTE OF DISPLACEMENT
0003 C666 261 CALL QIHM MULT PREV RESULT
0005 23FF 262 IN T2 MULT2 WANT TO CHECK 2 FLAG
0006 96E4 263 JNZ END2 GREATER THAN 512
0008 FF 264 MOV A, R7 LBYTE OF FPP
000A 86 265 MOV R2, A PUT IN R2
000C 2386 266 MOV A, 0000H PUT 480 INTO A
000E 34C3 267 CALL SBCTCT REMAINDER - 480
0010 95 268 CPL F6
0012 268 269 JFB END2 IF CARRY PBP - 480
0014 23B4 270 END3 MOV A, 0044H ADDRESS PAT LAMP
0016 29 271 OUT PL A RETURN IT ON
0018 0482 272 ENDO JMP START REPEAT

K-7
SOURCE STATEMENT

273 ORG 0100h
274 ; PRESSURE CALCULATION
275 ; THIS CALCULATION TAKES THE PRESSURE READING IN MY Takes
276 ; A TEMPERATURE READING ADDS OR SUBTRACTS A TEMPERATURE
277 ; CONNECTION TO AN INITIAL SLOPE READING MULTIPLIES THE NEW
278 ; SLOPE BY THE MY READING AND ADDS AN INITIAL OFFSET THE LSBYTE
279 ; IS STORED IN RS AND THE LSBYTE IN R2
280 ; POSITIVE TEMPERATURE
281 ; PRESSURE = (21 + (3T')X011) X MY + 23
282 ; NEGATIVE TEMPERATURE
283 ; PRESSURE = (21 - (3T')X017) X MY + 23

284 MOV A, 010h; GET PRESSURE DATA FROM
285 CALL GON.160; A/D CONVERTER
286 MOV R6, A; SAVE VALUE
287 MOV R2, R6h; ADD 429 PSI
288 CALL SBEXT; IF CARRY P < 429
289 MOV R2, A; LIGHT LAMP
290 MOV A, R8; GET VALUE BACK
291 MOV R7, A; STORE

292 MOV R6, A; GET TEMPERATURE DATA FROM
293 CALL GON.160; A/D CONVERTER
294 MOV R5, A; STORE
295 MOV R2, A; "ALSO IN R2
296 MOV A, R6h; GET 70° F IN ACCUM
297 CALL SBEXT; T-70 = T'
298 MOV R6, A; ;
299 MOV R2, A; ;
300 MOV R2, R7; ;
301 MOV R2, A; ;
302 MOV R2, A; ;
303 MOV R2, A; ;
304 MOV R2, A; ;
305 MOV R6, A; ;
306 MOV R7, A; ;
307 MOV R6, A; ;
308 MOV R6, A; ;
309 MOV R6, A; ;
310 MOV R6, A; ;
311 MOV R6, A; ;
312 MOV R6, A; ;
313 MOV R6, A; ;
314 MOV R6, A; ;
315 MOV R6, A; ;
316 MOV R6, A; ;
317 MOV R6, A; ;
318 MOV R6, A; ;
319 MOV R6, A; ;
320 MOV R6, A; ;
321 MOV R6, A; ;
322 MOV R6, A; ;
323 MOV R6, A; ;
324 MOV R6, A; ;
325 MOV R6, A; ;
326 MOV R6, A; ;
327 MOV R6, A; ;
328 10 Millisecond Subroutine
329 This subroutine uses the 8748 built in timer. The
330 counter is loaded to B00H
331 This gives a 10 millisecond countdown each time we
332 reach countdown we decrement a count in R2 so that
333 we can get multiples of 10 milliseconds.
334
335 MOV A,[81]
336 MOV T,A
337 STRT T
338 CONT:
339 JMP CONT
340 END:
341 DJNZ R2,NS
342 RET
343
344
345 Byte Store Subroutine
346 Byte store transfers the first 4 bits into the next RAM
347 address, then the second 4 bits into the next RAM address
348
349 MOV R8,A
350 BYST:
351 CALL WRITE
352 MOV A,R8
353 SWAP A
354 CALL WRITE
355 RET
356
357
358 WRITE Subroutine
359 Write data into RAM. First put data on bus with CE1=00
360 AND R8=H H T H THEN ADDRESS WITH ONLY 00 HIGH. THEN ADDRESS
361 WITH ALL HIGH TO TURF OFF MEMORY. R8 HAS 10H STORED AS AN
362 INITIAL CONDITION
363 WRITE
364 OUTL BUS: A
365 ORL A,R5
366 OUTL P2: A
367 ORL A,R5H
368 ORL P2: A
369 INC R5
370 INCR GET NEXT ADDRESS
371 RET
372
373 LSD Subroutine
374 This subroutine goes to memory and fetches a nibble and
375 stores it in then gets the second nibble combines then
376 AND WE GET THE WHOLE BYTE
377
378 344 MOVX R2, R8
379 CALL READ
380 MOV R8,A
381 SWAP A
382 MOV R8,A
383 STORE IN R8
LOC  OBJ  SEQ  SOURCE STATEMENT

