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The Space Superhighway: Enabling Active Debris Remediation Through an In-Space Logistics Infrastructure

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Space Superhighway Overview

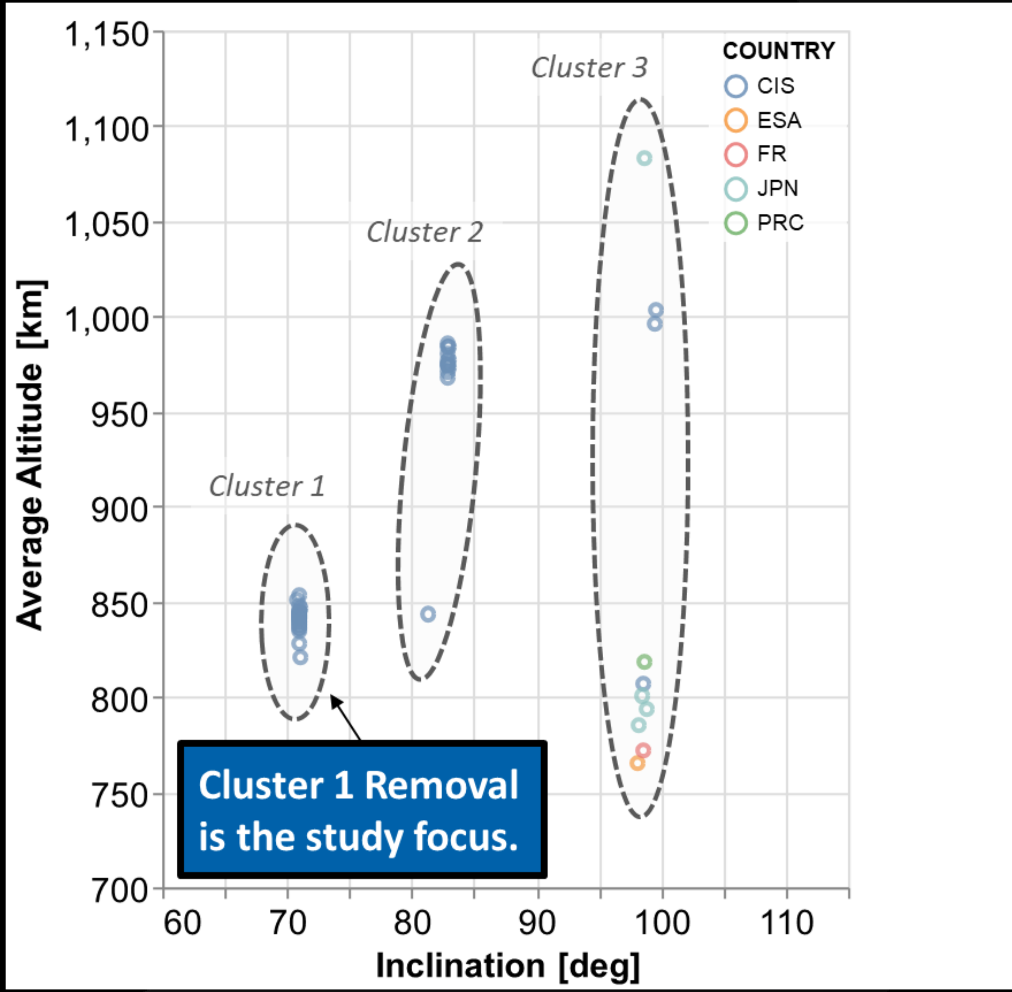
- **Space Superhighway (SSH)** – Space infrastructure network consisting of:
  - Regional Hubs
  - An in-space transportation network
  - Earth-to-orbit logistics

- The infrastructure can supply in-space assets with needed logistics, such as consumables, subsystem upgrades, or replacement units

- SSH was developed in 2021 through partnership between several NASA centers (Langley, Goddard Space Flight Center, Marshall Space Flight Center, and NASA Headquarters), other government agencies (U.S. Space Force and the Air Force Research Lab), and the Aerospace Corporation [1]

Active Debris Remediation Use Case

- Due to the expected high cost of persistent in-space assets, it is unlikely that any single use case will justify deployment of the SSH infrastructure
- A single concept was identified to show the potential benefits of using a previously deployed SSH infrastructure
- This approach in application to multiple use cases may provide justification for space infrastructure deployment
- This work focuses on using the SSH and refueling to remove 26 pieces of debris in LEO considered to be highly concerning [2]



Definitions

- **Regional Hub (RH)** – Element which has common interfaces for hosting a variety of commodities
- **Transit Element (TE)** – Element which transports mass between regional hubs or from a regional hub to a customer
- **Active Debris Remediation (ADR) –** activity to reduce the risk poised by orbital debris, such as removal or relocation to a graveyard orbit
- **Active Debris Remediation Vehicle (ADRV)** – Element which relocates debris to disposal orbit. The vehicle loiters at the centroid of the debris field to await refueling

