RSRM CASE ACCEPTANCE AND REFURBISHMENT REQUIREMENTS DESIGNED TO SATISFY STRUCTURAL, FRACTURE AND SAFETY CRITERIA

G.Z. Brinkerhoff
ATK Thiokol Propulsion
Brigham City, UT 84302

ABSTRACT

The RSRM (Reuseable Solid Rocket Motor) Program has been developed and implemented to support manned flight space travel. The Space Shuttle Vehicle utilizes two SRBs (Solid Rocket Boosters) to assist during the launch sequence and achieve the predefined orbit and mission objectives. A critical feature of this program involves post-flight SRB retrieval, disassembly and reuse of case structural components to manufacture future RSRM motors. To ensure these components can be safely reused, inspection criteria based on dimensional, structural and fracture requirements, has been established in the form of Engineering specifications and drawings. These criteria originated from actual hardware testing (both subscale and full scale) coupled with conventional Engineering hand calculations and computerized Finite Element Analyses (FEA). The intent of this paper is to provide an overview of the RSRM Case component refurbishment requirements and the associated case hardware inspection and evaluation processes that has been established to satisfy these requirements. Many of these processes have been recently upgraded to comply with environmental regulations, obsolescence concerns and technological advancements. Qualification of these process changes has been closely monitored and documented through test plans and reports.

INTRODUCTION

The reusable solid rocket motor (RSRM) is a segmented design consisting of 11 pieces of cylindrical hardware with an overall length of 116 feet and weighing nearly 1.25 million pounds. To facilitate the transportation, handling, motor assembly and reclamation of the hardware, the RSRM is broken down into four distinct groups known as casting segments as shown in Figure 1. structural load carrying capability but also maintain dimensional tolerances needed for adequate o-ring squeeze during motor operation. The case configuration of an RSRM consists of two joint types based on joint requirements. Those joints formed in Utah, when casting segments are built, are termed "factory joints". Joints formed in Florida when the casting segments are mated to form a full motor are identified as "field joints". Although these joints are similar in appearance as shown in Figure 2, each offers unique geometry and

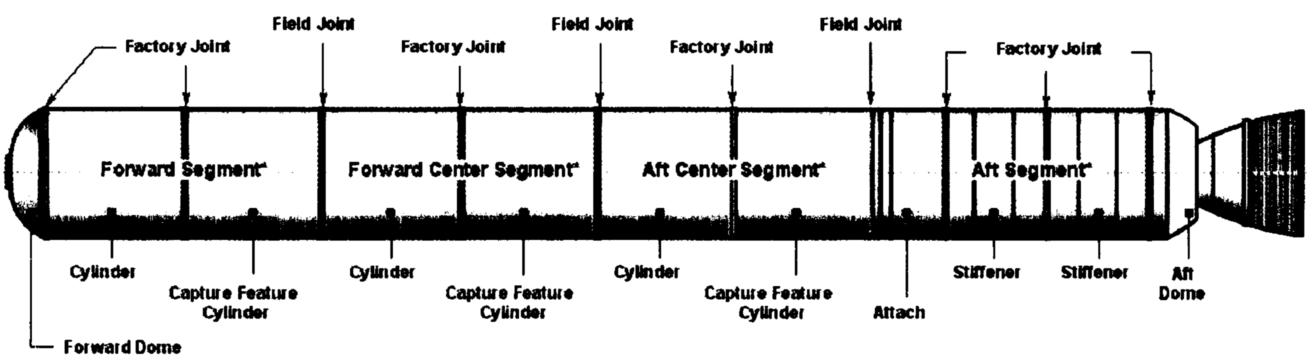

Figure 1

*Casting segments

These segments are mechanically joined together via a clevis and tang arrangement held with multiple shear pins. The function of these joints is not only to provide features that must be verified to ensure the form, fit and function of the part meet the engineering criteria and refurbishment requirements. The program plan of recovering spent RSRM hardware, which has flown, splashed in the ocean and been exposed to a corrosive salt environment presents many unique and technical challenges. These challenges and hardware conditions can be manifest as corrosion pitting, deformed shapes with associated residual stress, stress corrosion cracking, fretting, cracked stiffener flanges and many others. As the hardware ages through reuse, it is extremely important that a complete damage tolerance study be evaluated for each new discrepancy. This type of evaluation and new technical issues will require that the engineering criteria continue to be evaluated and updated as the RSRM program matures.

