The Integration of a Load Limiter to an Orbiter Over-Center Mechanism

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Abstract

This paper summarizes the design process used to relieve the predicted high loads on a Space Shuttle Orbiter mechanism prior to the STS-112 flight. The overloading of the mechanism was due to a dynamic response between the orbiter and payload that was specific to this payload's mass and attachment scheme. A solution was devised by adding a component that prevented overload of the mechanism. In addition, the introduction of the new component neither interfered with the normal operation nor required extra-vehicular activity from a crewmember. By utilizing rapid prototyping technology, engineers were able to verify clearances and feasibility while preparing to build the flight hardware. This design solution was successfully flown on STS-112 and STS-113.

Introduction

The Shuttle Remote Manipulator System (SRMS) (also known as the Shuttle Robotic Arm) is located and stowed on the port sill of the payload bay for orbiter launch and landing (Figure 1). The SRMS is used to deploy satellites into orbit or move and attach segments to the International Space Station. The SRMS is supported by four Manipulator Positioning Mechanisms (MPMs), which rotate the SRMS inboard to enable closure of the payload bay doors (stowed configuration) and outboard to allow clearance for the removal of payloads from the orbiter (deployed configuration).

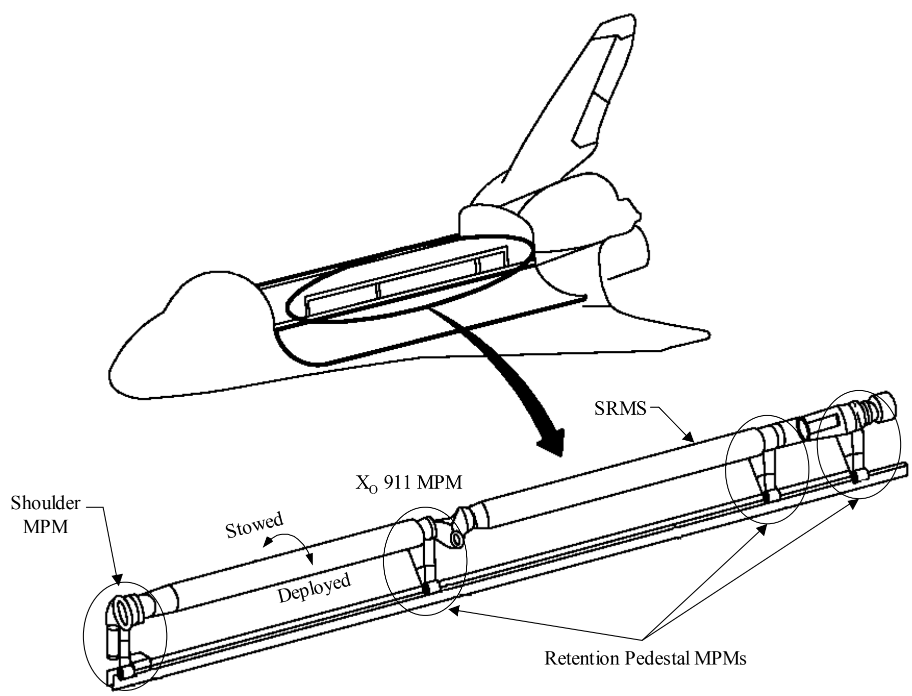

Figure 1. SRMS and X_o911 MPM Location

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Problem Description

Prior to the launch of the S1 Truss (STS-112, October 2002), unusually high loads were predicted in the X_o911 MPM due to the S1 Truss mass and unique attachment scheme using a dual keel Orbiter interface. As a result of the Solid Rocket Booster ignition overpressure and dynamic response between the S1 Truss and the Orbiter, a low frequency structural mode was excited in the SRMS. This mode, in turn, was predicted to cause a deflection in the X_o911 MPM that would overload and fail an internal MPM splined shaft (Figure 2). Because the MPM is an over-center mechanism, launch loads drive the mechanism further over center, thus increasing the splined shaft loads.

While there were many technical challenges associated with this problem, schedule was also important. Implementing a solution that would ensure a safe flight was of the utmost importance; however, the Orbiter was already at the launch pad and the S1 Truss could not be installed until this problem was addressed.

