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HYDRAULIC FLUID ANALYSIS FOR ANTENNA DRIVE SYSTEMS

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APRIL 1970

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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SUMMARY

Filtration in fluid power systems is employed to eliminate those foreign particles which tend to produce component wear and possible catastrophic failure. To ensure that the hydraulic system filters are cleaning the fluid, and also to permit detection of a component's impending failure, a program of periodic fluid analysis is performed. The Manned Space Flight Network site personnel have been supplied with fluid sampling kits which allow an initial fault detection capability. In addition, fluid specimens are forwarded to GSFC, Code 525 for detailed analysis. It is the expressed purpose of this program to develop a systematic approach to contamination control, and to establish a level of acceptability by which system reliability may be improved.

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INTRODUCTION

With the advent of the Apollo program it was recognized that the hydraulic drive systems for the Manned Space Flight Network tracking antennas should be made as reliable as possible. In order to attain the optimum performance and reliability expected, quality components were chosen and incorporated into a well designed system. To extend the reliability a program for hydraulic system fluid analysis was included as part of the routine maintenance procedure.

The program was initiated at Goddard Space Flight Center by the Antenna Systems Branch, Advanced Development Division in early 1966 and continued until station personnel assumed on-site control in March 1969. It was felt that an additional mode of trouble shooting and preventative maintenance could be utilized by the periodic removal of system fluid for detailed analysis. During the three year period many components were removed in time to prevent catastrophic failure and costly down time. In March 1969 the stations were sufficiently equipped and personnel adequately trained to take over the entire analysis function.

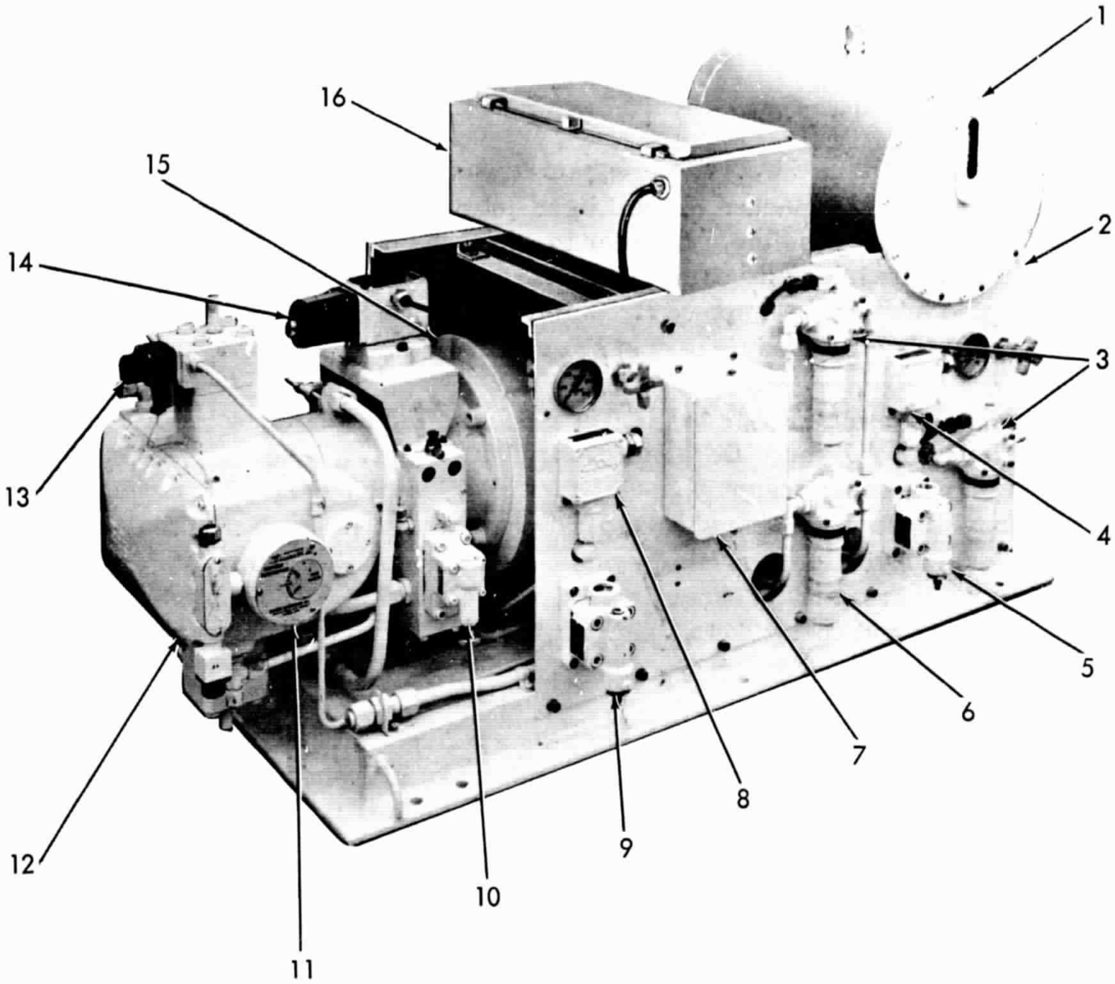
The following report describes the problems of hydraulic fluid contamination and the need for a contamination control program. In particular, the Unified S-Band Apollo Tracking Antenna Systems are discussed.

HYDRAULIC SYSTEM OPERATION

This section contains a brief operational description of the hydraulic drive package for the Unified S-Band Antenna System. The material is presented as background information which leads to a better understanding of the hydraulic drive function. A closer look at the major components involved may be found in Appendix 1. The drive unit for the 30-foot antenna is shown in Figure 1. Figure 2 is a diagram of the hydraulic system.

Drive Function

A continuously running electric motor drives a variable displacement servo pump which supplies hydraulic oil to two hydraulic motors. The pump is close coupled to the electric motor. Flow rate of the pump is controlled by an electronically operated servo valve in response to control signals from the servo subsystem. This servo valve positions the yoke of the servo pump, and the



1. RESERVOIR
2. DUAL VANE PUMP
3. FILTERS
4. PRESSURE SW.
5. RELIEF VALVE (CONTROL)
6. FILTER
7. CABLE JUNCTION BOX
8. PRESSURE SW.
9. RELIEF VALVE REPLENISH
10. RELIEF VALVE (SERVO PUMP)
11. YOKE POT
12. SERVO PUMP
13. SERVO VALVE
14. SOLENOID VALVE
15. AC MOTOR
16. BRAKE UNIT

Figure 1. Hydraulic Power Unit

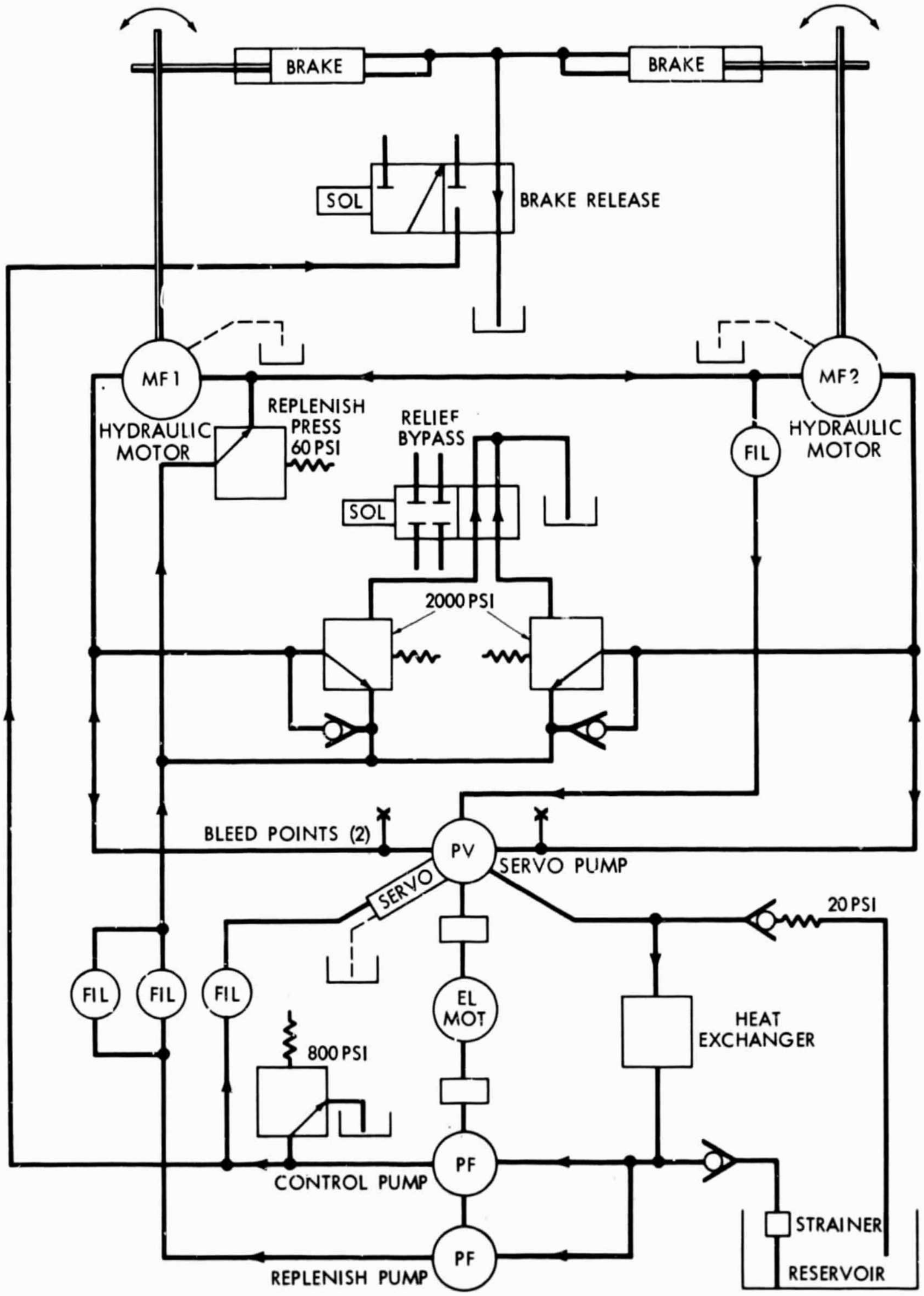


Figure 2. Hydraulic Circuit Diagram

servo pump yoke controls the amount of hydraulic oil pumped to the hydraulic motors. As the position of the yoke is varied, the arm of a potentiometer is also varied, and the output voltage developed by this yoke potentiometer is used as a feedback voltage for servo control.

