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AFML-TR-73-90
PART III

LONG LIFE ELASTOMERIC AIRCRAFT HYDRAULIC SEALS PART III

PARKER HANNIFIN CORPORATION
SYSTEMS DIVISION AND SEAL GROUP

MARCH 1976

TECHNICAL REPORT AFML-TR-73-90, PART III
FINAL REPORT COVERING PERIOD 15 FEBRUARY 1974 to 15 AUGUST 1975

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This final report was submitted by Parker-Hannifin Corporation, Irvine, California under Contract F33615-73-C-5122, Job Order Number 73400532, with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. T. L. Graham (AFML/MBE) was the Project Engineer.

This technical report has been reviewed and is approved for publication.

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FOR THE COMMANDER

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Air Force Materials Laboratory

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

Long life elastomeric hydraulic seals have been under development for a period of four and one-half years. Each stage has produced successful results, encouraging the attitude that further improvement could be accomplished. The compound development approach and the dynamic evaluation of O-rings as both rod and piston type seals has been described in previous reports.

One principle development was a compound that truly met the concept of a Type II

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) system. This compound AFE-XN1925-33 (Parker N756-75) was responsible for the creation of the interim specification MIL-R-83461 which may eventually replace MIL-R-25732.

Another accomplishment was the successful dynamic performance of fluorocarbon O-rings for at least 1000 hour service in two types of service. They are:

1. Rod seals in MIL-H-83282 oil with alternate pressures during cycling of 50 and 4000 psig over a temperature range of -65°F through 350°F.

2. Piston seals under the same conditions except that the temperature range was -10°F through 350°F.

The major accomplishment of the last one and one-half years of development and evaluation was the successful 1000 hour rod seal performance of three nitrile compounds tested at 325°F.

1. AFE-XN2135-10 is a compound developed from a new bound anti-oxidant polymer with emphasis toward a high modulus, tight state of cure.

2. AFE-XN2135-27 is a compound developed using a carboxylated nitrile polymer with emphasis toward dynamic abrasion resistance.

3. AFE-XN1925-25 is a compound developed early in the program similar to AFE-XN1925-33 but ideally matched to the characteristics of MIL-H-83282 where only -50°F performance was expected.

Other accomplishments during this later period concerned the performance of the backup system chosen for evaluations of O-rings above 275°F.

1. The same combination of metal and plastic used for 350°F test in previous programs was used for the 325°F evaluations.

2. Where uncut Revonoc 18158 was used for 275°F tests in previous work, scarf-cut backup rings of the same material successfully completed 1000 hour rod tests in this program.

FOREWORD

This report was prepared by Parker Hannifin Corporation, Systems Division, Irvine, California; and Parker Seal Company, Research & Development Laboratory, Culver City, California, under USAF Contract F33615-73-C-5122. The contract work was performed under Project 7340, "Nonmetallic and Composite Materials," Task No. 73405, "Elastomeric and Compliant Materials," and was administrated under the direction of Nonmetallic Materials Division, Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, with Mr. T. L. Graham (AFML/MBE) as Project Engineer. Prior development work under this program area was reported in AFML-TR-72-66, AFML-TR-73-90 AND AFML-TR-73-90 Part II. This report dated March 1976 covers a period of work from 15 February 1974 to 15 August 1975.

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SECTION I INTRODUCTION

Concern for the short life at high temperature of elastomeric seals which are qualified to the MIL-P-25732 specification has prompted the development work reported in Technical Reports AFML-TR-72-66 and AFML-TR-73-90 Parts I and II.

The first step in developing compounds that would meet the long life criteria set down by Wright Patterson Air Force Base Material Laboratories was to review the latest in known rubber polymer technology through the use of chemical laboratory screening tests and then apply the information to life tests in a dynamic rod fixture. The results indicated that a new low temperature fluorocarbon met the 1000 hour requirement and that a nitrile showed promise of doing so.

Because of the surprising low temperature performance of the fluorocarbon compound, Parker suggested a piston fixture to better evaluate low temperature performance of O-ring compounds. The second step utilized this piston equipment and found that the low temperature static sealing capability of any polymer could be predicted to be approximately 15°F below the TR10 value. A nitrile compound AFE-XN1925-33 (or Parker production number N756-75) met the requirements of 1000 hours of 275°F exposure and a cyclic service life test that included pressures alternating between 4000 psig and 50 psig with intermittent static pressure exposures at -65°F. The fluorocarbon experimental compound, which could no longer be considered since the raw polymer became unavailable, failed to seal below -40°F in piston rig tests. Some of the testing during this period was conducted using the new MIL-H-83282 hydraulic fluid

The introduction of MIL-H-83282 with its -40°F to +400°F or above service range further complicated evaluations. First indications were that present QPL materials for MIL-P-25732 shrank slightly in MIL-H-83282 fluid whereas they swelled in MIL-H-5606 oil. Some later versions of MIL-H-83282 used an additive to correct this problem but results varied depending upon the actual batch of oil.

In spite of these limiting factors, much of the information derived from the dynamic life tests was encouraging. It was found that with properly selected backup ring material and attention to design details, fluorocarbon O-rings could be used for extended service in MIL-H-83282 oils at 350°F and pressures up to 4000 psig.

The Systems Division of the Parker-Hannifin Aerospace Group has been responsible for managing this contract and the manufacture of test equipment. The Parker Seal Company Research and Development Laboratory has been responsible for the compound development, dynamic functional evaluation and the writing of this report.

SECTION II SUMMARY OF PROGRAM

As before, the ultimate objective of the development of "Long Life Elastomeric Hydraulic Seals" has been to develop a material which will be suitable for advanced aircraft systems over a temperature range of -65°F to +450°F with pressures up to 4000 psi.

Interim instructions modified the temperature range to a more immediately achievable -65 to +325°F.

A continuing philosophy in the program has been to concentrate on commercially available polymers or polymers that are approaching commercial availability. However, some work was accomplished on the second generation polymer, PNF, because of its promising characteristics even though its present cost is high. (1)

The study of the service life of each compound has been based on dynamic tests that fit into three categories:

1. Dynamic screening tests on the "Chew Tester."
2. Long life tests on a dynamic rod fixture.
3. Long life tests on a dynamic piston fixture.

From a basic knowledge of these materials and a study of the laboratory aging studies and dynamic screening tests, it has been possible to approximate the service capability of each class of elastomer.

(1) NOTE: Test data on phosphazene, one of the PNF materials, was included in the 1974 report.

Acrylonitrile compounds AFE-XN2135-10 and AFE-XN2135-27 have done even better than AFE-XN1925-33 in the test rigs at 325°F. These latter two compounds have successfully completed the 1000 hour test at 325°F using MIL-H-83282 oil and high pressure cycling at 4000 psig.

Fluorocarbon materials continue to be the most promising for high temperature service. Successful life goals of 1000 hours have been reached on O-rings with a combination backup system at 350°F with little damage. The material will not, however, perform adequately in piston or any O. D. applications below -10°F statically and the low temperature limit is even higher in dynamic applications.

This result points up the importance of evaluating polymers that have an inherent temperature capability covering the full range of the desired service. Fluorosilicone and PNF polymers fall into this category. Their known shortcoming is lack of extrusion resistance and short life in dynamic service.

As temperatures and pressures increase, the function of the total composite seal package becomes more important. The choice of materials and the details of design, including the antiextrusion device and the groove dimensions, become more critical.

Pressure systems that go as high as 1500 psig do not seem practical at temperatures as high as 275°F without backup rings. For higher pressures only filled PTFE or equivalent backup systems can be considered if long life is expected.

As test results are accumulated and the data are evaluated, it becomes more and more apparent that seal materials are reaching their limit and design approaches will have to be studied more thoroughly.

Seal design consideration in previous studies has been confined to the use of O-rings as the primary seal. In this report we started to evaluate the "T" seal but the investigation was limited. In the CONCLUSIONS of this report we will explain more fully our recommendation to devote more time to design detail than in the past.

CONCLUSIONS

The development work discussed in this report has not only provided the information needed to reach some very significant conclusions, but it also indicates some of the direction that future development work should take. The following are probably the most useful conclusions we have reached through these development tests.

1. Three nitrile compounds actually met the 1000 hour requirements for rod seal performance at 325°F: AFE-XN2135-10, AFE-XN1925-25, and AFE-XN2135-27.

2. One polyacrylate compound, AFE-XA2116-1, met the 1000 hour requirements for piston seal performance, but would only be good for -20°F performance. Also, the condition of the seals was not as good as the nitrile seals.

3. The fact that fluorocarbon is the best high temperature polymer was reaffirmed having met the 1000 hour requirement at 350°F for a piston seal. The successful use of scarf cut backups was also established. For piston seal service the limit still appears to be -10°F for static sealability and considerably higher for dynamic service. (Note: A glimmer of hope occurred at the very end of this program when it was announced that du Pont had a new polymer similar to the one reported on in Technical Report AFML-TR-72-66.

This early material ran into producibility problems. The new polymer may have overcome this difficulty.)

4. The backup design parameters selected for test appear to have been somewhat responsible for the successes in compound evaluation.

The results of the above accomplishments strongly indicate the need for more concentrated effort on sealing device design details. But to get the most out of materials in functional performance we have come to the following conclusions:

1. Acrylonitrile compounds meet most of the presently seen needs. Sealing hydrocarbon oils through a temperature range of -65 to +325°F appears to be possible if the particular oil is compatible with the compound.

2. Fluorocarbon compounds are the very best for high temperature service (350 - 400°F) and will still function remarkably well at -65°F in rod applications but they will not seal at low temperatures when used as piston seals or other configurations in which the primary sealing area is the outer surface of the sealing element.

3. Fluorosilicone and PNF have the desirable temperature range but lack stamina in severe dynamic and high pressure usage.

This all leads to the recommendation that design be used to overcome individual material shortcomings. Combinations of materials and attention to dimensional details is suggested.

Conclusions due to Rod Tests:

(i) Previous work indicated that filled PTFE backup rings would be needed if service at 275°F and pressures of 3000 psi or higher were required. Uncut backup rings had been used for this work so tests were repeated using scarf cut backup rings. The tests were successful even though the conditions were more severe. (The pressure was 4000 psig.)

(ii) An attempt was made to develop a high modulus, tightly cured nitrile that would be better than XN1925-33 and possibly perform at higher temperatures. XN2135-10 was developed using a new polymer that had bound antioxidants in the polymer, incorporated by the raw material supplier as the elastomer was polymerized.

This proved to be very successful. The 1000 hour objective was met even though the aging temperature was 325°F and the maximum pressure during cycling was 4000 psig.

Unfortunately this polymer was removed from the market due to the difficulty of producing the low acrylonitrile version. Higher acrylonitrile versions are still available.

(iii) XN1925-25 was chosen next for test because it had been developed to have most of the good characteristics of XN1925-33 plus improved high temperature capability in MIL-H-83282 oil. The performance test confirmed these properties, for the material passed the same test that the XN2135-10 had surmounted so successfully. This is the test mentioned above in which the seals were exposed to MIL-H-83282 oil for 1000 hours at 325°F, pressures up to 4000 psi, and low temperature testing at -65°F.

(iv) Compound XN2135-27 was developed, using a carboxylated nitrile base polymer, to improve dynamic wear resistance. Concern for equivalent compression set resistance as well as high temperature heat stability was unfounded, for it too, met the full 1000 hour objective as described for XN2135-10 and XN1925-25.

(v) It should be noted that we believe a large part of the successful performance of the three experimental nitrile compounds was due to the use of the unique backup system consisting of a metal washer in conjunction with the filled PTFE used previously. With this system nitrile can be expected to perform at higher temperatures than was possible with only a homogeneous PTFE backup ring.

(vi) We also conclude that the O-ring used in the test fixture as a wiper inadvertently aided in the success of the tests. It was there to collect any leakage that might occur, but at the same time it helped to exclude oxygen, which has a detrimental effect upon the aging of nitrile rubbers.

Conclusions due to Piston Tests:

(i) The piston fixture was used primarily for its more informative results in low temperature evaluations. Valuable information could be obtained in short term tests and compared to chemical laboratory TR10 values. It has been found that static sealability can be predicted at 15°F below the TR10 value. Dynamic capability did not fall entirely within the contract testing procedure and preliminary values indicate that substantial allowance will have to be made if low leakage is required. A test program needs to be developed to explore this area.

Another important use of the piston rig is to verify the long term rod fixture test results and to make certain that the desired temperature range has been maintained. It was previously reported and explained that O-rings will perform to lower temperatures on rod type designs than on piston types.

(ii) The previously successful long term piston test reported earlier was repeated maintaining performance capability over a -30 to +350°F temperature range using scarf cut backup rings and maximum pressure cycling at 4000 psig. This was done with the three sets (six O-rings, two at higher squeeze than MIL-H-5514) and all completed the 1000 hour objective. These tests were conducted using Parker's fluorocarbon compound V747-75.

SECTION III DEVELOPMENT OF HYDRAULIC SEAL MATERIALS

The work detailed in Technical Report AFML-TR-73-90 Parts I and II indicated the improvements that could be made in seal materials intended for use in aircraft hydraulic systems.

The most significant outcome of the early work was the development of Parker compound XN1925-53 (N756-75), which successfully completed the 1000 hour dynamic cycling test as outlined in the above reports.

Other interesting developments were: the outstanding low temperature performance of fluorocarbon compounds in the rod tests, the establishment of the good aging resistance of bound antioxidant acrylonitrile polymers, and the realization of relative lack of dynamic capabilities of polyacrylate compounds.

Increases in temperature from +275°F to +325°F presented new problems in material development. The fluorocarbon compounds could still be expected to perform the best at high temperatures but their low temperature properties limited them for use as piston seals.

N 756-75 which had done so well on the +275°F test failed after 581 hours at +325°F.

The polyacrylate compounds exhibited extremely high compression set.

Therefore, the aim of the compound development work discussed in this report has been:

1. To optimize the dynamic properties of acrylonitrile compounds for MIL-H-83282 serv. e while maintaining or improving compression set and high temperature aging properties.

2. To further investigate cure systems for polyacrylate compounds and determine their suitability for dynamic service, with emphasis on low temperature properties.

3. To further explore fluorocarbon capabilities.

These goals will be discussed in this section of the report.

III-1 DEVELOPMENT OF ACRYLONITRILE COMPOUNDS

The theory behind dynamic sealing and the attendant studies aimed at improving this property were presented in report AFML-TR-73-90.

The filler and curing system for Parker compound N756-75 (AFE-XN1925-33) had been optimized around this study for service at +275°F. At +325°F, however, the dynamic properties of N756-75 did not hold up. It was felt that a material with higher modulus was needed for the +325°F service.

Table shows several compounds which were evaluated for better dynamic properties.

Compound AFE-XN2135-10 was designed around N756-75 but was based on a bound antioxidant polymer (discussed in AFML-TR-73-90 Part II) and contained no plasticizer. The bound antioxidant feature of this compound afforded the extra protection necessary for functioning at the +325°F temperature and this compound successfully completed the 1000 hour dynamic tests.

The other experimental compounds listed in Table 1 consisted of either complete or partial replacements of the bound antioxidant material with conventional elastomers. This resulted in greatly increased modulus and reduced elongation, indicating that the bound antioxidant feature had a retarding effect upon state of cure. These materials were not evaluated dynamically due to their low elongations.

Compound N766-75 was evaluated at +325°F since it was specifically designed for use in the MIL-H-83282 oil. The success of this compound on the rod test can be attributed to the higher acrylonitrile polymer and filler level which contribute to improved abrasion resistance.

Table 2 shows another approach to improving modulus and dynamic properties. In these compounds Chemigum N917 was partially replaced with FRN-605, a carboxylated polymer. The carboxylated polymer greatly enhances the dynamic wear characteristics of acrylonitrile compounds.

The difference between AFE-XN2135-25 and AFE-XN2135-27 is the form of zinc oxide used. AFE-XN2135-27 which used the predispersed form of zinc oxide provided greater processing safety and improved compression set.

AFE-XN2135-27 successfully completed the 1000 hour cycling test on the rod rig with very little sign of wear.

III-2 POLYACRYLATE COMPOUNDS

In earlier studies the improved resistance of polyacrylate compounds to MIL-H-83282 oil over MIL-H-5606B oil has been noted. With this fact in mind it was the intention of this study to develop polyacrylate compounds with better low temperature, dynamic and compression set properties.

In Tables 3 and 3a (compounds AFE-XA2116-1, AFE-XA2134-4 and AFE-XA2134-5) two low temperature type polyacrylates with varying cure systems were evaluated.

Compound AFE-XA2116-1 successfully completed a 1000 hour dynamic rod test but showed severe degradation of the seals due to a nibbling effect. The low temperature end of the cycle had to be gradually raised from -30°F to -20°F to prevent excessive leakage. The O-rings displayed excessive compression set. The polymer in AFE-XA2116-1 has since been discontinued.

Compounds AFE-XA2134-4 and AFE-XA2134-5 showed an improvement of up to 12°F in low temperature properties over AFE-XA2116-1, however, the compression set on these materials was deemed too high to warrant a dynamic evaluation.

Elastomer blends of polyacrylate and epichlorohydrin were evaluated (see Table 4 compounds AFE-XA2134-8 and AFE-XA2134-9). The theoretical aspect of this approach is appealing since polyacrylate and epichlorohydrin elastomers have common cure systems and similar temperature ranges. Epichlorohydrin has slightly better low temperature performance.

AFE-XA2134-8 was subjected to a screening test on the piston rig and sealed at -50°F. AFE-XA2134-9 provided even better low temperature properties but both compounds exhibited poor compression set and were not subjected to dynamic testing.

It is apparent from this work that polymer modifications and/or cure system improvements will be necessary before polyacrylates can be considered viable candidates for -65°F to +325°F service.

III-3 FLUOROCARBON COMPOUNDS

The desirability of using fluorocarbon elastomers in high temperature hydraulic systems was discussed earlier in report AFML-TR-73-90 Part II.

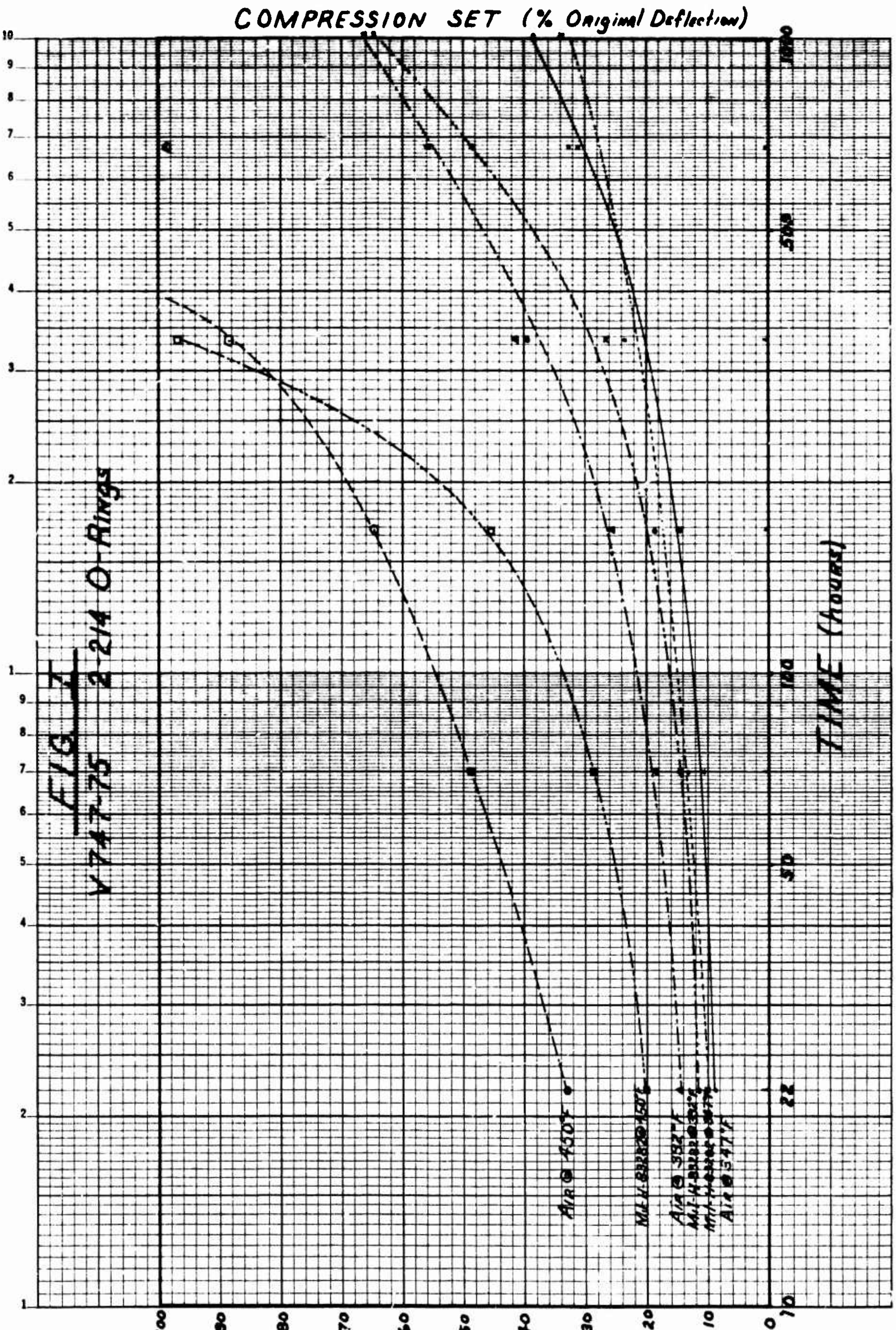
The limitation of this type of elastomer being low temperature performance, one purpose of the work done here was to investigate new low temperature resistant polymers.

In Table 5 du Pont's VT-R-4283 polymer was evaluated in compound AFE-XV2223-1. This material was received just prior to the end of the contract, therefore, it was not evaluated on the dynamic cycling rig. However, the compound was run on the chew tester and subjected to piston seal screening tests. The results were quite encouraging. The TR10 of -21°F is excellent for this type of material and the compression set of 44% should be sufficient to withstand 1000 hour testing. Further evaluations of this material are planned for the future.

III-4 COMPRESSION SET RESISTANCE OF FLUOROCARBON COMPOUNDS AT ELEVATED TEMPERATURES

With the increasing temperature requirements of hydraulic systems into the 325°F to 450°F range and pressures exceeding 3000 psig, it became apparent that additional data was required on the compression set resistance at these temperatures. A study was conducted on Parker's low compression set fluorocarbon compound, V747-75. In this study compression set was measured in air and MIL-H-83282 oil at 347°F, 392°F and 450°F for varying periods up to 1000 hours. (See Table VI) The results are presented in Figure I where it can be seen that at 347°F there is only a minimal increase in set for 22 hours to 168 hours in both air and MIL-H-83282 fluid.

With increasing temperatures the spread between air and MIL-H-83282 fluid values increased until approximately 290 hours @ 450°F, where the compression set in MIL-H-83282 fluid rises faster than in air. This would indicate a breakdown in the fluid is taking place which has an adverse effect upon compression set. From the available data, the maximum operational temperature for which fluorocarbons can be expected to adequately perform in the long term would be 400°F.



COMPRESSION SET (% Original Deflection)
FIG I
V747-75
2 214 O-Rings
TIME (hours)
AIR @ 430°F
AIR @ 382°F
AIR @ 347°F
100
90
80
70
60
50
40
30
20
10
0
10
22
50
100
500
1000

SECTION IV. DYNAMIC EVALUATION OF HYDRAULIC SEAL MATERIALS

IV-1 CHEW TEST EVALUATIONS AND THE EVALUATION OF BACKUP SYSTEMS

In Technical Reports AFML-TR-72-66, 73-90 and 73-90 Part II the use of the chew tester was discussed in detail. It continues to be an invaluable tool in screening dynamic characteristics of both seals and backup systems.

Through previous evaluations on backup systems only certain grades of filled PTFE or compounded designations have been used for 275°F and above. For temperatures of 325°F and above metal backup washers were used as well. All these details can be found in AFML-TR-73-90, Part II (October 1974).

One of the ongoing objectives has been to develop materials with better abrasion and extrusion resistance by exploring different filler systems and varying compound hardnesses. The chew tester then, is used to screen compounds for the long term rod and piston tests. One such compound, AFE-XN2135-27, came to our attention through this method and its successful performance in the rod tests is explained later.

Comparisons of fluorosilicones and phosphonitrilic fluoroelastomers (PNF) in the chew tester indicated that neither of these two elastomers are yet capable of long time service at high pressures with our present backup systems. The PNF material does, however, seem to have an edge in dynamic performance.

IV -2 EVALUATION OF SEAL MATERIALS ON THE ROD TEST RIG

IV-2-a EVALUATION OF AFE-XA1969-56 AT 325°F, 4000 PSIG, USING CAST IRON/REVONOC 18158 BACKUPS

It was reported in AFML-TR-73-90 Part II that AFE-XA1969-56 had successfully completed the 1000 hour test at 325°F maintaining sealability down to -40°F. This evaluation confirmed the fact that polyacrylates would perform better in MIL-H-83282 than MIL-H-5606 but indicated that further compounding would be necessary to overcome some of the evidence of nibbling and erosion of the O-rings. Further discussion and conclusions are included in this report. See Appendix I. (03-258 Addendum IV).

IV-2-b EVALUATION OF AFE-XN1925-33 IN MIL-H-83282/4000 PSIG/ 275°F COMPARING BACKUP TYPES (UNCUT, SCARF-CUT AND PARKER PARBAK)

It was concluded that Scarf-cut Revonoc 18158 provided adequate protection to O-rings up to 4000 psig in Type II systems but unfilled PTFE did not. The Parker Parbak became so hard and brittle that the tests were concluded 141 hours short of the 1000 hour goal. See Appendix II (Engineering Report 82-281 Revision B) scarf-cut backup rings were further evaluated in the piston rig. These results are discussed in Section IV-3-a.

IV-2-c A SPECIAL PLASTICIZER STUDY WAS CONDUCTED DUE TO THREATENED SHORTAGES

When it was learned that the plasticizer used both in AFE-XN1925-33 and Parker's QPL compound to MIL-P-25732 might become unavailable, a plasticizer substitution study was made. The long term dynamic tests indicated that an equivalent plasticizer, TP95, was available. This plasticizer performed equally well when substituted in the compound formula.

IV-2-d EVALUATION OF AFE-XN1925-33 IN MIL-H-83282/4000 PSIG 325°F

When it was learned that the Air Force was contemplating developing a fluid similar to MIL-H-83282 but with -65°F capability intended for 325°F service as well it was decided to test our best nitrile compound to these conditions. AFE-XN1925-33 was tested using the same previously successful backup system used in evaluating fluorocarbons at 350°F but under the environmental conditions described in the title. The tests were terminated after 251 hours and 49,800 cycles due to the excessive leakage of one of the four seals. Observation of the O-rings revealed that set was moderate, no real increase in hardness was evident and the front two O-rings showed no indications of nibbling. However, both of the O-rings on the far side of drive did show signs of nibbling. One of these was the failed O-ring which also had a split about one-fourth of an inch long.