0168  2464  383  CALL READ  GET MSD
0162  48  384  ORL R, RB  PUT BYTE TOGETHER
0163  83  385  RET

0164  80  390  READ  MOVY A, R8  DISABLE BUS
0165  2E  390  CLR A  ZERO ACCUM
0166  39  392  OUTL P1.A  CLEAR BUS
0167  FD  393  MOV R, RS  PUT INTO ACCUM
0168  4E  394  ORL R, R6  PUT A 3 IN FRONT OF ADDRESS
0169  3A  395  OUTL P2.A  AND OUTPUT TO RAM
016A  53F  396  ANL R, R6F  ENABLE READ
016C  4C48  397  ORL R, R6H  68 IN FRONT OF ADDRESS
016E  28  398  OUTL P2.A  *
016F  88  399  INS A, BUS  GET WORD FROM RAM
0170  88  400  INS A, BUS  TWICE
0171  13F0  401  ANL R, R6FH  MASK OUT LSD
0173  RF  402  MOV R7, R  STORE IN R7
0174  FD  403  MOV R, RS  GET ADDRESS BACK
0175  4E  404  ORL R, R6  PUT 7 IN FRONT OF ADDRESS
0176  53F  405  ANL R, R6FH  3 IN FRONT OF ADDRESS
0178  3A  406  OUTL P2.A  TURN OFF MEMORY
0179  FF  407  MOV R, R7  PUT WORD BACK IN ACCUM
017A  1D  408  INC R5  GET NEXT ADDRESS
017B  83  409  RET

017C  3A83  410  MULTIPLY  CALL SRSTC  10-10-T'
017E  9083  411  MOV R, INCH  : NEED 3 SHIFTS
0180  97  420  MULTI  CLR C  : SET CARRY = 0
0181  67  421  RRC A  : DIVIDE BY 2
0182  E900  422  DJNZ R, MULT  : DIVIDE 3 TIMES
0184  99  423  MOV R1,A  : STORE RESULT IN R1
0185  97  424  CLR C  : SET CARRY = 0
0186  F7  425  RLC A  : MULTIPLY BY 2
0187  69  426  ADD R, R  : ADD ADD 1
0188  89  427  MOV R1,A  : STORE IN R1
0189  83  428  RET

018A  2208  429  TAPCK SUBROUTINE  CALL TAPCK  GETS TEMPERATURE DATA FROM A/D (FOR RESERVOIR ANI AIR)
018C  2400  430  TAPK  CALL TAPK  CHECKS) TESTS TO SEE IF IT IS ABOVE 258F (= 121C) IF
018E  AA  431  IT IS TOO HIGH WE LIGHT THE TEMP LAMP

K-10
LOC  OBJ  SEQ  SOURCE STATEMENT

0196 FB  438  MOV R1,A ;SAVE IN R3
0190 2360 439  MOV R1,B#8H ;12H = 256F INTO ACCUM
0192 3461 440  CALL SBTCT ;A12Ti-
0194 B690 441  JFB EXCH ;IF CARRY TI=256F
0196 2340 442  MOV R1,A#8H ;ELSE ENABLE TEMP LAMP
0198 39  443  OUT PT,A ;LIGHT IT
0199 28  444  EXCH ;XCH R1,R2 ;SET Ti FROM R3
019A 2A  445  XCH R1,R2 ;PUT IT IN R2
0198 83  446  RET