The hydraulic motors, MF1 and MF2, are connected in series with the servo pump. Relief valves allow up to 2000-pound per square inch pressure to be developed in the supply lines between the servo pump and the hydraulic motors. Under normal conditions, 500 pounds per square inch are sufficient to drive the hydraulic motors and rotate the antenna. However, a number of factors may cause this pressure to vary. Strong winds, unbalance of the antenna structure, and friction in the gear reducers are examples of additional resistances that may affect the hydraulic pressure required to drive the antenna.

When motor MF1 receives hydraulic oil from the servo pump, it becomes the driving motor. Since the gear reducer assemblies and pinions associated with motors MF1 and MF2 mesh with a common bull gear, motor MF1 drives the bull gear, which causes motor MF2 to be driven backwards. Hydraulic oil is forced back to the servo pump through the normal inlet line to the motor. When motor MF2 is the driving motor, motor MF1 serves as a hydraulic pump, forcing hydraulic oil back to the servo pump.

The servo control for each hydraulic power unit is dependent upon an output of hydraulic oil supplied by the control pump with a fixed flow rating of 2 gallons per minute. An adjustable relief valve is set at 800 pounds per square inch and regulates the control pump discharge pressure. The replenishing hydraulic pump has a fixed flow rating of 5 gallons per minute. An adjustable relief valve set at 60 pounds per square inch, regulates the replenishing pump pressure. The full replenishing flow is far in excess of the minute leakages within the system; however, the excess hydraulic oil is used for the filtering and cooling operations.

The replenishing pump also provides pressure for the antibacklash function as it supplies makeup hydraulic oil for pump and motor leakages. The hydraulic pressure in the line connecting the motors in series (30 psi) is lower than in the lines connecting the servo pump and hydraulic motors. The latter pressure is the replenish pressure and is 90 psi. The 60 psi differential pressure across the motor(s) is regulated by the replenish pressure relief valve. Because their torques are in opposite directions, the hydraulic motors can rotate only enough to remove the backlash from the gear trains.

The major portion of the 5-gallon per minute flow replaces a portion of the hydraulic oil pumped through the hydraulic motors by the servo pump. This provides a cooler medium to replace hydraulic oil that has become heated by frictional losses in the pump, motors, and lines. After passing through a filter, the hydraulic oil, which originated at the dual-vane pump, passes twice through the servo pump case. The first entry is through the rear of the pump, near the cover, and the second is around the rotating group and valve plate. In the pump case, the oil picks up the heat generated by frictional losses in the servo pump case, and then passes into a drain manifold where it is combined with other drain and exhaust flows before it passes into the heat exchanger.

If the hydraulic oil temperature should reach 180°F, a fault condition exists and the system is shut down. Excessive temperatures can cause damage to elastomer seals in the system, and also induce pump and hydraulic motor failure due to low hydraulic oil viscosity.

FLUID ANALYSIS PROGRAM

Methods of Analysis

Two methods of fluid analysis were selected for the program. The first method consists of performing a particle count on a representative sample of hydraulic fluid as it circulates through the system. Fluid is taken from a specific bleed point (see Figure 2) located at the outlet of the main pump unit. A test of this type allows a qualitative analysis to be made at a definite period in time while the system is in an operating condition. In the event a particular test showed an unusually high count, a series of additional tests at shorter time intervals would be called for to determine whether the contamination level had changed.

The second method affords a gross test through the examination of filter sediment contents. The hydraulic drive system includes a number of filters located at specific points within the system. Examination of the sediment assists the investigator in detecting potential component failures through the type and quantity of material noted. Normally the diagnosis is made visually, however, when a particular residue is not readily recognized an emission spectroscope, infrared spectra, and/or x-ray diffraction analysis may be performed. All pertinent information concerning the system and its environment should be known in order to make the analysis complete.

Sampling Procedure

It was decided that samplings of 200 ML each would be a representative quantity of fluid to be shipped from the stations to GSFC for the analysis program. All selected stations were furnished with a supply of sterilized bottles and fluid sampling kits containing all the equipment necessary for fluid removal from pressurized systems. No formal instruction is required for use of this kit since directions are quite explicit and pictorially presented. During the embryonic stages of this program several stations cooperated in procedural development to establish criteria for laboratory techniques and communications between stations. A step by step procedure may be found in Appendix 2.

Points selected for sampling were: (1) one sample from each axis downstream from the main pump while the system is pressurized; and (2) the residue from each of the filters when the system is shut down. This fluid upon arrival at GSFC was drawn through test filter patches for particle count analysis, and visual microscopic identification readings. If visual identification was found to be inadequate chemical analyses were available at this activity.

Standard Millipore RA 1.2μ, 47 mm, white grid filter patches were utilized for all tests at the start of the program. It soon became apparent that the system filter bowl sediment created a silting problem for such a low porosity test filter. For this reason Millipore SS 3μ, 47 mm, white plain filters were selected. The plain filter could be used in this application since the filter sediment was not particle counted, but rather reviewed as to material content. The equipment used at GSFC was as follows:

1. Pyrex filter holder
2. One liter vacuum flask
3. Forceps with unserrated tip.
4. RAWG 94700, 1.2 gridded filters
5. SSWP 04700, 3.0 plain filters
6. Plastic disposable Petri dishes
7. 2 x 3 glass microscope slides
8. Vacuum-pressure pump
9. Freon TF (used as a cleansing agent)
10. Binocular microscope with 40x, 100x and 200x total magnification, adjustable illuminator and counter
11. Desk top clean cabinets (2 each). Fluid processing was accomplished in one clean cabinet and particle analysis determination in the other. The test set up is shown in Figure 3.

