Development of the Orion Crew-Service Module Umbilical Retention and Release Mechanism

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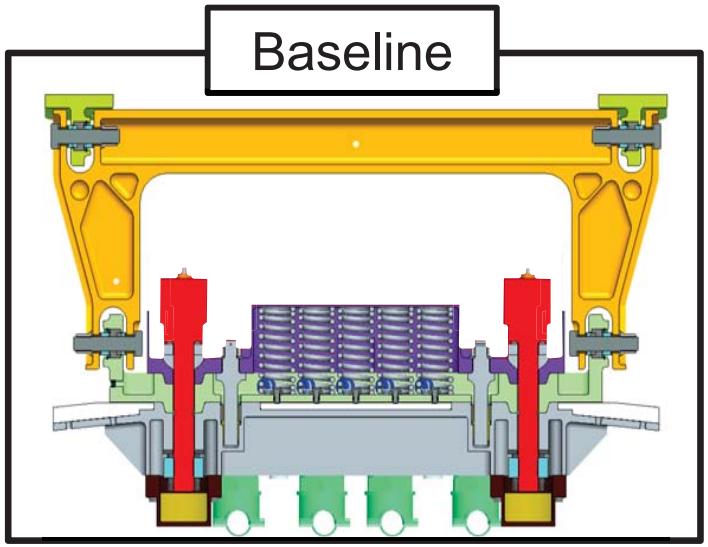
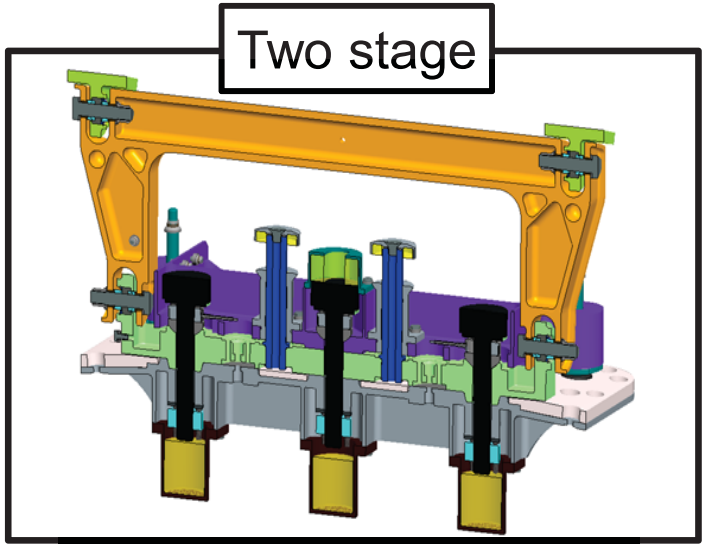
Outline

- Introduction
- Baseline plate separation concept
- Baseline testing failures
- Two stage design, modifications, analysis and testing
- Conclusions
- Lessons learned





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Introduction

Space Launch System (SLS)

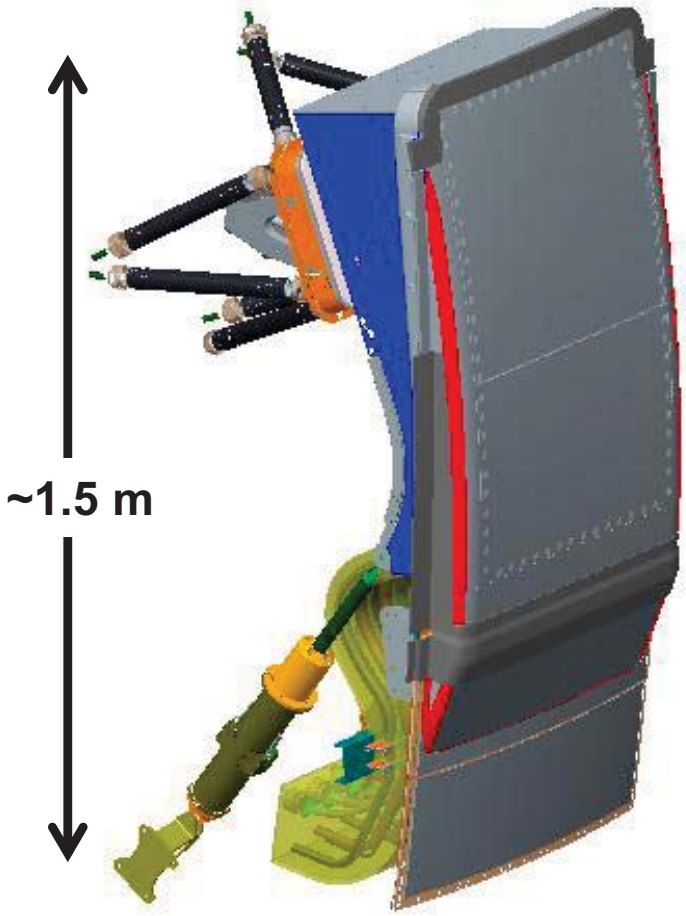
Orion Multi-Purpose Crew Vehicle (MPCV)

Launch Abort System (LAS)

Crew Module (CM)

Service Module (SM)

CM/SM Umbilical Mechanism



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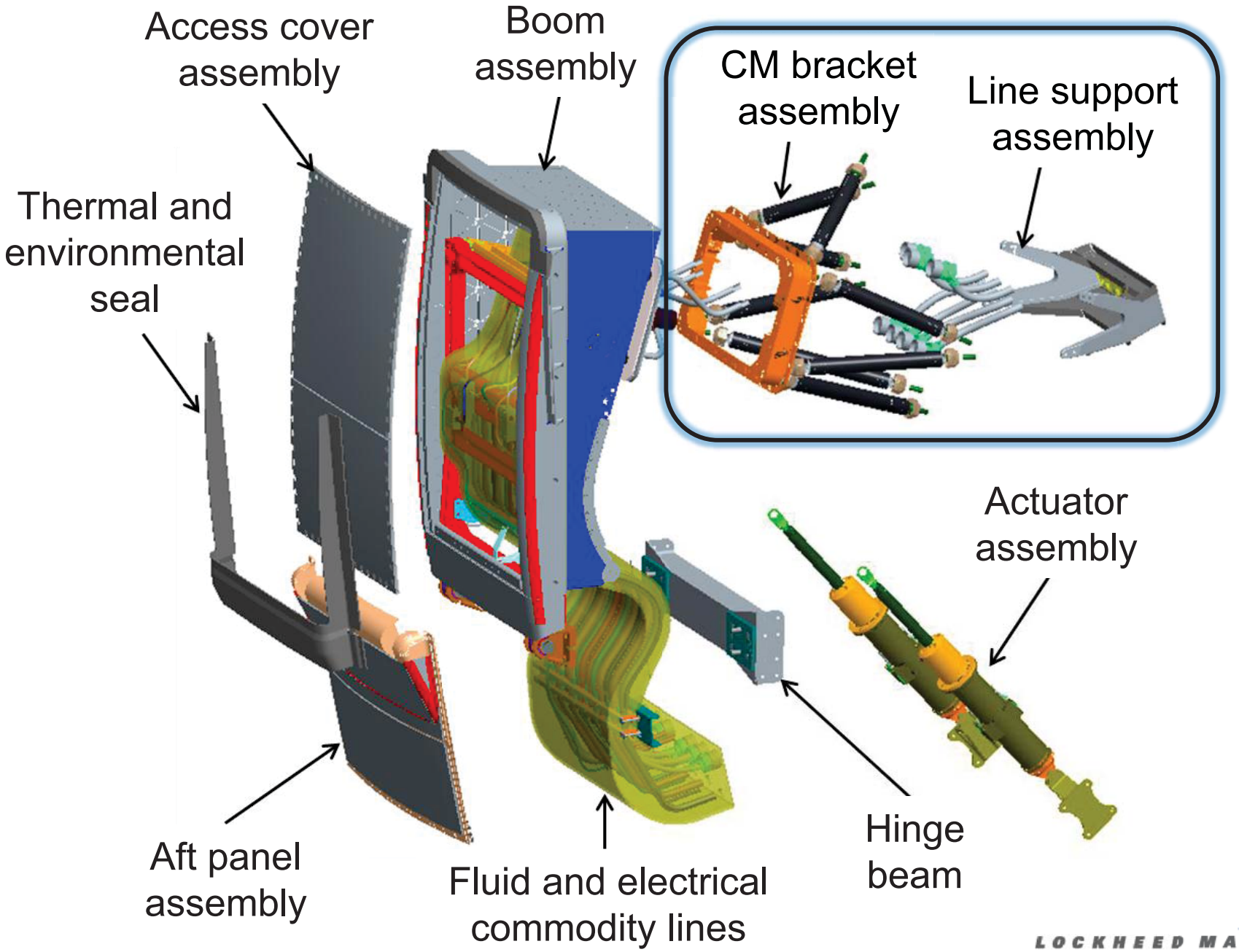
Umbilical Components



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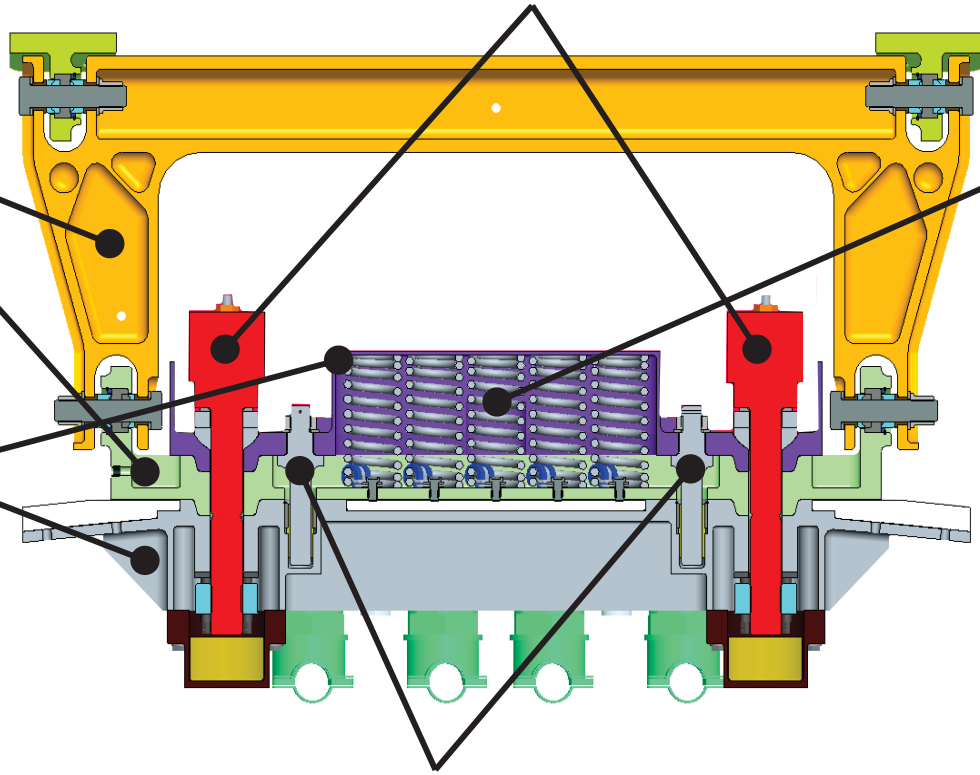
Baseline Plate Separation Design

Separation Bolts

Single event released the plates and the umbilical's structural connection to the CM.

