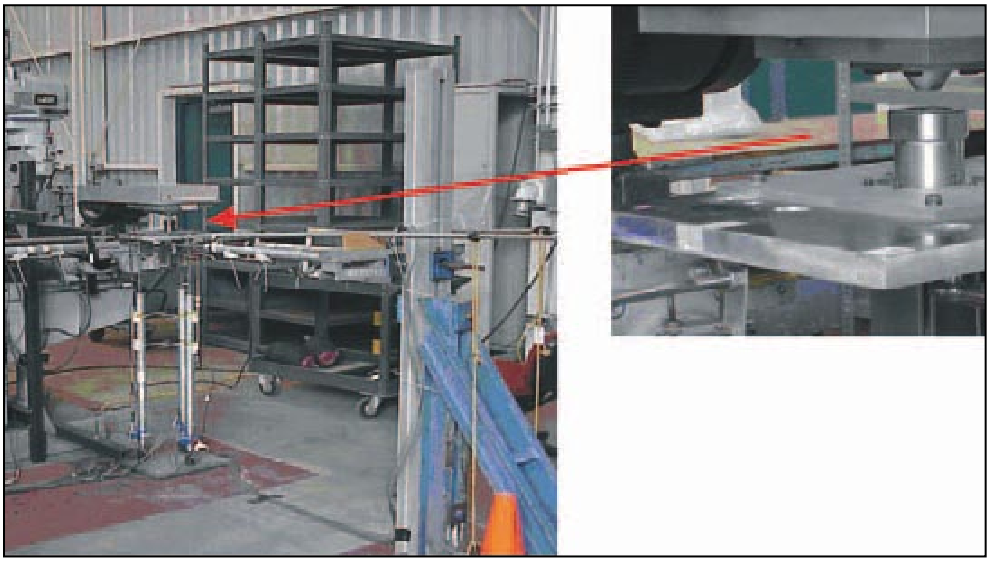
Boeing Makes the Connection to International Space Station

MSC.ADAMS Contact Optimization Reduces Simulation Run Time



"MSC.ADAMS includes contact optimization that substantially reduces simulation run time."

Customer:
The Boeing Company
www.boeing.com

Software:
MSC.ADAMS®

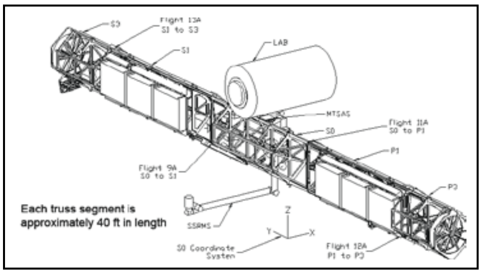
Summary:
Boeing is responsible for design, development, construction, and integration of the International Space Station (ISS) - integrated on-orbit from a series of segments transported up to the Station by the Shuttle. MSC.ADAMS was used for functional verification of the attachment interface mechanisms, which required a thorough representation of the contacting geometry. The MSC.ADAMS solid-to-solid contact force statement allowed simulation of the segment-to-segment attachment including various combinations of contact feature misalignment. The analysis reduced contact model development and helped Boeing minimize the possibility of introducing an error by providing stable, accurate solid-to-solid models.

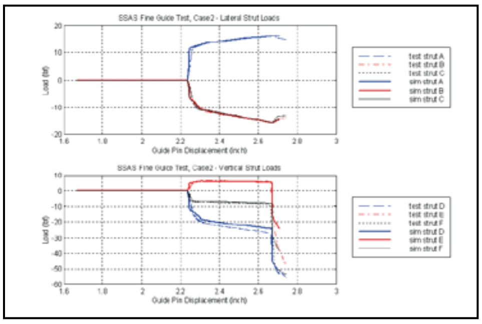
The external truss structure is integrated on orbit from a series of segments transported up to the Station by the Shuttle. Interface attachment is accomplished by extracting a truss segment out of the Shuttle payload bay using the Shuttle or ISS robotic arm, positioning the segment within the attach system capture envelope, and sequentially closing the capture latch. Figure 1 shows the assembled interface, including segment S0 connected to a lab module as well as to segments S1 and P1 which are in turn attached to segments S3 and P3. Attachment interface validation testing was prohibitively expensive and could only examine a small percentage of the possible initial conditions. Therefore, a series of analyses involving contact simulation were used to examine and validate the attachment interface performance.

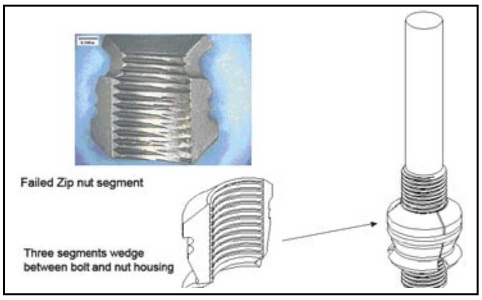
Problem Definition and Analysis
The segment-to-segment attachment interface includes ready-to-latch indicators, coarse and fine alignment guides, a capture latch, and supporting interface structure. Each of the contacting elements was idealized as one or more of the following contact representations: sphere to plane, line to line, line to arc, sphere to cone, sphere to torus, sphere to cylinder, arc to interior of cone, and arc to exterior of cone. Each of the contact equations was resolved to a pair of points representing the minimum distance between any two contacting elements.