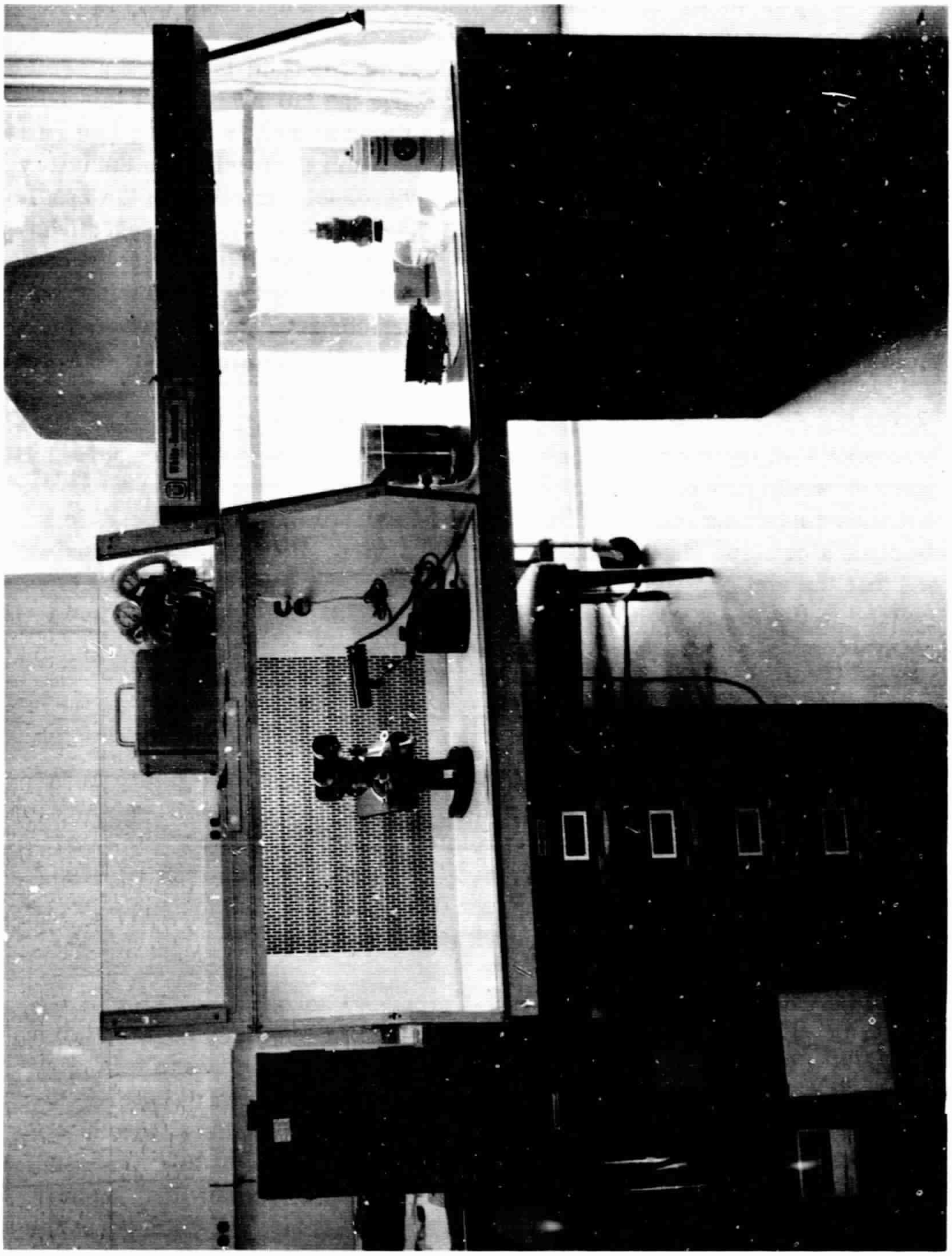


Figure 3. Laboratory Test Facility

As mentioned previously, samples were drawn from the hydraulic system at predetermined locations. The sample bottle was properly marked and was accompanied by form MP 538 giving the history of each shipment (see Appendix 3). This form contains such pertinent information as sample date, location of fluid sampling point, antenna system and fluid hours, fluid type, and a section for remarks relevant to the analysis. Following the lab processing this information was noted on the slide or petri dish as the case may be, and a test number assigned. Test results were recorded in the Fluid Contamination Study Log, and the samples filed away. To keep station personnel current with the results obtained, return form MP 558 was conceived (see Appendix 4). The test findings were forwarded to the station Maintenance and Operation (M & O) supervisor, and contained the date of test, particle counts, a description of the filter bowl sediment, and information or remarks concerning the tests. In this way questions pertaining to a particular test could be discussed with a minimum of reference.

After the procedures were tested and personnel trained, the stations were implemented with their own equipment. A transitional period was begun whereby the stations would process the fluid, make a diagnosis, and send the slides and petri dishes containing the test filters to GSFC for concurrence. Thus, form 558 became a critique sheet. This system was carried out until it was mutually agreed that the station could support the total effort. The Goddard Lab is being maintained in the event additional help may be afforded the network. During the program a total of 924 tests were processed by this activity.

Fluid Analysis

The program was instituted using two basic methods of analysis: (1) the particle count procedure, and (2) the material inspection. The latter approach actually resulted in the analysis of two related areas, the components material, and a water content factor. In some cases the water problem also affected the particle count process by clogging the test filters making it impossible to perform the actual counting procedure. Discussion of these areas follow.

Particle Counting—The particle count process was made as a trend analysis, that is, a determination of whether a particular system's contamination level has degenerated, improved, or stabilized. The first concern was to establish an acceptable level of contamination which represented the quality of filtration existing in the hydraulic drive system. Up to this time there was no set particle count limitations associated with a fluid system of this type and size. The tentative standard for hydraulic fluid systems as set forth by the Society of Automotive Engineers (ASME) was selected as a program guideline. This standard is shown in Figure 4.

Size Range (microns)	Contamination Class						
	0	1	2	3	4	5	6
5- 10	2700	4600	9700	24000	32000	87000	128000
10- 25	670	1340	2680	5360	10700	21400	42000
25- 50	93	210	380	780	1510	3130	6500
50-100	16	28	56	110	225	430	1000
>100	1	3	5	11	21	41	92
Total Number of Particles Larger than 5 Microns	3480	6181	12821	30261	44456	112001	177592

Figure 4. Contamination Levels SAE, ASTM and AIA Tentative Standard for Hydraulic Fluids

By August of 1967 data had been compiled from approximately 70 sample tests involving the 30-foot systems. The average count in the 5-15 micron range was found to be 15,628 particles which compares closely to the class 2 contaminant level. Subsequent data was obtained indicating that the average measurement was dropping as the drive systems break-in period continued. The particle count analyses represented a large number of sample tests taken from both the twelve 30-foot, and three 85-foot antenna systems over a period of almost three years. The resulting data are shown in Figures 5 and 6. These numbers have been established as the maximum acceptable contamination levels for the USB antenna systems.

During the data acquisition period the trend analysis was taking place. The analyst had an indication of an acceptable contaminant level based upon the earlier sampling average of 15,628 particles. This figure later dropped to 14,400 particles and has remained constant. Figure 7A shows a typical sample of a clean system, and Figure 7B is representative of a highly contaminated state. Any change in count that occurred in the periodic samples was noted and remedial action taken as required. These established particle count levels have proven to be attainable with reasonable care and handling.