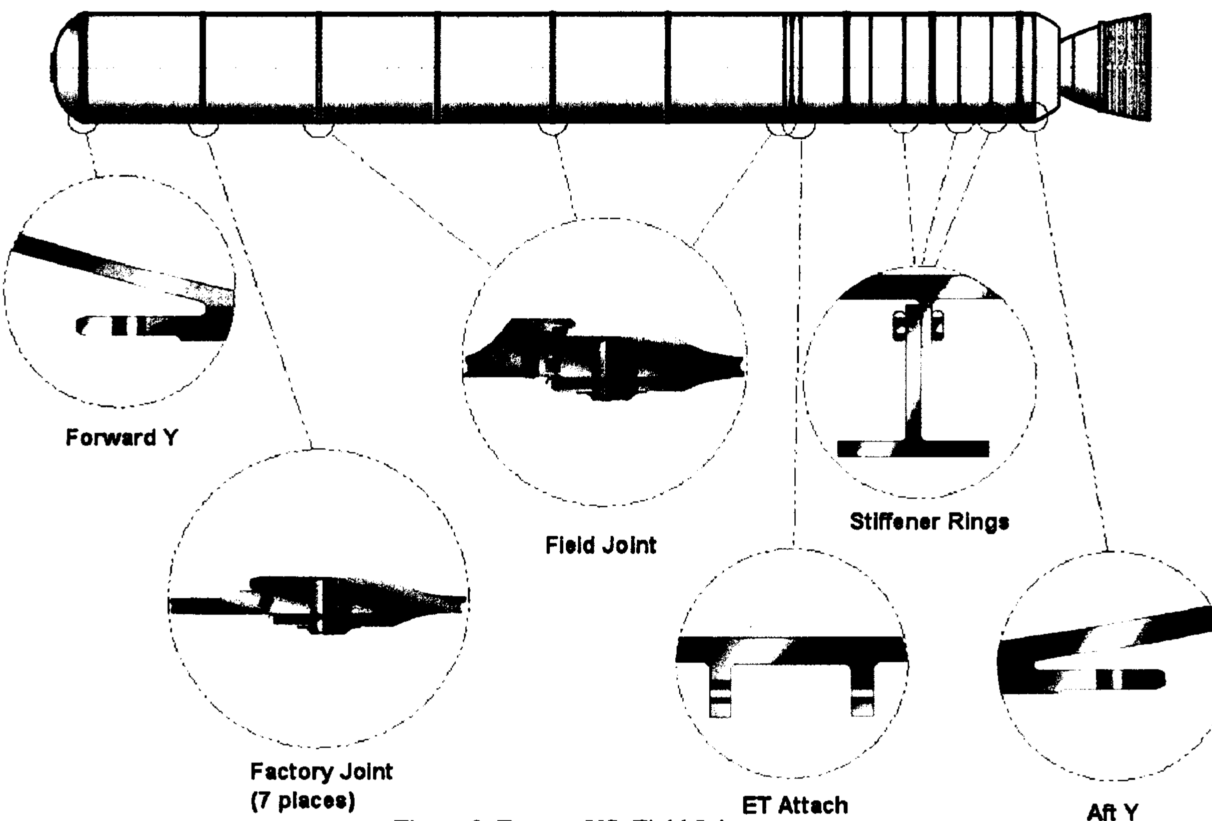

Figure 2 Factory VS. Field Joint

DESIGN AND ACCEPTANCE REQUIREMENTS

All of the requirements imposed on the design and reuse of RSRM hardware can be traced to the Contract End Item (CEI) Specification.[1.0] This document provides the baseline requirements and guidelines that must be met for technical disciplines such as structural, fracture control, material characterization, hardware reuse, etc.... These requirements become the baseline that is evaluated and incorporated into the design of the hardware and associated features. Structurally, the general safety factors that are applied as outlined in the CEI are 1.4 for ultimate capability and 1.1 for general yield criteria, based on the selected material capability. (Safety Factors are defined as the allowable stress divided by the actual stress.) By applying the appropriate safety factor to the stress state, hardware dimensions can be determined. For example, the minimum wall thickness in the membrane region using this approach is 0.450 inch for lightweight configuration hardware. This minimum dimension must be generically maintained for the life of the hardware, which has also been defined in the CEI specification of 20 uses (19 reuses). To accommodate this requirement from a processing viewpoint additional metal was included in the original design to account for metal loss experienced as a result of refurbishment.

