National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
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Reply to Attn of: 541 **May 3, 2004**

TO: 540/Recertification Program Manager/Stanley Chan

FROM: 541/Materials Engineering Branch/Yury Flom

SUBJECT: Hydra-Set Incident Investigation Report

INTRODUCTION

On March 4, 2004 a 5000 lbs capacity hydraulic load positioner Hydra-Set® Model "B" S/N A2-420 was undergoing its regular monthly maintenance at GSFC. At the conclusion of the 3000 lbs load test, the unit suddenly failed while still under load, allowing the piston to drop to its lowest point and releasing the entire quantity of hydraulic fluid, see Fig.1. While no damage to hardware or personnel injury was experienced during the incident, this anomaly was noted and the current investigation was initiated.

In response to this incident, an independent Investigation Team was formed consisting of Dr. Yury Flom (chair), Mr. Edgar Hemminger and Mr. Jerome Kosko. The purpose of the investigation was to determine the root cause of the Hydra-Set malfunction and, more importantly, to assess the impact of this incident on the remaining inventory of hydraulic positioners at Goddard.

This report discusses the technical details of the investigation, identifies the most probable causes of the Hydra-Set malfunction and offers recommendations to insure against similar incidents in the future.

If the reader finds some minor discrepancies between this report and any previously written or verbal data pertaining to this incident investigation, the information contained in this report takes precedence over all other technical communications released prior to this publication.

CONCLUSIONS

1. The root cause of the incident was the unseating of the retaining ring.

2. The unseating of the ring is related to the repeated use of the same, perhaps even the original retaining ring, which was installed in the unit when it was purchased in 1988.
3. In the course of its service life, repeated compressions of the same retaining ring during maintenance assembly and disassembly operations most likely deformed the ring beyond the manufacturer's dimensional specifications. This was verified by dimensional inspection of the failed ring.
4. As verified by static compression test, a deformed, out of specification ring, when properly seated, did not result in failure under load. However, the same ring when partially seated, did fail under load. The failure load depends on the severity of ring deformation and the degree of misalignment between the ring and the retaining groove.
5. The Investigation Team could not conclusively determine whether a properly installed out of specification ring experienced some rotation during normal maintenance operations and, as a result, became unseated under load, or the ring was incompletely seated during the last reassembly of the unit.
6. The investigation found no evidence of any latent manufacturing defects that might have contributed to the incident or gradually degraded the performance of the Hydra-Set.
7. Exercising the Hydra-Set within its working load range may not be sufficient to verify the correct seating of the retaining ring. It was demonstrated that even partially seated retaining ring can support certain axial thrust loads.

RECOMMENDATIONS

1. The retaining ring should be replaced with the brand new ring every time the unit is reassembled.
2. It would be beneficial if the hydraulic positioner and the retaining ring manufacturers emphasized the importance of the used rings replacement in their product literature or service manuals. This is particular important when the hydraulic equipment is used for handling critical hardware.
3. The installation of the retaining ring should be verified to assure full seating of the ring. This step should be mandated by the Hydra-Set re-assembly procedure. The verification of correct seating could be accomplished by dimensional check or by any other means such as "seating gage", as described later in the report.
4. Rotation of the load relative to the Hydra-Set should be avoided to prevent the ring from being unseated from the groove.

INVESTIGATION SYNOPSIS

The failed Hydra-Set was disassembled and the ring assembly components such as the retaining ring, bushing, piston rod and the lower head were delivered to the Materials Engineering Branch (MEB) for the evaluation, see Fig.2. All components were found to be physically intact with no material and dimensional discrepancies, except for the excessively deformed retaining ring and some minor scratches on the inner groove edge of the lower head. In order to better understand the interaction between the

Hydra-Set components when the retaining ring is not fully seated, a series of static compression tests were performed on the re-assembled components. It was found that even partially seated retaining ring could support high axial thrust loads. In addition, a test was performed to see if any rotation of the over-compressed but fully seated retaining ring might take place during regular monthly exercise of the unit. No evidence of such rotation was observed. However, some scratch marks on the groove bottom may be indicative of relative rotation between the ring and the groove. There was no direct evidence found that pointed to the incorrect installation of the retaining ring in the failed unit, however this cannot be ruled out as a possible cause for a partially seated retaining ring. Consequently, the Investigation Team concluded that either relative rotation or a partially seated retaining ring could offer a plausible explanation of the incident. A number of recommendations is offered to prevent similar incidents in the future. A detailed account of the investigation effort is given below.

DISCUSSION

SERVICE AND MAINTENANCE OF HYDRA-SET

The Hydra-Set under investigation is a manually operated 5000 lbs load capacity hydraulic actuator capable of positioning loads in very small vertical increments, see Fig.3 It was placed in service at GSFC in 1988. Since then it had been used numerous times for positioning of critical hardware. The factory trained and certified GSFC personnel had performed all inspection, cleaning, overhaul and re-certification procedures, except for one time when the unit was sent to the manufacturer in 1997.

A typical maintenance schedule performed on all Hydra-Sets at Goddard (NSI document # 40-06-186-2), including the unit under investigation, is given in Table 1.

The last time the failed unit was reassembled was in January 2004. Since then, the unit successfully completed two Frequent Inspection and Maintenance operations for January and February and was undergoing its third Frequent Inspection for March when the unit malfunctioned, as indicated earlier in the report.

<u>Important points</u>:

- The Hydra-Set Operation and Maintenance Manual supplied by the manufacturer did not call for the replacement of the old retaining ring with the brand new one when the unit is reassembled.
- The overhaul kit sold by the manufacturer does not include a new retaining ring.

MATERIALS

Retaining Ring:

The retaining ring was internal series N5000 W 162 manufactured by the Waldes Truarc company. The ring had zinc plate finish, was physically intact and showed no cracks.

Table 1 Maintenance Schedule.

PROCEDURE	FREQUENCY	PURPOSE	BRIEF DESCRIPTION
Frequent Inspection and Maintenance	Monthly	Maintain Hydra-Sets in good operating condition and detect any malfunctions	Visual examination for leaks, structural anomalies and operational tests not to exceed rated capacity*, check for reasonable accuracy (+/-0.5%) in vertical positioning and operation of fail-safe valve.
Periodic Inspection and Maintenance	Annual	Recertification of unit as liftworthy for critical operations	Consists of a static load test at 125% of rated capacity, operational tests and visual examination for leaks and structural anomalies, test of fail-save valve, calibration.
Scheduled overhaul	Every 24 months	Replacement of the seals and load proof test	Units are completely disassembled. All seals are replaced and components are inspected for damage. Unit is reassembled with new seals and other parts as needed. Static test to 200% of its load capacity.

Table note:

** - Typically, 60% of the maximum rated load is used for this procedure at Goddard.*

On both sides of the ring, the zinc plated surface had characteristic circumferential lines, as shown in Fig.4. Most likely these lines were the “foot prints” left on the zinc surface by the abutting edge of the inner groove. The fact that both sides of the ring have these imprints indicates a multiple use of this ring in the subject Hydra-Set. Hardness readings taken on the ring resulted in an average Rockwell “C” values of 51.5. This value is well within the hardness range of Rockwell “C” 47-52 specified in the Waldes Truarc manual for the carbon spring steel rings.