Coupler Link and CM Link

Load path between SM and CM sides of the umbilical.



Spring Pack

Force to separate the plates. Packaged in the middle of the plates to make the plate design lighter and more compact.

Connector Plates

The motion of these plates disconnected the commodity connections.

Guide Pins and Bushings

Guidance for the linear separation within the stated misalignment limits of the fluid and electrical connectors.

Electrical and Fluid Connectors

The electrical connectors

- Zero Separation Force (ZSF) design
- Uses wave springs to disengage pins from sockets.
- Ideally, external force not needed

The fluid connectors

- Proprietary LM design
- A dual o-ring seal
- Tight tolerances for leakage requirements.
- Mounting scheme that allows angular and lateral float

Baseline Development Testing

Parameters monitored

1. Force to separate the plates
2. Displacement at plate corners

Configuration 1

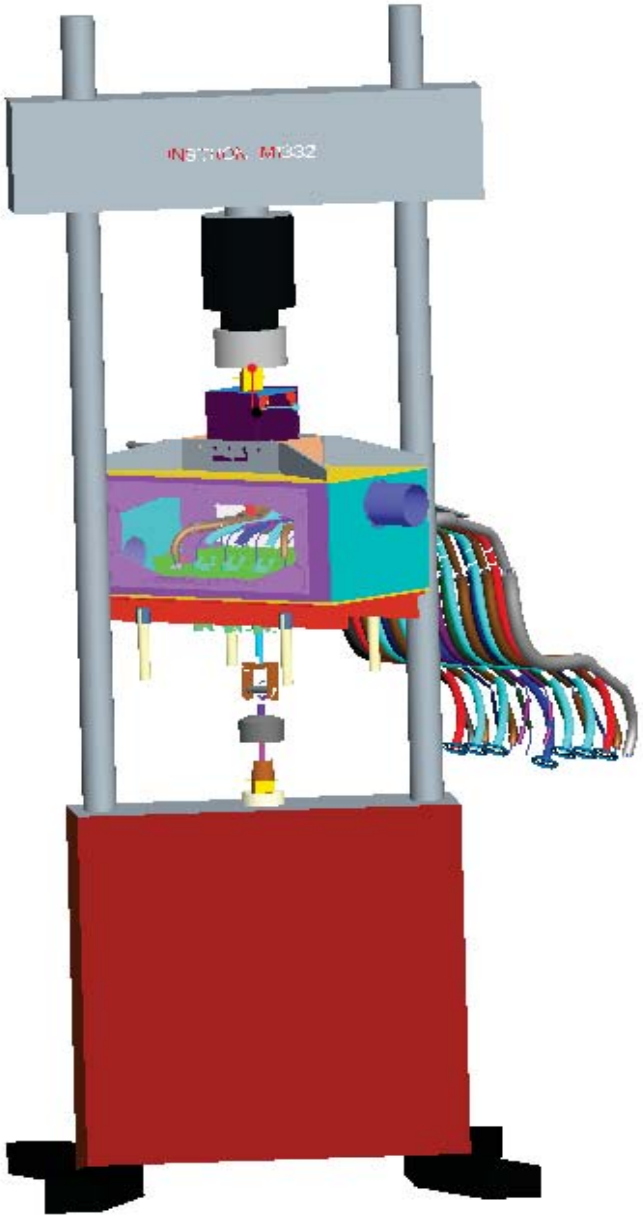
- Electrical and fluid connectors
- Plates bound at <1° relative angle
- Electrical connectors bound

Configuration 2

- Only fluid connectors
- Plates bound at ~2° relative angle
- Binding relieved by loosening mounting screw

Configuration 3

- Only fluid connectors
- Restored intended float to connector mounting
- Plates separated consistently



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Development Test Conclusion

The root causes of the baseline design failure:

1. Connectors did not have misalignment capabilities that were expected.

2. The mechanism displayed a tendency to misalign, which was not anticipated.

✓ The basic premise of the separation method had to change.

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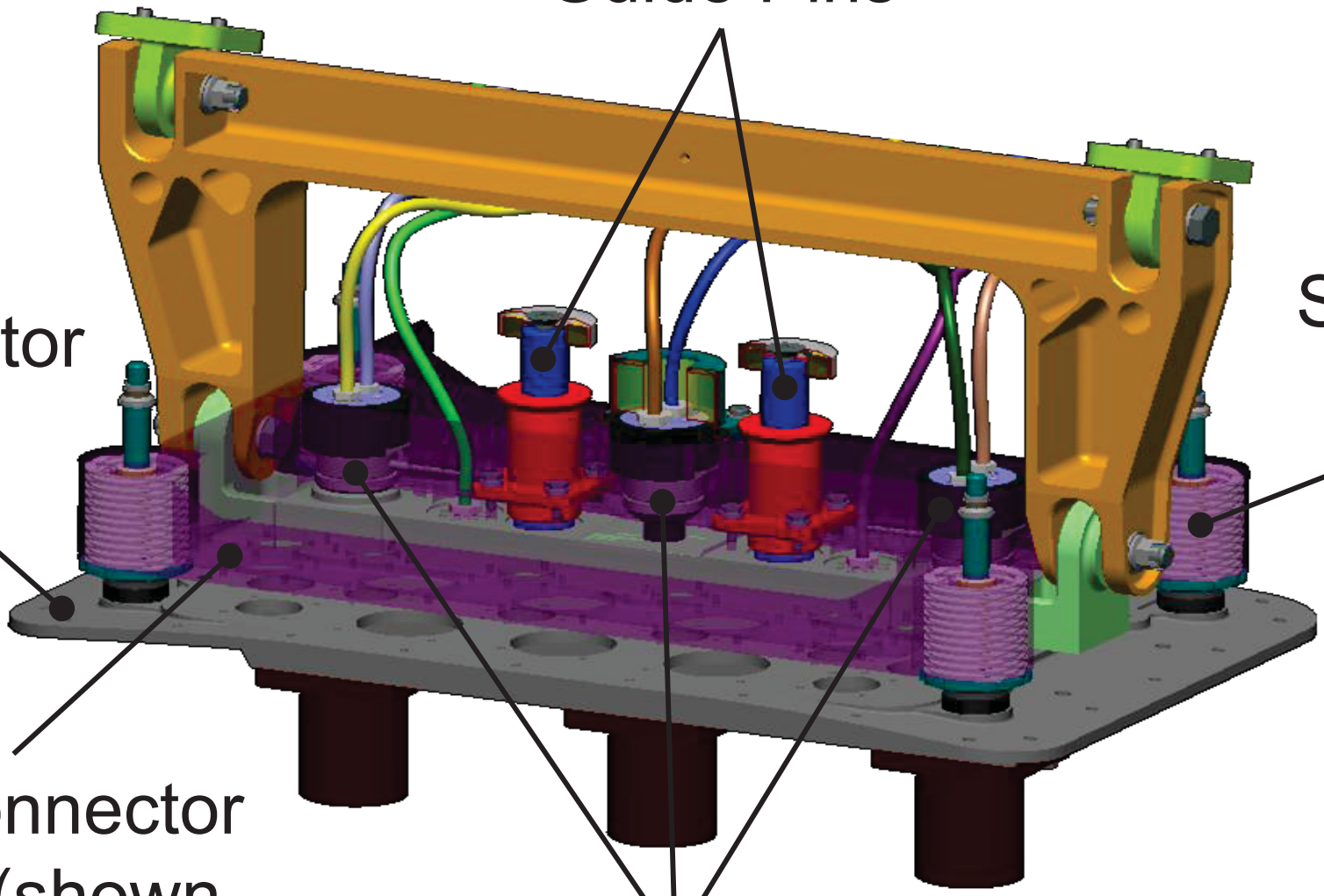
Two Stage Plate Separation Components