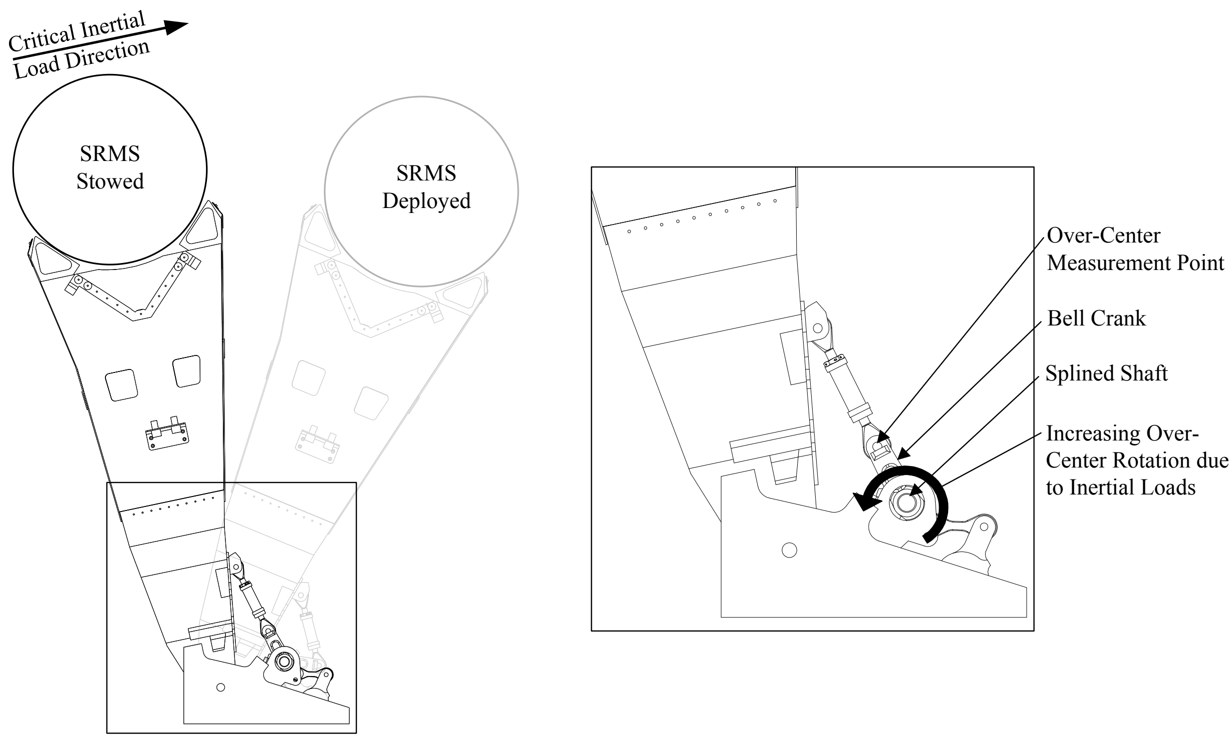

Figure 2. View Looking Aft with Load Applied to X_o911 MPM in Stowed Position

Solution Description

The solution involved devising a means of limiting the deflection in the MPM, thus preventing overload in the splined shaft. There were several constraints that had to be addressed in designing this solution: no permanent modifications were to be performed on existing orbiter hardware, interference with the function of the mechanism was prohibited, it had to be assembled on the launch pad, and the solution had to be designed and installed within a ten day schedule.

The design of a two-part assembly, named the Splined Shaft Load Limiter (SSLL), satisfied all the aforementioned requirements. The assembly, which sandwiched an existing MPM component, was located using existing MPM features and mechanically fastened together. The primary locating features on the MPM were lightening pockets on the Bell Crank (Figure 3). Matching protrusions were created on the SSLL to provide proper alignment. These protrusions also provided a shear reaction point on each half of the SSLL. The features that actually limit MPM rotation, thus relieving splined shaft loads, were the lower legs that are shown below. The lower legs contact the MPM pedestal (Figure 4) when the loads in the splined shaft approach its operational limit. As the mechanism starts to structurally overload the splined shaft, the legs contact the MPM Pedestal creating an alternate load path.

