



Orion Hardware in the Loop OIMU Stimulation Latency Effect on Navigation State Estimation

Christopher A. Ertl*
Robert C. Earl†

COPYRIGHT © 2024, The Charles Stark Draper Laboratory, Inc. All rights reserved. Published by the American Astronautical Society with permission.

Contractor Name: The Charles Stark Draper Laboratory, Inc.
Contractor Address: 555 Technology Square, Cambridge, MA 02139

Developed under Contract No. 80JSC021DA005 with the National Aeronautics and Space Administration

The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, or allow others to do so, for United States Government purposes. All other rights are reserved by the copyright owner.

*Sr. Member Technical Staff, The Charles Stark Draper Laboratory, 17629 El Camino Real, Suite 470, Houston, TX 77058.

†Guidance Navigation and Controls Engineer Staff, Lockheed Martin, 8740 Lucent Blvd, Highlands Ranch, CO, 80129

Table of Contents

- Background
- Problem Statement
- Analysis Approach
- Results
- Conclusion

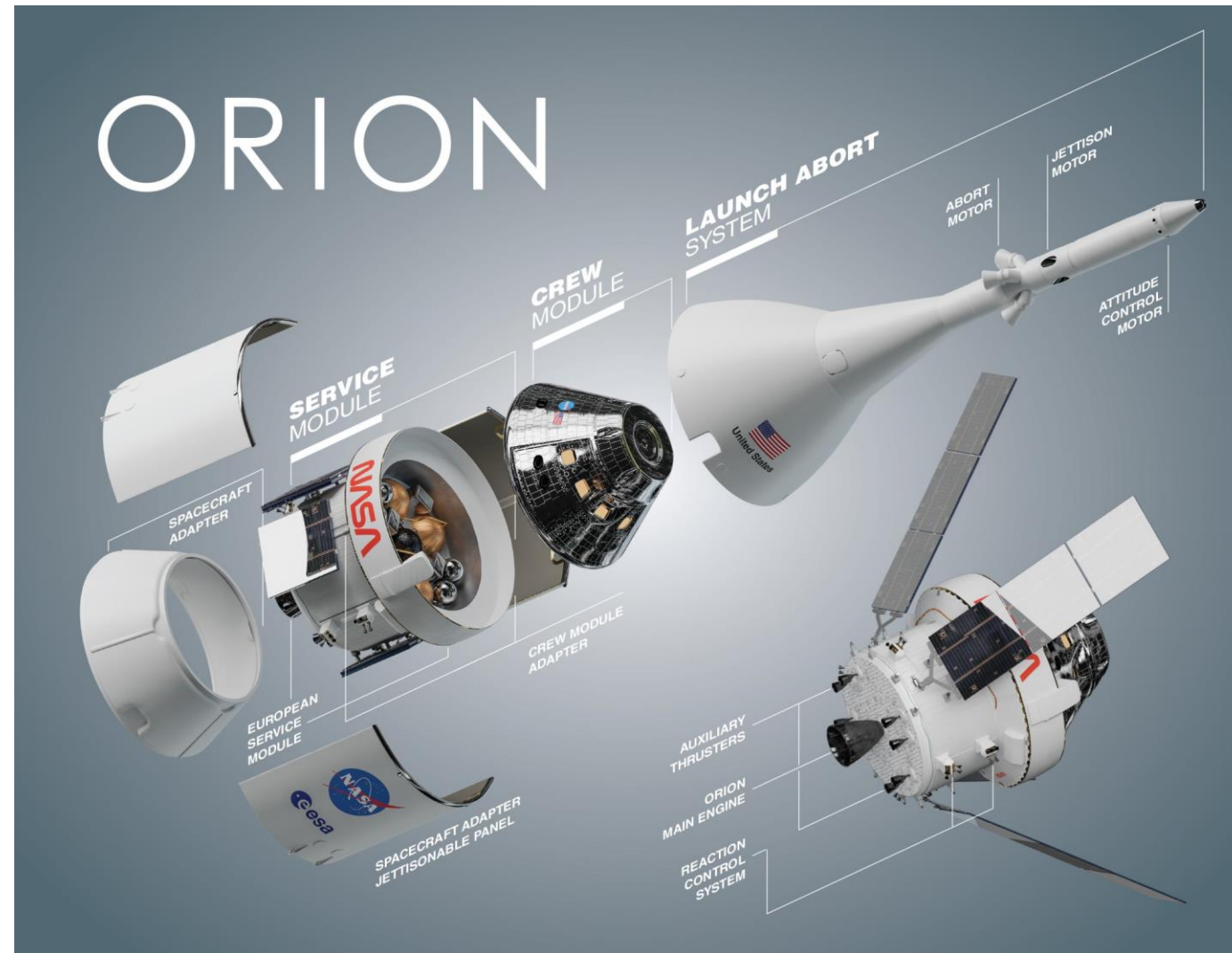


Image Credit: NASA



Table of Contents

- Background
- Problem Statement
- Analysis Approach
- Results
- Conclusion

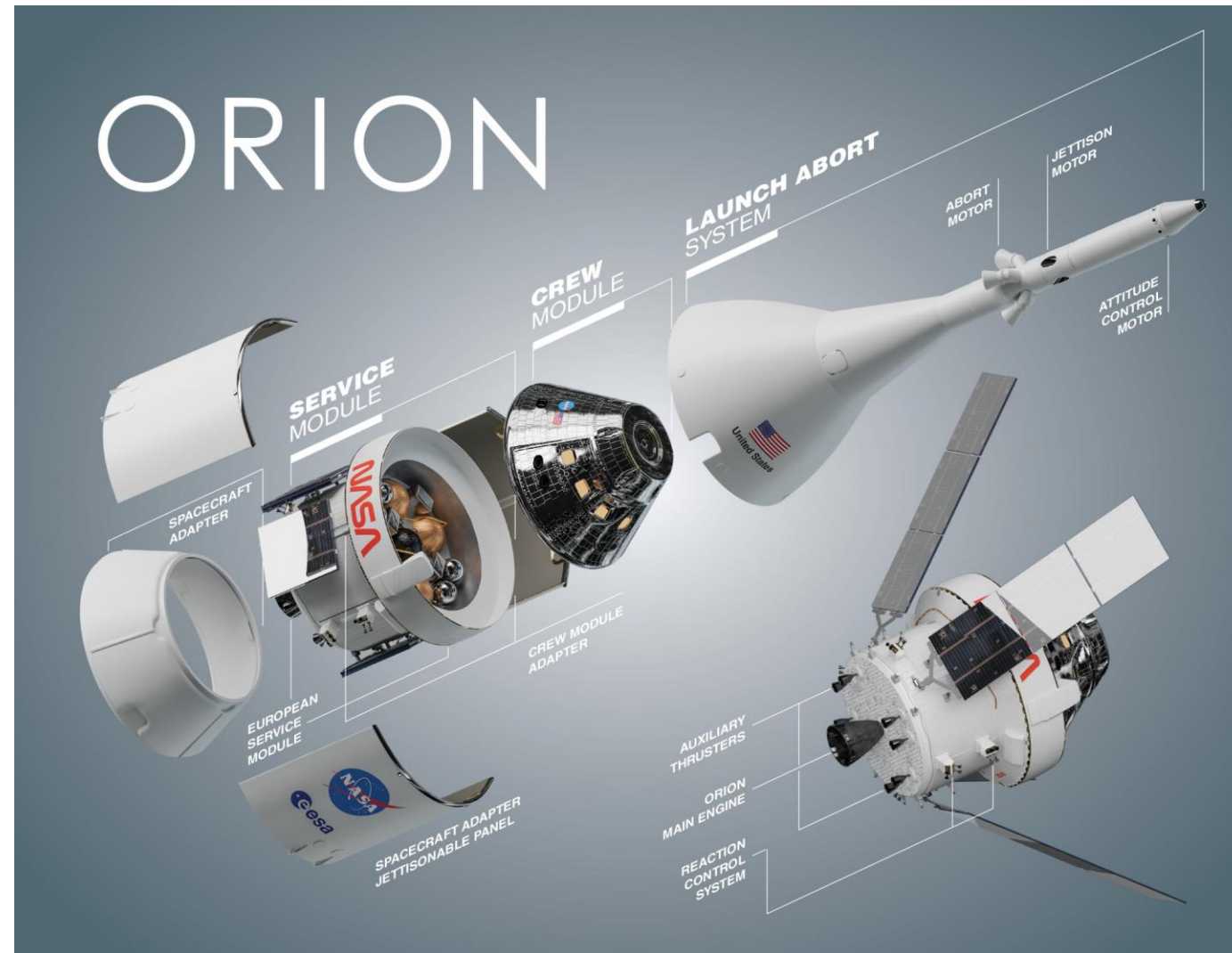


Image Credit: NASA



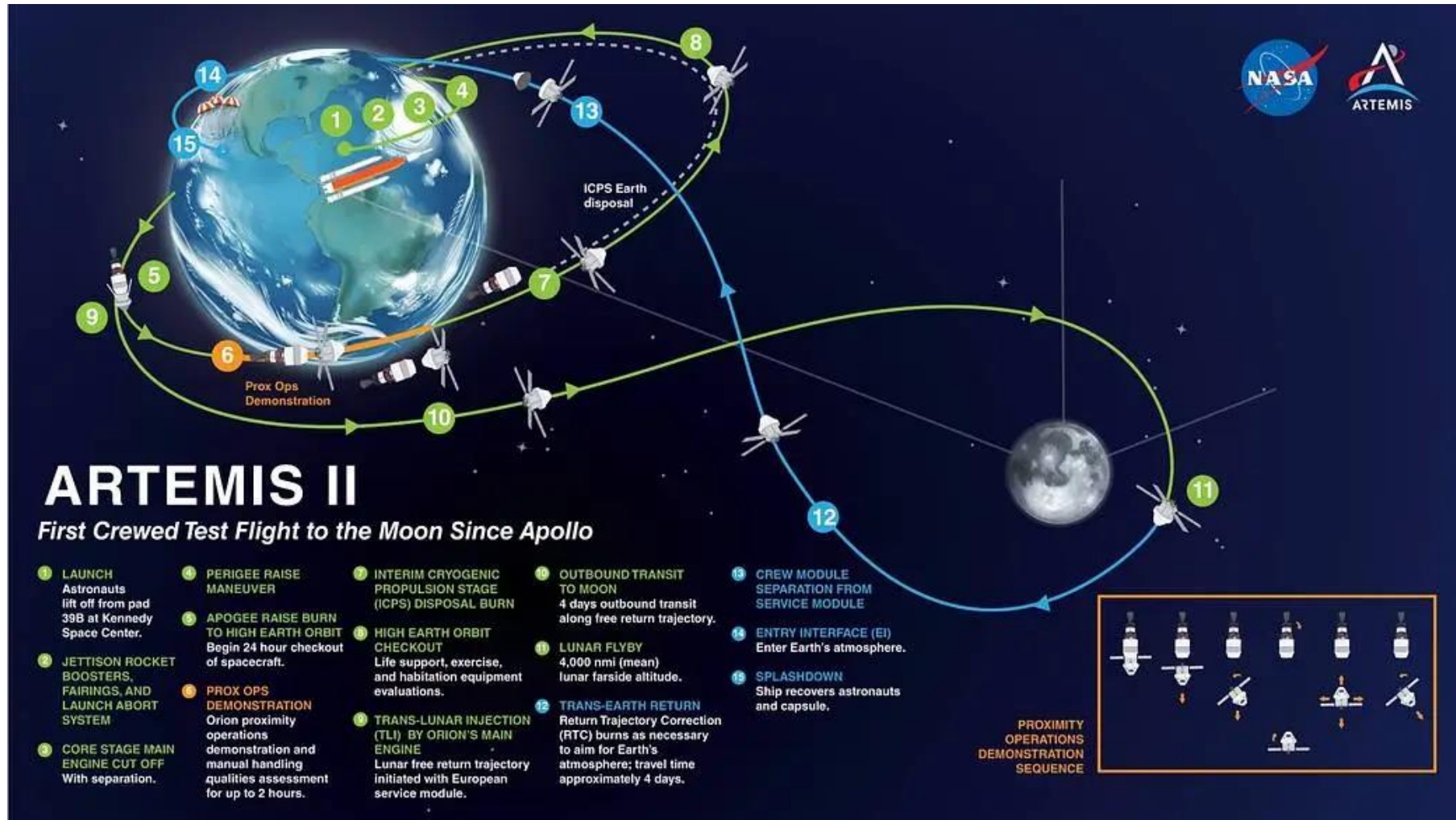


Image Credit: NASA





Background

Software In The Loop (SIL)

- What is it?