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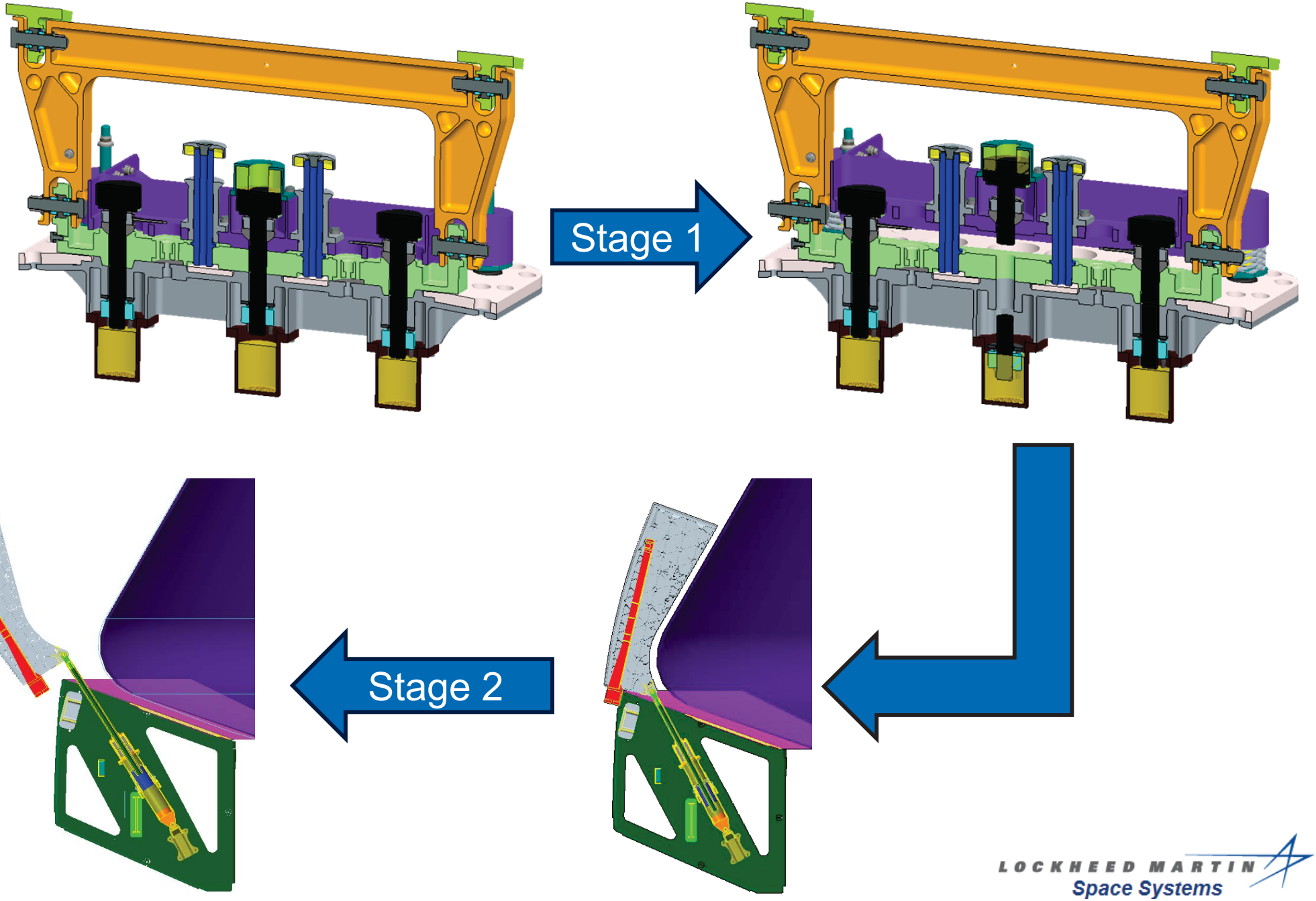
Two Stage Plate Separation Sequence



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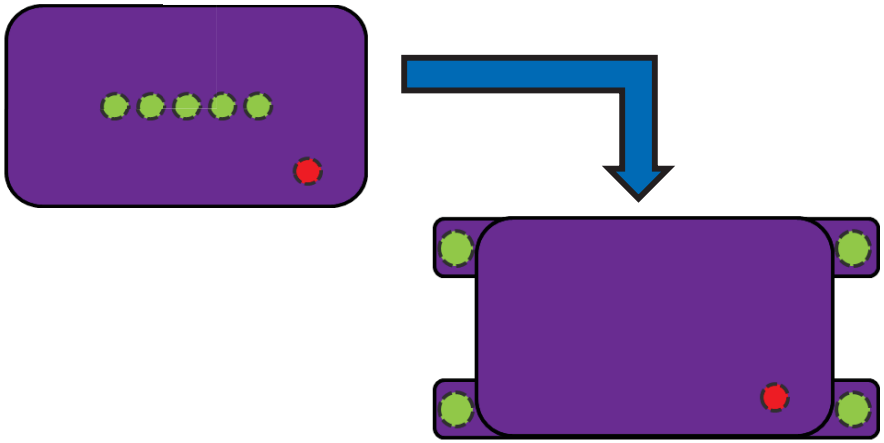
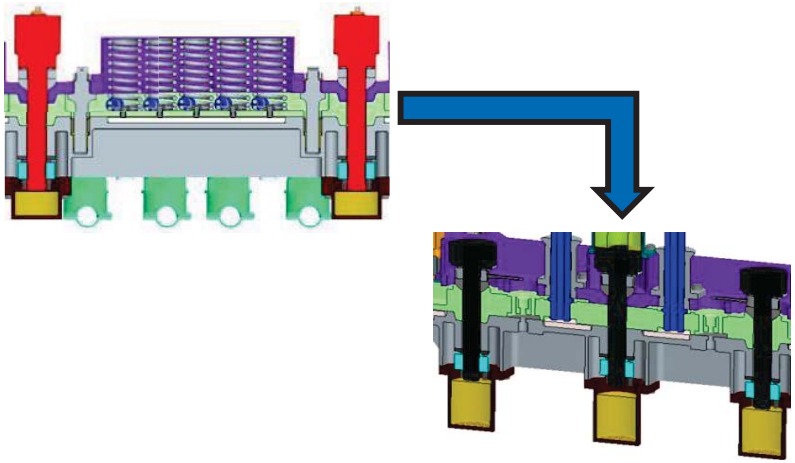
Two Stage Modifications

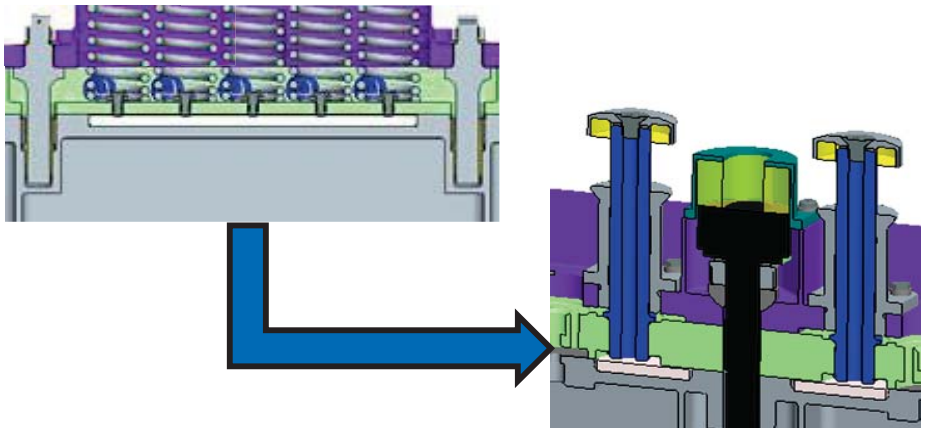
1 Separation springs moved to corners



2 Additional separation bolt



3 Redesigned guide pin & linear bearings system



4 Redesigned electrical and fluid connectors

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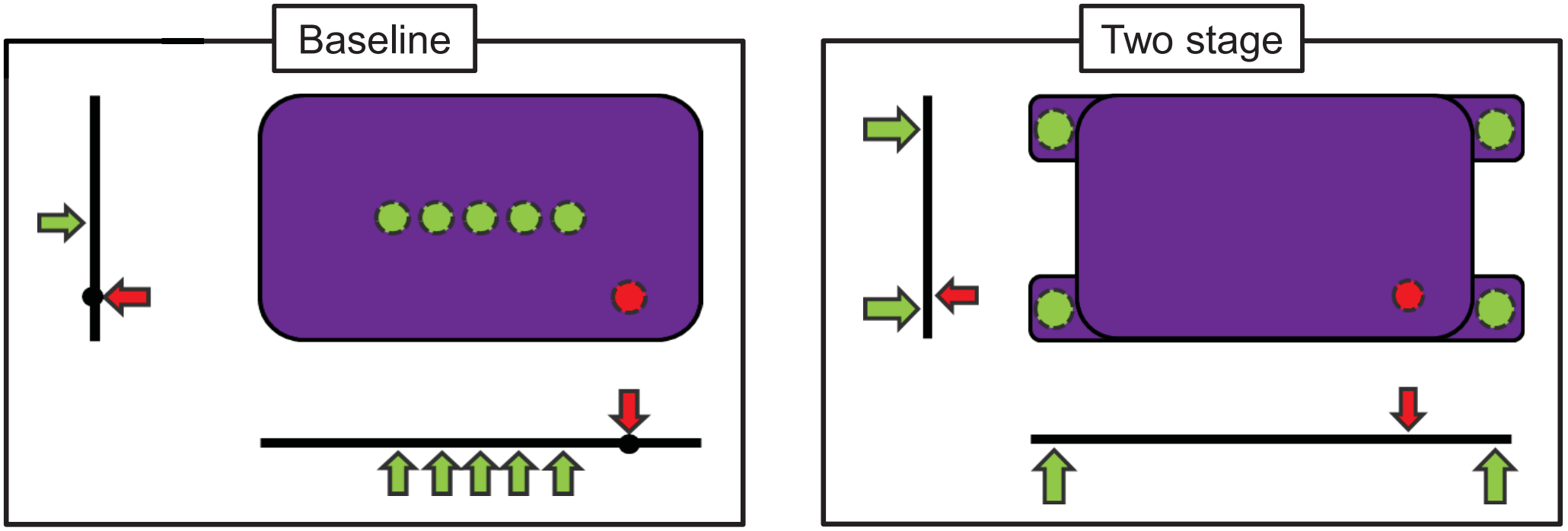
Two Stage Modifications

1 Separation springs moved to corners



Spring force (green)
Bound connector (red)

