

## **Orbiter Landing Gear Rigging, STS-114**

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### **Executive Summary**

During the STS-107 investigations, reviews of the landing gear door and seal OMRS requirements, it was determined that there was no clear direction to mandate compliance with the seal compression certification requirements. A CHIT was initiated to obtain the necessary data required to verify the seals were meeting the drawing requirements. The community was concerned that the landing gear mechanism was not capable of providing additional closing force on the door to meet this unaddressed seal load and still meet all the rigging requirements for the gear itself. The mechanism community developed a two-pronged approach to rig the gear. The first approach, using the door hook mechanism, failed to produce satisfactory results. The second phase of the plan was to adjust the door retract link in order to pull the door further into the landing gear cavity to increase the seal compression and allow the door hooks to more fully engage the door rollers. This approach ultimately was successful for both the Main Landing Gear and the Nose Landing Gear. While several MR conditions still exist within the rigging of all the gears, the overall condition of the gear as well as the compression on the seals has been improved. After the required seal compression was obtained, the perimeter tile step and gap as well as the thermal barrier compression was reworked into acceptable levels.

## **Purpose**

The purpose of this white paper is to outline the actions taken during STS-114 to rig the main landing gear (MLG) and nose landing gear (NLG) for flight taking into consideration the requirements of the structures community for door environmental seal compression and the tile community's requirements for step and gap.

## **Background**

Per request from the Columbia Accident Investigation Board, Orbiter Element was asked to evaluate the environmental seals on the main landing gear doors and the nose landing gear doors for the purpose of determining their potential contribution to the loss of the Shuttle Columbia. This review uncovered the fact that the seal installation drawings did not clearly specify what the compressed state of the seals should be after installation. The landing gear rigging specifications (MLO308-0028/0029) also do not specify a final seal compression. The certification of the seals (CR 05-GS17M10C) calls for 0.100 inch compression after flight deflections are taken into account. If the hardware is installed per print and the vehicle is rigged per all specification requirements, the seal compression will be in compliance with the CR. No documentation could be located that had ever addressed the requirement for seal compression during installation, rigging or between flights to maintain compliance with the certification.

## **Issue Description**

During original build, complete compliance with the landing gear rigging could not be achieved. Out of compliance conditions were documented by MR. In 1991, attempts were again made to adjust the rigging of the MLG to achieve better compliance with the rigging specification. It was discovered that during that exercise, some hardware was damaged due to overloading. The mechanism community originally felt there was very little that could be done to change the rigging of the landing gear without again damaging hardware. The rigging specification for the MLG door Inner Mold Line (IML) step is +/-0.030 inches. During previous attempts, MR approval was obtained to accept out of tolerance steps as large as 0.170 inches. This resulted in significantly lower seal compression values. It was feared that the increased loading on the mechanism from addressing the seal compression requirement would overload the mechanism and make rigging impossible.

## **Impacts**

Impact of not performing the rigging adjustments would be the need to process certification waivers for not meeting the seal compression requirement. This would

mandate cert rigor testing of the worst-case existing seal installation to confirm safe flight of the vehicle.

## **Summary of Inspection, Test, and Analysis**

USA Quality inspectors in the OPF's performed inspection of all landing gear seals in the fleet. Inspections were performed visually and determined that all seals had become permanently deformed and no longer meet drawing requirements for minimum seal height. In addition, the measurement of the gap for the seals indicated gross non-compliance with the compression requirements of the certification.