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ADR Baseline Concept

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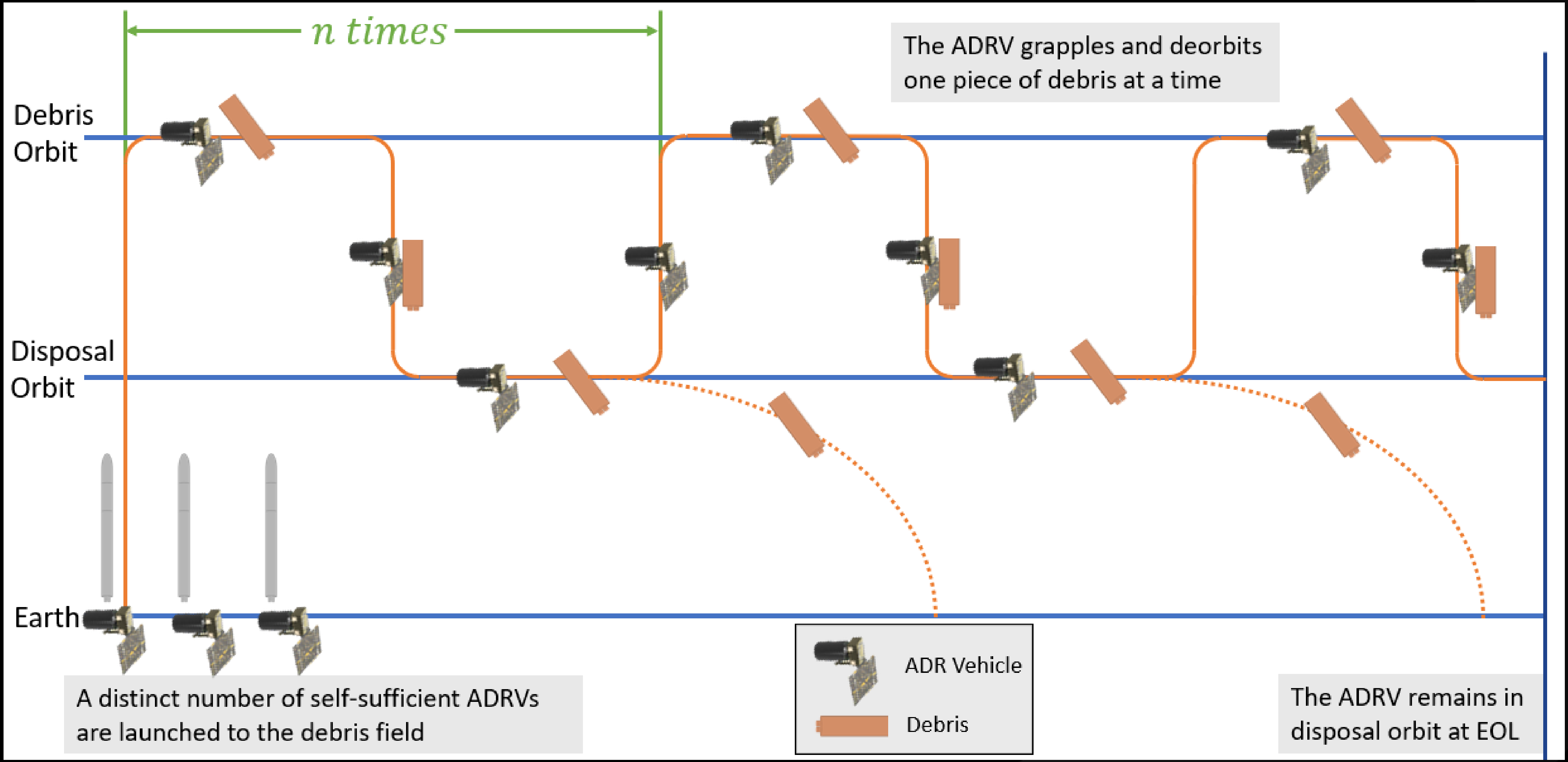
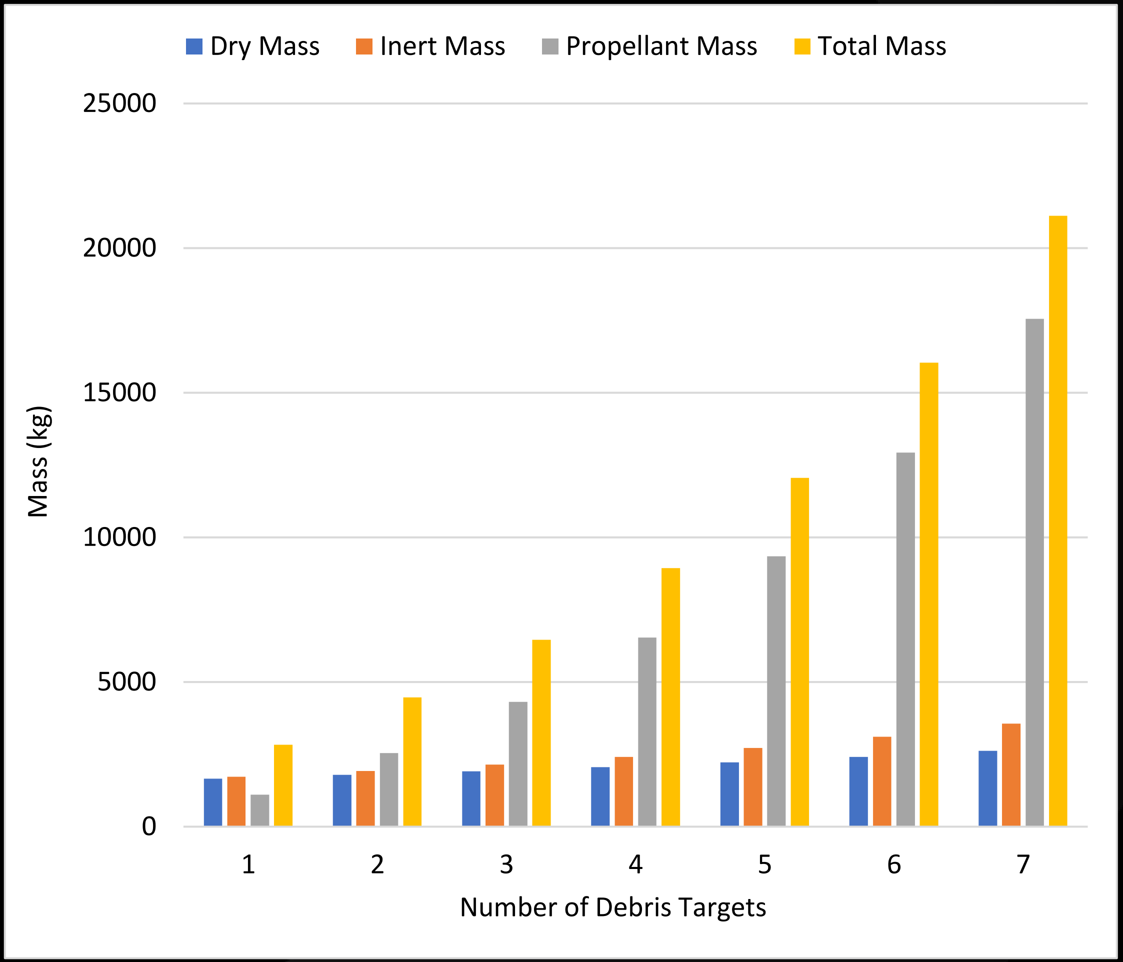
ADR Baseline ConOps