447
448
449  RESISTOR SUBROUTINE
450  FINDS CALCULATED VALUE OF RESISTANCE AND SUBTRACTS IT FROM
451  ACTUAL VALUE
452
019C B6A2 453 RSTR:  JFB SBRTN ;IF FB IS SET WE HAVE TO SUBTRACT
019D 6A  454  ADD R1,R2 ;ELSE WE ADD
019F A4  455  MOV R1,R2 ;STORE IN R2
019F 24A4 456  JMP FINI ;ADDITION COMPLETE
01A2 34E0 457  SBRTN:  CALL SBTCT ;STEP 1 ABOVE
01A4 2320 458  SBRTN:  MOV R1,R2 ;GET ACTUAL R FROM A/D
01A6 34A9 459  SBRTN:  CALL GONOGO ;AND PUT IN ACCUM
01A8 83  460  RET

461
462
463
464
465  GONOGO SUBROUTINE
466  THIS SUBROUTINE ENABLES THE SELECTED A/D CONVERTER
467  TO PUT DATA ON THE BUS THE DATA VALID OUTPUT OF THE A/D
468  IS CHECKED AND DATA IS ACCEPTED IF TRUE.
469
01A9 39  470  GONOGO:  OUT PT,A ;SELECT A/D CONVERTERS
01A4 8B  471  NOX:  INS A,BUS ;INPUT DATA FROM BUS
01A8 8B  472  NOX:  INS A,BUS ;TWISE
01AA F2B0 473  JBE OK: ;CHECK BIT 7 DATA VALID BIT
01B2 24A4 474  JMP NOX ;IF NOT VALID GET NEW DATA
01B0 537F 475  OK:  ANL A,A#7F ;IF OK MASK OUT MSB
01B2 83  476  RET

477
478  SUBTRACT SUBROUTINE
479  SUBTRACTS NUMBER IN ACCUMULATOR FROM NUMBER IN REGISTER R2
480  AND STORES THE RESULT IN R2, FLAG F8 IS "0" FOR POSITIVE
481  RESULT AND "1" FOR NEGATIVE
482
01B3 85  483  SBRTCT:  CLR F8 ;SET FLAG F8 TO 0
01B4 37  484  CPL A ;COMPLEMENT ACCUM
01B5 6A  485  ADD R1,R2 ;AND ADD TO R2
01B6 F8B0 486  JCE PLUS ;IF A CARRY RESULT IS PLUS
01B8 95  487  CPL F8 ;SET FLAG F8 TO "1"
01BA 37  488  CPL A ;COMPLEMENT ANSWER
01BB 87  489  DEC A ;SUBTRACT 1 AS WE ADD 1 NEXT STEP
01B8 17  490  PLUS:  INC A ;ADD 1 TO GET CORRECT ANSWER
01BB 9A  491  MOV R2,R2 ;STORE ANSWER IN R2
01BD 83  492  RET ;RETURN
SUBROUTINE

THE ALGORITHM FOLLOWS THESE STEPS:

1. THE REGISTERS ARE ARRANGED AS FOLLOWS
   - ACC = 0
   - Ri = MULTIPLIER
   - R2 = MULTIPLICAND
   - R3 = LOOP COUNTER (+8)

2. THE ACCUMULATOR AND REGISTER R3 ARE TREATED AS A REGISTER
   - PRIOR WHEN THEY ARE SHIFTED RIGHT

3. THE ACCUMULATOR AND R3 ARE SHARED RIGHT 1 PLACE. THUS THE
   LSB OF THE MULTIPLIER GOES INTO THE CARRY

4. THE MULTIPLICAND IS ADDED TO THE ACCUMULATOR IF THE CARRY
   BIT IS A '1'. NO ACTION IF CARRY IS A '0'.

5. DECREMENT THE LOOP COUNTER AND LOOP (RETURN TO STEP 2) UNTIL
   IT REACHES ZERO

6. SHIFT THE RESULT RIGHT 1 LAST TIME JUST BEFORE EXITING

THE ROUTINE

THE RESULTS WILL BE FOUND MSBYTE IN THE ACCUMULATOR AND
LSBYTE IN RI.

