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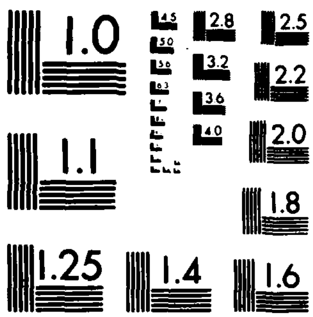

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FUEL SYSTEM O-RING LEAKS ON POST P.D.M. C-5A AIRCRAFT

C. J. FORZONO
SA-ALC/MMSH
Kelly AFB TX 78241

SEPTEMBER 1983

FINAL REPORT FOR PERIOD: MAY - SEP 1983

DIRECTORATE OF MATERIEL MANAGEMENT
UNITED STATES AIR FORCE
KELLY AIR FORCE BASE, TEXAS 78241

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the data developed and gathered as a result of fuel leaks around O-rings found in C-5 fuel systems following long periods of Programmed Depot Maintenance (PDM). The O-ring leaks occured when the fuel system was refilled after having been empty for 60-90 days during PDM. The study also involved an investigation of Buna-N O-ring shrinkage and swelling characteristics along with some testing of less or no shrinking O-ring materials like the phosphonitrilic fluoride (PNF) O-ring.

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PREFACE

This report presents the data developed and gathered as a result of an engineering study into the problem of fuel leaks around O-rings found in C-5 fuel systems following long periods of Programmed Depot Maintenance (PDM). The O-ring leaks occurred when the fuel system was refilled after having been empty 60-90 days during PDM. This study verifies the theory that the O-rings shrank during the PDM cycle and when a leak check was performed, leaks occurred.

Some tests accomplished through this study compliment those performed by Mr. Phil House of the Air Force Materials Laboratory. Information gathered through telephone conversations and meetings with fellow engineers, chemists, and maintenance personnel throughout the Air Force and industry also added to this report.

The author wishes to thank all those persons referenced throughout this report, and especially Mark Clemenson, the SA-ALC chemist that performed the O-ring tests, and Captain Jim Bothwell of MMSS for his assistance and liaison during the ground aircraft tests performed by the SA-ALC Maintenance Directorate.

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SECTION I

INTRODUCTION

Included within this report is a description of the problem, a statement of the objectives, an approach section describing how and what existing data was found, a review of the laboratory testing performed, and a presentation of the test results. With these factors understood, a number of conclusions/ recommendations are presented concerning the sealing characteristics of Buna-N type O-rings in all aircraft, not just in the C-5A, following long periods of exposure and lack of exposure to JP-4 jet fuel.

1. The Problem.

In early May of 1983, the first wing mod C-5A, ship number 68-214 came out of Maintenance after an approximate 88 day Programmed Depot Maintenance (PDM) cycle. At this point, the aircraft was filled with a purging fluid to check for any fuel leaks. A total of 27 leaks were identified as a result of this fuel leak check. The leaks found broke down as follows: 11 at wiggins coupling O-rings, 10 at O-rings on fuel boost pumps, 3 at access panel seals, 2 at fuel probe locations, and 1 at the sealant around a seal clip. These leaks were identified over a period of two weeks with the leak check fluid aboard. They were each visually noted and recorded by Gale Uzell of the C-5A Wing Mod office (SA-ALC/MMSH).

The initial theory concerning the 27 leaks on ship 68-214, was that the purging fluid used to perform the outbound fuel leak check was doing something chemically to the O-rings, which caused them to degrade and cease to adequately seal fluid. This theory was based on the fact that Telura 705 was a relatively new purging fluid, having replaced the long used Phillips 200 only 2 years earlier following an explosion of the Phillips 200 producing plant.

Some persons thought that such leaks had not occurred in the past when Phillips 200 was used. However, in talks with Maintenance personnel it was determined that such leaks were common in the past, and not just on C-5s. Data presented later confirms the fact that this problem was/is common throughout the Air Force. Apparently, the high interest in the C-5A Wing Mod Program brought this common problem to the surface.

2. Ojectives

a. Generally, to determine why the C-5A was experiencing a large amount of fuel system mechanical, O-ring type, fuel leaks during the fuel leak check near the end of the PDM cycle.

b. To determine if this problem was C-5 unique or common to other aircraft.

c. To determine the effects of the purging fluid, Telura 705, and the jet fuel, JP-4, on Buna-N O-rings used throughout the fuel system.

d. To develop valid solutions and recommendations to the problem on the presently produced C-5A wing mod aircraft, along with consideration of the remaining C-5A wing mod aircraft and the upcoming C-5Bs.

SECTION II

APPROACH

The approach to solving this problem was to first find out all that was known about fuel system O-ring type leaks occurring after long periods of maintenance. This step included telephone conversations and the exchange of test data with many technical experts, engineers, chemists and scientists from the Directorate of Energy Management; Air Force Materials Laboratory; Air Force Propulsion Laboratory; U.S. Navy Aircraft Fuel Systems Group; Warner Robins, Ogden, and Oklahoma City ALCs; SA-ALC Maintenance and Chemical Laboratory; United and TWA Airlines, and a number of O-ring Manufacturers. The data gathered included facts about Buna-N O-rings, new no-shrink and low-shrink O-ring compounds, purging fluids, fuels, aromatic properties of fuels, plasticizers in O-rings, and flash points. From this wealth of information, some questions were answered, and new ones arose. The second step to solving the problem included the running of some new tests to help answer remaining questions. With the results of these new tests, along with all the information gathered, the problem was studied and solutions developed.

SECTION III

DATA COLLECTION

1. <u>O-Rings</u>

a. Buna-N - The O-rings (also called seals) used throughout the C-5A fuel system are a black Buna-N rubbery material. They are used on items like Wiggins Fuel line couplings and within fuel boost pumps. This is the same O-ring material used on most, if not all, aircraft fuel systems in the military and industry. In the military, the Buna-N O-ring is developed per MIL-P-5315B entitled "Packing, Performed, Hydrocarbon Fuel Resistant." One of the more difficult requirements it must meet in this specification is the low temperature resilience test at -65° F. In order to meet this, the Buna-N O-rings contain 10 to 20% plasticizers which give then the needed flexibility at cold temperatures. These plasticizers are esters which are thought to be extracted from the O-rings when they are exposed to JP-4 jet fuel.[1]

Testing performed by Phil House of the Air Force Materials Laboratory, presented in Tables 1 and 2 show the swelling and shrinking characteristics of Buna-N O-rings in jet fuels.[2] Although JP-4, the jet fuel used on C-5A, was not one of the fuels used in the test, it does fall somewhere between the Type I and Type III fuels tested with the Buna-N O-rings.