 - SIL testing is a pure simulation testing environment where hardware components of the spacecraft system are model-based, enabling faster testing turnaround times
- Purpose:
 - Provides a less complex method of testing the functionality of flight software and its updates
 - Initial validation of flight software performance
 - Early detection of flaws in the flight software
- Challenges:
 - The simulation of the system is lower in fidelity compared to HITL testing due to the model-based hardware components of the system
- Orion SIL Environment:
 - **Ramtares**

Hardware In The Loop (HITL)

- What is it?
 - HITL testing integrates hardware elements of the spacecraft system with the simulation environment to aid in the testing and validation of the spacecraft system
- Purpose:
 - Provides a measure of performance of the flight software when integrated with system hardware
 - Assists in the identification of flaws in the flight software
- Challenges:
 - Ground testing of spacecraft systems can lead to non-flight-like effects that can mask the true performance of the system and software
- Orion HITL Facilities:
 - **Houston Orion Test Hardware (HOTH)**
 - Integrated Test Laboratory (ITL)



Table of Contents

- Background
- Problem Statement
- Analysis Approach
- Results
- Conclusion

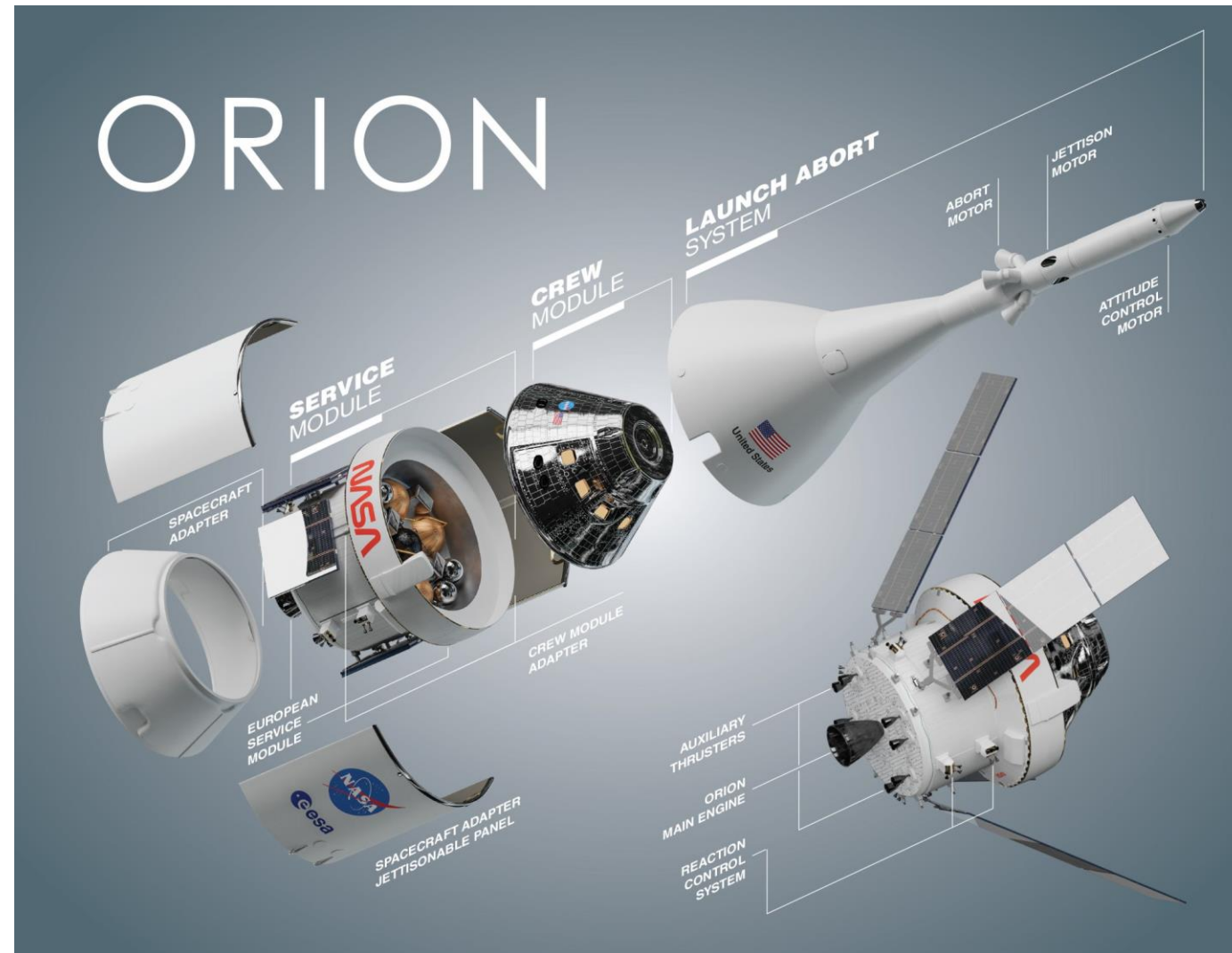
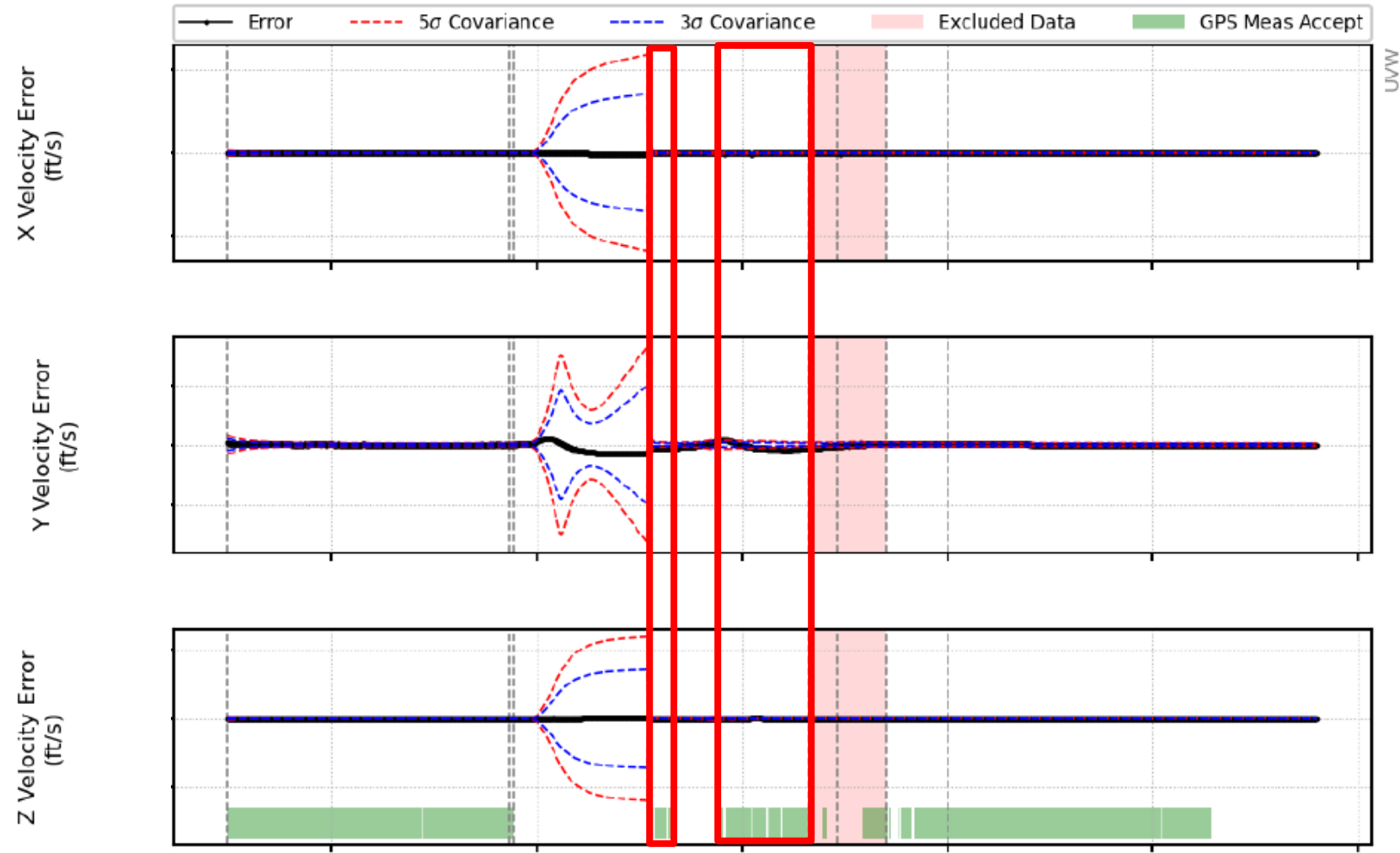


