

10th IAASS Conference El Segundo, CA May 15-17, 2019

USC Space Engineering Research Center (SERC) Design-Based Safe Operable Metrics for Earth Regime RPO

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The (Good) Problem:

"Non-traditional" Space Applications are here!

Rapid expansion in the number & types of commercial space applications is creating new opportunities for advanced space missions

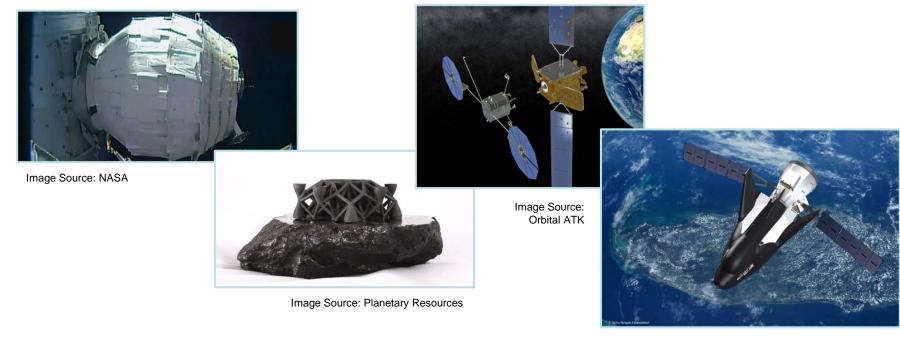


Image Source: UNOOSA / Sierra Nevada Corp

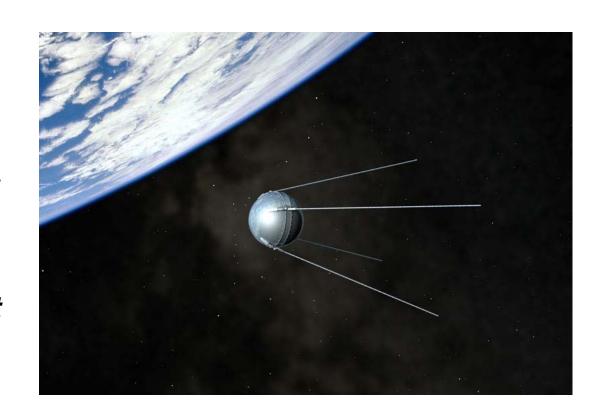
Challenge? How can governments/private sector work together to avoid more risk to the "global commons of space" for these emerging applications?



How is it done today? Through "Norms"

Much of the existing space governance framework is based on norms

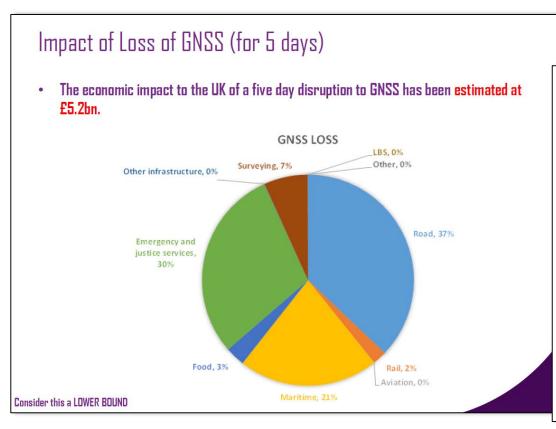
- Example: Freedom of overflight for satellite reconnaissance
 - Launch of Sputnik in 1957 helped set the norm that satellite overflight did not breach territorial sovereignty
 - By mid-1960s, freedom of overflight was a generally accepted norm
 - Was not codified into "hard law" until Outer Space Treaty of 1967



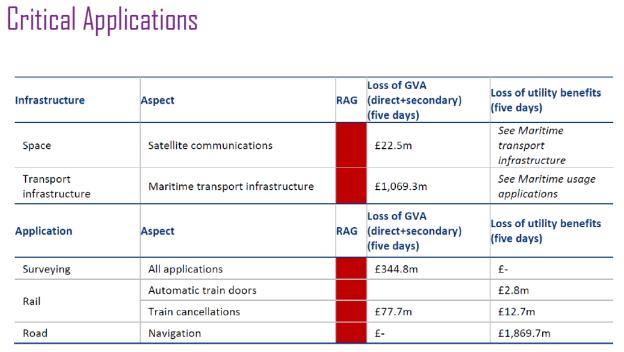


Quick example of Economic Impact analysis on loss of space assets that affect people/every day life...

