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FLUID CONTAMINATION SURVEY OF 143 NAVAL AIRCRAFT HYDRAULIC SYSTEMS

13 March 1963

Prepared under Navy, Bureau of Weapons

Contract NOw 62-0297-t
Task Order No. 62-2
Supplemental Agreement NSE-312

Final Report

DOUGLAS AIRCRAFT DIVISION • LONG BEACH CALIFORNIA

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1.0 ABSTRACT

A. A survey of hydraulic fluid contamination was made in which 79 airplanes, plus several test stands, were sampled. The results are presented in tabular and graphical form.

B. An analysis of the data of the survey leads to the conclusion that substantially cleaner systems can be maintained with no great increase in cost.

C. Recommendations are made concerning the maximum permissible level of contamination, and procurement of components which will operate reliably at the fluid contamination levels to which they will be subjected.

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3.0 INTRODUCTION

This test program was undertaken by Douglas Aircraft Company under Navy contract NOw 62-0297t, Task Order 62-2. Stated objectives of the contract are as follows:

1. Investigate actual contamination levels in service aircraft.

2. Determine minimum contamination level which can be consistently maintained in service.

3. Establish methods and procedures which can be used to insure that system components will be sufficiently contaminant resistant to operate in contaminated fluid without performance degradation or loss of reliability.

The handbook of maintenance instructions for each aircraft contains instructions for maintaining the hydraulic system in a clean condition. Most maintenance personnel have no clear conception of the nature of the contaminants most prevalent in hydraulic system, and are satisfied if the components, the filter elements, and the oil, look clean. Figure 1 shows some typical particle sizes related to filter ratings, valve clearances, etc.

While hydraulic fluid contamination has long been known to adversely affect some components, notably hydraulic pumps, failures usually occurred gradually, and could be detected before they became catastrophic.

The advent of hydraulically powered control systems, and more recently, the use of electro-hydraulic servo-control valves with these control systems, has made hydraulic fluid cleanliness vital to the satisfactory function of the aircraft and to the performance of its mission. Much attention has been focused on this area in recent years; so much so, that malfunctions traceable to other causes are sometimes blamed upon fluid contamination.

This contamination survey and analysis are intended, therefore, to answer the questions, (1) how clean are the hydraulic systems now? (2) how clean can we make them, economically? and (3) how can system reliability be assured at the contamination levels which it is practical to maintain?

4.0 FIELD SURVEY OF HYDRAULIC FLUID CONTAMINATION

4.1 Data Obtained and Procedures Used

Particle count of solid contaminants: 100cc of hydraulic fluid was filtered through a 0.8 micron filter membrane and the particles counted under microscopic examination per SAE Aircraft Recommended Practice 598. An average tare count was then subtracted. The hydraulic systems were sampled, and the fluid filtered, by methods and portable field equipment described in Appendix A.

Viscosity: Viscosity in centistokes at 100°F was determined by ASTM Method D445-53.

Neutralization Number: The acidity of the hydraulic fluid, an index to its corrosiveness, was determined by ASTM Method D974-58T. This is done by titration to an end point, using potassium hydroxide as the base and para-naphthol-benzein as an indicator. The results are expressed in milligrams KOH per gram of sample. The accepted limit is 0.5.

4.2 Systems Tested

One hundred forty four samples were obtained from 79 airplanes of 17 models plus several ground service test and fill stands. The table, Figure 3, lists the models and certain significant characteristics of their hydraulic systems. Figure 4 lists for each sample the airplane, system, squadron, and airbase. A total of 13 bases was visited.

4.3 Tabulation and Analysis of Results

4.3.1 Tabulation

Figure 4 is a composite table showing all laboratory analysis data for each sample, in addition to the identifying information such as airplane model and BuNo, total flight hours, squadron, base, etc.

The particle count is a rather unwieldy description of fluid contamination. A tentative set of standards has been adopted jointly by the SAE, ASTM, and AIA, defining contamination classes, according to the table, Figure 2. This is a convenient but imperfect index, as the particles are seldom present in the correct proportions to fit this table. To improve this correspondence for purposes of this report, use is made of "class plus" designations. For example, if the particle count in four of the five size ranges is within the limits of Class 3, but the fifth size range belongs in Class 4, the class is given in the composite data table as 3+.

4.3.2 Analysis of Results

Cleanliness level distribution, all aircraft.

The curve, Figure 7, shows the contamination class (per Figure 2) vs the percentage of all systems which exceed that class. This curve indicates that while the mean contamination level for all systems is about Class 4, 23% are dirtier than Class 5, and 11% are dirtier than Class 6. Figure 9 shows this information in bar-graph form.

Cleanliness level by model.

Figure 8 shows the cleanliness distribution by aircraft model, provided there are sufficient data to generate a curve. On several types of aircraft, three or less airplanes were tested. Figures 8E through 8H compare contamination levels of utility and flight control systems for four models. These curves show the flight control systems to be cleaner in each case, although the margins vary.

Contamination vs Flight time

The graph, Figure 5, shows contamination class vs total flight time on the airplane. This graph shows no trend, but has a random distribution, demonstrating that flight time is no index to contamination.

Contamination vs Viscosity

Figure 6 shows the contamination class vs viscosity of the fluid. There appears to be some relationship in thise case, but not sufficiently well defined to use viscosity as an index to contamination.

Contamination vs Geographical Location

While the data is not conclusive, there appears to be little correlation between hydraulic fluid contamination and geographical location. The P-2 aircraft, which was the only model checked in several locations, was quite consistent in contamination level. The three P2 airplanes in the Pacific Northwest

(Whidbey Island), which probably has a low airborne dust level, were slightly cleaner than average.

Identification of Contaminants

Microscopic examination, which is not considered a dependable method, indicates that a large part of the contamination in virtually all samples is rubberlike particles. This is indicated by color (black), texture and form (similar to eraser dust).

Some of the more heavily contaminated membranes were analyzed on a Jarrel-Ash 3.4 meter emission spectrograph.

This machine shows the presence and relative quantity of metallic elements, and except for rubber and plastic, most of the contaminants are metals or metallic compounds. The cleaner membranes do not contain enough material for reliable analysis.

The results of the spectrograph analysis are shown on the composite data table, Figure 4. The probable sources of the elements shown are:

Silicon	(Si)	Airborne dust; grinding compounds.	
Iron	(Fe)	Pump/actuator wear	Alloy steels
Nickel	(Ni)	" " "	
Chromium	(Cr)	" " "	
Copper	(Cu)	Pump wear	Aluminum bronze
Aluminum	(Al)	" "	
Titanium	(Ti)	Paint pigment	
Cadmium	(Cd)	Plating	
Tin	(Sn)	Solder - brazing	
Silver	(Ag)		

5.0 ANALYSIS OF CONTAMINATION SURVEY TO DETERMINE MINIMUM PRACTICABLE CONTAMINATION LEVELS

5.1 General

Cleaner hydraulic systems might be obtained by preventive measures, that is, by reducing or eliminating contamination at its source, by improving system filtration, or a combination of both. The data of the contamination survey, Paragraph 4.0, provides a basis for analyzing these approaches.

5.2 Prevention of Contamination

5.2.1 The sources of contamination are:

(a) "Built-in" contamination. Dirt in hydraulic components, lines, etc., as fabricated and not removed by system flushing before delivery.

(b) Contamination in new oil added to the system.

(c) Airborne dust infiltrating the system.

(d) Contaminants generated within the system by pump wear, packing wear, etc.

(e) Contamination from hands, tools, etc., introduced when a system is opened for maintenance reasons (includes overhauling of components).

(f) Contamination introduced by interchange of fluid with ground test equipment.

These will be discussed in order.

5.2.2 <u>"Built-In" Contamination</u>

All components of hydraulic systems contain some contamination, such as metal from machining and grinding, abrasive compounds from honing and lapping, dirt from hands and tools, etc. More is introduced during assembly of the system. Flushing of the system may remove a portion of this contamination before the airplane is delivered. The test data does not indicate that "new" airplanes have significantly, more or less, contamination than older ones. It may be of a different type however. For example, two low-time A-5 aircraft show the presence of silver, probably from soldering or brazing operations during manufacture.

This element is not significant in older aircraft. The aircraft manufacturers expend considerable effort to control contamination, but have generally rejected, as too expensive, clean-room assembly of components and other techniques applied to missile systems. This survey indicated that, at present at least, such efforts would largely be wasted as the systems would soon become contaminated from other sources.

5.2.3 Contamination in New Oil

New MIL-O-5606 hydraulic oil as purchased is usually moderately clean to dirty, (Class 4 to 6), although a cleaner grade (MIL-O-5606B) is available at a premium price.

Most of the aircraft currently in the Navy's arsenel require pressure-filling of the hydraulic systems, rather than pour-in filling. Most of these are filled with a hand operated fill stand such as the Alemite Model 7181 or a locally manufactured equivalent. This stand consists of a reservoir, hand pump, filter, and delivery hose.

The filter utilizes a paper AN 6235-3A element. In most cases, the oil is purchased in one gallon cans (sometimes one quart) and when a can is opened, the entire contents are used at once, (that is poured into the fill stand). The cans are opened with beer-can openers or service station type pouring spouts.

Three such fill stands were checked during the survey, and the oil they discharged varied from exceptionally clean to unacceptably dirty. (Class 0 to 7).

It appears that new oil may represent a significant source of contamination. It can be greatly reduced quite inexpensively. Throw-away filter elements per Specification MIL-F-27656 (5 micron absolute) can be obtained to fit in present filter housings, and will, in a single pass, remove virtually all particles. (These elements are not interchangeable with presently installed airplane filters because of their reduced flow and temperature capability). The delivery hose should be changed if it shows any evidence of deterioration, or be replaced with plastic-lined hose.

5.2.4 Airborne Dust Infiltrating the System

The majority of systems are sealed against infiltration of dust; many employing airless reservoirs, others use filtered air to pressurize the reservoir. The wide-spread incidence of silicon as a contaminant indicates that airborne dust does, nevertheless, find its way into the system. There appears to be no specific geographical area where this is most prevalent. The Naval air stations covered during this survey were mostly in coastal areas, so may not represent the worst dust environment.

Dirt and dust probably enter the hydraulic system by any of 4 routes (1) by infiltrating the filling stands and entering the hydraulic system with new oil (required to make up for normal attrition,) (2) with air vented to the hydraulic reservoir, or used to pressurize the reservoir, (3) by clinging to surfaces (piston rods) which are alternately exposed to atmosphere and to hydraulic fluid, and (4) from hands and tools during maintenance in which the system is opened.

5.2.5 Contaminants Generated Within the System

Any moving parts within the hydraulic system must be expected to generate wear particles which will contaminate the hydraulic fluid. By far the most important such source in most systems is the hydraulic pump. Particles of steel and bronze resulting from pump wear occur to some degree in most of the systems tested in this survey. Another significant source is the seals in the actuators, valves, etc., in the system. Particles from this source may be less damaging to hydraulic pumps than metallic particles, but may nevertheless cause valve sticking, silting,etc. These particles contribute greatly to "background color" in test filter membranes, because of their carbon black content. The most effective way to combat the generation of contaminants within the system is to maintain a clean system.

5.2.6 Contamination Introduced by Interchange of Oil With Ground Test Equipment

Most aircraft hydraulic systems are periodically connected to hydraulic ground test stands for functional or leakage tests, and this inevitably involves some interchange of fluid between airplane and test stand. Although the aircraft hydraulic system reservoir serves during test stand operation, the volume of oil in the test stand pump, filters, valves, and hoses may still be a substantial percentage of the airplane system volume. For example, one model of test stand uses two filters containing AN-6236-3 elements, each filter housing holding approximately one gallon of hydraulic oil. This stand is used with F-8 airplanes, whose power control systems have a capacity of 2.6 gallons. Test stand operation of such a system thus implies a 50% change of hydraulic oil. This fact emphasizes the importance of maintaining test stands in good condition, and further, indicates that by incorporating finer filters in the test stands, airplane systems would be cleaned whenever connected to a test stand. From the test results, it appears that the cleanliness of hydraulic oil in test stands was in most cases comparable to that in the airplanes in the same activity, which would be expected with the large exchange of oil with the aircraft systems. However, there were cases where the test stand fluid was cleaner, and dirtier, than the fluid in the airplanes.

Test stand maintenance was generally entrusted to a base maintenance activity, rather than to the aircraft squadron, and varied widely in quality. In some cases, it appeared questionable as to whether the prescribed servicing intervals were being observed. One squadron supplied photographs of ruptured filter elements found in their test stands.

5.3 Improved Filtration in Hydraulic System

5.3.1 Filters Available

(a) The Specification MIL-F-5504B (pleated paper element) filter is the most widely used on Naval aircraft. The elements conform to drawing AN 6235 or AN 6236. The plastic impregnated paper media, with a random distribution of pore sizes, traps a percentage of all sizes of particles. It has no "absolute" rating, but has a nominal rating of 10 microns.

(b) High performance aircraft of recent design generally use a stainless steel woven wire mesh filter element with a nominal rating of 10 microns and an absolute rating of 25 microns. These filters were usually bought to an airframe manufacturer's specification, but may now be purchased to Specification MIL-F-25862 (USAF). The uniform pores stop all large particles, but pass most particles smaller than the nominal rated size.

(c) Specification MIL-F-8815 describes a filter rated at 15 microns absolute, and approximately 2 microns nominal. Though no qualified product list had been issued as of this writing, qualification testing had been completed and submitted by at least one vendor. Filters conforming to this specification are used on A-6 aircraft (none of which were included in this survey) and have been flight tested on A4C aircraft (Ref. C).

(d) Filters made of sintered metal particles (bronze) are available in a variety of ratings, conforming to airframe manufacturer's or vendor's specifications.

(e) Specification MIL-F-27656 describes a filter with an absolute rating of 5 microns, and a nominal rating less than one micron. At least one qualified product is available, employing an epoxy-impregnated fiber media.

5.3.2 Filter Applications and Performance

When used within their limitations, the MIL-F-5504 paper filters do an excellent job. Of all airplanes checked in the contamination survey, those with the cleanest hydraulic systems were equipped with these elements. However, many of the dirtiest systems also used MIL-F-5504 filters. The reason for these dirty systems may be failed filter media, open by pass valves due to clogged elements, or damaged filter element seals. (The air bubble test of Specification MIL-F-5504B should preclude faulty elements being purchased). The handbooks of maintenance instructions for several models permit these elements to be cleaned with solvent and a soft brush and re-used. This practice should be stopped if it actually exists.

Visible particles on the surface may indicate trouble elsewhere, but will not clog the filter. The fine particles which clog the filter are deep in the pores and cannot be satisfactorily removed. Attempts to clean a paper filter can do little good, but may damage it.

The stainless steel wire filter elements are widely used because they will withstand higher temperatures and higher pressures, are free of media migration and are recleanable. Cleaning as practiced at squadron level, however, is ineffective. These filters effectively remove large particles, as shown in the particle counts, Figure 4, but do not stop many particles below their nominal rating. References A and B indicate that it is these smaller particles that affect servo-control valve performance. A comparison of systems cleanliness (Figure 8A) indicates that the wire mesh filters are not as effective as MIL-F-5504 paper filters used within their limitations.