Image Credit: NASA



Problem Statement

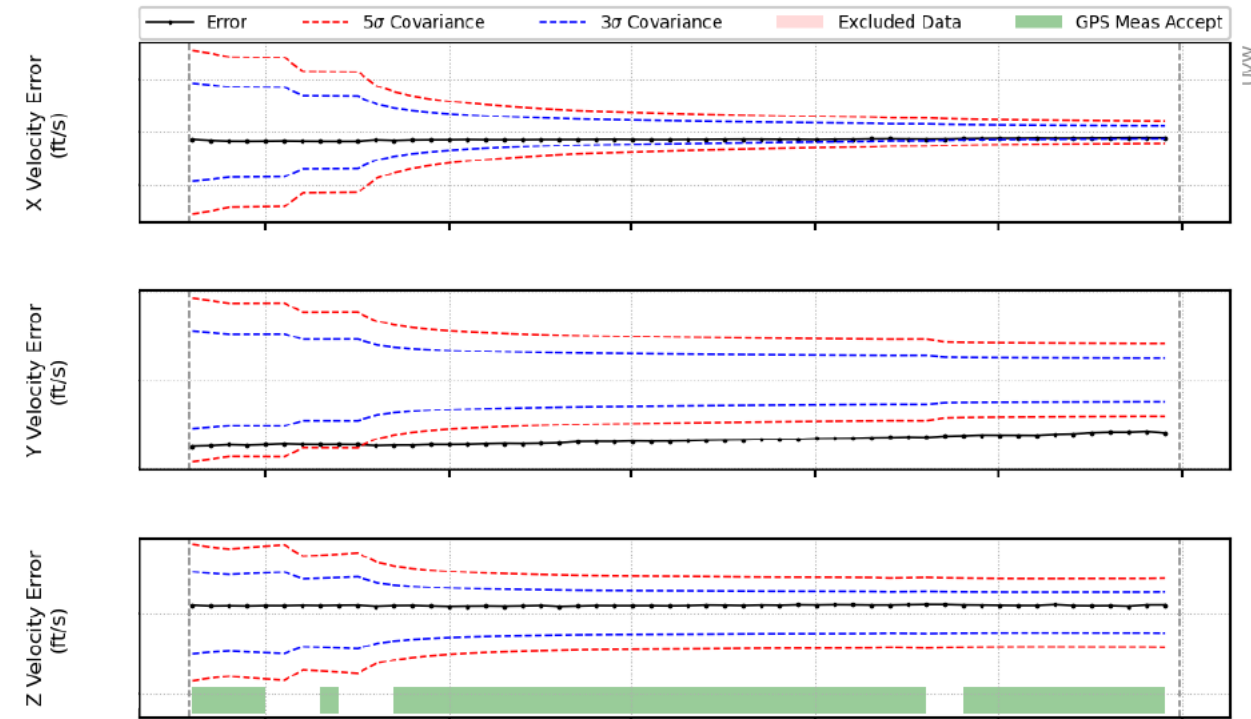
- Nominal entry trajectory for Orion involves a skip entry
- Velocity error in excess as to what was expected for entry was found during GPS reacquire after both GPS blackout
- Suspected differing measurement latencies from the sensors in the HOTH due to a non-flight-like effect from the OIMU stimulators