Dimensional inspection of the ring performed in accordance with the manufacturer’s recommended inspection procedure resulted in the average ring free diameter of 1.737 in. This falls below the ring diameter range of 1.779 – 1.839 in specified by the ring and Hydra-Set manufacturers. In addition, the ring was not flat but twisted slightly out of plane, see. Fig.5. The ring thickness was found to be 0.064 in., which agreed well with the manufacturer’s specification of 0.062 +/- 0.003 in.

Other than the “foot print” lines, the surface of the ring is relatively featureless except for one corner of one lug showing some evidence of scraping, as shown in Fig.5

Important observations:

- Free ring diameter is smaller than minimum diameter specified by the manufacturer
- Print marks are on both sides of the ring
- The ring is out of plane
- One corner of one lug is scraped
- No scratch pattern is found on the ring surface around the edges

Lower Head:

The lower head was visually inspected for possible damage or defects around and inside the inner groove. The groove edge that supports the axial thrust load was found to be sharp and physically intact. In one location, the edge was slightly deformed as shown in Fig. 6. In the same location one can see two vertical marks on the inside surface of the lower head bore. These marks extend all the way from the groove edge to the outside edge of the bore. In several locations, the groove bottom had some circumferential scratch marks, as shown in Fig.6

Furthermore, the groove dimensions were carefully measured on Mitutoyo Coordinate Measuring Machine BH 305. The groove diameter was found to be 1.710 in. +/-0.001 in. which indicated almost perfect circular uniformity. The bore diameter was found to be 1.620 in. Using these two values, the groove depth was found to be (1.710 – 1.620)/2 = 0.045 in. The groove width measured to be 0.068 in.

Hardness of the lower head body was an average Rockwell "B" value of 79 which is slightly below Brinell hardness of 149 given for a free cutting low carbon steel plate used for the lower head fabrication.

Important observations:

- Groove dimensions and uniformity were found to be well within the manufacturer's specifications
- For the most part, the abutting edge of the groove was free from damage.
- In one location the edge was flared.
- Two vertical scratch marks located in the vicinity of the edge flare.

Piston Rod Bushing:

The piston rod bushing was visually examined for possible defect and dimensional discrepancies. Examination of the bushing revealed no unusual scratch marks around its outer edge. The edge radius was about 0.016 in which is roughly ¼ of the maximum corner radius of 0.064 in specified by the ring manufacturer. By design, the bushing cannot make a physical contact with the piston, when the latter bottoms out on the inner face of the lower head, see Fig.3

Important observations:

- The piston rod bushing had no surface or dimensional anomalies.

Piston Rod:

An examination of the piston rod revealed no anomalies. The recess machined on the inner face of the piston helps to assure that the piston does not make any physical contact with the bushing, see Fig.3

STATIC COMPRESSION TEST

In order to better understand the behavior of the retaining ring and other components inside Hydra-Set under load, it was decided to perform a static compression test. The test was not designed to replicate the exact hydraulic interaction between the components. The test provided an approximate simulation of the partially seated retaining under static load. The investigation team felt that the test could be beneficial in determining the ability of a partially seated retaining ring to support static axial thrust loads. This, in turn, might lead to some clues as to what the possible failure mechanisms of the Hydra-Set were. The test schematic is shown in Figs.7 and 8. Table 2 contains a summary of all static tests performed.

Important observations:

- A partially seated retaining ring could still support high axial thrust loads. This was verified for a new ring and for an out of specification used ring.
- A fully seated but severely distorted ring with out-of-plane twist could also support very high thrust loads when its free diameter exceeded the diameter of the retaining groove.

FREQUENT EXERCISE TEST

In addition to static compression test, the Investigation Team had witnessed the Frequent Inspection and Maintenance test performed on a Model “C” Hydra-Set. The purpose of this test was to determine if any rotation within the ring assembly takes place during this monthly exercise. A position of the fully installed ring was marked relative to the lower head and the piston rod bushing. After the test, the ring position was inspected for any rotation. No relative rotation between the components was detected.

Important observations:

- Normal handling of the Hydra-Set under load during frequent exercise test did not cause any rotation within the retaining ring assembly.

Table 2. Axial Compression Tests

Test No.	Configuration	Loads Applied	Results
1*	Retaining ring is partially seated. Both lugs are in the groove. No lubrication	470 lbs for 5 min. Unload and check the ring position. Reload and repeat two more cycles***	Ring did not come out. Remained partially seated.
2*	Retaining ring is partially seated. Only one lug is in the groove. No lubrication	Three 470 lbs/5 min cycles	Ring did not come out. Remained partially seated.
3*	Retaining ring is partially seated. Only one lug is in the groove. Lubricated**** with hydraulic fluid.	Applied one 470 lbs/5 min cycle Increased load to 1003 lbs.	Ring did not come out. Remained partially seated.
4**	Deformed retaining ring is partially seated. Only one lug is in the groove. Lubricated	Maximum load observed during ramping up portion of the first cycle was 25 lbs	Ring came out of the groove
5**	Deformed retaining ring is fully seated. Lubricated	After first cycle load was increased to 1000 lbs	Ring did not come out. Remained fully seated
6**	Deformed retaining ring partially seated. Both lugs are out, but the opposite side of the ring is in the groove. Lubricated.	After first cycle load was increased and reached 786 lbs.	Ring came out of the groove at 786 lbs
7**	Deformed retaining ring is partially seated. Both lugs are in the groove. Lubricated.	After first cycle load was increased to 1000 lbs.	Ring did not come out. Remained partially seated.

Test notes:

** Tests 1 through 3 were performed with the used retaining ring removed from the fully operational 10,000 lbs capacity Hydra-Set (Model "C") which is almost identical in design to the failed Hydra-Set.*

*** Tests 4 through 7 were performed using the brand new ring that was deliberately over-compressed in a vice. It was also slightly bent out of flat. See Table 3 for ring dimensions.*

**** One full cycle consisted of the load ramp to 470 lbs, 5 min dwell and ramp-down segments. It was estimated that 470 lbs was the force acting on the ring when the Hydra-Set is loaded to 3000 lbs*

***** Lubrication with hydraulic fluid was used to simulate possible presence of the fluid in the inner groove of the Hydra-Set in service. The hydraulic fluid residue could have been left in the groove during unit re-assembly or possibly due to a small leakage around the seal*

ANALYSIS

The average free diameter of the ring from the failed Hydra-Set was compared with the Hydra-Set manufacturer's specification as well as Waldes Truarc company manual. In addition, the diameters of the over-compressed and the brand new, never used rings were measured as shown in Table 3.

Table 3. Average Free Diameters* of the W-162 Retaining Rings

Rings Inspected	Ring from Failed Unit	Used Ring from Model "C"	New Ring Compressed Once	Over-Compressed Ring	New Ring, Never Compressed	Del Mar Avionics Drawing No. A5-5227, sheet 1	Waldes Truarc manual
Average Free Diameter, inches	1.737	1.756	1.760	1.712	1.802	1.779 – 1.839	1.779 – 1.839

Note:

** - measured on the optical comparator*

As one can see from the Table 3, the Hydra-Set manufacturer's specification is identical to the manual value. From the first glance it appears that the +/- tolerance given for the ring diameter is quite large. If we compare the manual value with the new ring compressed once and with the used ring from Model "C" it becomes clear that the lower bound of 1.779 in encompasses the diameter reduction due to the plastic deformation experienced by the ring during the very first compression. It also confirms the Waldes - Truarc assertion that after first compression the ring undergoes plastic deformation and reduces its diameter to some stable value. According to Waldes Truarc repetitive compressions do not have any significant effect on this new diameter.