To accommodate this reuse requirement, the refurbishment process flow shown in Figure 3 has been developed. An overview of this flow highlights many critical processes that are performed in preparation to returning hardware to flight status. These processes have been selected and qualified based on compatibility with the hardware. Metallurgically, the material properties of the base material (D6AC high strength alloy steel) must not change. These changes can be introduced in a number of different ways. Issues such as heat affected zones and the selection of materials that contact the hardware are closely monitored and evaluated to prevent potential issues such as hydrogen embrittlement, stress corrosion cracking, dissimilar metal (galvanic type) action, corrosion pitting, etc.... Dimensionally, many of the tolerances on certain hardware features are very tightly controlled based on the form, fit and function of the part. Certain processes have shown to change these dimensions if not performed to the baseline parameters. This issue will be further discussed in the section on glass bead blasting.

Case Refurbishment Overview

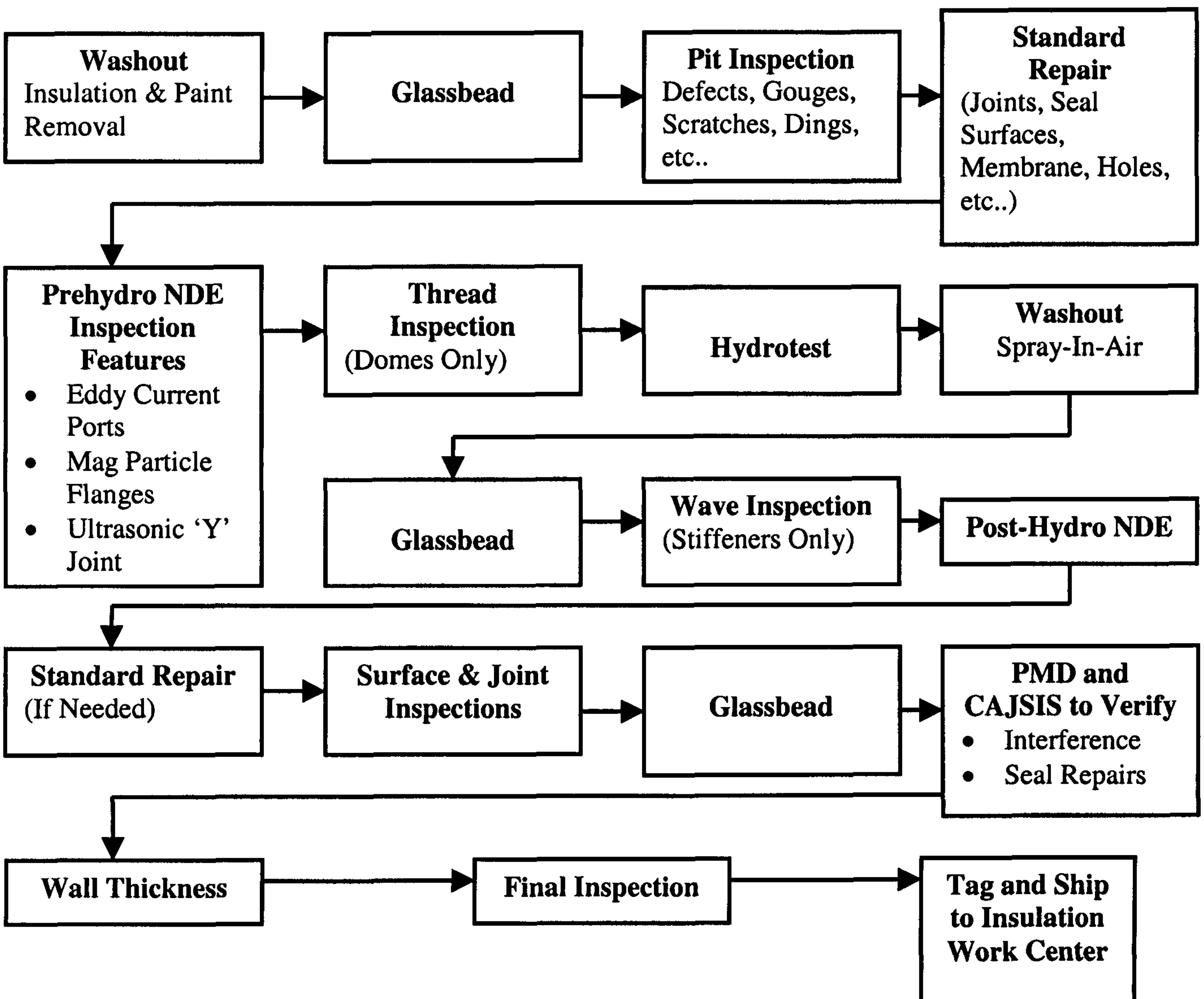

Figure 3

To satisfy the CEI requirements several Engineering documents have been established and imposed that outline the hardware acceptance criteria. Drawings used to perform the final machining also reference Engineering documents that must be met prior to hardware use or reuse. This direction and criteria is contained in Engineering Specifications that become the baseline used to derive hardware inspection plans and process flows. The scope of these documents begins at the bare metal refurbishment level, extend through the RSRM manufacturing process flow including the stacking operations at Kennedy Space Center (KSC). The primary specification that is referenced on the machine drawings is STW7-2744, Case Acceptance and Refurbishment Criteria.[2.0] Compliance to this document is required before an acceptance tag can be issued which allows the part to advance down the processing line. Violations or conditions that do not meet the requirements of this specification are documented on individual discrepancy reports. These reports are procedurally controlled in the Material Review Board (MRB) system by Quality Control. Dispositioning