Problem Statement

Region of Interest 1



Region of Interest 2

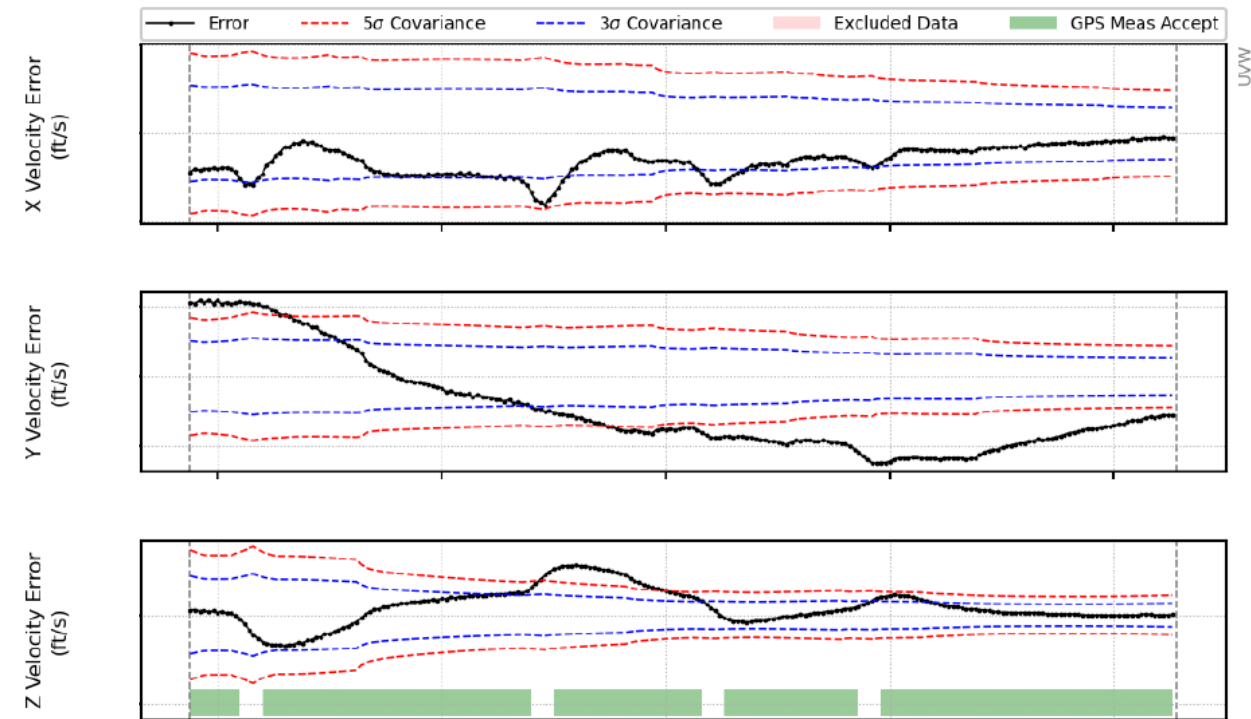


Table of Contents

- Background
- Problem Statement
- **Analysis Approach**
- Results
- Conclusion

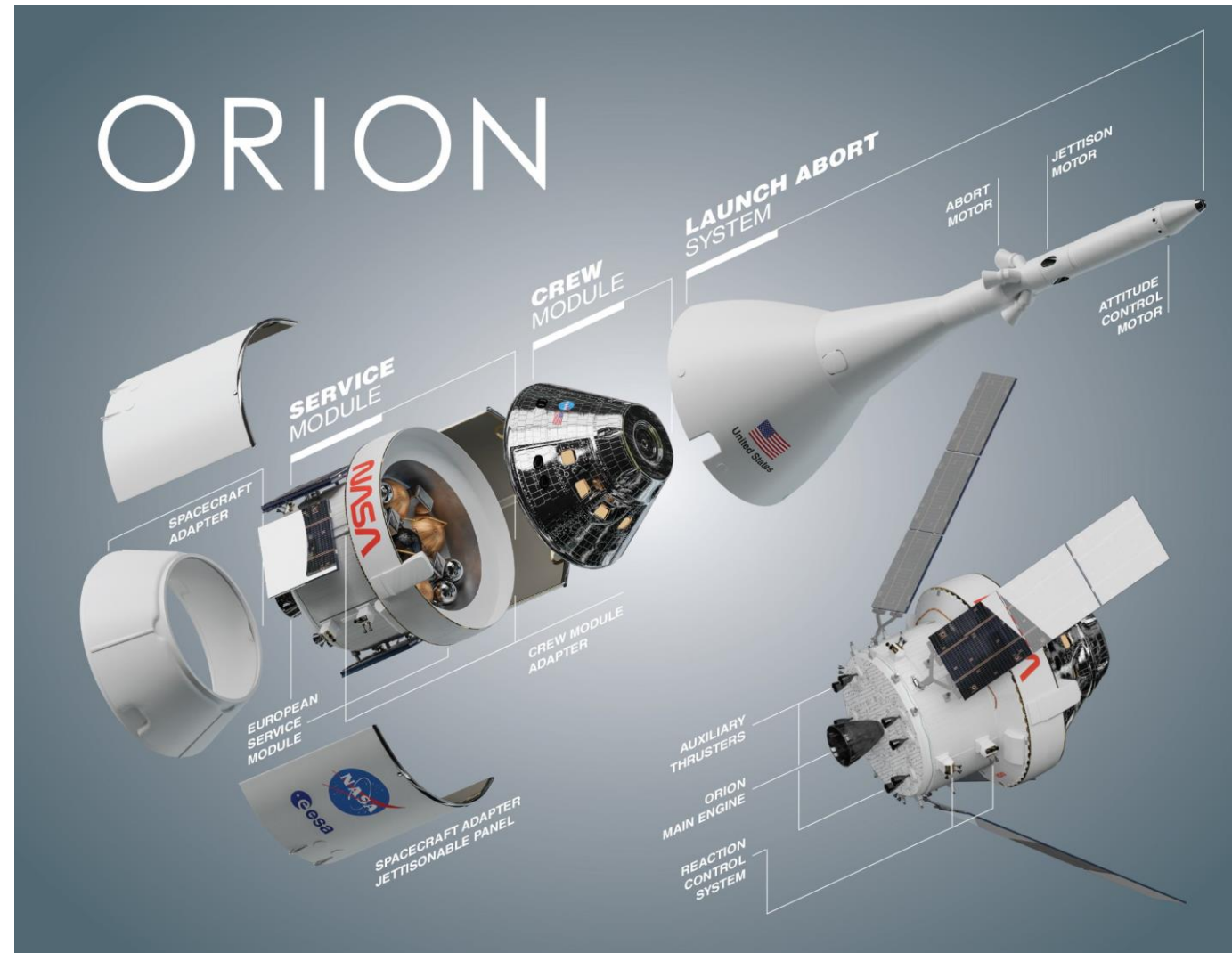


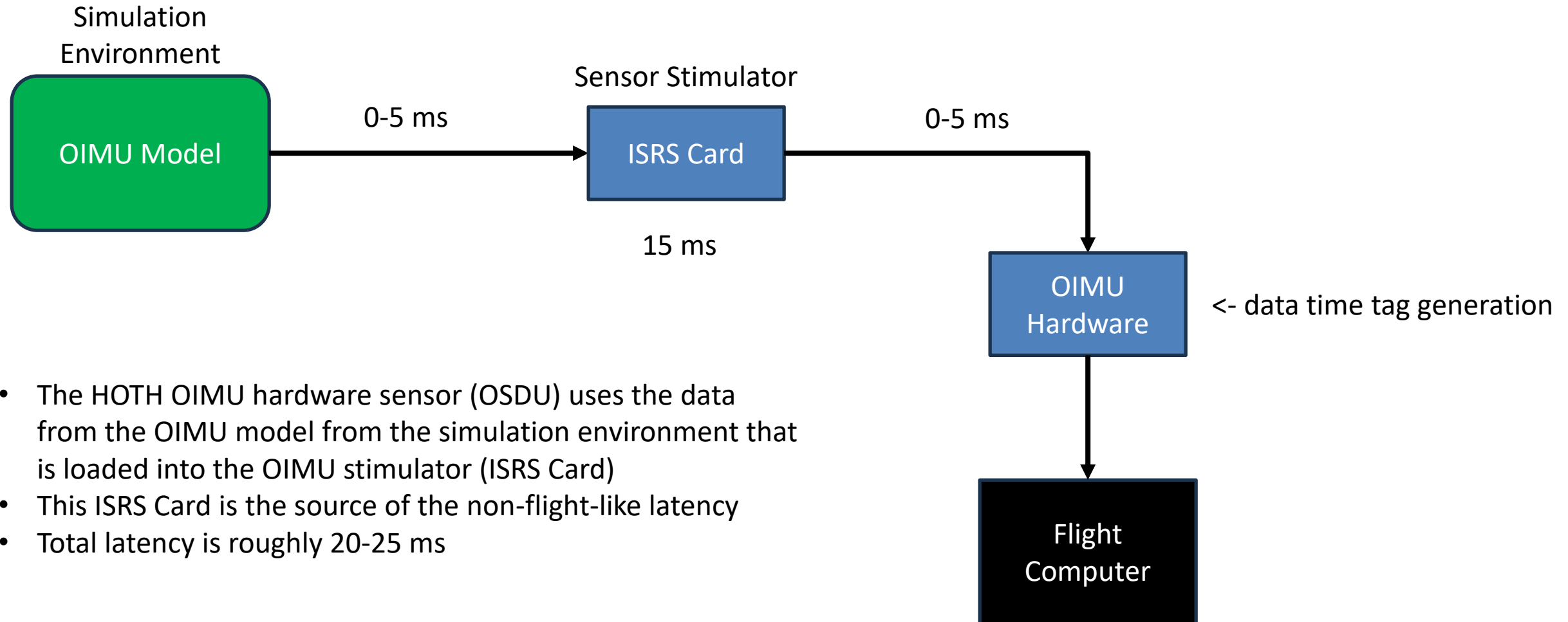
Image Credit: NASA





Analysis Approach

HOTH



- The HOTH OIMU hardware sensor (OSDU) uses the data from the OIMU model from the simulation environment that is loaded into the OIMU stimulator (ISRS Card)
- This ISRS Card is the source of the non-flight-like latency
- Total latency is roughly 20-25 ms





Analysis Approach

Ramtares

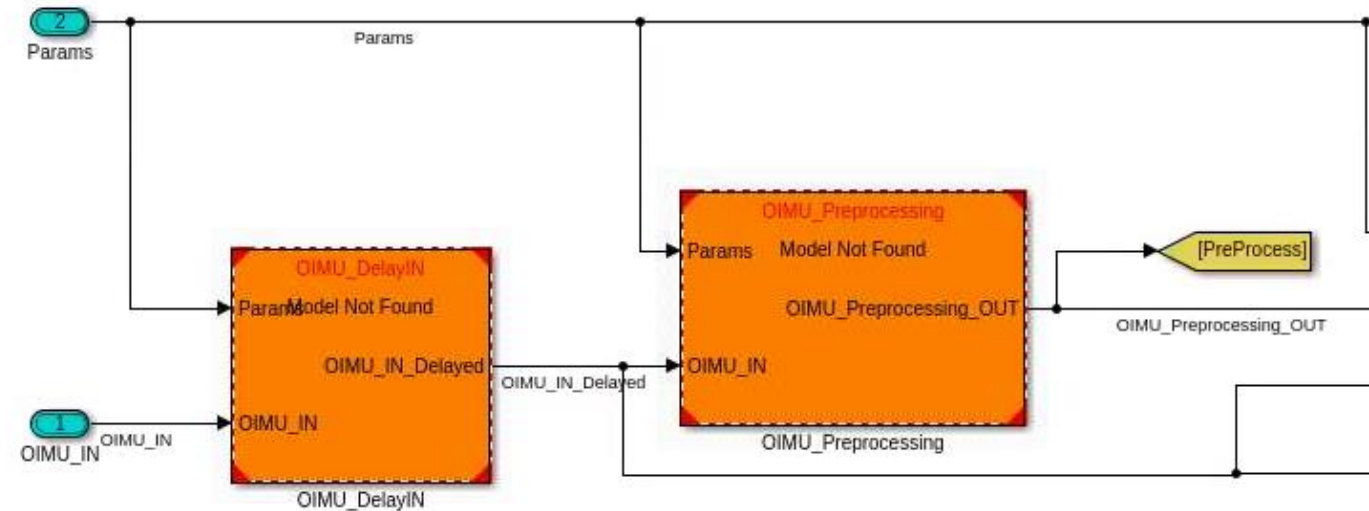
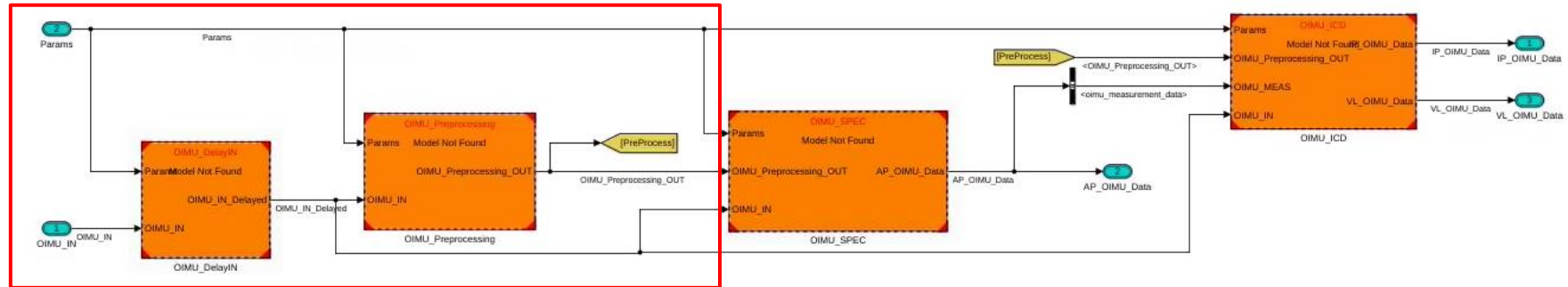