Some interesting information is provided in the Ring Inspection part of the Waldes Truarc manual. It states that as long the ring average free diameter is equal or more than maximum groove diameter, the ring is fully operative. Conversely, the play between the ring and the groove after installation indicates that the ring has been compressed excessively which may lead to application failure.

Comparing the lower head groove diameter with the Table 3 values indicates that all these rings are fully operative, since their diameters exceed 1.710 in. Indeed, a static test performed on the fully seated over-compressed ring (test # 5, Table 2) confirmed that even the smallest ring was capable of supporting axial thrust load as high as 1000 lbs, which exceeds the rated load capacity of the failed Hydra-Set (recall that 470 lbs axial thrust force is acting on the ring when the Hydra-Set is loaded to 3,000 lbs).

It is important to recognize that while the rings may be fully operative when subjected to static loading conditions, in cases of dynamic (sudden, impact or cyclic) thrust loads or relative rotation condition, the rated performance of the ring may be diminished if the components of the ring assembly are outside their dimensional specifications.

Consider the dimensional characteristics of the lower head inner groove, the retaining ring and the piston rod bushing that came from the failed Hydra-Set. The ring free diameter 1.737 in. (see Table 3) is outside the allowable range. The groove dimensions are well within the manufacture's specifications. The bushing's abutting edge has no chamfer and its corner radius is well below the maximum allowable radius (0.016 in. << 0.064 in.). Thus, neither the bushing nor the lower head have any dimensional discrepancies that would downgrade the performance of the retaining ring. As far as the ring is concerned, it is very difficult to tell whether it had the diameter of 1.737 in. prior to the last re-assembly or as a direct result of the ring being deformed when it was forced out of the groove during the accident. In any case, since its diameter exceeds the groove diameter, this ring meets the criterion of fully operative one, again providing that it is subjected to static loading.

A static or dynamic overload can be ruled out as possible causes of the incident, since the failure mode under such conditions would be a fracture of the retaining ring or the abutting edge of the inner groove. Therefore, we should consider other conditions that may lead to a different mode of Hydra-Set failure. One of these conditions is a relative rotation.

When the piston rod bushing exerts thrust on and rotates relative to the ring, frictional forces act on the ring body. This can cause the ring to "walk out" or otherwise unseat from the groove.

The ring manufacturer provides a formula to calculate maximum thrust load under rotation:

$$P\mathrm{rr} \leq \frac{\mathrm{s\,t\,E}^2}{\mu\,18\,\mathrm{S}}$$

Where: $\boldsymbol{P_{rr}}$ = allowable thrust load exerted on the ring by the bushing, **s** is maximum working stress of ring, **t** is the ring thickness, **E** is largest section of ring; **μ** is coefficient of friction between ring and the groove and **S** is bushing diameter. From the Waldes Truarc manual, **s** = 250,000 psi; **t** = 0.064 in.; **E** = 0.164 in.; for **μ** we can use 0.2 as given in the sample calculations in the manual and **S** = 1.5 in.;

If we substitute the values in the formula, the allowable thrust $\boldsymbol{P_{rr}}$ can not exceed 80 lbs! This is rather low load considering the fact that the ring is subjected to about 780 lbs thrust when the Hydra-Set is under maximum working load of 5000 lbs.

Since the rotation of piston rod can be transferred to the bushing only through the sealing O-rings, and the crane hook is equipped with the thrust bearing, it is not clear how any rotation of the load lifted by Hydra-Set can be transferred on the retained parts.

In fact, the Investigation Team did not observed any relative rotation as a result of the routine Hydra-Set exercise test performed for this very purpose. Nevertheless, the calculation above does demonstrate that the retaining ring is very sensitive to any rotational movements of the retained parts, particular when Hydra-Set is under heavy loads. In addition, some circumferential scratch marks observed in the bottom of the groove may be indicative of a relative rotation between the ring and the lower head, see Fig.6. Otherwise, these scratch marks could result from rotating the ring during previous installations and/or the attempts to rotate the ring within the groove to determine how snug the fit is between the ring and the groove. The hardness difference between the ring and the groove material is so large that the ring can scratch the groove easily when it is manually rotated while fully seated.

Another condition that can cause the ring to slip out of the groove when the Hydra-Set is under load is an incomplete or partial installation of the ring. It is possible to assemble the Hydra-Set with only partially installed retaining ring, since the unit does not have any design features that would preclude the incorrect seating of the retaining ring. Moreover, as the static test confirmed (see tests ## 1,2,3 and 7 in Table 2), a partially seated retaining ring can support static thrust loads as high as 1000 lbs! This means that depending on the Hydra-Set service conditions, a partially installed retaining ring may not “walk out” of the groove right away on the first loading cycle! Rather it continues to perform “normally” until the loading conditions change (static to dynamic) or it slowly creeps out of the groove if subjected to sustained loads over a long period of time. The amount of axial static thrust required to unseat a partially seated ring depends on its degree of misalignment, see Fig.8. For example, the static test demonstrated (see tests ## 4 and 6 in Table 2) that it might take as little as 25 lbs or as much as 786 lbs to force a partially seated ring out of the groove.

Since the components of the ring assembly were found to be intact with no evidence of physical damage, the Investigation Team believes that the ring became almost fully unseated prior to leaving the inner groove completely. It appears that only a corner of one lug was still keeping the ring in place when it finally was forced out of the groove during the last Hydra-Set exercise. Close examination of the abutting groove edge revealed a small flared portion of the edge and the two vertical scratch marks on the surface of the bore, as shown in Fig. 6 These features are consistent with the surface markings that would have been left by the retaining ring “walking out” of the groove with one of its lugs still partially located inside the groove. Most likely this was the lug that has some evidence of scraping action on the plated surface of one of its corners, as shown in Fig. 5.

Based on the results of this investigation we conclude that either a relative rotation and/or improper installation could eventually result in the unseating of the ring. It is difficult to say with high level of confidence what exactly caused the retaining ring to “walk out” of the groove. It was well beyond the scope of the current investigation to perform a comprehensive study on the effects of rotation of the Hydra-Set under load on the tendency of the retaining ring to unseat. Such study would require a significant amount of time and effort to account for various possible combinations of the hydraulic loads, loading conditions, etc. Instead, the Investigation Team felt it was more constructive to focus on the prevention aspects of similar incidences.

The most important recommendation resulted from this investigation is the replacement of the retaining ring with the new one when the Hydra-Sets are re-assembled. The new retaining ring should be included in the manufacturer's overhaul kit. In addition, the ring replacement action should be reflected in both, the Hydra-Set and the retaining ring manufacturer's literature and maintenance manuals. Furthermore, it would be very helpful to have some means of verification that the retaining ring is being fully seated every time the ring is replaced. A simple gage can be machined for this purpose as shown in Fig.9. It is also important to avoid any relative rotation within the ring assembly when the Hydra-Set is under the load.

A great deal of information on properties of the retaining rings used in this investigation was taken from the Waldes Truarc ring manual, available on their web site.

ACKNOWLEDGEMENT

The Investigation Team would like to thank Del Mar Avionics and Waldes Truarc for their assistance and cooperation in this investigation. Also, we would like to acknowledge the Mantech personnel in helping with the tests and making Hydra-Set components available for this investigation. An effort of Mr. Dave Puckett, MEB, in conducting the axial compression tests is very much appreciated. Finally, the authors would like to thank Mr. James Smith, Code 544 for creating 3D graphics used in this report.