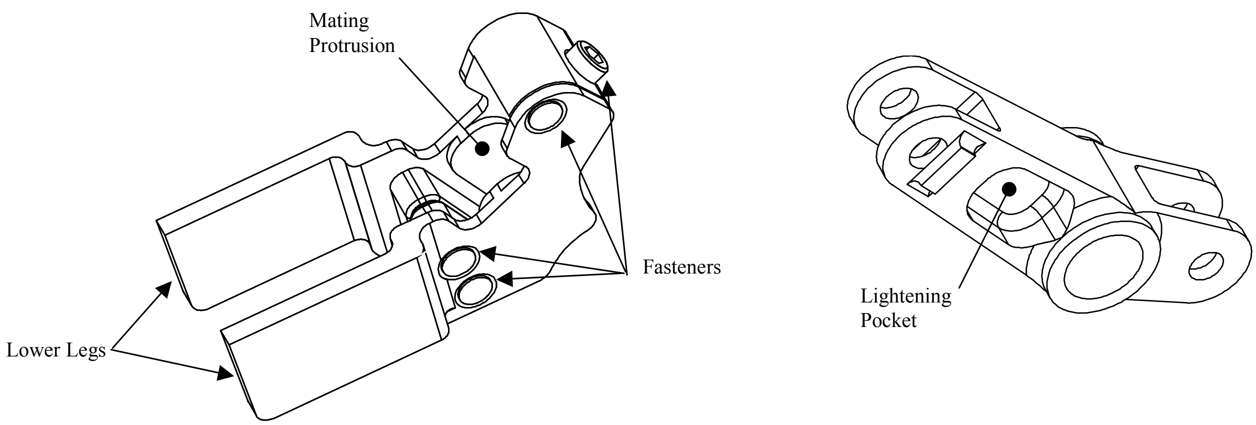

Figure 3. SSLL (Left) and MPM Bell Crank (Right)

