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# Boeing adopts AutoSEA2 Shock Analysis to assess risks during orbital assembly of the International Space Station

## THE CHALLENGE

- To assess the potential vibration shock damage to the SSU due to an astronaut or robotic arm operation impacting a critical electronics box.
- To perform a dual analysis approach using both FEA and SEA methods to span the entire relevant frequency range.

## THE STORY

*"The AutoSEA2 Shock Analysis tool enabled Boeing and NASA to assess potential damage to Space Station electronic boxes that might occur from inadvertent impacts during on-orbit assembly. The AutoSEA2 Shock Module ensured that the current assembly operations would not affect critical Space Station hardware, and eliminated the need to implement expensive operational and hardware changes."*

Ed O'Keefe,
Associate Technical Fellow in Noise and Vibration - Boeing

## THE BENEFITS

- Quick and effective modeling tool for high frequency assessment of shock vibration response.
- Confidence in the results based on the methodology and proven methods used by the AutoSEA2 Shock Module.

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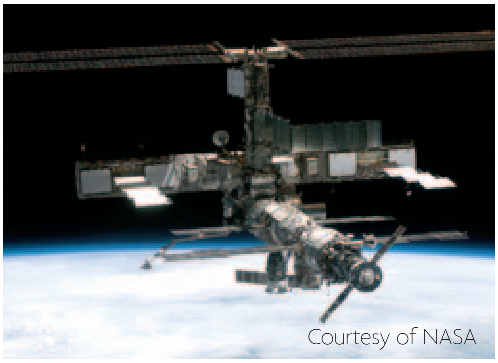

Courtesy of NASA

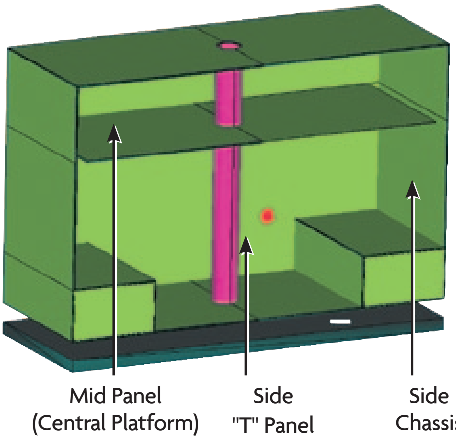
**An AutoSEA2 Shock Analysis was necessary to assess the consequences of a possible impact during Space Station orbital assembly operations.**

Boeing is contracted by NASA to perform assembly and operational assessments for the International Space Station (ISS). The ISS has a mass of about 1,040,000 pounds, measures 355 feet across and 290 feet long, with almost an acre of solar panels to provide electrical power to six state-of-the-art laboratories.

Some of the Station assembly activities require direct astronaut participation and robotic assistance to move components from the Space Shuttle to their proper locations on the expanding ISS structure.

Robotic assistance to move Station structure and components is provided by long robotic manipulator "arms" located on the Station modules. The Space Station Robotic Manipulator System (SSRMS) helps to move Station hardware components during the Station's assembly phase. One of the Station segments is a portion of the port truss used to support the outer solar arrays. These large solar arrays generate electrical power for the Station, and also contain electrical power management systems, including the Sequential Shunt Unit (SSU) electronic box. This box contains electronic components that regulate the power flowing from the Space Station solar arrays to the Station electrical systems.

Because of the importance of the SSU for Station power and operation, NASA needed to assess the potential damage to the SSU caused by an inadvertent impact. Some assembly operation scenarios showed that an impact could produce



AutoSEA2 model of the SSU electronics box for the shock analysis - Courtesy of Boeing shock vibrations for which the box was not originally tested and qualified. Consequently, NASA needed to determine if the impact shock force would generate vibration amplitudes that would exceed the original design and test levels. If the SSU shock responses exceeded the original test levels, then costly and time-consuming design changes would be required for the Station.

Some of the assembly operations require extremely delicate and close tolerance motion of the SSRMS arm. Movement of the arm close to electronic equipment boxes could possibly result in an impact generating shock vibrations. The SSU box is also located close to the path of astronaut Extra Vehicular Activity (EVA), and could be inadvertently impacted during other non SSRMS assembly operations.

### AutoSEA2 Shock Analysis has proved the most appropriate solution to span the large frequency range for the SSU.

The shock frequencies of interest ranged from low frequencies where Finite Element Analysis (FEA) methods were appropriate, to high frequencies where Statistical Energy Analysis (SEA) methods were needed. NASA and Boeing proposed a dual analysis approach using both FEA and SEA methods to span the frequency range for the SSU.

The AutoSEA2 Shock Module is not technically an SEA method. It uses the method of virtual mode synthesis. The AutoSEA2 model only provides a transfer function to which an equivalent dynamic system is fit to match.

Once a set of virtual modes are available, a transient, time domain solution can be obtained for the system and one can recover both subsystem response time histories as well as Shock Response Spectra.

AutoSEA2 Shock Analysis addressed two issues:

- The vibration response induced into the SSU electronics by an impact from the robotic arm operation or astronaut's kick
- The induced vibration environment that can be accepted before internal electronics damage

The analysis tool of choice for this task was the AutoSEA2 Shock Module, an analysis module that is contained in ESI's AutoSEA2 software.

The SEA model does not need to be recreated to perform the shock analysis in any desired frequency range. To increase the frequency range of the FE model, a finer mesh is required.

Increasing FE mesh resolution will affect computational time. Thus, if we compare SEA with FEA, from the perspective of computational efficiency we find:

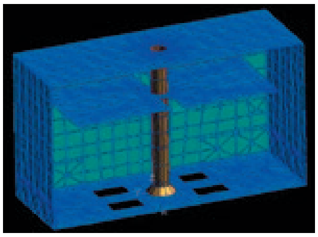
- SEA analysis on a PC: 1 minute, for an analysis from 10 to 10,000 Hz.
- FEA analysis on a PC: 10-minutes for an analysis from 10 to 2,000 Hz. The FEA model would have to be re-constructed in order to reach the required frequency of 10,000 Hz.

The SSU was modeled in the AutoSEA2 Shock Module in a conservative manner. The basic dimensions and panel thickness were taken from the detailed FEA model. The potential robotic and astronaut impact loads were then applied to several external SSU panels to determine the maximum SSU shock response at internal locations where the electronic components were mounted.

Then, the SSU qualification vibration test level was compared to the SEA predicted shock response. The comparison showed that the vibration qualification testing induces vibration loads greater than the predicted robotic or EVA shock vibration. Because the vibration testing adequately encompassed the shock response, NASA was able to conclude that the SSU will not be affected by any inadvertent impacts due to robotic or EVA activities.

As a consequence of this analysis, the AutoSEA2 Shock Module results provided the confidence that the assembly operations would not prevent a hazard to the Station nor astronauts, and no additional restrictions needed to be levied against assembly operations.

FEA model of SSU
electronic box
Courtesy of Boeing



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