of these reports is generally the responsibility of Design Engineering. The dispositions provide the technical rationale to either repair the condition, accept it without any type of repair or if needed remove the part form service. These dispositions are presented and reviewed by in-house MRB boards and if required, based on the issue or criticality, be reviewed at Marshall Space Flight Center for technical concurrence.

HARDWARE CLEANING AND REPAIR PROCESS

To support the refurbishment process the Engineering criteria directs the hardware be cleaned to the bare metal condition. Materials such as paint, chemloc, insulation, NBR, etc... are removed using several different techniques. This removal begins in the high pressure washout facility which is intended to remove insulation and paint. This process combines an inhibited high pressure water jet ranging from 10,000 to 36,000 psi, with full robotic control as shown in Figure 4. Materials are removed from both the internal and external surfaces of the hardware using multiple rotating jet heads. This system was recently modified and upgraded to provide more consistency and reliability with less facility down time. The ability of the washout process to effectively remove paint in the general acreage area has eliminated the need to perform this same operation with grit blast. Grit blasting has proven to be a very effective tool: however, the potential for base metal erosion is higher if this operation is not

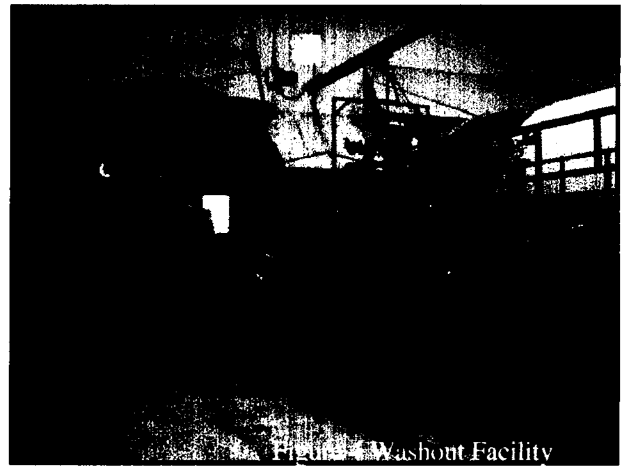

Figure 4 Washout Facility

performed correctly or repeated several times. The incorporation of removing paint in the washout facility has greatly enhanced the ability of the hardware to satisfy the 19 reuse requirement.

Plastic media blasting has recently been incorporated into the refurbishment process flow to remove paint and corrosion in difficult access areas such as the forward and aft dome y-joint areas. One of the big advantages of this process is that it can be used in very local areas without moving base material and altering hardware features. Previous experience with other techniques in these areas has shown signs of hardware damage such as rounding of corners and break edge removal, which can lead to structural issues such as reduction of bearing area, oversized hole conditions, etc....