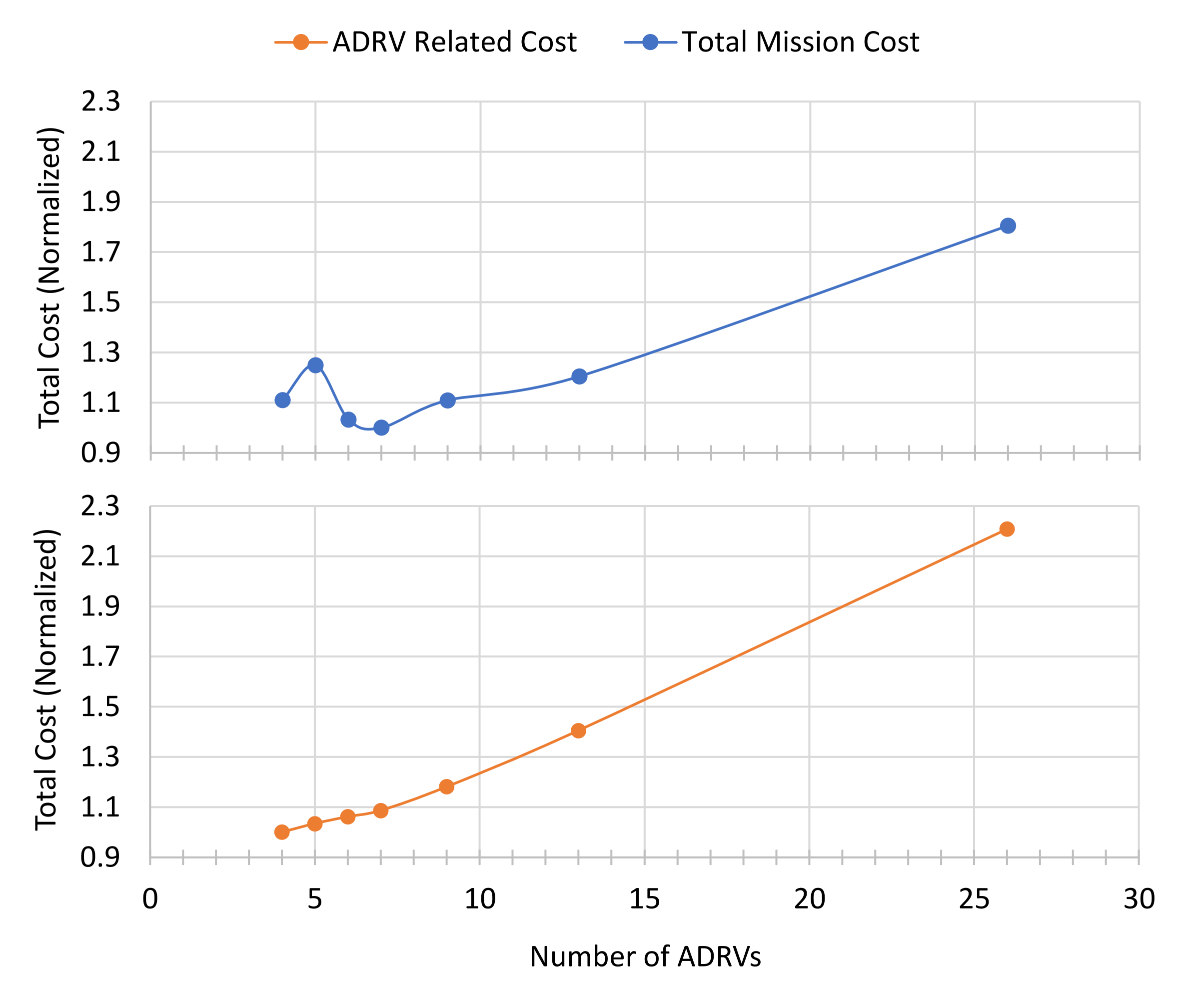
ADR Baseline ADRVs

- 13 ADRV models were designed using NASA's EXAMINE [3]
- Number of debris mitigated per ADRV ranged from one to 13
  - Beyond 7 debris targets per vehicle, vehicle cannot be manifested on launch vehicle
- Spacecraft uses NTO/MMH propellant and main propulsion system engines sized to model inputs



ADR Baseline Concept Cost

- NASA Project Cost Estimating Capability (PCEC) [4] used in conjunction with EXAMINE output to determine ADR Related Cost