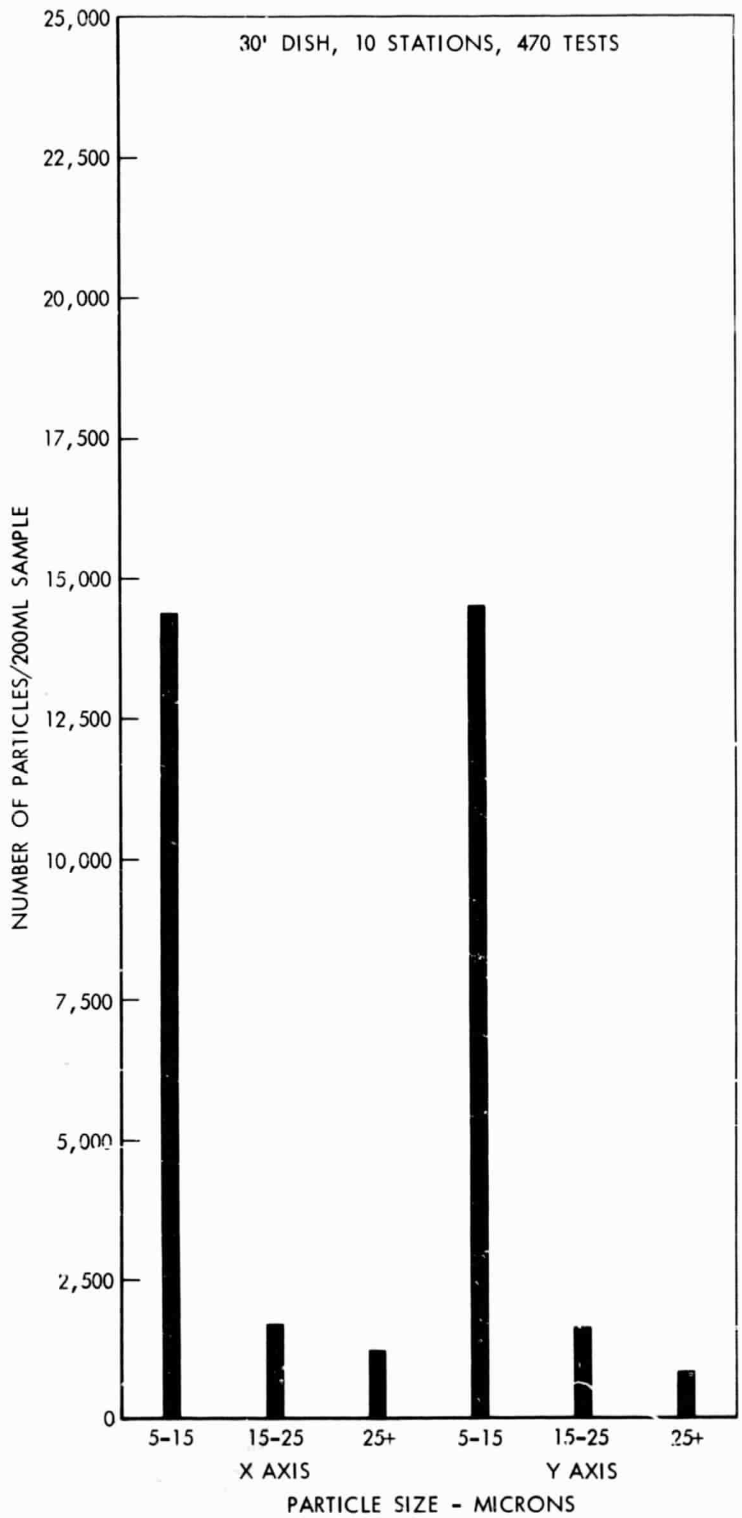


Figure 5. Particle Count Data - 30-foot Dish

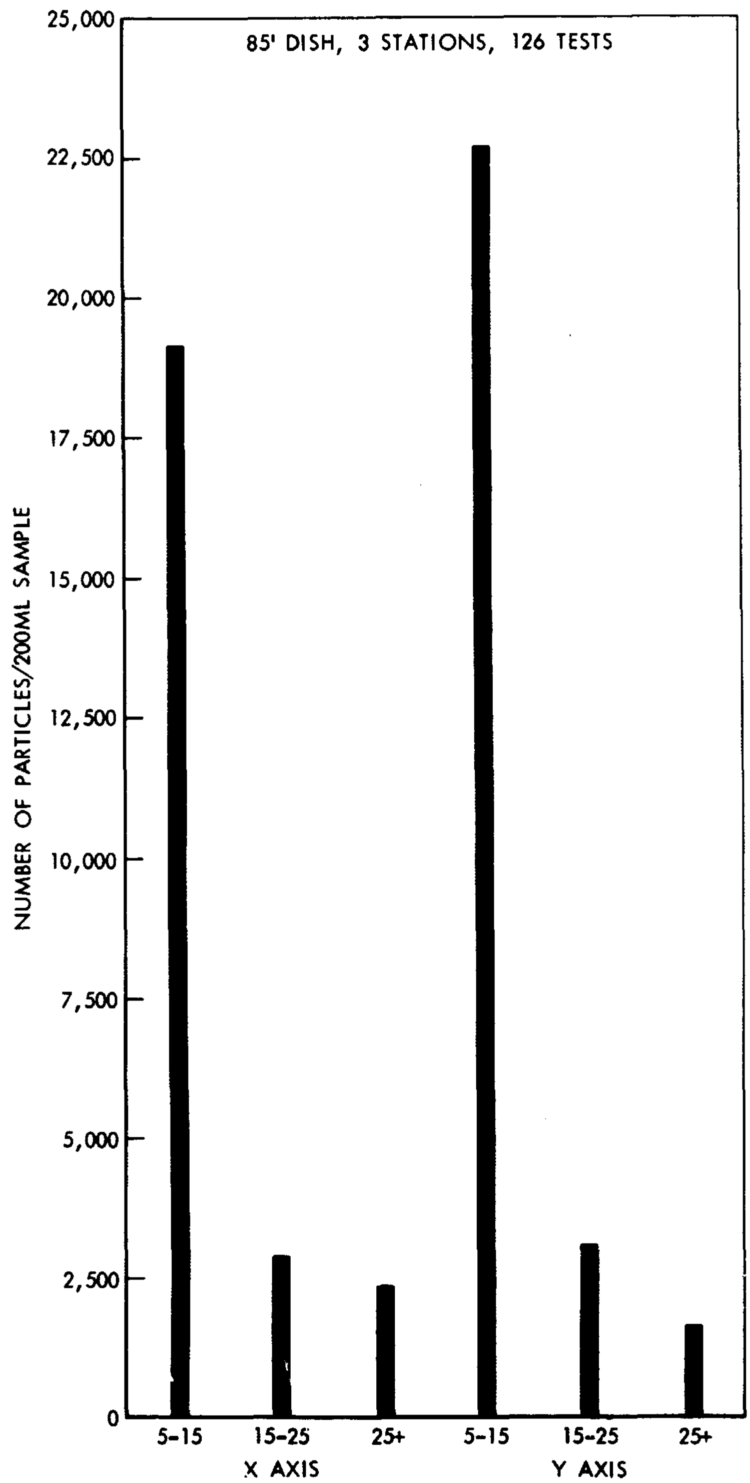
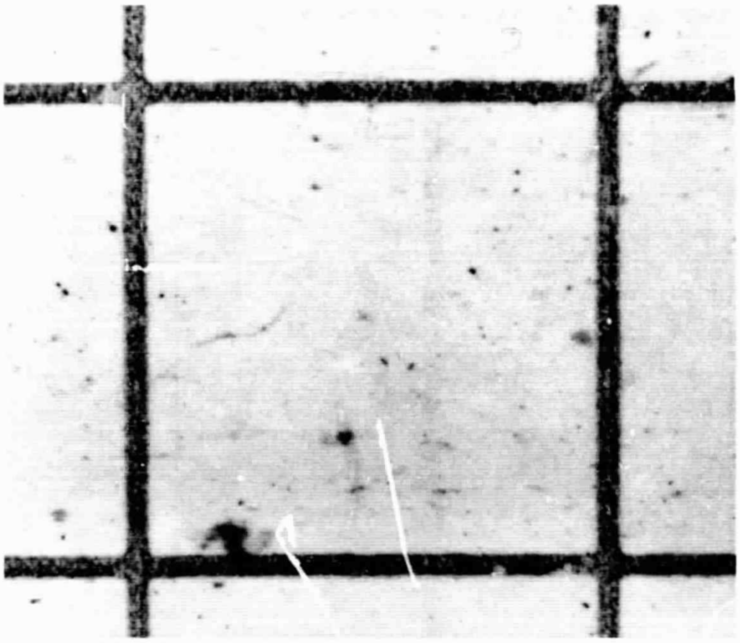


Figure 6. Particle Count Data - 85-foot Dish

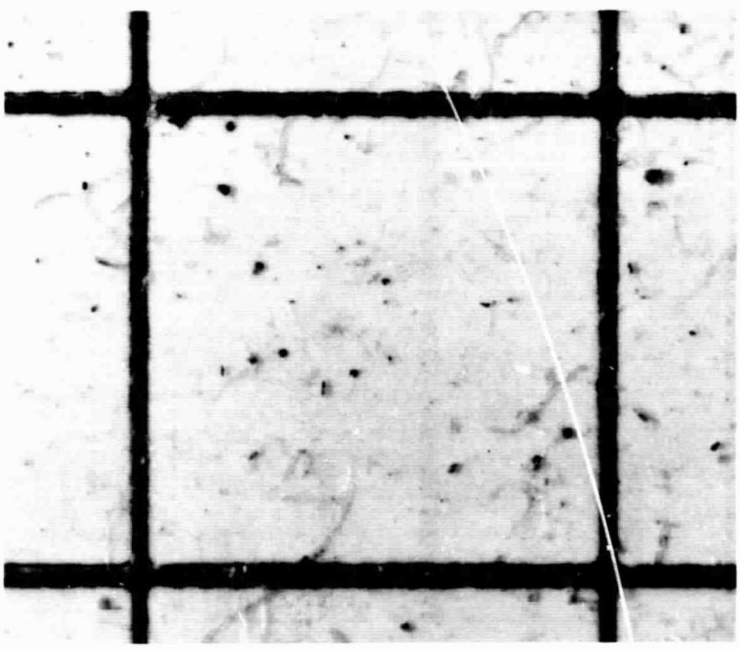


PARTICLE COUNT
(MICRONS)

5-15	15,550
15-25	1,618
25+	2,550
FIBERS	435

ENLARGED 20 X

(A) Maximum Acceptable Level



PARTICLE COUNT
(MICRONS)

5-15	20,750
15-25	2,115
25+	3,920
FIBERS	1,740

ENLARGED 20 X

(B) High Level Condition

Figure 7. Particle Count Test Samples

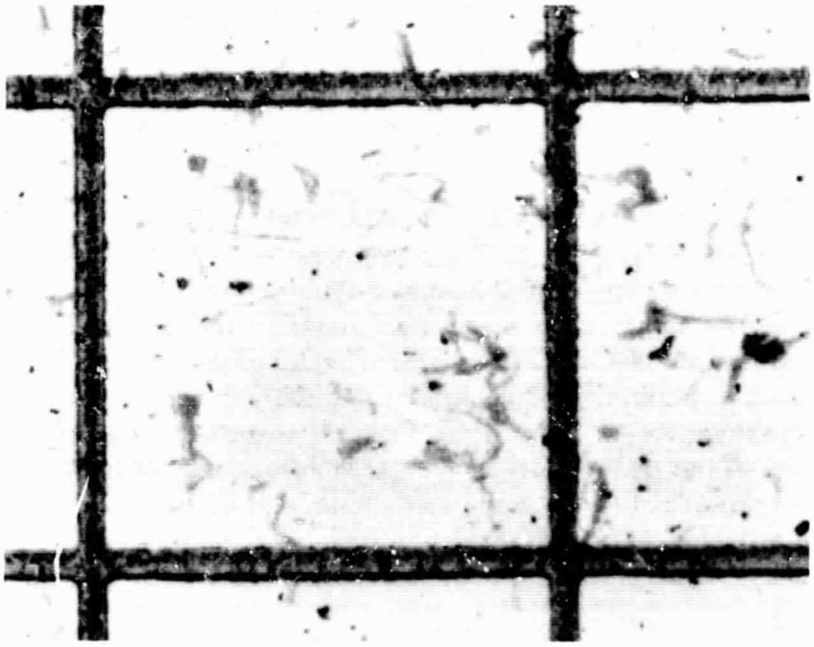
Material Examination—The material analysis was based on the type and quantity of the sediment found in each filtered specimen. The sample taken from a particular location within the system is related to the material makeup of the components upstream of the filter. Several samples that typify material findings are shown in Figures 8 and 9.

In general, sediment samples contain considerably more matter than do particle count samples. The sediment represents an accumulation over a long period of time; for example, 100 hours of system operation. It is important to note whether the contaminants seen are a metallic or a non-metallic material. Metallic findings are indicative of material wear of the system's components. In a component containing moving parts material will tend to degenerate through a normal wearing process. As in the particle counting procedure a trend analysis is useful to the trained observer. An increase in contaminant level from sample to sample, and taken at the same point within the system, is indicative of potential trouble. When an abnormal amount of contamination is present, an investigation is made into the cause, and the necessary action taken.