If you have any questions, please contact Dr. Yury Flom at Goddard Space Flight Center on 301-286-3274 or by e-mail yury.a.flom@nasa.gov.

Signatures:	Date:
Original is signed by Dr. Yury Flom	*04/30/2004*
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Original is signed by Mr. Edgar Hemminger	*05/03/2004*
Mr. Edgar G. Hemminger, Code 540	
Original is signed by Mr.Jerome Kosko	*04/30/2004*
Mr. Jerome G. Kosko, Code 302	

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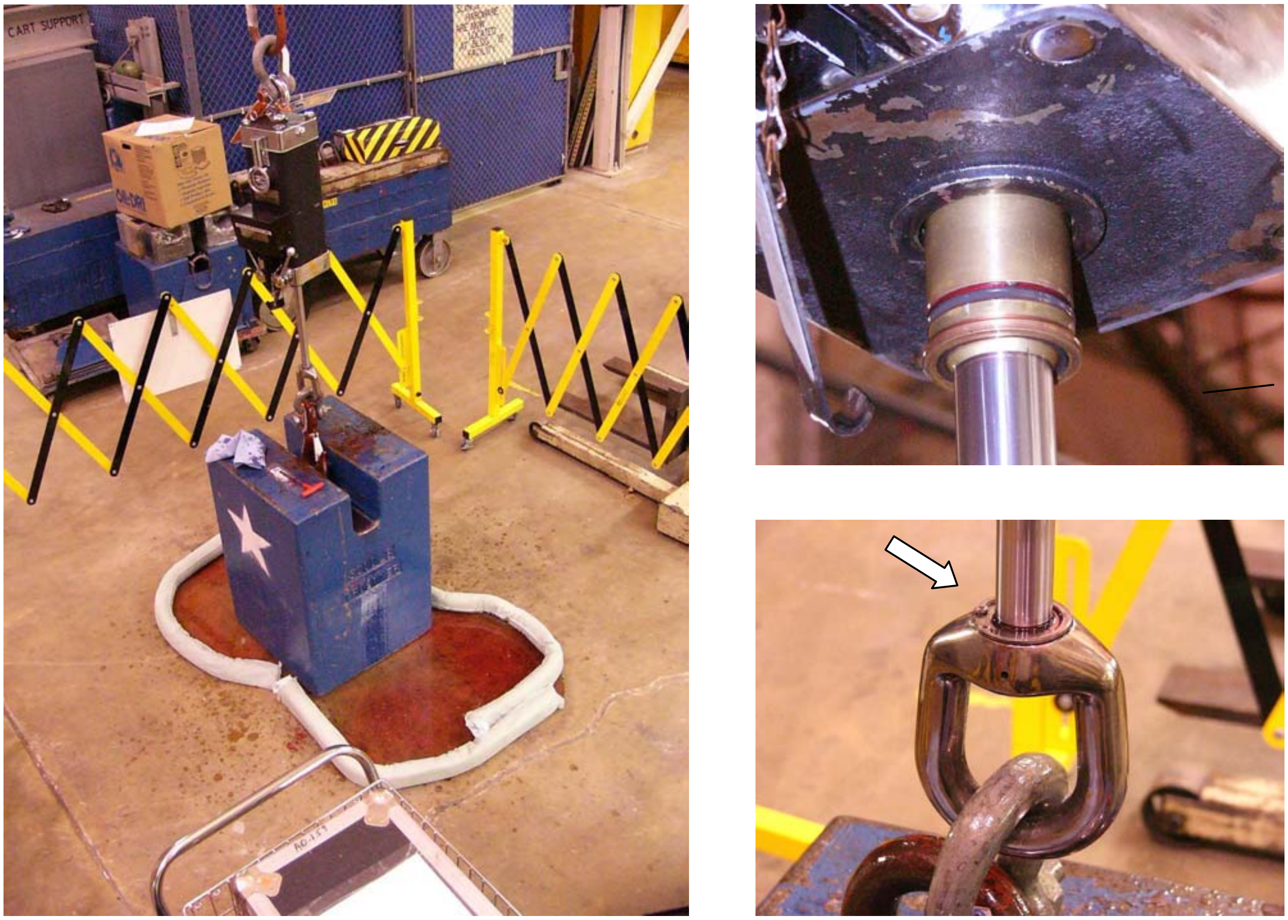
Distribution



These photographs show the Hydra-Set just after it let go. The close ups show the retaining ring (white arrow) captured by the clevis as it fell out and the ring assembly (top) that came out of the lower head following the ring.

The Hydra-Set is on the bench top awaiting for disassembly after the incident.

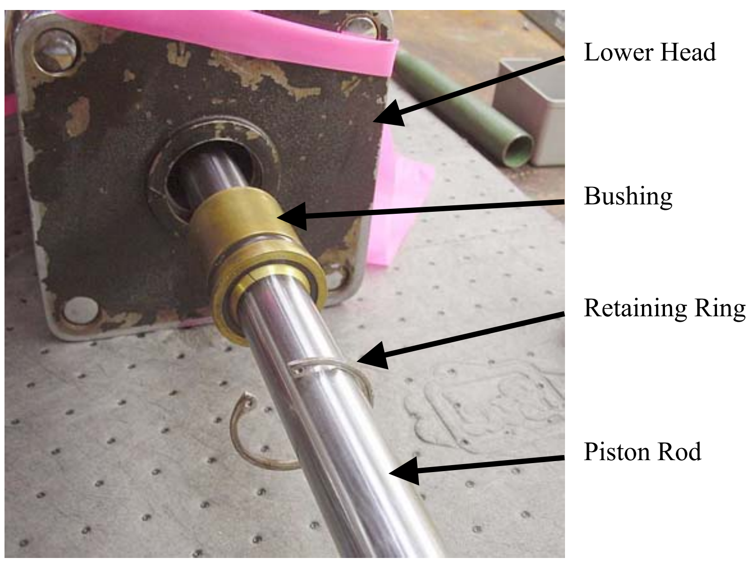


FIG.1 Model “B” S/N A2-420 Hydra-Set after the incident.