The Type I fuel used was an iso-octane representing a low swell fuel. The Type III was 70% iso-octane and 30% toluene (an aromatic) representing a high swell fuel. These Type I and III test fuels are described in Federal Spec TTS-735. JP-4 ranges from 10 to 25% aromatics. From Table 2, it is shown that with the higher aromatic fluid, Type III, the Buna-N O-ring increases volumetrically (swells) by 24.4% with the initial soak, and shrinks 6.8% below its original volume after a drying period. With repeated soaking and drying, the swelling and shrinking slightly decreases and increases respectfully.

TABLE 1* Volume Changes of O-Rings, Tyep I Fluid
(Iso-Octane, Low Swell Fluid)

O-Ring Compounds	Buna-N Type Mil-P-5315	PNF Type	Low Shrink Buna-N (Stillman)	Low Shrink Buna-N (Fed. Mogul)	Fluorosilicone Mil-R-25988
(at 77° F)					
After 70 hrs in Type I	+3.3%	+5.5%	+6.7%	+6.2%	+15.5%
After 48 hrs in Air, Dry	-3.7%	+1.1%	+2.2%	+0.7%	- 0.2%
After 2nd 70 hrs in Type I	+0.4%	+4.8%	+6.1%	+5.6%	+15.8%
After 2nd 48 hrs in Air, Dry	-4.9%	+1.9%	+1.6%	-0.4%	- 0.3%
After 3rd 70 hrs in Type I	-1.3%	+5.0%	+5.0%	+3.7%	+13.1%
After 3rd 24 hrs in Air, Dry	-5.9%	+2.1%	+0.7%	-1.0%	+ 0.2%

*Air Force Materials Laboratory Data

TABLE 2* Volume Changes of O-Rings, Type III Fluid
(70% Iso-Octane, 30% Toluene, High Swell Fluid)

O-Ring Compounds	Buna-N Type Mil-P-5315	PNF Type	Low Shrink Buna-N (Stillman)	Low Shrink Buna-N (Fed. Mogul)	Fluorosilicone Mil-R-25988
(at 77° F)					
After 70 hrs in Type III	+24.4%	+10.9%	+30.3%	+26.8%	+19.2%
After 24 hrs in Air, Dry	- 6.8%	+ 3.2%	+ 0.4%	- 4.0%	- 1.1%
After 2nd 70 hrs in Type III	+22.1%	+12.2%	+36.2%	+32.4%	+15.2%
After 2nd 24 hrs in Air, Dry	- 7.6%	+ 2.0%	- 0.24%	- 4.7%	- 0.4%
After 3rd 70 hrs in Type III	+21.3%	+11.9%	+30.4%	+25.4%	+19.2%
After 3rd 24 hrs in Air, Dry	- 7.8%	+ 3.5%	+ 1.6%	- 4.9%	- 0.36%

*Air Force Materials Labor-

The swelling is due to the aromatics entering the Buna-N O-ring, while the shrinkage is a result of the fuel removing plasticizers from the Buna-N O-rings.[2]

b. Phosphonitrilic Fluoride (PNF) - This O-ring material was also tested by Phil House and is presented in Tables 1 and 2, along with the Buna-N data. PNF has considerably less swell than Buna-N in the type III fuel (See Table 2), with only a 10.9% swell, and does not shrink at all after drying. The nonshrinking is attributed to the lack of plasticizers. If there are no plasticizers, they cannot be extracted by fuel reactions. PNF is presently qualified under an AMS 7261 specification entitled "Rings, Sealing Phosphonitrilic Fluoride, High Temperature Fluid Resistant FZ Type". The PNF O-ring is far superior to the Buna-N in its ability not to take a compression set with time. However, like many of the fluoride type seals, PNF is more expensive than Buna-N. Some say 7 to 10 times more expensive than the Buna-N O-ring.[4] It is felt that once PNF becomes more widely used its cost will drop. One pilot plant with a large production capability is now under development.[2] PNF O-rings are presently in use on the F-15 actuator stabilizer, and the F-16 static brake system.[3] It is also used throughout the Navy's Phoenix missile.[4]

c. Low Shrink Buna-N - A new Buna-N type O-ring is presently under development through the efforts of the Air Force Material Laboratory and Phil House. Data on it is also shown in Tables 1 and 2. To obtain its less shrink characteristic, the amount of plasticizers were reduced. Basically, the theory is with less plasticizers to be entracted out by JP-4, the less the O-ring will shrink. In comparison to the standard Buna-N O-ring, data found in Tables 1 and 2 indicate that the low shrink Buna-N did not shrink after drying, while the standard Buna-N continually exhibited over 6% shrinkage upon drying. The obvious concern with less plasticizers is how will the material do against the -65°F resilience test of MIL-P-5315B. It is felt that although there is a lesser amount of plasticizers, the JP-4 itself will take the place of the reduced amount of plasticizers and so long as the O-ring is in a fuel environment it will meet such cold temperature requirements.[2] The low shrink (reduced plasticizer) Buna-N is presently having an AMS industry standard written to cover it, and hopefully the cost will be similar to the standard Buna-N O-ring.

2. Fluids, Purging/Fuel.

Purging fluids are developed in accordance with MIL-F-38299B "Fluid, Purging, for Preserving Fuel Tanks of Jet Aircraft." Some of the requirements are that they must: (1) consist of hydrocarbon compounds, (2) have maximum viscoscity of 5 centistokes at 100°F and (3) have a minimum flash point of 200°F. For years, a purging fluid known a Phillips 200, having a flash point of 200°F, was used by the Air Force.

A few years ago the Phillips plant exploded and as a result Phillips 200 purging fluid was no longer available.

Telura 705 was chosen at SA-ALC as the replacement for the nonavialable Phillips 200 since there was no other purging fluid available that could meet the specification. Although Telura 705 had a maximum viscosity of 6.5 centistokes at 100°F, 1.5 centistokes higher than the spec allowed, it met the other requirements. Telura 705 is manufactured by Exxon. It is an isoparafinic hydrocarbon with a very small percentage of high molecular weight aromatics. It is water-white in color, similar to a light mineral oil in appearance and has a flash point of 255°F.[6] Telura 705 is much less toxic than JP-4 fuel, and is primarily used as an animal feed pelletizing agent, a dust suppressant and a dry cleaning oil. Telura 705 and Phillips 200 are both basically hydrocarbon fluids and should not present any noticeable differences in their compatibility with fuel sealants like Buna-N O-rings.[5]