In the early stages of the test program samples were found which showed an excessive amount of metallic contaminant in the Y-axis replenish and control filters. Microscopic examination revealed an extremely high copper content as exhibited in Figure 9A. By relating to its material make-up, the generating source was believed to be the system heat exchanger. Functionally, the heat exchanger turbulators deflect the fluid flow on to the walls of the cooling coils. The heat exchanger, located in the X-axis wheelhouse, rotates as the antenna rotates. As a result, the turbulators are displaced so as to create chaffing of the copper coils. The heat exchanger unit was repositioned 90 degrees to be parallel to the X-axis of rotation in order to minimize this condition. Subsequent test samplings showed a definite reduction in contamination level.

Other samples were received from the field indicating an abnormal high content of silver-gray metallic particles in the X-axis control filter. This condition is shown in Figure 9B. A great number of these particles exceeded 500 microns in size. To verify the findings, additional specimens were requested for further evaluation.

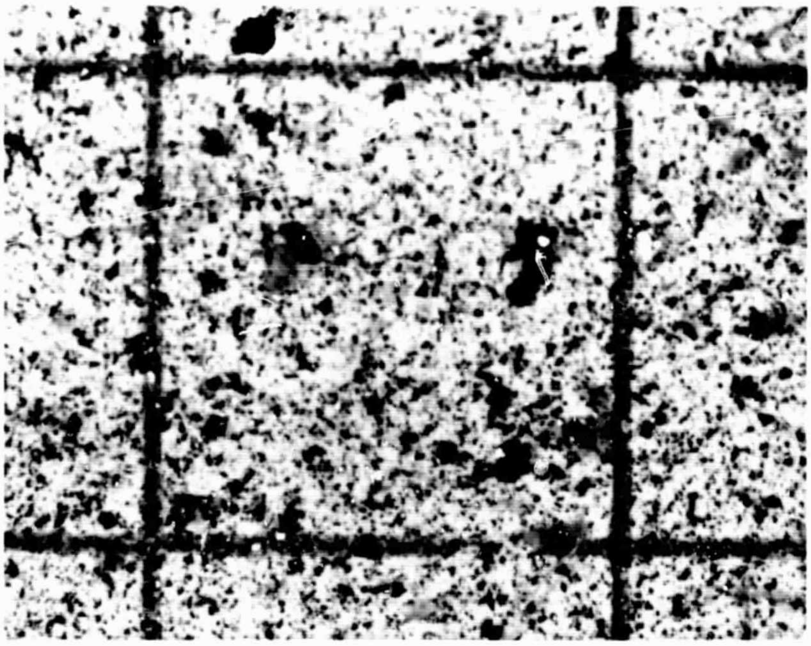
The supplemental samples were received and processed in a similar manner as before, and the high metallic content was again noted. Because the evidence presented itself only in that area, the primary suspect was the control vane portion of the dual-vane pump. Based on the evidence, it was recommended that the X-axis dual-vane pump be replaced at the earliest reasonable time



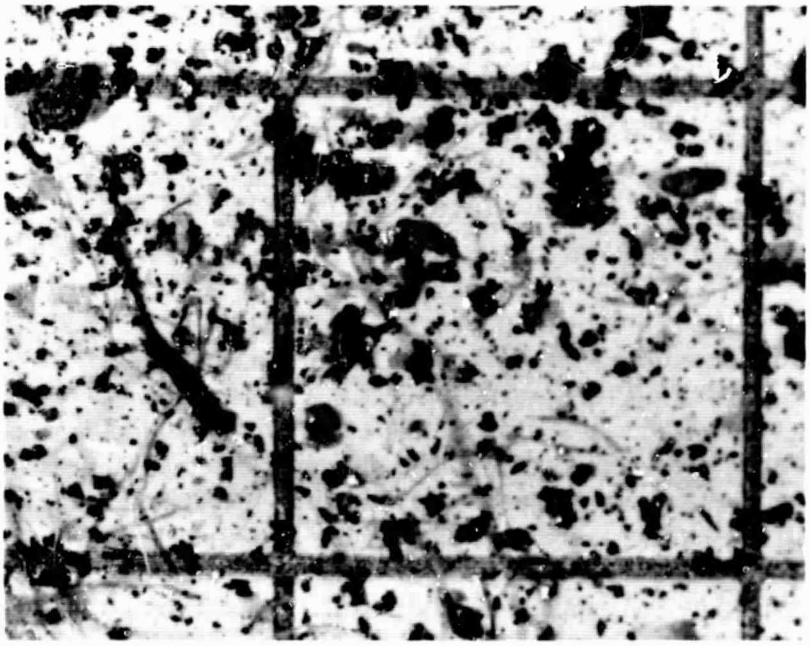
(A) Clean Sample (Enlarged 20x)

(B) Extremely Dirty Sample (Enlarged 20x)

Figure 8. Filter Sediment Content Samples



(A) Excessive Copper Content (Enlarged 20x)



(B) Excessive Ferrous Content (Enlarged 20x)

Figure 9. Filter Sediment Content Samples

in order to avert a potential system breakdown during a tracking mission. In addition, a request was made to return the suspect unit to this activity for inspection.

Upon disassembly, it was ascertained that considerable galling of the control ring, and some wearing of the inner body face had taken place. This condition verified the findings detected through the filter sediment analysis. Examination of the pump vanes also showed a grooving on the tips of each vane with hot spots detected on the leading edges.

The pump unit had logged 1740 operational hours prior to removal. It is possible that the pump's vane-ring assembly was approaching normal life expectancy; however, lack of adequate filtration may very well have precipitated the wearing process. As may be seen in Figure 2, a filtering strainer located in the reservoir offers only a partial protection to the dual-vane pump. The normal flow of fluid bypasses this strainer taking the path through the heat exchanger. When this happens the fluid is not filtered until after passing through the pump unit. Analyses of these downstream filter samples have generally reflected extremely dirty conditions, and in many instances particles exceeding 500 microns have been noted. In order to enhance system reliability and attain maximum component life a return line filter was installed at the outlet of the heat exchanger. Samples taken after this system modification was incorporated have shown a marked drop in the contaminants appearing in the pump outlet filters.

Water Contaminant—A number of fluid samples were received from the field showing an abnormally cloudy appearance. When attempting to draw the fluid through the test filter, it was noted that approximately 50 milliliters of fluid would clog the filter pores. In a normal process 200 milliliters will pass easily. A microscopic examination of the residue revealed a crust formation causing the stoppage, which is shown in Figure 10.

In order to determine the nature of the problem, several fluid specimens were submitted for detailed laboratory analysis. The results of these tests indicated the impurities to be predominently a hydrocarbon substance, most likely due to the breakdown of the base oil. The residue samples were analyzed by means of emission spectroscopy. The elements detected in significant amount were: calcium, aluminum, copper, and titanium. No attempt was made to obtain quantitative results, therefore, the results are strictly qualitative. Consideration was also given to the filter paper to assure that no major contributions were caused by the supporting filter patch. Therefore, the elements present are believed to be due to wear of the systems moving parts.

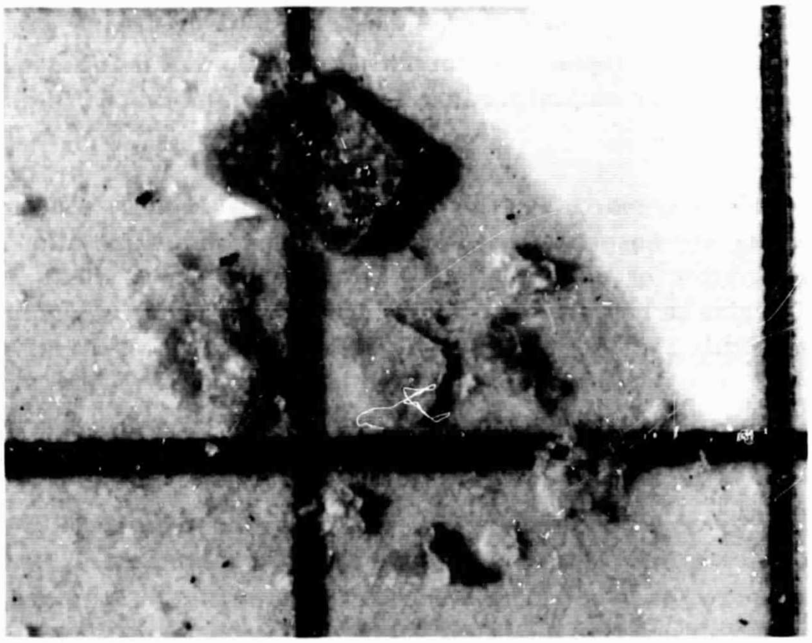


Figure 10. Water Contaminated Sample (Enlarged 20x)

An initial test for water content was performed using the Karl Fisher Titration method. The five fluid samples tested showed a water content ranging from 0.203 to 6.47 mg H_2O/ml of oil.

The five "used" hydraulic oil samples and one sample of the "unused" oil were also analyzed on a gas chromatograph to determine what, if any, organic materials were present in the used samples that were not present in the unused oil. Two of the samples, which from the previous test were known to have an extremely high water content, appeared to contain two materials of rather high concentration not detected in the unused oil. These materials were separated out in a liquid nitrogen trap and the samples analyzed on a mass spectrograph. The smaller of these two samples was found to be methyl alcohol. The second was much larger and determined to be a mixture of ethyl alcohol and water. This finding suggests that these alcohols were probably formed by the hydrolysis of high boiling esters in the original hydraulic fluid. The remaining three fluid samples appeared to have only the same major constituents as the unused oil.