Table of Contents

- Background
- Problem Statement
- Analysis Approach
- **Results**
- Conclusion

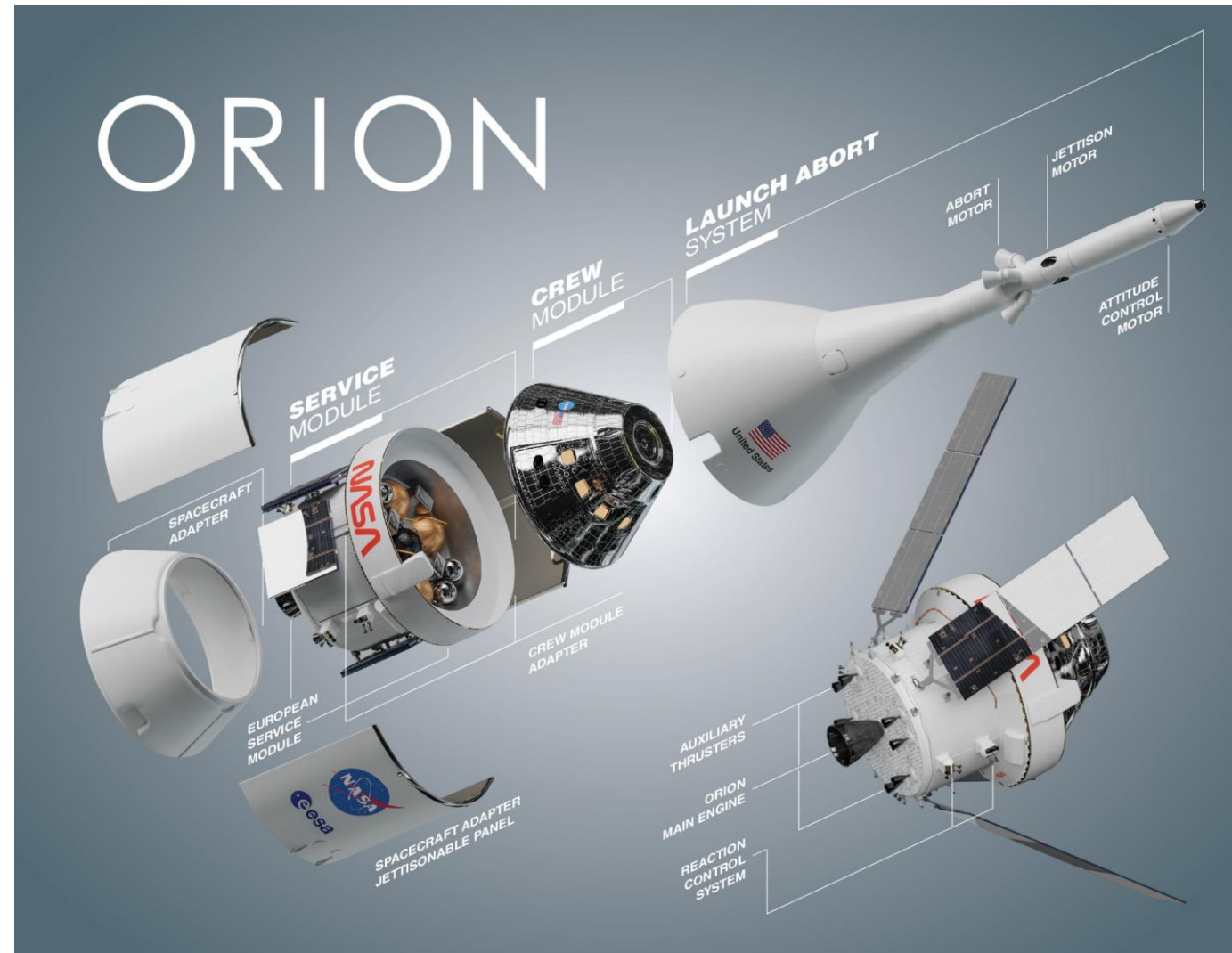


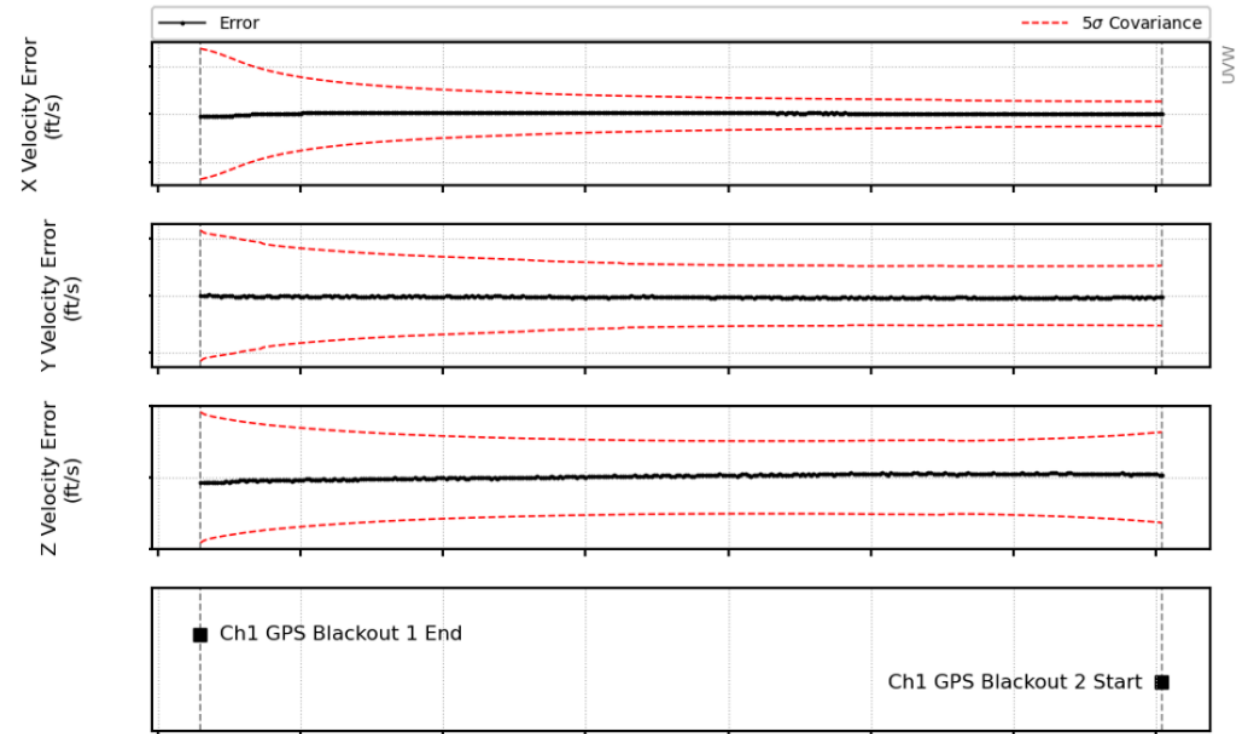
Image Credit: NASA



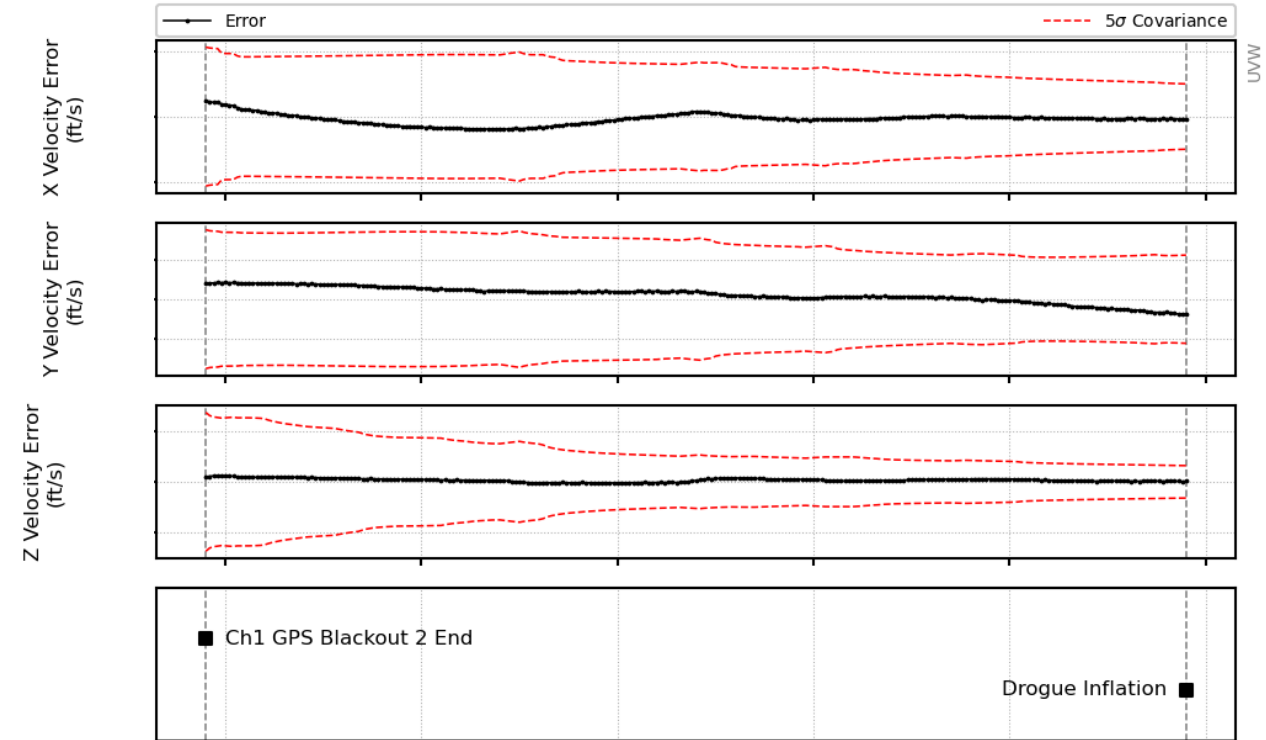


Results (0 ms of Latency)