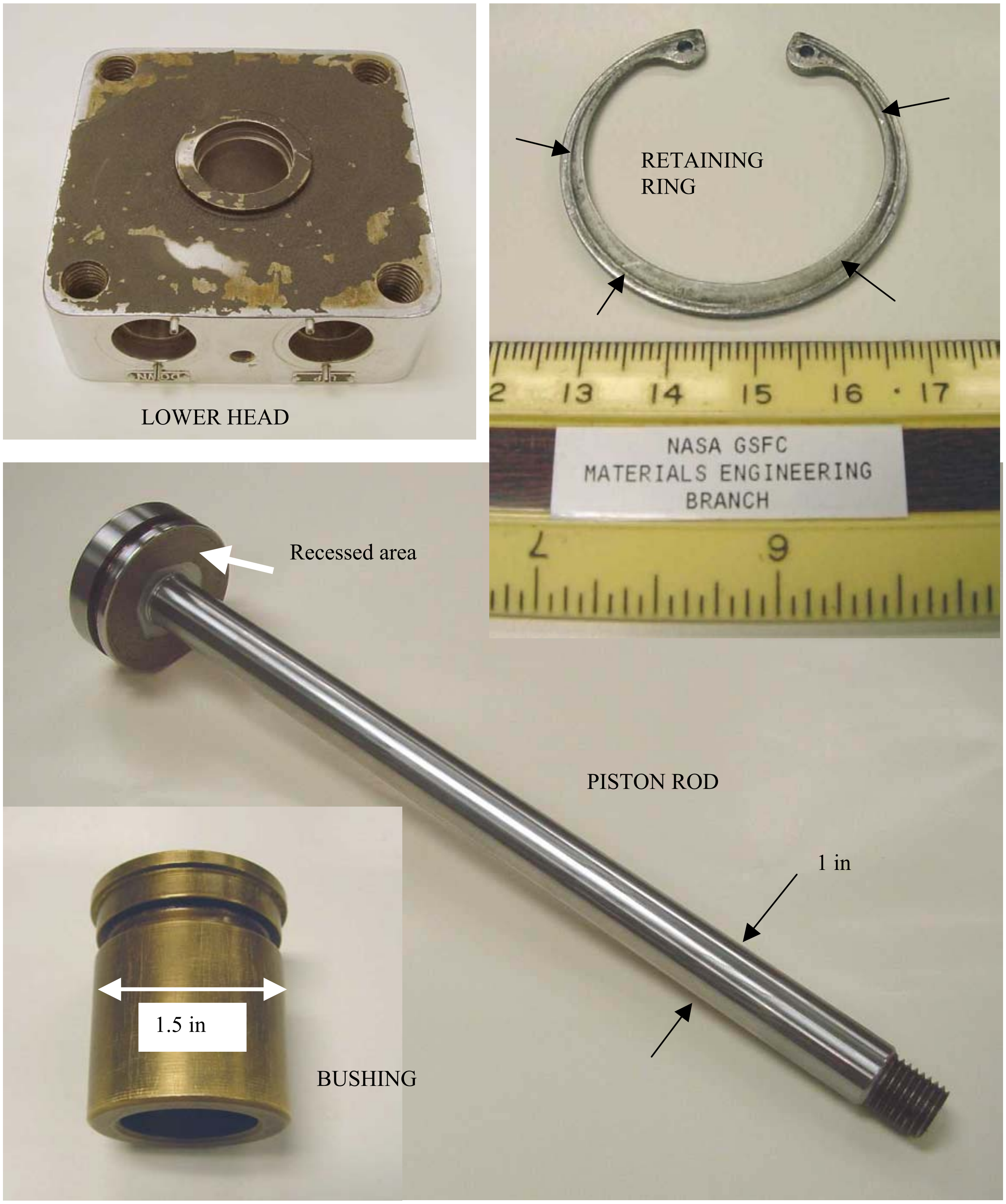


FIG. 2 Hydra Set components delivered to the Materials Branch for examination. Note that piston has a recessed area to prevent mechanical contact with the bushing. The retaining ring has a “footprint” line (black arrows) from the contact with the abutting edge of the inner groove.

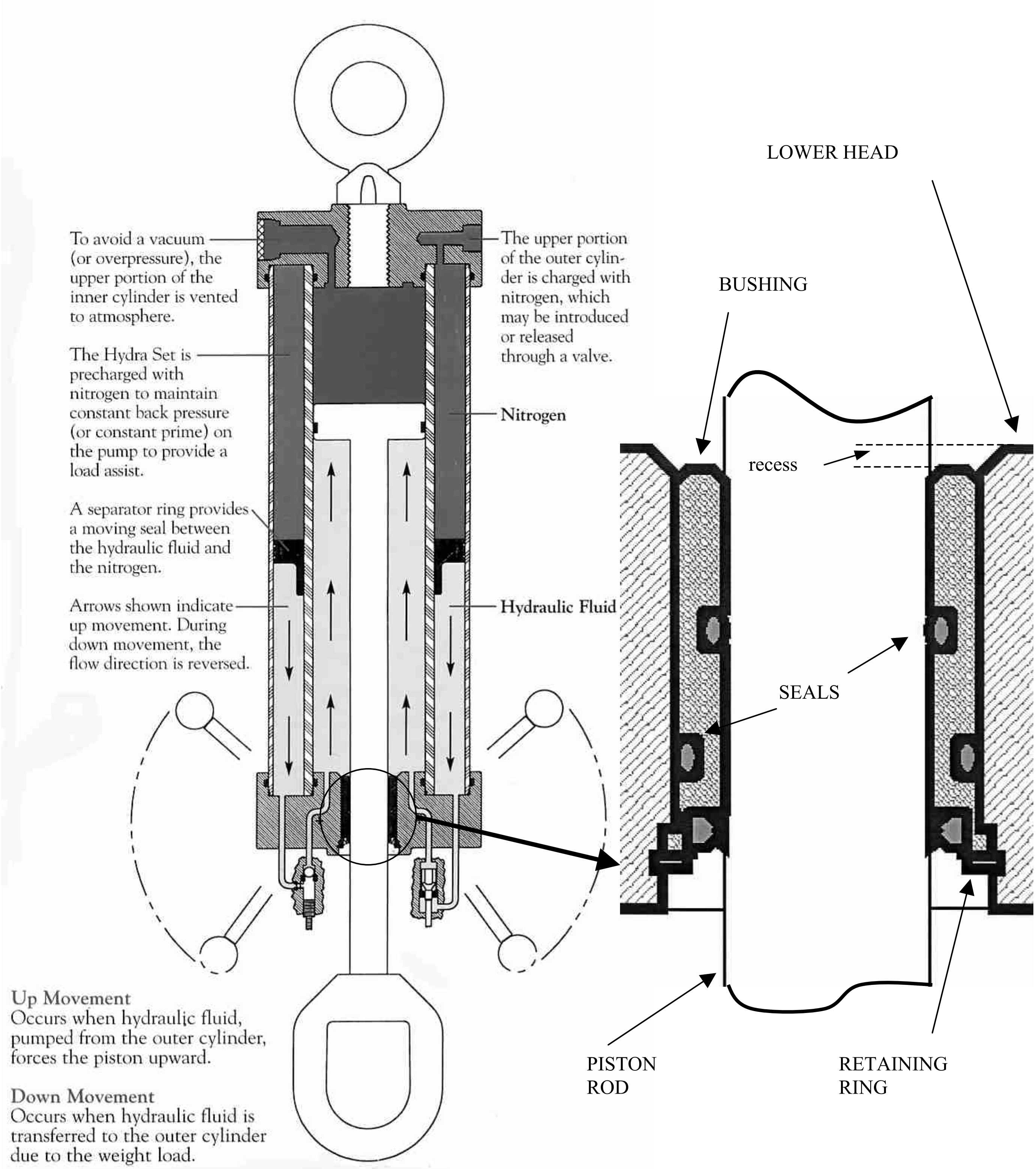


FIG.3 A cross section of the Hydra Set that explains its operation. An expanded view on the right shows the details of the retaining ring assembly. Note that the bushing is located below (dashed lines on the expanded view) the inner face of the lower head. This design feature assures that the piston never makes a physical contact with the bushing when it bottoms out against the internal face of the lower head.