✓ Provides a more stable and even application of spring separation force

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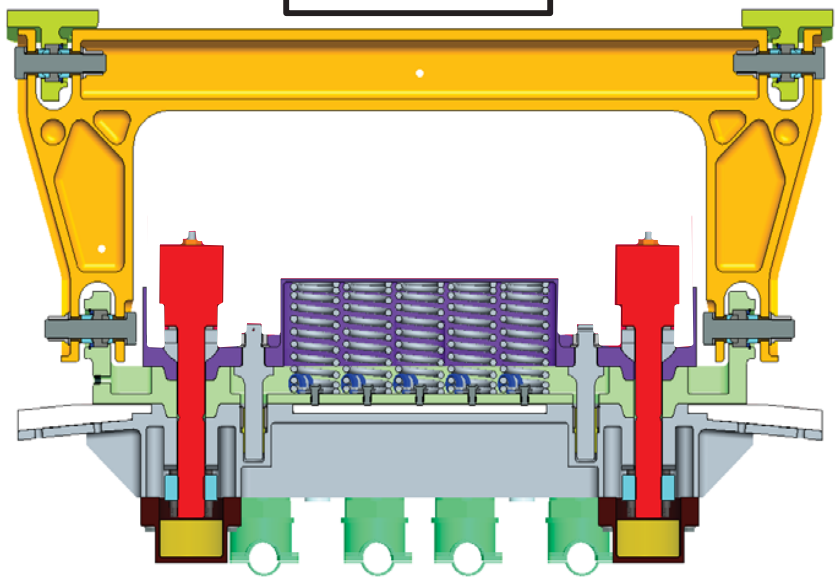
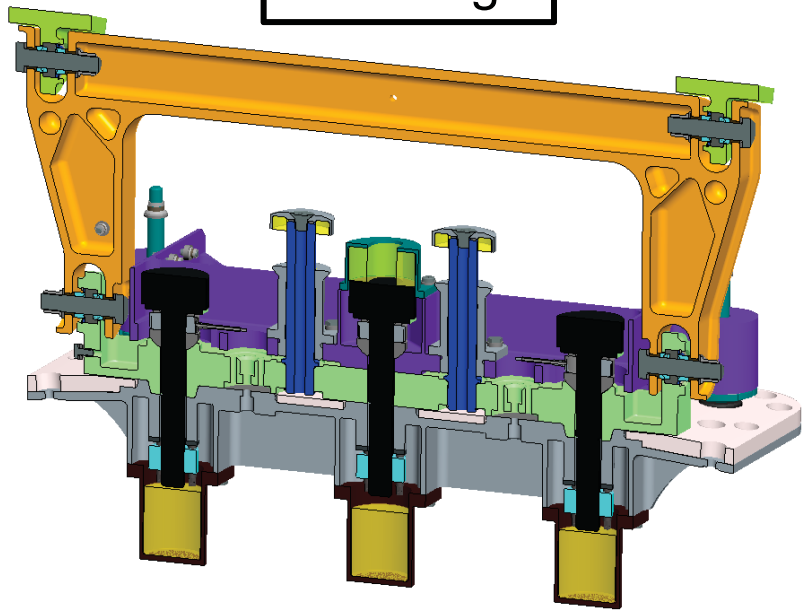
Two Stage Modifications

2 Additional separation bolt

Baseline



Two stage



- ✓ Allows separation in two stages
- ✓ Completely decouples linear and rotational motion

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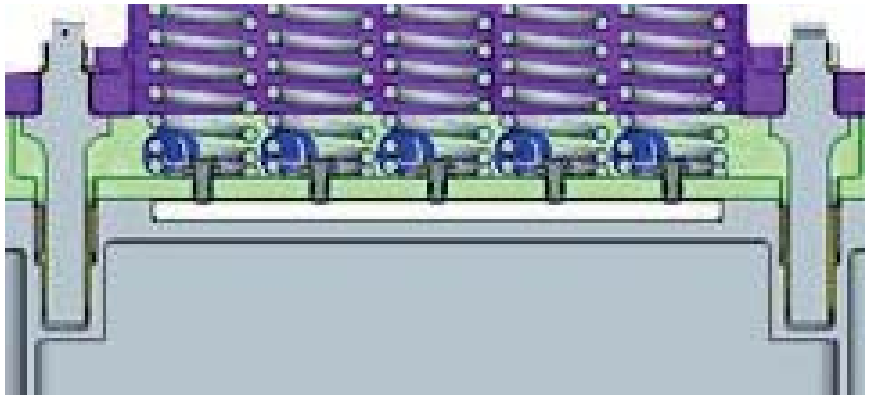
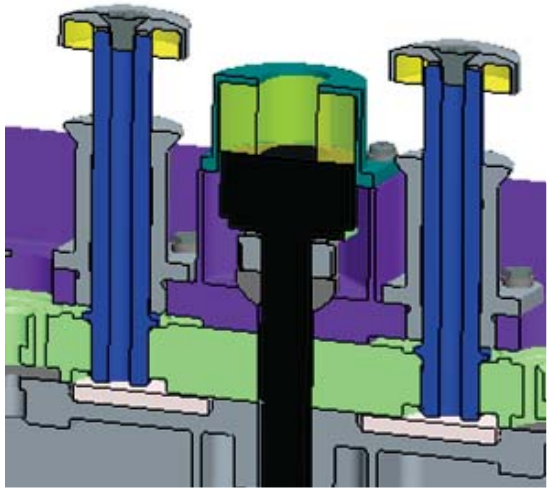
Two Stage Modifications

3 Redesigned guide pin & linear bearings system

Baseline



Two stage



- ✓ Larger to withstand higher offset loads
- ✓ Closer tolerances
- ✓ More precise control over plate alignment
- ✓ Tighter control over connector location

Two Stage Modifications

4 Redesigned electrical and fluid connectors

Electrical connectors

- ✓ Anti-binding features and modifications
- ✓ Built and tested to a specification

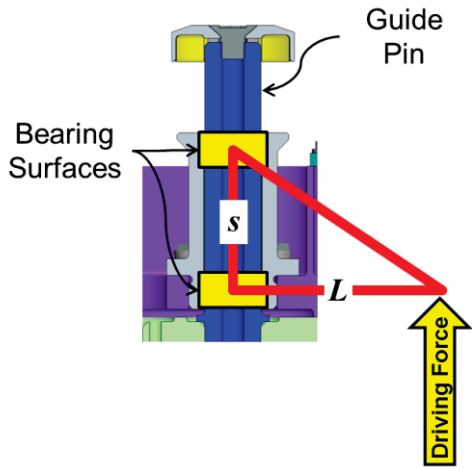
Fluid connectors

- Proprietary LM design
- Dual o-ring seal

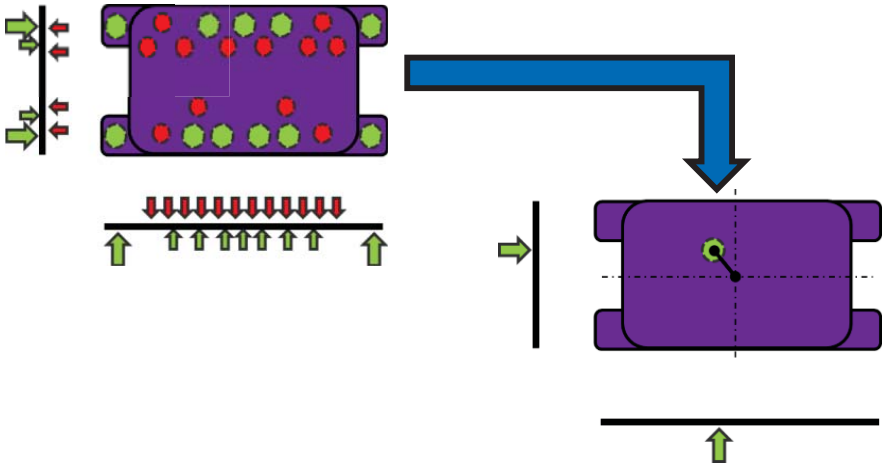
- ✓ Changed mounting scheme
- ✓ Removed angular float
- ✓ Tighter lateral float control

Two Stage Binding Analysis

1 Susceptibility of linear guide system to binding

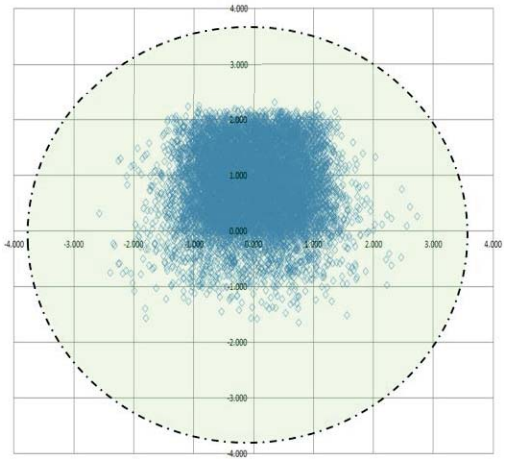


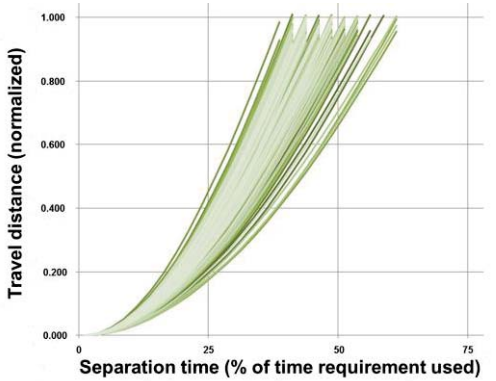
2 Sum assisting and hindering forces



3 Monte Carlo analysis to assess binding and timing

4 Evaluate results





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Two Stage Binding Analysis

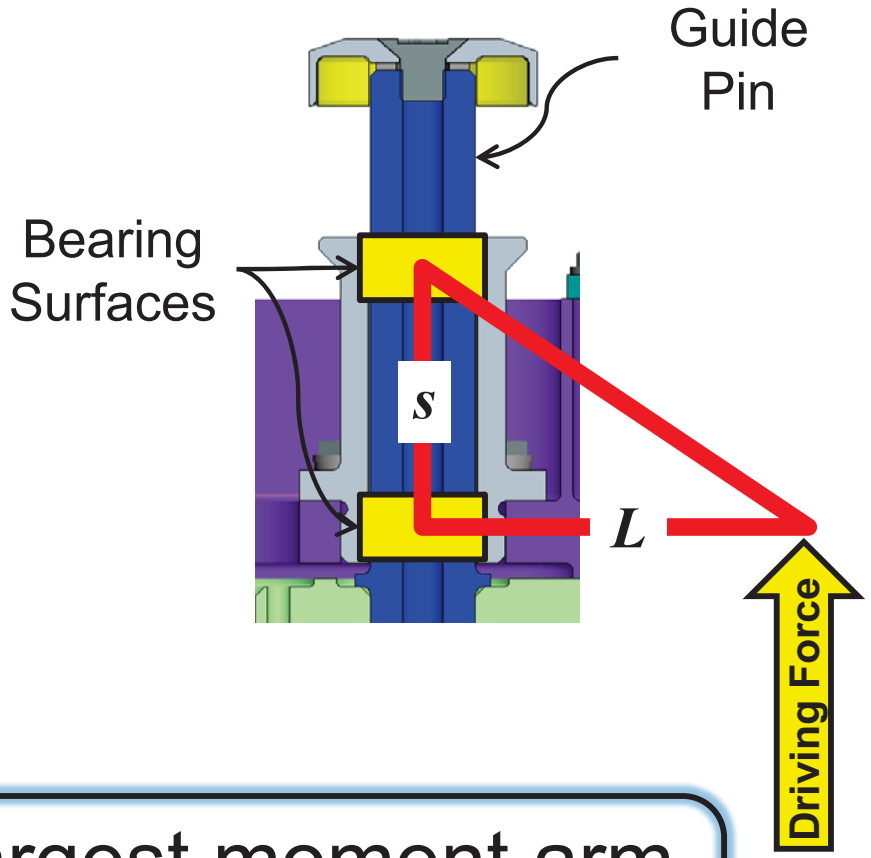
1 Explore susceptibility of linear guide system to binding