Sintered bronze filter elements were employed in only one aircraft included in this survey; the F-8. In this aircraft, its performance varied widely, much like the paper elements, with systems both cleaner and dirtier than any system with wire mesh filter elements (Ref. Figure 9). The overall performance of the sintered bronze filters appears somewhat better than the wire mesh filters, or roughly equal to the paper filters (Figure 8A).

The MIL-F-8815 filter is a relatively new development, and combines the best features of the MIL-F-5504 filter (fine particle removal) with the advantages of the wire mesh filters. The media used in the A-6 aircraft application, and tested in A-4C aircraft, consists of a stainless steel wire mesh backing and an overlay of stainless steel particles, all sintered together.

In the A-4C flight test program, conducted by NATC (Ref C) the use of the MIL-F-8815 filter element resulted in a gradual but significant improvement in the performance of the automatic flight control system.

Mil-F-8815 filtration appears to be the best choice for new aircraft designs, in spite of higher initial cost. The use of a pressure differential indicator permits maximum usage to be obtained from each element, and permits elimination of frequent inspections (which often result in contaminating the system).

The MIL-F-27656 filter, which employs epoxy impregnated fiber media, is reported to be performing well in commercial airline tests, and may be adopted by at least one airline as standard equipment (Ref. H). At least one qualified product is available. Because of its temperature limitation (approx. 250°F) and the fact that a larger unit is required for equivalent flow, fighter and attack aircraft may find it unsuitable. For other aircraft, and for ground support equipment, it should be seriously considered.

5.4 Other Factors Affecting Contamination Levels

A study of the test data shows that in general, the systems with the most contaminant generating components (actuators, etc.) are the dirtiest.

Figure 10 is a graph showing average contamination class vs. number of actuators in the system. For systems with paper (MIL-F-5504)filters, the distribution appears random, but for systems with metal filters, the correlation is surprisingly good. The implication is clear that complex systems require more filtration than simple ones.

It does not necessarily follow that the actuators produce all, or even most of the contamination. More flow demand requires the hydraulic pump to operate under load more often, thus increasing its wear.

5.5 Estimate of Practicable Minimum Contamination Level.

Figure 7 shows that in current Naval aircraft, more than half the hydraulic systems meet a contamination level of Class 4 or better. If all systems were that clean, there would be little trouble caused by contamination. However, about a quarter are dirtier than Class 5, the recommended limit, and more than 10 percent are dirtier than Class 6, which is 4 times as dirty as Class 4.

A number of positive steps toward cleaner systems is listed below:

(1) Use MIL-F-8815 or better filtration on airborne systems.

(2) Use MIL-F-27656 or equivalent filtration on all system filling and ground test equipment.

(3) Discontinue cleaning and re-use of paper elements (as now permitted by several HMI's).

(4) Use redundant filtration (two or more filters in series).

(5) Use filter media in proportion to the number of components in the system, rather than the maximum pump flow.

(6) Purchase only hydraulic pumps which have satisfactorily completed a run-in test.

On new designs, where most or all of the above steps can be taken, class 4 cleanliness level or better should be consistently attainable.

On existing aircraft, where only a few of the foregoing suggestions are practical, Class 5 or better should be a practical goal.

6.0 PROCUREMENT OF CONTAMINANT-RESISTANT HYDRAULIC SYSTEM COMPONENTS

6.1 Types of Failures

Contamination induced failures of hydraulic system components may be grouped into three categories, as follows:

A. Malfunctions due to single large particles (or a few large particles) interfering with the motion of moving parts (reseating of valves, etc.).

B. Loss of performance due to wear and eventual failure (hydraulic pumps and motors, etc.).

C. Loss of performance when frictional forces become significant with respect to driving forces, or when contamination affects the driving forces (servo control valves).

A secondary type of failure has also been reported. Worn hydraulic pumps produce greater pulsation fluctuations in the delivery pressure, thus inducing fatigue failures in lines and other components. Data to substantiate this seems to be lacking.

6.1.1 Single Particle Failures

A particle large enough to plug an orifice, prevent a valve from seating, etc. is large enough to be easily seen, and would be stopped by the coarsest filter. Its presence is indicative of carelessness on the part of manufacturing, overhaul or maintenance personnel. Failure to deburr a drilled passage at the time of manufacture, for example, may eventually result in the burr being dislodged into the system. Good maintenance, and the application of screens (coarse filters) at critical points will prevent this type of failure.

6.1.2 Wear Failures

All moving parts are subject to wear at points of contact, but few hydraulic system components are subject to continuous movement. The principle exceptions are hydraulic pumps, and continuous duty hydraulic motors (such as alternator drives). Infiltration of the precision fits by fluid-borne particle results in wear, scoring, and increased clearances. This sometimes causes sudden failure, but more often results in a gradual loss of efficiency.

It has been shown (Reference D) that by monitoring the contamination produced during a running-in period, potentially troublesome pumps can be detected by the manufacturer. This procedure has been incorporated in specification MIL-P-19692A (WEPS) (Reference E) but is not generally applied because of the costs involved. This run-in test, in abbreviated form, is used in the procurement of some hydraulic pumps (A-4 aircraft) and has reduced pump rejections. Reference D claims a 50% increase in pump life was achieved on F-8 aircraft. If this is true the cost of the run-in procedure should be justified. Reference D also describes typical design and manufacturing changes which may increase pump durability. To our knowledge, there is no data which relates pump endurance to fluid contamination levels, so no specific goal can be defined for a contamination level which will result in improved pump life.

Wear in other components is usually not serious within the life expectancy of military airplanes. Testing of actuators to specification MIL-C-5503, for example, serves to reveal potentially troublesome wear points, which can usually be eliminated through redesign.

6.1.3 Frictional Failures

Control valves, in particular electrohydraulic servo valves, may have limited force available to drive the valve spool. Frictional forces may become great enough to cause degradation of performance, although little or no wear has occurred.

Servo valves, also called transfer valves or hydraulic amplifiers, are usually designed to produce hydraulic flow output proportional to an electric current input, and are used in most autopilots, missile guidance systems, etc. It is the performance of these units, more than any other factor, which has focussed attention on hydraulic fluid contamination in the last few years.

Tests per References A and B were conducted by this contractor in an attempt to find the contamination level which will yield satisfactory servo valve performance. The results may be summarized as follows:

Class 6 - Hydraulic Fluid - Performance is degraded

Class 5 - Hydraulic Fluid - Performance is stable

Class 4 - Hydraulic Fluid - Performance improves

These results were obtained with three different models or servo valve, so are regarded as being generally applicable. Flight test corroboration was obtained (Reference C) although the fluid contamination was not monitored. Three A-4C airplanes were equipped with filters manufactured to meet specification MIL-F-8815 (identical with the elements used in the laboratory tests per References A and B.). Figure 4 of this report indicates the initial contamination level in A-4C utility systems would have been Class 5 to Class 6. Reference C states "Prior to the installation of the 2-15 micron APM filter element in the model A4D-2N airplane, the performance of the AFCS was slowly deteriorating to an unacceptable level. This deterioration was evidenced by increasing random control movements and feedback near the trimmed position when in the Control Stick Steering (CSS) mode. After filter installation the performance appeared to level off for a period of approximately 8-10 hours, then improve slowly. Random control movements and stick feedback were not eliminated completely, but did decrease to an acceptable level." This test program involved 127 sorties flown by 23 pilots.

It was found that the electrical circuit could be adjusted to minimize the effect of servo valve degradation. Nevertheless, it seems clear that a Class 5 contamination level is marginal for this type of equipment, with Class 4 or better to be desired.

6.1.4 Outlook for Contaminant Resistant Components

A review of the nature of contaminant-caused failures and the possible courses of action to obtain contaminant resistant components leads to the conclusion that little progress can be expected in this area.

In hydraulic pumps, for example, the combinations of metals and hardnesses used are normally those found by experience to have the best wear resistance. The clearances are dictated by volumetric efficiency and mechanical considerations. Future developments in metallurgy may bring improvements, but the most positive action at present appears to be use of a run-in procedure (Per MIL-P-19692A, or some variation thereof).

The other major contaminant-sensitive components, servo-control valves or other special close tolerance valves, have close tolerance slides and small orifices dictated by performance and leakage requirements. In specific applications, greater leakage might be tolerable, but servo-control valves are seldom designed for a specific application. Increased slide-driving force can be attained by using larger diameter slides, but this affects frequency response. Since many presently available servo-control valves work well with Class 4 contamination levels and fairly well with Class 5 contamination (at least for airplane applications) it appears the most feasible approach is to provide hydraulic systems which meet these levels.

6.2 Specification Changes

The only military specifications covering contamination resistance of hydraulic system components are:

A. MIL-H-8775B (Reference G), which requires a 25 micron absolute filter to be used for qualification or preproduction tests of components. Finer filtration is not to be used unless called for in the detail specification.

B. MIL-P-19692A (WEPS) (Reference E) specifies MIL-F-8815 filtration for the "normal" endurance test of a hydraulic pump, but no filtration for the "overload" endurance test. This specification also specifies a break-in run for every pump, the effluent fluid to be checked by a filter patch test.

C. MIL-V-27162 (USAF) (Reference F) for electro-hydraulic servo-control valves limits the contamination level in the test equipment by by particle count. (Figure 11)

No change is recommended for MIL-H-8775B, as the filter specified should result in a contamination level comparable to that of the airplane system. No change is recommended for MIL-P-19692A (WEPS), as the test without filtration is sufficiently severe.

Specification MIL-V-27162 (USAF) should be revised to specify a minimum, rather than a maximum, contamination level for the preproduction life test. This minimum level should be about the same as that now specified as maximum, which is about Class 5 (Figure 11).

7.0 DISCUSSION

7.1 Maintenance Practices

The majority of maintenance personnel contacted during the contamination survey had some awareness of the importance of hydraulic system cleanliness and made an attempt to keep their systems clean. They have little idea of the degree of cleanliness required, as evidenced by the fact that one squadron, informed in advance of the contamination survey, had obtained some fruit jars into which to draw oil samples. The jars were carefully wiped out with a clean rag.

Most maintenance officers stated that they had little or no hydraulic contamination trouble. Several were concerned that the hydraulic fluid in shock struts became dark and apparently more viscous.

It appears that system cleanliness must be inherent in the system design, the design of the ground support equipment and the prescribed servicing practices. Although there should be a continuous effort to acquaint maintenance personnel with the importance of hydraulic system cleanliness, "better maintenance" alone will do little to achieve it.

7.2 System Flushing

Apparently flushing of hydraulic systems is rarely practiced. None of the squadrons visited ever flushed a hydraulic system unless a complete failure of a hydraulic pump occurred. One O & R facility changes oil in airplanes undergoing repair, provided an oil sample is shown to be excessively contaminated by the SAE-ARP 598 procedure. One airplane was checked during its first engine run after completing this procedure (Figure 4, Sample No. 51) and found to be little cleaner than other airplanes of this model. The small particle count (5 to 15 microns) was substantially lower however. This system had been pronounced satisfactory by the O & R laboratory. Conclusions to be drawn from this example are:

A. A hydraulic system should be drained immediately after an engine run, so the maximum amount of dirt will be in suspension in the fluid.

B. Very fine filtration (MIL-F-27656 for example) should be used on the filling equipment.

C. Evaluation of contamination by samples drawn from a static system is of questionable validity.

When it was suggested that a particularly dirty system be flushed, a squadron maintenance officer replied that he did not have suitable equipment for the job. Apparently that judgment was correct; however, an ordinary test stand with a finely filtered discharge flow is the principal requirement. (At the time of the survey, two of the three hydraulic stands in that squadron were inoperative.)

Considerable publicity has been given to flushing stands which "recondition" hydraulic fluid in addition to filtering it. The composite data table, Figure 4, shows such fluid properties as viscosity and acidity remain within acceptable limits, which indicates that such equipment is unnecessary. A separate study (Reference H) indicates that the use of such equipment is prohibitive (at least for commercial operations) in terms of airplane down-time and man-hours expended.

Specification MIL-H-5606 fluid is inexpensive enough to permit it to be discarded and replaced periodically. Such replacement should be made a part of every PAR procedure. Even if not required for other reasons, it would tend to reduce the accumulation of wear particles too small to be removed by filtration.

7.3 Filter Servicing Policy

The Handbook of Maintenance Instructions for most models of aircraft calls for periodic removal and visual inspection of filter elements at intervals of 30 or 60 hours. The element is to be cleaned or replaced "if contaminated".

Visual inspection of filter elements is not effective. Large, visible particles do not clog the filter, though they are indicative of trouble elsewhere (e.g. a failing pump). Particles which clog a filter are not visible, and even under magnification can hardly be detected. Also, the cleaning accomplished at squadron levels is of little value.

A far better approach is the use of a differential pressure indicator to show when the element is clogged. This method is incorporated in specification MIL-F-8815. Not only does this give a positive indication of a loaded filter, but also assures that the full capacity of the element will be used.

In addition, unnecessary opening of the system, with the attendant danger of introducing contamination, is eliminated. As currently practiced, it is possible that a filter element which is fully loaded but looks clean will remain in service, and all flow will go through the by-pass relief valve in the filter housing, so that effectively there is no filtration.

It is recommended that no attempt be made to reclean hydraulic filter elements at squadron level. Paper elements should be discarded upon removal. Metal elements should be forwarded to a facility equipped for ultrasonic and/or chemical cleaning, flow checking, bubble point checking, etc.

7.4 Filter Performance in a System

A filter will remove various percentages of different particles, and these percentages vary with concentration of particles, rates of flow, and as the "filter cake" acts as an additional filter. The contaminants generated within the system vary with system activity and with contamination level (that is, a pump wears out faster in a dirty system.). All these variables make it virtually impossible to design a filter which exactly meets the system requirements. Choosing the filters strictly on the basis of rated flow appears to be inadequate.

It has been reported that a system which has been "supercleaned" by intensive filtration tends to stay clean. This is undoubtedly because pump wear particles are generated at a reduced rate, which the normal filter can cope with. In dirty systems, wear particles are generated at a rate faster than the filter can remove them. This suggests a balance point of contamination may exist, where dirtier systems tend to get dirtier, and cleaner systems tend to get cleaner. This would only occur, however, with filter elements which remove a substantial percentage of all sizes of particles. Thus, several systems with paper filters were found in the "superclean" category-class 0 or 1, whereas no metal-filtered system was that clean. Some paper-filtered systems were also among the dirtiest tested. The metal filters give more consistent results, even though the average cleanliness level is not as good as with paper.

7.5 Contamination Tests

Contamination test procedures such as SAE-ARP 598 are beyond the capability of squadron maintenance, though they are employed to some extent at the O & R base level.

It is suggested that a sampling system such as described in Appendix A could be used at either maintenance level. Instead of microscopic examination of the filter membrane, it can be visually compared with standard "go-no-go" membranes. This method has been used successfully with a missile system, where requirements were much more stringent.

8.0 CONCLUSIONS

1. Approximately one-fourth of the hydraulic systems in Naval aircraft are contaminated beyond the maximum level recommended for reliable, trouble-free operation. (Class 5)

2. Filter elements of 25 micron absolute rating woven wire mesh, per specification MIL-F-25682 or equivalent, are only marginally acceptable or are unsatisfactory in many applications.