Economic loss of GNSS for 5 days from any cause...



"Economic Impact of the loss of GNSS to the UK", Andy Proctor, UK Government PNT Group, Delegate to ESA Board of Navigation, Nov 2017





Proposed Solution:

Consortium for Execution of Rendezvous and Servicing Operations (CONFERS)

Goal: Develop and introduce industry-consensus standards for new emerging applications for cooperative rendezvous and proximity operations and on-orbit servicing (RPO & OOS)











USC Charter: Survey current RPO & OOS Operations & Recommend Changes/Inputs

"Rendezvous and Proximity
Operations (RPO)": Timelines,
actions, maneuvers between two
different space platforms from distance
(>100km) to within several meters

First year tech focus: Complete

"On-Orbit Servicing (OOS)":
Timelines, actions, maneuvers, interactions, manipulations, between two different space platforms within several meters to contact/dock/grapple/connect etc.

Second year tech focus: In Progress

- 1. Database survey of past RPO missions revealed no specific "standard" on rendezvous schema (distance, velocity, gates, phases, etc)
 - 1. No concurrence on use of specific nomenclature or lexicon to describe rendezvous
 - 2. No concurrence on graphical representation or depiction of "rendezvous"
- 2. First set of RPO safety metrics created to begin discussions with industry
- 3. Initial survey with first industry members candidates
- 4. RPO survey results and metrics presented in Bremen Germany at IAC



Results of 1st year: Three initial RPO Metrics created for discussion

#1: Contact Velocity

#2: Remote Influence

#3: Control Accuracy

Metric value
$$x = \frac{v_{projected}}{v_{max}}$$

Metric value
$$x = \frac{\omega_{projected}}{\omega_{max}}$$

Metric value
$$x = \frac{MCO}{ECD}$$

- Inputs: Physical values of Servicer and Client Spacecraft, desired performance
- Outputs: Unitless ratios; <1 : safe, >1 : risky

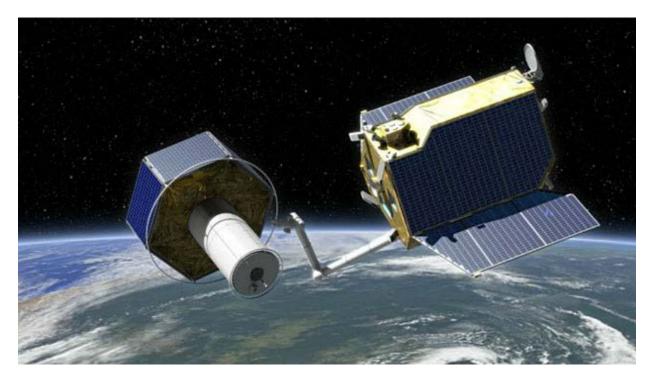
Metrics applied to past (and current) missions appear to follow ratio of "low riskiness"...