$$\frac{L}{s} > \frac{1}{2\mu}$$

Binding condition

$$\frac{L}{s} < \frac{1}{2\mu}$$

No-binding condition



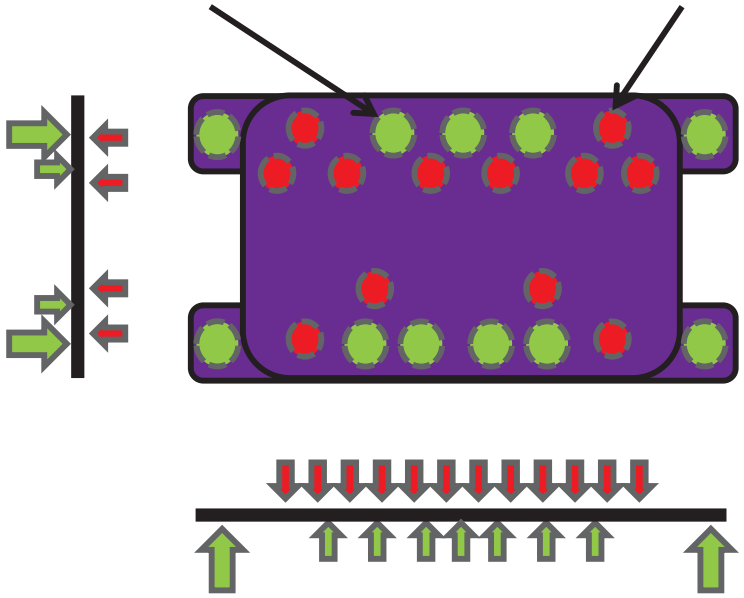
✓ $L_{critical}$ calculated – largest moment arm that results in a no-binding condition.

Two Stage Binding Analysis

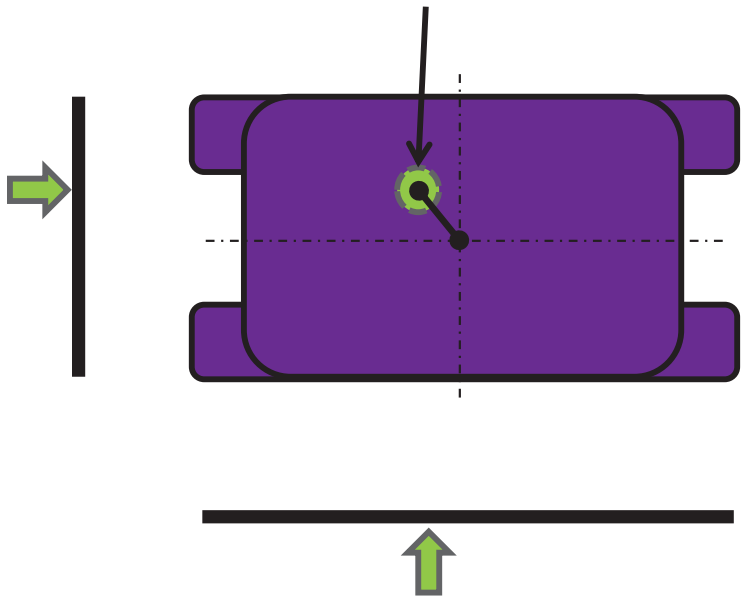
2 Summing assisting and hindering forces

Assisting forces (green)

Hindering forces (red)



Resulting equivalent moment arm (less than $L_{critical}$?)



✓ $L_{critical}$ compared to equivalent moment arm of all assisting and hindering forces

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Two Stage Binding Analysis

3 Monte Carlo analysis for binding and separation timing

Variables:

1. Spring force
2. Electrical connector separation force
3. Fluid connector hindering force
4. Forces from bending fluid lines and electrical harnesses

Four configurations simulated:

1. Four nominal separation springs
2. Three nominal separation springs and one with one coil out
3. No electrical connectors forces
4. Double electrical connector forces

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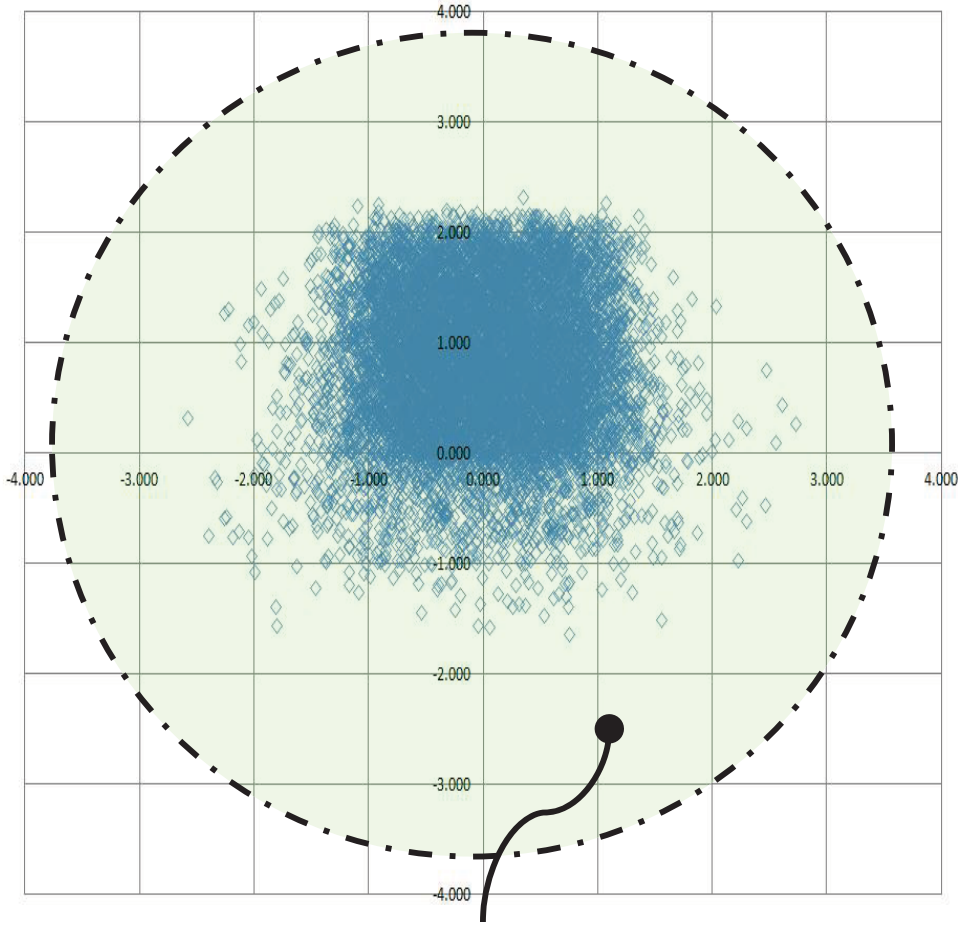
Two Stage Binding Analysis

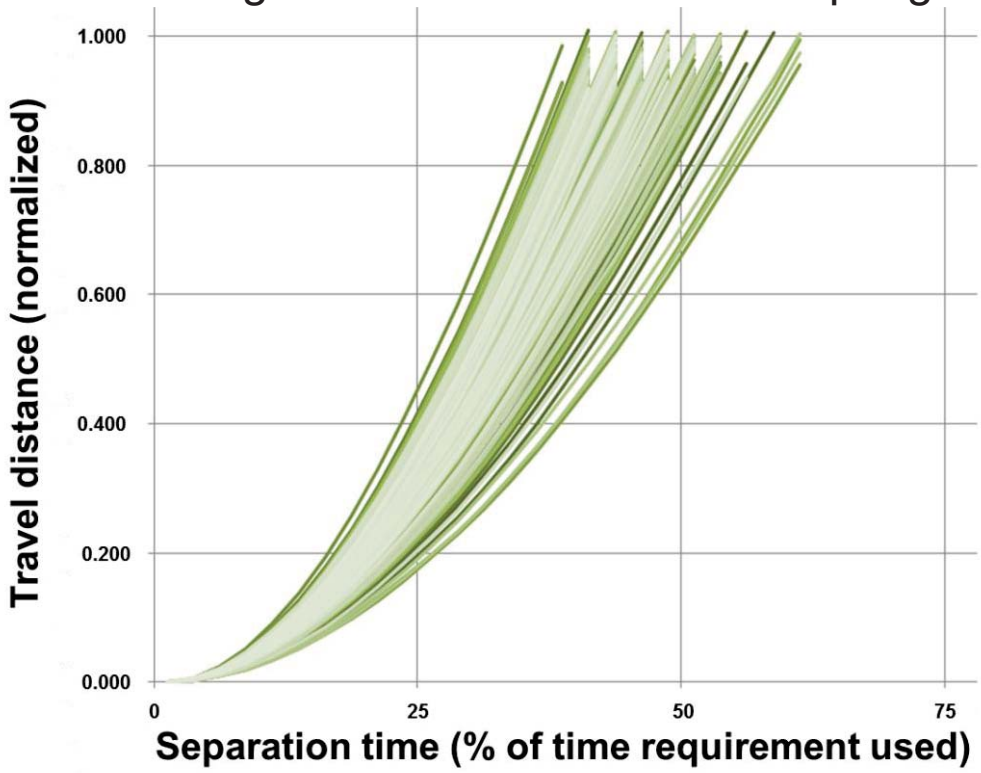
4 Evaluate results

Equivalent Moment arm
Configuration 1 – Four Nominal Springs



Circle Radius = $L_{critical}$

Timing Results
Configuration 1 – Four Nominal Springs



- ✓ All configurations showed no binding or timing issues.
- ✓ Good with up to six coils out on one spring.