*Room Temperature* Compression Tests (Load vs. Stroke) and Room Temperature Flow tests were performed in 2004 using both old configuration seals and new configuration seals. Testing was performed by Glenn Research Center (GRC). Testing was performed under the following conditions:

- 24 hour duration and 31 day duration testing
- Multiple % compression settings
- Environmental Conditions: Room Temperature
- Leak rates checked at 1 psi and 2 psi

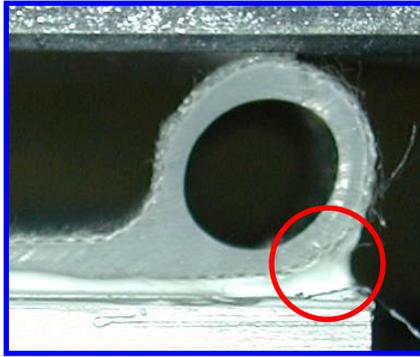
The Boeing analysis group determined there should be sufficient load carrying capability in the landing gear to increase the load in the door closing portion of the mechanism. This would provide better gap measurements on the doors to comply with the seal compression certification.

## **Actions Taken**

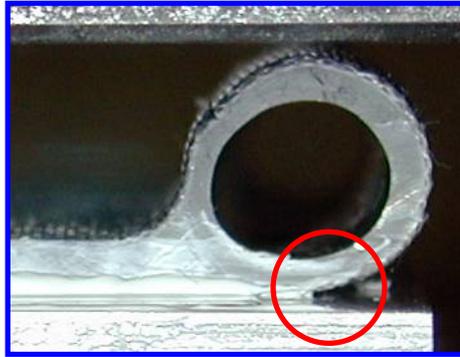
In order to prevent any potential overload condition (Similar to the 1991 damage), three links in the MLG mechanism were instrumented with strain gages to monitor, real time, the changes in the load on the hardware due to adjustments. (V070-510349 link, V070-510452 link and the ME162-0009-0011 link) No hardware on the NLG was instrumented.

### **MLG Door Rigging**

The initial rigging check-out run performed with the new seals installed indicated significant load increase on the system. The door stop measurements and the door hook measurements indicated the doors did not close properly. Based on some preliminary seal testing done at GRC that indicated the seal bond line configuration had a significant affect on the seal loading, the fillet bond on the bulb side of the seals was removed allowing the seals to function properly. (Reference Figure: RTV Fillet and Clean Bond Line) After this correction the RH door closed properly but the LH door did not. This run did not take into account the MR shims that would be required to meet seal compression requirement.



RTV Fillet



Clean Bond Line

The first consideration for adjusting the rigging involved increasing the preload in the door hook mechanism. However, initial measurements of the preload indicated it was already higher than allowed per the rigging spec. The instrumentation on the door hook linkage provided the data to support accepting this higher preload. The decision was made to not increase the preload any further, since there were concerns about the door hook mechanism timing and the risk of possible damage to the tips of the hooks and/or door rollers. It was also determined that torsional deflection in the torque tube between the uplock mechanism and the door hook linkage was a limiting factor in the ability to achieve full hook travel. This was demonstrated during the first cycle with the shims installed, when the door hook mechanism stalled and could not fully close the door. Analysis showed that this condition did not cause any damage, but proved this method of adjustment would not solve the issue.

The second approach used to adjust the rigging involved shortening the door retract link. A baseline cycle was run to determine the loading in the system. (1700 lbs LH, 2400 lb RH) At this time, in areas where the seal compression did not meet the certification value, MR shims were installed to decrease the door gap and increase seal compression. This had the effect of increasing the load on the door closure mechanism but remained under the 5000 lb max allowable. The V070-510452 link was adjusted incrementally and hydraulic cycles of the MLG were run. Modelers clay was used to take gap measurements at several points around the perimeter of the doors and at key points in the mechanism, such as door stops, hook stops and roller gaps. Several cycles were usually required for each adjustment to limit the amount of clay used on each cycle. The load values from the instrumented struts indicated the hardware remained within design tolerances for all rigging adjustments. (Approximately 3000 lbs on both sides) The total change to the 452 link for proper compression of the seals and hook engagement was 2.5 turns shorter on the LMG and ½ turn shorter on the RMG. Adjustments to the door stops, hook stops and bungee striker were also made. MR approvals were obtained for stop bolt gaps, out of spec adjustment on the door hook link and the door retract link. More than twenty MLG cycles were required to complete this work.