Mission Details				Metrics			
Name	Primary Organization	Target	Date	Contact Velocity	Remote Influence	Control Accuracy	
STS-41C	NASA	Solar Max	4/9/84	0.1523	0.154	0.245	
Dragon	SpaceX	ISS	5/22/12	0.0295	0.00585	0.0198	
Apollo 11 (LEM)	NASA	CSM	7/21/69	0.8119	0	6.45	
MEV-1	Northrop Grumman	Intelsat-901	2020	0.3221			
RESTORE-L	SSL	Landsat-7	2022	0.2909			
O.CUBED	Airbus	TBD (GEO)	2023	0.393			



Second Year Initiative

- Develop background on OOS "Safety" and "Interfaces"
- Develop OOS Topology of Functions/Attributes from the initial Mission architecture
- Assess existing Standards (domain agnostic) against Topology
- Initially Populate Quantitative values for topology attributes
- Develop process to Identify most relevant Functions: Attributes suitable for Standards
- Initial look at transit orbit optimization for RPO missions from projected spatial density plots

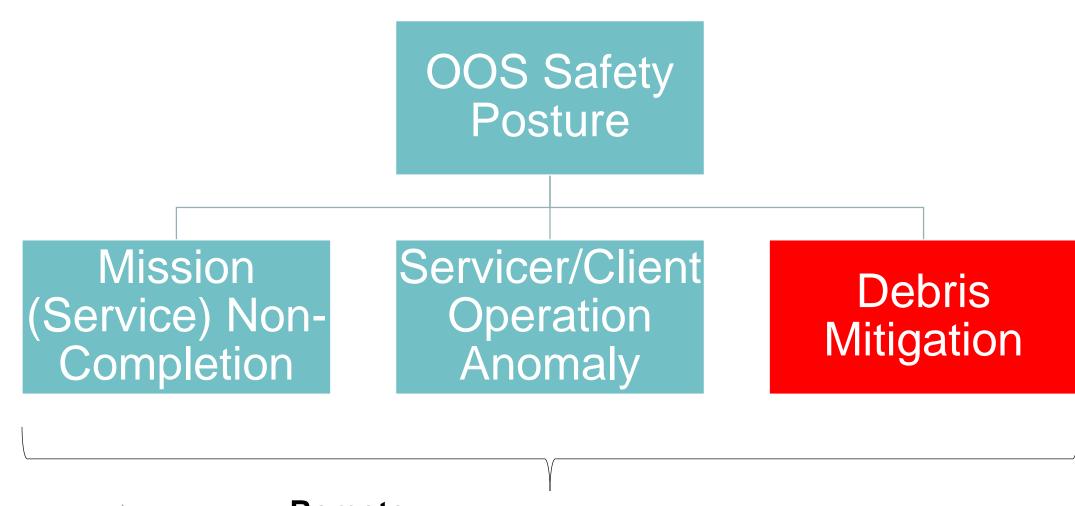


On-Orbit Servicing Example

Credit: Astrium Services



Initial OOS Safety Posture drivers



RPO Metrics

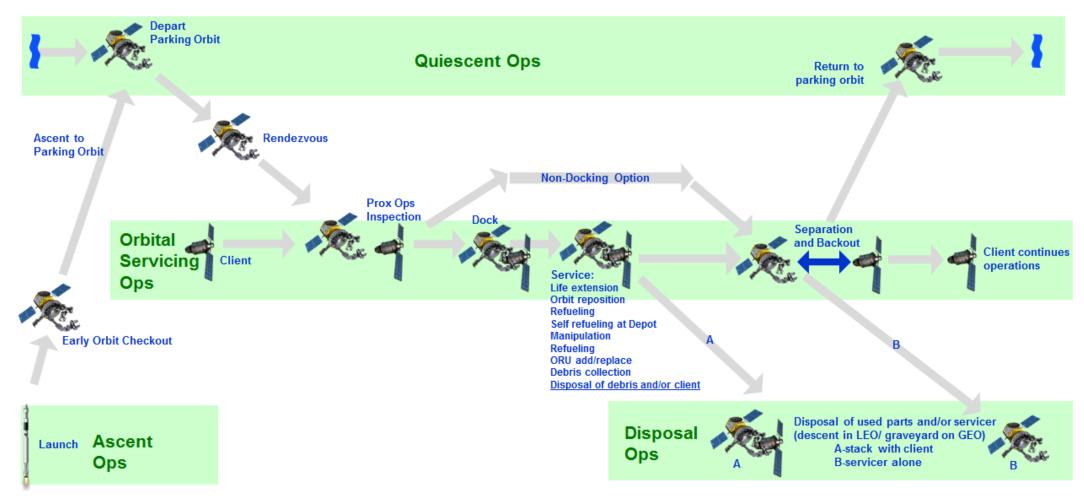


Remote Influence/Interference

Contact Actions



CONFERS draft initial architecture describes various OOS mission "elements"