IV-2-e EVALUATION OF AFE-XN2135-10 IN MIL-H-83282/4000 PSIG 325°F

The partial success of AFE-XN1925-33 at 325°F encouraged further nitrile compound development and a moderately high modulus compound based on a new nitrile elastomer containing a bound antioxidant was prepared and evaluated for dynamic sealing performance. This compound, AFE-XN2135-10, successfully completed the 1000 hour test, which was rather remarkable, since experience has indicated that nitrile type elastomer seals rapidly deteriorate at temperatures above 275°F. We attribute a large part of this success to the use of the special backup system. However, soon after the completion of this test it was learned that the supplier was having trouble manufacturing the low acrylonitrile version of this particular type polymer.

IV-2-f EVALUATION OF AFE-XN1925-25 IN MIL-H-83282/4000 PSIG 325°F

Since compound AFE-XN1925-25 was specifically developed to be compatible with MIL-H-83282, it was also evaluated to the new criteria. It too passed the 1000 hour rod seal test. Details of these test results are discussed in Appendix III. (Rod Test No. 203)

IV-2-g EVALUATION OF AFE-XN-2135-27 IN MIL-H-83282/4000 PSIG 325°F

In further effort to find substitutes for AFE-XN2135-10, a compound based on a carboxylated nitrile/nitrile rubber blend was developed that performed well on the chew tester. This compound, AFE-XN2135-27, also passed the 1000 hour test. In fact, the appearance of the O-rings at the end of the test looked the best of all candidate nitrile seals evaluated. The set was small and the rubber was still soft and resilient. Two of the four O-rings had split damage but no nibbling was evident.

An error made in this series of tests led to a seemingly improved seal assembly. The wiper rings used to collect the leakage had normally been made from the same compound as the test specimen. Two fluorocarbon O-rings had inadvertently been used which retarded the oxidation hardening process. Details are reported in Appendix IV (Rod Test No. 203-1) and in Appendix V (Rod Test No. 203-2).

IV-2-h EVALUATION OF PARKER L677-60 IN MIL-H-83282/4000 PSIG/325°F

Even though the chew test results had indicated that fluorosilicone materials were not yet suitable for this kind of dynamic service, it was decided to see how long they would go in order to have a bench mark for comparison. L677-70 is made from the high tear strength polymer and meets MIL-R-25988 Class I Grade 70. It failed after only 124 hours, having completed 31,200 cycles. It was just about what we would have expected but it does give us a chance to get direct comparison to PNF polymers when they are evaluated. See Appendix VI. (Rod Test No. 203-3)

IV-2-i EVALUATION OF AFE-XN1925-33 IN MIL-H-83282/4000 PISG/325°F

As AFE-XN1925-33 had not yet been sufficiently tested to compare its performance to the newer nitrile compounds, two additional test runs were made. The first test which used AFE-XN1925-33 as wiper seals was terminated after 466 hours and 52,800 cycles due to excessive fluid leakage. Because of the findings in IV-2-g concerning the wiper rings, it was decided to repeat the test using fluorocarbon O-ring wipers. The second set of tests was also terminated for the same reason after 581 hours and 87,800 cycles. Details will be found in Appendix VII (Rod Test No. 203-4) and in Appendix VIII (Rod Test No. 203-5).

IV-3 EVALUATION OF SEAL MATERIALS ON THE PISTON TEST RIG

IV-3-A EVALUATION OF CUT BACKUP RING SYSTEMS FOR PISTON SEAL PERFORMANCE

Parker compound V747-75 has been used in all previous evaluations as representative of MIL-R-83248 qualified seals. Short term tests had previously indicated that this compound had only a static sealing capability in the Piston Rig down to -10°F. However, in this evaluation -30°F was selected as the low temperature limit of the test cycle to see what difficulties might be encountered at this relatively low temperature. These seals not only survived the 1000 hour high temperature dynamic cyclic testing but sealed effectively at -30°F. The tests also indicated that scarf cut backups were nearly as suitable as uncut rings as used in previous tests. Straight cut rings are not suitable.

Splitting of the metal backup ring was explored for the first time and no real adverse effects were noted See Appendix IX (Engineering Report No. 05-249 Addendum XI) for details.

IV-3-b DESIGN STUDY FOR A LARGER SIZE PISTON RIG

We know that you cannot automatically take the dimensions of one design, then increase them and expect equal performance. Increasing the bore diameter introduces several new variables which can have an adverse effect on the performance of seal components. Due to the increased surface area of O-ring contact and consequently the increased frictional load O-ring seals are more prone to spiral and fail. The support of the backup ring systems can also be adversely effected by this seemingly simple dimensional alteration of hydraulic hardware. With these factors in mind a larger diameter piston test cell was fabricated and adapted to the present piston test equipment for further evaluating the performance of promising seal material composites (see Appendix X Engineering Report No. 05-249 Addendum XII for design details).

IV-3-c EVALUATION OF AFE-XA2116-1 IN MIL-H-83282/3000 PSIG/325°F

AFE-XA2116-1 (a polyacrylate based candidate seal material) essentially completed the 1000 hour test. After 968 hours and 149,400 cycles the test was terminated. The test samples showed severe set and some erosion on the O.D. surface next to the backup rings. The static seals became harder and took more set than the test seals but were still somewhat resilient. There was considerable random leakage of fluid during the course of the test. The initial low temperature sealing capability was -30°F. After repeated high temperature exposures, these seals proved to be ineffective at temperatures below -20°F.

IV-3-d EVALUATION OF WRIGHT-PATTERSON AIR FORCE BASE COMPOUND VS93 IN THE SHORT TERM PISTON TEST

A short term dynamic test procedure was used to first of all determine the low temperature static sealing capability and then to see how it changes with cycle time and high temperature aging. After 16 hours at -65°F pressure was applied and the VS93 seals were noted to be leaking. The temperature at which leakage stopped was -40°F. After cycling and aging for six hours at 325°F the low temperature cycle was repeated. Leakage did not stop until -35°F was reached. Further testing was not considered warranted.

IV-3-e EVALUATION OF THE NEW 2-3/4" DIAMETER PISTON RIG

The new piston rig pod, with a bore diameter of 2-3/4 inches was installed in the test rig and was given a trial test run to determine if there were any equipment operational problems. Parker V747-75 seals were used in combination with MIL-H-83282 hydraulic fluid for the equipment check-out test run. A temperature excursion set of tests was conducted that showed a continual increase in friction. The tests were terminated after three days because it was observed that the drive mechanism was not strong enough to overcome the

the frictional force build-up. An analysis of the problem and the proposed corrective measures are reported in Appendix XI (Engineering Report No. 05-249 Addendum XIII).

IV-3-f EVALUATION OF THE PROPOSED BACKUP SYSTEM IN THE NEW 2-3/4" PISTON RIG

Once the drive mechanism was modified, evaluations of the candidate backup design combinations were resumed. The increased size of the rig did indeed present new problems. This is reported on in detail in Appendix XII (Engineering Report No. 05-249 Addendum XIV). High friction and severe wear of the filled PTFE were of primary concern.

IV-3-g EVALUATION OF AFE-XA2134-8 IN MIL-H-83282/4000 PSIG/325°F

A low temperature polyacrylate developed during this period was briefly evaluated. The 1-1/8" piston test rig set-up was used. Even though AFE-XA2134-8 did have better low temperature sealing capability than previous compounds, its dynamic sealing performance at 325°F was inadequate.

IV-3-h SECOND STAGE EVALUATION OF 2-3/4" PISTON RIG

The design engineer for all of the test equipment used so far in this test program retired at this point in time. Evaluation of the new test pod continued and the severe extrusion of the sacrificial backup material was noted and reported. Photographs of these test specimens and other details are presented in Appendix XIII (Engineering Report No. 00-291).

IV-3-i EVALUATION OF BACKUP SYSTEM DESIGN VARIATIONS

The high friction and the various degrees of wear of the backup material did not seem to markedly affect the surface condition of the O-rings for short term evaluations. Therefore several design modifications were evaluated, each seemingly reducing the friction condition. The backup system seems to be the biggest key to successful performance in going from small to larger piston diameters. The test results and the design details are reported in

Appendix XIV	Engineering Report No. 00-291-1
Appendix XV	Engineering Report No. 00-291-2
Appendix XVI	Engineering Report No. 00-291-3
Appendix XVII	Engineering Report No. 00-291-4
Appendix XVIII	Engineering Report No. 00-291-5

Each report shows progress in performance. It also shows that once material development has reached a point where progress is difficult, careful consideration to design characteristics is about the only way further significant improvement can be achieved. We feel that the seal development effort should not be limited to O-ring seal design but should be broadened to include other shapes as well as combinations of new improved materials. The first step, however, should be to try to meet performance requirements without drastically modifying the design of present hydraulic hardware components. Ease of retrofit and standardization considerations are the reasons for imposing this restriction.

ACRYLONITRILL COMPOUNDS

Table 1

Formulations

Compound No.	AFE-XN1925-25 N766-75	AFE-XN2135-10	AFE-XN2135-21	AFE-XN2135-23
Krynac 2750	95.0	-	-	-
SBR 1500	5.0	-	-	-
Chemigum N967	-	100.0	-	-
Chemigum N917	-	-	100.0	-
Chemigum N665	-	-	-	70.0
Ameripol CB220	-	-	-	30.0
Magnesium Oxide	5.0	5.0	5.0	5.0
B8465 Cadmium Oxide	5.0	-	-	-
Zinc Oxide	-	5.0	5.0	5.0
N550 FEF	30.0	30.0	30.0	30.0
N774 SRF	30.0	30.0	30.0	30.0
N990 MT	30.0	-	-	-
Aminox	1.0	1.0	1.0	1.0
Antioxidant ZMB	1.0	1.0	1.0	1.0
Sarat 500	-	1.0	1.0	1.0
Dibutoxyethyl Sebacate	5.0	-	-	-
Diethylhexyl Azelate	5.0	-	-	-
Varox	3.0	3.0	3.0	3.0
Original Physical Properties: (2-214 O-rings)				
Hardness, Shore A, pts	72	73	79	77
Tensile Strength, psi	1590	1990	2170	1790
Elongation, %	148	162	111	122
Modulus @100% Elongation,psi	851	939	1800	1390
Compression Set 70 Hours @275°F (2-214 O-rings)				
% Original Deflection	45.1	51.4		
Temperature Retraction				
TR10 °F	-39	-45		

ACRYLONITRILE COMPOUNDS

Table 2

Formulations

Compound No.	AFE-XN2135-25	AFE-XN2135-27
Chemigum N917	80.0	80.0
FRN-605	20.0	20.0
Agerite Resin D	2.0	2.0
Stearic Acid	1.0	1.0
HiSil EP	30.0	30.0
N650 GPF-HS	40.0	40.0
Zinc Oxide	5.0	-
Polydispersion A(ZCN) D85	-	6.0
Di(Butoxy-Ethoxy-Ethyl) Formal	10.0	10.0
Dicup 40C	5.0	5.0
Original Physical Properties (2-214 O-rings)		
Hardness, Shore A, pts	73	74
Tensile Strength, psi	1460	1470
Elongation, %	175	149
Modulus @ 100%, Elongation, psi	678	856
Aged in MIL-H-83282 70 Hrs @ 302°F (% Change)		
Hardness, Shore A	75(+2)	75(+1)
Tensile Strength, psi	399(-73)	386(-74)
Elongation, %	31(-82)	28(-81)
Modulus @ 100%, Elongation, psi	-	-
Volume Change, %	+6.7	+7.4
Compression Set 70 Hours @302°F (2-214 O-rings)		
% Original Deflection	54.9	41.9
Temperature Retraction		
TR10 °F	-47	

POLYACRYLATE COMPOUNDS

Table 3

Formulations

Compound No.	AFE-XA2116-1	AFE-XA2134-4	AFE-XA2134-5
Polysar XPRD 433	100.0	-	-
Hycar 4043	-	100.0	100.0
Sulfur	0.25	0.25	0.25
Aminox	2.0	-	-
Agerite White	-	2.0	2.0
Stearic Acid	2.0	1.0	1.0
Acrawax C	-	2.0	2.0
N550 FEF	70.0	80.0	80.0
N326 HAF-LS	-	-	-
Sodium Stearate	1.75	-	-
Potassium Stearate	0.75	4.0	-
Curative C50	-	-	7.0

Original Physical Properties: (6"x6"x.075" slabs)

Hardness, Shore A, pts.	72
Tensile Strength, psi	1970
Elongation, %	171
Modulus @ 100% Elongation, psi	1060

POLYACRYLATE COMPOUNDS

Table 3a

Formulations

Compound No.	AFE-XA2116-1	AFE-XA2134-4	AFE-XA2134-5
Original Physical Properties: (2-214 O-rings)			
Hardness, Shore A, pts		81	81
Tensile Strength, psi		1370	1320
Elongation, %		333	309
Modulus @100% Elongation, psi		458	527
Aged Physical Properties			
Aged in Air 70 Hrs @302°F (% Change)			
Hardness, Shore A	80(+8)		
Tensile Strength, psi	1710(-13)		
Elongation, %	155(-9)		
Modulus @ 100%, psi	1080(+2)		
ASTM #3 Oil 70 Hours @302°F (% Change)			
Hardness, Shore A	57(-15)		
Tensile Strength, psi	1670(-15)		
Elongation, %	182(+6)		
Modulus @ 100%, psi	707(-33)		
Volume Change, %	+15.0		
MIL-H-5606B Oil 70 Hrs @275°F (% Change)			
Hardness, Shore A	60(-12)		
Tensile Strength, psi	1570(-20)		
Elongation, %	165(-4)		
Modulus @ 100%, psi	765(-28)		
Volume Change, %	+15.0		
MIL-H-83282 Oil 70 Hrs @275°F (% Change)			
Hardness, Shore A	66(-6)		
Tensile Strength, psi	1690(-14)		
Elongation, %	171(0)		
Modulus @ 100%, psi	820(-23)		
Volume Change, %	+8.2		
Compression Set (2-214 O-rings) 70 Hours @ 275°F			
% Original Deflection		61.7	86.8
Compression Set (2-214 O-rings) 70 hours @ 302°F			
% Original Deflection	48.1		
Temperature Retraction			
TR10°F	-14	-26	-25

POLYACRYLATE COMPOUNDS

Table 4

Formulations

Compound No.	AFE-XA2134-8	AFE-XA2134-9
Cyanacril C	70.0	-
Hycar 4043	-	50.0
Herchlor C	30.0	50.0
Stearic Acid	1.0	1.0
Empol 1024	3.0	3.0
N330 HAF	50.0	50.0
Span 60	0.5	0.5
Aminox	1.0	1.0
NBC	0.5	0.5
Dyphos	5.0	5.0
Phenothazine	0.5	0.5
Curative M-17	1.75	-
Diak #1	-	1.25

Original Physical Properties - (2-214 O-rings)

Hardness, Shore A, pts	71	75
Tensile Strength, psi	1400	1300
Elongation, %	241	214
Modulus @ 100% Elongation, psi	520	652

Compression Set (2-214 O-rings) 70 Hours @ 275°F

% Original Deflection	-	79.4

Temperature Retraction

TR10°F	-19	-39

FLUOROCARBON COMPOUNDS

Table 5

Formulations:

Compound No.	AFE-XV2223-1
DuPont VT-R-4283	100.0
N990 MT	30.0
Calcium Hydroxide	4.0
Triallyl Isocyanurate	4.0
Varox	3.6
Original Physical Properties (2-218 O-rings)	
Hardness, Shore A, pts.	69
Tensile Strength, psi	2220
Elongation, %	208
Modulus @ 100% Elongation, psi	677
Specific Gravity	1.82
Aged in ASTM #3 Oil 70 Hours @212°F (% Change)	
Hardness, Shore A	67(-2)
Tensile Strength, psi	1970(-11)
Elongation, %	191(-8)
Modulus @ 100% Elongation, psi	655(-3)
Volume Change, %	+1.6
Compression Set 70 Hours @392°F (2-218 O-rings)	
% Original Deflection	44.1
Temperature Retraction	
TR10 °F	-21

TABLE 6

COMPRESSION SET RESISTANCE OF FLUOROCARBON COMPOUNDS
at
ELEVATED TEMPERATURES IN AIR AND MIL-H-83282 FLUID

Compound No. Parker V747-75 - 2-214 O-rings

COMPRESSION SET, 25% DEFLECTION - % ORIGINAL DEFLECTION (2-214 O-RINGS)

IN AIR AT 347°F

22 Hours	8.6	336 Hours	23.5
70 Hours	13.3	672 Hours	32.4
168 Hours	14.7	1008 Hours	38.2

IN MIL-H-83282 AT 347°F

22 Hours	10.0	336 Hours	26.5
70 Hours	11.4	672 Hours	30.9
168 Hours	14.3	1008 Hours	33.9

IN AIR AT 392°F

22 Hours	14.3	336 Hours	41.2
70 Hours	18.6	672 Hours	55.9
168 Hours	25.7	1008 Hours	66.2

IN MIL-H-83282 AT 392°F

22 Hours	11.4	336 Hours	39.7
70 Hours	14.3	672 Hours	48.5
168 Hours	18.6	1008 Hours	64.7

IN AIR AT 450°F

22 Hours	32.9	336 Hours	88.2
70 Hours	48.6	672 Hours	98.5
168 Hours	64.3	1008 Hours	100.0

IN MIL-H-83282 AT 450°F

22 Hours	20.0	336 Hours	97.1
70 Hours	28.6	672 Hours	102.9
168 Hours	45.6	1008 Hours	104.4

APPENDIX I.

Engineering Report No. 03-258 Addendum IV

Dynamic Rod Seal Evaluation - Compound XA1969-56
Investigation of the Operation of the Seal Backup System

1.0 INTRODUCTION, PURPOSE OF THE TEST

1.1 The purpose of this test was to determine the suitability of the O-rings made of the XA1969-56 compound for operation at low and at elevated temperatures. The test was a standard 1000 hours test and was performed within the temperature range of -40°F to 325°F and at the maximum fluid pressure of 4000 psi. The O-ring back-up system was identical with the system described in the Report No. 03-258 Addendum II. That fact provided an opportunity of rechecking the suitability of this system for operation at 325°F. This report is concerned mainly with that matter.

2.0 CONCLUSIONS

2.1 The back-up system composed of a ML-1296 Revonoc 18158 sacrificial back-up ring and of a ML-1327 cast-iron supporting back-up ring performed very well and remained fully functional at the completion of the 1000 hours test. The condition of its components was similar to the condition of the back-up system components inspected after the termination of the test discussed in the Report No. 03-258 Addendum II.

There was no evidence of rolling of the O-rings, the cross section of which assumed a D shape with the flat side leaning against the back-up ring. An extensive nibbling was noticeable at the convex, upstream side on two of the four O-rings tested. The nibbling extended only over the area immersed in the fluid, while the area wedged within the walls of the groove remained smooth. No cause for the nibbling could be determined, but it did not seem likely that this nibbling could be caused by a malfunctioning of the back-up system. The suitability of polyacrylates will be discussed further in another section.

3.0 BACKGROUND

3.1 The test run between October 29, 1973 and January 5, 1974 was performed under the following conditions.

3.1.1 Test Rig

Rig #1 for dynamic rod seal evaluation.

3.1.2 Components Tested

3.1.2.1 2-214 O-rings of the XA1969-56 compound.

3.1.2.2 ML-1294 Revonoc 18158 back-up rings.

3.1.2.3 ML-1327 Cast-iron back-up rings

3.1.2.4 2-218 Static O-rings of the XA1969-56 compound

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3.1.3 Test Fluid per MIL-H-83282

3.1.4 Test Conditions

3.1.4.1 Fluid pressure range 50 to 4000 psi.

3.1.4.2 Temperature range -40°F to 325°F

3.1.5 Test Procedure

Standard test procedure for a 1000 hours material evaluation test. The Test Data Sheets are enclosed as Appendix 1. The test was completed without incident.

3.1.6 Comments on Test Results

The report on the conditions of the seal components inspected after completion of the test is enclosed as Appendix II. The summary of the findings is given in 2.0.

APPENDIX II.

Engineering Report 82-281, Revision B

Comparison of ParBak, Scarf-cut Teflon and Revonoc Backup Rings

1.0 BACKGROUND AND PURPOSE

Engineering Report 05-249, Addendum XI, demonstrated that straight cut backup rings are not suitable, but that scarf-cut Revonoc backup rings can prevent extrusion and damage to the O-ring up to 4000 psi and 350°F in piston applications with MIL-H-83282 oil.

This test was conducted to compare the performance of Parbaks and standard unfilled Teflon scarf-cut backup rings with the Revonoc type in standard type II systems. Hence, the standard MIL-H-5606 fluid was used and the maximum temperature was reduced to 275°F.

This reduction in the high temperature limit of the test permitted us to use N756-75 nitrile O-rings. They were shown to be adequate up to 275°F in Engineering Report 03-258 Addendum I where the material was listed by its experimental number, AFE-XN-1925-33.

2.0 CONCLUSIONS

2.1 Scarf-cut Revonoc backup rings provide adequate protection to O-rings up to 4000 psi in type II systems.

2.2 Parbak backup rings in N300-90 nitrile rubber cannot be used in dynamic seals in type II systems, as they become so hard and brittle that they are subject to early damage.

2.3 Scarf-cut unfilled virgin Teflon backup rings provide better protection than Parbaks in type II systems, but they are not likely to survive for 1000 hours at 275°F in dynamic applications.

3.0 RESULTS

Failure of Parbaks caused both tests to be discontinued. Pods 1 and 2 had been exposed to the maximum 275°F temperature for only 102 hours. Pods 3 and 4 had accumulated 859 hours at that temperature, only 141 hours short of the 1000 hour goal.

3.1 Backup Rings

The Teflon backup rings had extruded a thin feather of material along the rod, .010 to .050" long and approximately .004" thick all around the inner circumference on the low pressure side. Face width was no longer uniform, but varied from .111 to .121 on one, and .107 to .119 on the other. The scarf-cut was not the narrowest portion on either backup. (See Figure 1)

3.1 Backup Rings (continued)

The Revonoc backup rings had feathered in a manner similar to the Teflon specimens but appeared to be worn less than the Teflon backups, having face widths from .119 to .123. Since they had been exposed to approximately eight times as much wear as the Teflon rings, the Revonoc seems to be a much tougher backup ring material. (See Figure 2)

The Parbaks were all badly nibbled around the inner circumference and had hardened. Those in pods 3 and 4 had become brittle from high temperature aging, while those in pods 1 and 2 had been exposed to the 275°F temperature for much less time, and were still slightly flexible. (See Figure 3)

3.2 O-Rings

The O-rings protected by Teflon backup rings had been nibbled intermittently near the inner circumference, apparently where they contacted the inside diameters of the backup rings.

The O-rings paired with Revonoc backups were virtually intact, (one had a very small nick at one point) but the inside surface that had contacted the rod was somewhat flattened.

The O-rings tested with Parbaks were all nibbled on the inside diameter to some extent, with deep bites eroded away in the failed rings. (See Figure 4)

Damage to the O-rings due to the scarf-cut was minimal. On the rings protected by Teflon backups, there was a slight smooth dimple apparently caused by the scarf-cut. Although the rings had been somewhat nibbled, none of that seemed to have been caused by the scarf-cut.

On the rings protected by the Revonoc backup rings, one had a small pit in a location that could have been caused by the scarf-cut. The other ring did not have any evidence of the scarf-cut backup ring.

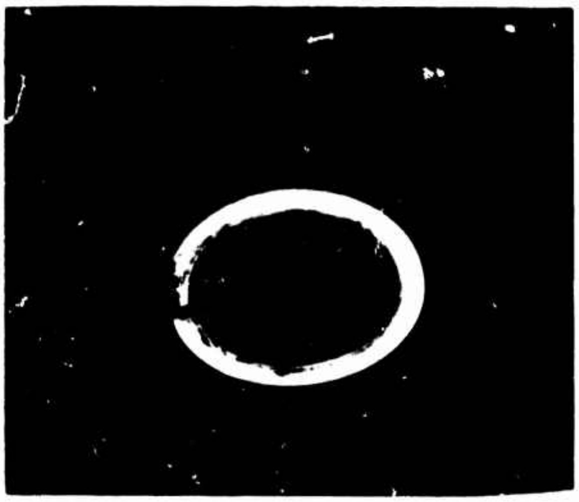


FIGURE 1.

MS28774 scarf-cut Teflon backup ring from yoke No. 2 after 102 hours accumulated time at 275°F.

Test stopped due to failure of Parbak in same test apparatus. (Yoke No. 1)

Note feathered protrusions at I.D. (Pin at top center I.D. was used to suspend ring for photo.)

FIGURE 2.

ML1359 scarf-cut Revonoc backup ring from yoke No. 4 after 859 hours accumulated time at 275°F.

Test stopped due to failure of Parbak in same test apparatus. (Yoke No. 3)

Face width after test measured .120 to .123.

~~RESTRICTED~~

FIGURE 3.

82-214-N300-90 Parbak from yoke No. 1. Failed after 102 hours accumulated time at 275°F

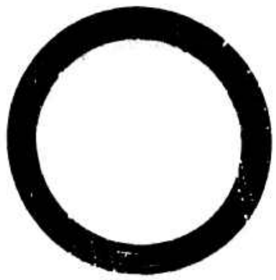
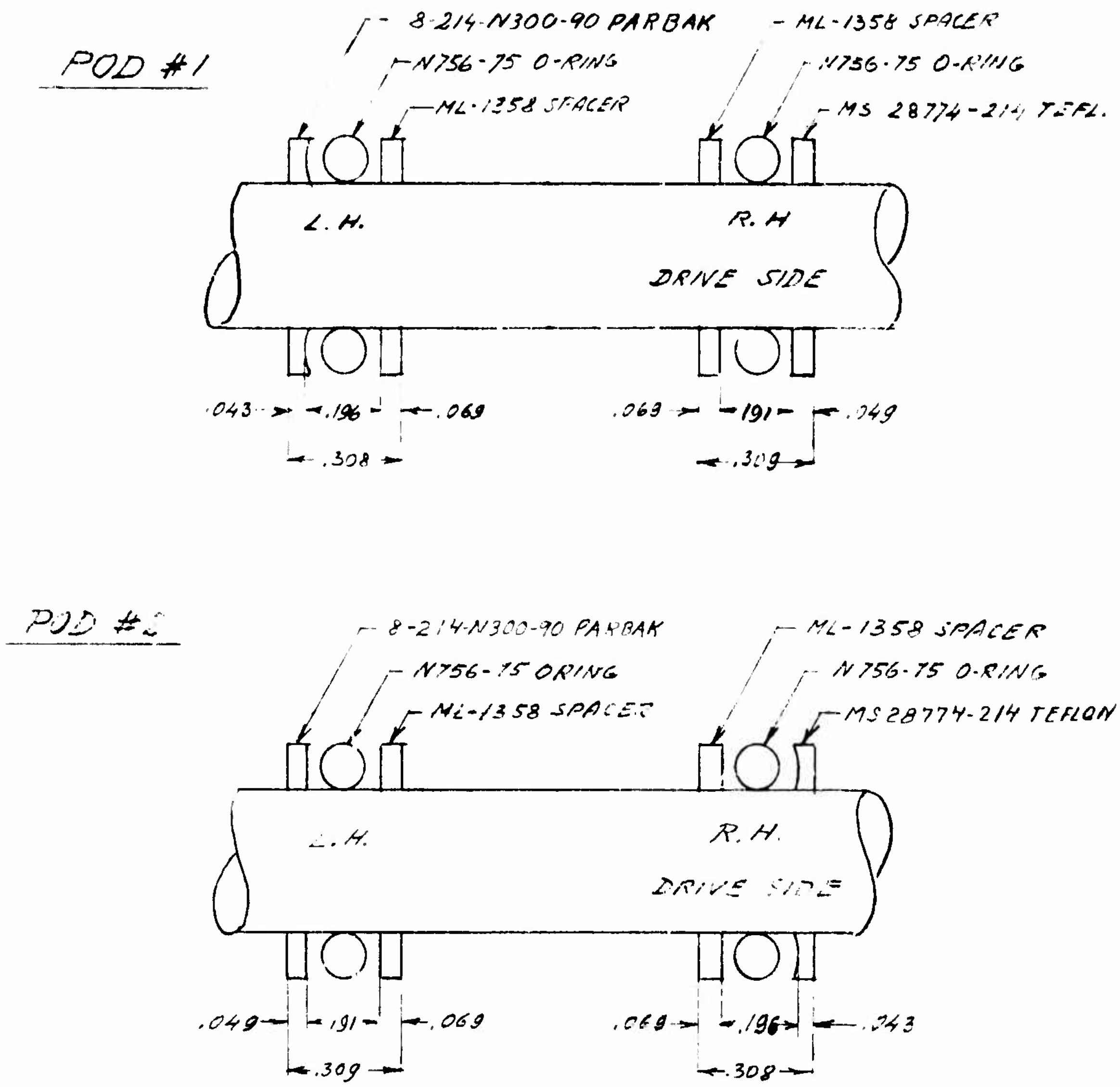


FIGURE 4.