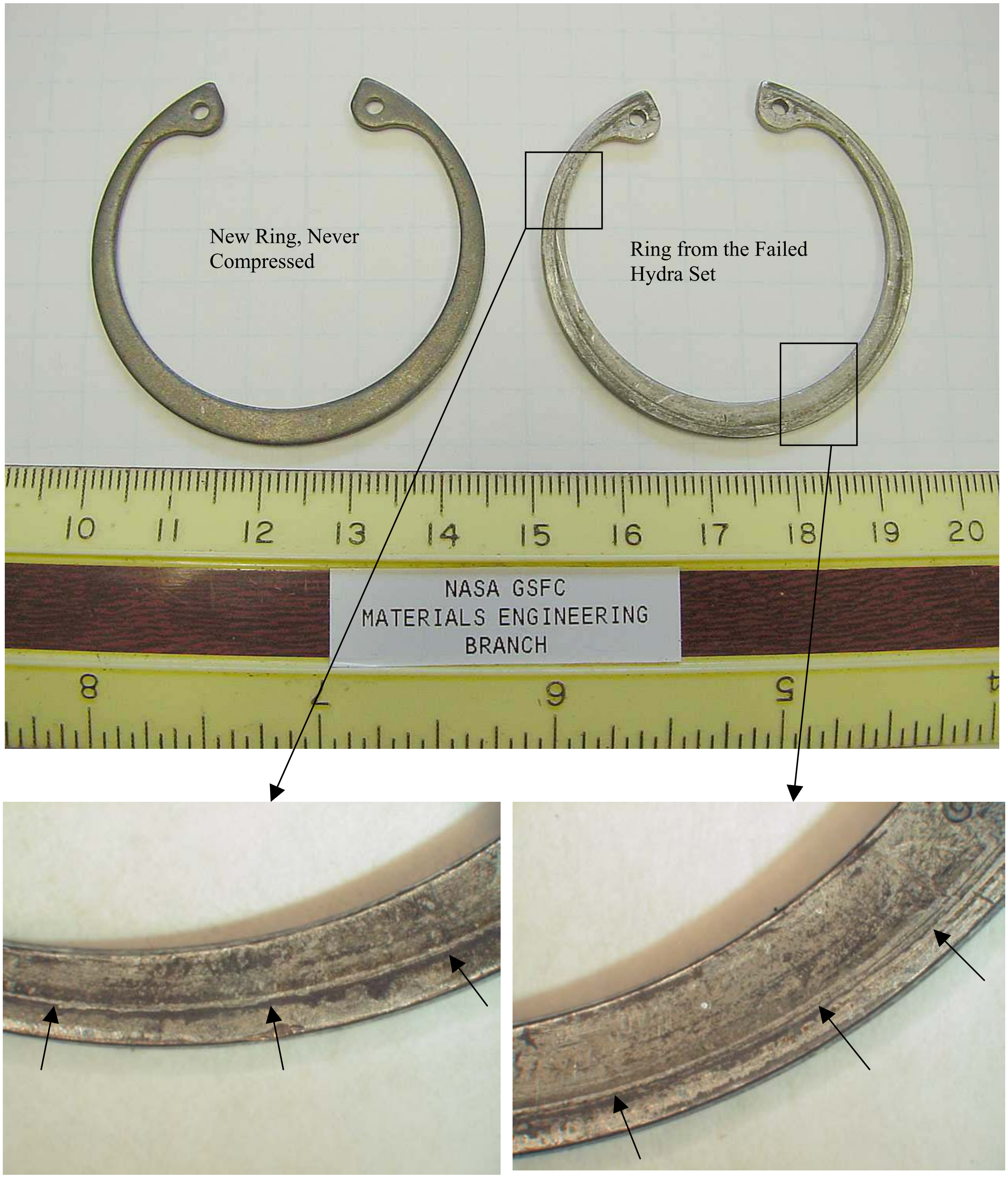
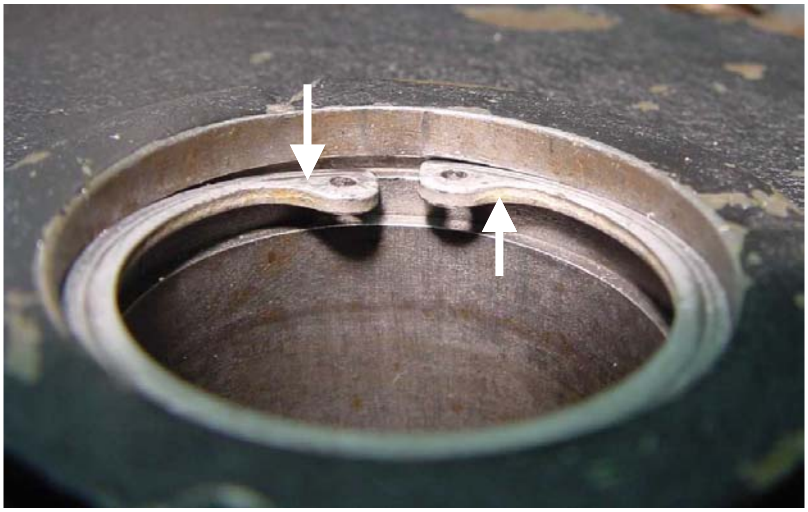


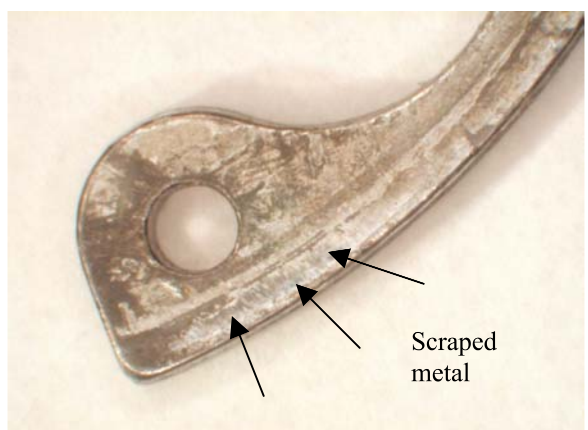
FIG. 4. A side-by-side view of the two Internal series N5000 W 162 rings (top) and the close-ups of the failed ring showing "foot print" line running around the entire circumference on both sides of the ring.



A

B

C



D

FIG.5 The lugs in failed ring are slightly bent out of plane as indicated by white arrows (top). Here, the failed ring was partially re-installed into the lower head to illustrate the ring deformation. Photos A-D provide close-ups of all four corners of the lugs. Only corner D shows some scraped zinc plating.