01BE BE88 517 BMPY: MOV R3, #08H SET LOOP COUNTER TO 8
01C0 27 518 CLR A CLEAR ACCUMULATOR
01C1 97 519 CLR C CLEAR CARRY BIT
01C2 34C 520 DMP1: CALL DMLRT DOUBLE SHIFT RIGHT R3
01C4 6C7 521 AND R1 INTO CARRY
01C6 8A 522 JNC DMP2 IF CARRY = 1 ADD ELSE DON'T
01C7 EBC 523 ADD R3,R2 ADD MULTIPLICAND TO ACCUMULATOR
01C9 34C 524 DMP2: DANZ R3,DMP1 DECREMENT LOOP COUNTER AND
01C8 83 525 LOOP IF NOT ZERO
01C9 34C 526 CALL DMLRT
01C8 83 527 RET
01C9 83 528
01CA 79 529
01CC 67 530 DMLRT: RRC A ROTATE RIGHT THRU CARRY
01CD 29 531 XCH A,R1 GET R1 IN ACCUM
01CE 67 532 XCH A,R2
01CF 29 533 XCH A,R3 PUT R1 BACK
01D0 83 534 RET
01D1 95 535
01D1 95 536
01D1 23E 537 MPK1: MOV R, #20H GET R VALUE FROM A/D
01D3 349 538 CALL GON000 PUT IN ACCUMULATOR
01D5 8HC 539 MOV R2, #95CH IF R MUST BE LESS THAN
01D6 795 540 .11 5/15 /15 S = R +D
01D6 795 541 .11 5/15 /15 S +D = R +D
01D6 795 542 .11 5/15 S = R +D
01D7 7A3 543 CALL SBTCT .95CH = R VALUE
01D9 95 544
01DA 8DF 545
01DC 23E 546 MOV R, #94H ELSE LIGHT RESERVOIR
DIVIDE ROUTINE

WE DIVIDE A 16 BIT DIVIDEND BY AN 8 BIT DIVISOR

LSBYTE OF DIVIDEND IS IN R2

LSBYTE OF DIVIDEND IS IN R3

DIVISOR IS IN THE ACCUMULATOR

WE CHECK FOR THE FIRST '1' IN THE DIVISOR WHICH TELLS US HOW MANY DIVISIONS.  WE ADD THE 2'S COMPLEMENT OF THE DIVISOR TO THE DIVIDEND.  THE RESULTING CARRY IS SHIFTED INTO THE LSB.

POSITION OF THE LSB THAT RESULTING CARRY IS SHIFTED INTO.