2-214-N756-75 O-ring from yoke No. 1

Failed after 102 hours accumulated time at 275°F.

~~RESTRICTED~~



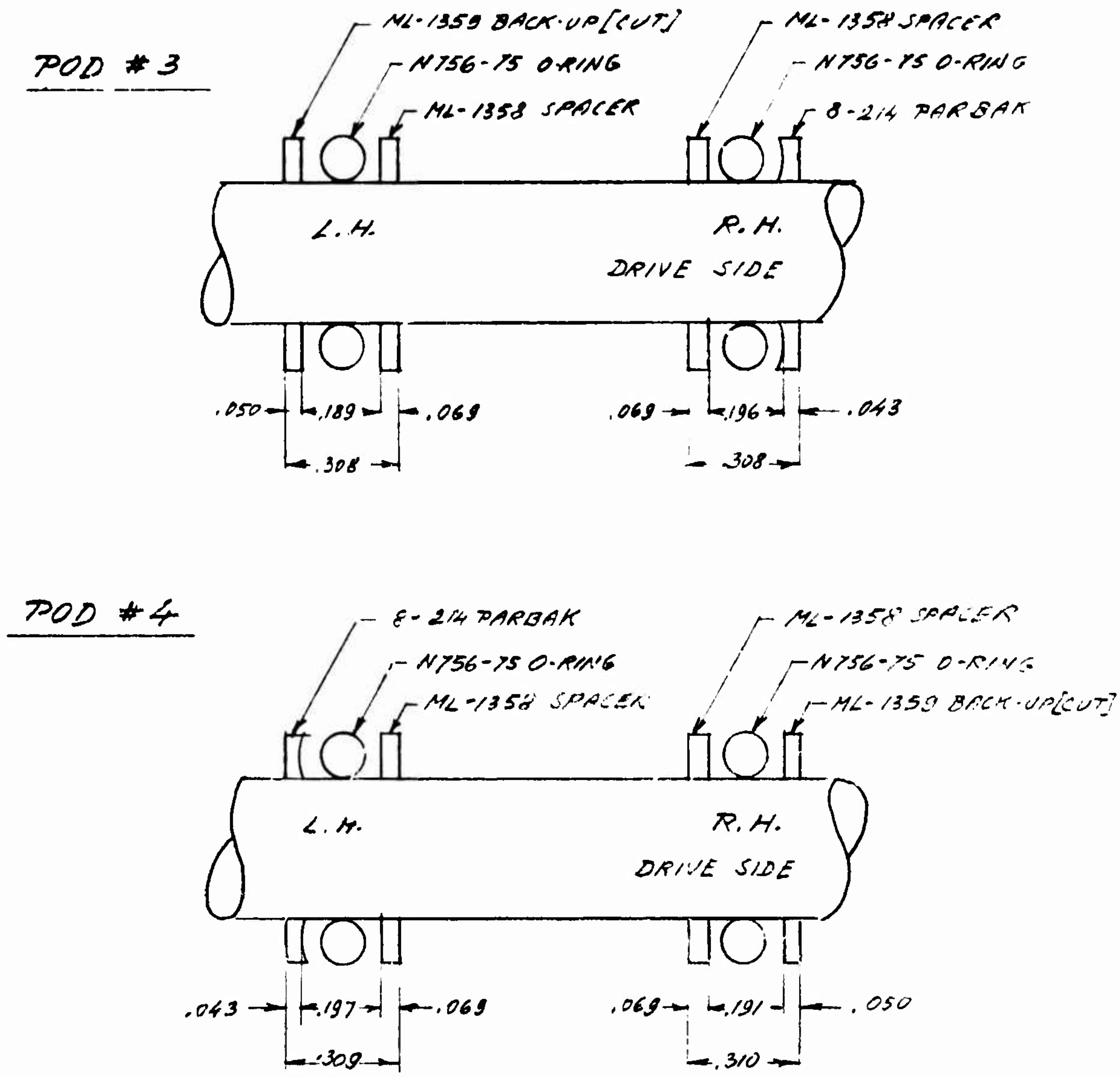
ARRANGEMENT OF O-RING SEALS
FOR BACK-UP RING TEST

FIG. 5

RESTRICTED

8-8-74
RR

4.12.74



ARRANGEMENT OF O-RING SEALS FOR BACK-UP RING TEST

FIG. 6

RESTRICTED

8-8-74 RAR. 4.12.74 K.T.K

TEST SUMMARY APPENDIX III

Dynamic Rod Test No. 203
Date Requested: 3-18-75

Project Number R10,518
Date Completed: 5-6-75

PURPOSE:

To determine whether compound N766-75 is suitable for hydraulic service from -65 to +325°F. (AFE-XN1925-25)

CONCLUSIONS:

Compound N766-75 is superior to the older nitrile compounds for this type of use, though it does not perform as well as experimental compound XN-2135-10, for which the base polymer is no longer available.

PROCEDURE: Standard long term rod test

Temperature Range: -65 to +325°F
124,800 cycles completed including 940 hours at 325°F

SEAL ASSEMBLY per ML1474-203

TEST ELEMENTS:	POD NO. 1	POD NO. 2
Seals	2-214-N766-75	Same
Backups	ML1294 Revonoc 18158 and	Same
	ML1323 Cast Iron	Same
Wipers	2-214-N766-75	Same
Fluid	MIL-H-83282 hydraulic fluid	
Pressure	4000 psig	

OBSERVATIONS AND DISCUSSION:

Each seal ring was flattened on the face that had contacted the backup rings, while the other face was still rounded. The inner corner of the flattened faces had minute cracks that could be seen when the rings were flexed. Type A durometer reading of the flattened faces was 86, and of the rounded faces was 75.

Apparently the oil in the system protected one face of the rings from air aging, while some air had reached the faces adjacent to the backup rings. Nevertheless, the rings completed the test with no major leakage occurring.

TEST SUMMARY APPENDIX IV

Dynamic Rod Test No. 203-1
Date Requested: 4-7-75

Project Number R10,518
Completed 5-29-75

PURPOSE:

To determine the suitability of experimental nitrile compound XN2135-27 for hydraulic service from -65 to +325°F.

CONCLUSIONS:

This compound may have some potential as a high temperature hydraulic service compound. Due to a mistake in conducting the test, it also appeared that fluorocarbon wiper rings might be preferable to nitrile.

TEST PROCEDURE: Standard . ng term rod test

Temperature Range: -65 to +325°F
111,700 cycles completed including 830 hours at 325°F

SEAL ASSEMBLY per ML1474-203 except O-ring material

TEST ELEMENTS:	POD NO. 3	POD NO. 4
Seals	2-214-XN2135-27	(A)
Backups	ML1294 Revonoc 18158	Same
	and ML1323 Cast iron	Same
Wipers	2-214-XN2135-27	(B)
Fluid	MIL-H-83282 hydraulic fluid	
Pressure	4000 psig	

OBSERVATIONS AND DISCUSSION:

The test was stopped due to leakage from both ends of Pod No. 3. The good conditions of two rings in Pod 4 lead us to suspect they were fluorocarbon. The specific gravity of all the rings was checked, with Pod 4 results per notes (A) and (B) below. (The intention had been to run only XN2135-27 seals and wipers.) The three nitrile wipers had become so hard they broke on removal, and the nitrile O-ring protected by the fluorocarbon backup ring was in much better condition than the other two. A piece had broken out of the outboard seal ring on No. 3,and it had been nibbled in other areas. The drive end ring had split at the parting line projection around 120°, and it also showed signs of nibbling. The drive end seal ring on the No. 4 pod, which had been protected by a fluorocarbon wiper, was intact except for a few light nibbling marks. Based on these observations, tests 203-2 and 203-5 were conducted using V747-75 fluorocarbon O-rings as wipers for nitrile O-ring seals.

(A) Outboard end had fluorocarbon O-ring seal, drive end had XN2135-27 seal.

(B) Outboard end had XN2135-27 O-ring wiper, drive end had fluorocarbon wiper.

TEST SUMMARY APPENDIX V

Dynamic Rod Test No. 203-2 Project Number R10,518
Date Requested 6-2-75 Date Completed: 7-29-75

PURPOSE:

To determine whether fluorocarbon wiper rings will protect XN2135-27 nitrile rod seals in high temperature hydraulic oil better than nitrile wipers.

CONCLUSIONS:

Fluorocarbon wipers seemed to extend the life of these XN2135-27 nitrile O-rings.

TEST PROCEDURE: Standard long term rod test

Temperature range: -65 to +325°F
140,400 cycles completed including 1020 hours at 325°F

SEAL ASSEMBLY per ML1474-203 except O-ring material.

TEST ELEMENTS:	POD NO. 1	POD NO. 2
Seals	2-214-XN2135-27	Same
Backups	ML1294 Revonoc 18158	Same
	and ML1323 Cast iron	Same
Wipers	2-214-V747-75	Same
Fluid	MIL-H-83282 hydraulic fluid	
Pressure	4000 psig	

OBSERVATIONS AND DISCUSSION:

These seals completed the full 1000 hours, and more, at 325°F without significant leakage. After the test, the rings were generally softer than the rings of test 203-1:

		TYPE A DUROMETER HARDNESS	
		Ring Adjacent to Backup Ring	Ring Facing High Pressure Oil
Test 203-1	#3 Outboard	85	74
	#4 Outboard	(Fluorocarbon Ring)	(Fluorocarbon ring)
Test 203-2	#1 Outboard	70	69
	#2 Outboard	71	77

(continued)

Rod Test 203-2 (continued)

TYPE A DUROMETER HARDNESS

		Ring Adjacent to Backup Ring	Ring Facing High Pressure Oil
Test 203-1	#3 Drive end	77	73
	#4 Drive end	75 (Fluoro wiper)	74 (Fluoro wiper)
Test 203-2	#1 Drive end	69	71
	#2 Drive end	71	74

Two of the rings from this test were badly damaged, one being split at one point, and a piece had torn out of another, so that it was a mystery how they had been able to maintain a seal. Some of the damage could have been on disassembly. Nevertheless, they had taken less set than the two rings of test 203-1 that had been protected by nitrile wiper rings as evidenced by the larger radial cross section diameters:

		Radial Cross Section Diameter	Protected by
Test 203-1	#3 Outboard	.127/.129	Nitrile wiper
	#3 Drive end	.128/.130	Nitrile wiper
	#4 Outboard	(Fluorocarbon Ring)	----
	#4 Drive end	.129/.131	Fluorocarbon wiper
Test 203-2	#1 Outboard	.131/.133	Fluorocarbon wiper
	#1 Drive end	.131/.133	Fluorocarbon wiper
	#2 Outboard	.129/.131	Fluorocarbon wiper
	#2 Drive end	.130/.132	Fluorocarbon wiper

TEST SUMMARY APPENDIX VI

Dynamic Rod Test No. 203-3
Date Requested: 6-2-75

Project Number R10,518
Date Completed: 6-12-75

PURPOSE:

To determine the feasibility of using L677-70 fluorosilicone O-rings as high temperature hydraulic oil seals.

CONCLUSIONS:

Fluorosilicone rubber is not tough enough to withstand the wear in this type of dynamic application.

TEST PROCEDURE: Standard long term rod test

Temperature range: -65 to +325°F
31,200 cycles completed including 124 hours at 325°F

SEAL ASSEMBLY per ML1474-203 except O-ring material

TEST ELEMENTS:	POD NO. 3	POD NO. 4
Seals	2-214-L677-70	Same
Backups	ML1294 Revonoc 18158	Same
	and ML1323 Cast iron	Same
Wipers	2-214-L677-70	Same
Fluid	MIL-H-83282 hydraulic fluid	
Pressure	4000 psig	

OBSERVATIONS AND DISCUSSION:

The test was stopped prematurely due to leakage from all seals at room temperature.

Physically, all the rings were still soft and flexible after the test, but the seal rings were nibbled at the ID, and all the rings, including the wipers, were flattened at the ID, apparently due to wear. The drive end ring from rod number 4 was badly extruded.

TEST SUMMARY APPENDIX VII

Dynamic Rod Test No. 203-4
Date Requested: 6-13-75

Project Number R10,518
Date Completed: 7-16-75

PURPOSE:

To check the effectiveness of N756-75 O-ring as seals and wipers in high temperature hydraulic service.

CONCLUSIONS: N756-75 does not appear to be suitable for this type of service.

TEST PROCEDURE: Standard long term rod test

Temperature range: -65 to +325°F
52,800 cycles completed including 466 hours at 325°F

SEAL ASSEMBLY per ML1474-203 except O-ring material

TEST ELEMENTS	POD NO. 3	POD NO. 4
Seals	2-214-N756-75	Same
Backups	ML1294 Revonoc 18153	Same
	and ML1323 Cast iron	Same
Wipers	2-214-N756-75	Same
Fluid	MIL-H-83282 hydraulic fluid	
Pressure	4000 psig	

OBSERVATIONS AND DISCUSSION:

The test was stopped due to severe leakage from all seals at -65°F.

There was no noticeable damage on any of the seal rings, though the wipers had all become so hard and brittle that they broke on removal.

The seal rings had hardened somewhat, with type A durometer readings ranging from 79 to 84. They had also taken a set, the radial cross section diameters measuring between .127 and .129.

TEST SUMMARY APPENDIX VIII

Dynamic Rod Test No. 203-5 Project Number R10,518
Date Requested: 7-23-75 Date Completed: 9-3-75

PURPOSE:

To determine whether fluorocarbon wipers will extend the life of N756-75 O-ring seals in high temperature hydraulic service.

CONCLUSIONS:

Fluorocarbon wipers appear to extend the life of N756-75 O-rings to some extent.

TEST PROCEDURE: Standard long term rod test

Temperature range: -65 to +325°F
87,800 cycles completed including 581 hours at 325°F

SEAL ASSEMBLY per ML1474-203 except O-ring material

TEST ELEMENTS:	POD NO. 3	POD NO. 4
Seals	2-214-N756-75	Same
Backups	ML1294 Revonoc 18158	Same
	and ML1323 Cast iron	Same
Wipers	2-214-V747-75	Same
Fluid	MIL-H-83282 hydraulic fluid	
Pressure	4000 psig	

OBSERVATIONS AND DISCUSSION:

The test was stopped due to severe leakage from the drive end seal of Rod No. 4.

In comparing with test 203-4, the fact that this test ran longer would seem to indicate that the fluorocarbon wiper rings made a real improvement in seal life (even though it was not enough to pass the 1000 hour requirement). Examining the seal rings, however it was found that these had generally hardened more, ranging from 80 to 93 Type A durometer (vs. 79 to 84), the radial cross sections were smaller, measuring .123 to .126 (vs. .127 to .129) indicating a greater amount of set, and three of the rings had been nibbled. The one ring that appeared to be undamaged was the ring that had leaked.

APPENDIX IX

Engineering Report No. 05-249 Addendum XI

Effect of the Straight-cut and Scarf-cut Backup Rings
on the
Operation and Wear of Seal Components

Addendum XI

1.0 BACKGROUND

1.1 The seal components for this 1000 hour test were assembled according to the recommendations and schemes specified in the Report No. 05-249 Addendum X, with the exception of the cylinder #1. In this cylinder the Retainer ML-1202 Revison A was mounted in lieu of the Retainer ML-1349. The functional effect of this departure from the original instructions is discussed in 4.2 and 4.3.

2.0 CONCLUSIONS

2.1 The rings with straight cuts are not recommended as backups for elastomer O-rings, especially if these rings are made of relatively hard plastics as filled Teflon (Tetralon, Revonoc or Rulon). Under certain conditions, which may occasionally occur in service (due to improper dimensions, tolerances, thermal shrinkage, or wear) an extrusion gap may open between the ends of the cut ring. Such a gap displaying sharp edges may be highly damaging to the O-ring pressurized to the point of extrusion. A progressive cracking and chipping of the O-ring material by the sharp edges of the backup ring may dig in the O-ring a groove (See Figure 1) locally weakening the O-ring and leading to its failure.

2.2 A scarf-cut backup ring, which does not form an extrusion gap should provide in most cases an adequate support for the O-ring. A number of small, shallow pits, with well rounded edges, noticeable along 1/6 of the circumference of the O-ring's face adjacent to the scarf-cut backup ring, in case of the front O-ring in the cylinder #2, was probably ground by the protruding edge of the scarf-cut. This would indicate that the changes in the scarf-cut overlap caused by the circumferential thermal expansion and contraction of the backup ring could cause a slight rotation of the backup ring. The scarf-cut would in this case operate like a ratchet. However, the smallness of the above pits after the strenuous 1000 hour test and the fact that no pits were found on the rear O-ring in Cylinder #2 would indicate that the damaging effect of a scarf-cut is benign and can be tolerated.

2.3 In the case of the step-cut piston ring, which was proposed in lieu of the present continuous cast iron ring for pistons of large diameters, the sacrificial plastic backup ring would be extruded against a gap of limited depth but displaying sharp edges. It is expected however that because of high plasticity at elevated temperatures of the material of the sacrificial backup ring, the dead end gap will be filled with the limited amount of that material without impairing the supporting ability of the thick backup ring. Properly programmed tests will be required to check the validity of the above assumption.

3.0 TEST CONDITIONS

3.1 Components Tested

(See Figure 1 in Report No. 05-249 Addendum X)

3.1.1 Cylinder No. 1 Front End

ML-1202 Revison A Retainer (low squeeze)

V747-75 2-214 O-ring

ML-1294 Revonoc Backup Ring straight cut (two rings)

ML-1293 Cast Iron Backup Ring

3.1.2 Cylinder No. 1 Rear End

The same as the Front End

3.1.3 Cylinder No. 2 Front End - (See Figure 1 in Report #05-249 Addendum X)

ML-1203 Revision A Retainer (normal squeeze)

V747-75 2-214 O-ring

ML-1294 Revonoc Backup Ring scarf-cut (two rings)

ML-1293 Cast Iron Backup Ring

3.1.4 Cylinder No. 2 Rear End

The same as the Front End

3.1.5 Cylinder No. 3 Front End (See Figure 3 in Report #05-249 Addendum X)

ML-1204 Revision A Retainer (high squeeze)

V747-75 2-214 O-ring

ML-1296 Revonoc Backup Ring straight cut (two rings)

ML-1300 Cast Iron Backup Ring

3.1.6 Cylinder No. 3 Rear End

The same as the Front End

3.2 Test Fluid

Per MIL-H-83282

3.3 Operational Conditions

3.3.1 Standard 1000 Hours Test Procedure

3.3.2 Fluid Pressure Range 50-4000 psi

3.3.3 Temperature Range -30°F to 350

4.0 DISCUSSION OF THE TEST AND OF THE TEST RESULTS

4.1 The 1000 hours test including 137,080 pressure cycles was completed without incident (See Appendix 1.)

4.2 According to the recommendations of the Report #05-249 Addendum X the operation under the low squeeze was to be eliminated and a new Retainer ML-1349 (normal squeeze, identical with the Retainer ML-1203 Rev. A) was to be used in lieu of the Retainer ML-1202 Rev. A. The new Retainer ML-1349 was however not delivered in time for the test, and the low squeeze Retainer ML-1202 Rev.A was mistakenly assembled in the Cylinder #1. The error was compounded by assembling the backup rings ML-1294 (normal squeeze) with the low squeeze Retainer. Unexpectedly the above error turned to our advantage.

4.3 As a result of the intensive development effort, the design of the components of our typical seal has been optimized to such an extent that the wear of these components was very small after the 1000 hours test.

The after-test inspection of the seal components of the Cylinder #3 revealed that both straight cut backup rings fitted the cylinder bore with zero gap between the ring's ends. In this cylinder the backup rings were properly matched with the retainer's grooves. The O-rings showed no surface damage. It was evident that at room,and at elevated temperatures, the backup rings operated with zero or near zero gaps. While this evidence was very satisfactory from the operational standpoint, it did not provide warning upon the damaging affect of large gaps.

On the other hand the after-test inspection of the seal components of the Cylinder #1 revealed that both straight-cut backup rings fitted the cylinder bore with .012 - .015 gap between the ring's ends. It was evident that due to the mismatch discussed in 4.2 the backup rings maintained large gaps during most of the operational phases. The damage to the front O-ring is shown on Figure 1. In case of the rear O-ring, two parallel cracks were noticeable across the O-ring. The distance between the cracks was about the same as the width of the groove in the front O-ring.

4.4 Because it was likely that in some of the seal applications the straight-cut backup rings might not be properly matched and might operate with positive gaps, the use of the backup rings with straight cut was not recommended.

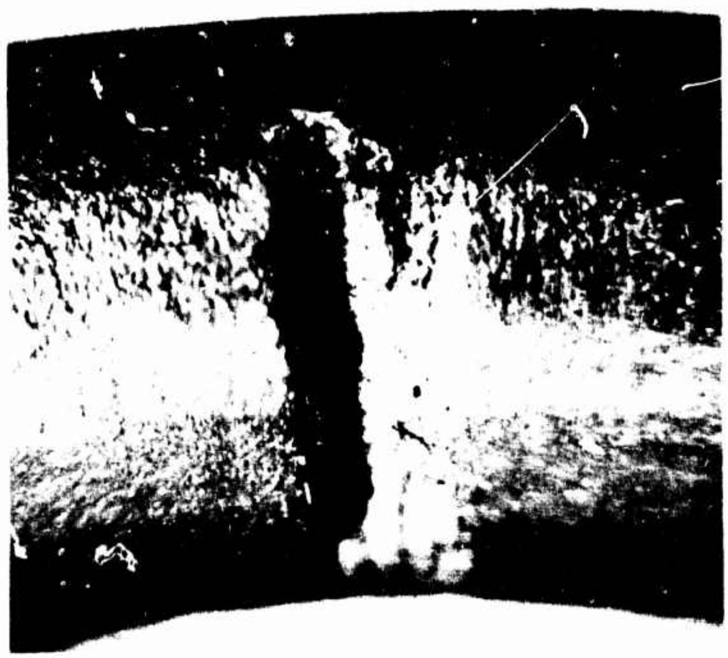


Figure 1.

APPENDIX X.

Engineering Report No. 05-249 Addendum XII

Study of the Operational Conditions of the Piston Components in Case of the Off-Center Position of the Piston

Addendum XII

According to the information obtained from the Hydraulic Division of the Aerospace Group in Irvine, the maximum diametric clearance between the cylinder bore and the guiding surface of the piston is approximately .010 in case of actuators of 2-3 inch cylinder bore diameter. This clearance takes into account the expansion of the cylinder bore diameter under pressure.

The purpose of this study is to evaluate the positions of the piston assembly components and the widths of the potential extrusion gaps in the case where the side loads would throw the piston off center, pressing it tight against the wall of the cylinder bore thus enlarging the gaps at the opposite side of the piston to their maximum possible widths.

The test fixture on which the 2.75 diameter cylinder will be mounted was designed as to prevent the build-up of side loads. Thus the piston cannot be moved out of center by application of external forces.

In order to achieve the off-center position of the piston required in this test, the piston was made of three parts. (Figure 1) The main part of the piston (the Piston Body ML-1366) which carries the O-rings and the backup rings, can move laterally off-center of the cylinder bore thanks to the liberal clearances between the Piston Body and the Rod ML-1368 guided in the cylinder.

A Guide ML-1367 mounted at each end of the Cylinder Body and centered on the groove I.D. "A" is provided with two circumferential surfaces. The surface determined by the diameter "C" fits slidingly in the cylinder bore with close tolerances. It is however machined off-center to the surfaces "B" and "A", thus maintaining off-center the Piston Body ML-1366.

In case of the lateral shift of the Piston Body as described above, the center line of the piston remains parallel to the center line of the cylinder bore. That may not occur in case of the actuators, where the piston is moved out of center by external lateral loads. However, the analysis has shown that within the existing tolerances, the angular deviation of the center lines would be so small that its effects can be totally neglected. Thus the system described above is fully representative for all types of off-center shift of the piston.

Figure 2 is a schematic layout of the cylinder-piston cross section showing the dimensions of the pertinent diameters and clearances in a case where the piston guided by the surface "C" as in Figure 1 is in the central position with the cylinder bore. In this case, the maximum depth of the gland would occur at the side "G" (.1895 - .1900) while the minimum depth (.1795 - .1800) would be at the side "H."

Since the O-ring would be squeezed more in the gland at the side "H" than at the side "G" it would tend to move the piston off center towards the side "G" as far as it would go. Figure 3 shows the gland depths and clearances in that position.

Addendum XII

The dimensions of the plastic backup ring shown on Figure 4 were determined upon the data specified on Figure 3. In this case the backup ring would be free to extrude into the maximum gap of .009 - .011. Figure 5 depicts the case where a cast iron backup ring was mounted at the inlet of the extrusion gap to close it. The sacrificial plastic backup ring was provided with a lip to fill the gap between the metal piston ring and the bottom of the groove. The lip is thin enough to permit the metal piston ring to float and be guided by the cylinder bore. It will however reduce the volume of the sacrificial backup ring's material which could flow into the gap when the material became soft at high temperature. Thus it will reduce the distortion and the alteration of the basic shape of the sacrificial backup ring.

A delicate problem connected with the above system of simulation of the off-center position of the piston is the fact that the depth of the gland is uneven along its circumference even in the off-center position (Figure 3). While it should not affect substantially the operation of the O-rings, it might create some problems with the plastic backup rings. These rings are fairly rigid at room and at moderately elevated temperatures. For obvious reasons their O.D. and I.D. are concentric.