These test results show that water in hydraulic fluid is a significant contributor to the overall contamination problem.

Most fluid systems operating at temperatures of 70 to 100°F can contain 50 to 200 parts per million (ppm) of water in true solution. The presence of this water is undetectable by optical means since it is a solution and is not present in the form of droplets.

In fluid containing more than the saturation value, water exists in the form of droplets which are suspended in the oil. These droplets are often so fine that even at concentration of up to 1000 ppm the oil appears to be clear. Above 1000 ppm, the oil begins to be obviously cloudy, and the presence of water in these quantities is readily recognized by visual observation. The state of dispersion of the fluid will vary depending upon the additives present. A high grade hydraulic fluid, containing anti-corrosion, anti-wear additives, etc., will tend to maintain the water in the form of very fine droplets.

The solubility of water in hydraulic fluid decreases very rapidly as the temperature is reduced. Water out of solution collects as liquid, or ice, and can cause corrosive damage. The presence of water, both free and in a dissolved state, is conducive to oil breakdown by chemical oxidation with resultant acid formation. A hydraulic fluid which is free of water, even when exposed under oxidizing conditions at high operating or environmental temperatures, shows substantially reduced tendency to form organic acids. The presence of organic acid compounds would be extremely harmful in terms of corrosion. A water content, either free or in a dissolved state causes viscosity change and the generation of solids harmful in terms of clogging orifices and filters, and general abrasive wear.

It is difficult to determine exactly how water may penetrate a hydraulic system. Several possibilities exist, and the most probable being moisture condensation from the air. It is also reasonable to consider that rain or spray may enter through vents, filler caps, inspection plates etc., or in rare cases, that water was present in new fluid as received from the manufacturer.

The hydraulic system should be flushed and refilled with new hydraulic fluid whenever any of the following conditions exist:

1. The neutralization number of the fluid exceeds 0.5 indicating that the fluid has oxidized and become acidic.

2. Examination of contaminants removed from filters and low points in the system reveals the presence of corrosion products.

3. Insoluble precipitates are produced by the reaction of water with the fluid additives.

CONCLUSION

The search to improve the operational life of fluid power systems has led to a better understanding of the conditions which cause degradation of performance and poor reliability. Contamination generated internally is a serious problem in complex fluid systems particularly during long periods of operation. The time that a hydraulic component initially begins to fail is the time to identify the problem. A faulty component can in time cause the failure of other components within the system.

In the case of the USB 30-foot and 85-foot antenna drive systems discussed in this report the following criteria were established as part of the maintenance program.

1. The maximum acceptable particle count level in the 5-15 micron range for the 30-foot system is 14,400 particles, and for the 85-foot system 22,500 particles.

2. An increase in contaminant level from one examination period to the next is a warning of component wear and potential system failure. When this condition is noted remedial action is taken.

3. The presence of water in a hydraulic system contributes to fluid breakdown by chemical reaction. The system is flushed and refilled with new fluid when an acidic condition is detected.

The fluid analysis program has proven to be a valuable asset to the maintenance of the hydraulic drives for the Manned Space Flight Network. Continued observation of these established guidelines should contribute favorably to their successful operation and reliability. The criterion which developed from this study may also be applied to fluid systems of similar type and size.

ACKNOWLEDGMENTS

The authors acknowledge the assistance received from the Materials Research and Development Branch, Systems Division, Code 735. Particular recognition is given to Mr. T. Sciacca and Mr. P. Sarmiento for their work on contaminant determination.

Special acknowledgment is also given to the many personnel of the Manned Space Flight Network tracking stations who supplied the fluid samples and statistical data for the analysis program.

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APPENDIX 1
HYDRAULIC COMPONENT DESCRIPTION

Servo Pump - Figure A1

The servo pump primarily consists of a housing, a rotating group, a port plate, a port block, and a yoke mounted on two trunnion pins. Since the servo pump is a variable displacement pump, the volumetric output is varied by use of an integral controlling device which controls the working relationship of the internal parts of the pump's operating mechanism. This controlling device is commonly called the servo pump yoke (hanger). Direction as well as volume of flow through the servo pump is determined by the position of this servo pump yoke. An electric drive motor rotates the pump shaft, the cylinder barrel, the creep plate and the piston assembly. These components make up that part of the pump known as the rotating group assembly. The creep plate is held concentric with the wear plate, and permits the rotating group to rotate relative to the yoke assembly. The yoke position is controlled by two actuators (not shown) which are operated by a servo valve. As the yoke angle changes, the excursion of the pistons in the cylinder barrel change resulting in a change of flow rate. When the angle of the yoke to the pump shaft is zero, no pumping action results. The servo pump has a flow rating of 0 to 20 gallons per minute. The working pump pressure is normally limited to 3000 pounds per square inch, however, the 30-foot system is limited to 2000 pounds per square inch. The maximum allowable speed of the hydraulic motors for this system is 4400 rpm which is equivalent to an 18.3-gallon per minute flow of Hydraulic oil from the servo pump.

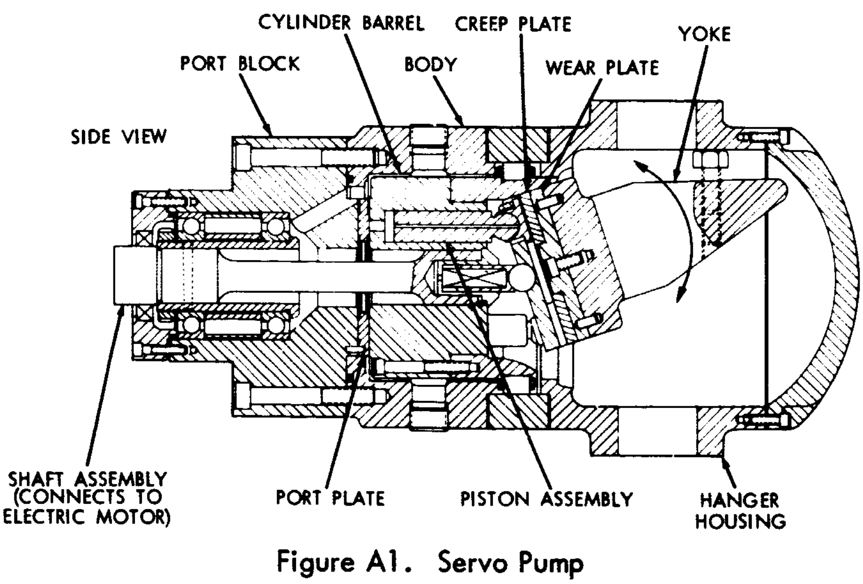

Figure A1. Servo Pump

Servo Valve - Figure A2

A servo valve is used to control the operation of the servo pump. This servo valve is an electrohydraulic device normally used to drive hydraulic actuators or motors in closed loop servo system. The flow rate of the servo valve is 1 gallon per minute at 1000 pounds per square inch pressure drop across the valve. The first stage is driven by a force motor that is balanced in all axes against the effects of lateral accelerations and vibration. The jet pipe (hydraulic preamplifier) allows virtually full differential pressure to be applied to the second-stage spool. This differential pressure causes movement of the spool. Pressure balance of the hydraulic preamplifier prevents displacement of the second-stage spool due to variations in the supply or return hydraulic oil pressure. The servo valve positions the yoke actuators of the pump to vary the displacement and control hydraulic oil flow to the motors. When the servo valve is centered the servo pump yoke is stationary. The direction of hydraulic oil flow depends upon which side of center the servo valve spool is moved.