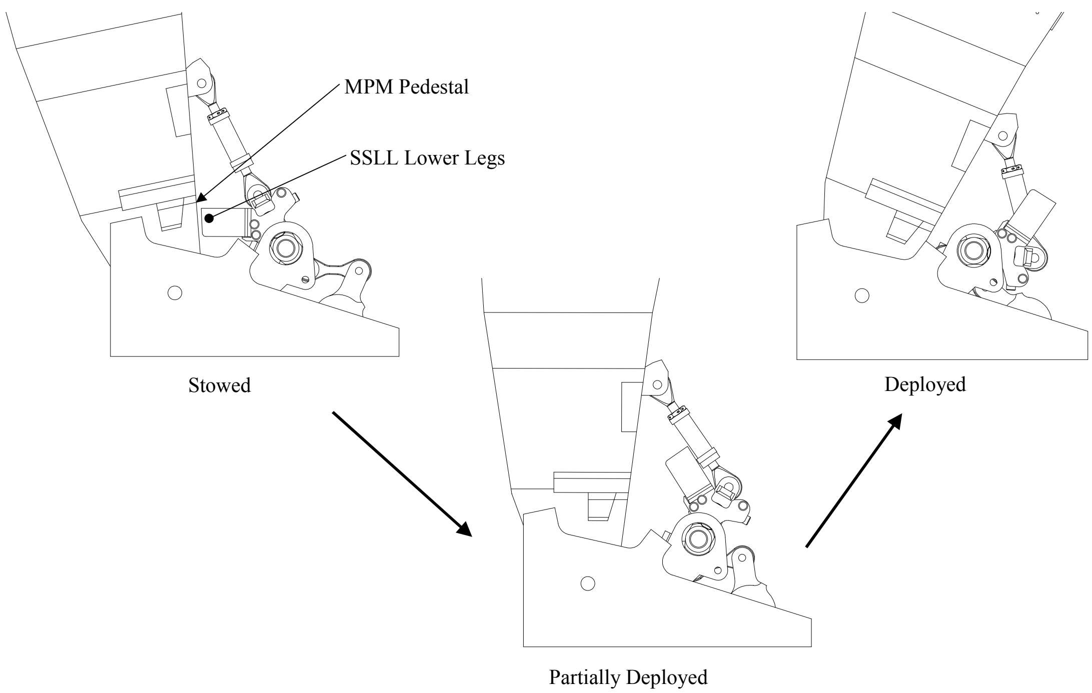

Figure 4. Sequential MPM Deployment referencing Figure 2 Detail View

During the design process, kinematic modeling and rapid prototyping were used to optimize the design and streamline the installation. To ensure that interferences were eliminated, a kinematic model was built to examine the MPM through its full range of motion. The results of the model are shown in Figure 4 with clearances verified in the stowed through deployed position. Rapid prototyping was used to create full scale, high-fidelity plastic parts that were used in fit checks on other Orbiters, to verify the ease of installation, and to create installation procedures. The critical features on the prototypes were manufactured within 0.25 mm (0.010 in) of their theoretical values. The information obtained through the use of rapid prototypes provided valuable information that was incorporated into the final design of the SSLL. The SSLL was successfully flown on STS-112 and subsequently, on STS-113 due to payload similarities.

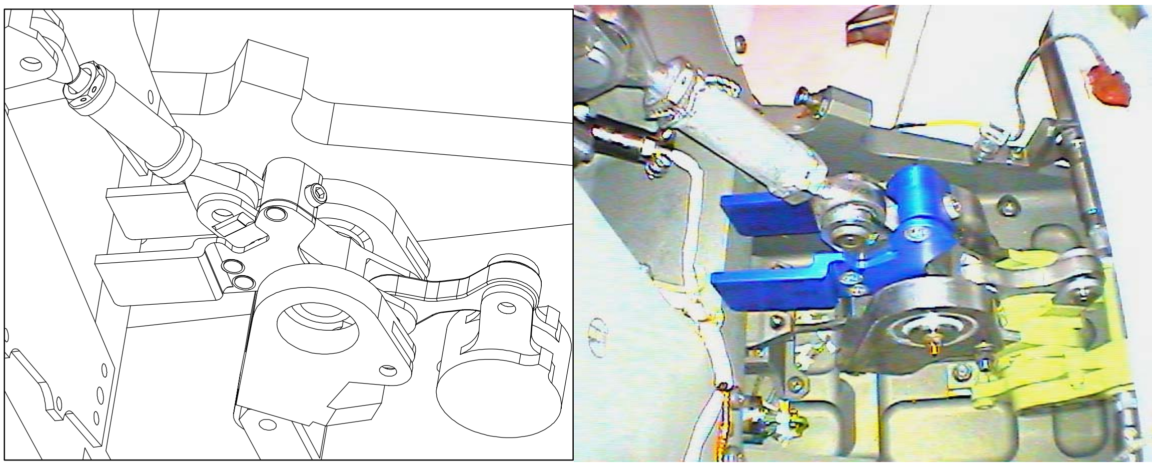

Figure 5. Isometric View of Model (left) and SSLL Installed for STS-112 (right)

Lessons Learned

Installation procedures for complex mechanisms are often difficult to determine in a timely manner with common solid modeling practices. In this case, rapid prototyping was used to create full-scale plastic parts that not only helped create installation procedures, but also verified assembly clearances. The MPM was operated through its full range of motion with a prototype of the SSLL installed; this allowed engineers to check for interferences while technicians rehearsed installation procedures.

For this design process, existing features on an MPM component were used to locate the new hardware. In designing the first version of the SSLL, engineers overlooked a subtle drawing revision on this particular feature. The use of rapid prototypes provided immediate feedback to correct the SSLL design with minimal cost and no schedule impact.

Conclusion

This design process provides a good model for maintaining a critical schedule and minimizing design risks. The use of a high fidelity kinematic model and a rapid prototyping process contributed to a design that increased the load carrying capability of the over-center mechanism with no impact to the launch schedule. At the time this paper was written, the SSLL had successfully flown on two separate missions (STS-112 and STS-113).