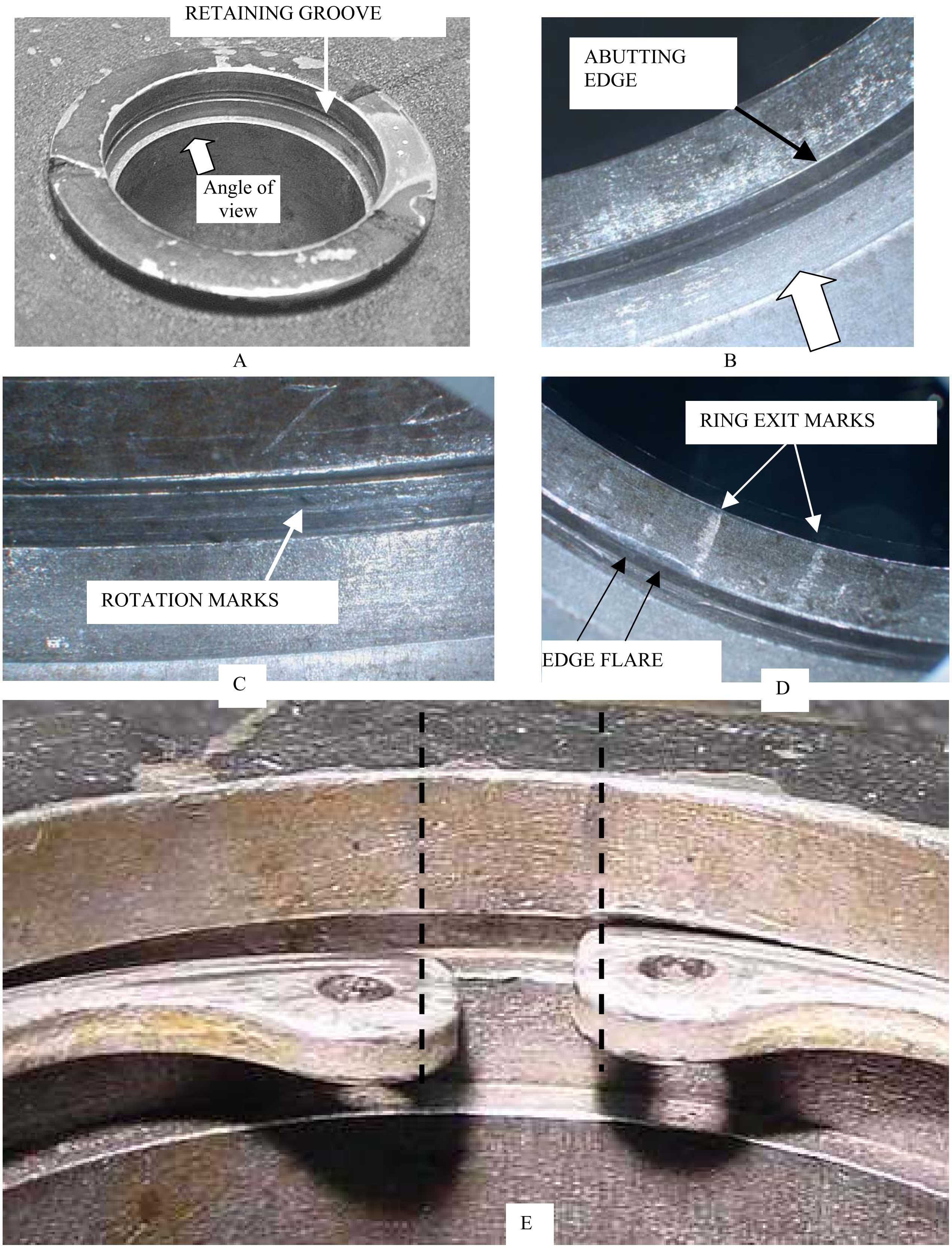


FIG.6. Top photos show inner groove (A) and a typical appearance of the abutting edge (B). Note the angle of view used to take a close-up photo. Some rotation marks can be seen on bottom of the groove (C). View D reveals two vertical marks and some edge damage possibly left by the ring lugs on the way out. The distance between vertical marks (dashed lines) is very similar to the gap between the lugs when the ring is about to come out of the groove (E).

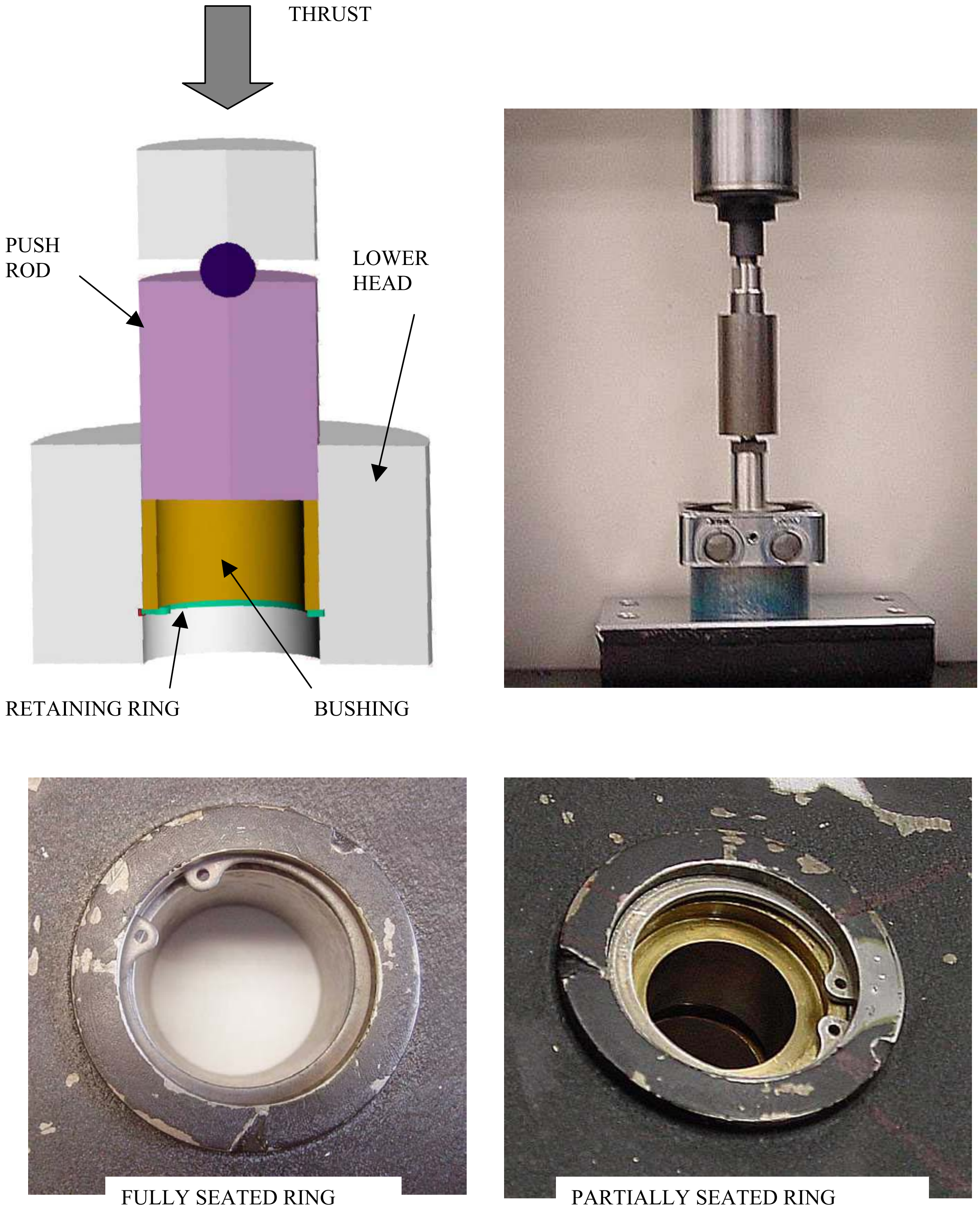


FIG.7 A schematic 3D cross sectional view of the static compression test (top left) showing application of the axial thrust on fully seated retaining ring. Top right photograph depicts the actual test setup. Bottom photos show fully seated (left) and one of the possible orientations of the partially seated (right) ring.