To start, with the Plastic Backup Rings ML-1378 and ML-1379 were made .184 ± .001 deep. In the piston position as per Figure 3, Figure 4 and Figure 5, they will fit the gland with interference at the side H but with a radial clearance at the side G. They will cooperate with the O-rings in pushing the piston to the off-center position. The interference at the side H should present no problem as it would soon disappear during the initial breaking-in run. It appears also that the possible clearance at the side "G" would be too small to be injurious to the O-ring.

The percentage of fill of the net gland cavity by the O-ring volume was calculated in Appendix 1 attached to this report. The volume of the O-ring calculated from the catalog dimensions was increased by 15% to cater for the differential thermal expansion and for swell.

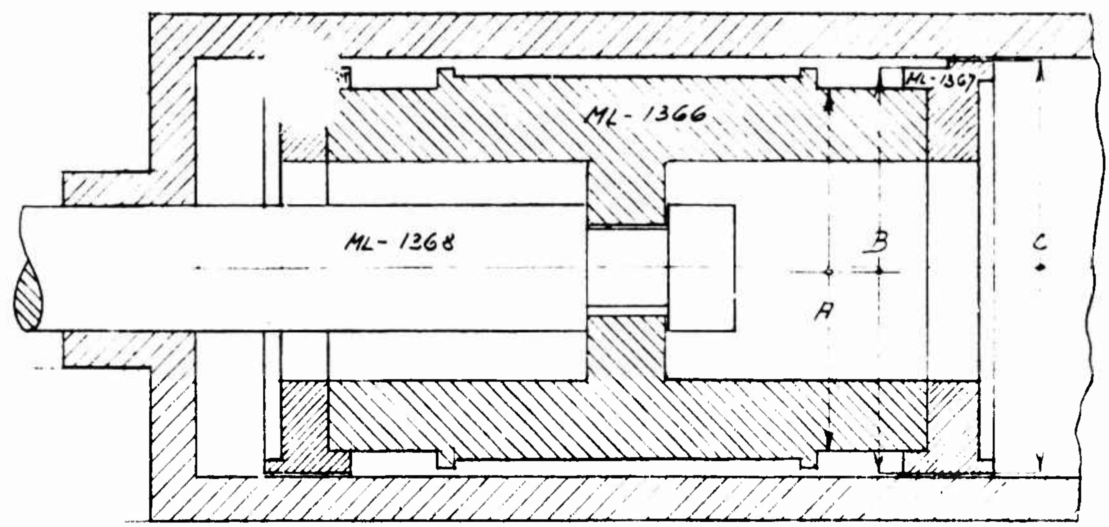


FIG. 1.

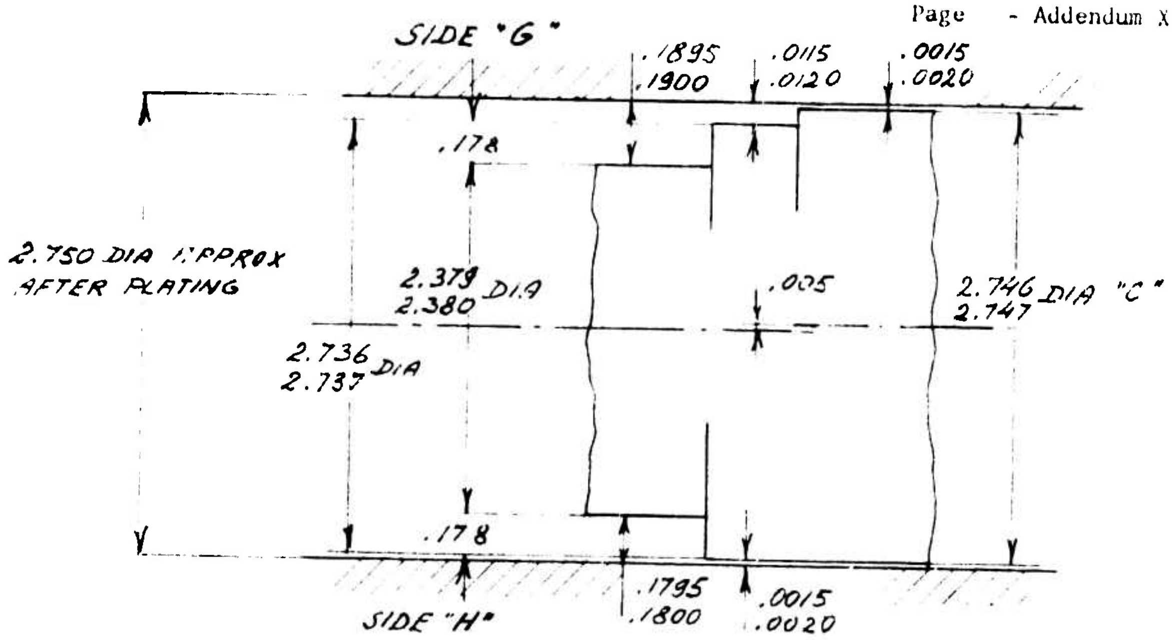


FIG. 2.

PISTON'S GUIDE SURFACE "C" IN THE CENTRAL POSITION

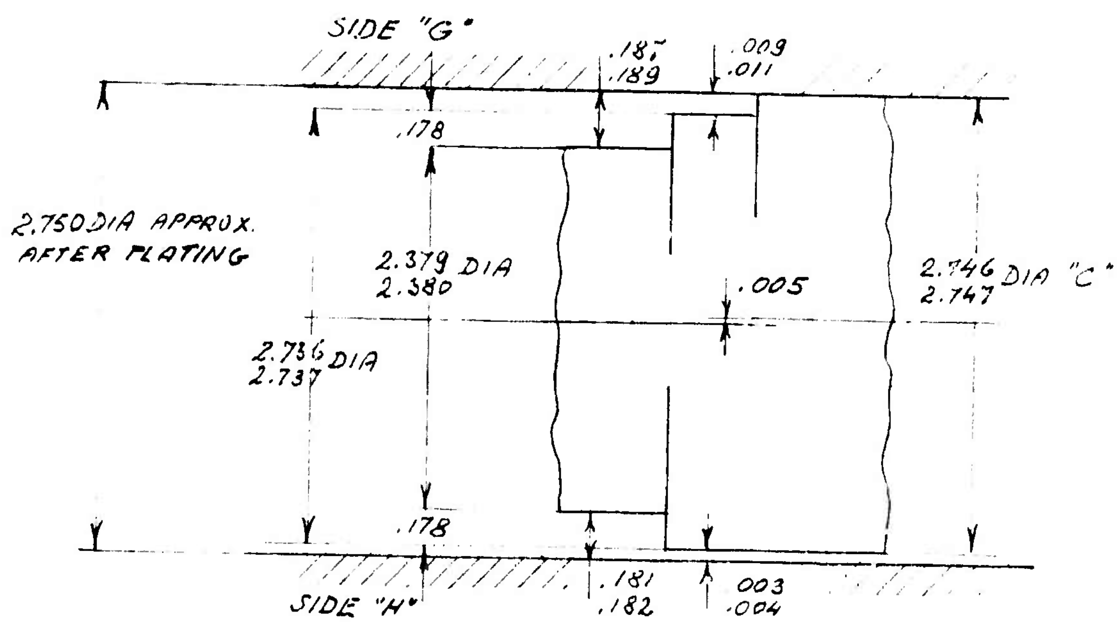
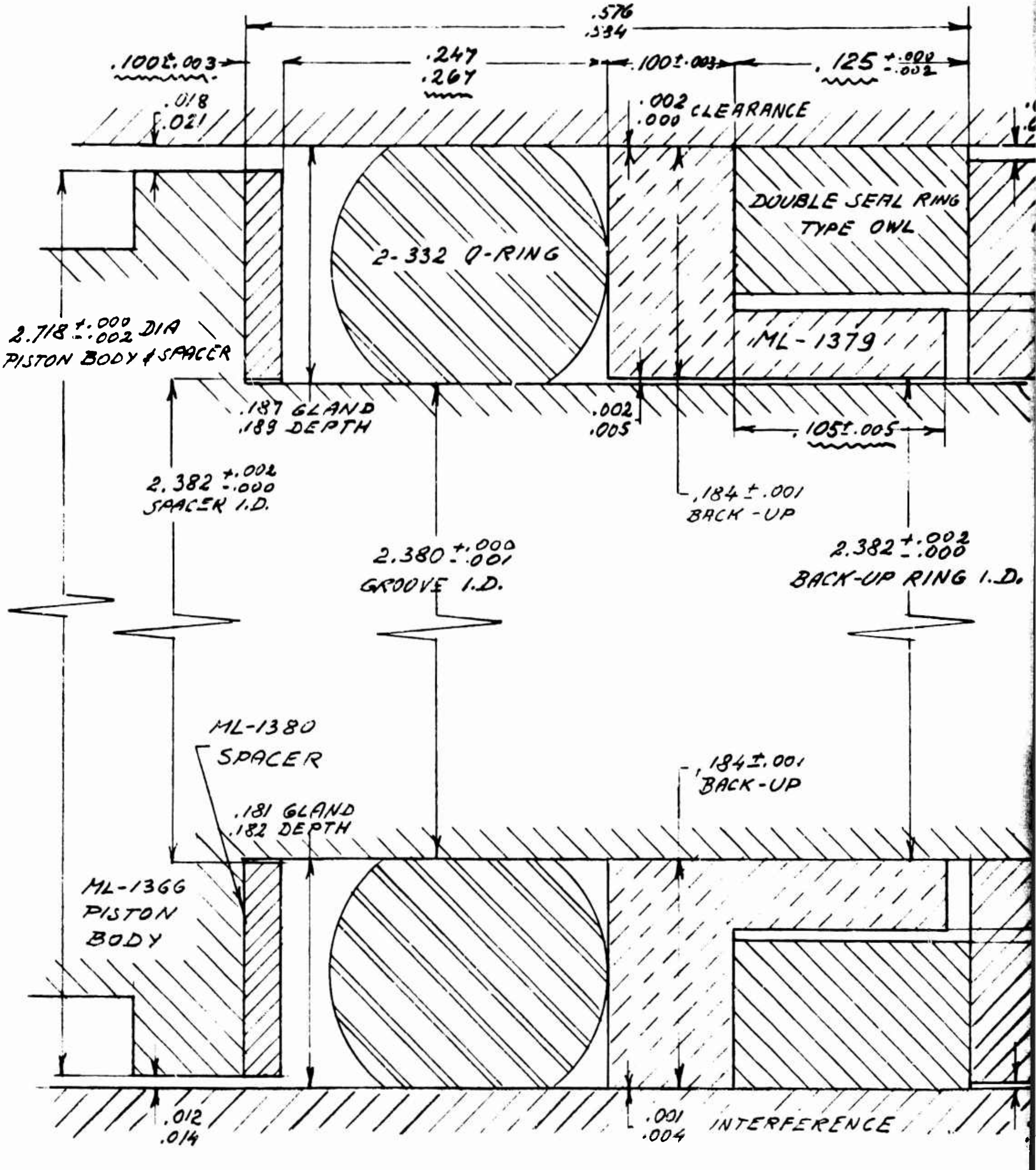


FIG. 3.

PISTON'S GUIDE SURFACE "C" OFF CENTER


.576
.534
.100±.003
.247
.267
.100±.003
.125 +.000 -.002
.018
.021
.002
.000 CLEARANCE
DOUBLE SEAL RING
TYPE OWL
2-332 O-RING
2.718 +.000 -.002 DIA
PISTON BODY & SPACER
ML-1379
.187 GLAND
.189 DEPTH
.002
.005
.105±.005
2.382 +.002 -.000
SPACER I.D.
.184±.001
BACK-UP
2.380 +.000 -.001
GROOVE I.D.
2.382 +.002 -.000
BACK-UP RING I.D.
ML-1380
SPACER
.184±.001
BACK-UP
.181 GLAND
.182 DEPTH
ML-1366
PISTON
BODY
.012
.014
.001
.004 INTERFERENCE

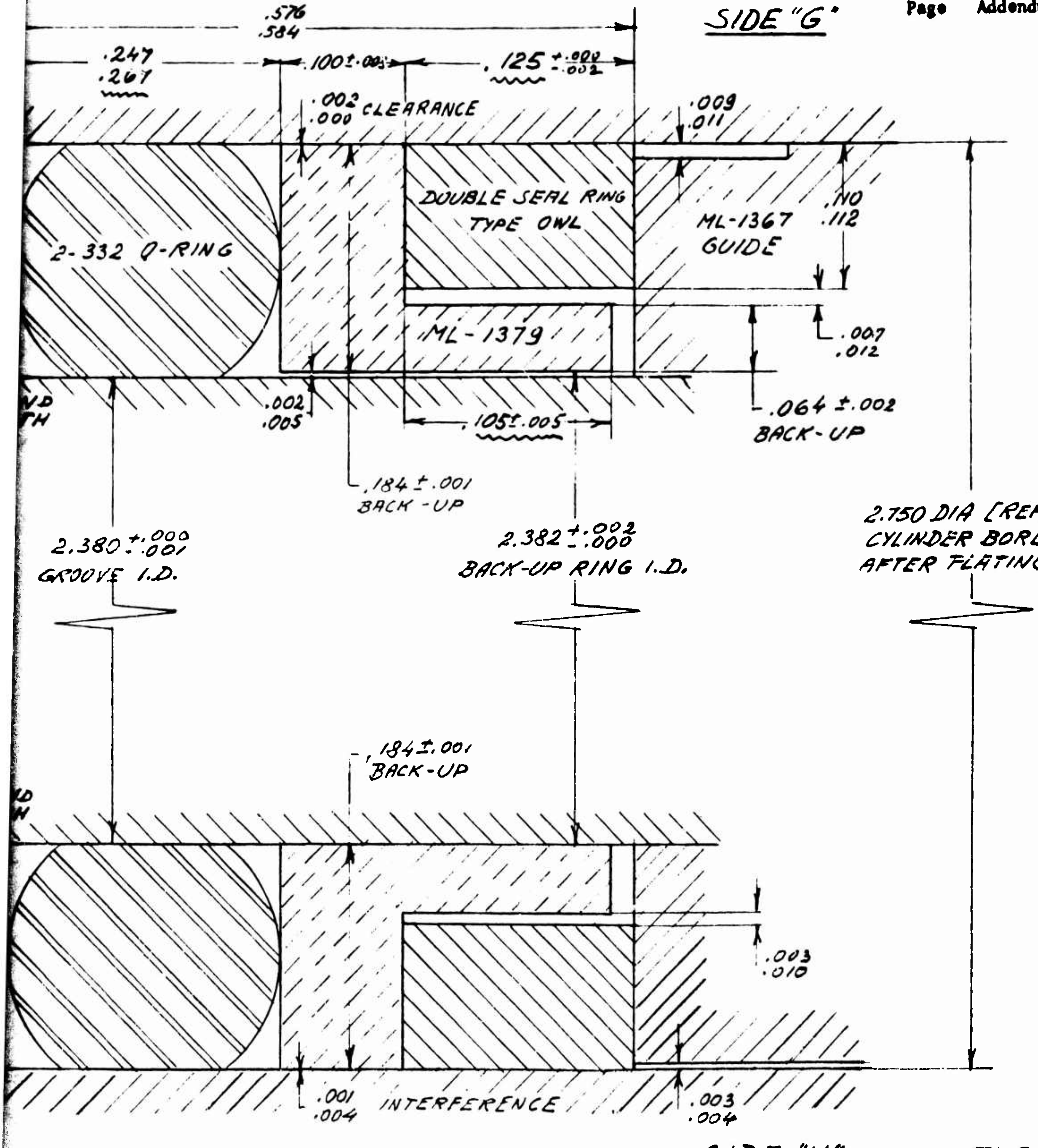
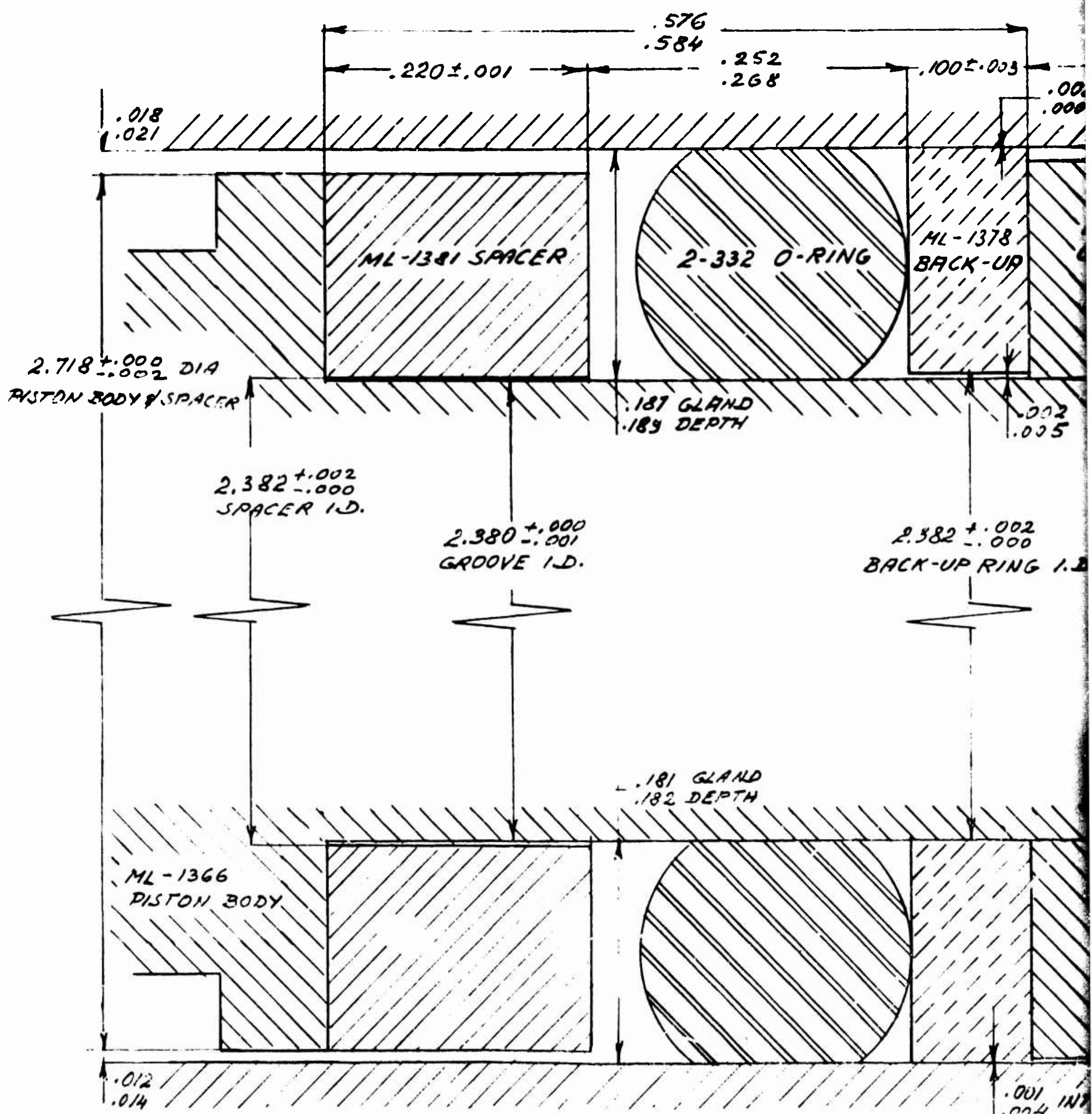

SIDE "G"
.576
.584
.247
.267
.100±.005
.125 +.000 -.002
.002
.000 CLEARANCE
.009
.011
DOUBLE SEAL RING
TYPE OWL
2-332 O-RING
ML-1367
GUIDE
.110
.112
ML-1379
.007
.012
.002
.005
.105±.005
.064 ±.002
BACK-UP
.184 ±.001
BACK-UP
2.750 DIA (REF)
CYLINDER BORE
AFTER PLATING
2.380 +.000 -.001
GROOVE I.D.
2.382 +.002 -.000
BACK-UP RING I.D.
.184±.001
BACK-UP
.003
.010
.001
.004
INTERFERENCE
.003
.004
SIDE "H"

FIG. 4

2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ML-1381 SPACER
2-332 O-RING
ML-1378
BACK-UP
2.718 +.000 -.002 DIA
PISTON BODY & SPACER
.187 GLAND
.189 DEPTH
.002
.005
2.382 +.002 -.000
SPACER I.D.
2.380 +.000 -.001
GROOVE I.D.
2.382 +.002 -.000
BACK-UP RING
.181 GLAND
.182 DEPTH
ML-1366
PISTON BODY
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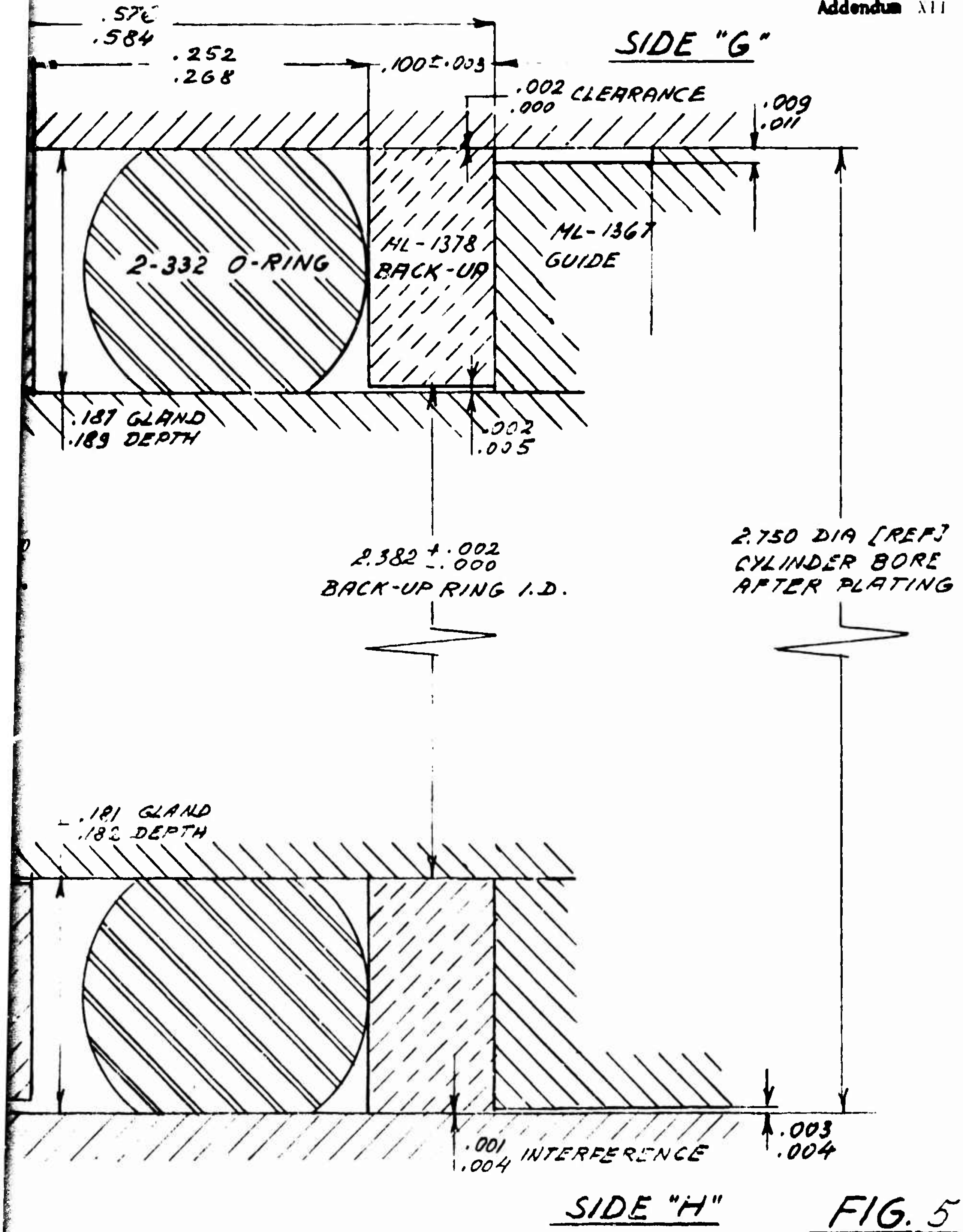
.001
.004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SIDE "G"
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BACK-UP
ML-1367
GUIDE
.187 GLAND
.189 DEPTH
.002
.005
2.382 +.002 -.000
BACK-UP RING I.D.
2.750 DIA [REF]
CYLINDER BORE
AFTER PLATING
.181 GLAND
.182 DEPTH
.001
.004
INTERFERENCE
.003
.004
SIDE "H"

FIG. 5

APPENDIX XI.

Engineering Report No. 05-249 Addendum XIII

Study of the Dynamics of the Drive of the Piston Seal Test Fixture ML-1198 Revision A

Addendum XIII

INTRODUCTION

The subject of this report is the study of the changing pattern of forces, loads and reactions occurring in the drive system of the Piston Seal Test Fixture ML-1198 Revision A. The findings of this study were used to optimize the design of the drive and to issue operational instructions to facilitate the start of the fixture under adverse conditions induced by the cold soak test.

CONCLUSIONS AND RECOMMENDATIONS

1. With the existing geometry of the drive system of the Piston Seal Test Fixture, the lateral loads imposed on the balls of the ball bushings are relatively small not exceeding 0.172 of the operational torque of the driving shaft of the gear box (See ML-1494).

2. The torque transmitted to the drive system, and thus the forces generated in the system depend on the frictional resistance of the driven components, mainly that of the O-rings and of the backup rings.

3. At the end of each stroke large pushing and pulling forces are generated in the Yoke Rod (Item 10 on ML-1198, Revision A) by a relatively small torque input. This is due to the mechanical advantage characteristic to the force pattern occurring at and near each end of the stroke. This mechanical advantage can be utilized to break the ice, which often forms on the rods during the cold soaking test. If the crank (hub of the gear box shaft) is lined up with the connecting rod in the innermost position before the start of the cold soak test, a very large force will be available for breaking up the ice without overloading the motor. Because very small lateral forces occur at that position of the driving components, this rather brutal operation will not harm the bushings nor the rod.

4. Because the lateral loads are applied on the rod outside of the support provided by the bushings, the reactions to those loads are concentrated on the outermost balls of the two bushings assembled in tandem. The selection of a proper clearance between the balls and the rod is very important for the proper operation of the system. Tight clearances minimize wobbling of the rod in the ball sleeves and favor spreading of the supporting reactions over the balls adjacent to the end ones, provided that some deflection of the bushings under loads is possible. However, very tight fit may become critical in the installation where the bushings are press-fitted in the housing or where a substantial temperature differential between the rod and the bushings may occur.

5. To assure a better control of the clearance between the balls and rod, and to facilitate replacement of the worn bushing, a layout where the bushings are snug fitted in the housing and retained by snap rings is preferable to a layout, where the bushings are pressed into the housing.

6. A reduction of the loads on the balls is obtained if the load is distributed over two rows of balls as in Figure 1. In case of the drive where the lateral loads are reversible, bushings with an even number of ball tracks are recommended.