- Total Mission Cost includes ADR Related Cost and cost to deliver ADRVs to debris field
- Cost minimum when 4 debris are mitigated per vehicle (7 total ADRVs)
- This total cost used as a benchmark for comparison with SSH-enabled cost



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SSH-Enabled ADR Concept

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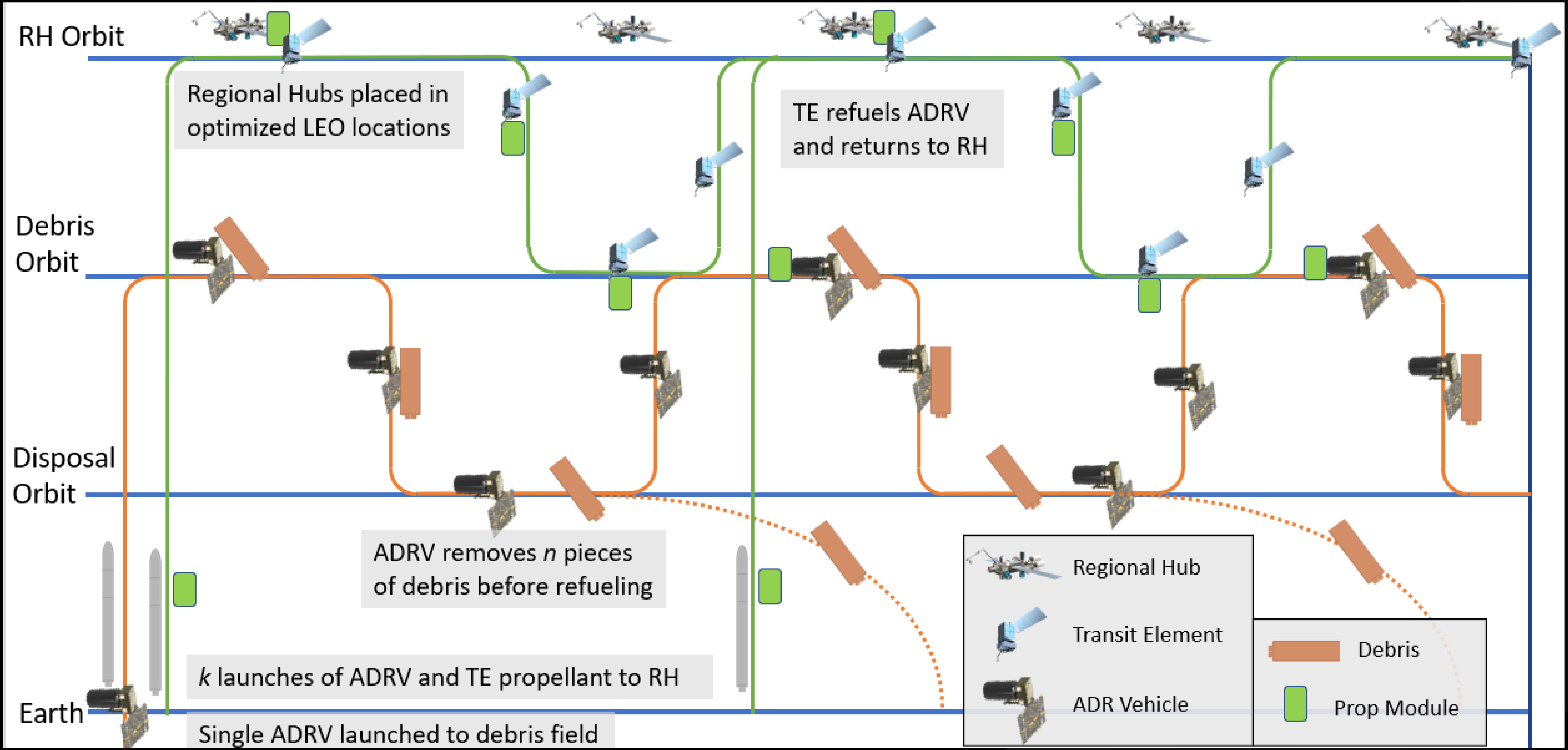
SSH-Enabled ADR Concept Overview