Another fluid, JP-5 jet fuel, which has a flash point of only 140°F, is also referenced as an acceptable purging fluid in Air Force Technical Order 1-1-3, paragraph 4.3.b. However, JP-5 does not meet the purging fluid spec MIL-F-38299B. Its flash point of 140°F, which when compared to -20°F of JP-4, is probably why it is listed in the T.O. as purging fluid. It can bring the remains of the JP-4 in the empty fuel system vapor spaces above the 120°F LEL requirement; but, not a quickly and safely as a purging fluid. JP-4 is the jet fuel used on all C-5A aircraft, except when it is refueled in the United Kingdom. JP-5 is used. Both JP-4 and JP-5 are produced per the requirements of MIL-T-5624L "Turbine Fuel, Aviation, Grades JP-4 and JP-5." JP-4 is not an isoparaffinic hydrocarbon; but rather, more a mixture of different paraffins; a wide-cut-gasoline-type fuel.[5] JP-4 can have aromatics ranging from 10 to 25 percent; but, it usually consist of 12-13 percent low molecular weight aromatics.[7]

3. Related Experiences

a. Ogden ALC. Ogden ALC fuel system personnel were also experiencing excessive Fuel Syustem leaks at O-ring sealing points when running a leak check with Telura 705 following 60-90 days of PDM on F-16s and F-4s coming out of hangers after long periods of maintenance without JP-4. They switched from Telura 705 to JP-4 for outbound fuel leak checks. They feel that the JP-4 swells up those O-rings which may have leaked if Telura 705 had been used as the leak check fluid. Fuel system maintenance personnel claim that non-structual O-ring type leaks which are noticed shortly after filling with JP-4, disappear after about an hour and one-half.[8] Any Wiggins couplings still found leaking after this time usually only require a one quarter hand turn in order to stop the leak.[5]

b. Warner Robins ALC. Warner Robins ALC fuel system personnel are experiencing O-ring leak problems similar to those found on the C-5A. In their case, the purging fluid used during the post PDM leak check is Phillips 220.[9] The aircraft handled by Warner Robins ALC include the C-141, C-130 and F-15 aircraft.

c. Sacremento ALC. They also experienced similar problems when they used a purging fluid for outbound leak checks. Now they use JP-4 or JP-5 for outbound leak checks. To get the LEL down prior to bringing aircraft into the hangar, they use Braco/999 (per MIL-F-38299B).[10]

d. Oklahoma City ALC. They do not experience a noticeable problem. They do use JP-5 as the post PDM leak fluid.[11] JP-5 does contain aromatics which should cause swelling of those O-rings that have shrunk during the long PDM cycle when fuel is removed.

e. Lockheed Georgia Co. LGC uses JP-5 as the purging fluid for its incoming C-5A wing mod aircraft; but, when the new wing is put on, new O-rings are installed. Therefore, the O-rings, not having been exposed to JP-4 do not shrink in their dry condition.[12] Lockheed personnel also became involved in this study of post PDM fuel system leaks and as a result wrote a report covering their testing.[15] The Lockheed report number is Materials and Processes (M&P) No. 63.

f. Airlines. Both United and TWA indicated that they had no excessive post maintenance O-ring type fuel leak problems. They also stated that under normal conditions their aircraft are left full of fuel and only once every 7 years or 25,000 flight hours are the fuel tanks/system emptied. This empty conditon usually only lasts 2-3 weeks. These companies use two different purging fluids; one called Sultrol by Phillips, the other LPA solvent by Conoco.[13, 14]

SECTION IV

NEW TESTING

1. Laboratory Tests

These laboratory tests were performed here at SA-ALC and were done to provide additional data needed in analyzing the problem and developing an acceptible solution. These were accomplished over a 2 month period and covered the following areas: verification of the Air Force Material Laboratory (AFML) tests; a simulation of what an O-ring sees before, during and after PDM; the swell rate of Buna-N O-rings exposed to JP-4; and the Buna-N swelling characteristics of three newly developed purging fluids.

a. Verification of AFML Tests. As the title states, these tests verified those performed by the Air Force Materials Laboratory; however, JP-4 was used as the test fluid instead of the Type I and III iso-octane fluids used in AFML tests. Three types of O-rings were used in these tests. The first was the standard Buna-N (MIL-P-5315B) used on the C-5 aircraft. It was obtained from supply under NSN 5330-00-250-0226 and was manufactured by Acushnet Process Company. The other 2 O-ring types were the Low Shrink Buna-N and the Phosphonitrilic Fluoride (PNF) per AMS 7261. These latter 2 were obtained from Sargent Industries, Stillman Seal Division. All the O-rings tested had a 1 inch diameter.

The actual tests involved running three O-rings of each type through a series of soak and dry operations, similar to those of the AFML tests. The tests were performed in accordance with ASTM D471. The temperature of the JP-4 during the soak/immersion periods was approximately 75°F. The tests cycle was: (1) 70 hours immersion in JP-4, (2) 48 hours in an air circulating oven at 120°F, (3) 70 hours immersion in JP-4, (4) 48 hours in an air circulating oven at 120°F, (5) 70 hours immersion in JP-4, and (6) 48 hours in an air circulating oven at 120°F. The volumes of the O-rings (a mass in air and water calculation) were recorded before the start of the tests and at the end of each immersion and drying period. The volume changes at the end of each period for all three different O-rings were calculated using the equation found in Section 16.2 of ASTM D471. These volume changes, measured from the initial recordings, are presented in Table 3.[15]

The standard Buna-N O-ring results show that they swell significantly; as high as 25% above the initial value when immersed in JP-4. Also, with each cycle of immersion and drying, the swelling does reduce; but, only slightly, e. g. from 25.4% down th 24.6% after one cycle. Another significant result for the standard Buna-N is the negative volume changes, or shrinkages, noted after the 48 hour drying periods. The O-rings shrank 6.5% after the first cycle, and got worse with each cycle; e. g. -7% and the -7.2%. These swell and shrink figures match the data found by AFML (see Tables 1 & 2). The tests obviously demonstrate that standard Buna-N O-rings swell in JP-4. This occurs because of the large concentration of aromatic fluids in JP-4 fuel. The shrinking of the standard Buna-N O-rings occurs because the JP-4 reacts with the O-ring and extracts out some of the plasticizers (esters) that contribute to the make-up of the O-ring.[1, 2]

The low shrink Buna-N O-ring test data shows that they swell about 27% less and shrink about 40% less than the standard Buna-N O-rings. (See Fig 1). Here also, the shrinking occurs because of the loss of plasticizers extracted by the JP-4. However, since the low shrink Buna-N O-ring has a lesser amount of plasticizers than the standard Buna-N, less plasticizer is removed and less shrinkage occurs. Hence the name, low shrink Buna-N.