DISCUSSION

Drawing ML-1494 is a diagrammatic representation of forces occurring in the components of the drive mechanism of the Piston Seal Test Fixture (ML-1198 Revision A) during the operation of the fixture. The reactions R_1 and R_2 produced by the drive forces in the ball bushings are assumed to be concentrated on the last outboard balls of the two ball bushings assembled in tandem.

The circumferential force "P" was assumed as the basic unit, and all forces and reactions are expressed in multiples or in fractions of "P".

$P = \frac{T}{0.95}$ where "T" is the torque on the drive shaft of the gear box,

and 0.95 is the radius on which "P" is applied.

In Case 1, the angle between the above radius and the connecting rod is 90°, thus the total circumferential force is transmitted by the connecting rod to the yoke rod (Item 11 on ML-1198, Revision A). The horizontal component "H" of the above force directed in the axis of the yoke rod is 0.994P, while the vertical component S = 0.1048P produces the reactions R_1 = 0.1628P and R_2 = 0.0542P.

In Case 2 where the crank is at 45° from its innermost position the horizontal component H is slightly increased, while the reactions R_1 and R_2 are decreased to 0.1339P and .03069P respectively.

In Case 3, the crank is 10° off its innermost position where the crank, the connecting rod and the yoke rod would be in line. Here the horizontal component H = 5.199P due to large mechanical advantage occurring at this position of the crank. The reactions R_1 and R_2 are only 0.1252P and 0.0299P.

In case of the complete lineup of the crank, of the connecting rod and of the yoke rod, the forces L and H would be theorectically infinitely large.

It should be kept in mind, however, that such large forces do not occur usually in the driving mechanism. The force transmitted to the yoke rod is determined by the friction in the drive mechanism, mainly by the friction resistance of the O-rings and of the backup rings pressing against the respective cylinder bores.

Addendum XIII

For simplicity's sake, it could be assumed that the coefficient of friction would not change with velocity within the piston velocity range (from maximum at the middle of the stroke to zero at the reversals). If the friction resistance "C" is assumed as constant under the given pressure conditions, the torque required to drive the fixture would fluctuate between 0.96C and theoretically zero.

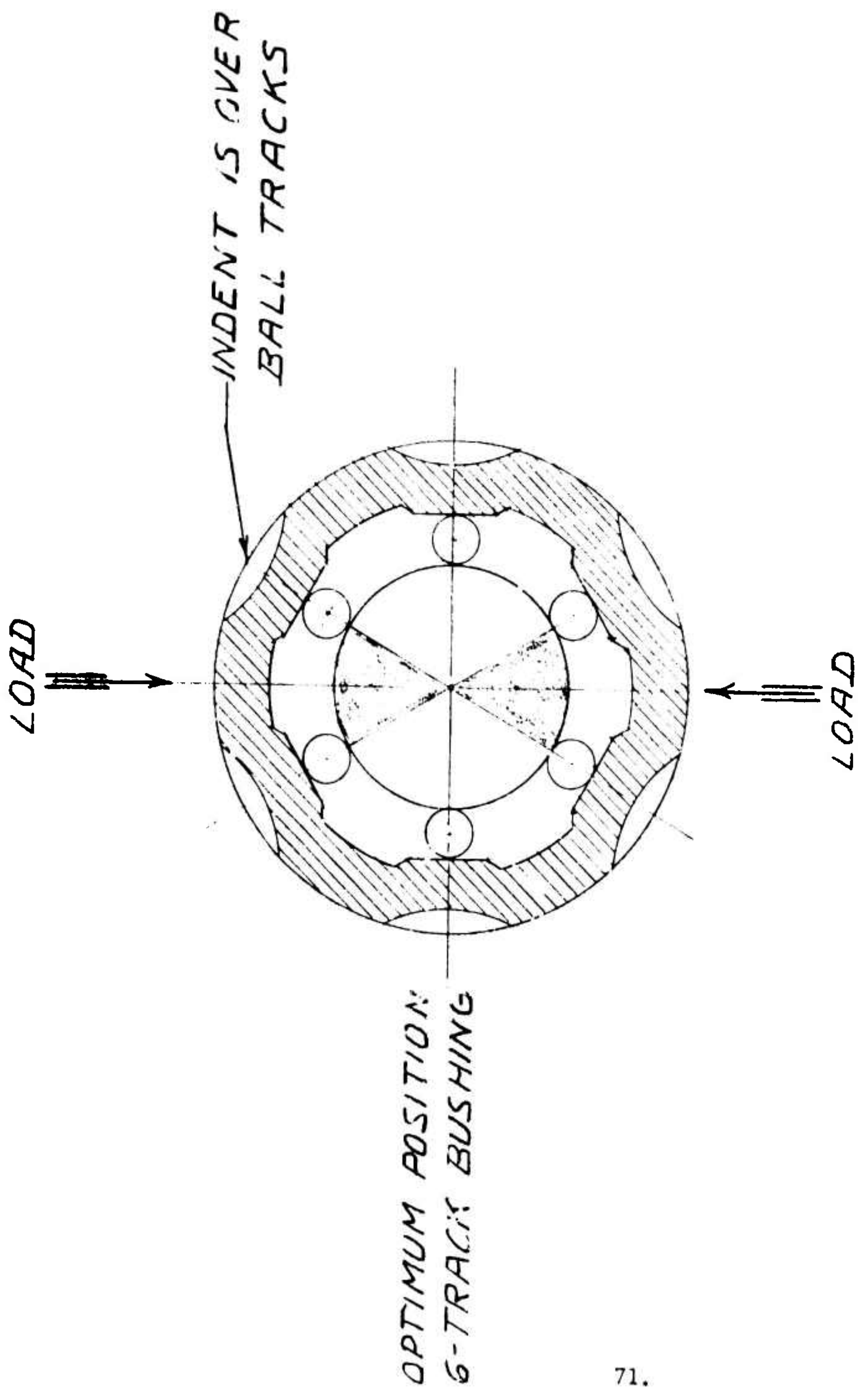
The mechanical advantage resulting in the very high force component in the connecting rod can be utilized to break the ice, which often builds up on the rods during the cold soaking test. If the crank was lined up with the connecting rod in the innermost position before the start of the cold soak test, a very large force would be provided to break the ice without overloading the motor.

The brinelling loads produced by the outboard balls of the bushing would be insignificant because of the very low lateral loads in the vicinity of the innermost (or outermost) position of the crank. The location of the reaction forces R_1 and R_2 (ML-1494) is based on the assumption that the side loads are carried exclusively by the outermost balls of the pair of ball bushings mounted in tandem. This assumption would be true in case of the perfectly rigid bushings and of a positive clearance between the balls and the rod. The choice of a proper clearance between the balls and the rod is very difficult in case of the layout as on ML-1198 where the side loads are applied at the rod-end protruding beyond the supporting balls and where the system must operate within a wide range of temperatures. To utilize the possible minuscule give-in of the bushings and to spread the load over more balls than the outermost ones, a closest possible fit should be used. This fit, however, may become marginal in case of a substantial temperature differential between the rod and the ball bushings.

Based on the experience accumulated during the operation of the Rod Seal Rig Drawing 5718000 and after some rod failures the diameter of the Rod ML-1432 in the ML-1198 Revision A Test Fixture was established at 1.2465 - 1.2475 thus by .0015 .0025 smaller than the maximum diameter permitted by the Thomson Industries for the Precision Series A bushings operating at room temperatures.

A reduction of loads on the balls is obtained if the load is distributed over two rows of balls as in Figure 1. In case of the drive where the lateral loads are reversible, bushings with an even number of ball tracks are recommended. The ball bushings in the Cylinder Seal Test Fixture ML-1198 Revision A have six ball tracks.

Using a snug fit between the bushing and the housing and holding the bushings in position by snap rings is preferable to securing the bushings in the housing by press fit. It permits a better control of the clearance between the balls and the rod and it facilitates replacement of the worn bushings.



CIRCUMFERENTIAL POSITIONING
FOR MAXIMUM ROLLING LOAD CAPACITY.

FIG. 1.

APPENDIX XII

Engineering Report No. 05-249 Addendum XIV

Abbreviated Test of the Piston Ring Used as a Secondary Backup
in the
2.75" Diameter Cylinder - Proposed Development Tests

Addendum XIV

1.0 INTRODUCTION

1.1 The test reported here was performed in order to check the operation of an antiextrusion device consisting of a sacrificial plastic backup ring and a standard step-cut cast iron piston ring.

The tests reported in Reference 2 demonstrated that the only suitable material for the backup rings designed for operation at elevated temperatures (within the range of 275°F to 400°F) was a filled Teflon (Tetralon 720, Revonoc 18158 or Rulon J).

However these materials were still subject to extrusion and to dragging into the gap present between the cylinder bore and the piston when these components were assembled with clearances necessary for their normal operation.

At pressures and temperatures not exceeding 3000 psi and 275°F respectively, the aforementioned extrusion and dragging of the backup ring material was low enough to permit a successful completion of the 1000 hours test adopted as a typical procedure for the AFML-TR-72-66 and 73-90 projects. When the operational pressures and temperatures exceeded the above limits, the rate of the backup ring extrusion became high enough to cause premature failures of the seals.

1.2 The rate of the dynamic extrusion of the aforementioned backup rings could be reduced, however, to acceptable limits at pressures up to 4000 psi and at temperatures reaching 350°F by installing a floating cast iron backup ring downstream of the above reinforced Teflon backup ring. By making it floating in the piston groove, the cast iron ring could be fitted in the cylinder bore with a .002 - .003 diametrical clearance without jeopardizing the operation of the cylinder piston assembly.

1.3 While extending the range of pressures and temperatures at which the plastic backup rings could operate, the continuous (uncut) cast iron backup ring displayed the following shortcomings:

1.3.1 It still permitted dynamic extrusion of the plastic backup rings, although at a reduced and acceptable rate.

1.3.2 It could not prevent the extrusion rate from becoming excessive in case of wear or ovalization of the cylinder or of the cast iron ring itself. The wear of the cast iron ring could occur in spite of its floating ability. (See Reference 16.)

1.3.3 The extrusion gap had to be kept very small not withstanding the size of the cylinder bore. The requirement of keeping the diametrical clearance between the cylinder bore and the cast iron ring very small, while already expensive on cylinders of small diameters would for obvious reasons, become prohibitive in case of large cylinders.

1.3.4 The continuous cast iron rings could be installed only in open grooves.

1.4 It appeared that the above shortcomings could be eliminated by substitution of the continuous cast iron backup rings with the conventional cut piston rings. The piston rings which are designed to seal against gas leakage could provide a 100% effective barrier against extrusion of plastic material. They would fit snuggly in the cylinder bore and would tolerate a fairly large cylinder ovalization and its own wear.

Being a mass production component, they would be inexpensive. They could be assembled in closed grooves.

1.5 However, a number of problems would have to be overcome before the piston rings could be accepted as suitable components of a backup system designed for operation under adverse temperature and pressure conditions:

1.5.1 The bearing pressure, which the piston ring exerts against the cylinder bore,depends among other factors on the ratio between the ring diameter and its wall (width in the radial direction). On the other hand, a certain ratio must be maintained between the O-ring cross section and its diameter when the O-ring is used as a dynamic seal. This requirement is mandatory to assure uniform rolling of the O-rings and to avoid a spiral failure.

1.5.2 When a standard piston ring was mounted in the groove of an O-ring selected for a 2.75 diameter cylinder, a substantial gap was left between the piston ring I.D. and the bottom of the groove. (See Figure 1) This gap had to be filled to reduce the extrusion of the plastic backup ring into it when the system was operated at 350°F and under 4000 psi pressure. The Revonoc ring ML-1379 was therefore designed with an L shaped cross section. A small gap had to be still maintained between the protruding lip of the Revonoc ring and the piston ring I.D. to permit the piston ring to float and to assume a position off-center to the center line of the Piston Body. The Piston Body, ML-1366, was mounted off-center to the cylinder bore as per geometry described in Reference 20.

1.5.3 It was anticipated that at the temperature of 350°F and under 4000 psi cycling pressure, the material of the sacrificial plastic backup ring would flow into the gap between the piston ring I.D. and the bottom of the groove filling this gap completely, but letting the piston ring assume its correct position with respect to the cylinder bore.

1.5.4 It was also expected that the material of the sacrificial plastic backup rings would flow into the gap between the two ends of the cut piston ring. In order to reduce the volume of the material extruded into the above gap, a step-cut piston ring was selected. However, a small gap had to be tolerated to cater for the manufacturing tolerances and to prevent seizing of the piston ring in the cylinder bore in case of adverse thermal expansion of the piston ring.

The piston ring used in this test was a standard off-shelf part and the gap between the step-cut ends was larger than that which would be recommended for this particular application.

1.5.5 It was further expected that the softened material of the sacrificial backup ring filling the aforementioned gaps would act like a high viscosity fluid and would transmit the 4000 psi pressure to the exposed surfaces of the piston ring. This would increase considerably the bearing pressure of the ring against the cylinder bore, accelerating the wear of the softer component.

1.6 The test reported here was presented as a preliminary abbreviated test, performed with the purpose of checking the operation of this unique system and assessing the magnitude of each of the factors discussed above. It would thus permit adaptation of the proper corrective measures.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 The test reported here demonstrated that a conventional piston ring mounted floatingly downstream of the sacrificial plastic backup ring could prevent effectively extrusion of the latter into the clearance between the cylinder bore and the piston.

2.2 The backup ring material softened at elevated temperatures was extruded, as it was expected, into the space between the piston ring's inner circumference and the bottom of the groove and into the space between the ends of the piston ring filling these spaces entirely. Behaving like a high viscosity fluid, the softened material transmitted the operational pressure on the adjacent piston ring's walls exerting strong radial forces pressing the piston ring against the cylinder bore.

2.3 The above compression forces would most likely accelerate the wear of the piston rings and thus prove to be undesirable. However, a certain amount of radially oriented forces might be necessary to improve the adhesion of the piston ring to the cylinder bore and to permit the piston ring to adapt itself to a possible deformation or ovalization of the cylinder bore.

Addendum XIV

2.4 The very short test conducted up to date did not permit evaluation of the rate of wear of the tested piston ring. However, the above wear rate shall be determined through long duration tests at the earliest opportunity to serve as base for evaluation of the effectiveness of the modifications and improvements applied to the system.

2.5 Two ways of reduction of the piston ring wear may be investigated:

2.5.1 Filling the gap between the piston ring and the bottom of the piston groove with a metal ring which may be cut if necessary. Such a ring should fit snuggly in the piston groove. A small gap should be left between this ring and the piston ring to provide the latter with a certain freedom of flotation. Such a gap might allow a limited amount of extrusion and thus might create moderate radial forces improving the adhesion of the piston ring to the cylinder bore.

The gap between the piston ring ends should be kept as close to zero as practical. The type of operation in the hydraulic applications tends to equalize the temperatures of the cylinders and of the piston and thus makes unnecessary a large allowance for a differential thermal expansion of these components.

2.5.2 Another alternative would be the interposition of a thin metal ring between the sacrificial backup ring and the piston ring. Such a ring described in Reference 16 performed very well. It would practically eliminate extrusion of the material of the sacrificial backup ring into the gap between the piston ring and the groove, and it would reduce considerably the extrusion into the gap between the piston ring ends.

If necessary for assembly into a closed groove, the additional ring might be also cut, or a kind of spiral snap ring might be tried.

2.5.3 The test Reference 19 demonstrated that a scarf cut of the sacrificial backup ring would not jeopardize its performance.

3.0 TEST PROCEDURE

3.1 Test Installation and Test Specimens

3.1.1 The test was performed on the 2.75 diameter Cylinder Assembly to ML-1361 using an off-center piston as per Reference 20. The cylinder assembly was mounted in the fixture No. 2 The two 2-332 O-rings were of V747-75 compound.

3.1.2 The seal assembly as per Figure 1, including the piston ring and a sacrificial Revonoc 18158 backup seal, was mounted on the drive side of the piston.

The seal assembly as per Figure 2 (without the piston ring) was mounted on the outboard side of the piston. It served as a base against which the operation of the piston ring could be assessed.

3.1.3 The test fluid was per MIL-H-83282.

3.1.4 The test pressure was cycling between 50 psi and 4000 psi. Every second cycle was performed at 4000 psi pressure.

3.1.5 The number of cycles scheduled: as much as could be accumulated during the three eight-hour runs. At the beginning of each run, the test rig was to be heated to 350°F while operating.

3.2 Operational Procedure

3.2.1 The Test Data Sheet is enclosed as Appendix 1. The test had to be terminated at the end of the second hour of the third run. However, enough data was accumulated to permit the assessment of the piston ring performance.

3.3 Inspection of the Test Specimens After Termination of the Test

3.3.1 Seal Assembly as per Figure 1.

3.3.1.1 Piston Ring

The wall thickness of the piston ring varied between .100 and .107. The magnitude of wear could not be measured directly with a sufficient accuracy, but the wear was evident by the fact that the gap between the step-cut ring ends was increased from 0.035 to 0.068.

The working surface of the piston ring was shiny with very fine lines in the direction of the motion, but without scratches. Small burrs were detectable at both outer corners of the ring.

3.3.1.2 Revonoc 18158 Backup Ring ML-1379

Figure 3A shows the cross section of the ML-1379 Backup Ring with its design tolerances. Figure 3B shows the cross section of the same ring with the

3.3.1.2 (cont.) dimensions recorded during the after-test inspection.

Figure 4 is the photograph of the cross section Figure 1B.

The gap between the Piston Ring I.D. and the bottom of the groove was filled completely with the material displaced from the vertical portion of the backup ring body.

The total absence of extrusion lip as confirmed on the photographs Figure and 5 and Figure 6 where the Seal Assembly containing the Piston Ring is shown at the left side of the picture. The photograph, Figure 6, shows however that a substantial volume of the Backup Ring material was extruded into the gap between the ends of the Piston Ring leaving a deep indentation on the upstream side of the backup ring

3.3.1.3 O-Ring

The 2-332 O-ring displayed an array of radially oriented wear marks at the side adjacent to the backup ring, thus indicating that the O-ring was rolling during the piston operation. The wear marks were faint with no measurable depth, leaving the O-ring's surface practically intact.

No foreign material was found in the cylinder chamber at this side of the piston.

3.2.2 Seal Assembly as per Figure 2

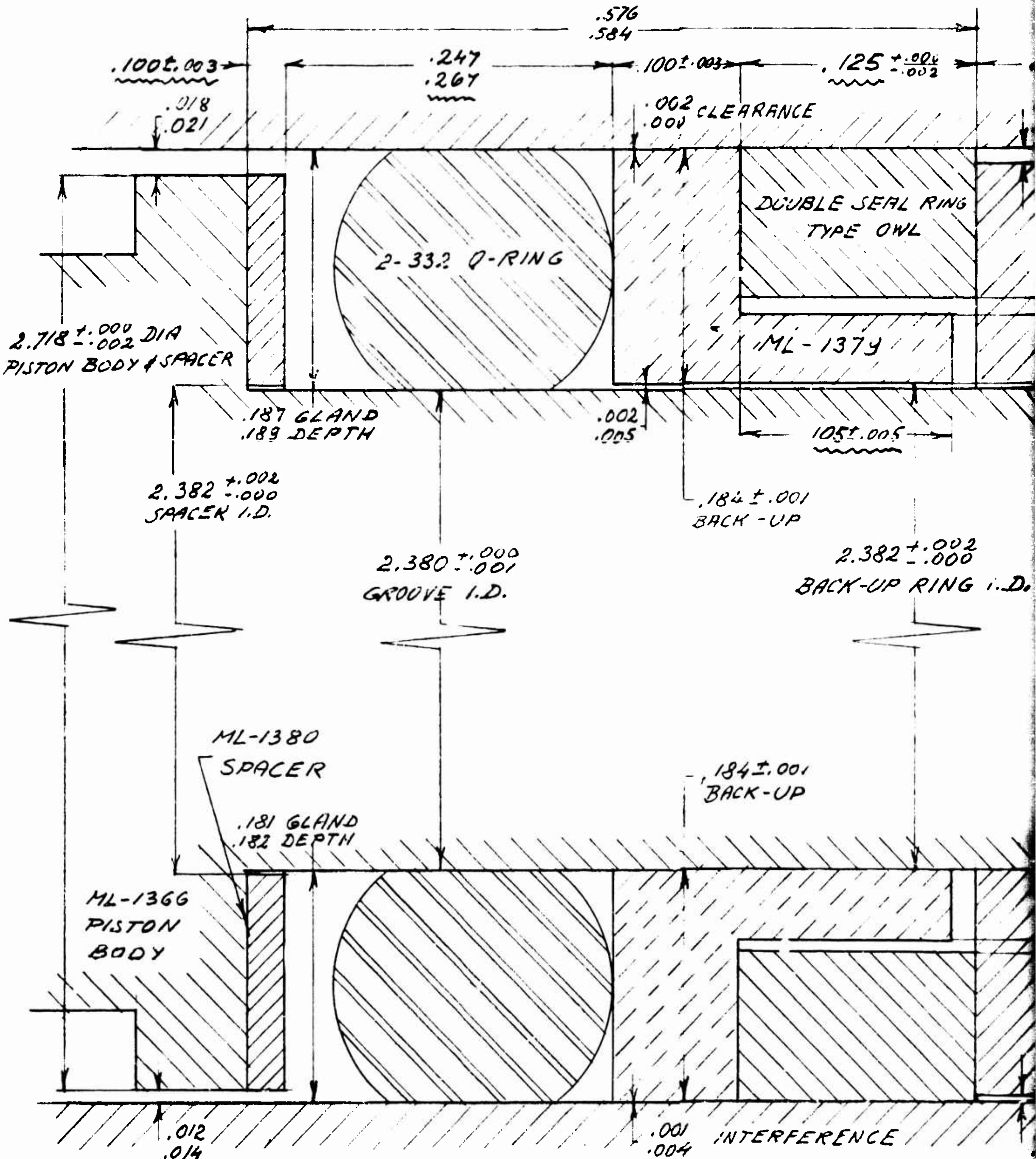
3.3.2.1 Figure 7A shows the cross section of the ML-1378 backup ring with its design tolerances. Figure 7B shows the cross section of the same ring with the dimensions recorded during the after-test inspection.

Figure 8 is the photograph of the cross section Figure 7B. The back-up ring was cut here across. The section side "G" shown at the top half of Figure 2 where the piston's off-center was the greatest. (Step 0.16 long and 0.009 - 0.011 maximum depth) The length and the thickness of the lip varied around the backup ring circumference reflecting the change of depth of the step "M". The photographs Figure 5 and Figure 6 reveal that the backup ring's material was extruded much further, but portions of the lip were gradually torn away, 3.3.2.1 (cont.) shredded, and dragged across the piston's guiding surfaces. A certain amount of the shredded backup ring material was found in the cylinder chamber at that side of the piston.

3.3.2.2 O-Ring

The 2-332 O-ring displayed an array of radially oriented wear marks similar to these described at 3.3.1.3. Also noticeable was a circumferential groove, very shallow along one half of the circumference, but deepening along the other half. The O-ring material was eroded along 1/6 of the groove circumference (See Figure 9).

Since the moderate extrusion of the backup ring (as per Figure 8) did not deprive the O-ring of support, no connection between the O-ring's erosion and the backup ring performance could be established.