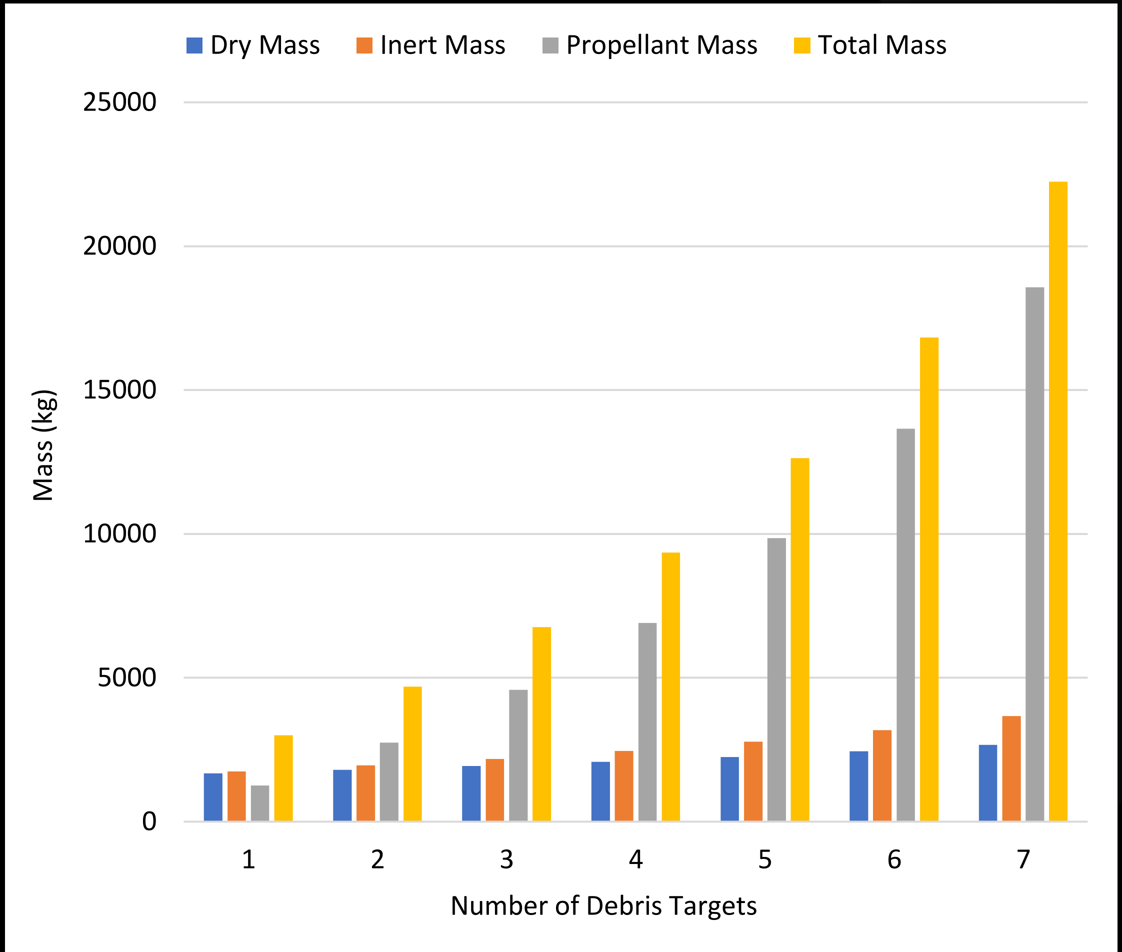
- Single ADRV launched to debris field
- TE refuels ADRV at debris field by transferring propellant modules from the regional hub
  - Only one ADRV deployed to debris field
  - Propellant module mass is defined through inert mass fraction (IMF)
- Total cost is the cost to use the SSH plus the ADRV development and deployment cost
- **This concept assumes emplaced SSH infrastructure (RH and TE)**