The PNF O-rings swelled very little compared to the Buna-N O-rings (See Fig 1). Their swell was only 3.6% on the average, and it did not decrease or increase with the successive cycles. As for shrinking, for all practical purposes, there wasn't any. After each cycle, the average shrinkage was about a -0.15%. The PNF O-rings are not affected very much by the JP-4 fuel, they contain no plasticizers, and their -65°F temperature characteristics are acceptible.

TABLE 3 Volume Changes of O-Rings (JP-4 Fuel)

MATERIAL	Chg in Vol After 70 Hrs in JP-4 (%)	Chg in Vol After 48 Hrs at 120^{o} F (%)	Chg in Vol After 70 Hrs in JP-4 (%)	Chg in Vol After 48 Hrs at 120^{o} F (%)	Chg in Vol After 70 Hrs in JP-4 (%)	Chg in Vol After 48 Hrs in 120^{o} F (%)
MIL-P-5315	+ 25.4	- 6.5	+ 24.6	- 7.0	+ 24.3	- 7.2
Non Shrink Buna N	+ 19.3	- 3.3	+ 17.7	- 4.3	+ 17.0	- 4.4
AMS 7261 PNF	+ 3.7	- 0.16	+ 3.6	- 0.12	+ 3.6	- 0.16

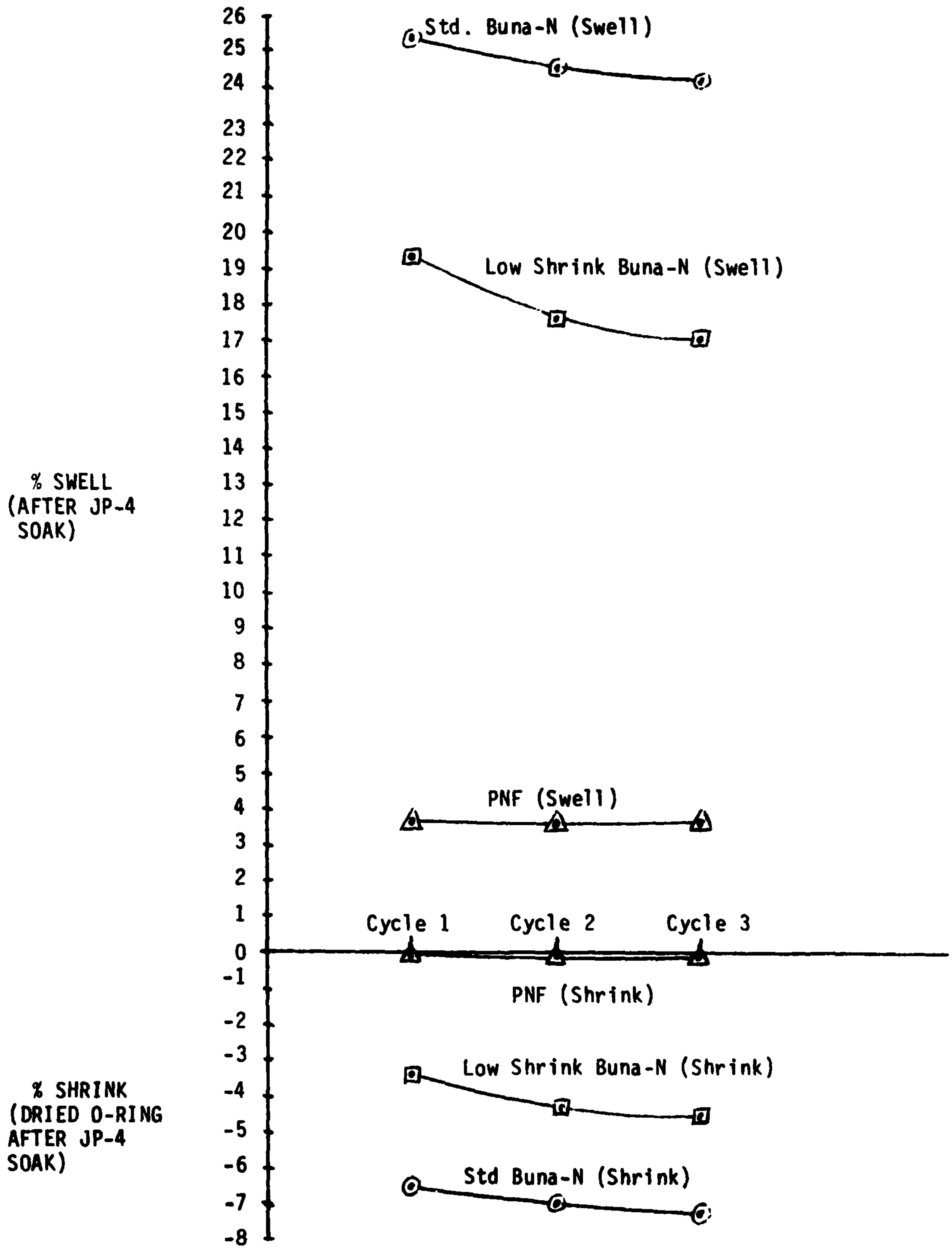


FIGURE 1. SWELL, SHRINK DATA

b. Simulated PDM Cycle. This test was developed to expose the Buna-N O-rings to JP-4, Telura 705, and air in a manner similar to that which the actual aircraft O-rings are exposed during a PDM cycle. Prior to coming into the depot for PDM, the fuel system is full, the O-rings are wet with JP-4, then the system is flushed/purged with Telura 705; then drained and dried over 88 days while maintenance is being performed, then another Telura 705 exposure during the post PDM leak check, and finally, the aircraft is refueled with JP-4 prior to departure. This was the PDM cycle that ship 68-214 saw and it had 27 leaks during the post PDM leak check. These tests were an attempt to repeat such a PDM cycle to see if the Telura 705 was causing the final leak problem.