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CLEARANCE
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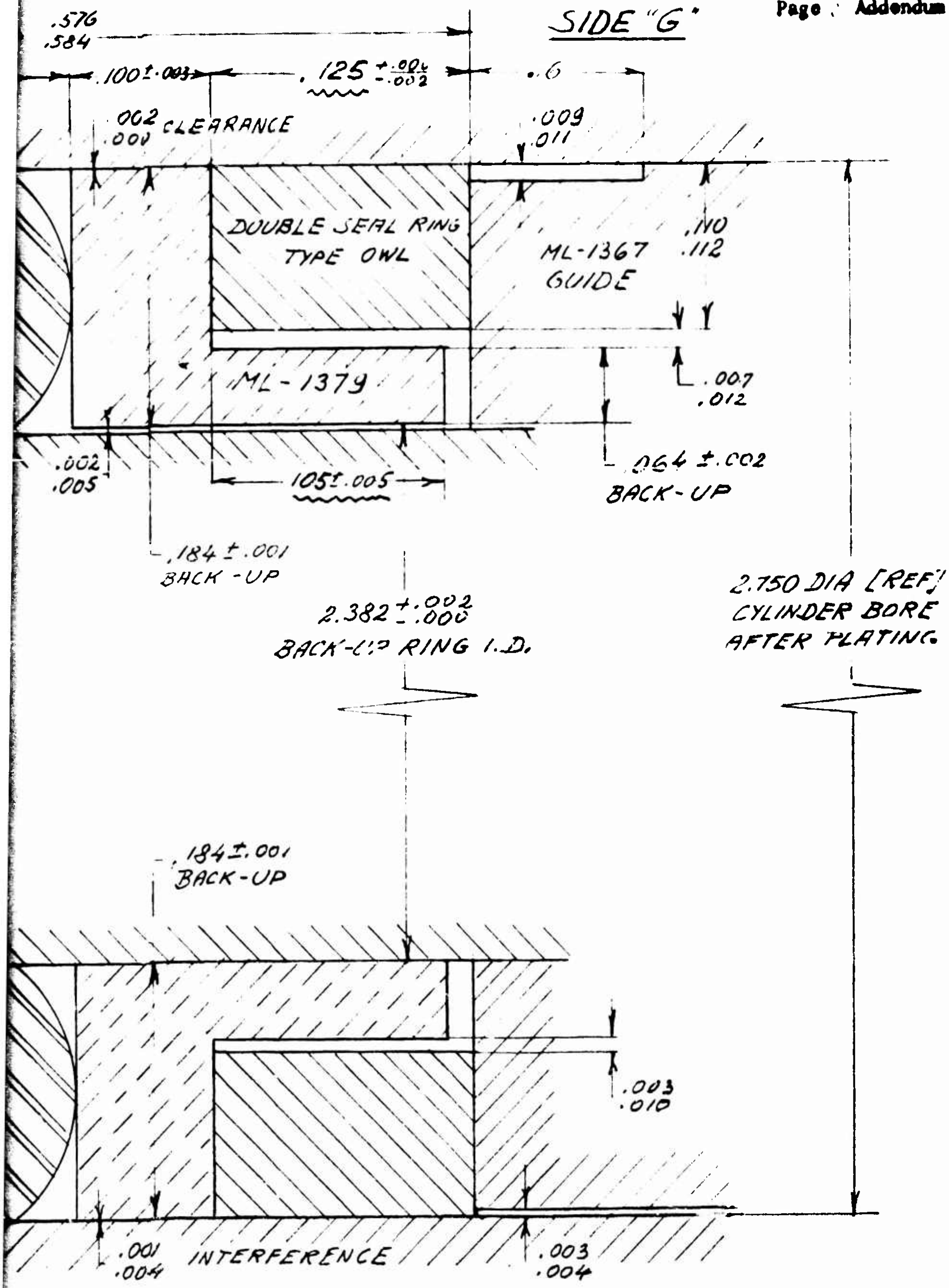
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TYPE OWL
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.064 ±.002
BACK-UP
.184 ±.001
BACK-UP
2.750 DIA [REF]
CYLINDER BORE
AFTER PLATING
2.382 +.002 -.000
BACK-UP RING I.D.
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BACK-UP
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.004 INTERFERENCE
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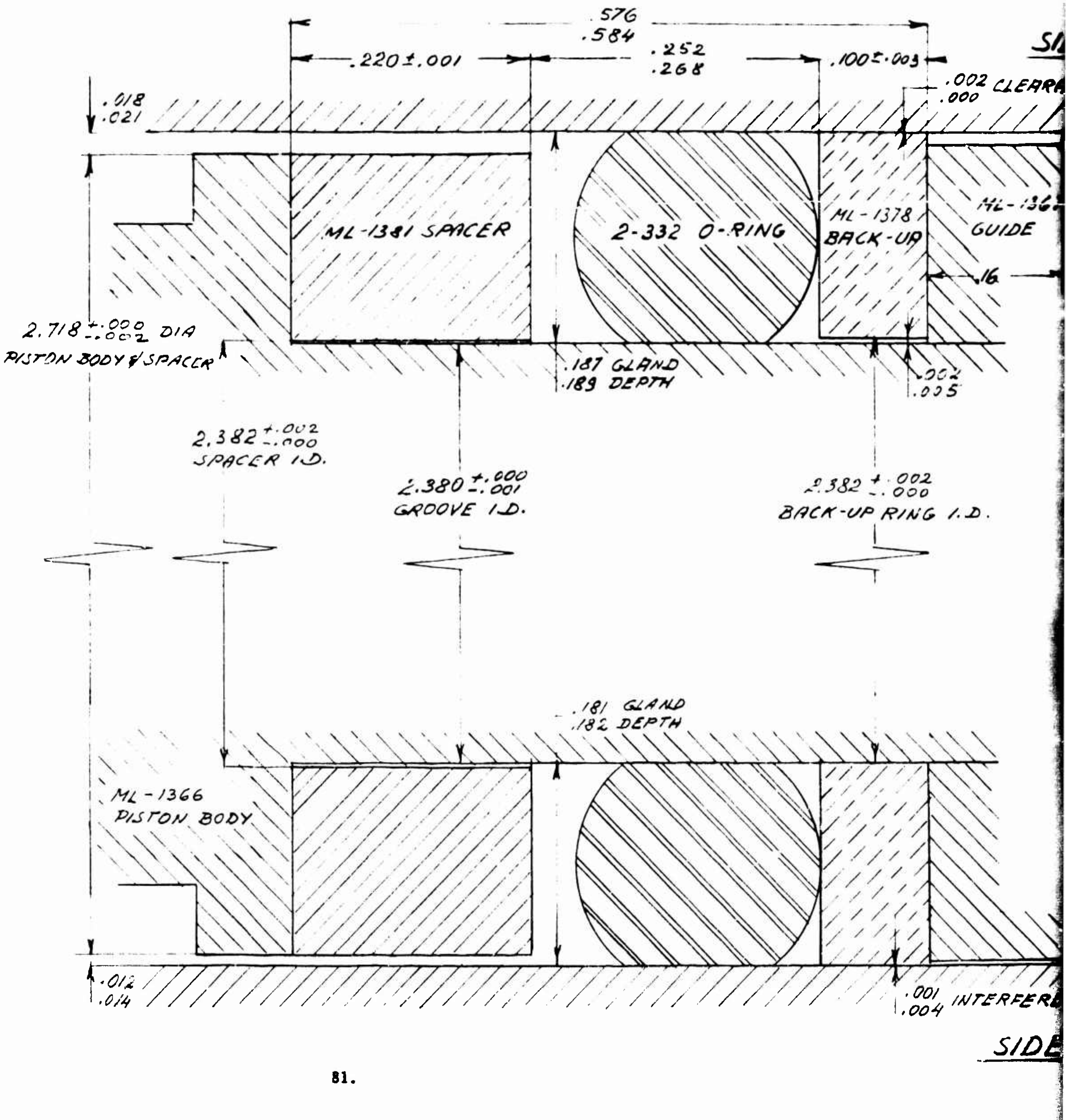
.004

SIDE "H"

FIG. 1



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ML-1381 SPACER
2-332 O-RING
ML-1378
BACK-UP
GUIDE
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2.718 +.000 -.002 DIA
PISTON BODY & SPACER
.187 GLAND
.189 DEPTH
.002
.005
2.382 +.002 -.000
SPACER I.D.
2.380 +.000 -.001
GROOVE I.D.
2.382 +.002 -.000
BACK-UP RING I.D.
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ML-1366
PISTON BODY
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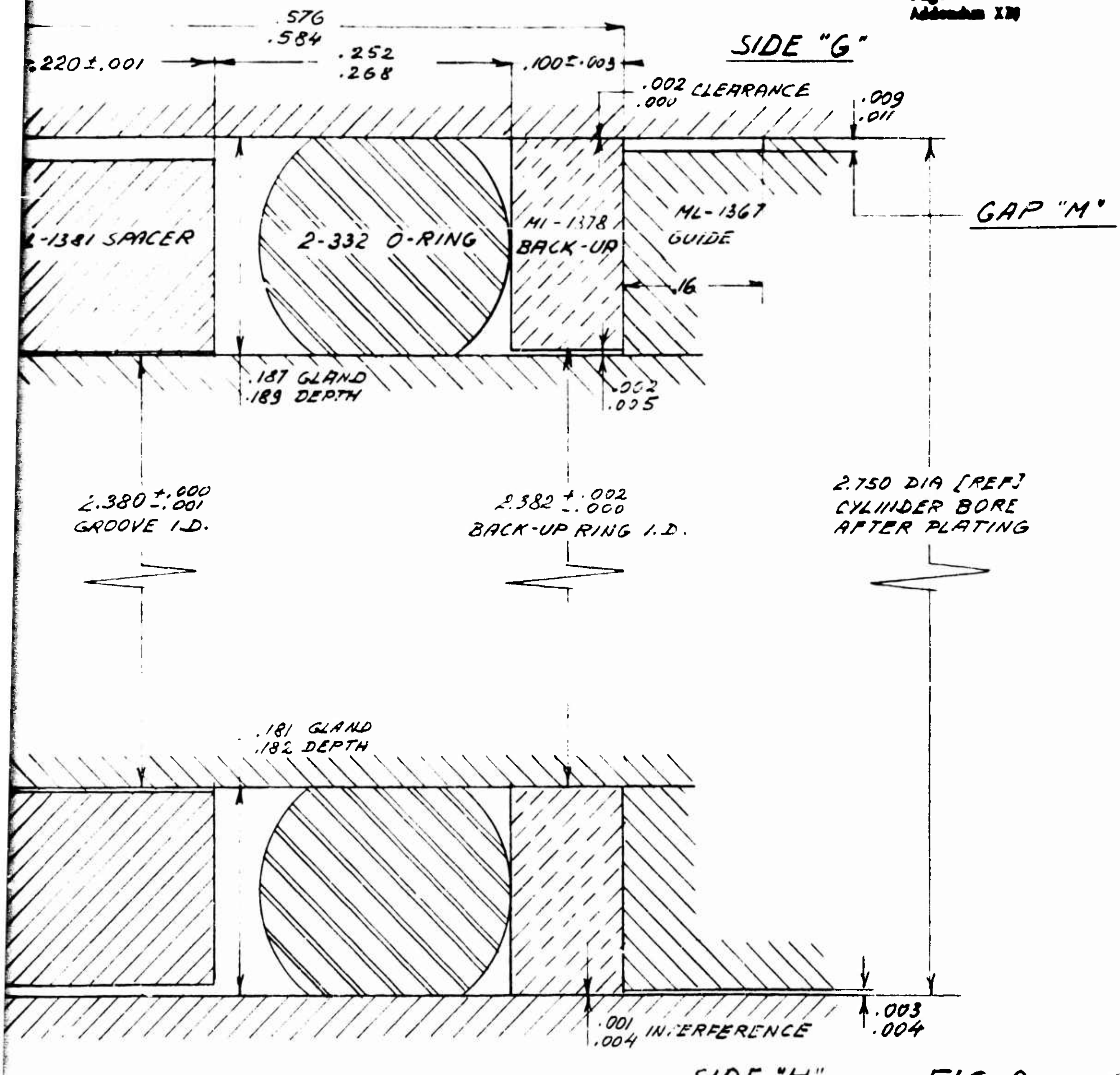
.004 INTERFERE
SIDE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.000
.009
.011
GAP "M"
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2-332 O-RING
ML-1378 BACK-UP
ML-1367 GUIDE
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.189 DEPTH
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.005
2.380 +.000 -.001
GROOVE I.D.
2.382 +.002 -.000
BACK-UP RING I.D.
2.750 DIA [REF]
CYLINDER BORE
AFTER PLATING
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.182 DEPTH
.001
.004
INTERFERENCE
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SIDE "H"

FIG. 2

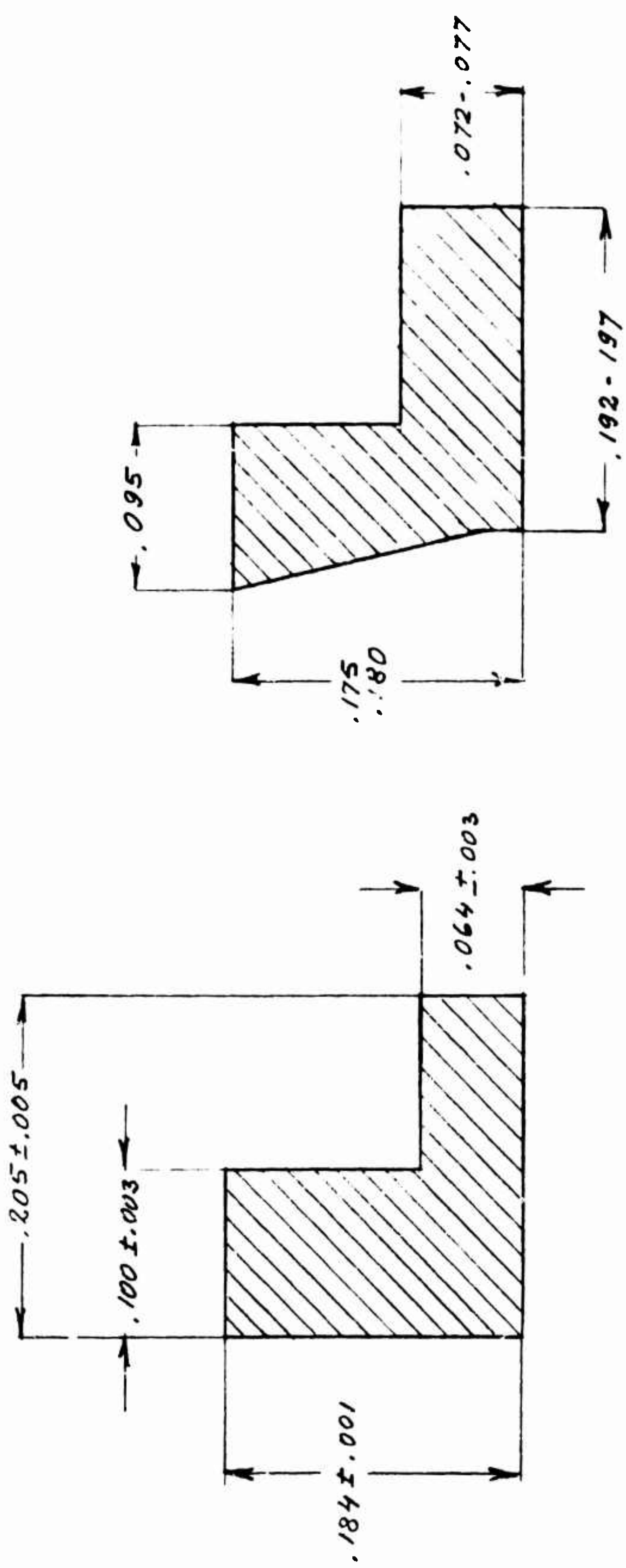


FIG. 3.

Figure 4

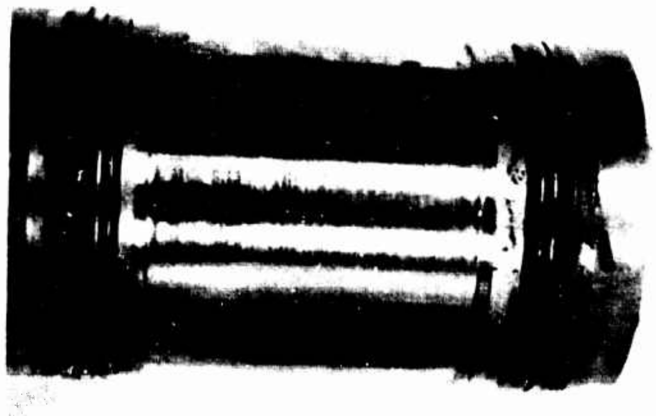


Figure 5

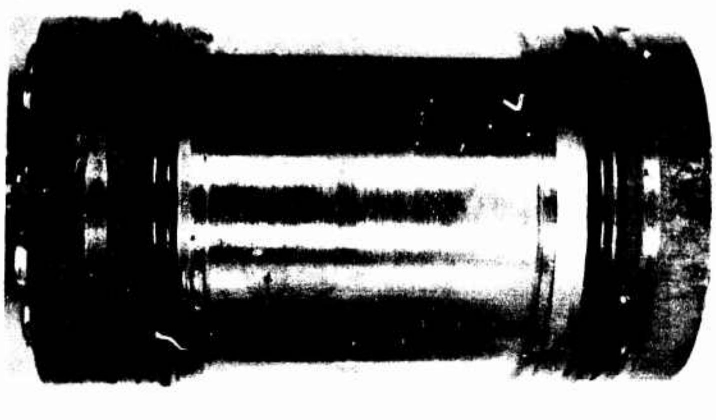


Figure 6

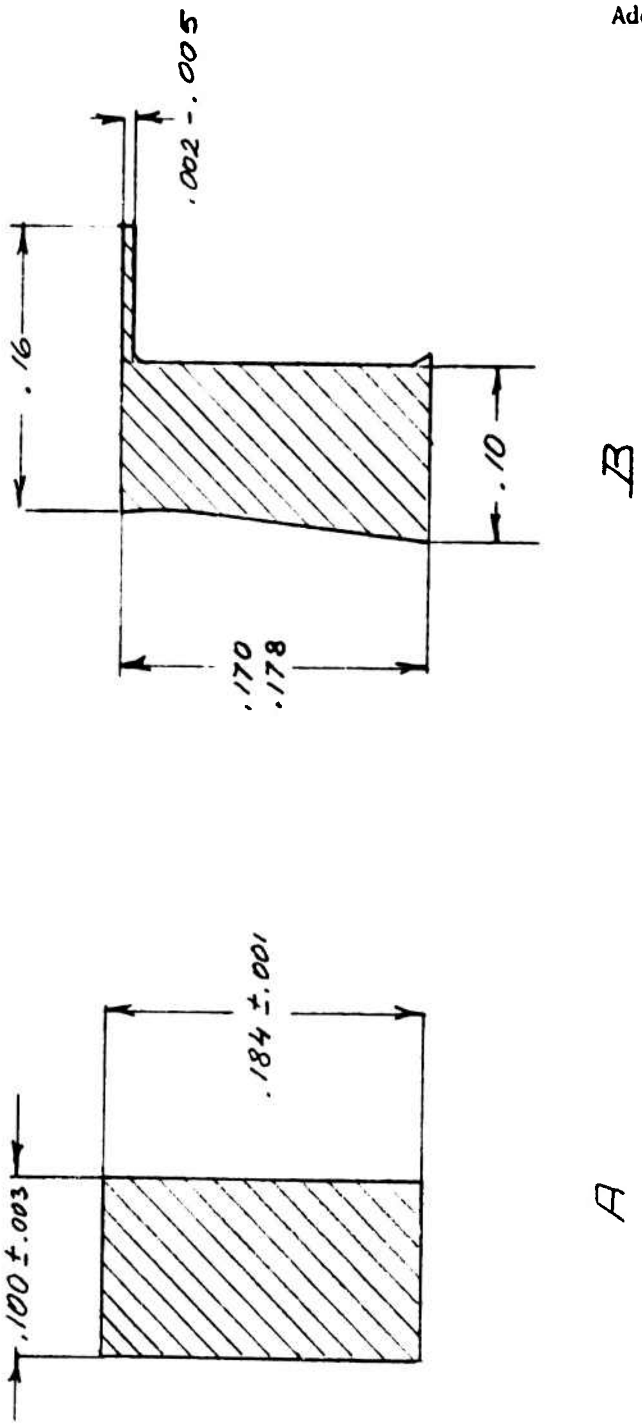


FIG. 7

Figure 8

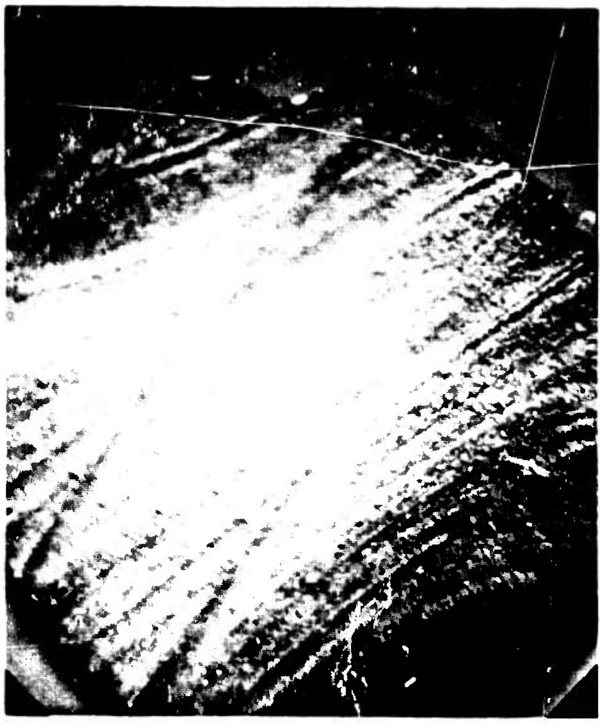


Figure 9

REFERENCES

Reference No. 1 Report No. 03-257 Revision A

Development of Backup Rings for High Pressure, High Temperature Seals
(p = 4000 psi t = 275°F)

Reference No. 2 Report No. 03-257 Addendum II

Tests of Suitability of Meldin P1-15Y, Astrel 360 and Rulon J as Materials for High Pressure, High Temperature Backup Rings
(p = 4000 psi T = 350°F)

Reference No. 3 Report No. 03-258

Dynamic Rod Seal Evaluation Compounds XN1925-25 and XN1925-23
(p = 3000 psi t = 275°F)

Reference No. 4 Report No. 03-258 Addendum I

Dynamic Seal Evaluation Compounds XN1925-33 and XV1836-10
(p = 4000 psi t = 275°F)

Reference No. 5 Report No. 03-258 Addendum II

Dynamic Rod Seal Evaluation Compound V747-75 Investigation of the Operation of the Seal Backup Ring System
(p = 4000 pis t = 350°F)

Reference No. 6 Report No. 03-258 Addendum III

Dynamic Rod Seal Evaluation Compound V747-75 Investigation of the Operation of the O-Ring and the Seal Backup System at 450°F
(p = 4000 psi t = 450°F)

Reference No. 7 Report No. 03-258 Addendum IV

Dynamic Rod Seal Evaluation Compound XA1969-56
Investigation of the Operation of the Seal Backup
System
(p = 4000 psi t = 325°F)

Reference No. 8 Report No. 05-249

Dynamic Evaluation of Test Material Interim
Technical Report
O-Rings of AFE-XV1836-7 Compound Tested on the
No. 2 Fixture.
(p = 3000 psi t = 275°F)

Reference No. 9 Report No. 05-249 Addendum I

Dynamic Evaluation of Test Material Interim
Technical Report
O-rings of XN1925-24 Compound and Backup Rings
of Tetralon 720
Tested on the No. 2 Fixture
(p = 3000 psi t = 275°F)

Reference No. 10 Report No. 05-249 Addendum II

Dynamic Piston Seal Evaluation of Test Material.
Interim Report. O-Rings of AFE-XN1814-98 Compound
and Backup Rings of Tetralon 720 with MIL-H-5606B
Hydraulics Fluid.
(p = 3000 psi T = 275°F)

Reference No. 11 Report No. 05-249 Addendum III

Dynamic Evaluation of Test Material. Interim Test
Reports, O-Ring of N304-70, XV1836-2, XV1836-10,
XV1836-11, VS-35, XV1836-7 and XV1836-2. Backup
Rings of Tetralon 720 and Revonoc 18158 Tested on
the Number 2 Fixture.

Reference No. 12 Report No. 05-249 Addendum IV

Dynamic Evaluation of Test Material. Interim Technical Reports. Investigation of the Operation of the Revonoc 18158 Backup Rings during the 1000 Hours Test of the XN1925-33 O-Rings (P = 3000 psi t = 275°F)

Reference No. 13 Report No. 05-249 Addendum V

Dynamic Evaluation of Test Material. Interim Technical Reports. Investigation of the Operation of the Revonoc 18158 Cum Cast Iron Backup Rings during the 1000 hours Test of the V747-75 O-Rings (p = 4000 psi t = 350°F)

Reference No. 14 Report No. 05-249 Addendum VI

Completion of the Tests Reported in Addendum V. Investigation of the Operation of the Revonoc 18158 Cum Cast Iron Backup Rings during the 1000 Hours (p = 4000 psi t = 350°F)

Reference No. 15 Report No. 05-249 Addendum VII

Investigation of the Operation of the Revonoc 18158 Cum Cast Iron Backup Rings at 450°F. Review of the Results of Tests Performed at 275°F, 350°F and 450°F.

Reference No. 16 Report No. 05-249 Addendum VIII

A Preliminary Test at 350°F of a Backup System Consisting of Two Revonoc 18158 Backup Rings, of the Intermediate Ring and of the Cast Iron Ring (p = 4000 psi t = 350°F)

Reference No. 17 Report No. 05-249 Addendum IX

Investigation of the Operation of the V747-75 O-rings with the Revonoc 18158 Backup Rings During the 1000 Hours Test at a Minimum Test Temperature of 400°F (p = 4000 psi t = 400°F)

Addendum XIV

Reference No. 18 Report No. 05-249 Addendum X

Dimensional Analysis and Assembly Instructions for the Seals with Cut Plastic Backup Rings

Reference No. 19 Report No. 05-249 Addendum XI

Effect of the Straight-cut and Scarf-cut Backup Rings on the Operation and Wear of Seal Compounds ($p = 4000$ psi $t = 350°F$)

Reference No. 20 Report No. 05 249 Addendum XII

Study of the Operational Conditions of the Piston Components in Case of the Off-Center Position of the Piston

Reference No. 21 Report No. 05-249 Addendum XIII

Study of the Dynamics of the Drive of the Piston Seal Test Fixture ML-1198 Revision A

APPENDIX XIII

Engineering Report No. 00-291

2-3/4" Piston Fixture with ML1361-102 Seal Assembly

PURPOSE:

In developing a reciprocating, hydraulic O-ring seal for operating at temperatures up to 350°F and pressures to 4000 psi, it is necessary to provide adequate backup for the O-ring. In earlier tests, it was found that a metal ring plus a filled Teflon ring showed real promise. The metal ring must be split to permit it to adjust to tolerance variations in the bore it contacts. Use of a split metal ring also makes it possible to use a simpler one-piece piston. In the previous test, a filled Teflon type backup ring was used adjacent to a split metal ring. The assembly developed very high friction, apparently due to the Revonoc material extruding into the gap and forcing the metal ring hard against the bore.

In this test, a thin intermediate ring was sandwiched between the Revonoc and the split cast iron backup ring so that the gap in the face of the cast iron ring was covered.

CONCLUSIONS:

In this test, the gap in the face of the cast iron ring was covered, but not the gap on the inside. Hence the Revonoc ring still extruded into it, and friction continued to be high. Furthermore, leakage was observed during much of the test, and excessive leakage started after only 118 hours' exposure to the high temperature. It was concluded, therefore that in the next test an intermediate ring should be used that would extend from the cylinder bore to the bottom of the groove, preventing the Revonoc from reaching the split ring.

PROCEDURE:

The seal/backup ring system was assembled per ML1361-102 in both ends of the piston. It was thought that the eccentric condition of the ML1367 piston guides had contributed to the high friction experienced on the previous test, so they were remachined per the revision A drawing to allow them to center themselves.

The piston was checked for leakage while cycling at room temperature, and 350°F.

RESULTS:

Assembly before the test, and disassembly afterwards, were difficult due to frictional drag. After the test, the piston was reinserted into the cylinder with various combinations of the O-ring backup elements, and it was found that the O-ring alone caused sufficient friction that a heavy hand load was necessary to assemble and the piston had to be tapped with a hammer to get it out of the cylinder. The Revonoc backup ring had extruded up into the

RESULTS: (continued)

inside gaps in the piston rings which could tend to open the piston ring more forcefully against the bore, increasing the frictional drag. On re-assembling after the test, however, using the O-ring alone, and the Revonoc cast iron backup combination alone, the O-ring created more drag than the backups at room temperature.

Slow leakage was observed throughout most of this test when pressure was applied. The rate was greatest at the lowest temperature (-65°F) but continued at a lower rate while cycling as the temperature was increased. Plus 35°F was the lowest temperature at which a static seal was achieved. During cycling there was slight leakage even at +350°F and 50 to 4000 psi pressure.

The test was stopped during a +20°F low temperature cycle due to excessive leakage from the outboard end. The seals had been exposed to a temperature of 350°F for 118 hours and to low temperatures varying from -65 to +35°F for 16 hours. The piston was static much of the time during the test, but it had been reciprocated some 30,000 times with a stroke of 1.86 inches at a rate of 30 cycles per minute.

On disassembly, the head end, which had not leaked, was found to contain a quantity of flakes. (Figure 5) A few of them were larger than 1/2" X 1/2" in size and varied in thickness from .0025 to .0055". (Figure 6) The O-ring appeared to be in good condition, but the ML1379 Revonoc backup ring was severely distorted due to creep. The edge that contacted the O-ring and the bore appeared to be nibbled. The flakes had apparently come from this backup ring, but how they were formed and how they got past the piston ring into the head end of the cylinder is not known at this time. The approximate dimensions of the Revonoc backup ring, the Teflon spacer and the O-rings after the test are shown in Figures 1, 2, and 4.

After the test, the outboard end, where the gross leakage had occurred was quite clean. There was less distortion of the Revonoc backup ring, though the Teflon backup/spacer looked similar to the one at the head end. The O-ring looked slightly distorted. Placed free on a flat surface, it assumed an elliptical shape and the ends curved upward approximately .100" from the surface. It appeared to have worn unevenly, and the cross section was not uniform, but it was within standard tolerance limits at all points.

The table below compares the volumes of parts after the test with the volumes of unused parts.