Each of the Mission Elements translates to more detailed "Execution Functions" that translate into hardware or software to enable the Mission Element to succeed

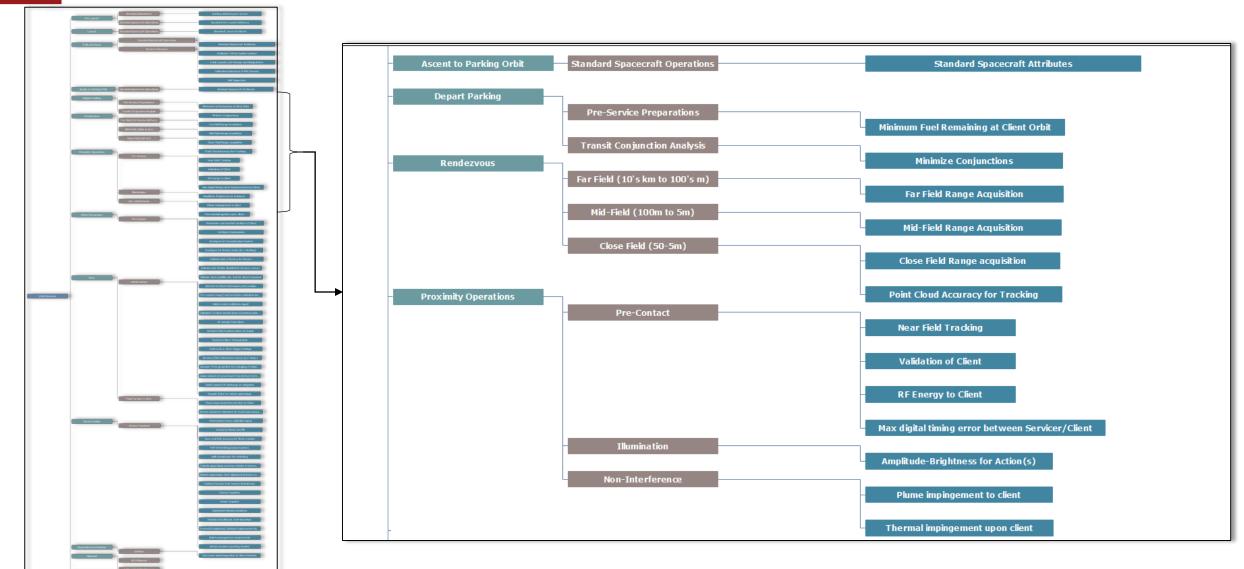


Decomposition of OV-1 Mission Element into Initial "OOS Topology"

- An initial Topology was created to attempt to capture the various functions and attributes that could contribute to a Mission Element
- The elements of the Topology were defined as "functions" and "attributes"
- "Function" defined as an activity required to affect a particular OV-1 OOS element
 - There can be multiple functions required for each element
 - Functions are defined as actions that are either primary or secondary activities that correspond to a particular event in the OV-1 for a particular Service
- "Attribute" defined as the quantitative metric or characteristic to enable a function to be executed or satisfied
 - Depicted as "Function: Attribute" in our internal nomenclature
- Finding Attributes in many cases are straightforward
 - Many have measurable value metrics that can be logically assigned or estimated or calculated
- What is not straightforward is identifying attributes that affect "Safety" as defined in our OOS analysis context at the beginning...
 - Subject of next 6 months of analysis



Initial OOS Topology





Inspirations to Draw From





Terrestrial Servicing Platforms and their "safety protocols" may provide valid communicable analogies for OOS industry to consider...