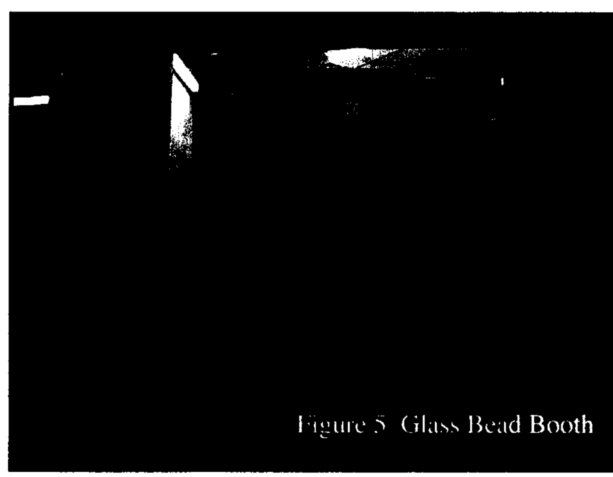

Figure 5 Glass Bead Booth

Glassbead blasting is the process used to remove corrosion and clean all surfaces of the hardware prior to processing and inspection. This process can be and is used several times during the refurbishment flow to inhibit corrosion and prolong the exposure of bare metal to the atmosphere. The operational parameters that have been established such as air pressure, standoff, dwell time, etc... are controlled to minimize any impact to the base metal. Recent funding has been provided to install fully automated glass bead booths as shown in Figure 5. These new facilities will provide full motion and positioning control, which will result in a more uniform blasting of the hardware. Previous beading operations were performed manually with the operator positioned in the booth. The new facility is safer for both hardware and the people performing this operation.

In support of minimizing the use of ozone depleting chemicals (ODC) the use of methyl chloroform as a cleaning solvent has been greatly reduced as part of refurbishment. The largest consumer was the vapor degrease pit, which utilized methyl at elevated temperatures to remove contaminants such as grease and foreign material from the surfaces of the hardware. To continue this cleaning operation and be compliant with environmental requirements the "spray-in-air" operation has been implemented. This process as shown in Figure 6 is very similar to a large-scale dishwasher, in that spray nozzles are used to clean surfaces with a detergent based inhibited water. This operation plays a key role in not only cleaning hardware surfaces but it also helps control the migration of contaminants and foreign material into other process operations.

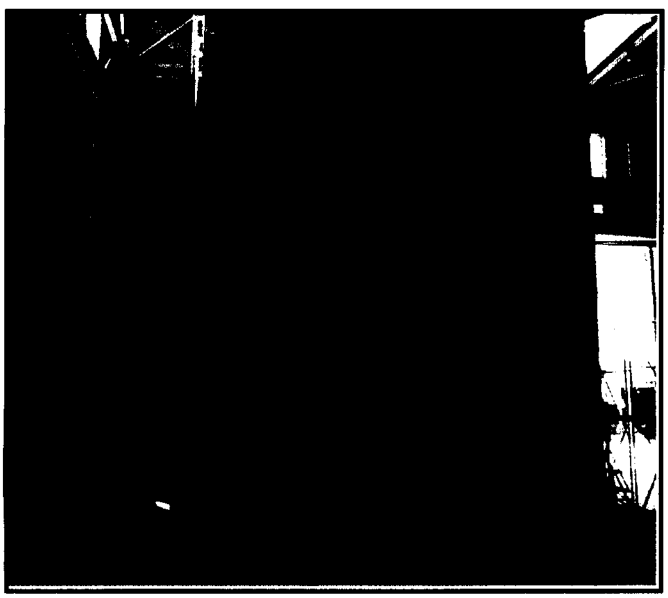

Figure 6 Spray-In-Air

NONDESTRUCTIVE EVALUATION (NDE) AND FRACTURE CONTROL

One of the requirements in the CEI specification incorporates the need to implement fracture control criteria if a structural failure of a part would cause a catastrophic event.[3.0] Fracture Control is the application of policies and procedures, which are intended to prevent a catastrophic structural failure due to the propagation of flaws or crack-like defects at any time during the hardware life cycle. This applies during material selection, hardware fabrication, testing and through out various phases of the hardware service life including refurbishment processing. A basic assumption that requires fracture implementation is that all structures contain flaws and/or crack-like defects. This assumption may indeed determine the minimum life of the hardware if the flaw is assumed to exist in the most critical location and orientation. Hardware falling within these guidelines is deemed "Fracture Critical" which requires identification on the component drawing and full fracture control overview. All the RSRM case hardware is Fracture Critical and requires special policies and considerations. In support of this requirement the Case Fracture Control Plan[5.0] has been written which documents compliance to the CEI requirements.