	Head End	Outboard End	Unused Part
ML1379 Revonoc Backup Ring	2.6869cc (-17%)	3.1414cc (-3%)	3.2285cc
MS28774-332 Teflon Backup	1.7014cc (-2%)	1.6742cc (-4%)	1.7354cc
2-332-V747-75 O-Ring	4.6216cc (+3%)	4.6162cc (+3%)	4.4955cc

Judging from the apparent volume change, based on the volume of the unused parts, the head end Revonoc backup ring lost an appreciable amount of material, while the O-rings swelled slightly in the fluid. The reason for the slow leakage throughout the test and for the gross leakage at the outboard end that concluded the test is not known.

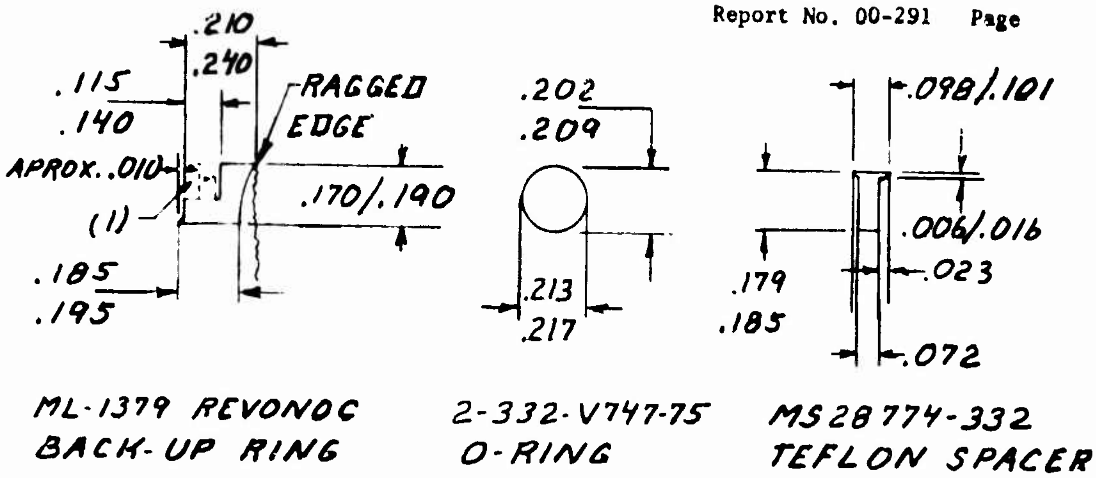


FIGURE 1 - ELEMENTS FROM HEAD END AFTER TEST 2X SIZE

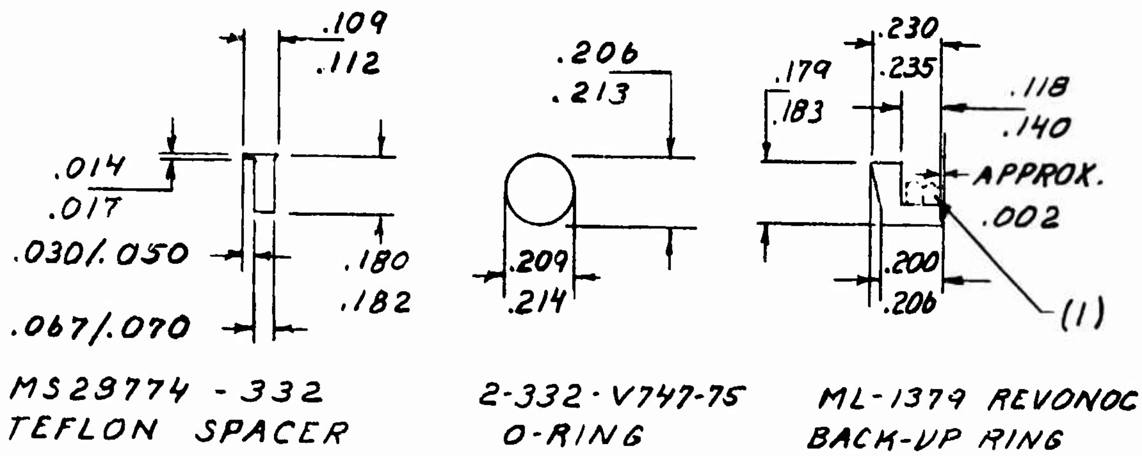


FIGURE 2 - ELEMENTS FROM OUTBOARD END AFTER TEST 2X SIZE

(1) TWO SMALL FINGERS ON EACH REVONOC BACK-UP FROM EXTRUDING INTO GAPS IN CAST-IRON BACK-UP RING.

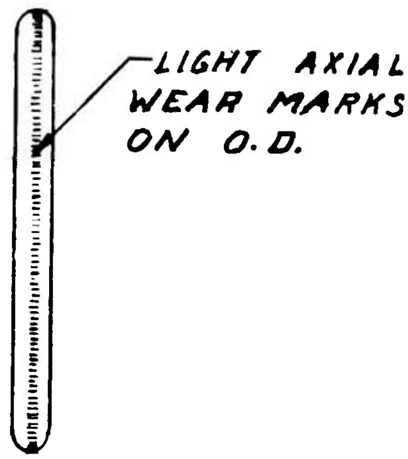


FIGURE 3. END VIEW OF HEAD END O-RING

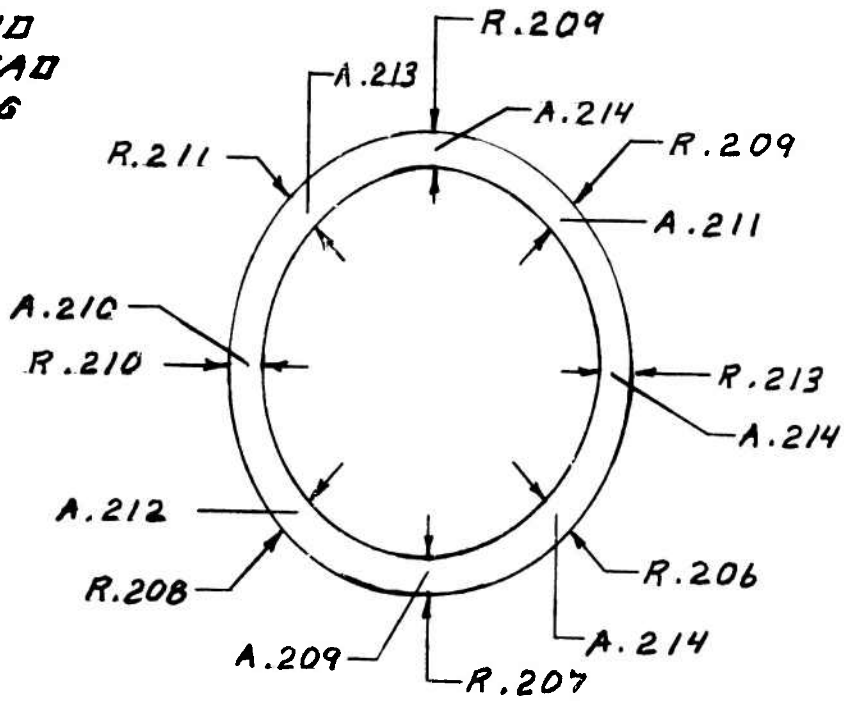


FIGURE 4 O-RING FROM OUTBOARD END - W DIMENSION AT VARIOUS POINTS A = AXIAL DIMENSION
R = RADIAL DIMENSION

Figure 5.

Flakes Found in Head End after Test

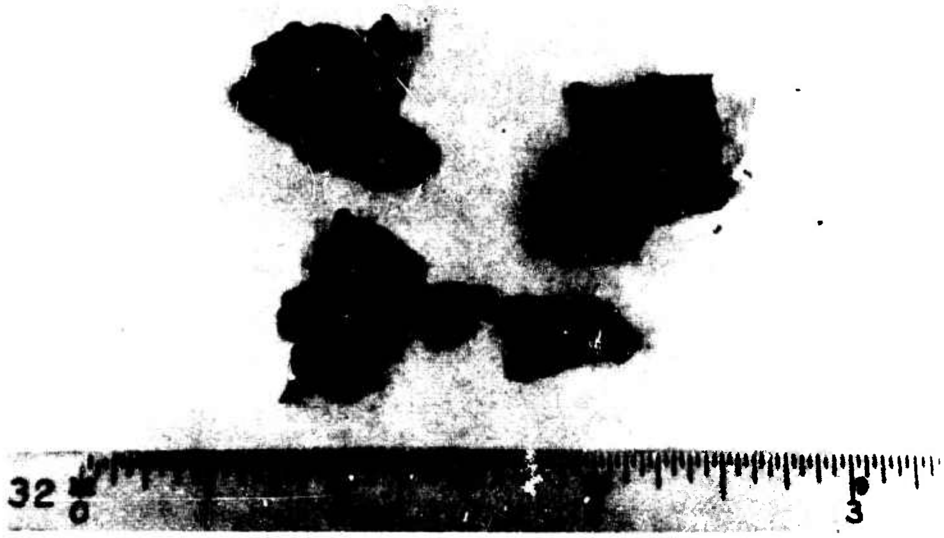


Figure 6. Few Large Flakes from Head End

Figure 7. Close-up of Seal/Backup Elements from Head End

APPENDIX XIV

Engineering Report No. 00-291-1

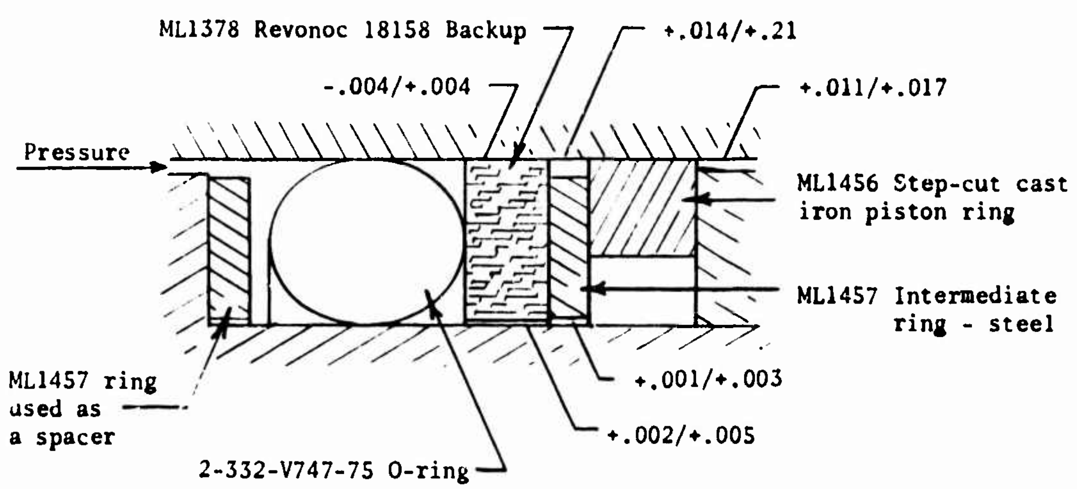
2-3/4" Piston Fixture with ML1361-103 Seal Assembly

BACKGROUND AND PURPOSE:

While the previous test was being conducted, a high frictional drag load was indicated by the very obvious deflection of the motor platform that occurred on each high pressure stroke. During the elevated temperature phases of the test, the sound that accompanied these strokes led us to believe that the drag was even greater at high temperatures.

The portion of the Revonoc backup ring under the cast iron ring had extruded up into the gun in the cast iron ring, and it was felt that the force exerted by this extruding Revonoc must have caused the cast iron piston ring to rub very forcefully against the cylinder bore. If the friction load of the cast iron ring could be materially reduced, it was felt that the total friction of the system might be brought down to more acceptable levels and the extrusion of Revonoc material might be controlled.

For this test, therefore, a flat Revonoc ring was used, rather than the stepped design of the previous test. An intermediate steel ring was assembled between the Revonoc backup and the cast iron piston ring. This steel ring fitted the bottom of the groove very closely to prevent the Revonoc from flowing under the cast iron ring. Clearance was left around the O. D. of the intermediate ring to assure that it would not rub the cylinder bore and wear it. Although the Revonoc would flow into this clearance, it was felt that a Revonoc wear surface here was preferable to a rubbing steel surface. Figure 1 shows the type of assembly used.



FIGURES INDICATE DIAMETRAL CLEARANCE RANGE. A MINUS SIGN INDICATES INTERFERENCE

FIGURE I. SEAL BACKUP ASSEMBLY

Reference ML1361-103A

CONCLUSIONS:

Frictional drag was still very high, but extra drag at high temperature was probably due to thermal expansion of the Revonoc. A scarf-cut Revonoc backup ring with a slight gap at room temperature, therefore may reduce friction. This is planned for the next test in this series to be followed by a bi-material backup ring assembly in which a very small cross section metal ring is inserted into a notch cut around the O.D. of the Revonoc backup on the low pressure side. This design should reduce friction further by reducing the metal backup area that contacts the bore.

PROCEDURE:

The test elements were assembled as shown in Figure 1 above (and drawing ML1361-103). The system was filled with MIL-H-83282 hydraulic fluid. Testing was conducted per the following procedure:

1. The seals were checked for leakage at room temperature at 30 cycles per minute for 100 cycles with fluid pressures of 50 psig and 4000 psig applied on alternate cycles.

2. Cycling was discontinued and the temperature reduced to -65°F for 16 hours at zero pressure.

3. The seals were checked for leakage at -65°F and 4000 psi pressure for 15 minutes. Since leakage was observed, the system was warmed up gradually in 20°F steps, using the 4000 psi pressure to check for leakage at each step. The temperature, at which leakage first ceased was +20°F.

4. Cycling was started at +20°F and 4000 psi, and the system was then heated to 350°F, with the pressure maintained at 4000 psi.

5. The amount of accumulated leakage was recorded each two hours after the heating was started until a total of eight hours was accumulated at 350°F.

6. The seals were soaked at -10°F and 0 pressure for 16 hours.

7. The seals were checked for leakage at -10°F and 4000 psi pressure for 15 minutes.

8. Cycling was started at -10°F and 4000 psi and the system was then heated to 350°F.

9. The amount of accumulated leakage was recorded every two hours after the heating was started for a total of 8 hours.

10. Test discontinued.

RESULTS:

Initial room temperature breakaway friction measured fifty-seven pounds.

The seals leaked during the first low temperature phase until the temperature was increased to +20°F. During the second low temperature phase, there was no leakage at -10°F. A lower temperature was not tried. (Note: This is evidence of the temperature hysteresis effect we have heard of recently.)

During the first 350°F phase there were 10 cc and 14 cc leakage from the drive and outboard ends respectively after the first two hours, reducing to zero after the last four hours.

During the second 350°F phase, there was greater leakage, 30 and 70 cc, after the first two hours, reducing to .5 cc each after the fourth two hour period.

A high friction drag occurred, similar to that experienced in the previous test.

During the test, the seals had been exposed to a temperature of 350°F for 16 hours and to low temperatures, from -65 to +10°F, for 33 hours. The piston had been cycled 27,600 times with a stroke of 1.86 inches at a rate of 30 cycles per minute.

Most of the cycling was done at 350°F.

On disassembly, there were many flakes of Revonoc between the seals and outside of them though the quantity was less than in the previous test. The outside edge of the Revonoc backup rings was scored with axial wear marks from rubbing against the cylinder bore. There was also a definite step approximately .009" high all around the outer periphery where the material had extruded over the intermediate steel ring. At the maximum temperature, it must have had a uniform outside diameter but in cooling off, the body of the Revonoc backup must have shrunk appreciably while the intermediate steel ring prevented the extruded portion from shrinking (see Figure 2). This condition was found on both of the Revonoc backups.

It seems likely that the force generated by the expansion of the Revonoc material at 350°F may have caused a large portion of the frictional drag because the high temperature would expand the outside diameter by approximately .033" if it were not confined.

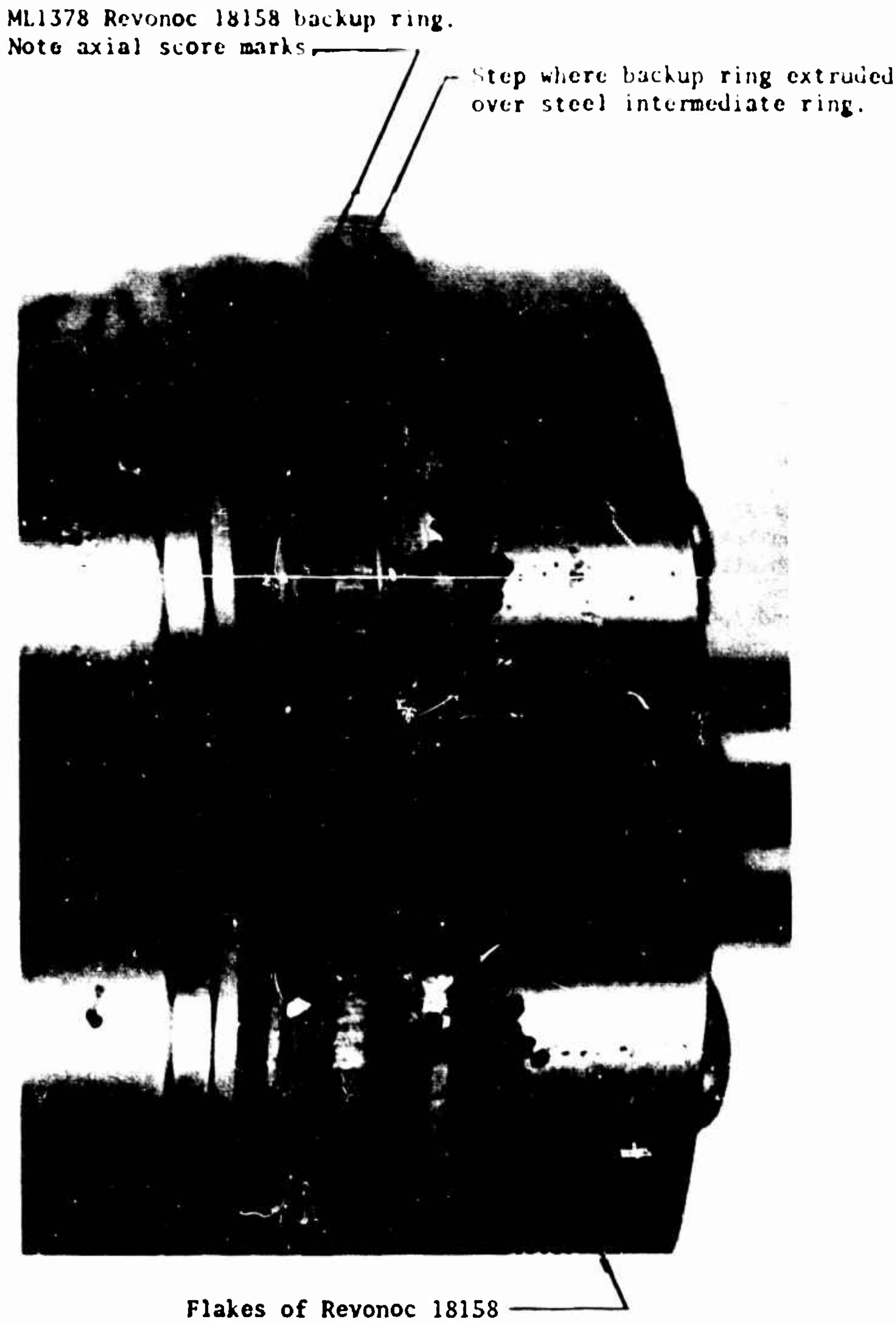


FIGURE 2.

SEAL BACKUP ASSEMBLY AFTER TEST

APPENDIX XV

Engineering Report No. 00-291-2

2-3/4" Piston Fixture with ML1361-103B Seal Assembly

BACKGROUND AND PURPOSE:

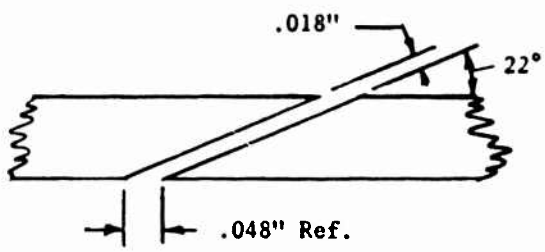
In the previous test, (the ML1361-103 seal assembly), a high frictional drag was experienced and many flakes of the Revonoc 18158 had been abraded off the backup ring, even though the Revonoc had been prevented from creeping under the cast iron backup ring. It was realized that the friction was probably due to the thermal expansion of the Revonoc material. In this test, the Revonoc backup ring was scarf cut and some material was removed to allow it to expand at elevated temperature to test this idea.

CONCLUSIONS:

The 350°F temperature of this test may be too high for the Revonoc 18158 material. The next test will be run at only 300°F to check this possibility. If this seems to be the case, we'll need to look for backup materials with higher temperature capability.

PROCEDURE:

The test elements were assembled in accordance with drawing ML1361-103B. This is also the same as Figure 1 of Report 00-291-1 (-103) except that the Revonoc backup rings were scarf cut on an angle of 22°, using a saw cut .018" wide. This allows for approximately .048" circumferential expansion, which is roughly half the amount expected at the maximum temperature of 350°F. It was felt that some interference could be absorbed at maximum temperature, and the scarf cut should allow the free ends to overlap if expansion loads became very high.



Scarf cut Revonoc backup ring -

Edge view showing scarf cut
5 X Size

Test cycling was similar to that used for the -103 test with modifications for initially finding friction loads at various temperatures, as the Dillon gage was inserted in this test. To spare the gage, no power cycling was conducted until after the friction loads had been determined.

RESULTS: Friction loads:

Temperature °F	Fluid Pressure psig	Friction Force Breakaway Pounds	"Running" (1) Pounds	
72	0	100-105	70	
72	3000	480-500	480-500	
72	4000	580-600	580-600	
-65	0	35-40	35-40	leaked
-10	3000	300	280	
-10	4000	400	250	leaked
0	3000	500	400	
0	4000	300	250	
350	0	200	180	
350	3000	510	510	
350	4000	630	630	

(1) Since the piston was reciprocated by turning the drive belt by hand, to avoid unnecessary stress on the Dillon gage, the "running" speed was very slow, - well under one foot per minute. Therefore, "running" friction in this test is very close to or identical with breakaway friction.

Number of cycles completed: 27,000

Number of hours at 350°F: 239

Reason for stopping test: Severe leakage from drive end.

INSPECTION:

Drive End: There was a notch nibbled out of the O-ring at the cut portion of Revonoc backup ring. The overlapping portion of the Revonoc ring was completely gone, leaving a shallow V-shaped void adjacent to the O-ring with a narrow channel at the apex where there was no Revonoc backup material left. This was apparently the cause of the seal failure. The remaining portion of the O-ring was still in good condition. (See Figure 1)

Outboard End: Similar to drive end except that the loss of the Revonoc material had not yet progressed quite as far. Although the O-ring was still supported, the support would have been lost in a very short period of time. (See Figure 2)

There were some flakes of Revonoc 18158 in the cylinder, and the evidence of wear and extrusion over the intermediate ring were similar to the previous test.

ANALYSIS:

The abrasion or extrusion of the Revonoc 18158 material in all the 2-3/4" piston tests at 350°F may indicate that this temperature is too high for this Revonoc material. The next test, therefore, will be conducted at 300°F.

FIGURE 1 - SEAL FROM DRIVE END OF PISTON

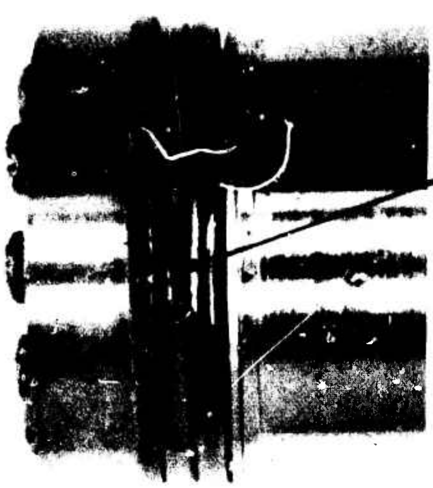


FIGURE 2 - SEAL FROM OUTBOARD END OF PISTON

APPENDIX XVI

Engineering Report No. 00-291-3

2-3/4" Piston Fixture with ML1361-103A-1 Seal Assembly

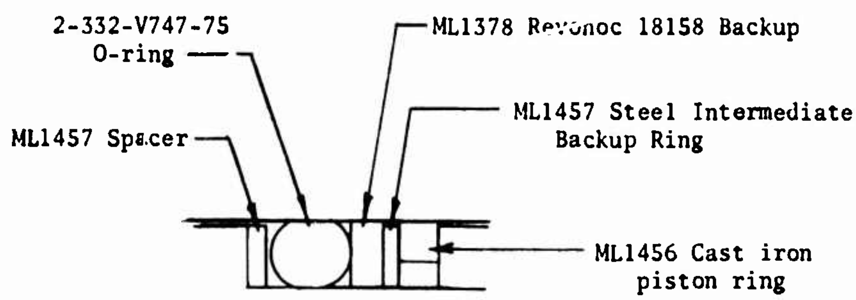
OBJECT:

To determine if the 350° temperature is too high for Revonoc 18158.

CONCLUSIONS:

The flaking of the Revonoc backup ring material was probably caused by the interference fit, which increased with rising temperature.

ASSEMBLY:



PROCEDURE:

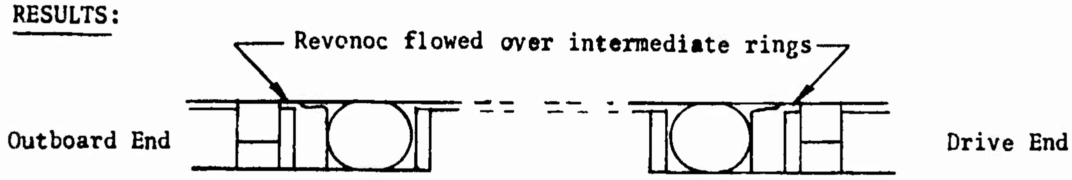
Temperature: 300°F

30,600 cycles at 0 to 4000 psig pressure.

17 hours at 300°F.

Cycling: Friction loads were checked initially, then the piston was reciprocated during working hours at 300°F, 50°F cooler than test 103 until 17 hours had been accumulated at this temperature. The seals were then examined.

RESULTS:



Toward the end of the test, the fixture started groaning during the pressure cycles as in test 103. On cooling to room temperature, the piston could not be moved in the bore with a bench press, and the assembly was heated to 250°F to soften the Revonoc so the piston could be removed. The high friction forces and the flowing of the Revonoc over the intermediate rings could have been caused by the initial interference between the Revonoc backup ring and the bore. Since there were no more ML1378 Revonoc backup rings on hand, it was decided to clean up the O.D. of the two that had been used in this test, and reuse them with the resulting clearance, which would accommodate some thermal expansion, in the next test, No. 105.

Friction Loads	Temperature	0 Pressure Breakaway	0 Pressure Running	4000 psig Pressure Breakaway	4000 psig Pressure Running
	72°F	140 lb.	130 lb.	980 lb.	920 lb.
	-65°F	50 lb.	30 lb.	-	-
	+20°F	200 lb.	150 lb.	over 1000	1000 lb.
	+300°F	140 lb.	140 lb.	700 lb.	650 lb.
	+300°F*	100 lb.	100 lb.	830 lb.	760 lb.