Resilient operation of engine ("propulsion") system to avoid collision

Clear control for "Robotic arm" to avoid service failure

Clear View for arriving ("Rendezvousing") at servicing location

Clear communication for locating servicing item



Mining of initial Space standards list for quantitative information*

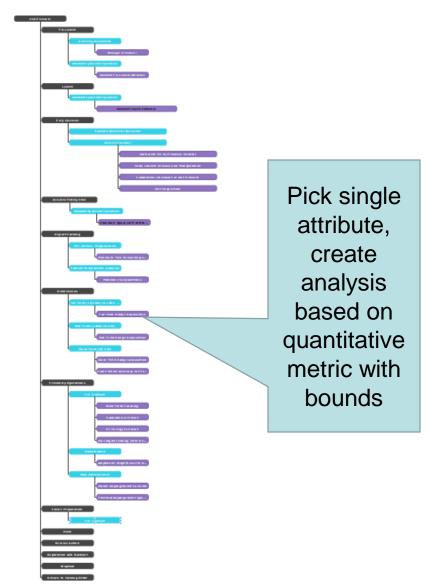
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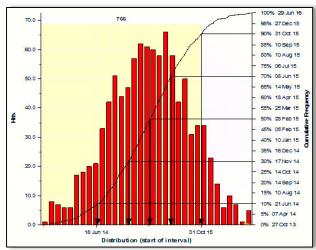
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Disposal of GEO satellites ISO 26872:2010 deplete energy sources Telerobotics CCSDS 540.0-G-1 PROPOSED STANDARD	05	measuring Residual Fuel	150 23339:2010		I	I	*
Telerobotics CCSDS 540.0-G-1 PROPOSED STANDARD		Disposal of GEO satellites	ISO 26872:2010		Y	I	Y
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Early Operations ISO 10784-1:2011 Common language and form to document early operations (SC startup after LV separation)		. C.C. ODOUCS				-	
			Early Operations	ISO 10784-1:2011 Common language and form to document early operations (SC startup after LV separation)			

	CCSDS 940.0-G-1 PROPOSED STANDARD						
	Early Operations	ISO 10784-1:2011	Common language and form to document early operations (SC startup after LV separation)				
	Space Solar Panels - ESD testing	ISO 11221:2011	Qualification and characterization testing for plasma interactions and electrostatic discharges on solar array panels in space				
Debris Avoidance	Prevention of Break-Up of Unmanned Vehicles	ISO 16127:2014	Reduce risk of in-obrit breakup of unmanned SC, during and after operational life (deplete energy sources safely, shutdown systems)		Υ		
		ISO 21347:2005	General requirements for fracture control technology	Y	Y	Y	
	Avoiding Collisions	ISO/TR 16158:201	techniques for perceiving close approaches, estimating collision probability, probability of survival, emaneuvers to avoid collision	Υ	Y	Y	
008	Measuring Residual Fuel	ISO 23339:2010	Estimate the mass of remaining usuable propellant (LEO or GEO)			Y	
	Disposal of GEO satellites	ISO 26872:2010	Requirements to safely dispose of GEO satellites s.t. they will not re-enter op, region for 100 yrs, deplete energy sources	Y		Y	
	Telerobotics	CCSDS 540.0-G-1	PROPOSED STANDARD			Υ	

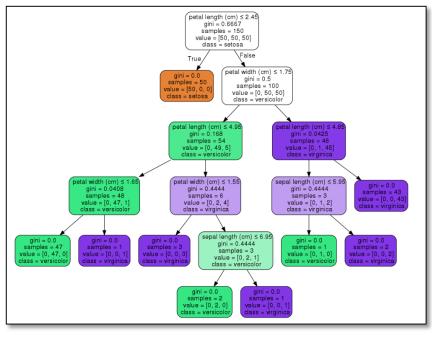


Proposed process to identify most relevant attributes for OOS uses data decision trees for sensitivity analysis