The data from these tests are presented in Table 4. The simulated PDM cycle consisted of standard Buna-N O-rings being immersed in JP-4 for 70 hours, then immersed for 24 hours in Telura 705, air dried for 48 hours in a circulating oven, back into Telura 705 for 24 hours and lastly, immersed again in JP-4 for 70 hours. The first 2 groups found in Table 4 were control groups and were not exposed to the Telura 705. The 25% swell after 70 hours in JP-4 was expected since this phase was similar to those tests recorded in Table 3. After 24 hours in Telura 705, however, the swell dropped to 6.3 and 6.0%. What appeared to have happened was that the Telura 705 was doing its job, that is it removed the low flash point aromatics so that the fuel system's Lower Explosion Level (LEL) would be above a flash point of 120°F, which is required before an aircraft can be brought into the hanger. With aromatics removed, the O-ring swelling goes down. The 48 hours of drying took both the controlled group O-rings and the test group O-rings down to a negative volume change or shrinkage of about -6%. Again, this was not unexpected. With the removal of plasticizers from the first exposure of JP-4, shrinkage was expected. From this data, it is apparent that the Telura 705 had no detrimental chemical reaction type affect on the Buna-N O-rings. If anything, those exposed to the Telura 705, shrunk 0.5% less than

TABLE 4 Simulated O-Ring Experieinced PDM Cycle

Group	Set #	Chg in Vol After 70 Hrs in JP-4 (5)	Chg in Vol After 24 Hrs in Telura 705	Chg in Vol After 48 Hrs at 120^{o}F (%)	Chg in Vol After 24 Hrs in Telura 705	Chg in Vol After 70 Hrs in JP-4 (%)
Control	1	+ 25.6	NE	- 6.1	NE	+ 24.9
Control	2	+ 25.2	NE	- 6.4	NE	+ 24.5
Test	1	+ 25.1	+ 6.3	- 5.9	- 4.4	+ 23.9
Test	2	+ 24.1	+ 6.0	- 5.8	- 4.3	+ 22.8

Note 1 - NE is Not Exposed

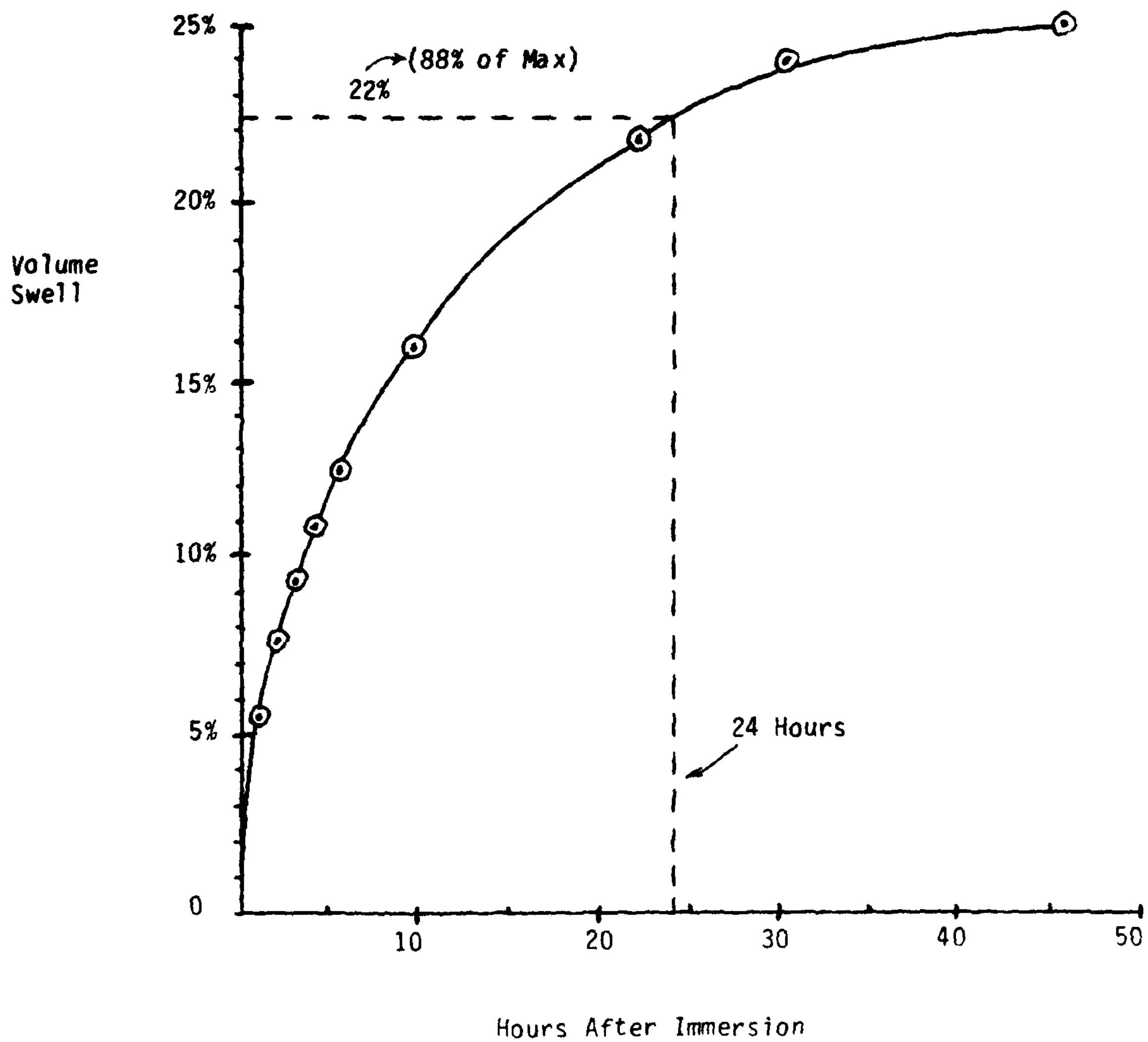
Note 2 - Volume change is always from original volume those not exposed. Then, when the dried O-rings were re-exposed to Telura 705 for 24 hours, they actually swelled about 1.5%. The final swelling of both groups of O-rings back to around 24% after being immersed in JP-4 again for 70 hours was again expected. The basic conclusion should be that the using Telura 705 as a leak check fluid following a long period of maintenance, where the O-rings are probably dry, is acceptable assuming you understand that you might find leaks around O-rings that have shrunk as a result of losing their plasticizers to JP-4. The Telura 705 is not causing the leaks, it is just not causing the O-rings to swell enough to make up for the volume lost to the removal of plasticizers.

c. Swell Rate of O-Rings in JP-4. Figure 2 presents a graph of hours of immersion in JP-4 versus percent swell of the standard Buna-N (MIL-P-5315) O-rings. The curve starts with a rapid climb and then gradually levels off at about 25% swell. After one hour of soaking in JP-4, the Buna-N O-ring swelled 6%. In five hours, it swelled 12%. In 24 hours it swelled 22.5% or about 90% of the maximum swell of 25%.

d. Test of New Purge Fluids. Three potential purging fluids were developed that would still meet the purging spec requirement of a 200°F flash point and cause O-ring swelling. Ideally, such a purging fluid would be used as a post PDM leak check fluid. It would have the safety characteristic of a purging fluid, that is, a 200°F flash point, and would cause the shrunk Buna-N O-rings to swell and reseal themselves. Those that still leaked would be fixed; but, again the high flash point and lack of a nitrogen inerting environment found when tanks are filled with fuel would make maintenance repair of the leaks much easier.