3. Existing systems can be maintained in a cleaner condition by employing better test stand filtration, better filling stand filtration and periodic system flushing. In some aircraft systems, the use of additional filters or a different filter media may be justified.

4. Cleaning and reuse of MIL-F-5504 paper filters should be discontinued, except as an emergency measure. Cleaning of metal filters at squadron level should be discontinued.

5. The number and sizes of filters in new systems should be in proportion to system complexity rather than maximum pump flow.

6. Special flushing and fluid reconditioning stands being contemplated will be unnecessary if use is made of the improved filter media which has become available (MIL-F-8815 and MIL-F-27656).

7. No great improvement in contaminant-resistance of hydraulic system components appears likely. No procurement specification changes are recommended, except a minimum contamination level for life-testing servo-control valves.

9.0 REFERENCES

(A) Report ES 29862 - Evaluation of Contamination Tolerance of Servo Valves and Contamination Levels in Hydraulic Systems, Aircraft Division Douglas Aircraft Company.

(B) Report ES 40348 - Servo Valves, Comparative Test of the Effect of Contamination on Performance, Aircraft Division, Douglas Aircraft Company

(C) Report P49AE-32-1 - Evaluation of 2-15 Micron Filter Element in the A4D-2N Utility Hydraulic System, Service Test Division, Naval Air Test Center - 6-13-61

(D) Contamination Control for Cleaner, More Reliable Pumps - by J. H. Ballantoni and A. B. Billet, Aviation Age (Periodical) January 1958, Page 138

(E) Specification MIL-P-19692A (WEPS) - Pumps, Hydraulic, Variable Delivery, General Specification for - 12-1-60

(F) Specification MIL-V-27162 (USAF) - Valves Servo Control, Electro-Hydraulic, General Specification for - 10-6-59

(G) Specification MIL-H-8775B - Hydraulic System Components, Aircraft and Missiles, General Specification for - 11-8-61

(H) Society of Automotive Engineers Technical Paper 575B - Commercial Jets - Hydraulic System Contamination versus Airline Maintenance - by R. H. Lesser - October 1962

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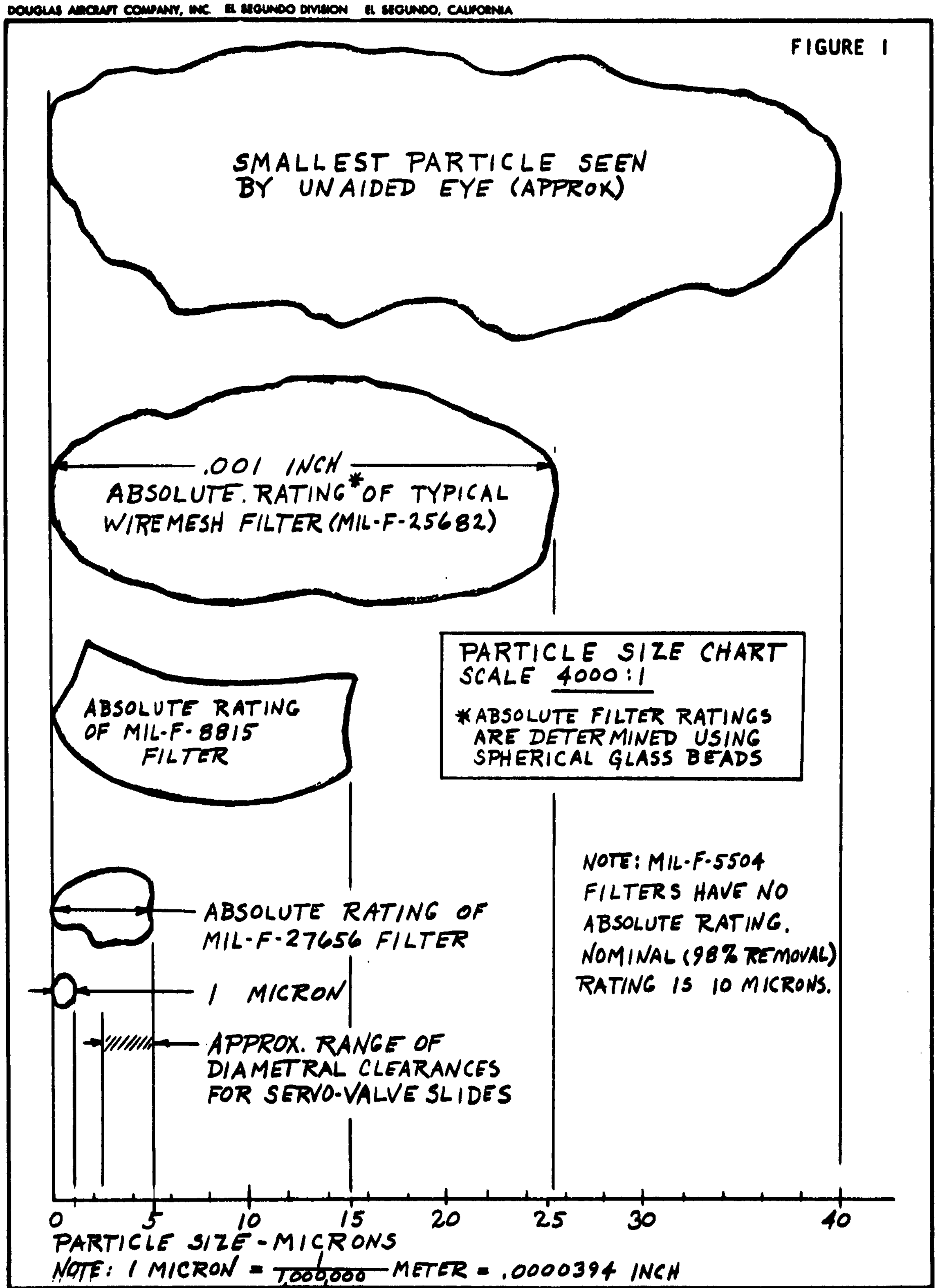

CONTAMINATION LEVELS

SAE, ASTM, AND AIA TENTATIVE STANDARD
FOR HYDRAULIC FLUIDS

Size Range (Microns)	Contamination Class							
	0	1	2	3	4	5	6	7-10
2.5-5	Pending							PENDING
5-10	2700	4600	9700	24,000	32,000	87,000	128,000	
10-25	670	1340	2680	5,360	10,700	21,400	42,000	
25-50	93	210	380	780	1,510	3,130	6,500	
50-100	16	28	56	110	225	430	1,000	
100	1	3	5	11	21	41	92	

FIGURE 2

Notes: (1) The particle size ranges used in this program were 5-15 microns and 15-25 microns, instead of 5-10 and 10-25. The table was used without change.

(2) The use of a plus sign with a class designation in this report means that four of the five size ranges were within the limits for that class, but one size range had a count which exceed the limit for that class, but not of the next higher class.

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AIRCRAFT HYDRAULIC SYSTEM SAMPLING DATA & DESIGN INFORMATION

AIRCRAFT MODEL	NUMBER TESTED	NUMBER OF BASES	SYSTEM DESIGN INFORMATION: SYSTEM NAME	SYSTEM PRESS (PSI)	MAX FLOW (GPM)	NUMBER & TYPE OF PUMPS	HYDRAULIC FILTERS: LOCATION	HYDRAULIC FILTERS: TYPE	NO. △ OF ACTUATORS	ELECTRO-HYDRAULIC SERVOS	APPROX AVG. CONTAMINATION LEVEL (REF)
A3A A3B RA3B (A3D-1) (A3D-2) (A3D-2P)	9	3	UTILITY	3000	19 (12 FOR RA3B)	2 VARIABLE VOLUME PISTON-TYPE	1-PRESS LINE	10μ PAPER	34 (JATO OMITTED)	NO	5.5
			SURFACE CONTROL	2000	6	1 VARIABLE VOLUME, PISTON TYPE	1-PRESS LINE	10μ PAPER	3	NO	4.2
			AILERON CONTROL	2000	6	1 VARIABLE VOLUME PISTON TYPE	1-PRESS LINE	10μ PAPER	2	NO	
A4B (A4D-2)	2	2	UTILITY	3000	5.8	1 VARIABLE-VOL PISTON TYPE	2-PRESS LINE 1 CASE DRAIN	10μ PAPER	22	NO	6.5
			FLIGHT CONTROL	3000	5.8	1 VARIABLE-VOL PISTON TYPE	2-PRESS LINE 1-CASE DRAIN	10μ PAPER	3	NO	2.5
A4C (A4D-2N)	5	3	UTILITY	3000	5.8	1 VARIABLE-VOL PISTON TYPE	2 PRESS LINE 1 CASE DRAIN	10μ NOM WIREMESH	22	YES	5.6
			FLIGHT CONTROL	3000	5.8	1 VARIABLE-VOL PISTON TYPE	2 PRESS LINE 1 CASE DRAIN	10μ NOM WIREMESH	3	YES	3.5
A5A (A3J-1)	3	1	#1	3000	30	2 VARIABLE-VOL PISTON TYPE	1-PRESS LINE 1-SYST. RET. 1-BRAKE RET. 1-CASE DRAIN	10μ NOM WIREMESH	11	YES	4
			#2	3000	30	2 VARIABLE-VOL PISTON TYPE	1 PRESS LINE 1 SYST RET 1 CASE DRAIN	10μ NOM WIREMESH	52	YES	6
F4B (F4H-1)	7	3	UTILITY	3000	30	2 VARIABLE-VOL PISTON TYPE	1-PRESS LINE 1-RETURN LINE 1-CASE DRAIN 1-AIRDUCT SYST	10μ NOM WIREMESH	30	YES	5
			P.C. #1 OR P.C. #2 △	3000	26	1 VARIABLE-VOL PISTON TYPE	2-PRESS LINE 1-RETURN LINE 1-CASE DRAIN 1-LATERAL SERVO	10μ NOM WIREMESH	13	NO	4.4

FIGURE 3
SHEET 1 OF 3

FORM 30-250 (7-51)

FIGURE 3
SHEET 2 OF 3

AIRCRAFT HYDRAULIC SYSTEM SAMPLING DATA & DESIGN INFORMATION

AIRCRAFT MODEL	NUMBER TESTED	NUMBER OF BASES	SYSTEM DESIGN INFORMATION: SYSTEM NAME	SYSTEM PRESS (PSI)	MAX FLOW (GPM)	NUMBER & TYPE OF PUMPS	HYDRAULIC FILTERS: LOCATION	HYDRAULIC FILTERS: TYPE	NO. △ OF ACTUATORS	ELECTRO-HYDRAULIC SERVOS	APPROX A/C CONTAMINATION LEVEL (REF)
F6A (F4D-1)	3	1	UTILITY	3000	5.4	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE	10µ PAPER	28	NO	5
			ELEVON	3000	5.2	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE 1-YAW DAMPER	10µ PAPER 2µ PAPER	3	YES	4.7
F8A F8E (F8U-1) (F8U-2NE)	9	3	UTILITY	3000	16.5	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE 1-CASE DRAIN 1-N.G. STEERING	5µ SINTERED 10µ MESH MAGNETIC	25	YES	4.7
			POWER CONTROL #2 △	3000	12	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE 1-CASE DRAIN	5µ SINTERED 10µ MESH	7	YES	3.9
AF-9J TF-9J (F9F-8B) (F9F-8T)	3	1	UTILITY	1500	14.5	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE 1-STAB. ACT. LINE	10µ PAPER 10µ PAPER	33	NO	3.7
F11A (F-11F-1)	3	1	UTILITY	3000	9	1 VARIABLE-VOL PISTON TYPE	1 PRESS LINE 1 CASE DRAIN	10µ PAPER 10µ PAPER	26	YES (STEER-DAMPER)	3.7
SH-34G SH-34J (HSS-1) (HSS-1N)	2	2	PRIMARY	1500	5.5	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE	10µ PAPER	3	NO	3
			AUXILARY	1500	5.5	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE	10µ PAPER	4	NO	
SH-3A (HSS-2)	3	1	UTILITY	3000	—	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE (UTIL MANIFOLD)	10µ PAPER	10	NO	4
			PRIMARY	3000	—	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE	10µ PAPER	6	YES	6.

FORM 30-250V (7-51)

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AIRCRAFT HYDRAULIC SYSTEM SAMPLING DATA & DESIGN INFORMATION

AIRCRAFT MODEL	NUMBER TESTED	NUMBER OF BASES	SYSTEM DESIGN INFORMATION: SYSTEM NAME	SYSTEM PRESS (PSI)	MAX FLOW (GPM)	NUMBER & TYPE OF PUMPS	HYDRAULIC FILTERS: LOCATION	HYDRAULIC FILTERS: TYPE	NO. △ OF ACTUATORS	ELECTRO-HYDRAULIC SERVOS	APPROX A/C CONTAMINATION LEVEL (REF)
T1A (T2V-1)	1	1	UTILITY	1500	8.3	1 VARIABLE-VOL PISTON TYPE	1 PRESS LINE	10μ PAPER	24	No	7
T2A (T2J-1)	3	1	UTILITY	3000	2.4	1 VARIABLE-VOL PISTON TYPE	1-PRESS LINE 1-RETURN LINE 1-ELEV VALVE IN	10μ PAPER	9	No	3.3
P2E (P2V-5F)	4	2	UTILITY	1500	4	2 FIXED VOL GEAR TYPE	1-PRESS LINE 1-RESERVOIR	10μ PAPER	21	No	3.1 (P2E and P2H)
P2H (P2V-7)	9	4	UTILITY	3000	7.5	2 VARIABLE VOL PISTON TYPE	1 PRESS LINE 1-RESERVOIR	10μ PAPER	21	No	
E1B (WF-2)	3	1	UTILITY	1500	24	2 VARIABLE-VOL PISTON TYPE	2-PRESS LINE 2-RUDDER MECH	10μ PAPER	21	No	5.3
S2A, S2E (S2F-1) (S2F-3S)	7	3	UTILITY	1500 (3000)	20	2 VARIABLE-VOL PISTON TYPE	2 PRESS LINE 1-RUDDER TRIM (S2E ONLY)	10μ PAPER 10μ PAPER	60 (32 W.F. LOCK CYLS)	No	4.9 (S2A, S2E and EC-1A)
EC-1A (TF-1Q)	1	1	UTILITY	1500 (3000	20	2 VARIABLE-VOL PISTON TYPE	2-PRESS LINE	10μ PAPER	55 (32 W.F. LOCK CYLS)	No	
EC-121K (WV-2)	2	1	UTILITY	1700	48	4 VARIABLE-VOL PISTON TYPE	4-PRESS LINE 2-RETURN LINE	.005 METAL 10μ PAPER	25	No	2.5

NOTES:
1. △ APPROX COUNT - INCLUDES HYDRAULIC MOTORS
2. △ POWER CONTROL # 1 NOT TESTED DUE TO ACCESSIBILITY
3. △ EQUIVALENT SYSTEMS - ONLY ONE TESTED

FIGURE 3
SHEET 3 OF 3

FORM 30-250 (7-51)