Run monte carlo analysis based on the bounds, with worst case inputs that create a database of results

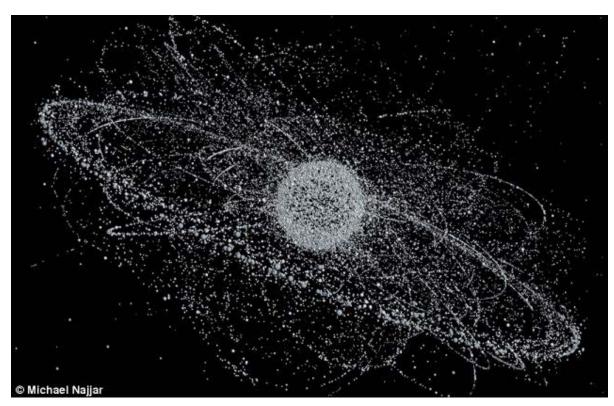


Apply the data base to a dynamic data decision tree to uncover sensitivity to the performance of the attribute based on the bounds



Increasing Spatial Density in Orbit

- Upcoming space servicing companies are proposing first operations outside of high value and heavy spatial density orbits
- An unprecedented surge in new constellations with not just hundreds but thousands of new satellites are in progress.
- As servicing satellites transit high density zones, the risk of collisions becomes greater

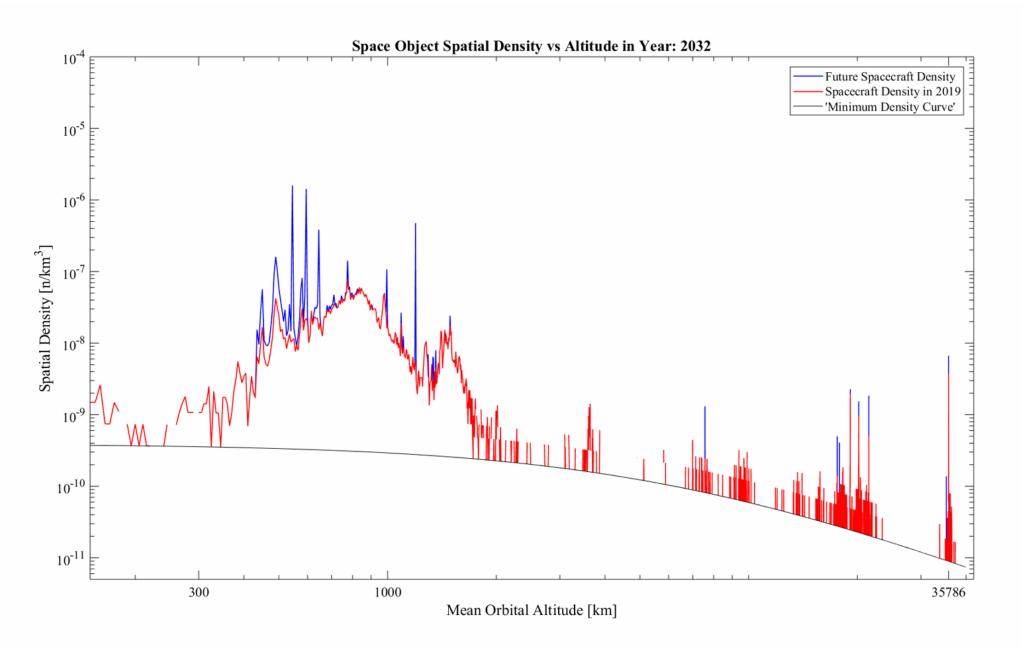


Satellites & Debris in Orbit (2013)