Region of Interest 1



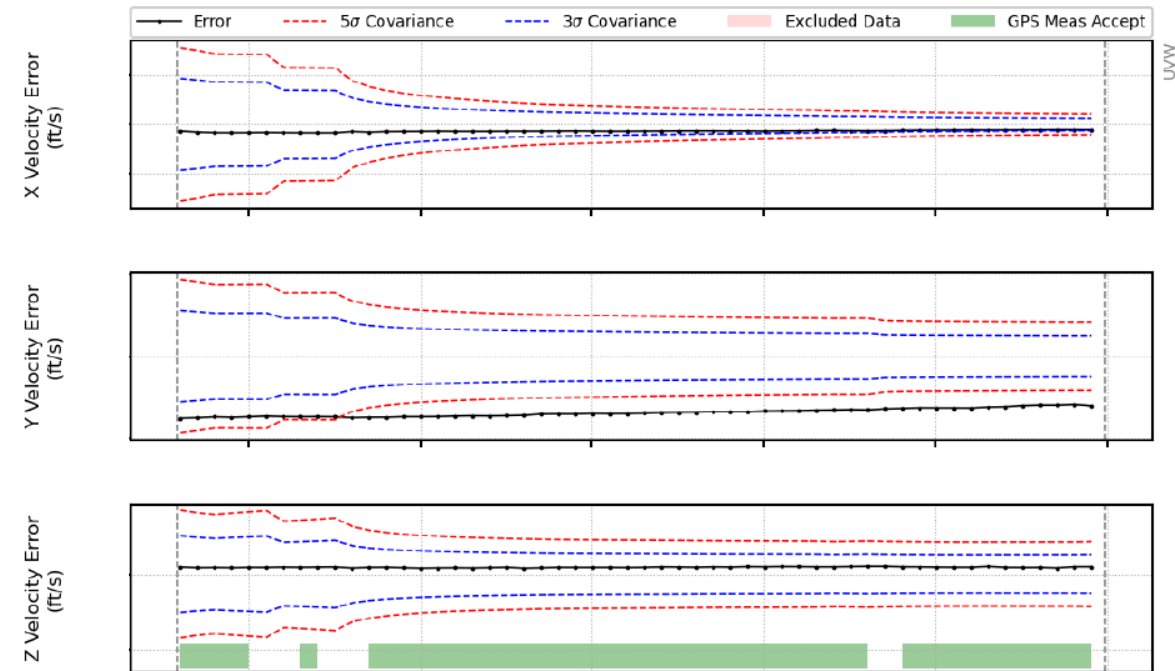
Region of Interest 2





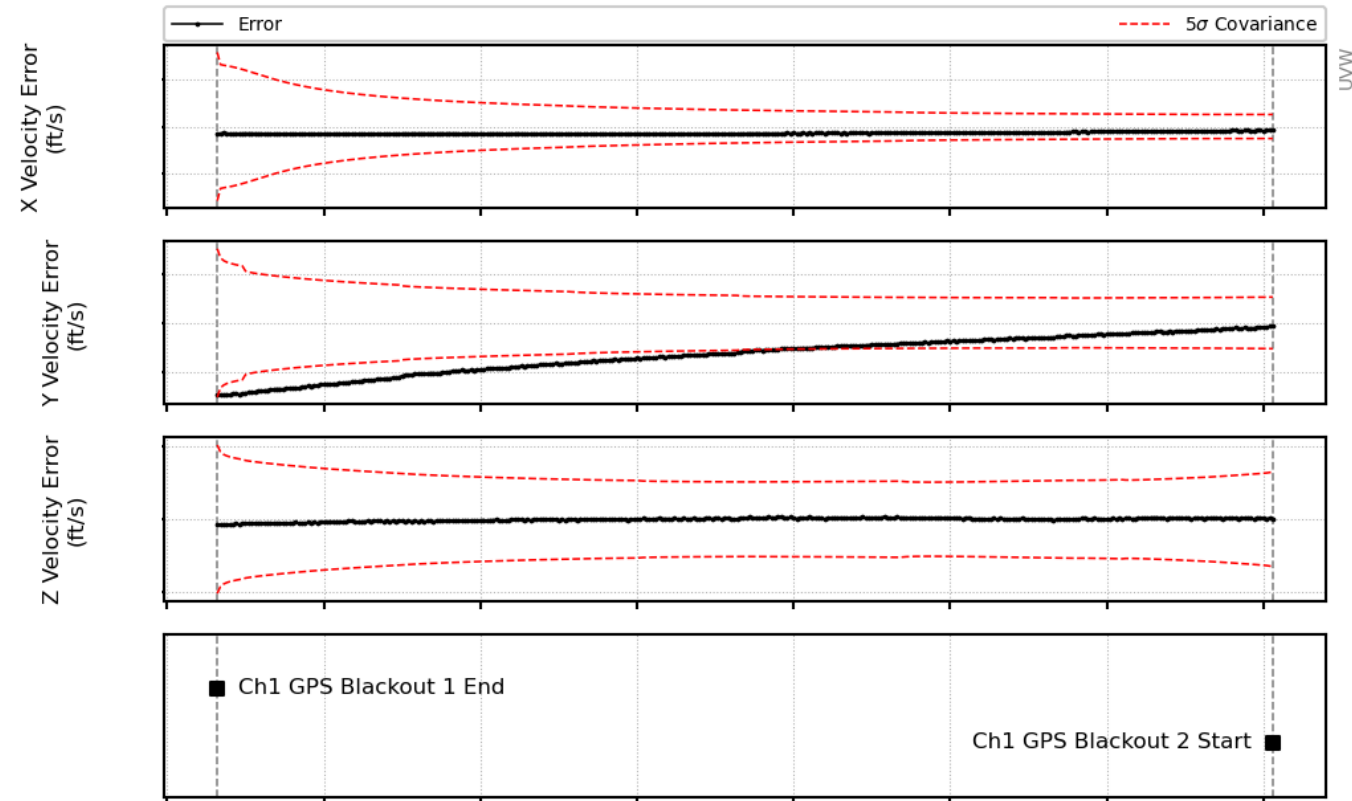
Results (25 ms of Latency)