SSH-Enabled ADR ConOps



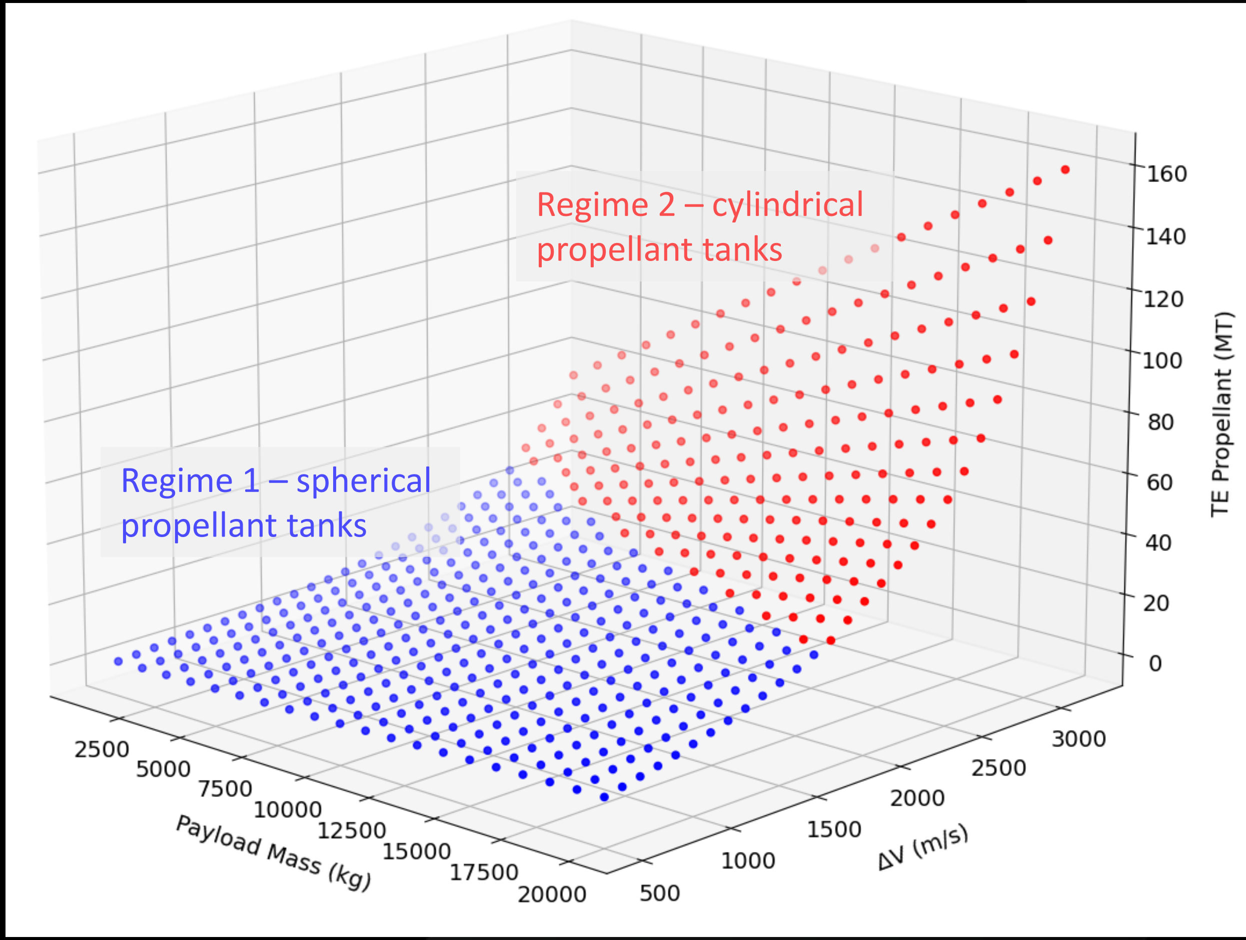
SSH ADRVs

- 13 ADRV models were designed using NASA's EXAMINE [3]
- Number of debris mitigated between refueling operations ranged from one to 13
  - Beyond 7 debris mitigated between refueling operations, vehicle cannot be manifested on launch vehicle
- SSH-ADRV returns to a stable orbit after mission due to refueling capability and potential future utility