COMPOSITE DATA TABLE

FIGURE 4 (SHEET 1 OF 6)

SAMPLE NO	BASE LOCATION	ACTIVITY	ACFT MODEL	BU/NO	HYDRAULIC SYSTEM	DATE TAKEN (1962)	FLIGHT HOURS TOTAL	FLIGHT HOURS SINCE PAR	VISCOSITY	NEUTRALIZATION NO	PARTICLE COUNT / 100 CC 5-15µ	15-25µ	25-50µ	50-100µ	100+µ	BACKGROUND COLOR	CONTAM CLASS	EMISSION SPECTROGRAPH ANALYSIS	REMARKS	SAMPLE NO
1	NAS Norfolk	VFAW-3	F6A	134826	ELEVON	10-11	1273		—	—	18000	2700	2000	171	23	VERY LIGHT TAN	5			1
2	"	VFAW-3	"	"	UTILITY	10-11	"		—	—	36000	2400	600	57	57	MEDIUM GRAY	5+		PACKED BELOW 5µ METALLIC PARTICLES 7X	2
3	"	VFAW-3	F6A	139171	ELEVON	10-11	1307		—	—	10,000	1400	1000	57	57	VERY LIGHT TAN	4+			3
4	.	VFAW-3	"	"	UTILITY	10-11	"		—	—	34,000	5400	104	57	52	MEDIUM GRAY	4+		PACKED BELOW 5µ METALLIC PARTICLES AT 7X	4
5	"	VFAW-3	F6A	134921	ELEVON	10-11	1258		—	—	11700	2100	1500	57	12	VERY LIGHT GRAY	4		FEW VISIBLE BLACK PARTICLES	5
6	"	VFAW-3	"	"	UTILITY	10-11	"		—	—	12000	1440	500	66	13	LIGHT GRAY	3+			6
7	"	VAW-11	E1B	148903	UTILITY	10-12	751		—	—	76000	5400	1500	500	42	DARK GRAY	5		PACKED BELOW 5µ	7
8	"	VAW-11	E1B	148900	UTILITY	10-12	884		—	—	COULDN'T COUNT				16	—	7	MAJOR: Si MINOR: Cu, Ca, Fe, Al, Ti	RESINOUS PARTICLES & METALLIC CHIPS	8
9	"	VAW-11	E1B	147228	UTILITY	10-12	1334		—	—	10,000	1260	360	36	20	MEDIUM GRAY	3+		ABOUT 70CC SAMPLE FEW BLACK & METALLIC PARTICLES AT 7X	9
10	"	VS-41	S2A	136585	UTILITY	10-12	2584		—	—	17,000	1000	300	57	17	DARK GRAY	3+		FEW BLACK & METALLIC PARTICLES AT 7X	10
11	"	VS-41	S2A	136590	UTILITY	10-12	1844		—	—	4412	360	134	57	27	LIGHT GRAY	3+			11
12	"	VS-41	S2E	149258	UTILITY	10-12	55		—	—	14000	7200	700	36	42	MEDIUM GRAY	4+		METALLIC PARTICLES AT 7X	12
13	"	VU-7	F8A	145384	P.C. 2	10-15	1035		—	—	60,000	6000	3000	171	37	MEDIUM GRAY	5		FEW METALLIC PARTICLES AT 7X	13
14	"	VU-7	"	"	UTILITY	10-15	"		—	—	27000	2000	27	16	2	DARK GRAY	2+		PACKED BELOW 5µ	14
15	"	VU-7	F8A	142412	UTILITY	10-15	1260		—	—	9000	2000	400	16	5	LIGHT GRAY	3			15
16	"	VU-7	"	"	P.C. 2	10-15	"		—	—	9000	3000	300	16	6	MEDIUM GRAY	3			16
17	"	VU-7	F8A	143795	P.C. 2	10-15	1045		—	—	18000	2700	59	16	11	LIGHT GRAY	3			17
18	"	VU-7	"	"	UTILITY	10-15	"		—	—	COULDN'T COUNT			34	22	DARK GRAY	7	MAJOR: Si MINOR: Cu, Ca, Fe, Al		18
19	"	VP31	P2H	135569	UTILITY	10-15	270		—	—	4412	320	44	21	22	CLEAN	2+			19
20	"	VP31	P2H	145910	UTILITY	10-16	—		—	—	16000	2700	74	66	17	VERY LIGHT GRAY	3+		BLACK PARTICLES AT 7X	20
21	NAAS Ream	HS-8	SH34J	148958	AUXILIARY	10-16	128		—	—	9000	800	15	21	11	CLEAN	2+			21
22	"	HS-8	"	"	PRIMARY	10-16	"		—	—	6000	170	1	7	3	CLEAN	1+			22
23	NAS Miramar	VF-124	F8A	143714	P.C. 2	10-17	1375		—	—	22000	4000	134	11	17	LIGHT TO MEDIUM GRAY	3+			23
24	"	VF-124	"	"	UTILITY	10-17	"		—	—	COULDN'T COUNT			11	15	DARK GRAY	7	MAJOR: Si, Cu, Fe MINOR: Ca, Ti, Al	RESINOUS PARTICLES AND METALLIC CHIPS	24

COMPOSITE DATA TABLE

FIGURE 4 (SHEET 2 OF 6)

SAMPLE NO	BASE LOCATION	ACTIVITY	ACFT MODEL	BuNo	HYDRAULIC SYSTEM	DATE TAKEN (1962)	FLIGHT HOURS TOTAL	FLIGHT HOURS SINCE PAR	VISCOSITY	NEUTRALIZATION No	PARTICLE COUNT / 100 CC 5-15µ	15-25µ	25-50µ	50-100µ	100+µ	BACKGROUND COLOR	CONTAM CLASS	EMISSION SPECTROGRAPH ANALYSIS	REMARKS (µ = MICRONS)	SAMPLE No
25	NAS MIRAMAR	VF-124	F8A	145387	UTILITY	10-17	1103		—	—	9000	4500	49	31	17	MEDIUM TO DARK GRAY	3+		METALLIC PARTICLES AT 7X	25
26	"	VF-124	"	"	P.C 2	10-17	"		—	—	8000	2000	9	31	27	MEDIUM GRAY	3+		FEW METALLIC PARTICLES AT 7X	26
27	"	VF-124	F8E	149169	P.C. 2	10-17	327		—	—	4000	3200	540	111	57	MEDIUM GRAY	4+			27
28	"	VF-124	"	"	UTILITY	10-17	"		—	—	4500	3600	104	63	57	LIGHT TO MEDIUM GRAY	4+		FEW METALLIC PARTICLES AT 7X	28
29	"	VF-121	F4B	148397	UTILITY	10-17	214		—	—	200,000	29,000	5000	115	9	LIGHT GRAY	6+		PACKED BELOW 5µ	29
30	"	VF-121	"	"	P.C. 2	10-17	"		—	—	45,000	12000	2000	91	17	LIGHT GRAY	5		APPEARANCE OF SAND AT 7X PACKED BELOW 5µ	30
31	NAS WHIDBEY	VAH-2	A3B	147649	UTILITY	10-19	1237	505	—	—	COULDN'T		COUNT		151	DARK GRAY	7		APPEARED TO BE WHITE PAINT, LIGHT COLORED PLASTICS, METAL CHIPS	31
32	"	VAH-2	"	"	SURF CONT	10-19	1237	505	—	—	50,000	12000	5000	330	78	MEDIUM GRAY	6	MAJOR: SN, SI MINOR: Fe, Si, Al, Cu, Ag, Zn	MANY METALLIC AND BLACK PARTICLES AT 7X PACKED BELOW 5µ	32
33	"	VAH-2	"	"	AILERON	10-19	1237	505	—	—	12,000	5000	1000	41	25	LIGHT GRAY	4			33
34	"	VAH-2	A3B	147648	UTILITY	10-19	1224	509	—	—	180,000	9000	104	41	12	DARK BROWN TO BLACK	5+		PACKED BELOW 5µ	34
35	"	VAH-2	"	"	SURF CONT	10-19	1224	509	—	—	30,000	3600	350	43	2	LIGHT GRAY	3+		FEW ASSORTED PARTICLES AT 7X	35
36	"	VAH-2	"	"	AILERON	10-19	1224	509	—	—	41,500	3800	184	51	27	LIGHT GRAY	5			36
37	"	VAH-2	TEST STAND	REDCO TOOL DIV S/N 8165-69		10-19	—	—	—	—	180,000	2000	64	71	7	DARK GRAY	5+		METALLIC PARTICLES AT 7X PACKED BELOW 5µ	37
38	"	VAH-123	A3A	135418	UTILITY	10-19	2365	418	—	—	2000	900	24	51	12	LIGHT GRAY	2+		FEW VISIBLE BLACK PARTICLES	38
39	"	VAH-123	"	"	SURF CONT	10-19	2365	418	—	—	572	90	14	0	0	LIGHT GRAY	0		FEW BLACK PARTICLES AT 7X	39
40	"	VAH-123	"	"	AILERON	10-19	2365	418	—	—	22000	1800	25	17	10	CLEAN	3			40
41	"	VAH-123	TEST STAND	REDCO TOOL DIV MODEL 10908 S/N B16139		10-19	NEW	NEW	—	—	13500	1600	54	37	11	LIGHT GRAY	3		FEW VISIBLE BLACK PARTICLES	41
42	"	VP-1	P2H	135580	UTILITY	10-19	4548	1014	—	—	7200	1400	108	8	9	CLEAN	2+		FEW BLACK PARTICLES AT 7X	42
43	"	VP-1	P2H	145913	UTILITY	10-19	2674	782	—	—	1100	150	4	0	0	CLEAN	0			43
44	"	VP-17	P2H	135614	UTILITY	10-19	4023	145	—	—	542	290	24	0	0	CLEAN	0			44
45	NAS QUONSET	VAW-33	EC-1A	136788	UTILITY	10-30	2549	273	11.1	.084	300,000	8000	8000	2500	370	DARK GRAY	7	MAJOR: Fe, Si, Cr, Al, Zn MINOR: Mo, Cd, Sn, Ag	MANY BLACK PARTICLES AT 7X	45
46	"	NAS QUONSET	T1A	142539	UTILITY	10-30	844	86	—	—	36000	14000	1000	600	124	VERY LIGHT GRAY	6+		MANY VISIBLE BLACK PARTICLES	46
47	"	"	TEST STAND	GREER HYDRAULICS MODEL PC-3C-10V-H S/N FF-2032		10-31	—	—	—	—	18000	2200	284	141	47	MEDIUM GRAY	4+		FEW VISIBLE BLACK PARTICLES	47
48	"	"	FILL STAND	HANDPUMP STAND AN6235-3 FILTER		10-31	—	—	—	—	180000	45000	11000	1300	52	VERY LIGHT GRAY	7		MANY VISIBLE BLACK PARTICLES	48

COMPOSITE DATA TABLE

FIGURE 4 (SHEET 3 OF 6)

SAMPLE NO	BASE LOCATION	ACTIVITY	ACFT MODEL	BuNo	HYDRAULIC SYSTEM	DATE TAKEN (1962)	FLIGHT HOURS TOTAL	FLIGHT HOURS SINCE PAR	VISCOSITY	NEUTRALIZATION No	PARTICLE COUNT / 100 CC 5-15μ	15-25μ	25-50μ	50-100μ	100+μ	BACKGROUND COLOR	CONTAM CLASS	EMISSION SPECTROGRAPH ANALYSIS	REMARKS	SAMPLE NO
49	NAS QUONSET	NATU	SH-34G	138479	AUXILARY	10-31	1954	420	—	—	4500	1800	64	61	8	CLEAN	3			49
50	"	NATU	"	"	PRIMARY	10-31	1954	420	11.3	.090	3600	1800	150	83	28	CLEAN	3+		ASSORTED PARTICLES AT 7K	50
51	"	VA-46	A4C	148532	UTILITY	10-31	583	NEW	—	—	34000	4000	1500	340	29	MEDIUM GRAY	5		MANY METALLIC PARTICLES AT 7K FIRST RUN AFTER PAR	51
52	"	NATU	S2A	133219	UTILITY	10-31	2583	180	11.4	.087	1800	70	49	32	11	MEDIUM GRAY	2+			52
53	NAS PAX RIV	WST	P2H	140469	UTILITY	11-6	3228	240	—	—	35000	2000	600	500	190	CLEAN	6+		VISIBLE BLACK PARTICLES	53
54	"	WST	EC-121K	135753	UTILITY	11-6	3000	216	12.3	.073	1420	570	24	36	4	CLEAN	2		FEW VISIBLE BLACK PARTICLES	54
55	"	NATC	P2E	124896	UTILITY	11-6	4221	118	13.5	.078	2400	90	44	36	27	VERY LIGHT GRAY	3+			55
56	"	NATC	EC-121K	135750	UTILITY	11-6	4205	263	12.9	.073	2000	70	24	7	11	LIGHT GRAY	2+		-	56
57	NAS OCEANA	VU-2	F8A	143738	UTILITY	11-7	1021	230	11.7	.073	60,000	1400	49	36	9	MEDIUM GRAY	3+	MAJOR: Fe, Cr, Al, Si, Mg, Zn MINOR: Mn, Cd, Sn	METALLIC CHIPS AT 7K PACKED BELOW 5μ	57
58	"	VU-2	"	"	PC-2	11-7	1021	230	—	—	23000	1200	234	32	20	MEDIUM GRAY	3+	MAJOR: Fe MINOR: Si, Cr, Al	PACKED BELOW 5μ	58
59	"	VU-2	F8A	141354	UTILITY	11-7	799	127	11.4	.067	12,000	1000	59	26	12	MEDIUM GRAY	3+		METALLIC CHIPS AT 7K PACKED BELOW 5μ	59
60	"	VU-2	"	"	PC-2	11-7	799	127	9.4	.070	4000	70	34	14	5	LIGHT GRAY	1+			60
61	"	VU-2	FILL STAND	ALEMITE AN 6235	MOD 7181-3A FILTER	11-7	—	—	13.4	.067	912	34	9	0	0	CLEAN	0	—	—	61
62	"	NATC	NEW OIL	FROM 1 GT	CAN	11-7	—	—	14.5	.084	—	—	—	—	—	—	—	—	MEET ALL NEW OIL SPECIFICATIONS	62
63	"	VF-10	F4B	150418	UTILITY	11-8	91	—	11.0	.073	35000	1400	34	44	29	LIGHT GRAY	5			63
64	"	VF-101	"	"	PC-1	11-8	91	-	11.0	.064	32000	370	134	5	9	LIGHT GRAY	3+	-		64
65	"	VF-101	F4B	148372	UTILITY	11-8	351	-	10.7	.067	15000	2000	134	38	14	MEDIUM GRAY	3+		METALLIC CHIPS AT 7K PACKED BELOW 5μ	65
66	"	VF-101	"	"	PC-1	11-8	351	-	10.9	.078	72,000	2400	64	16	0	MEDIUM GRAY	4+	MAJOR: Sn MINOR: Fe, Al, Cd, Cu, Zn.	PACKED BELOW 5μ	66
67	"	VF-101	F4B	150422	UTILITY	11-8	18	-	10.9	.067	13500	3600	900	58	25	MEDIUM GRAY	4+		PACKED BELOW 5μ	67
68	"	VF-101	"	"	PC-1	11-8	18	-	10.8	.078	13500	1500	300	66	30	LIGHT GRAY	4+		METALLIC CHIPS AT 7K PACKED BELOW 5μ	68
69	"	VF-101	TEST STAND	BEACON STEEL CO MOD 1141 S/N 137	-GF	11-8	—	—	—	—	4800	270	44	1	0	LIGHT GRAY	1			69
70	"	VF-101	TEST STAND	BEACON STEEL CO MOD 114 S/N 20	14-F	11-8	—	—	—	—	1200	120	34	32	12	LIGHT GRAY	3			70
71	"	VA-66	A4C	148466	UTILITY	11-8	749	176	10.3	.073	93000	4900	460	330	40	MEDIUM GRAY	5+		PACKED BELOW 5μ	71
72	"	VA-66	"	"	FLT CONT	11-8	749	176	—	—	19000	1000	180	3	11	LIGHT GRAY	3			72