The use of non-destructive evaluation (NDE) techniques is an integral part of meeting fracture control requirements and can be used to establish flaw sizes. Probability of Detection (POD) curves have been established based on the inspection technique at a 90%/95% confidence level. In general, NDE inspection capabilities on RSRM fracture critical items must be able to detect flaw sizes that meet safe-life rationale. Safe life is defined in NASA HDBK 1453 as " A metallic part is defined as safe-life if it can be shown that the largest undetected flaw that could exist in the part will not grow to failure when subjected to the cyclic and sustained loads and environments encountered in four complete mission lifetimes". Several different NDE techniques are employed as baseline processes during the refurbishment of RSRM case hardware to screen for crack-like flaws.

The engineering acceptance criteria, as identified in STW7-2744, is "No detectable surface discontinuities shall be allowed". It should be noted that the engineering philosophy regarding known or detected cracks is to remove them regardless of crack size or orientation. NDE is then re-performed to ensure, based on the inspection capability, the crack is no longer detectable. This process is usually controlled by MRB (Material Review Board) policies and procedures. The final acceptance of the hardware condition may include NDE evaluation using several different qualified techniques and in some instances also include a follow-up proof testing after the repair is complete.

Magnetic Particle (MT) inspection as shown in Figure 7 has been widely used through out the history of the RSRM program. This technique (wet fluorescent

method) involves creating a magnetic field on the part that is being inspected followed by coating the part with metallic particles suspended in a fluorescent solution. Cracks at or near the surface, disturb the magnetic field, causing the metallic particles to migrate and gather at these sites. This disturbance is visually detectable and is performed with the aid of a black light. This process is performed in accordance with MIL-STD-1949A[4.0] and planning requirements. To ensure repeatability and reliability, the amperage level is controlled to ensure adequate magnetization and gauss levels are achieved. This inspection is used in the general case acreage and joint areas but has shown limitations in areas that are considered limited access because of unique geometry (threads, leak test ports, FWD dome y-joint, etc...). For these areas other techniques have been qualified and implemented.

Ultrasonic Inspection is used during the refurbishment process on a very limited basis. This inspection relies on the principle of generating sound waves in an inspection region and monitoring this wave for defect indications. The only hardware feature inspected by this technique is the membrane region of the forward dome y-joint. This system is calibrated to EDM notches that have been machined into actual y-joint samples. This process calibration process ensures inspection repeatability and reliability.

Eddy Current (ET) was introduced into the refurbishment and acceptance process flow during the mid 1980s timeframe. The need for this type of technique was obvious when considering the limitations of applying MT to areas or features that are not physically and visually accessible. This technique invokes eddy currents (circular electric currents) into a part by an alternating magnetic field. Flaws in the part disturb these currents which results in a parameter change in the field, which can be measured (voltage, impedance, inductance, etc...). This technique is calibrated to standards that represent the geometry or feature of the hardware being inspected which also include flaws (EDM notches) of known sizes. System alarms or thresholds can be set that notify the inspection process when these limits have been exceeded. This calibration process ensures inspection repeatability and reliability.

In an effort to improve the reliability of metal hardware non-destructive inspection, a team consisting of NASA and ATK personnel conducted an industry wide review of NDE inspection systems. The objectives in mind were to replace the visual-based systems with automated sensor based capability, provide digital data storage for archiving needs and perform automated data evaluation. This effort began in 1998 and included round robin testing of many different NDE techniques and approaches. Eddy Current was selected based on the results of the round robin testing and the inspection and storage capability. Two independent vendors combined their expertise in the fields of motion control and NDE inspection capability to form the Automated Inductive Inspection Systems (AIIS) currently installed at ATK, Clearfield, Utah. Two systems were developed and implemented (see Figure 8), one for the case cylindrical hardware and the other to inspect the nozzle and igniter hardware.