The three test purging fluids tested all used Telura 705 as the base fluid. This was because Telura 705 has a flash point of 255°F. Three aromatic fluids; Toluene, Ethylbenzene, and Cyclosol 63 (a 97% aromatic solution made by Shell Corp) were individually added to the base fluid until a mixture having a

FIGURE 2. SWELL VS TIME
(NEW BUNA-N O-RINGS IN JP-4 FUEL)



flash point close to 200°F was obtained. The Toluene mixture developed contained 1% Toluene and 99% Telura 705. The Etheylbenzene mixture developed contained 2% Etheylbenzene and 98% Telura 705. The Cyclosol 63 mixture developed contained 10% Cyclosol 63 and 90% Telura 705. Table 5 presents the amount of swell standard Buna-N O-rings exhibited when immersed in each of the these 3 test fluids over a number of different immersion times. After 24 hours none of these 3 test fluids were very successful in swelling O-rings. The best mixture was the 10% Cyclosol 63 which caused the Buna-N O-rings to swell 4.2% after 24 hours. After almost 5 days, the Cyclosol 63 mixture caused the Buna-N O-rings to swell only to 7.7%.

The swell characteristic of pure Telura 705 was also checked during these tests. It caused the Buna-N to swell 0.5% after 3 days. Apparently, in the cases of the new mixtures, the percentages of aromatics were not great enough to give Buna-N O-ring swells similar to those experienced when JP-4 was used. If the percentages were increased, the flash points would drop even farther below the purging fluid specification of 200°F, which would be unacceptable.

2. Aircraft Tests

About 2 months after the start of this project, SA-ALC Maintenance personnel decided that they would temporarily stop leak checking outbound C-5As with Telura 705. They began a program to high level (filling all the fuel tanks) at least 4 C-5As with JP-4 and see how quickly the Buna-N O-rings would swell and stop leaks such as those found on ship 214. The data from these tests are presented in the Appendix. The data includes information on leaks detected on outbound (after 2 months of hanger PDM) C-5As where a 24 hour JP-4 high level fuel leak test was performed and on inbound (prior to entering the hanger) C-5As where a 4 hour JP-4 high level fuel leak test was performed. On the first 2 outbound aircraft to be checked, 67-173 and 68-211, only those leaks still noted at the end of the 24 hour high level soak were recorded on

TABLE 5 Swell of Buna-N O-Rings in Different Purging Fluids

Purging Fluid	Flash Point of Fluid	Percent Swell of O-Rings After 1 Day	3 Days	at 4.8 Days
10% Cyclosol 63 90% Telura 705	190^{0} F	4.2	-	7.7
2% Ethylbenzene 98% Telura 705	180^{0} F	1.2	-	2.2
1% Toluene 99% Telura 705	180^{0} F	0.9	-	1.3
100% Telura 705	244^{0} F	-	0.5	-

the AFLC Form 937 "Inspection Condition Record." Starting with the third outbound aircraft, 67-174, maintenance was asked to record all leak defects noticed immediately after the filling was complete and at 6 hour intervals up to the end of the 24 hour soak period.

The data from the outbound checks showed a sharp reduction of Wiggins Coupling leaks; but Buna-N O-ring leaks at booster pumps still appeared to be a problem. Possibly the JP-4 swelling characteristics were responsible for the reduction in Wiggins Coupling leaks, and it appears to have reduced the booster pump O-ring leak problem by 50%. When comparing the leak data of the first outbound tests, it should be noted that aircraft 214 had O-rings on it that had experienced at least 2,000 flight hours while these other aircraft have recently left Lockheed with their new wings and only have 30 to 200 flight hours. Therefore, there may be some relationship between the higher flight hours of aircraft 214 and the number of leaks it had which we could not test for on these present, newer, less flown aircraft.

SECTION V

CONCLUSION

The goal of this study was to determine why O-ring type leaks were occurring on post PDM C-5A aircraft and to develop a solution to the problem. This goal was accomplished through a detailed investigation into the parameters relating to the problem, i. e. the O-ring materials, purging fluid, fuel, maintenance procedures, and maintenance environment. Presented below are a number of conclusions obtained through the data research and testing.

1. Buna-N O-ring used in the C-5A fuel system is common throughout the Air Force and Commercial Airlines.

2. Buna-N O-rings swell as much as 25% in JP-4 because of the aromatic properties of JP-4.

3. Buna-N O-rings shrink as much as 7% when left without JP-4 during long periods (about 60 days) of PDM hanger maintenance. (This shrinkage results from the removal of O-ring plasticizers extracted earlier by the JP-4, which becomes apparent when the high swelling properties of JP-4 are removed.

4. A newly approved, and more expensive O-ring called Phosphonitrilic Fluoride (PNF) does not shrink in JP-4, swells considerably less, and meets the -65°F O-ring resilience requirement.

5. A new O-ring, called a Low-Shrink Buna-N, is another way for possibly reducing leakage resulting from excessive shrinkage during drying. It has considerably less plasticizers. It therefore, shrinks less and meets the -65°F resilience requirement so long as it is in contact with JP-4.

6. The present C-5A purging fluid, Telura 705, does not react detrimentally with the Buna-N O-rings. It causes very little (+.5%) to no swelling of the Buna-N O-rings. Telura 705 has a good high flash point, and is similar to the previously used Phillips 200 purging fluid. Telura 705 is environmentally safer than the old Phillips 200, the newer Phillips 220 and the jet fuels like JP-4 and JP-5.

7. JP-5 has a relatively high flash point of +140°F, compared to the -20°F flash point of JP-4; however, JP-5 does not meet the purging fluid specification (MIL-F-38299B) requirement of a 200°F flash point. It causes Buna-N O-rings to swell about 15%.

8. Other Air Force Air Logistics Centers have experienced post PDM fuel leaks on aircraft that have been in the hanger, unfueled for long periods. Three have been switched to either JP-4 or JP-5 as the post PDM leak check fluid, two (one being SA-ALC) have stayed with using purging fluids as the leak check fluid.

9. Commercial Airlines have not experienced a similar problem because they do their hanger maintenance with fuel onboard, and only leave the fuel system totally empty 2-3 weeks once every 7 years when they inspect fuel tanks.

10. Attempts were not successful in developing a purging fluid that will meet the 200°F flash point requirement and cause sufficient swell of Buna-N O-Rings to lessen the number of fuel system O-ring related leaks.

SECTION VI

RECOMMENDATIONS

1. It is recommended that JP-4 jet fuel be used as the fluid in performing the post hanger PDM fuel system leak check for C-5 aircraft which use Buna-N as the primary fuel system O-ring material. Along with this, the purging fluid Telura 705 should be retained as the fluid used to bring the lower explosive level of the fuel system down to acceptable limits prior to bringing C-5s into the hanger for PDM.