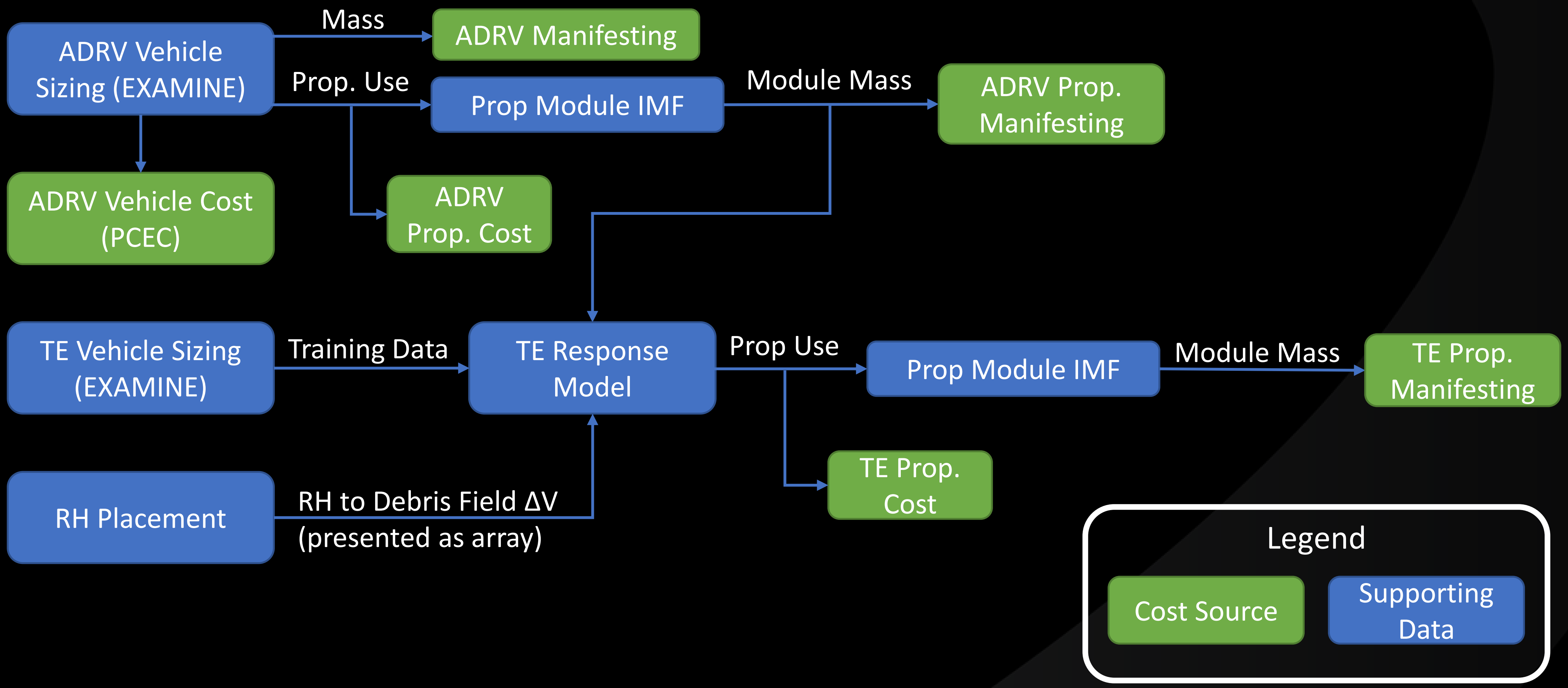


Transit Element Response Model

- EXAMINE model created for a TE which moves propellant from the RH to the ADRV
  - NTO/MMH propulsion system
  - Payload masses between 1,000 kg and 20,000 kg
  - ΔV capability between the RH and the ADRV ranging from 500 m/s to 3,200 m/s
- EXAMINE output converted into a response model
  - Ingests the desired payload mass and ΔV and outputs vehicle parameters, such as:
    - Propellant mass used during payload delivery
    - Vehicle diameter and length
    - Dry mass
    - Launch mass
- From observation, TE propellant mass is more sensitive to ΔV than to payload mass