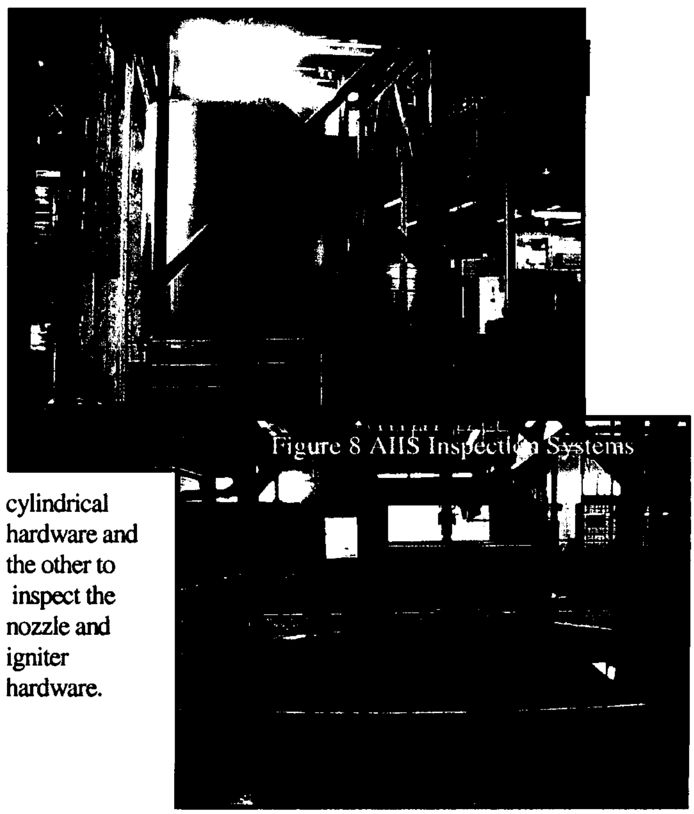

Figure 8 AIIS Inspection Systems

Each system offers full robotic control to place the various sleds and probes in the correct orientation to perform eddy current inspection. The inspection data is reviewed real time by the "auto analysis" feature of the inspection tool in addition to being reviewed by the inspector who operates the system. This data is then digitally stored outside the system for future reference and review if needed. Currently the AIIS systems are being used to inspect flight hardware on a side-by-side basis with MT, which is called out in the Engineering criteria. This inspection phase provides an opportunity to demonstrate the robustness of these systems and a comparison of inspection results. Future discussions will address inspection redundancy and engineering criteria. These systems are considered "state of the art" and greatly enhance the reliability of the metal hardware inspection.

PROOF TESTING

One of the most critical operations performed as part of hardware acceptance and refurbishment processing for flight is the proof test operation as shown in Figure 9. This operation is performed on each case component to verify the structural integrity of the part and screen critical flaws in the hardware. These flaws can manifest themselves such as cracks, material voids or laps, inclusions or in general, any type of material discontinuity (surface or subsurface) that can initiate or propagate a crack. The proof test operation was designed to internally pressurize the membrane regions to a predefined load of 1.12 X MEOP (Maximum Expected Operational Pressure). This load is the minimum used to screen any flaw larger than the Critical Initial Flaw size (CIFS) that is assumed to exist on the hardware. In other words, the CIFS is the largest flaw that will survive a proof test cycle and not grow to a critical failure size if the flight part were to be cycled thru four missions under normal operating conditions. This approach satisfies the safe-life criterion that is required in the CEI Specification. The proof test philosophy and various CIFS sizes, based on hardware location, are documented in the Case Fracture Control Plan.[5.0]

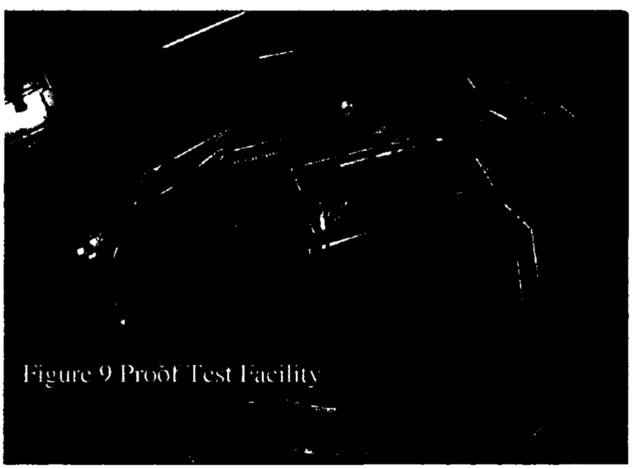

Figure 9 Proof Test Facility

The proof test arrangement varies based on the configuration of hardware that is being tested. The most common arrangement for the case cylindrical components is shown in Figure 10. This arrangement not only provides a closed pressure system it also incorporates tooling spools intended to better duplicate flight conditions. These spools allow the joint ends to expand radially outboard similar to the deflection experienced during flight. This movement increases the stress state and effectiveness of proof test to screen for flaws in the joint regions.