COMPOSITE DATA TABLE — FIGURE 4 (SHEET 4 OF 6)

SAMPLE NO	BASE LOCATION	ACTIVITY	ACFT MODEL	BuNo	HYDRAULIC SYSTEM	DATE TAKEN (1962)	FLIGHT HOURS TOTAL	FLIGHT HOURS SINCE PAR	VISCOSITY	NEUTRALIZATION NO	PARTICLE COUNT / 100 CC 5-15μ	15-25μ	25-50μ	50-100μ	100+μ	BACKGROUND COLOR	CONTAM CLASS	EMISSION SPECTROGRAPH ANALYSIS	REMARKS (μ = MICRONS)	SAMPLE No
73	NAS OCEANA	VA-43	A4C	147843	FLT CONT	11-8	747	217	—	—	18000	600	19	5	15	MEDIUM GRAY	3+			73
74	"	VA-43	"	"	UTILITY	11-8	747	217	11.3	.074	72,000	4800	900	111	26	DARK GRAY	5		PACKED BELOW 5μ	74
75	"	VA-43	A4B	145060	UTILITY	11-8	765	174	—	—	60,000	8000	1500	700	110	MEDIUM GRAY	6		PACKED BELOW 5μ METALLIC & BLACK PARTICLES AT 7X	75
76	"	VA-43	"	"	FLT CONT	11-8	765	174	—	—	4200	70	14	0	0	LIGHT GRAY	1			76
77	"	VA-43	TEST STAND	REDCO TOOL DIV EQ W. BENDIX	2 MICRON FILTER	11-8	—	—	—	—	1430	90	34	86	16	MEDIUM GRAY	3+		PACKED BELOW 5μ	77
78	"	VU-2	F8A	145348	P.C. 2	11-8	1215	145	—	—	45000	1500	284	190	6	MEDIUM GRAY	4+	MAJOR: Fe, Al, Cu MINOR: Mn, S, Cr, Cd, Y, Sn	PACKED BELOW 5μ	78
79	"	VU-2	"	"	UTILITY	11-8	1215	145	—	—	70,000	3600	450	270	32	DARK GRAY	5	MAJ: Zn, Fe, Cr, Al, Mg, Cd MIN: Si, Mn, V, Cu	PACKED BELOW 5μ METALLIC PARTICLES AT 7X	79
80	NAS JAX	VAP-62	RA-3B	144841	AILERON	11-13	1023	334	—	—	912	220	104	81	9	LIGHT GRAY	2+			80
81	"	VAP-62	"	"	SUR CONT	11-13	1023	334	10.4	.067	46000	1800	300	9	12	LIGHT GRAY	4+			81
82	"	VAP-62	"	"	UTILITY	11-13	1023	334	9.6	.084	21000	690	59	71	5	LIGHT GRAY	3			82
83	"	VAP-62	RA-3B	144829	AILERON	11-13	670	70	—	—	9600	370	9	0	0	CLEAN	1+			83
84	"	VAP-62	"	"	UTILITY	11-13	670	70	10.7	.087	17000	570	104	61	52	LIGHT GRAY	4+			84
85	"	VAP-62	"	"	SUR CONT	11-13	670	70	10.7	.090	44000	510	124	0	1	LIGHT GRAY	4+		PACKED BELOW 5μ FEW METAL PARTICLES AT 7X	85
86	"	VAP-62	RA-3B	144837	UTILITY	11-13	1031	399	10.3	.078	40800	1380	304	231	63	MEDIUM GRAY	5+		PACKED BELOW 5μ METALLIC PARTICLES AT 7X	86
87	"	VAP-62	"	"	SUR CONT	11-13	1031	399	9.1	.090	24000	1700	84	74	27	LIGHT GRAY	3+		PACKED BELOW 5μ FEW METALLIC CHIPS AT 7X	87
88	"	VAP-62	"	"	AILERON	11-13	1031	399	—	—	30000	4000	2000	1000	119	LIGHT GRAY	6+	MAJOR: Fe, Cd, Cu, Zn MINOR: Mn, Cr, Sn	PACKED BELOW 5μ METALLIC PARTICLES AT 7X	88
89	"	VAP-62	FILL STAND	LOCAL MANUF AN6235	-3A FILTER (30 CC CHANGE)	11-13	—	—	—	—	40,000	2400	224	9	9	LIGHT GRAY	3+			89
90	"	VAP-62	TEST STAND	GREER S/N FF COMMERCIAL	PC3C-10WH 2166 10M FILTER	11-13	—	—	—	—	2800	94	44	17	11	LIGHT GRAY	2+			90
91	"	VP-30	P2H	143174	UTILITY	11-13	2903	762	12.4	.073	812	90	29	17	7	CLEAN	2+			91
92	"	VP-30	P2H	140984	UTILITY	11-13	3611	62	12.6	.070	512	70	34	15	11	CLEAN	2+			92
93	"	VP-30	P2H	141238	UTILITY	11-13	3135	93	12.6	.076	1160	40	54	21	22	CLEAN	3+			93
94	"	VP-30	TEST STAND	HENRY MOD 9 S/N 6	SPEN ECO 0625 25-32	11-13	—	—	—	—	1700	120	54	21	39	CLEAN	4+			94
95	NAS CECIL	VA-46	A4C	147741	UTILITY	11-14	805	418	12.1	.081	120,000	4500	500	400	42	MEDIUM GRAY	5+	MAJOR: Fe, Cr, Cd, Cu, Zn. MINOR: Mn, Si, Al, Ca, Mg.	PACKED BELOW 5μ METALLIC PARTICLES AT 7X	95
96	"	VA-46	"	"	SUR. CONT	11-14	805	418	—	—	3000	320	104	76	37	MEDIUM GRAY	4+		PACKED BELOW 5μ METALLIC PARTICLES AT 7X	96

FIGURE 4 (SHEET 5 OF 6)

COMPOSITE DATA TABLE

SAMPLE NO	BASE LOCATION	ACTIVITY	ACFT MODEL	BuNo	HYDRAULIC SYSTEM	DATE TAKEN (1962)	FLIGHT HOURS TOTAL	FLIGHT HOURS SINCE PAR	VISCOSITY	NEUTRALIZATION NO.	PARTICLE COUNT /100 CC 5-15μ	15-25μ	25-50μ	50-100μ	100+μ	BACKGROUND COLOR	CONTAM CLASS	EMISSION SPECTROGRAPH ANALYSIS	REMARKS	SAMPLE NO
97	NAS CECIL	VA-46	A4C	147748	UTILITY	11-14	1013	454	11.2	0.076	12,000	6000	1800	160	42	DARK GRAY	5+		PACKED BELOW 5μ FEW METALLIC PARTICLES AT 7X	97
98	"	"	"	"	SURF. CONT	11-14	1013	454	—	—	2400	270	59	16	14	LIGHT GRAY	3+			98
99	"	VA-106	A4B	144900	SURF. CONT.	11-14	1756	509	—	—	1420	90	64	61	39	VERY LIGHT GRAY	4+			99
100	"	"	"	"	UTILITY	11-14	1756	509	11.8	0.073	18000	4200	1800	460	410	LIGHT GRAY	6+		BLACK PARTICLES VISIBLE METALLIC PARTICLES AT 7X	100
101	NAS SANFORD	VAH-3	A5A	149286	#1	11-15	82	-	—	—	450,000	9000	900	14	7	DARK GRAY	6+	MAJOR: Fe, Cr, Sn, Cu, Ag MINOR: Al	PACKED BELOW 5μ, METALLIC PARTICLES AT 7X	101
102	"	"	"	"	#2	11-15	82	-	12.6	0.087	36000	4200	720	41	7	LIGHT GRAY	3+		BLACK & METALLIC PARTICLES AT 7X	102
103	"	"	A5A	148925	#1	11-15	346	-	11.7	0.078	15000	170	44	16	13	DARK GRAY	3+		PACKED BELOW 5μ	103
104	"	"	"	"	#2	11-15	346	-	11.5	0.062	12000	2500	59	31	22	LIGHT GRAY	3+			104
105	"	"	A5A	148258	#1	11-15	294	-	—	—	300,000	4500	2000	171	17	DARK GRAY	6+	MAJOR: Sn, Cu, Ag, Be MINOR: Fe, Cr, Al, Cd		105
106	"	"	"	"	#2	11-15	294	-	11.4	0.056	34000	1080	224	91	16	LIGHT GRAY	4			106
107	"	"	A3A	135425	UTILITY	11-15	2310	493	10.9	0.059	130,000	11,600	2400	870	360	DARK GRAY	6+	MAJOR: Al, Fe, Si, Mg, Ca MINOR: Cr, Cu, Ti, Ni	PACKED BELOW 5μ MANY METALLIC PARTICLES AT 7X	107
108	"	"	"	"	SURF. CONT	11-15	2310	493	10.8	0.073	13000	810	224	76	13	LIGHT GRAY	3			108
109	"	"	A3B	138932	UTILITY	11-15	852	9	11.5	0.070	97000	24000	6000	4500	250	LIGHT GRAY	7	MAJOR: Al, Fe, Si, Mg, Ca MINOR: Cr, Cu, Ti, Ni	MANY VISIBLE METALLIC PARTICLES	109
110	"	"	"	"	SURF. CONT	11-15	852	9	11.5	0.064	132,000	11600	1800	3000	2000	LIGHT GRAY	7	MAJOR: Al, Fe, Si, Mg, Ca MINOR: Cr, Cu, Ti, Ni	PACKED BELOW 5μ VISIBLE BLACK AND METALLIC PARTICLES	110
111	"	"	A3A	135427	UTILITY	11-15	2067	200	8.5	0.059	102,000	6700	284	300	77	DARK GRAY	6	MAJOR: Al, Fe, Si, Mg, Ca MINOR: Cr, Cu, Ti, Ni	PACKED BELOW 5μ METALLIC PARTICLES AT 7X	111
112	"	"	"	"	SURF. CONT	11-15	2067	200	9.4	0.062	1412	150	44	47	16	LIGHT GRAY	3+			112
113	"	"	TEST STAND	NO NAMEPLATE. USED ON [illegible]		11-15	-	-	—	—	7000	300	104	9	13	VERY LIGHT GRAY	2+			113
114	NAS KEY WEST	VF-41	F4B	145419	UTILITY	11-16	254	-	—	—	35000	1200	164	45	13	LIGHT GRAY	4		PACKED BELOW 5μ	114
115	"	"	"	"	PC-1	11-16	254	-	—	—	27000	2000	384	74	11	LIGHT GRAY	3+		PACKED BELOW 5μ	115
116	"	"	F4B	149431	UTILITY	11-16	307	-	10.6	0.084	110,000	4200	480	86	42	LIGHT GRAY	5+		PACKED BELOW 5μ	116
117	"	"	"	"	PC-1	11-16	307	-	10.4	0.078	69000	570	104	111	36	LIGHT GRAY	5			117
118	"	"	F4B	149412	UTILITY	11-16	273		10.5	0.090	72000	1600	224	15	4	LIGHT GRAY	3+		PACKED BELOW 5μ	118
119	"	"	"	"	PC-1	11-16	273		—	—	19000	420	104	15	6	LIGHT GRAY	3			119
120	"	VP-26	P2E	131535	UTILITY	11-17	4748		13.0	0.073	27000	1300	94	23	2	CLEAN	2+			120

DOUGLAS AIRCRAFT COMPANY INC

COMPOSITE DATA TABLE

FIGURE 4 (SHEET 6 OF 6)

SAMPLE No	BASE LOCATION	ACTIVITY	ACFT MODEL	BuNo	HYDRAULIC SYSTEM	DATE TAKEN (1962)	FLIGHT HOURS TOTAL	FLIGHT HOURS SINCE PAR	VISCOSITY	NEUTRALIZATION No	PARTICLE COUNT / 100 CC 5-15μ	15-25μ	25-50μ	50-100μ	100+μ	BACKGROUND COLOR	CONTAM CLASS	EMISSION SPECTROGRAPH ANALYSIS	REMARKS	SAMPLE No
121	NAS KEY WEST	VP-26	P2E	131525	UTILITY	11-17	3652	15	13.6	.081	13000	510	84	66	5	CLEAN	3			121
122	"	VP-26	SP-2E	128363	UTILITY	11-17	4223	192	13.6	.087	8000	810	79	53	8	CLEAN	2+			122
123	"	VX-1	S2A	136463	UTILITY	11-17	3383	239	10.4	.076	24000	1400	175	71	67	LIGHT GRAY	5+			123
124	"	VX-1	S2E	149260	UTILITY	11-17	98	–	12.7	.095	26000	2900	440	341	32	DARK GRAY	5		PACKED BELOW 5μ	124
125	"	VX-1	S2D	147873	UTILITY	11-17	959	166	12.5	.084	63000	2400	520	141	18	MEDIUM GRAY	4+		PACKED BELOW 5μ	125
126	"	HS-1	SH-3A	148045	UTILITY	11-18	667	90	–	–	13000	1000	350	281	102	LIGHT GRAY	5+			126
127	"	HS-1	"	"	PRIMARY	11-18	667	90	11.0	.084	54000	6300	4200	16	13	LIGHT GRAY	5+			127
128	"	HS-1	SH-3A	148036	UTILITY	11-18	384	150	11.3	.067	10000	420	340	11	8	LIGHT GRAY	2+			128
129	"	HS-1	"	"	PRIMARY	11-18	384	150	–	–	210000	9000	3200	66	14	MEDIUM GRAY	5+	Major: Al, Fe, Si, Mg, Cu Minor: Cr, Cu, Ti, Ni	PACKED BELOW 5μ	129
130	"	HS-1	SH-3A	148974	UTILITY	11-18	318	–	11.5	.095	14700	1600	220	111	6	LIGHT GRAY	3			130
131	"	HS-1	"	148974	PRIMARY	11-18	318	–	–	–	24600	4400	2000	500	40	LIGHT GRAY	5+		SHREDDED RUBBER APPEARANCE	131
132	"	HS-1	TEST STAND	RECO-ELECTRIC 166 67 S/N [illegible]-70223		11-18	–	–	–	–	75000	1050	34	21	20	MEDIUM GRAY	4+	Major: Cu Minor: Fe, Mg, Cd Sn	PACKED BELOW 5μ	132
133	NAAS MERIDIAN	NAAS MERIDIAN	T2A	147459	UTILITY	11-19	858	342	–	–	1512	420	99	51	42	VERY LIGHT GRAY	4+			133
134	"	VT-7	T2A	148211	UTILITY	11-19	906	444	–	–	1300	85	9	5	6	VERY LIGHT GRAY	2			134
135	"	VT-9	T2A	148157	UTILITY	11-19	879	541	–	–	4300	530	84	71	13	LIGHT GRAY	3			135
136	"	VT-7	TEST STAND	GREER PC 36- S/N FE-	HYDRAULICS 10VH [illegible]24	11-19	–	–	–	–	1900	320	64	41	37	VERY LIGHT GRAY	3+			136
137	"	VT-9	TEST STAND	RECO P/N 11000C S/N B2N-2	TOOL DIV	11-19	–	–	–	–	1412	110	74	6	2	CLEAN	0+			137
138	NAAS KINGSVILLE	VT-23	F11A	141757	UTILITY	11-20	1450	341	–	–	78000	1500	500	211	2	DARK GRAY	4+	Major: Cu, Sn Minor: Fe Si, Mg, Zn	PACKED BELOW 5μ METALLIC PARTICLES AT 7X	138
139	"	VT-23	F11A	141863	UTILITY	11-20	1402	171	11.3	.062	7400	210	124	17	17	LIGHT GRAY	2+			139
140	"	VT-23	F11A	141798	UTILITY	11-20	1092	291	11.5	.067	5900	270	234	58	12	LIGHT GRAY	3			140
141	"	VT-21	AF-9J	141162	UTILITY	11-21	2049	98	12.1	.078	26000	1600	334	54	26	DARK GRAY	3+		METALLIC AND BLACK PARTICLES AT 7X	141
142	"	VT-21	TF-9J	146368	UTILITY	11-21	2469	175	11.3	.084	15000	1800	24	32	5	MEDIUM GRAY	2+		METALLIC AND BLACK PARTICLES AT 7X	142
143	"	VT-21	TF-9J	142954	UTILITY	11-21	2609	557	11.7	.090	22000	1500	94	51	34	MEDIUM GRAY	3+		METALLIC AND BLACK PARTICLES AT 7X	143
144	"	VT-21	TEST STAND	BEACON PO 14 S/N 44	STEEL CO 14F	11-21	–	–	–	–	11000	1450	294	71	67	MEDIUM GRAY	4+		METALLIC AND BLACK PARTICLES AT 7X	144