SSH-Enabled ADR Cost Flowchart



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Results and Future Work

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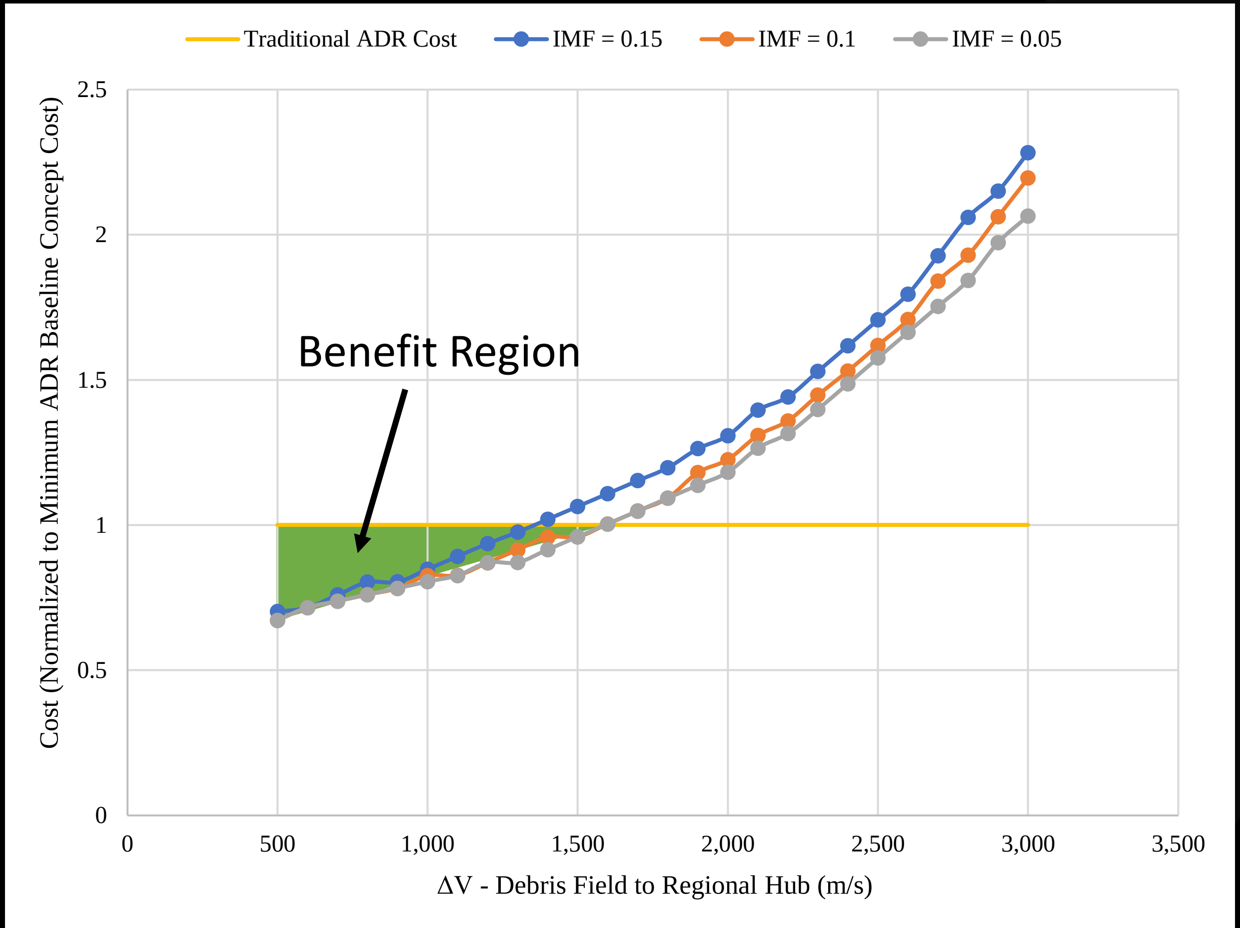
SSH-Enabled ADR Utilization Cost and Takeaways

- This comparison assumes emplaced SSH infrastructure, such as a TE and RH
- The example ADR use case is more cost effective through using the SSH when the TE travels less than **~1,600 m/s** to resupply ADRV
  - Benefit threshold varies between 1,300 and 1,600 m/s, depending on the IMF of the propellant modules
- 1,600 m/s may be realistic with proliferated RHs or RHs placed/relocated for specific missions
  - Nodal precession could be used to reduce ΔV at expense of total mission time



Concluding Remarks

- Deploying in-space infrastructure is unlikely to be cost effective for any one concept
- With a collection of concepts, there may be overall benefit through reuse of assets such as RHs and TEs
- Apply these methods to other SSH-enabled concepts:
  - Other debris fields within LEO/GEO (cluster 2 and 3)
  - Commercial refueling
  - In-space assembly

References

1. Tomek, D., et al., "The Space Superhighway: Space Infrastructure for the 21st Century," *20th IAA Symposium on Building Blocks for Future Space Exploration and Development*, IAC-2022, 20 Sept. 2022, URL: https://iafastro.directory/iac/paper/id/73702/summary/ [retrieved 27 November 2023]
2. McKnight, D., "Identifying the 50 statistically-most-concerning derelict objects in LEO," *Acta Astronautica*, Vol. 181, 2021, pp. 282-29, URL: https://doi.org/10.1016/j.actaastro.2021.01.021 [retrieved 27 November 2023]
3. Komar, D., Hoffman, J., Olds, A., and Seal, M., "Framework for the Parametric System Modeling of Space Exploration Architectures," AIAA 2008-7845. *AIAA SPACE 2008 Conference & Exposition*. September 2008.

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Questions?

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