* After 17 hours @ 300°F

APPENDIX XVII

Engineering Report No. 00-291-4

2-3/4" Piston Fixture with ML1361-105 Seal Assembly

Parker SEAL COMPANY
CULVER CITY, CALIFORNIA

REPORT: 00-291-4 REV:
PAGE: 1

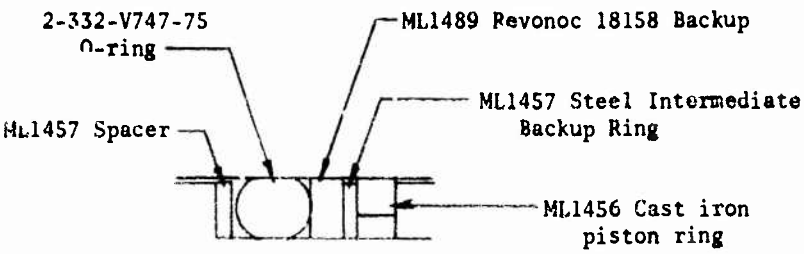
OBJECT:

To determine if interference of Revonoc causes flaking.

CONCLUSIONS:

It was primarily the interference of the Revonoc material that caused flaking in the earlier tests. This interference also seems to have caused more friction, particularly at high pressure.

ASSEMBLY:



PROCEDURE:

Temperature: 300°F, 350°F, Room Temperature, 20°F

59,850 cycles at 0 to 4000 psig pressure

33 hours at 300/350°F

Cycling: (1) Found friction loads
(2) Cycled 16.5 hours at 300°F, Examined seals
(3) Cycled 17 hours at 350°F, Examined seals
(4) Cycled 17 hours at R. T., Examined seals
(5) Cycled 8 hours at +20°F, Examined seals

Explanation: This test was run using the same identical parts as test 103A-1, but the Revonoc backup ring O.D.'s were cleaned up to allow .012" diametral clearance at room temperature before retesting, and the machined backups were given a new part number.

RESULTS:

No flakes were found after any step of this test, and all test components were in good condition, though the dynamic portion of both O-rings was slightly roughened, and the Revonoc 18158 material had flowed into the clearance around the intermediate rings during the initial 300°F testing. After each testing phase, the piston came out of the cylinder bore easily. During room temperature cycling, there was a loud groaning sound on the pressure strokes. The testing was stopped after eight hours at 20°F due to the increasing leakage rate experienced. (Up to 32 cc in two hours at the outboard end.)

It is surprising that no evidence of O-ring extrusion was found after room temperature testing in spite of the wide clearance gap around the Revonoc backup ring.

Friction Loads	Temperature	0 Pressure Breakaway	0 Pressure Running	4000 psig Pressure Breakaway	4000 psig Pressure Running
	72°F	150 lb.	60 lb.	800 lb.	780 lb.
	-65°F	10 lb.	10 lb.	-	-
	+20°F	150 lb.	90 lb.	750 lb.	700 lb.
	+300°F	110 lb.	90 lb.	590 lb.	580 lb.

APPENDIX XVIII

Engineering Report No. 00-291-5

2-3/4" Piston Fixture with ML1361-104 Seal Assembly

2-3/4" PISTON FIXTURE WITH ML 1361-104 SEAL ASSEMBLY

ENGINEERING REPORT 00-291-5

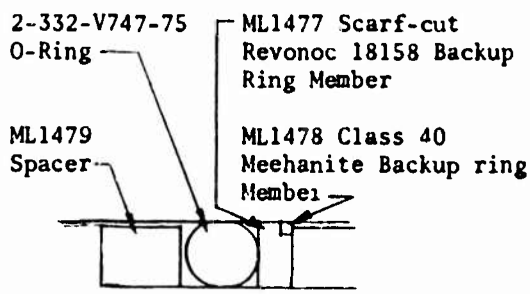
PROJECT: R10,518

OBJECT: To determine (1) whether a compact bi-material backup system has less friction than a more standard type; (2) whether scarf-cut backup rings without interference will extrude.

CONCLUSIONS: (1) The more compact bi-material type backup design used for this test does not reduce friction noticeably. (2) Scarf-cut backup rings without interference seem to resist extrusion more effectively than those with interference, and yet the area of the scarf-cut still "necks down" leaving very little protection against extrusion for the O-ring after cyclying a short time at elevated temperature. (3) Large diameter fluorocarbon O-ring piston seals do not seal effectively to very low temperatures.

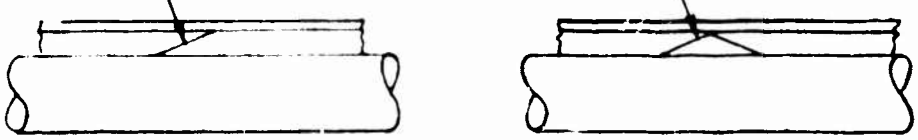
Temperature + 350°F, RT, + 20°F, 350°F
61,200 cycles at 350°F and 4000 psig
34 hours at 350°F
Cycling (1) Found friction loads
(2) Cycled 16 hours at 350°F. Examined seals.
(3) Cycled 16 hours at RT. Examined seals.
(4) Cycled 16 hours at +20°F. Examined seals.
(5) Cycled 18 hours at 350°F. Examined seals.

Assembly ML1361-104



EXPLANATIONS: The "bi-material" backup rings had been prepared several weeks earlier. The Revonoc backup members were made with a scarf-cut and with no interference in the groove at room temperature. The cut was incorporated to relieve interference loads that might develop with increase in temperature, and the large cast iron piston ring of the earlier tests was replaced with a .030" wide meehanite ring to determine whether the wide metal-to-metal contact of the piston rings had been causing much of the frictional drag. Although the cut no longer seemed necessary based on the results of the preceding test (ML 1361-105 assembly reported in 00-291-4), it seemed worthwhile to run the assembly to check on the friction factor, and to see whether a scarf-cut backup without interference would perform any better than the earlier one, which had considerable interference as the temperature increased.

RESULTS: Friction was not reduced noticeably. The scarf-cut portion of the Revonoc backup,



however, had necked down until only a narrow band of Teflon was left to protect the O-ring after the first 16 hours at 350°F. Although the seal was operated an additional 16 hours at room temperature, 16 hours at +20°F, and 18 hours at 350°F, no further degradation of the Revonoc backup rings was observed. The test was stopped simply because there seemed to be nc reason to continue cycling at 350°F.

In this test, as in number 00-291-2 (ML 1361-105 assembly), the seals leaked rather rapidly (approximately 12 cc per hour) at +20°F, and a loud groaning sound accompanied the pressure strokes much of the time.

On completion of the test, the only noticeable damage, when the piston was first removed from the bore, was the reduced section at the scarf-cut Revonoc joints, as mentioned above. When the components were removed from the piston, however, the O-ring from the drive side was found to be nibbled in the area that had faced the scarfed joint of the backup ring. The O-ring from the outboard end had light radial score marks on the face adjacent to the backup.

Both Revonoc backups had feathered slightly into the static joint under the ML 1367A piston guide, but there was no sign of material escaping over the tiny ML 1478 metal backup at the OD.

Friction Loads	Temperature	O Pressure Breakaway	O Pressure Running	4000 psig Pressure Breakaway	4000 psig Pressure Running
	72°F	200	150	600	600
	-65°F	10	10	-	-
	+20°F	150	70	800	600
	350°F	100	100	620	620

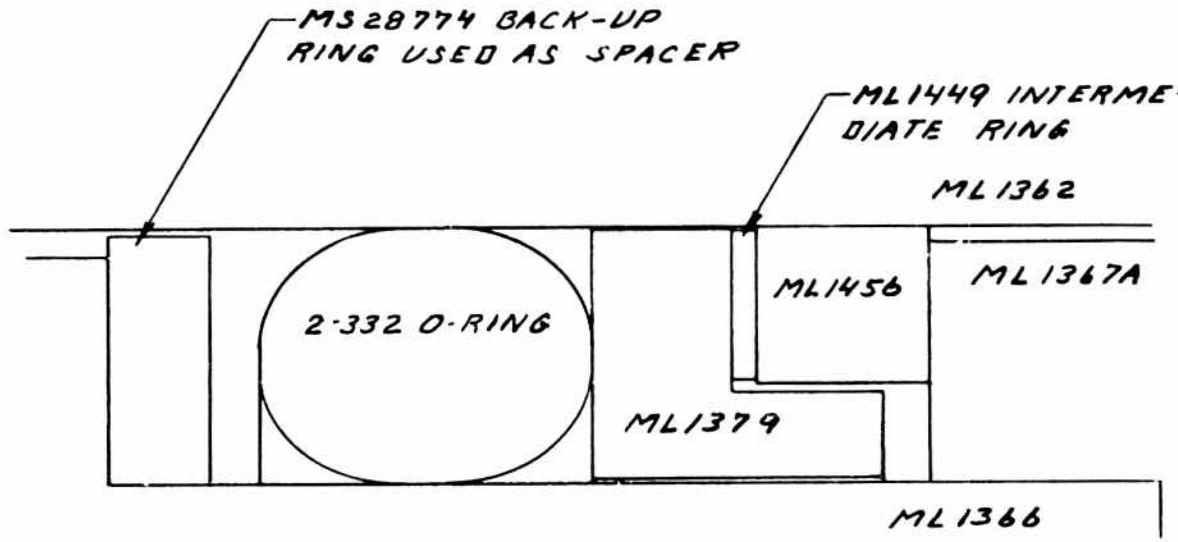
	350 psig Pressure Breakaway	350 psig Pressure Running
350°F	290	250

APPENDIX XIX

Reference Engineering Drawings

ML1361-102 Rev. A
-103 Rev. A
-103 Rev. B
-104
-105
ML1474-203

REV.	CHANGES	DATE	ECN NO.	CHK.	APP.
–	COPIED FROM "B" SIZE - NO CHANGES	[illegible]	RJR		



UNLESS OTHERWISE SPECIFIED	SIGNATURES		DATE
DIMENSIONS ARE IN INCHES TOLERANCES DEC. FRACT. ANGLES	DR BY	RJR	2-3-75
	CHK BY		
	APPD BY		
MACHINED SURFACE ROUGHNESS PER PS-31	REF.		
SCALE 10 X SIZE			

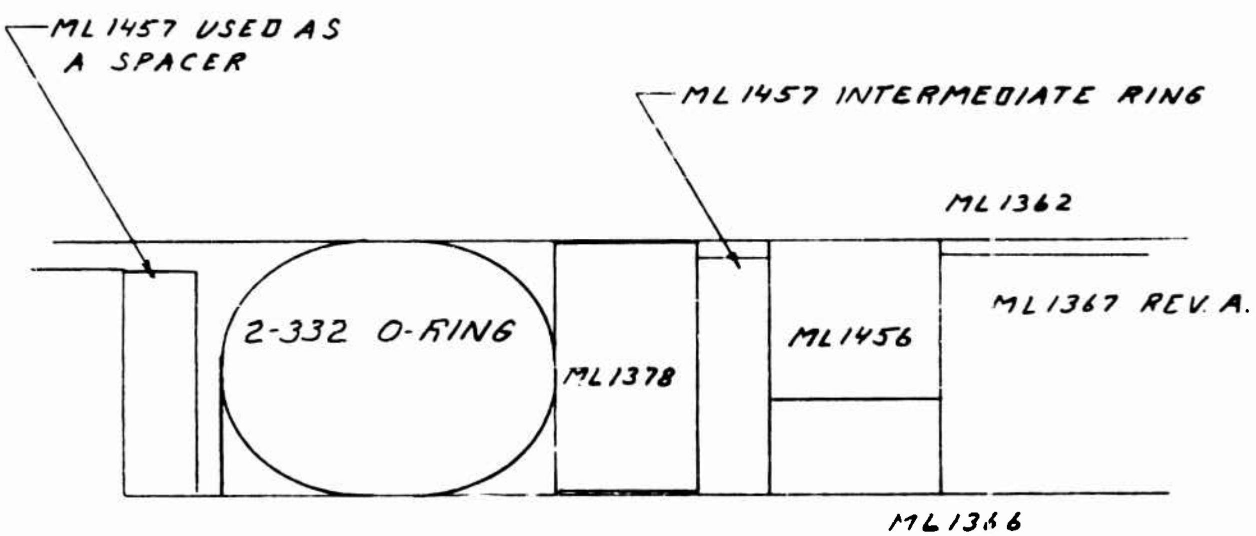
Parker SEAL COMPANY
CULVER CITY CALIFORNIA

TITLE ML1361 SEAL ASS'Y WITH "L" BACK-UP AND INTERMEDIATE RING

SIZE	CODE IDENT NO. / PRODUCT CODE NO.	DWG. NO.	REV.
A		ML1361-102	A

PS 10567-12

REV.	CHANGES	DATE	ECN NO.	CHK.	APP.
—	COPIED & SIMPLIFIED FROM "B" SIZE DWG	9-10-75		[illegible]	



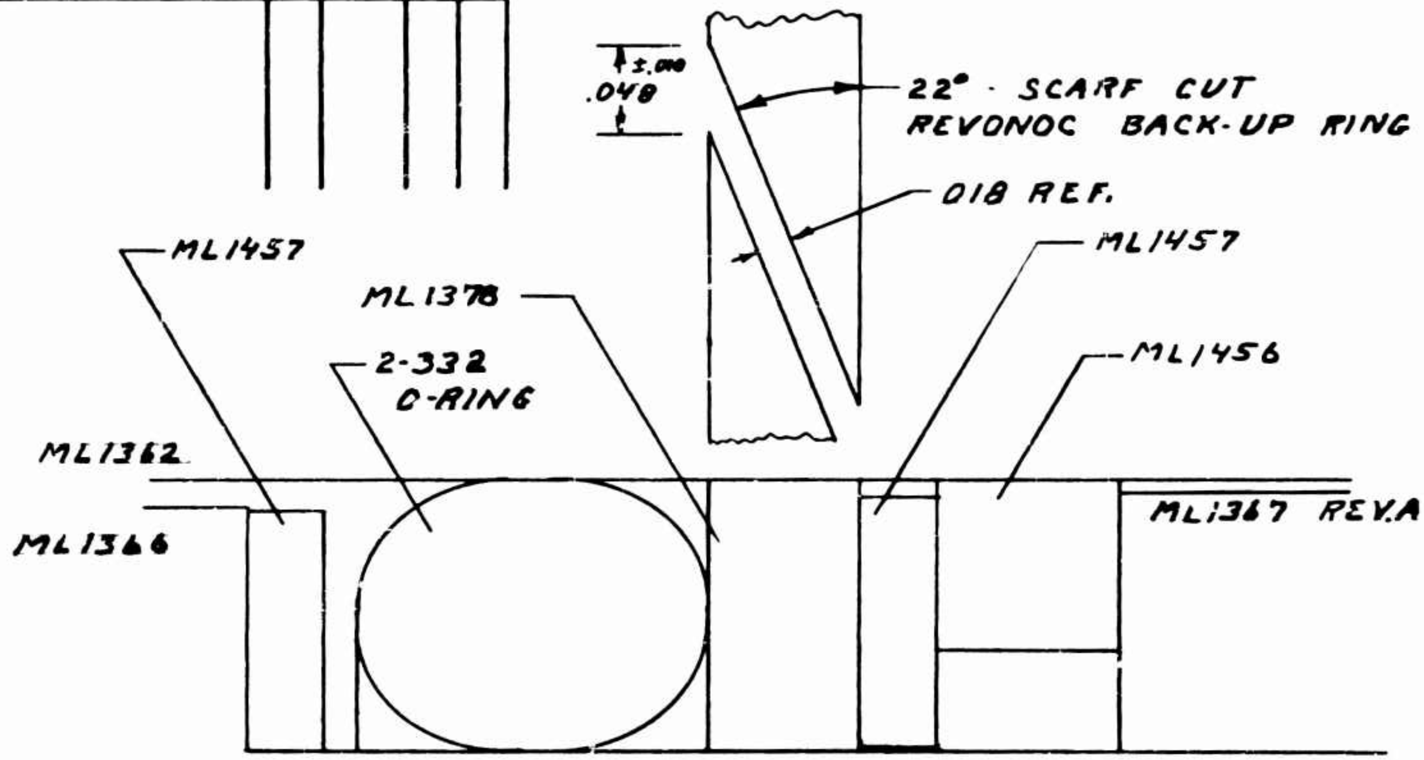
UNLESS OTHERWISE SPECIFIED	SIGNATURES		DATE
DIMENSIONS ARE IN INCHES	DR BY	1-30-75	[illegible]
TOLERANCES	CHK BY		
DEC. FRACT. ANGLES	APPD BY		
MACHINED SURFACE ROUGHNESS PER PSCS1	REF.		
SCALE 10 X SIZE			

Parker SEAL COMPANY
CULVER CITY CALIFORNIA

TITLE BACK UP SYSTEM WITH FULL INTERMEDIATE RING

SIZE	CODE IDENT NO. / PRODUCT CODE NO.	DWG. NO.	REV.
A		ML 1361-103	A

PS 10567-12



SAME AS ML1361-103 REV.A EXCEPT REVONOC BACK-UP RING IS SCARF CUT TO RELIEVE STRESS WITH HIGH TEMP. EXPANSION.

.048 GAP AT R.T. SHOULD CLOSE AT 185°F.

REV.	CHANGES	DATE	ECN NO.	CHK.	APP.

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
DEC. ±.005 FRACT. ±1/64 ANGLES ±1°
MACHINED SURFACE ROUGHNESS PER PBCSI
SCALE 10 X SIZE

	SIGNATURES	DATE
DR BY	RDP.	4-21-75
CHK BY		
APPD BY		

REF.

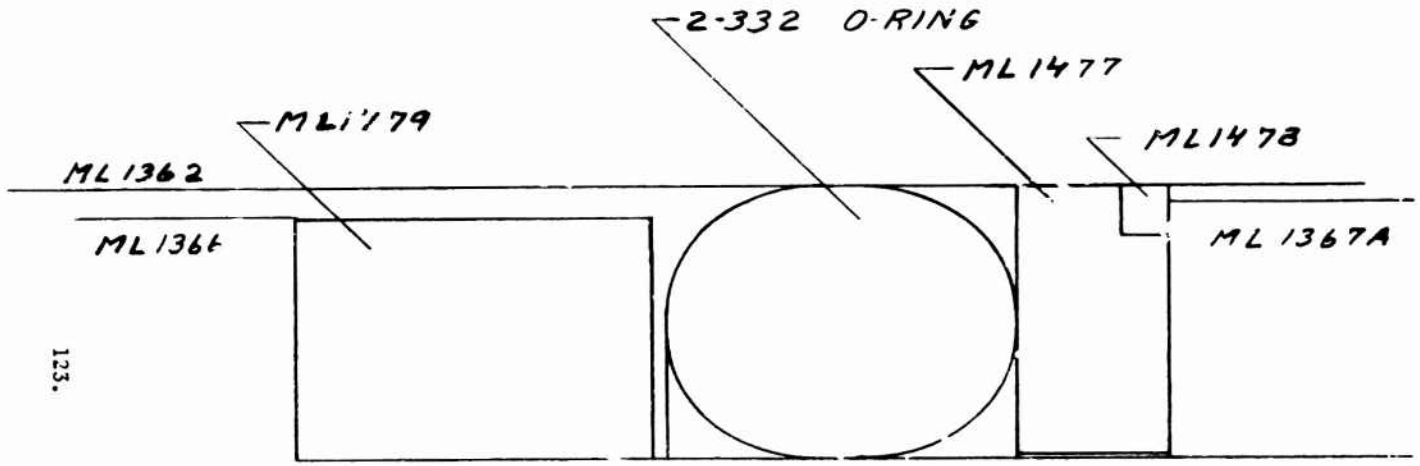
Parker SEAL COMPANY

TITLE BACK-UP SYSTEM WITH FULL INTERMEDIATE RING

SIZE A

DWG. NO. ML 1361-103

PS 10567-12



SMALL SECTION METAL BACK-UP, ML1478, TO REDUCE FRICTION. REVONOC BACK-UP, ML1477, IS SCARF CUT TO EXPAND WITH PRESSURE AND RELIEVE STRESS WITH TEMPERATURE CHANGES. ITS ROOM TEMPERATURE O.D. IS .020" LESS THAN BORE TO PROVIDE .013 MAXIMUM OD. INTERFERENCE AT 350°F. DEPTH IS .002" LESS THAN MINIMUM GLAND DEPTH TO PREVENT INTERFERENCE OF SECTION AT 350°F.

REV.	CHANGES	DATE	ECN NO.	CHK.	APP.

UNLESS OTHERWISE SPECIFIED	SIGNATURES		DATE
DIMENSIONS ARE IN INCHES TOLERANCES DEC. ±.005 FRACT. ±1/64 ANGLES ±1°	DR BY	RJR.	1-18-75
	CHK BY		
	APPD BY		
MACHINED SURFACE ROUGHNESS PER PSC51	REF.		
SCALE 10 X SIZE			

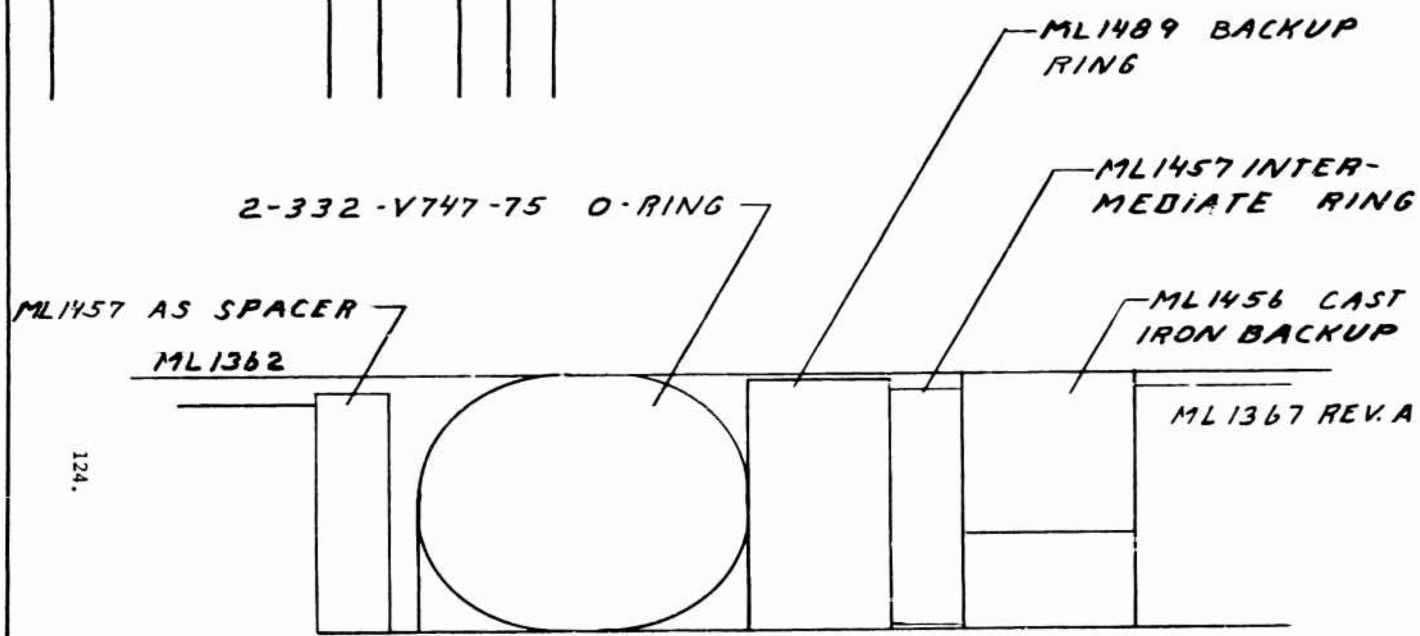
Parker SEAL COMPANY
CULVER CITY CALIFORNIA

TITLE ML1361 SEAL ASSEMBLY WITH BIMATERIAL BACK-UP

SIZE A | CODE IDENT NO. / PRODUCT CODE NO. | DWG. NO. ML1361-104 | REV.

PS 10567-12

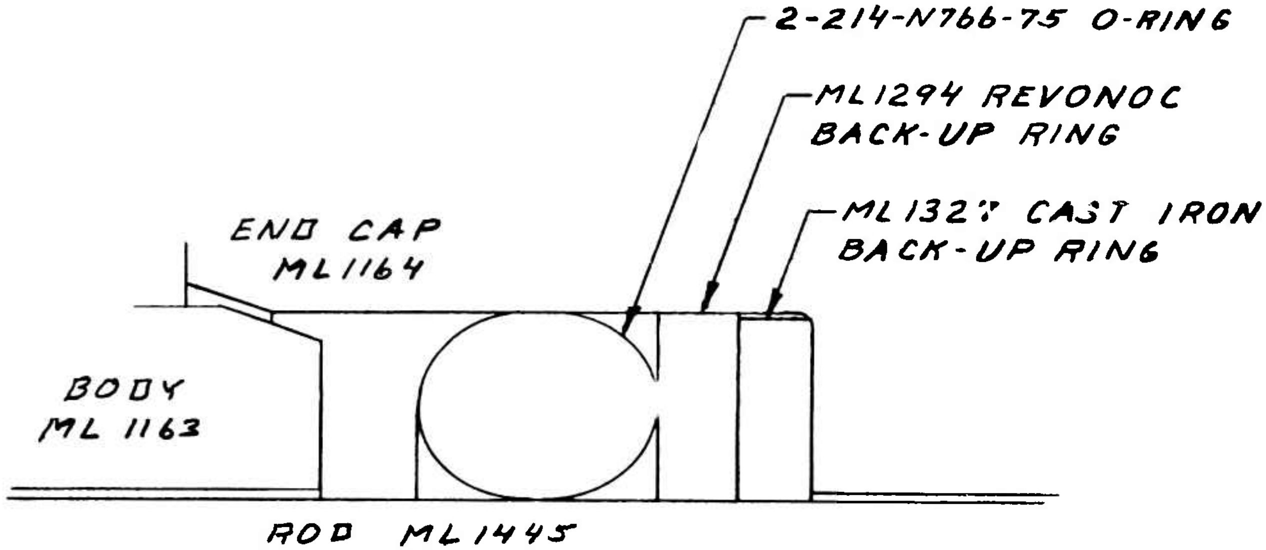
REV.	CHANGES	DATE	ECN NO.	CHK.	APP.



SAME AS ML1361-103A ASSEMBLY EXCEPT ML1489 BACKUP RING

UNLESS OTHERWISE SPECIFIED	SIGNATURES	DATE	Parker SEAL COMPANY, CULVER CITY, CALIFORNIA
DIMENSIONS ARE IN INCHES TOLERANCES DEC. FRACT. ANGLES	DR BY RR	6-11-75	TITLE BACKUP SYSTEM WITH BACKUP CLEARANCE
	CHK BY		
	APPD BY		
MACHINED SURFACE ROUGHNESS PER PSC51	REF.		SIZE A; CODE IDENT NO. / PRODUCT CODE NO.; DWG. NO. ML1361-105; REV.
SCALE 10 X SIZE			

PS 10567-12



SEAL CAVITY FOR ROD TEST FIXTURE 5718000 (AEROSPACE DWG)

R.G.R. 3-25-75
10 X SIZE
ML1474 - 203