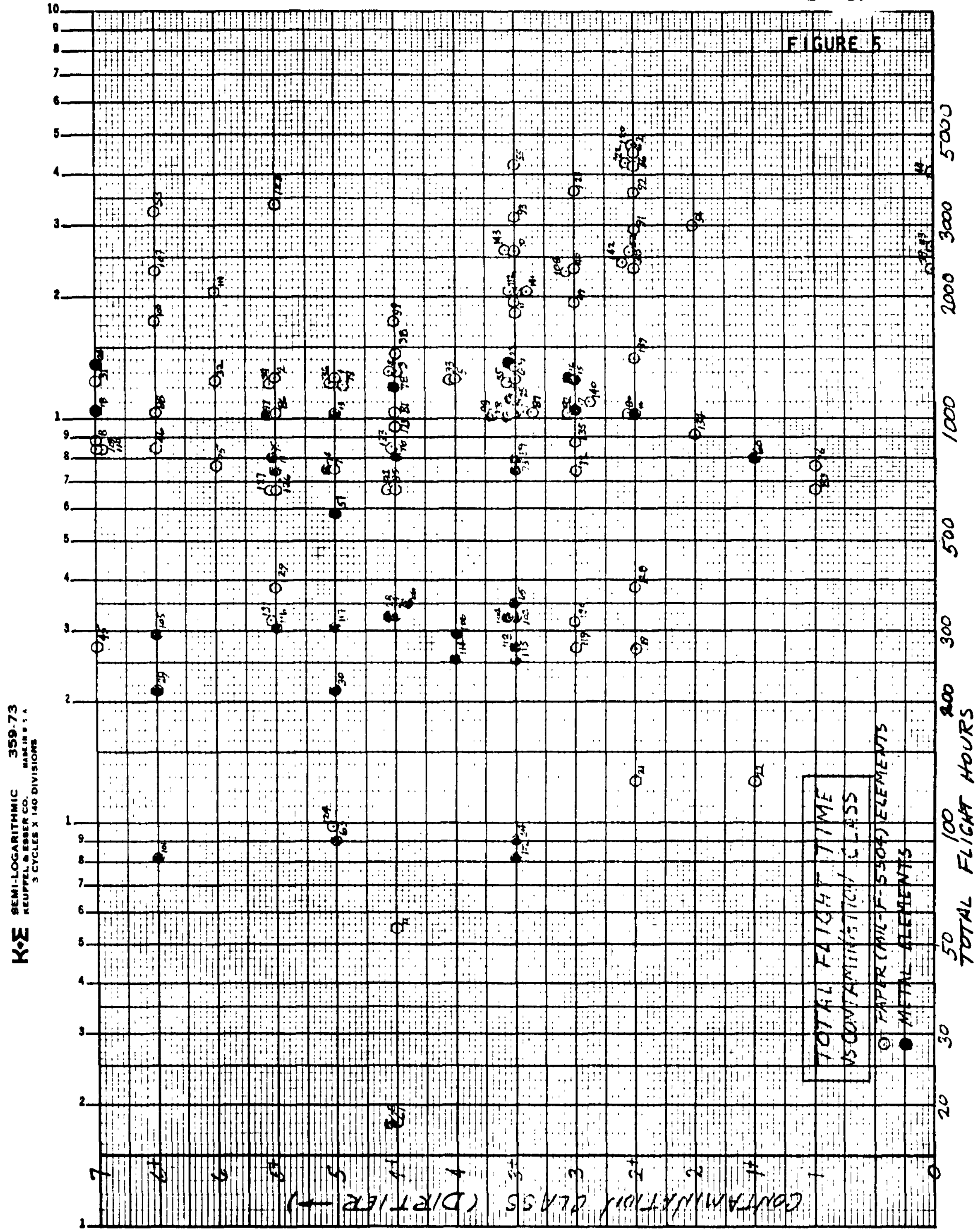


FIGURE 5
TOTAL FLIGHT TIME VS CONTAMINATION CLASS
PAPER (MIL-F-5504) ELEMENTS
METAL ELEMENTS
TOTAL FLIGHT HOURS
CONTAMINATION CLASS (DIRTIER →)
K·E SEMI-LOGARITHMIC 359-73
KEUFFEL & ESSER CO.
3 CYCLES X 140 DIVISIONS

DOUGLAS AIRCRAFT COMPANY, INC.

ADI 30-250-1 (9-51)