### NLG Door Rigging

Prior to any adjustments to the NLG mechanisms, the MR approved minimum thickness shims were installed on the sealing surfaces of the doors. The subsequent cycles of the NLG revealed that the doors were not closing properly due to the additional loads from the seals. Several door stop bolts had gaps that were out of spec (greater than 0.010 in.). Additionally, the door hooks were not fully engaging the door rollers, and the tile steps between the LH and RH doors exceeded 0.120 in. (s/b less than 0.060 in.).

In the design of the NLG, the LH door overlaps the RH door. It also contains the door rollers that are engaged by the door hooks. Since the position of the RH door was acceptable from a tile, seal, and mechanism perspective, the LH V070-510684 door retract link was shortened to pull the LH door further closed. Initial measurements of the 684 link indicated that it was already a half turn shorter than permitted in the rigging spec. The first couple of adjustments (shortened in half turn increments) provided some improvement. However, several subsequent cycles were deemed invalid when it was discovered that the nose wheel well vent plug had been installed for four cycles. This was done to support the PVD positive pressure test of the NLG, but had a negative affect on the ability to properly close the NLG doors. Once the vent plug was removed, and additional adjustments were made to the 684 link, the hook engagement was measured to be within the tolerance of the rigging spec (ML0308-0028). Overall, the 684 link was shortened 1.5 turns during the rigging process. (Total of 2 turns shorter than spec) Stress analysis verified that the final loads in the retract link and the upstream hardware were acceptable. Stop bolts along the centerline were adjusted to obtain the proper gaps (less than 0.010 in.) with the exception of the mid-aft stop bolt. There was evidence that this stop could contact the LH door during closure, resulting in structural damage. LT-80 tape was used to reduce the stop gaps at the mid-aft location and at the two aft centerline door stops. These two stops are riveted pads, and cannot be easily adjusted.

After completion of the NLG rigging, some of the tile steps across the door centerline were still out of spec. Thermal evaluation determined that several areas could not be accepted, and some of the tiles along the centerline were shaved to reduce the steps. MR approvals were obtained for stop bolt gaps, door bungee striker gaps and door retract link length being out of spec. More than twenty NLG cycles were required to complete this work. In addition, multiple manual cycles were also required.

### **Forward Work**

Next flight and in the future, the seal compression will be monitored to ensure any set the seals may take does not invalidate the compression requirement. The post flight OMRSD is being reviewed for update to include specific instructions on how to monitor this condition. The PRT is evaluating designs for a Go-No Go gage to be used to confirm acceptance.

EO's will be generated to both the seal installation drawing and the rigging specifications to address the need to verify seal compression after rigging adjustment to the landing gear.

Boeing is investigating the feasibility of generating field rigging specifications for the landing gear to address future issues with this hardware.

## **Conclusion**

From the data collected during the rigging of the landing gear outlined above, it can be concluded that there is some capability in the mechanism to adjust rigging to meet the requirements of the structures group to maintain seal compression, to meet the requirements of the TPS group to maintain step and gap requirements and for the mechanism group to still maintain proper specification requirements.

## **Alternative Points of View**

In the course of this evaluation, the Ground Ops upper management discussed the concern that the team was choosing to make adjustments to one section of the rigging spec without performing the rigging from start to finish. The team was unable to reach consensus on this issue because of the lack of field rigging specs. A final check of all of the pertinent rigging points was performed and addressed prior to the completion of the work. Boeing is looking into field rigging specs for the landing gear to preclude this type of concern in the future.

The opinions, conclusions, and recommendations expressed in this White Paper are my own, and do not represent a larger group or team consensus. Input from Robert Emerson and Mike Stoner of USA was utilized in the development of this paper. This has been coordinated with the USA Subsystem Area Managers, Boeing Sub-System Managers (SSM), and the USA Ground-Ops Area Managers (GAM) from Mechanisms, Structures and TPS systems.