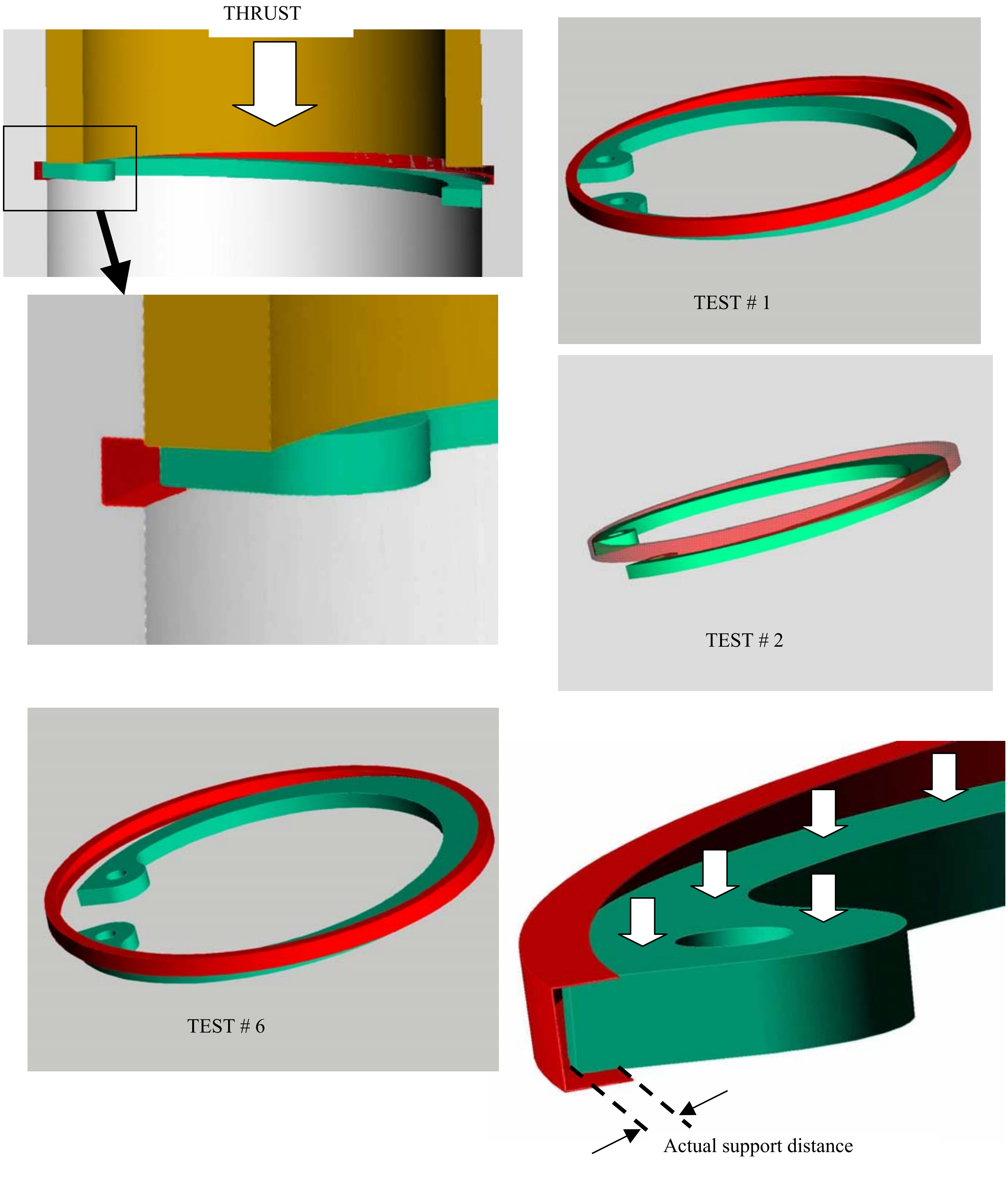


FIG.8 A schematic 3D view of the partially seated retaining ring under axial load (top left). Also shown schematically are various positions of the partially seated ring during compression test. Depending on the actual support distance it may take different amount of thrust (white arrows) to unseat the ring.

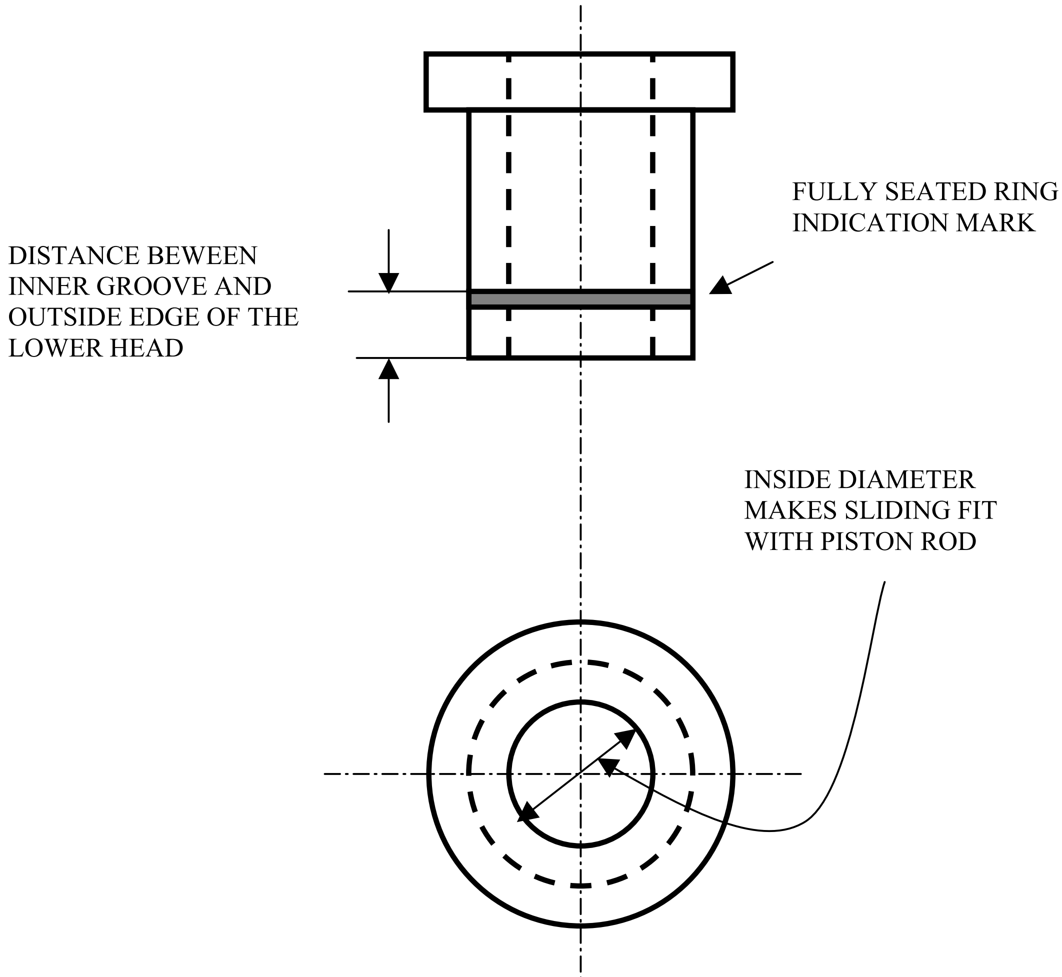


FIG.9 Example of a simple gage that may help to verify a correct seating of the retaining ring. The gage would slide over the piston rod prior to installing the clevis. When the gage makes a contact with the retaining ring, the indication mark will be below the outside edge of the lower head.