It should be noted that the aircraft tests, which showed that using JP-4 as the leak check fluid was acceptable, were accomplished on recently rewinged C-5s. This means that the Buna-N O-rings under test were only a few months old. Using JP-4 as the leak check fluid on a C-5 with 4 or 5 years service, i. e. aged O-rings, might result in a large number of fuel leaks and a potentially greater fire hazard than what has been observed.

In order to reduce the potential fire hazard, consideration should be given to the use of JP-5 over JP-4 as the leak check fluid. JP-5's flash point of 140°F, its 15% swelling of Buna-N O-rings, and its acceptability as a C-5A fuel makes it an attractive alternative to the -20°F flash point of JP-4.

2. It is recommended that the future use of a non-shrinking O-ring for C-5B be seriously considered. At the moment, Phosphonitrilic Fluoride (PNF) O-rings, which have already been approved for aircraft fuel systems, look the most promising. The PNF O-ring is far superior than the Buna-N in its ability to resist compression set and it does not shrink upon drying after having been exposed to JP-4.

The PNF O-ring is more expensive than the Buna-N. However, even at $3.50 versus 50 cents, when you're looking at less than 1000 O-rings per C-5A, the initial cost is quickly recovered by its advantages. The primary advantage of the PNF O-rings would be that a safe purging fluid, like Telura 705 with a flash point of 255°F, could be used to perform the post PDM leak check.

This greatly reduces the fire hazard associated with leaking JP-4. Also, a fuel leak detected with JP-4 as the leak check fluid requires extensive aeration of the tank prior to entry by Maintenance personnel, plus the hazard of working in a nitrogen inerted environment. A fuel tank leak detected with Telura 705 as the leak check fluid, only requires a simple draining operation and then repair. Also, with PNF's high resistance to compression set, less maintenance should result since many an O-ring leak is a result of compression set.

3. It is recommended that the Buna-N O-rings found in the fuel system booster pumps be replaced with Phosphonitrilic Fluoride (PNF) O-rings on a number of C-5A aircraft not yet through the wing modification at Lockheed. Boost pump leaks still seem to be a problem even with the use of JP-4 as the post PDM leak check fluid. A practical use such as this could very well help the boost pump leak problem and provide some actual C-5A usage data on the newer PNF O-rings.

BIBLIOGRAPHY

REFERENCES

1. Sieron, Jerry K., Fluids, Lubricants and Elastomers Branch, MLBT, Air Force Wright Aeronautical Laboratories, Wright Patterson AFB OH 45433 (513 255-5375)

2. House, Philip A., Materials Engineering Branch, MLSE, Materials Laboratory, Air Force Wright Aeronautical Laborateries, Wright Patterson AFB OH 45433 (513 255-7483)

3. Straus, Frank., Mechanical Branch, ASD/ENFEM, Wright Patterson AFB, OH 45424 (513 255-4158)

4. Jackson, Dan., Stillman Rubber, Carlsbad, CA 92008 (714 438-1011)

5. Burris, Judith F., Chemist, Product Engineering Branch, Directorate of Energy, SA-ALC/SFTT, Kelly AFB TX 78241 (512 925-7613)

6. Brian, Tom., Chemist, Product Engineering Branch, SA-ALC/SFTT, Kelly AFB TX 78241 (512 925-7613)

7. Mortel, Charles., Fuels Branch, POSF, Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Wright Patterson AFB OH 45433 (513 255-7431)

8. Hall, or Galie., Ogden ALC Fuel Maintenance Personnel, OO-ALC/ Hill AFB UT (AUTOVON 458-3161)

9. Cleghorn, Jack and Caserio, John, Fuel System Maintenance Branch, WR-ALC/MABETB, Robins AFB GA (AUTOVON 468-4452 and 3786)

10. King, John and Myers, Iran., Sacramento ALC, Fuel Maintenance, SM-ALC/ MABPKA, McClellan AFB CA 95652 (AUTOVON 633-5081)

11. Hamb, Russell., Fuel Systems Maintenance Branch, WR-ALC, Robins AFB GA, (AUTOVON 735-6570 or 2753)

12. Borders, Mike and Knowles, Guy., Materials and Processes Engineer, Zone 53, Dept 7227, Lockheed Georgia Co., Marietta GA 30063 (ext 3394)

13. Malgoire, John., Fuel System, United Airlines (415 876-6493)

14. Surkert, Larry and Best, Bob., Fuel System, TWA (816 891-4877)

15. Clemenson, Mark., Chemist, Chemical Laboratory Section, SA-ALC/ MAQCA, Kelly AFB TX 78241 (512 925-8314)

APPENDIX

RECORDED DATA ON C-5A DEPOT LEVEL

24 HOUR OUTBOUND HIGH LEVEL FUEL LEAK CHECKS
AND
4 HOUR INBOUND HIGH LEVEL FUEL LEAK CHECKS

OUTBOUND 24-HOUR LEAK CHECKS

Aircraft: C-5A - 67-173 (Checked 6 Aug 83)

Leaks Detected	Disposition
#4 Main Drain Plug	(Not Recorded on the data sheet for this aircraft)
#3 Aux Drain Plug	
#3 Ext Drain Plug	
#3 Main Drain Plug	
#2 Ex Drain Plug	
#2 Main Drain Plug	
#4 Ext Boost Pump O-Ring	
#3 Aux Boost Pump O-Ring	
#1 Ext Boost Pump O-Ring	
#2 Aux Boost Pump O-Ring	
#4 Aux Boost Pump Housing	
#1 Aux Access Door	

OUTBOUND 24-HOUR LEAK CHECKS

Aircraft: C-5A - 68-211 (Checked 2 Sep 83)

Leaks Detected	Disposition
#1 Main Access Door	Retorqued IAW 1C-5A-2-5.
#4 Main Access Door	" " "
#1 Aux Access Door	" " "
#3 Main Booster Pump (BP) Elect Conduit	Replaced o-ring on elect conduit Connector.
#1 Main Booster Pump (BP)	Replaced 2 o-rings.
#2 Main BP	" " "
#1 Aux BP	" " "
#1 Ext BP	" " "
#3 Main BP	" " "
#4 Aux BP	" " "
#4 Ext BP	" " "
Right Vent Box Drain Plug	Replaced with new drain plugs.
#4 Ext Range Drain Plug	" " " " "

OUTBOUND 24-HOUR LEAK CHECKS

Aircraft: C-5A - 67-174 (Checked 15 Sep 83)

Leaks Detected (Immediately after filling)