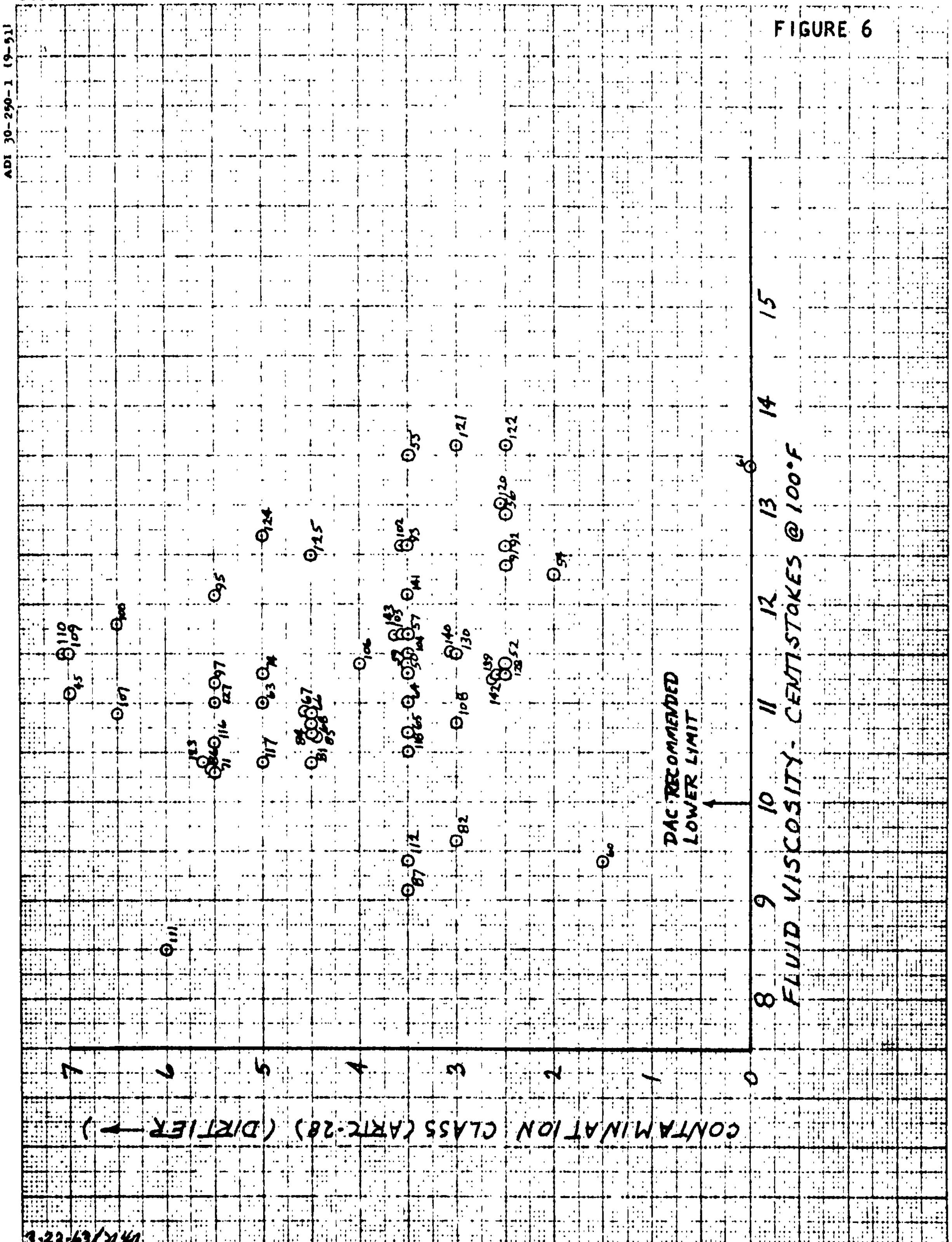


FIGURE 6

3-23-63

FIGURE 7

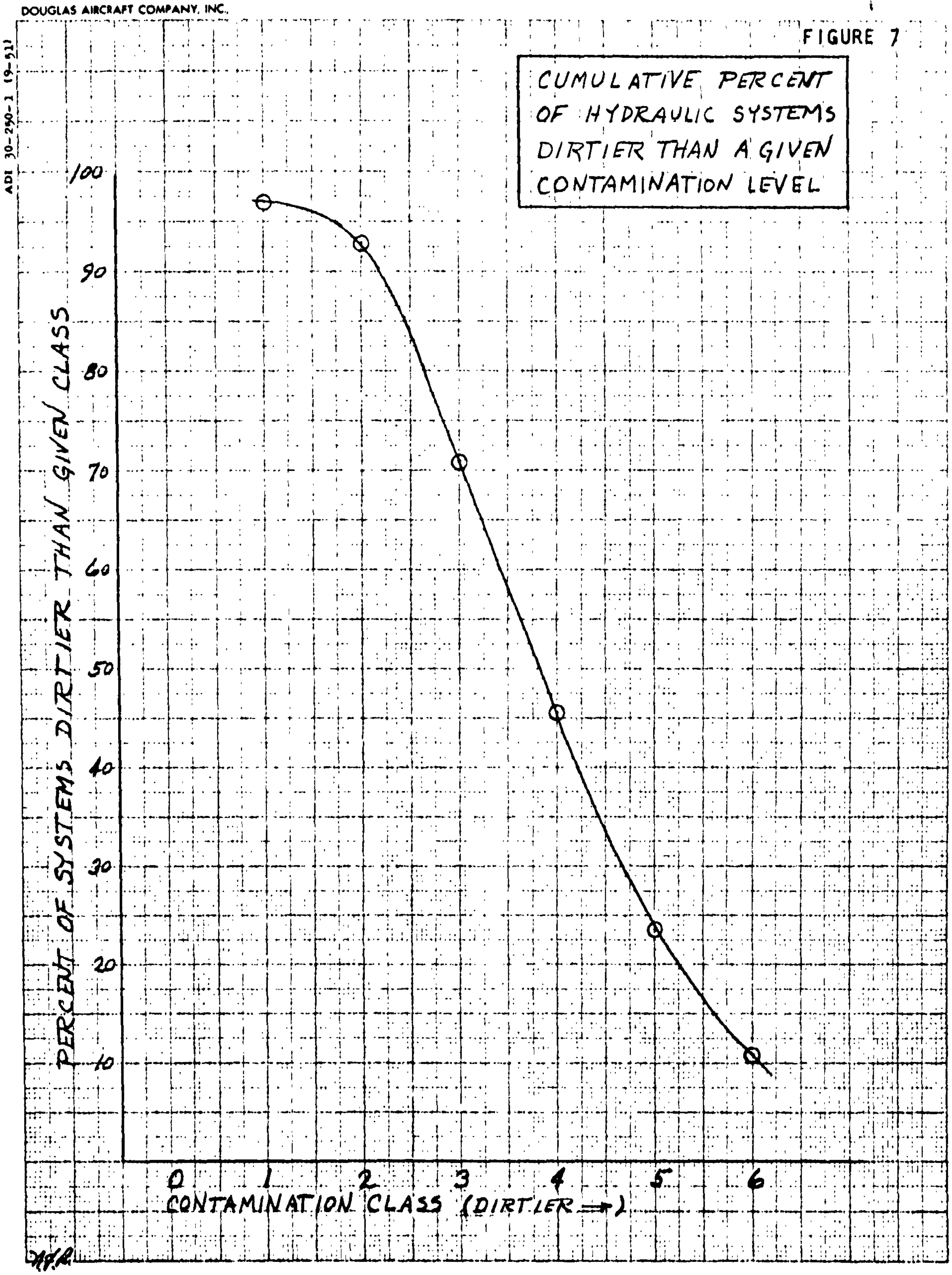
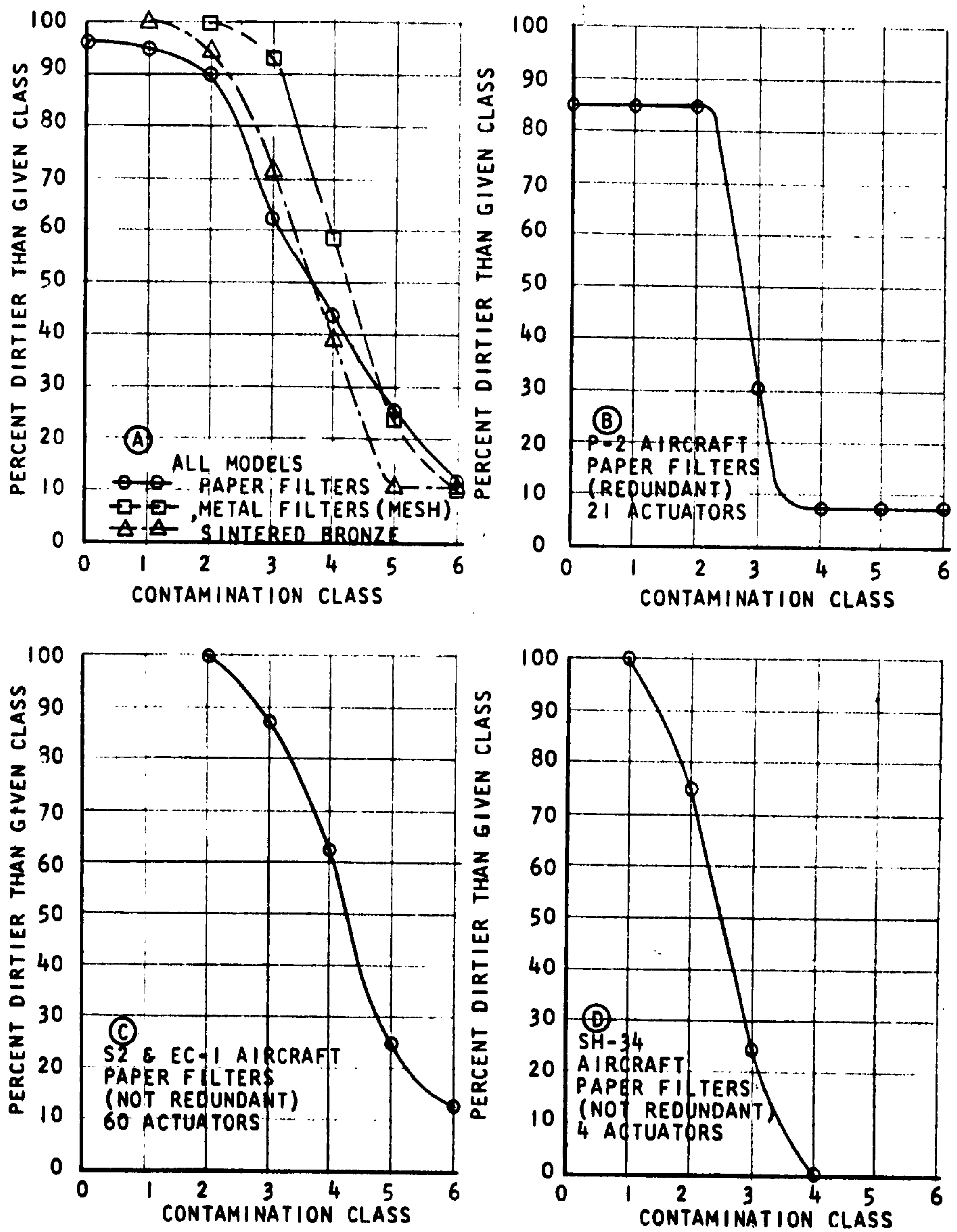
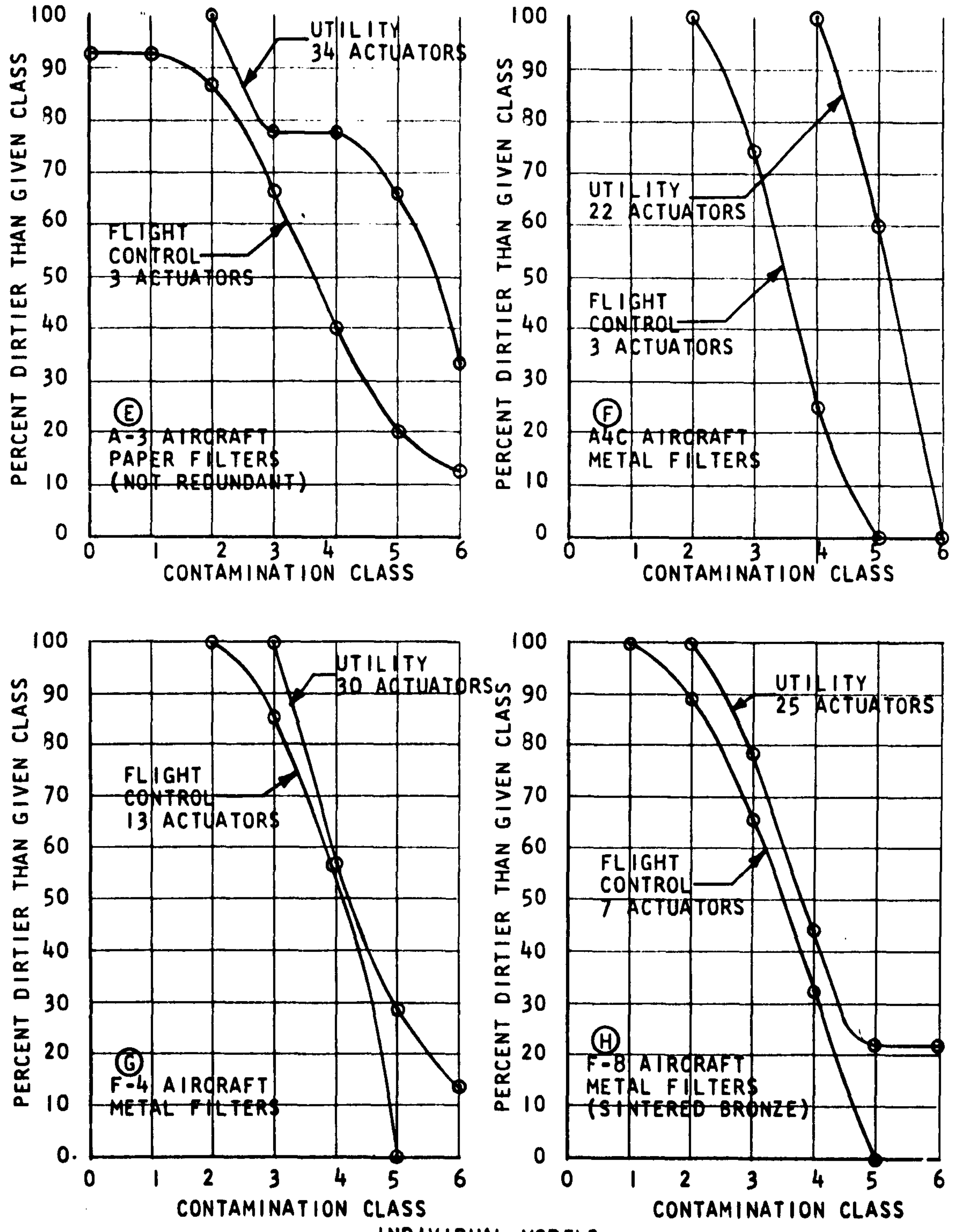

CUMULATIVE PERCENT OF HYDRAULIC SYSTEMS DIRTIER THAN A GIVEN CONTAMINATION LEVEL
PERCENT OF SYSTEMS DIRTIER THAN GIVEN CLASS
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
CONTAMINATION CLASS (DIRTIER →)

FIGURE 8
SHEET 1 OF 2



INDIVIDUAL MODELS
PERCENT OF SYSTEMS DIRTIER THAN GIVEN CLASS

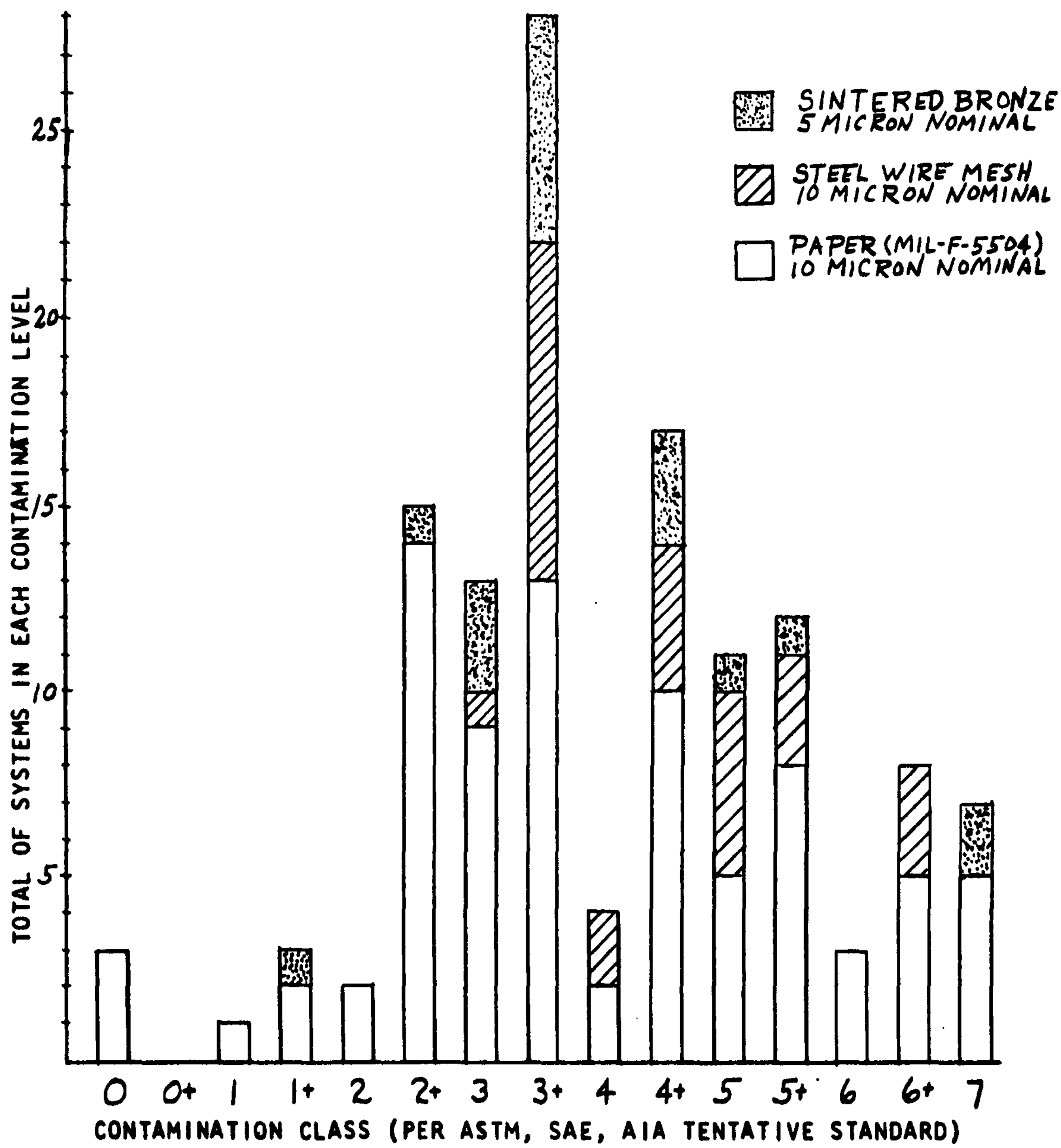
DOUGLAS AIRCRAFT COMPANY, INC. EL SEGUNDO DIVISION EL SEGUNDO, CALIFORNIA



INDIVIDUAL MODELS
PERCENT OF SYSTEMS DIRTIER THAN GIVEN CLASS

DOUGLAS AIRCRAFT COMPANY, INC. EL SEGUNDO DIVISION EL SEGUNDO, CALIFORNIA

FIGURE 9



TOTAL SYSTEMS AND TYPES
OF FILTRATION IN EACH
CONTAMINATION CLASS

FORM 30-25 (7-51)

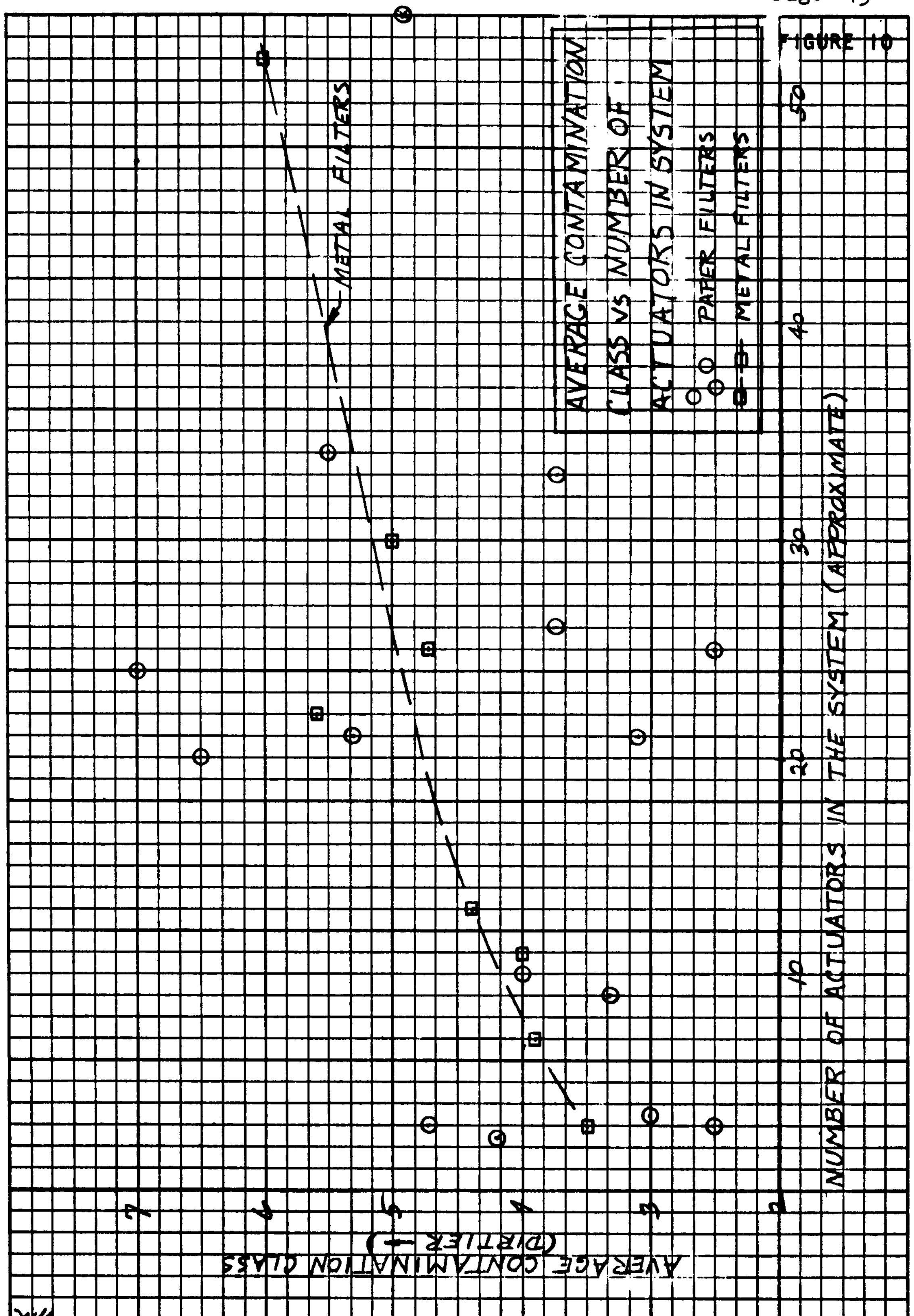

AVERAGE CONTAMINATION CLASS VS NUMBER OF ACTUATORS IN SYSTEM
PAPER FILTERS
METAL FILTERS
METAL FILTERS
NUMBER OF ACTUATORS IN THE SYSTEM (APPROXIMATE)
10
20
30
40
50
AVERAGE CONTAMINATION CLASS
(DIRTIER →)
2
3
4
5
6
7