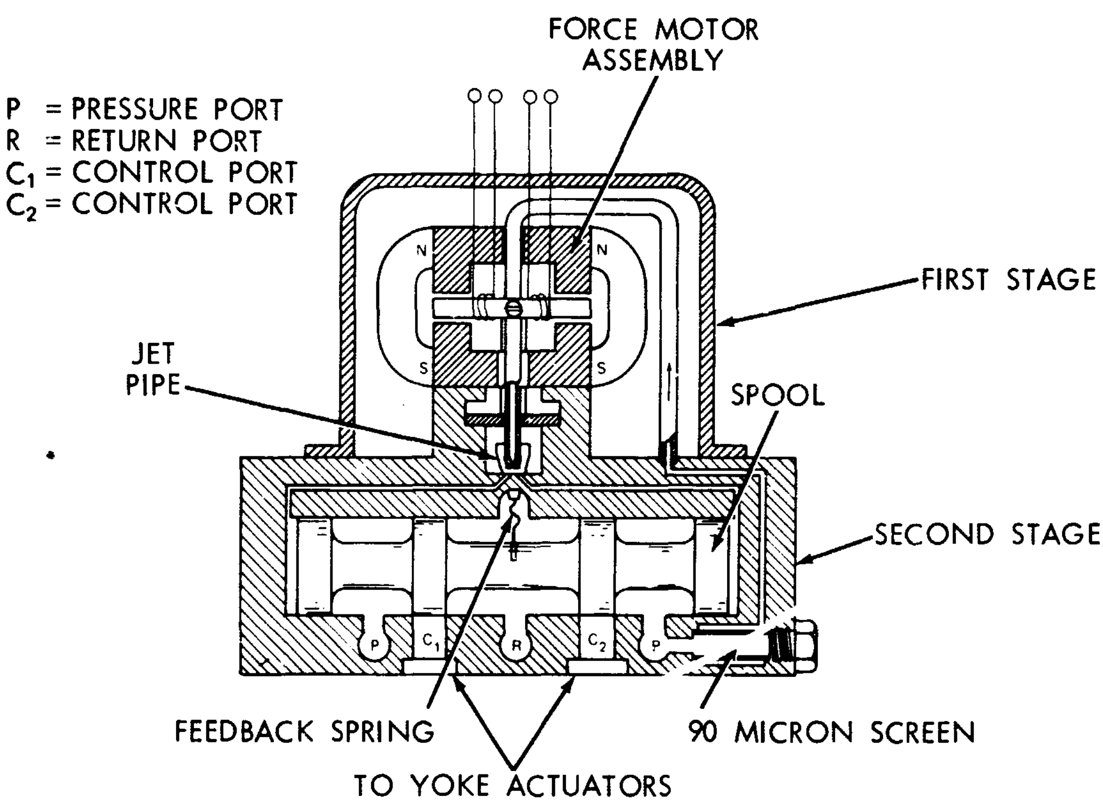

Figure A2. Servo Valve

Dual-Vane Pump - Figure A3

A constant displacement, dual-vane hydraulic pump is mechanically coupled to the right-hand shaft of the electric motor. This pump consists of two separate pumping devices in one housing which are driven by a common shaft. Each pump has its own outlet port but shares a common inlet port. Two cylindrical rotors with movable vanes in radial slots rotate in eliptical rings. As the rotors turn, centrifugal force drives the vanes outward so that they are always in contact with the inner surface of the rings. The vanes divide the area between the rotors and the rings into a series of chambers, which vary in size according to their positions around the rings. The inlet of the pump is located where the chambers are expanding in size. Hydraulic oil is drawn into the pumps by the partial vacuum caused by this expansion. The hydraulic oil is then carried to the outlet side of each pump where the chambers contract and force the fluid through the outlet port.

Working pressures in the two outlet ports of the dual-vane pump are controlled by two adjustable relief valves. In the control output, the 2-gallon per minute flow of hydraulic oil is limited to 800 pounds per square inch and supplies hydraulic oil to the servo valve, and also supplies the hydraulic pressure to release the antenna brakes. In the replenishing output, a 5-gallon per minute flow of hydraulic oil is regulated at 60 pounds per square inch and furnishes replenishing hydraulic oil for the servo pump, hydraulic pressure for the system antibacklash function, filtering, and servo pump case cooling.

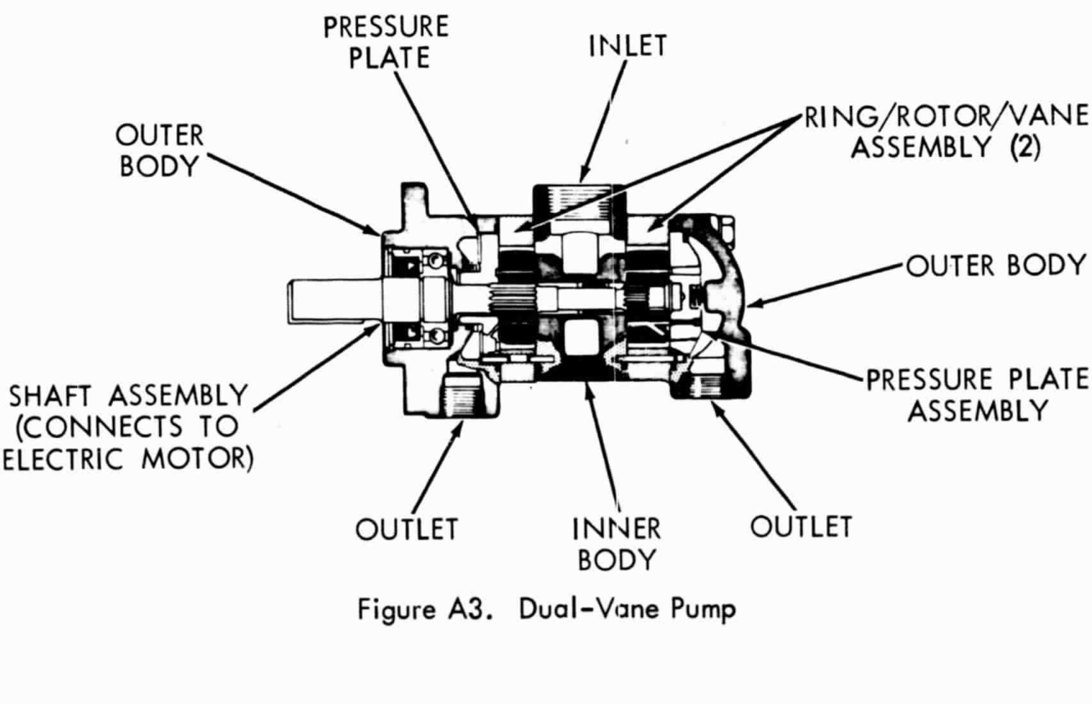

Figure A3. Dual-Vane Pump

Hydraulic Motors - Figure A4

Fixed displacement hydraulic motors are used in the hydraulic subsystem. The shaft, piston and cylinder block assemblies revolve as an integral unit, which is referred to as the rotating group. The valve plate has two curved ports, each extending nearly 180° and separated by solid areas. Necessary porting in the valve plate is connected to the cylinder by ports in the face of the cylinder block. When hydraulic pressure is applied to one of the valve plate ports, it is felt by the pistons joined to that port through the cylinder block. The pistons are forced to move away from the valve plate due to the fixed displacement angle, thus causing the entire rotating group to turn. As the rotation continues, the pistons move toward the valve plate, and the hydraulic oil in the cylinder bores is discharged into the low pressure port of the valve plate. If the application of the high and low pressures is reversed at the ports, the rotating group turns in the opposite direction. Therefore, the direction of rotation of the hydraulic motor is determined by which valve port plate is subjected to high pressure. Since the hydraulic motors are set at a fixed 30° angle, providing constant displacement, the speed of the motor shaft is determined by the flow rate of the hydraulic oil supplied to the valve plate.

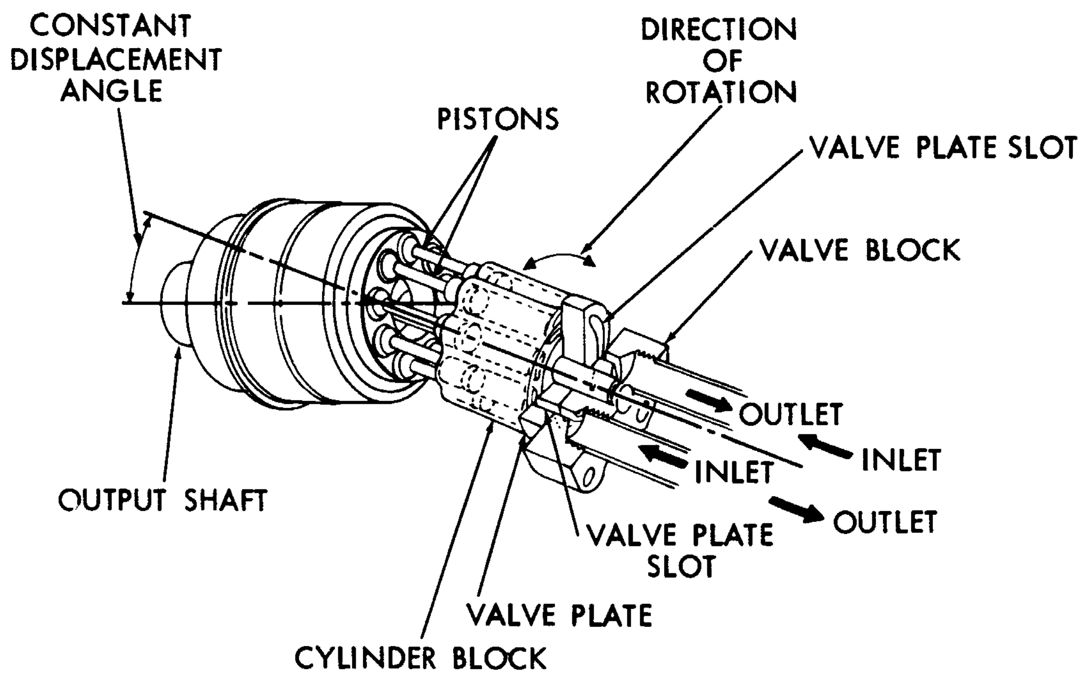

Figure A4. Hydraulic Motor

Heat Exchanger

Oil from the hydraulic system drain manifold is forced through the heat exchanger to keep the fluid within a safe operating temperature range. A 1/4-horsepower electric motor powers a fan that blows air over the coils of the heat exchanger as hydraulic oil flows through the coils. The heat exchanger is capable of dissipating 6 horsepower in heat from a 7-gallon per minute flow of hydraulic oil. The heat dissipation is rated with hydraulic oil at a temperature of 160°F and an ambient air temperature of 120°F.