#4 Main Access Door Screws

#2 Ext Range Boost Pump O-Rings

Fuel Probe Wiring Entry Point into Tank, Leading Edge

Leaks Detected (After 6 hours of soaking)

#4 Main Access Door Screws---------------(Repeat)

#2 Ext Range Boost Pump O-Ring-----------(Repeat)

Fuel Probe Wiring Entry----------------(Repeat)

#1 Main Drain Plug

Leaks Detected (After 12 hours of soaking)

#4 Main Access Door Screws----------------(Repeat)

#2 Ext Range BP O-Rings-------------------(Repeat)

Fuel Probe Wiring Plug-----------------(Repeat)

#1 Main Drain Plug------------------------(Repeat)

#4 Aux Inbd Access Door

#4 Iso-Valve Wiggins Nut

Leaks Detected (After 18 hours of soaking)

#4 Main Access Door Screws---------------(Repeat)

#2 Ext Range BP O-Rings------------------(Repeat)

Fuel Probe Wiring Entry---------------(Repeat)

#1 Main Drain Plug-----------------------(Repeat)

#4 Aux Inbd Access Door------------------(Repeat)

#4 Iso-Valve Wiggin Nut------------------(Repeat)

Aircraft: C-5A - 67-174 (Continued)

Leaks Detected (After 24 hours of soaking)

#4 Main Access Door Screws------------------(Repeat

#2 Ext Range Boost Pump O-Rings-------------(Repeat)

Fuel Probe Wiring Entry------------------(Repeat)

#1 Main Drain Plug--------------------------(Repeat)

#4 Aux Inbd Access Door---------------------(Repeat)

#4 Iso-Valve Wiggins Nut--------------------(Repeat)

Left Vent Box Door Screws

#1 Aux Outbd Tank Door

INBOUND 4-HOUR LEAK CHECK

Aircraft: C-5A - 67-170 (Checked 28 Jul 83)

Leaks Detected

None

Aircraft: C-5A - 69-002 (Checked 25 Aug 83)

Leaks Detected

#2 Main Drain Plug

#2 Aux Drain Plug

#1 Ext Range Drain Plug

#3 Ext Range Drain Plug

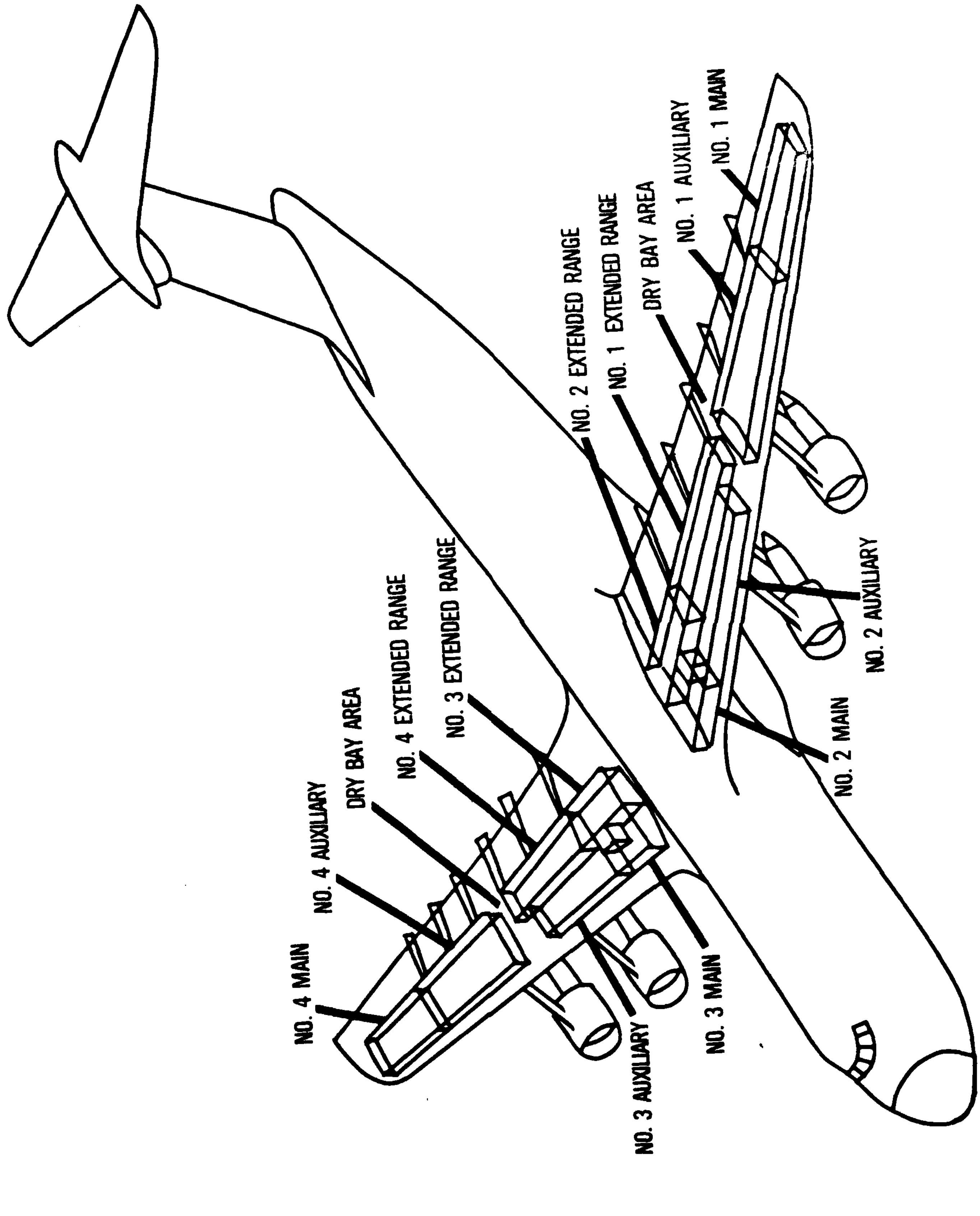
#3 Ext Range Boost Pump

#4 Aux Outbound Tank

#1 Aux Outbound Tank

Left Wing Vent Box

Right Wing Vent Box


NO. 1 MAIN
NO. 1 AUXILIARY
DRY BAY AREA
NO. 1 EXTENDED RANGE
NO. 2 EXTENDED RANGE
NO. 2 AUXILIARY
NO. 2 MAIN
NO. 3 EXTENDED RANGE
NO. 4 EXTENDED RANGE
DRY BAY AREA
NO. 4 AUXILIARY
NO. 4 MAIN
NO. 3 AUXILIARY
NO. 3 MAIN

LMED

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