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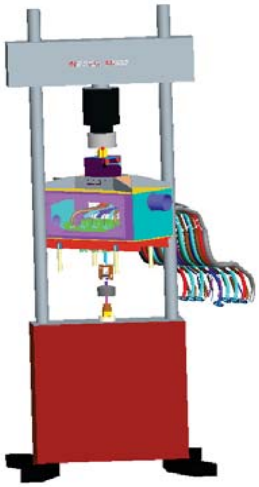
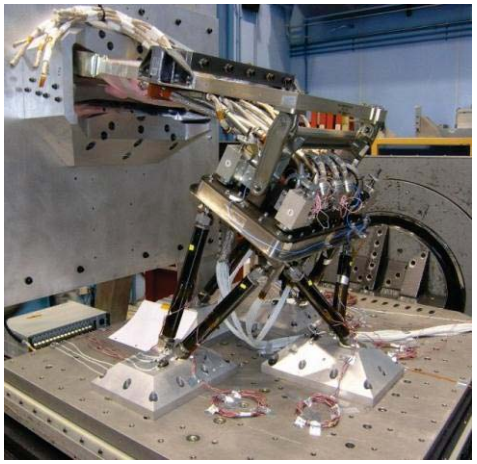
Two Stage Development Testing

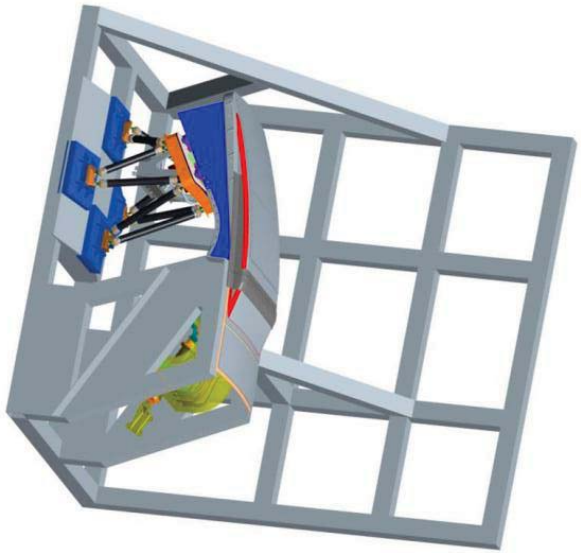
1 Stage 1 separation



2 Vibration



3 Full speed functional



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Two Stage Development Testing

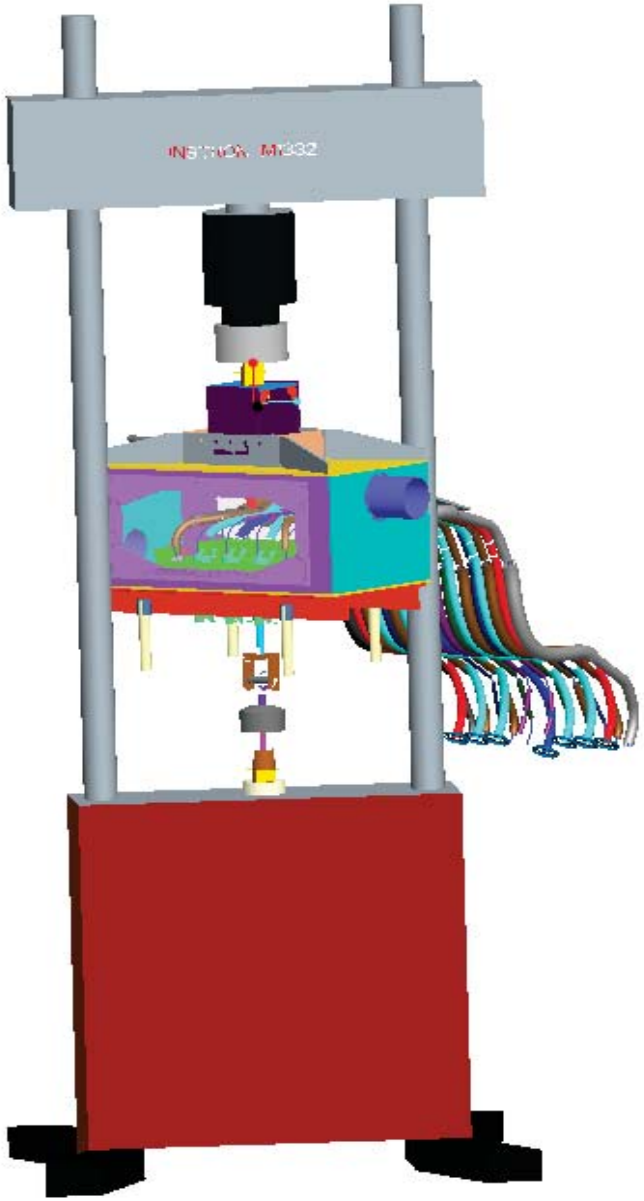
1 Stage 1 Separation

Primary objectives:

1. Determine separation force characteristics
2. Verify no-binding occurs

Test	Electrical Connectors	Fluid Connectors	Pressurized Fluid Lines	Temperature Level
1	-	-	-	Ambient
2	Yes	Yes	-	Ambient
3	Yes	Yes	-	Cold
4	Yes	Yes	-	Ambient
5	Yes	Yes	-	Hot
6	Yes	Yes	Yes	Ambient
7	Yes	Yes	Yes	Cold
8	Yes	Yes	Yes	Hot
9*	Yes	Yes	Yes	Ambient

✓ All tests and data showed no binding and good margins, including the spring-out case (*test 9)



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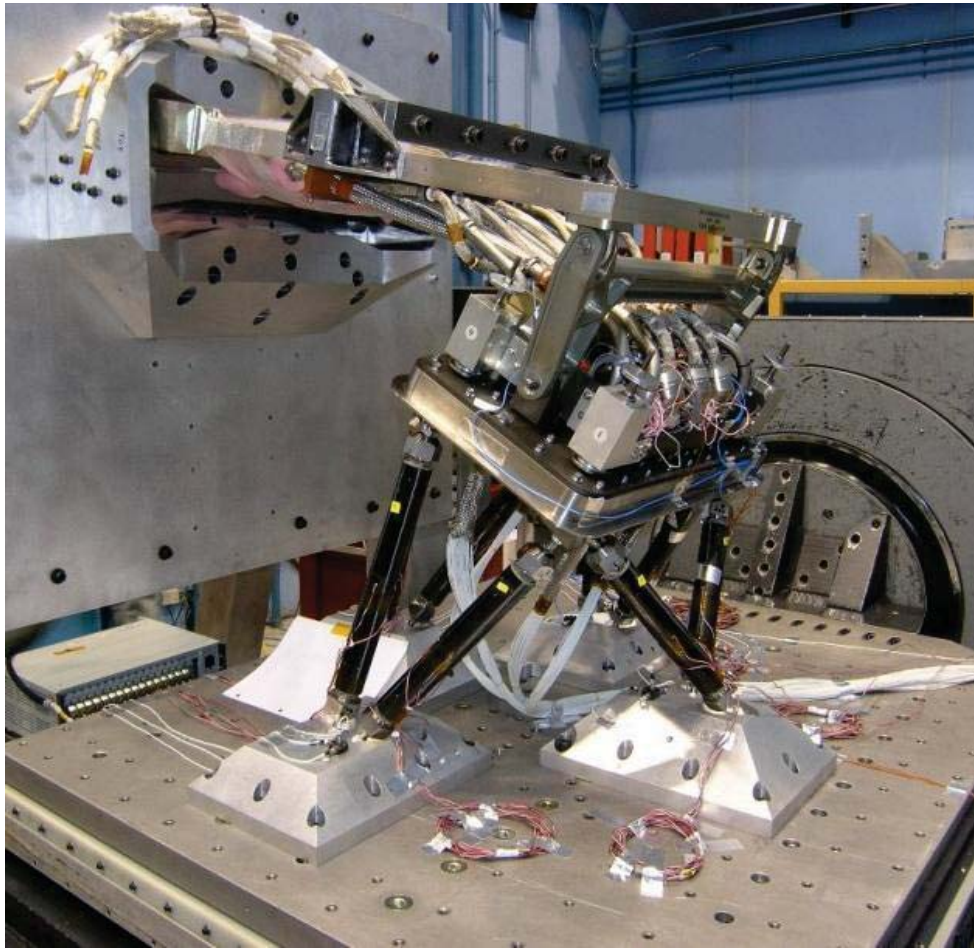
Two Stage Development Testing

2 Vibration

Primary objective:

Subject the umbilical assembly to qualification environments prior to the functional test