Two temperature operated switches control the heat exchanger fan operation. When the hydraulic oil temperature rises above 100°F, the first temperature switch closes. As the hydraulic oil temperature reaches 120°F, the second temperature switch closes. Operation of this switch activates the heat exchanger fan which operates until the hydraulic oil inlet temperature drops below 100°F. The third temperature switch activates when the hydraulic oil temperature exceeds 180°F. This is a fault condition because excessively high hydraulic oil temperatures may cause damage to hydraulic components and oil seals. Operation of this switch causes the hydraulic power units, including the heat exchanger fan, to shut down and the antenna brakes to be applied.

Hydraulic Reservoir

The hydraulic reservoirs contain replenishing hydraulic oil for their respective axis installations. Atmospheric pressure is maintained in the X-axis reservoir through a breather arrangement consisting of a desiccator/filter connected by tubing to the filler at the top of the reservoir. The Y-axis desiccator/filter is connected by tubing through the center of the end plate to an internal hydraulic swivel joint which supports a tube and float. The float, free to move about the swivel joint, keeps the open end of the tube above the oil in the reservoir to ensure proper breathing regardless of tipping caused by antenna rotation. The desiccator/filter is installed on the top side of the end plate on both reservoirs. The suction line to the vane pump has a strainer attached and is mounted on the swivel joint so that replenishing hydraulic oil is supplied to the vane pump in all antenna positions. A check valve on the suction line, and relief valves on all lines exhausting into the reservoir, prevent the reservoir from overflowing during antenna rotation. Since the X-axis hydraulic power unit does not move when the antenna is rotated, swivel joints, floats, and check valves are not required inside the X-axis hydraulic reservoir. A quantity/temperature gauge mounted in the front end of the hydraulic reservoirs provides a visual indication of the quantity and temperature of the hydraulic oil in the reservoir.

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APPENDIX 2
FLUID ANALYSIS PROCEDURES

Procedure for Performing Particle Count Analyses

1. All samples are to be taken with the hydraulic power units running, but not while the antenna is being rotated.

2. Allow the hydraulic power unit to run normally until the hydraulic oil temperature reaches 100°F minimum.

3. Attach "sampler" to the valve from which the sample is to be taken, being careful not to introduce any contamination.

   NOTE: Particular attention should be given to cleanliness of the fluid containers and the Bomb Sampler equipment in order to avoid contamination from outside sources.

4. Bleed off approximately 800 milliliters of fluid through the filter bypass. (See instructions in Bomb Sampler Kit case for bypass valve operation). Discard this fluid.

5. Bleed off 200 milliliters of the UNFILTERED fluid through the filter BY-PASS to obtain sample for analysis.

   NOTE: Steps 6 through 17 outline the preparation procedure.

6. The test is performed using the Contamination Analysis kit. Reference may be made to Millipore booklet ADM-30.

7. Using forceps, remove the 1.2 micron filter patch from the container and place the grid marked side up on the Pyrex filter holder base.

8. Lock the funnel to the base with the clamping device.

9. Pour the entire contents of the sample bottle into the funnel.

10. Rinse the sample bottle with a CLEAN solvent (Freon TF or petroleum ether) and add the contents to the funnel. DO NOT USE ISOPROPYL ALCOHOL.

11. Apply vacuum to the filter flask.

12. While some liquid still remains in the funnel (approximately 1/2 inch above filter patch), release vacuum and use solvent to wash down interior of funnel.

13. Re-apply vacuum and pull remainder of the fluid through the filter patch. Do not subsequently rinse the funnel walls or filter surface, and avoid disturbing the even distribution of particles. Release the vacuum.

14. Remove the clamping device and funnel.

15. Using forceps, remove the filter patch and place it on a glass slide.

16. Place another glass slide over the specimen and tape the ends together with "masking tape."

17. Identify the specimen for future reference, i.e., circuit location, date, time, etc.

18. Place the slide sample on the microscope stage.

19. Count the number of particles in designated size ranges (5-15, 15-25, 25 + micron) in randomly selected fields using 100 power magnification.

20. When less than the entire filter surface is counted it will be necessary to multiply the number of particles actually counted by a statistical FACTOR which represents the number of particles on the entire filter surface. The factor to be used is 62.2. This figure is to be multiplied by the actual number of particles counted.

    NOTE: The figure 62.2 is the result of using the full eyepiece scale at 100 power magnification and counting 10 unit areas.

    $$\text{FACTOR} = \frac{960}{3.08\,LN} \text{ where:}$$

    960 = effective filtering area in mm^2 of filter

    3.08 = width in mm of filter grid square

    L = length in mm of measuring eyepiece scale

    UNIT AREA = the full scale of measuring eyepiece (L), taken across one grid square on filter patch. (3.08L)

    N = number of unit areas counted

Example

L = 0.5 mm

N = 10 areas counted

Particles actually counted (5-15 micron) = 241

$$\text{FACTOR} = \frac{960}{3.08X.5X10} = 62.2$$

Particle count = 241 X 62.2 = 15,000

21. Record particle count.

Procedure for Performing Filter Sediment Content Analyses

1. Using care not to add any additional contaminants, remove the filter bowl and pour the contents into a CLEAN, DRY bottle.

2. Rinse the bowl with Freon TF or petroleum ether and add to the sample. DO NOT USE ISOPROPYL ALCOHOL.

3. Using forceps, remove the 3-5 micron filter patch from the container and place on the Pyrex filter holder base.

4. Lock the funnel to the base with the clamping device.

5. Pour the entire contents of the sample bottle into the funnel.

6. Rinse the bottle with solvent as above and add the contents to the funnel.

7. Apply vacuum to the filter flask.

8. While some liquid still remains in the funnel (approximately 1/2 inch above filter patch), release vacuum and use solvent spray to wash down interior of funnel.

9. Re-apply vacuum and pull remainder of the fluid through the filter patch. Do not subsequently rinse the funnel walls or filter surface. Release the vacuum.

10. Remove the clamping device and funnel.

11. Using forceps, remove the filter patch and place it in a petri dish.

12. Identify the specimen for future reference.

13. Place the dish on the microscope stage.

14. Using 100x or 40x magnification, scan over entire filter surface.

15. Write up a word summary of what was observed in step 14 and file for future reference.

Procedure for Cleaning Equipment

The equipment used during testing should be cleaned before and after each use. If possible a sonic cleaner or rinse tank should be used but if none is readily available the following procedures should be employed:

a. With glass base mounted on filtering flask, as with regular testing, place low micron rated filter patch on base. Patch preferably should be of a smaller rating than used in tests (e.g., 0.8μ vs. 1.2μ).

b. Clamp funnel to base and fill with clean solvent.

c. Apply vacuum and draw solvent through apparatus.

d. Thoroughly rinse funnels and beakers used in testing and store in clean, lint-free area.

APPENDIX 3
ANTENNA SYSTEM HYDRAULIC FILTER AND FLUID INFORMATION

"Sample Copy"

TO: MSFN Depot   Date________________

Bendix Field Engineering Corporation
Logistics Operations
4615 Hollins Ferry Road
Baltimore, Maryland 21227 (Telephone 247-0800)

MARK FOR RESHIPMENT TO:

Mr. George Winston
Code 525, GSFC
Greenbelt, Maryland 20771

FROM: M&O
(Station)

Antenna type and/or No.________________

BOMB FLUID SAMPLE

From X___ Y ___ Axis   Test point location________________

Type of fluid used________________   Temperature ________________

Hours of operation: (1) Using this fluid______(2) For antenna system______

(3) Since Complete Overhaul of System ________________

Abnormal temp? Yes___ No___ (If Yes, comment below.) Date of test________

Person performing the test ________________

FILTER & SEDIMENT BOWL CONTENTS

Removed from X ___ Y ___ Axis   Date removed ________________

Filter type ________________ Type of fluid ________________

Location in the system ________________

Hours of operation: (1) Filter ____ (2) System ____ (3) This fluid ______

Reason for removing this filter ________________

____

Comments/Recommendations ________________

____

____

This form is to be forwarded with each component shipped to MSFN Depot
MP-538

APPENDIX 4
RECORD OF TEST RESULTS
"SAMPLE COPY"

TO :

FROM: Mr. George Winston, Code 525
Goddard Space Flight Center
Greenbelt, Maryland 20771

STATION ______________ SAMPLE DATE ______________

GSFC Lab Test Numbers (a) ________ (b) ________ (c) ________ (d) ________
(e) ________ (f) ________ (g) ________ (h) ________

(a) X AXIS Bomb Sample Particle Count:

5-15 MICRON ____________ 15-25 MICRON ____________

25 + MICRON ____________ Fibers ____________

(b) X AXIS Control Filter ______________________________

____

(c) X AXIS Replenishment Filter ______________________________

____

(d) X AXIS Gresen Filter ______________________________

____

(e) Y AXIS Bomb Sample Particle Count:

5-15 MICRON ____________ 15-25 MICRON ____________

25 + MICRON ____________ Fibers ____________

(f) Y AXIS Control Filter ______________________________

____

(g) Y AXIS Replenishment Filter ______________________________

____

(h) Y AXIS Gresen Filter ______________________________

____

Remarks: ______________________________

____

____

MP 558