HOTH Results



- It is expected that Ramtares results will not exactly match the HOTH results

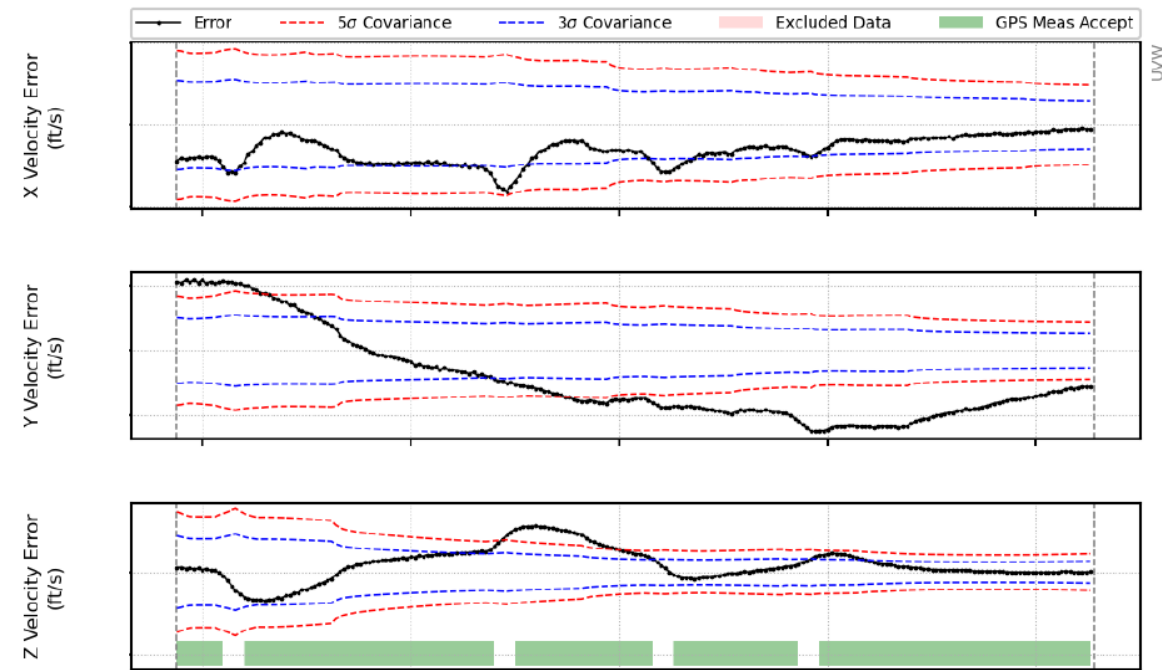
Ramtares Results





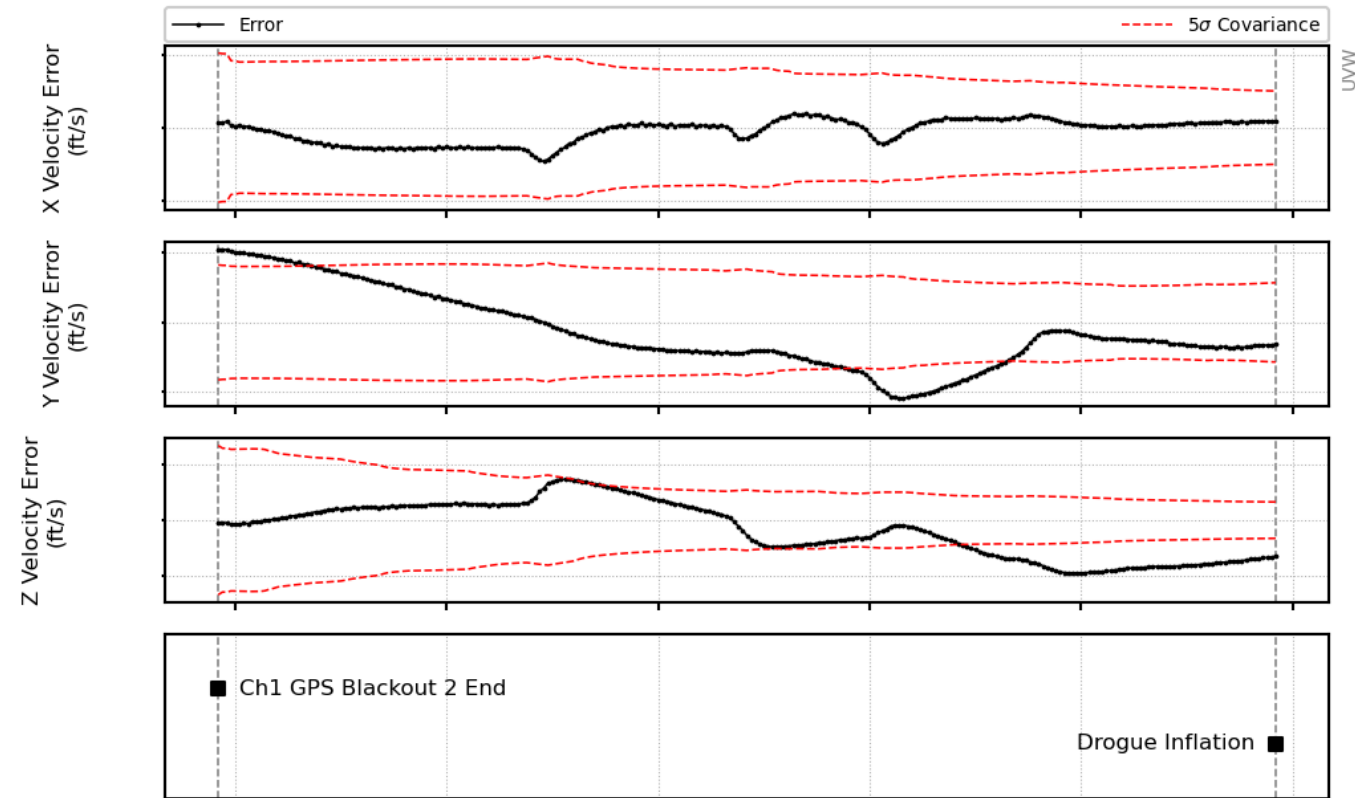
Results (25 ms of Latency)

HOTH Results

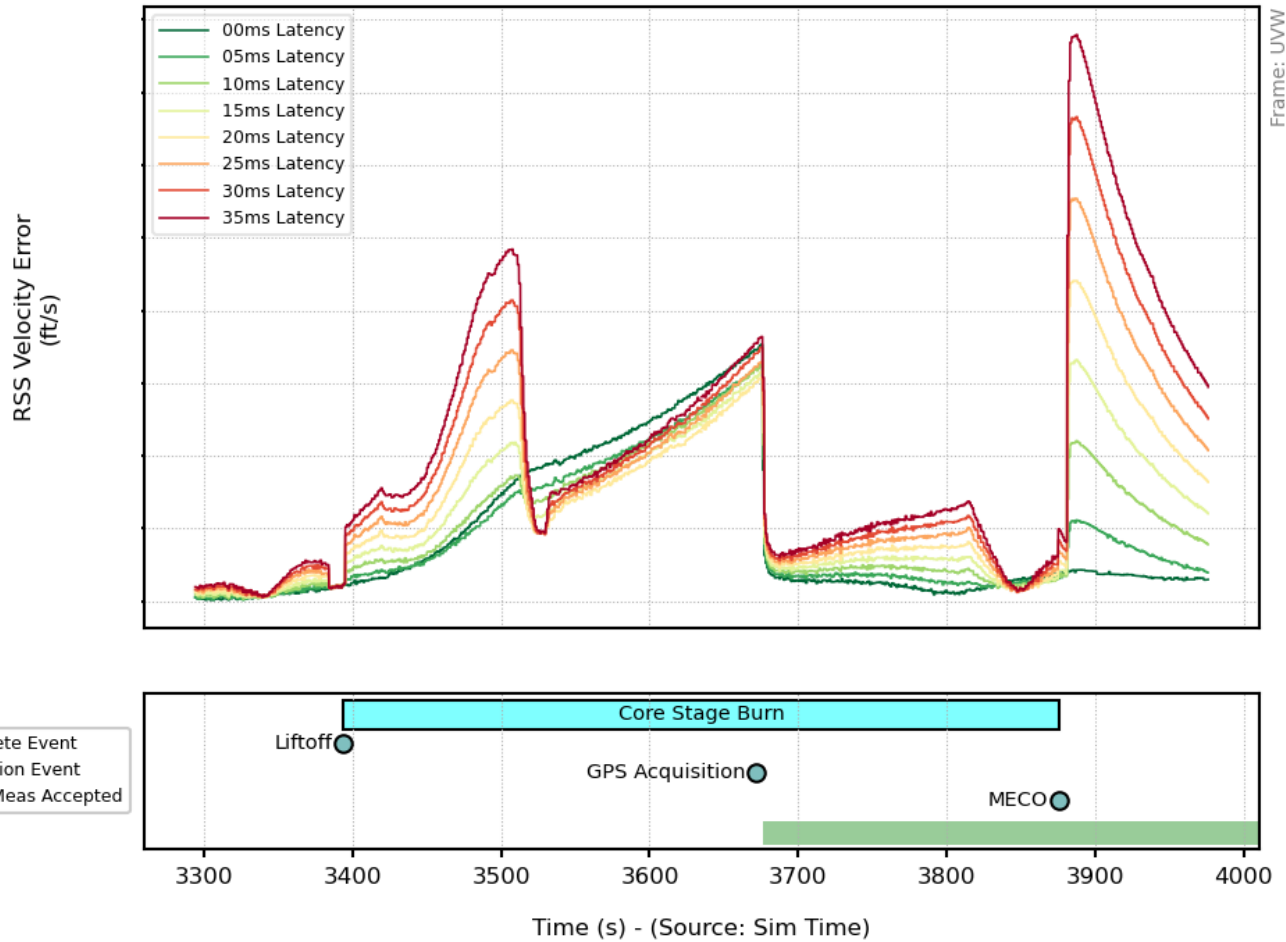


- It is expected that Ramtares results will not exactly match the HOTH results

Ramtares Results



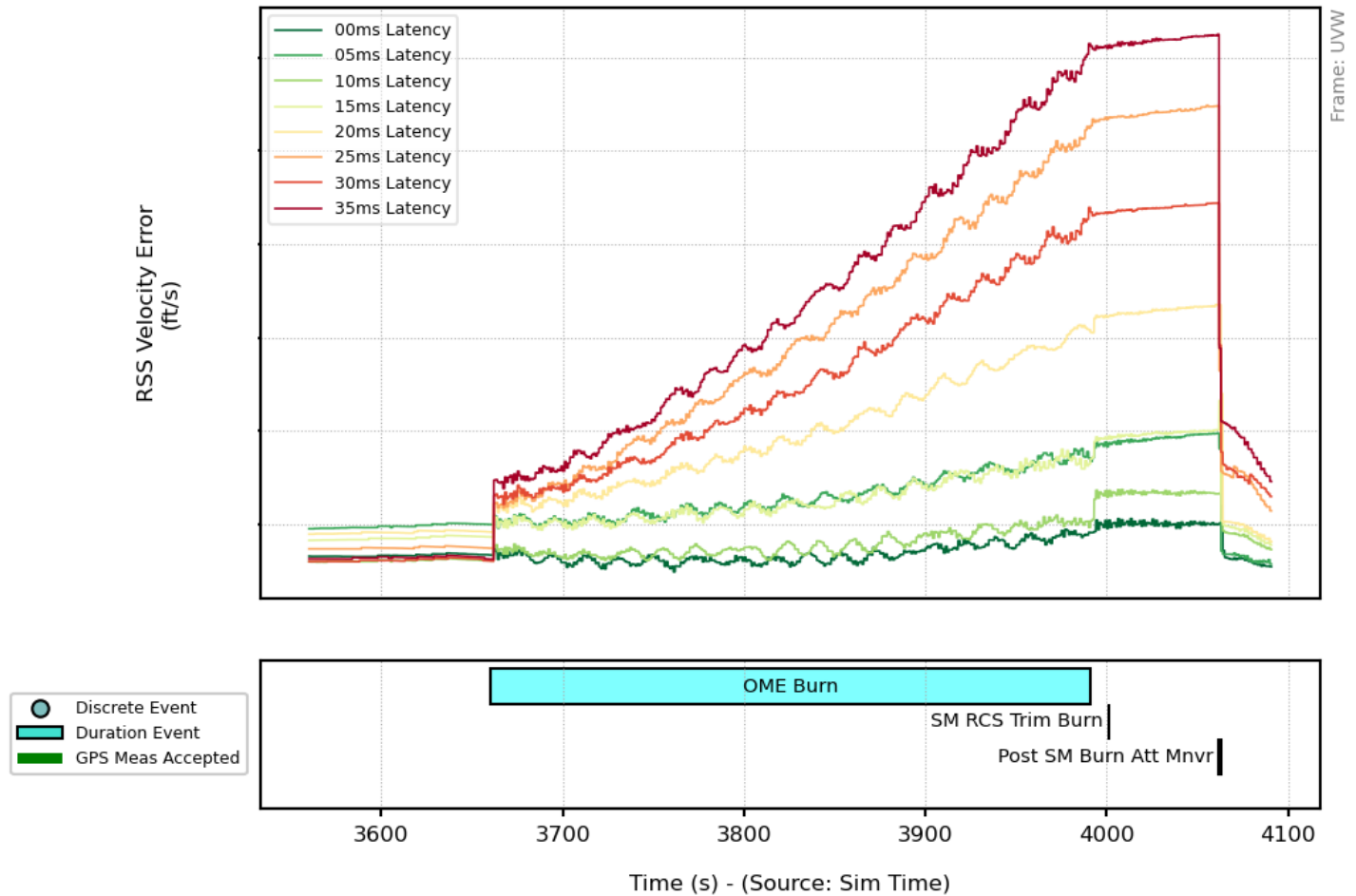
Results (Ascent)