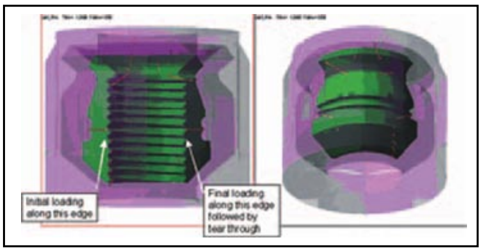
Model validation was accomplished using component-level tests of the contacting features. Testing was performed on the coarse guides, fine guides, and the capture latch. Testing was performed by slowly moving the contacting elements together while measuring test table strut displacement and force. The results of the tests were then compared with simulation results (Fig. 2). This was followed by Monte Carlo studies of attachment interface initial conditions (Fig. 3). These simulations included a flexible representation of the Shuttle Remote Manipulation System (SRMS) or the Space Station Remote Manipulation System (SSRMS) including gearbox stiffness and brake slip. Capture latch representation included the drive motor rate and position control loops.

The attachment interface has motorized bolts at the four fine guide locations. These bolts are extended and tightened following capture latch closure. Problems due to segment temperature differences, thermal distortion, and manufacturing tolerances were discovered late in the design cycle. Design









changes were made to the coarse and fine alignment guides to ensure acceptable coarse guide-to-fine guide handoff as well as adequate seating on the fine guide interface following capture latch preload. Verification of acceptable handoff and interface seating could not be performed with the existing Segment to Segment Attach System (SSAS) contact representation. The coarse and fine guide simulations were replaced with MSC.ADAMS solid-to-solid contact elements. These elements were also validated against the component-level test data.

The solid model of the fine guide cones was slightly crowned, within the design tolerance for that part, and the cone was also subdivided into four pieces. These changes improved model performance when the fine guides were fully seated. The resulting model (Fig. 4) allowed verification of acceptable coarse guide-to-fine guide handoff and fine guide seating but ran rather slowly, with each simulation requiring several hours of CPU time to complete.

Each motorized bolt interface includes a ZIP nut to ensure bolt-to-nut engagement over the possible range of initial translation and rotation offsets (Fig. 5.) The ZIP nut is subdivided into three segments, which float between the nut housing and the bolt. One of these ZIP nuts failed during testing at a torque level well below the required value (Fig. 6). A free body diagram of a nut segment was desired but the complicated three dimensional shape made this impossible. The failure selectively tore out threads on one side of each of the nut segments. The failure was eventually tracked down to a manufacturing problem that was corrected by inspecting the ZIP nuts.

A contact model was developed which provides the desired free-body diagram. A single nut segment was subdivided into four solid bodies all connected to one MSC. ADAMS part. Contact force statements were added between each of these segment solid bodies, the nut housing, and the bolt for a total of eight contact equations. The nut housing was attached to ground and the bolt was restrained to a single degree of freedom rotation. The nut segment part was left floating, constrained only by the contact forces. The initial simulation required five days of run time to complete using MSC.ADAMS V12. The results replicated the failure mode.

The nut initially loaded along the trailing thread edge of each segment but as the load increased, that segment edge rotated away from the bolt up into the housing while the leading edge picked up the load. The bolt continued to rotate and eventually the bolt threads passed through the leading edge of the segment, matching the failure mode. The same model was exercised using MSC. ADAMS 2003 Beta and it ran in under 20 minutes.

Selecting the Best Approach

Two approaches have been used to represent contact with friction. The first approach uses vector algebra and reduces the contact simulation to a point-to-point contact by identifying the minimum distance points between two geometric features. This approach requires considerable time to develop the equations and code user-written subroutines. The models run quickly but are limited to simple geometric shapes. The probability of introducing modeling errors is high due to the large number of user-written equations and user contact feature definition. The solution becomes indeterminate when line-to-surface or surface-to-surface contact occurs.

The second approach uses the solid-tosolid contact force equation developed by MSC.ADAMS. Contact is not limited to simple geometric shapes as was demonstrated in the ZIP nut contact problem. CAD model solid geometry is generally easy to obtain which greatly reduces model development time. The MSC.ADAMS solid-to-solid contact force algorithm develops one contact force vector for each interference solid. This also reduces contact model development and minimizes the probability of introducing an error. MSC. ADAMS 2003's contact optimization feature substantially reduced simulation run time.

Subdividing individual part solids into several pieces and making minor adjustments to the surface geometry provided stable, accurate solid-to-solid contact models. The SSAS cup-to-cone fine guide would not run properly without making these modeling adjustments. The ZIP nut contact simulation also required subdividing the nut segment into several solid pieces in order to obtain a stable solution.

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