THE LSB POSITION OF THE LSBYTE THE FINAL ANSWER IS STORED IN MEMORY

MOV R3, #0
CLEAR R3

MOV RS1,#0
CLEAR RS1

CLR F0
CLEAR FLAG F0

CLR C
CLEAR CARRY

MOV R1, #10000H
INITIAL # OF DIVIDE STEPS

AND R1, R8FFH
TO SEE IF ACCUM # 8

IJE X7
WANT TO AVOID DIVIDE BY 0

RLC A
WANT FIRST '1' SO WE KNOW HOW MANY DIVIDE STEPS

INC R1
SAME AS ABOVE

JNC X1
FIRST ONE

RRC A
RETURN 1 TO ACCUM

CPL A
2'S COMPLEMENT

INC R4
2'S COMPLEMENT

MOV R4, A
SAVE DIVISOR

CLR A

CLR C

CPL C

RRC A

DNC R5, X6

MOV R5, A

MOV R4, A

ADD R4, R2
SUBTRACT DIVISOR FROM DIVIDEND

JC X5
IF FLAG SET WAS A CARRY

JNC X3
IF NO CARRY NO CHANGE

CLR C
WANT TO SET CARRY TO 1

CPL C

MOV R2, A
ELSE PUT NEW RESULT IN R2

MOV R3, X3
LSBYTE IN ACCUM

RLC A
SHIFT CARRY INTO LSB

MOV R3, A
PUT BACK

CLR F0
CLEAR FLAG F0

MOV R4, A
LSBYTE IN ACCUM

RRC A
SHIFT CARRY INTO LSB

JNC X4
NO CARRY DON'T SET F8

CPL F8
IF CARRY SET F8

MOV R2, A
PUT BACK

MOV R4, X4
GET DIVISOR BACK

DNC R1, X2
CONTINUE DIVISION

K-13
LOC OBJ SEQ SOURCE STATEMENT

8232 FE 683 X7 MOV A,R6
8233 5R 684 RAN A,R2
8234 18 685 INC R0 ;GET NEXT MEMORY POSITION
8235 18 686 MOV A,R6,A ;STORE IN MEMORY
8236 18 687 INC R0 ;NEXT MEMORY LOCATION
8237 FB 688 MOV A,R3 ;LSBYTE TO ACCUM
8238 10 689 MOV A,R6,A ;AND STORE IN MEMORY
8239 03 690 RET

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8238 4B 622 LXUP1: MOV R3,A ;STORE XT IN R3
823B 8CE 623 MOV R4,BCH ;START WITH 14 IN R4
823D 006 624 MOV R5,0000H ;START WITH 182 IN R5
823F FB 625 REPT1: MOV A,R3 ;XT IN ACCUM
8240 2A 626 MOV R2,A ;AND PUT IN R2
8241 FD 627 MOV A,R5 ;182-14N
8242 34E3 628 CALL SBTCT ;XT = ( 182 - 14N )
8244 FD 629 MOV A,R5 ;GET 182-14N
8245 83F2 630 ADD A,0FF2H ;SUBTRACT ANOTHER 14
8247 AD 631 MOV A,R5-A ;NEW VALUE BACK IN R5
8248 FC 632 MOV A,R4 ;PUT R4 INTO ACCUM
8249 07 633 DEC A ;A CONTAINS ANSWER
824A 634 634 JZ 9NMR1 ;IF R4 = 0 END ROUTINE
824C AC 635 MOV R4,A ;ELSE PUT RESULT BACK IN R4
824D B3F 636 JFB REPT1 IF R0 XT < ( 182 - 14N )
824F 83 637 JFMR1: RET

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8250 1B 653 LXUP2: MOV R3,A ;STORE XT IN REG 3
8251 8C 654 MOV R4,00CH ;START WITH 12 IN R4
8253 00B 655 MOV R5,0000B ;START WITH 176 IN R5
8255 FB 656 REPT2: MOV A,R3 ;XT IN ACCUM
8256 AA 657 MOV R2,A ;AND INTO R2

K-14
<table>
<thead>
<tr>
<th>LOC</th>
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<td>FD</td>
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<td>MOV A, R5</td>
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<td>ADD A, 0BFH</td>
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<td>FC</td>
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<td>MOV R4, A</td>
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<td>DEC A</td>
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<td>674</td>
<td>; QUAD MULTIPLY</td>
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<td>; FIRST MULTIPLY I AND R7 (LSBYTE)</td>
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<td>; DROP LSBYTE OF RESULT</td>
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<td>; AND ADD MSBYTE OF RESULT TO R5</td>
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<td>; THEN MULTIPLY I AND R6 (MSBYTE)</td>
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<td>; TO R5 AND MSBYTE OF RESULT TO R4</td>
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<td>685</td>
<td>ADD A, R5</td>
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<td>MOV RS, A</td>
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<td>XCH A, R5</td>
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<td>MOV R5, 0FH</td>
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**USER SYMBOLS**

- BMP1: 01C2
- BMP2: 01C7
- BMPY 01BE
- BYST 0147
- CONT 013F
- DBLRT 01CC
- DEEP 0143
- DIVIDE 0200
- END2 00E4
- ENDS 00E1
- EXCH 0199
- FINI 0144
- GONOO 0199
- LDKP 023A
- LDR2 025A
NADC 81073-80

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MACRO ASSEMBLER, V2.0

ASSEMBLY COMPLETE, NO ERRORS