✓ The desired levels were achieved in all three axes without significant issues

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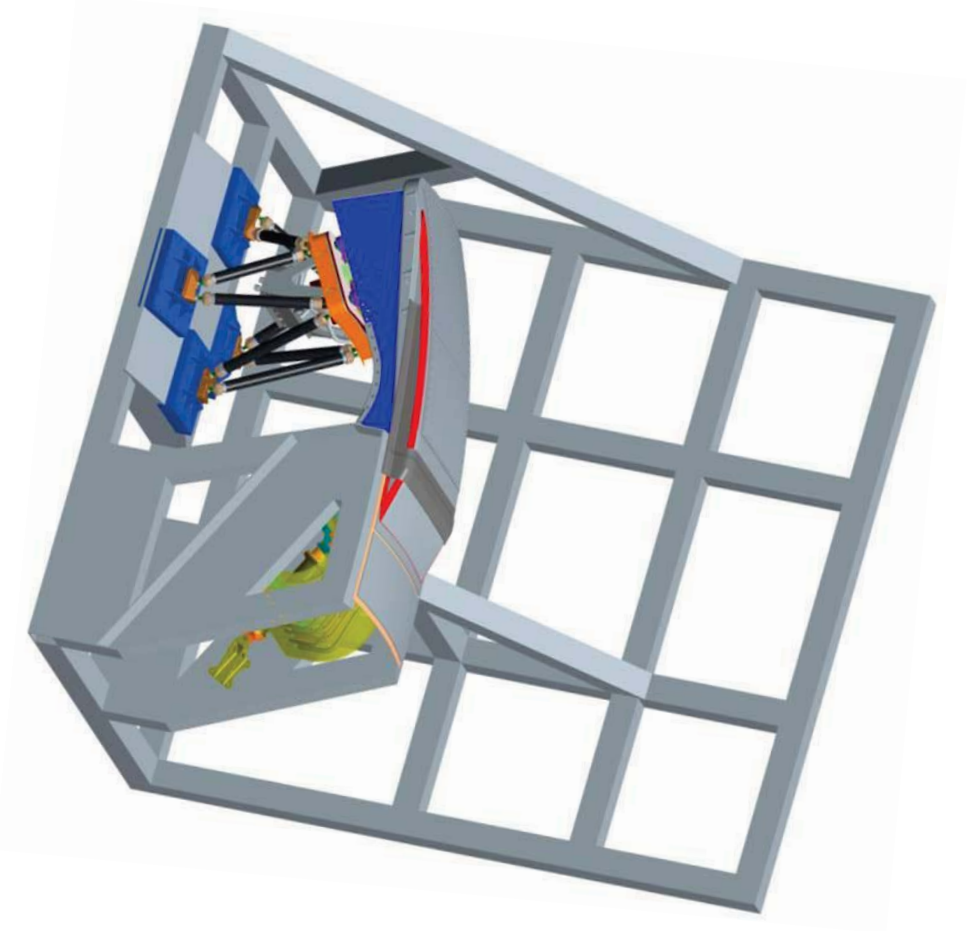
Two Stage Development Testing

3 Full speed functional



Primary objectives:

1. Obtain shock environment due to separation bolts
2. Demonstrate the separation of the two stages after exposure to qualification vibration levels

- ✓ Shock from separation bolts not a threat
- ✓ No unexpected damage or wear
- ✓ ***Two stage design approved for flight umbilical mechanism***

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Lessons Learned

1. Linear guide system dominance
2. Verify performance of off-the-shelf hardware
3. Separation force applied at the corners
4. Monte Carlo simulation very effective
5. Development testing essential

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Summary

1. Confident the two stage design will perform well for EFT-1 and all future Orion flights

2. This method of separating a cluster of electrical and fluid connectors can be used in many applications

3. The analysis methods for assessing binding can be easily adapted to different connector configurations and commodity sets

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Back up

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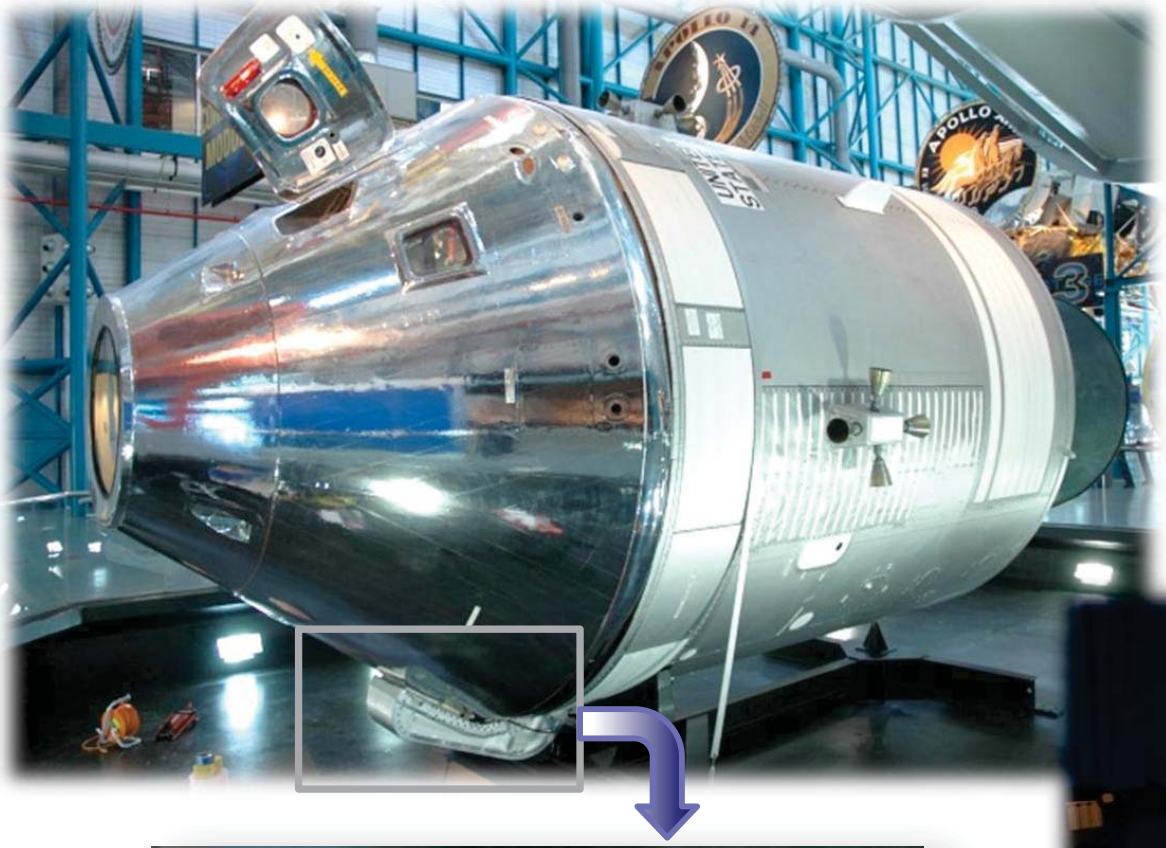
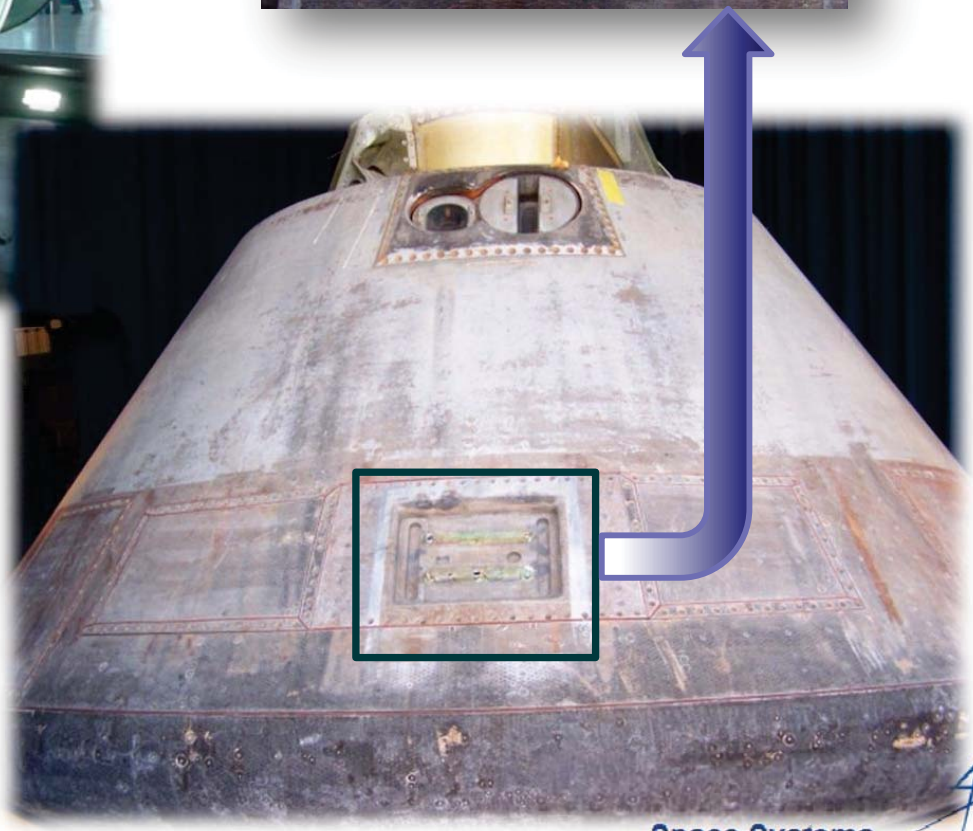
Apollo CSM Umbilical