FIGURE 10

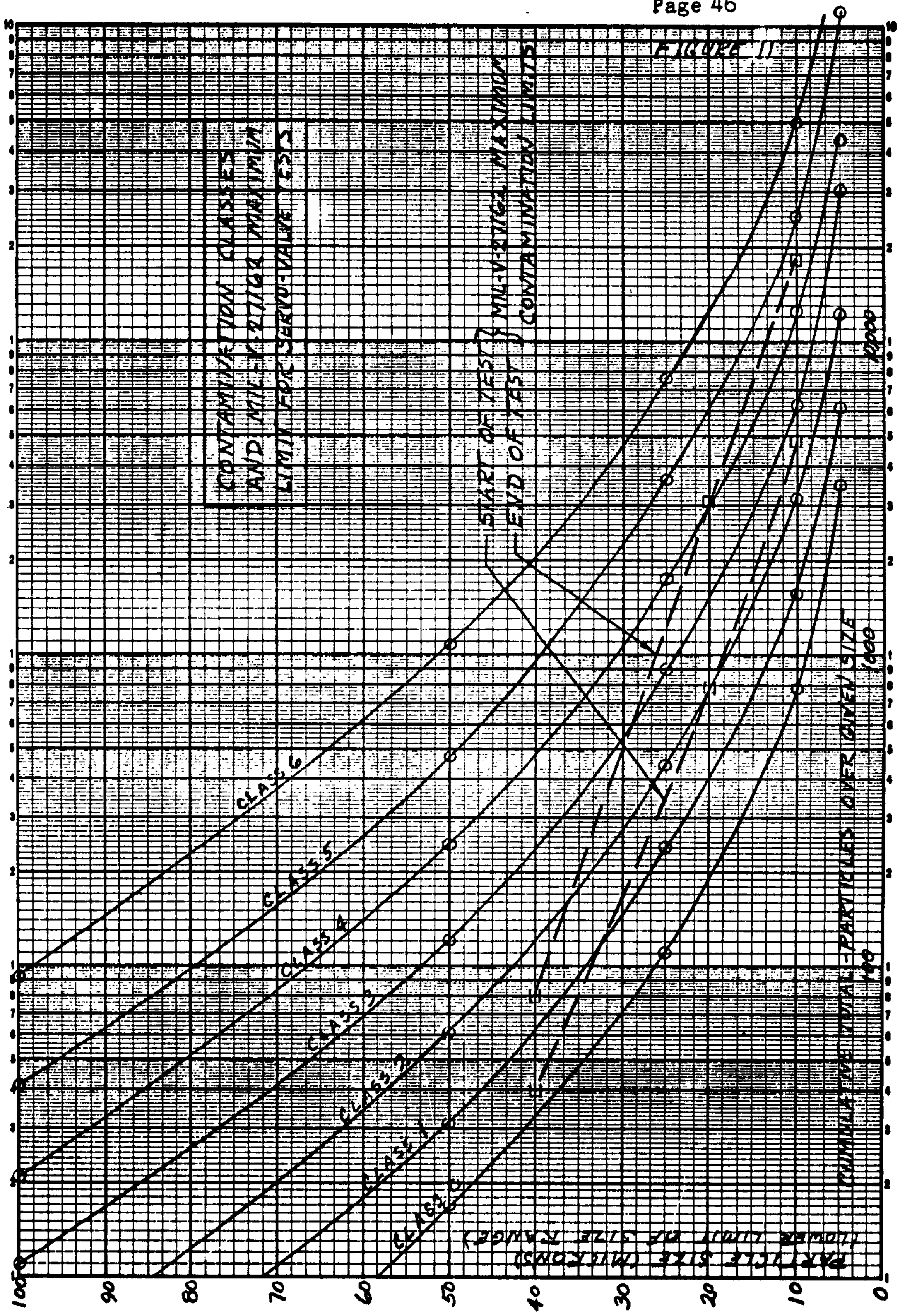


FIGURE 11
CONTAMINATION CLASSES AND MIL-V-27162A MAXIMUM LIMIT FOR SERVO-VALVE TESTS
START OF TEST
END OF TEST
MIL-V-27162A MAXIMUM CONTAMINATION LIMITS
CLASS 6
CLASS 5
CLASS 4
CLASS 3
CLASS 2
CLASS 1
CLASS 0
CUMULATIVE TOTAL-PARTICLES OVER GIVEN SIZE
100
1000
10000
PARTICLE SIZE (MICRONS) (LOWER LIMIT OF SIZE RANGE)
100
90
80
70
60
50
40
30
20
10
0

APPENDIX A

SAMPLING PROCEDURE AND EQUIPMENT FOR HYDRAULIC SYSTEM CONTAMINATION SURVEY

Particulate contamination in the hydraulic systems tested was determined by preparing a filter membrane on-site, filtering 100 cc of hydraulic fluid. The samples were obtained from pressurized, circulating systems, utilizing the Douglas 5819486 hydraulic fluid contamination tester (Figures A-1 and A-3).

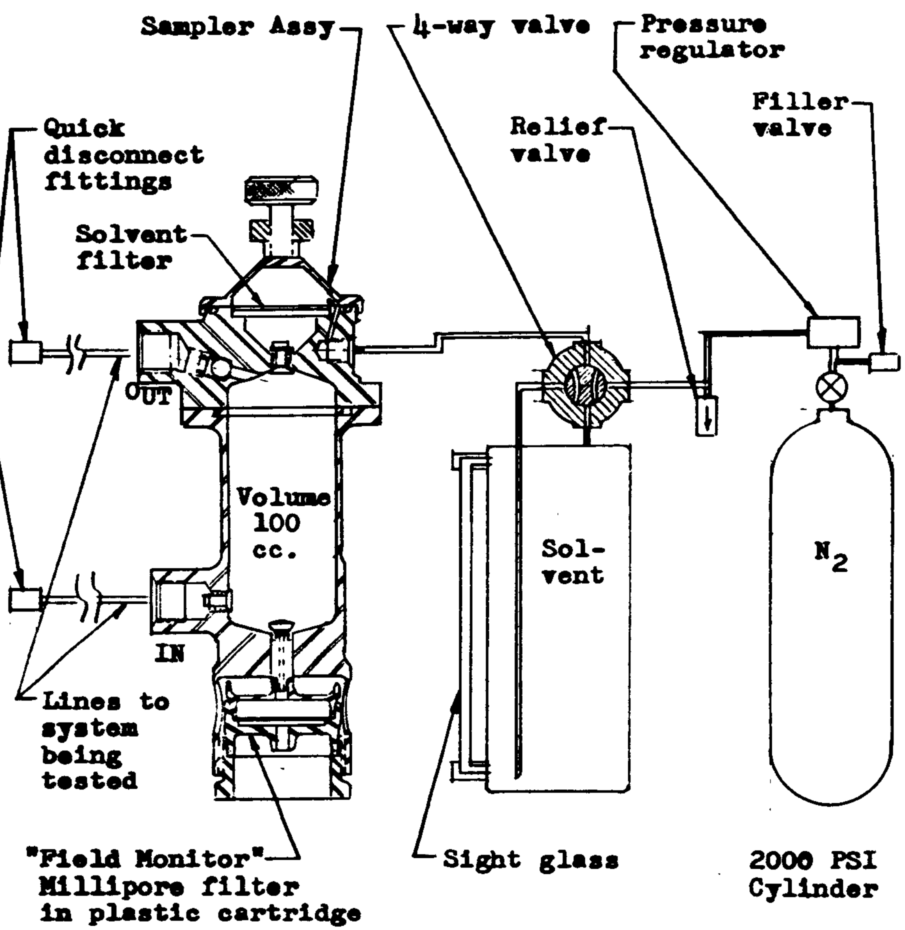
The sampler was connected to the system under test, using a parallel, series, or open circuit hookup as required (Figure A-2). With the aircraft engine(s) running and various portions of the system actuated (control surfaces, speed brakes, etc.) fluid, was circulated through the sampling chamber. After at least three minutes of operation, the system was shut down and the sampler disconnected. The trapped 100 cc sample was then passed through a .08 micron filter membrane of approximately 9 sq. cm. effective area. The membrane was rinsed with filtered solvent to remove all hydraulic oil, then dried with filtered nitrogen. The membrane, in a plastic capsule, was then sealed, identified, and stored for later evaluation. For about half the systems, a liquid sample was also taken in a clean can for evaluation of viscosity, acidity, etc.

In general, airplanes belonging to regular operating squadrons were tested. In some cases, squadrons had been suddenly deployed, leaving only a few airplanes assigned to the air base, or undergoing progressive aircraft repair (PAR) etc.

Testing was carried out on the flight lines, in such a manner as to avoid interfering with regular flight operations. This frequency involved waiting until airplanes and/or flight-line personnel were available. Where possible, airplanes which required an engine run for maintenance purposes were sampled, and no more than three airplanes in a squadron were tested to avoid excessive demands on a squadon's manpower.

The squadon maintenance personnel were cooperative and helpful. The Douglas Customer Service Organization rendered invaluable assistance in making arrangements with various squadons, shipping samples, etc. Equally helpful were individual representatives of the Lockheed, Grumman, Chance-Vought, and North American Companies, and local Bureau of Weapons Representatives.

FIGURE A1



OPERATING PROCEDURE:

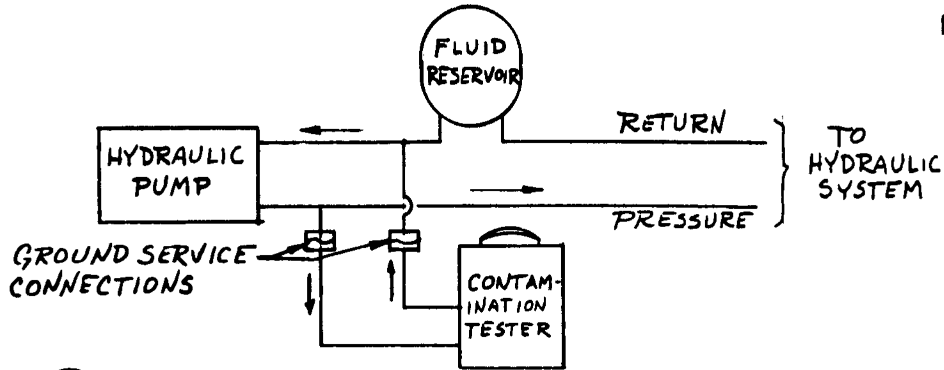
A - Preparation
1 - Fill solvent container.
2 - Charge nitrogen bottle.
3 - Install Millipore filter membrane in solvent inlet chamber.

B - Testing
1.- Connect hydraulic system to tester
2 - Operate system for 3 minutes to circulate fluid thru tester.
3 - Disconnect hydraulic system
4 - Install "Field Monitor" in base of sampler.
5 - Turn 4-way valve to "Solvent" and allow to flow until red color disappears from effluent.
6 - Switch 4-way valve to "Nitrogen" to purge solvent from sampler and dry filter membrane.
7 - Turn 4-way valve to "Off"
8 - Remove effluent filter patch, identify and store.

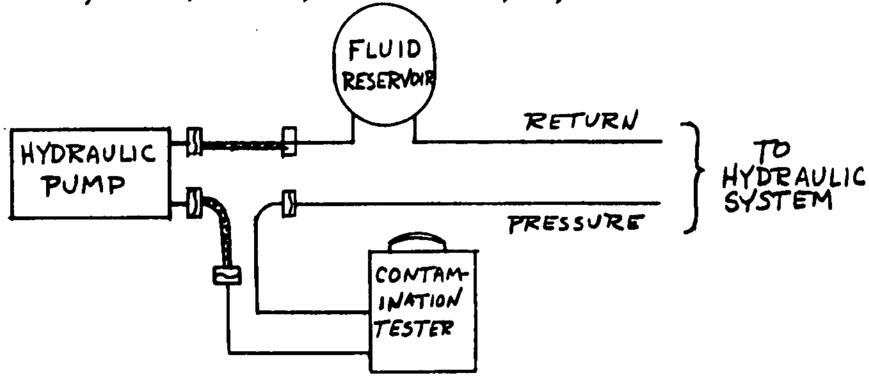
HYDRAULIC FLUID CONTAMINATION TESTER
(Portable Unit for Field Use)

DOUGLAS AIRCRAFT COMPANY, INC. EL SEGUNDO DIVISION EL SEGUNDO, CALIFORNIA

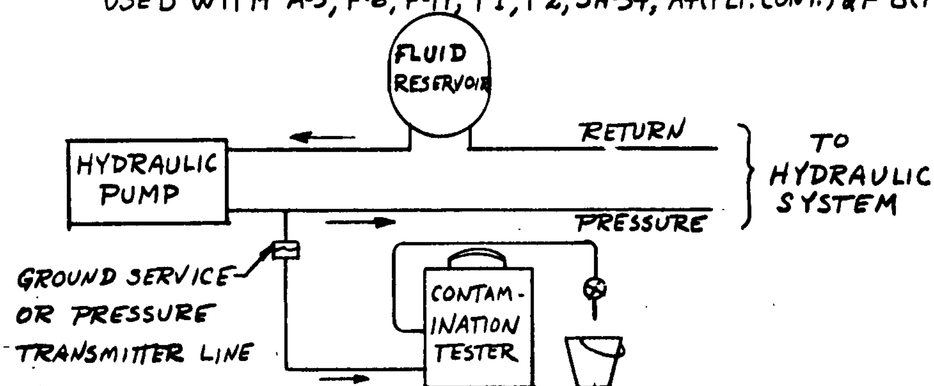
FIGURE A2



(A.) SHUNT-TYPE CIRCUIT. USED WITH A-3, A-4(UTILITY) E-1, EC-1, EC-121, F-8 (UTILITY), F-9, AND P-2 AIRCRAFT.



(B.) SERIES CIRCUIT (WHERE NO EXTERNAL CONNECTIONS WERE PROVIDED, OR A CHECK VALVE PREVENTED PRESSURE OUTFLOW) USED WITH A-5, F-6, F-11, T1, T2, SH-34, A4(FLT. CONT.) & F-8(FLT. CONT.).



(C.) OPEN CIRCUIT HOOKUP (WHERE RECIRCULATION NOT FEASIBLE) USED WITH F-4 & SH-3 AIRCRAFT.

— SCHEMATIC DIAGRAMS —
HYDRAULIC CONTAMINATION TESTER
INSTALLATION - VARIOUS AIRCRAFT

FORM 30-250V (7-51)