Credit: Michael Najjar

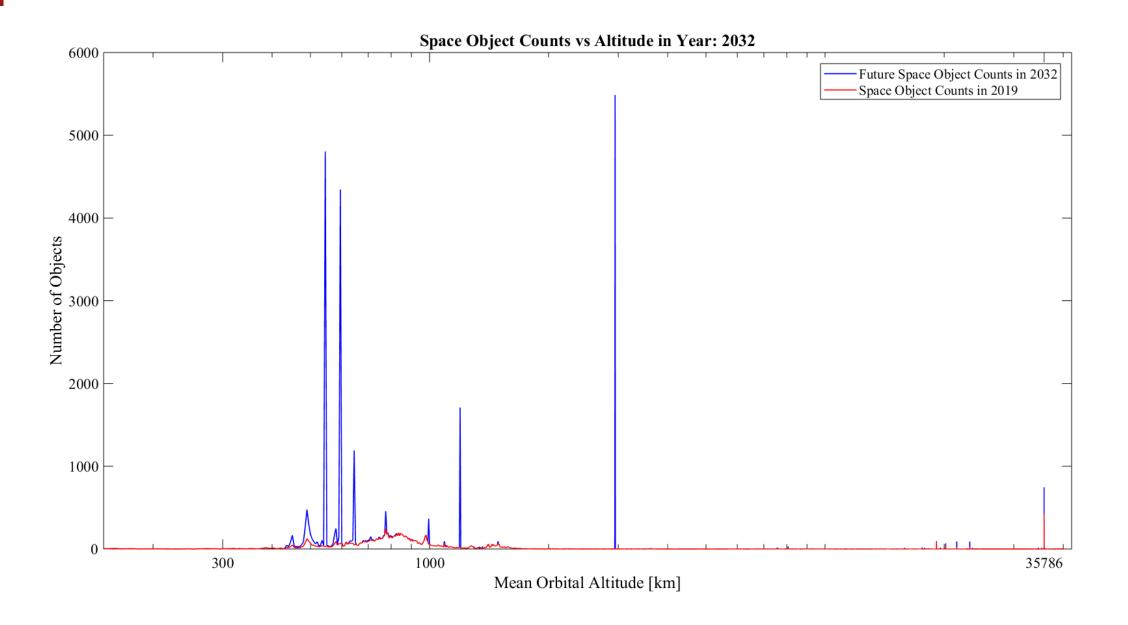


Historical/Projected Spatial Density





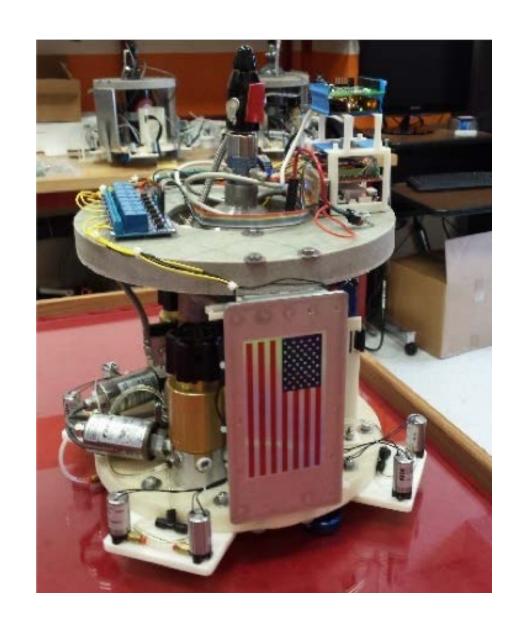
Historical/Projected Spacecraft Numbers/Altitude





Summary

- 1st Year RPO metrics proposed appear to still hold up to contemporary missions
- Initial creation of topology out of OOS "OV-1" completed
- Creation of "function:attribute" mapping provides for first look at quantitative values
- Looking at standards from multiple domains provides informed approach to "space standard" analysis
- Initial consideration for determining what is critical "safety" attribute will continue
- Initial data for transit orbit optimization/consideration for RPO missions created
- Possible functional tests of defined metrics on hardware testbeds in the future





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