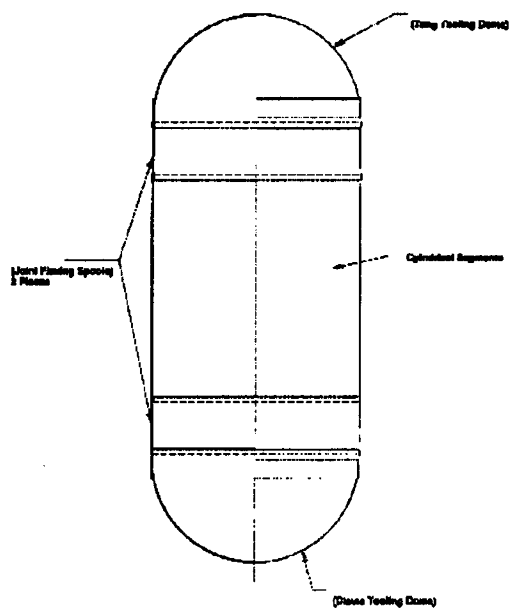

Figure 10 Test Arrangement

Closing out the proof test configuration are tooling domes with port holes that are used to fill and drain the system in such a manner to prevent creating any type of vacuum. The pressurization fluid is non-compressive hydraulic oil, which is non-corrosive and compatible with the hardware from a metallurgical standpoint. This fluid is preconditioned to fall within a specified temperature range during the proof test cycle that screens critical flaw sizes over the temperature range currently approved for flight conditions.

Proof test is a very effective method of performing nondestructive evaluation of flight hardware. This technique supplemented by additional NDE methods (Magnetic Particle, Eddy Current, Dye Penetrant and

Ultrasonic Inspection) is the preferred way of screening for cracks in RSRM hardware, which also satisfies all CEI requirements.

SUMMARY AND CONCLUSIONS

The objectives of the refurbishment process are to rebaseline used hardware and return it to flight status. This is accomplished by inspection, baseline processing and testing to the requirements documented in engineering specifications. These requirements have been established based on analysis and testing both at the full scale and subscale levels. Early in the program burst tests were conducted to evaluate critical parameters such as cyclic behavior of the hardware, ultimate load capability and failure point behavior. These types of testing along with numerous static tests have been used to validate the baseline design and process flow. Any changes to this baseline will require qualification by static test as part of the approval process. Information gathered from detailed hardware inspections performed after each test or flight become part of a massive database of information and understanding that exists on the RSRM program. This database consists of literally thousands of points of information for each piece of hardware that is extremely helpful in monitoring for any type of change or out of family condition. By maintaining process control downstream of the refurbishment operation, hardware that has successfully completed the refurbishment process will be certified for flight use.

REFERENCES

1.0 CPW1-3600 Revision E, Prime Equipment Contract End Item Detail Specification, Contractual Agreement Between NASA and ATK

2.0 STW7-2744 Revision AH, Acceptance Criteria New & Refurbished Case Segments

3.0 MSFC-HDBK-1453, Fracture Control Program Requirements

4.0 MIL-STD-1949A, Inspection, Magnetic Particle

5.0 TWR-16873 Revision E, Fracture Control Plan For Space Shuttle RSRM Case

National Aeronautics and Space Administration

Routing Slip

	Mail Code	Name
1	MP71	John Pea
2	AD34	Betty Fowler
3		
4		
5		
6		
7		

Action	
Approval	
Call me	
Concurrence	
File	
Information	
Investigate and Advise	
Note and Forward	
Note and Return	
Per Request	
Per Phone Conversation	
Recommendation	
See me	
Signature	
Circulate and Destroy	

For your disposition please.

Thanks!

OK Dn

Name	Tel. No. *(or Code)* & Ext.
Betty Fowler	4-4529
Code *(or other designation)*	Date
AD34	May 2, 2003

NASA FORM 26 SEP 96 PREVIOUS EDITIONS ARE OBSOLETE.