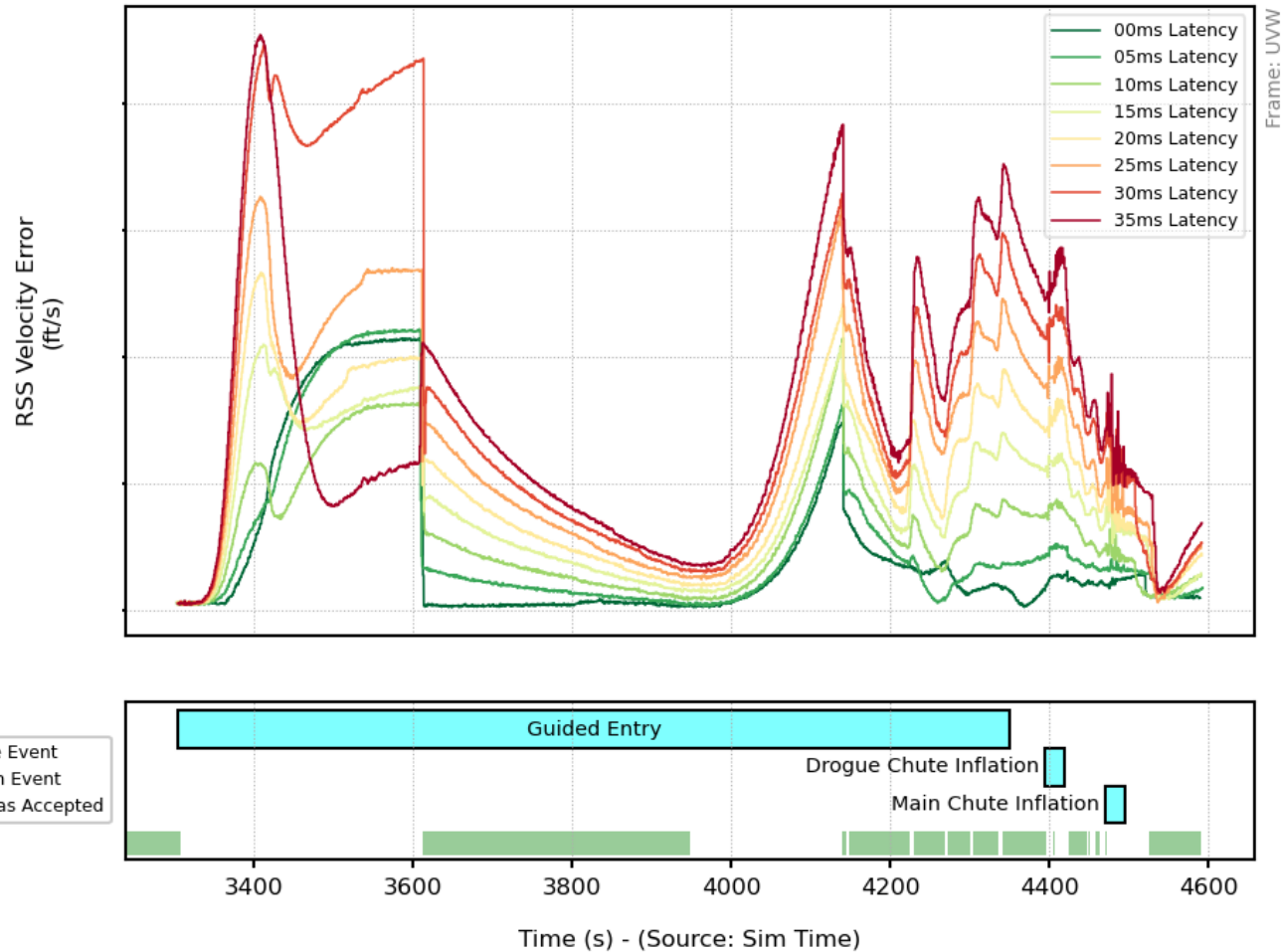
- Ascent phase spans from pre-launch to the beginning of the orbit phase
- After GPS acquisition, the runs with higher latency produce larger velocity errors with an exception at just before Main Engine Cut Off (MECO)

Results (Orbit)

- Orbit scenario simulates a burn on-orbit using Orion Main Engine (OME) for Trans-Lunar Injection (TLI)
- With lower dynamics and a lack of GPS measurements, the effect of OIMU stimulator latency is reduced compared to the ascent and entry cases



Results (Entry)



- The Entry scenario starts at the guided entry event
- After both GPS blackouts during guided entry we can see that velocity error increases with more OIMU stimulator latency

Table of Contents

- Background
- Problem Statement
- Analysis Approach
- Results
- Conclusion

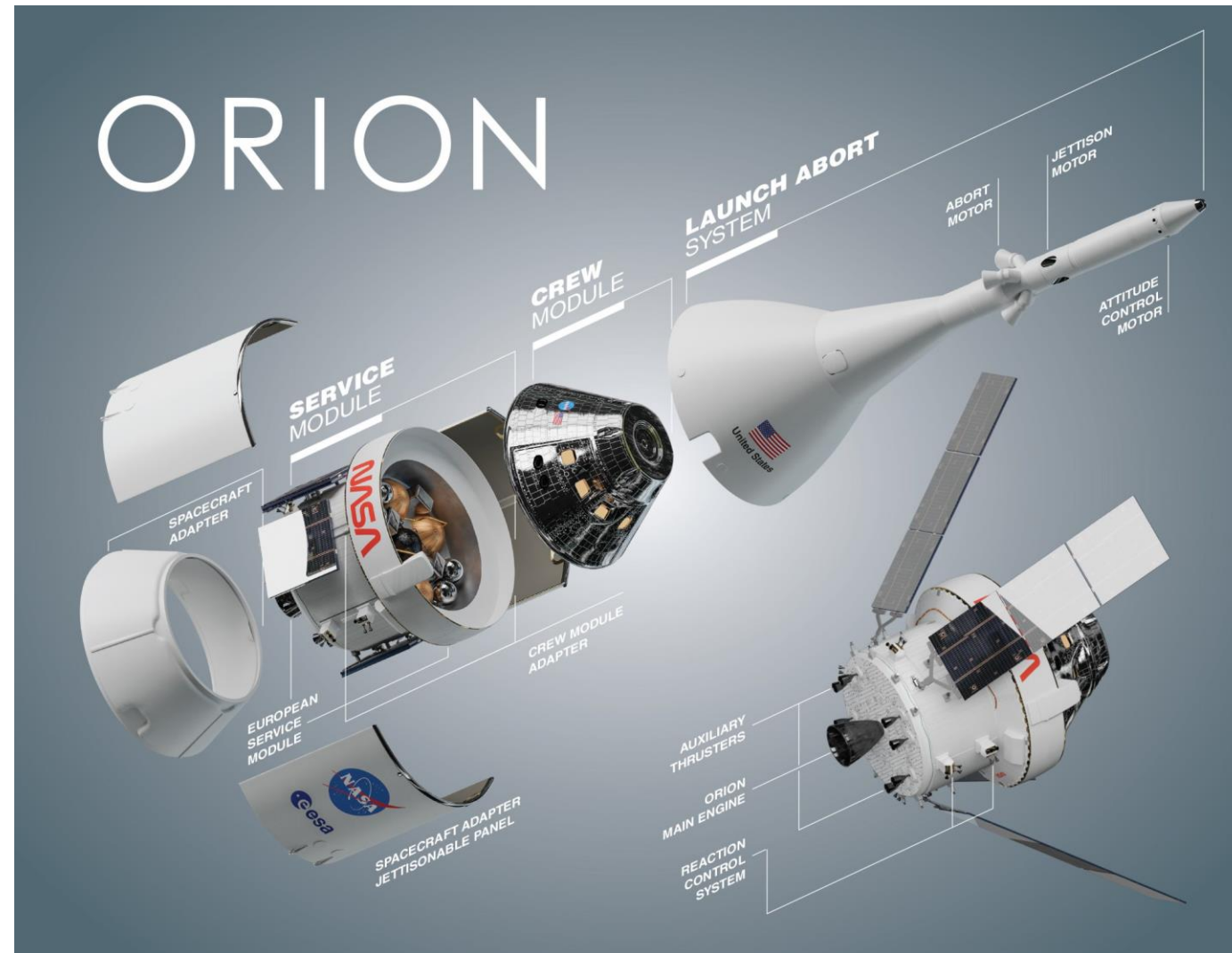


Image Credit: NASA





Conclusion

- While analyzing the results of a nominal entry test in the HOTH, it was found that excess velocity error was occurring after GPS reacquisition following both GPS blackout periods
- It was discovered that a non-flight-like effect, OIMU stimulator latency, paired with the negligible GPS measurement latency was a major contributor to the excess velocity error
 - This was shown using a pure simulation environment with the emulation of the OIMU stimulator latency in the OIMU model
- A set of simulation runs for ascent, orbit, and entry was complete to demonstrate the effect of OIMU stimulator latency on position and velocity
 - The results showed that with periods of high dynamics (ascent and guided entry) and GPS measurements, the effect of OIMU stimulator latency was pronounced in the velocity error
 - During moment of low dynamics and a lack of GPS measurements, these effects were less pronounced
- Future work
 - Performing a similar analysis on Artemis III scenarios
 - Developing a postprocessing compensation for OIMU lab latency





Acknowledgement

This work was authored by employees of Draper under Contract No. 80JSC021DA005 with the National Aeronautics and Space Administration. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, or allow others to do so, for United States Government purposes. All other rights are reserved by the copyright owner.





Orion Hardware in the Loop OIMU Stimulation Latency Effect on Navigation State Estimation

Christopher A. Ertl
Robert C. Earl

COPYRIGHT © 2024, The Charles Stark Draper Laboratory, Inc. All rights reserved. Published by the American Astronautical Society with permission.

Contractor Name: The Charles Stark Draper Laboratory, Inc.
Contractor Address: 555 Technology Square, Cambridge, MA 02139

Developed under Contract No. 80JSC021DA005 with the National Aeronautics and Space Administration

The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, or allow others to do so, for United States Government purposes. All other rights are reserved by the copyright owner.