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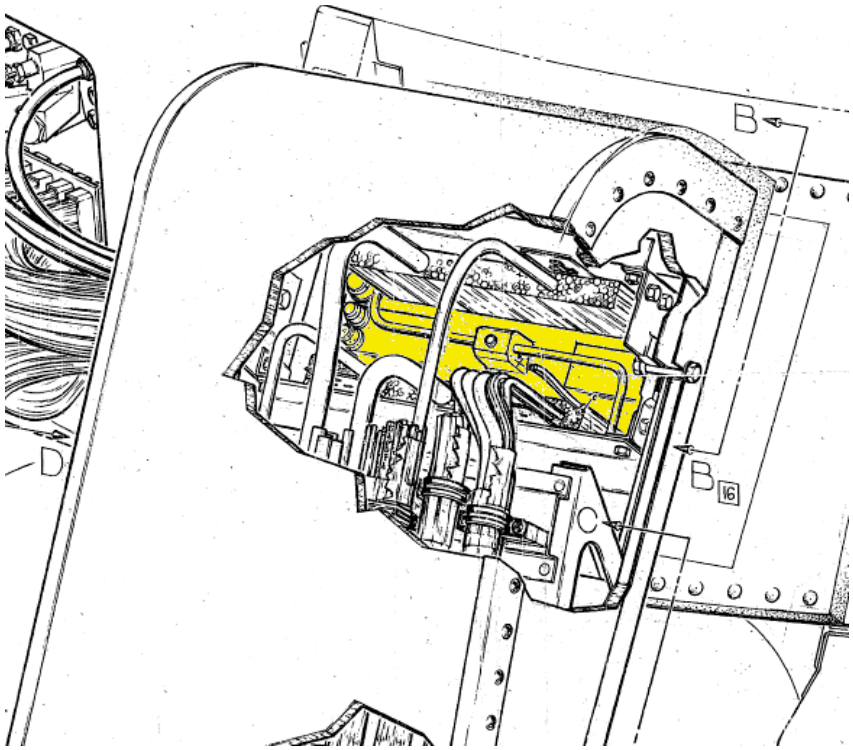
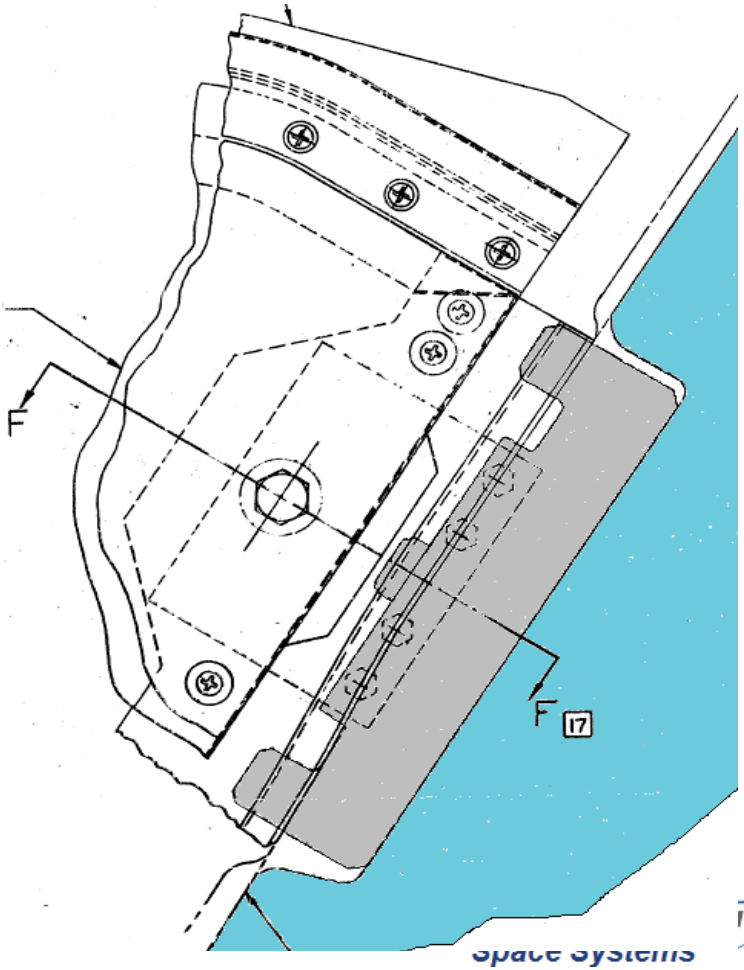
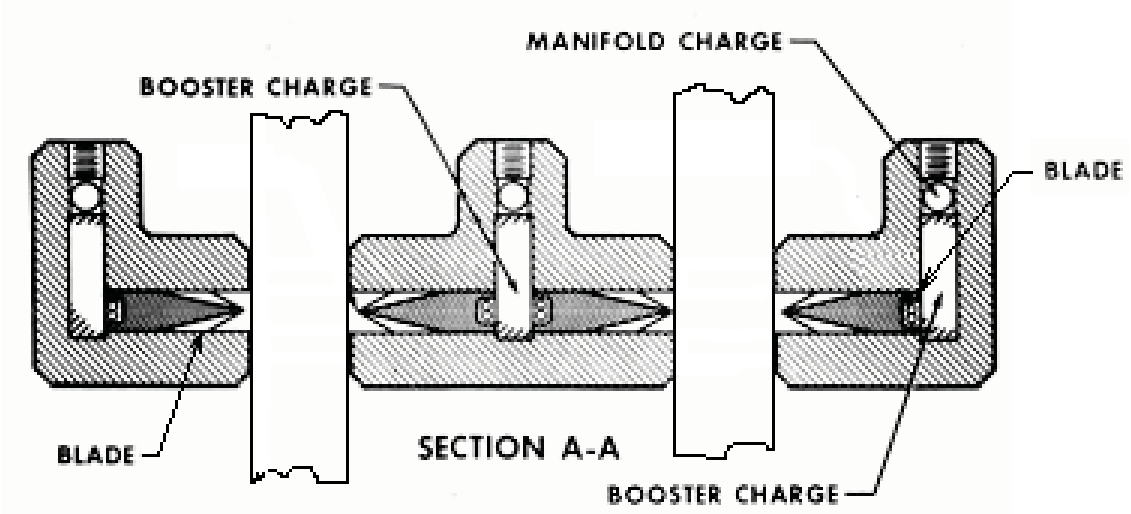
Apollo CSM Umbilical



All the commodities were packaged into two rectangular blocks that were cut by the redundant blades.





Apollo CSM Umbilical

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Guillotine/Connector Trade Study

LM chose to use connectors for the following main reasons:

1. It increased the **flexibility** and decreased the **cost** at the component level.
   - The guillotine is a **one use item** and different tubing for each test run.
   - The connectors could also be designed for **several separations**.

2. It was estimated to have **less mass** by about 40% - 50%.

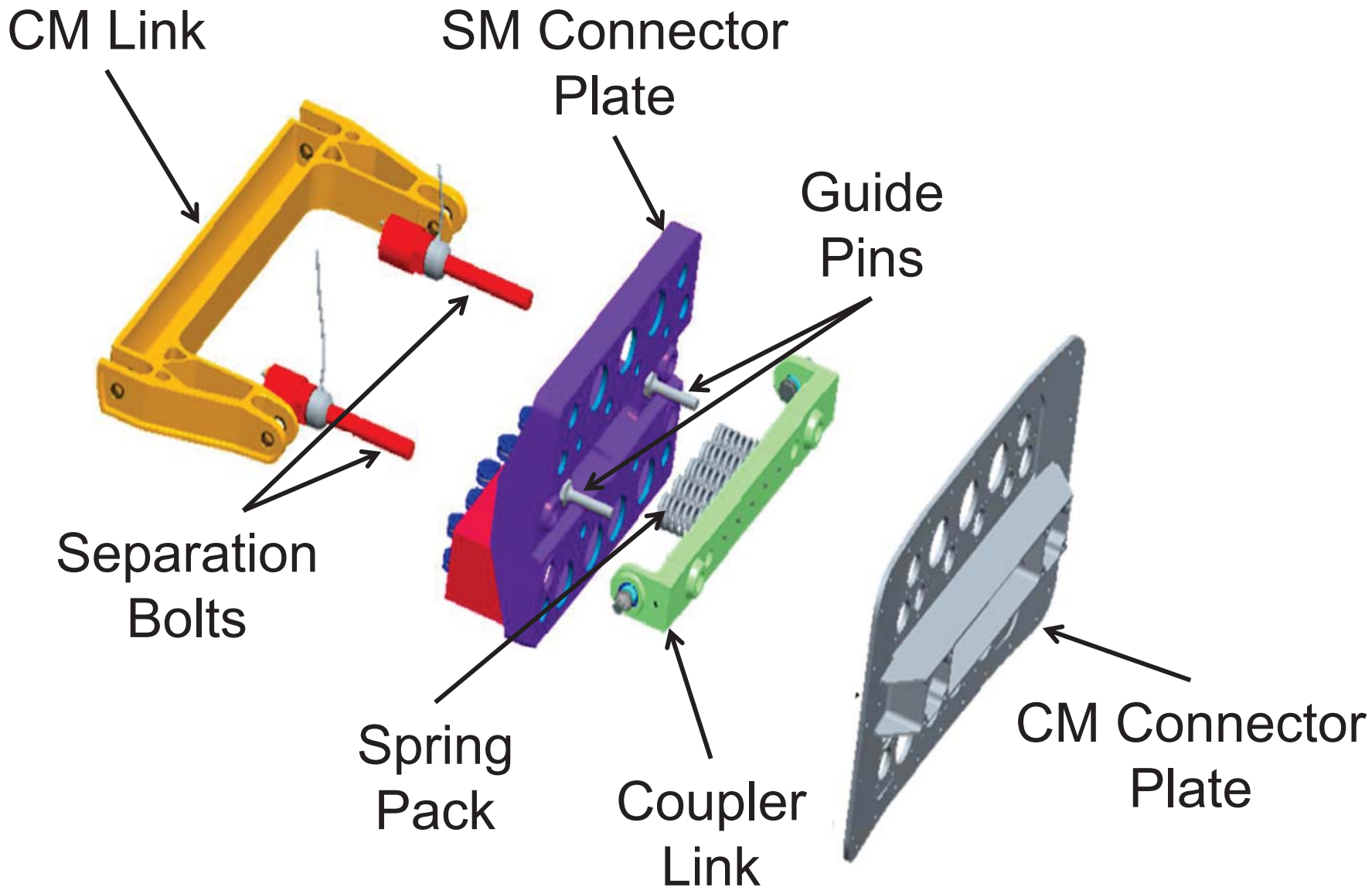
3. The connectors were considered to have a **higher** technology readiness level (**TRL**) and need less development.
   - A guillotine system to cut multiple fluid and electrical lines would be a custom design that would need a large development program.

4. Connectors **simplified** the assembly and integration process (**safer** to handle and easier to install).

Lessons Learned

- The linear guide system needed to be the dominant element for controlling the plate orientation and connector positioning. Allowing too much play in the guide system and connector mounting (in an attempt to allow the connectors to float to prevent binding) did not work well. Dividing the umbilical separation into two carefully constrained and timed events addressed the root cause of the binding failures by providing better control of the plate orientation.
- The off-the-shelf electrical connector design did not perform as expected in the umbilical mechanism application. The cost and schedule impacts from writing a specification and purchasing validated connectors could have been partially mitigated by verifying the actual performance of the off-the-shelf connector design.
- The separation force from the plate springs is more effective when distributed to the corners of the plates. This provided a more stable application of the separation force. Furthermore, it ensured that there would never be zero separation force being applied to a bound connector.
- The Monte Carlo simulation was very effective in dealing with the number of variables affecting the separation and the uncertainty associated with each one. It allowed for rapid assessment of numerous trades and contingency scenarios. The envelope of the design was quickly and effectively identified. It gave LM confidence that this separation configuration met force and timing margins.
- Finally, development testing of the CSM umbilical retention and release mechanism proved to be essential in discovering unknown and unanticipated issues and helped to validate analytical predictions.

Baseline Plate Separation Design



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