AIAA/ANSI S-155-#:####(X)

Secretariat: XXXX

Rendezvous and Proximity Operations (RPO) and On Orbit Servicing (OOS) –Spacecraft Fiducial Markers

New Work Item

Warning

This document is not a Standard. It is distributed for review and comment. It is subject to change without notice and may not be referred to as a Standard.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Contents

Foreword

The American Institute of Aeronautics and Astronautics (AIAA) is…

Boilerplate

This document was prepared by AIAA On-Orbit Servicing and Assembly Committee on Standards.

This is the first edition of this document.

Any feedback or questions on this document should be directed to the AIAA.

Introduction

This document outlines ~~the~~ Re~~R~~endezvous, P~~and P~~roximity ~~O~~Operations and On Orbit Servicing (RPO/OOS) Rendezvous Fiducial Markers and Operating Zones service providers are expected to follow in order to ensure safe operations and to encourage a healthy RPO/OOS industry. Space fiducial markers improve robustness to orbital conditions such as lighting, and increase observability and relative position and orientation estimation performance of navigation sensors and computer vision systems, leading to enhanced safety of on-orbit operations. Standards for space fiducials can also provide economic benefit through interoperability. If OOS client spacecraft from multiple organizations are designed to conform to the standard, servicer spacecraft can complete their objectives for multiple clients without a need for specialized sensors and algorithms.

International law, treaties, and agreements have been researched for compliance and reference.

This document is intended to elaborate ISO 24330 Space Systems – Rendezvous and Proximity Operations and On-Orbit Servicing Programmatic Principles and Practices. Initial drafts are derived from the GSFC support to the Artemis Program and NASA Restore-L Program and produced by the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) team, an international team of about 45 companies promoting standardization for RPO/OOS missions to improve safety and promote development of the RPO/OOS industry.

CONFERS is an independent, self-sustaining forum created to advocate and promote the spacecraft servicing industry and encourage responsible commercial RPO/OOS. CONFERS collaborates on research, development, and publication of voluntary consensus principles, best practices, and technical and safety standards. CONFERS also engages with national governments and international bodies on policy and oversight of spacecraft servicing activities.

Following initial draft input industry input at large has been supported through the AIAA standards development process, with strict compliance to ANSI guidance.

There are no patent licensing issues associated with the content of this standard.

Rendezvous and Proximity Operations (RPO) and On Orbit Servicing (OOS) – Rendezvous Fiducial Markers and Operating Zones

1 Scope

The intended scope of this document is to establish Rendezvous and Proximity Operations (RPO) and On-Orbit Servicing (OOS) standard spacecraft fiducial markers. Supporting spacecraft-spacecraft interoperability and safety, this document outlines functional, physical, and operational requirements for space fiducial markers (also known as cooperative relative navigation aids) used in RPO and OOS, including capture and manipulation of in-space assets. While patterns for spacecraft fiducial markers are not specified, some examples of shown which may exhibit one or more pattern characteristics.

~~Both robotic and Human Spaceflight (HSF) spacecraft. International Space Station practices, SpaceLogisitics MEV-1 and NASA's Restore-L are used as a basis for this standard.~~

This standard is intended to apply to a broad array of RPO/OOS industry participants from spacecraft equipment manufacturers, spacecraft operators, service providers, developers of RPO/OOS simulation, planning and safety tools, and insurers. It is intended to help establish responsible norms of behavior for RPO and OOS that industry participants will achieve and promote throughout the global industry.

Both robotic and Human Spaceflight (HSF) spacecraft may use this standard, although HSF may require markings specifications beyond the content of this standard. International Space Station practices, SpaceLogisitics MEV-1 and NASA's Restore-L are used as a basis for this standard.

Requirements in this standard start from the functional requirement. Physical requirements express systems or components used to satisfy requirements. Operational requirements express sequential use of physical systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

2.1 ISO 24330 Space Systems – Rendezvous and Proximity Operations (RPO) and On-Orbit Servicing (OOS) Programmatic Principles and Practices

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
Control Volume
A volume of space established for non-interference and to assure relative navigation control while the servicer spacecraft and client space object are within close proximity. (May also be called Proximity Operations Control Volume or Operations Zone)

Commented [NBJ(51]: Is it to establish standard markers (use this specific pattern) or to establish "standards for fiducials" without specifying a specific pattern? I think the intent is the latter, but I also think it would be helpful to actually have a few options on specific patterns (it would help with interoperability if there is a standard pattern)

3.2
Docking
Process wherein a servicing spacecraft's GNC actuators are used to execute a controlled contacting trajectory to a Client Space Object in such a manner as to align and mesh the mechanical interface mechanisms.

Alternative: Controlled contacting trajectory to align and mesh the servicing spacecraft's GNC actuators with the mechanical interface mechanisms of the client space object.

3.3
Fiducial Markers
Lines, shapes and patterns which serve as a reference for distance or orientation

Commented [NBJ(52]: This captures the fiducials for an imaging system, but not for a ranging system (ie a lidar). Here's another definition from Wikipedia that better but not perfect: "A **fiducial marker** or **fiducial** is an object placed in the field of view of an imaging system that appears in the image produced, for use as a point of reference or a measure. It may be either something placed into or on the imaging subject, or a mark or set of marks in the reticle of an optical instrument."

3.4
On-Orbit Servicing (OOS)
On-orbit activities by a servicer spacecraft which requires rendezvous and/or proximity. This may include Servicing Operations. See 3.14

3.5
Passively Safe Trajectory
A trajectory which will not interfere with a convex envelope, volume, zone or any area defined to avoid contact with sufficient margin of the client space object when control is lost.

3.6
Proximity Operations
Series of orbital maneuvers executed to place and maintain a spacecraft in the vicinity of another space object (artificial or natural bodies) on a relative planned path for a specific time duration to accomplish mission objectives

3.7
Rendezvous
Wherein two space objects (artificial or natural bodies) are intentionally brought close together through a series of orbital maneuvers at a planned time and place

4 Spacecraft Fiducial Markers

Need some introduction here, perhaps

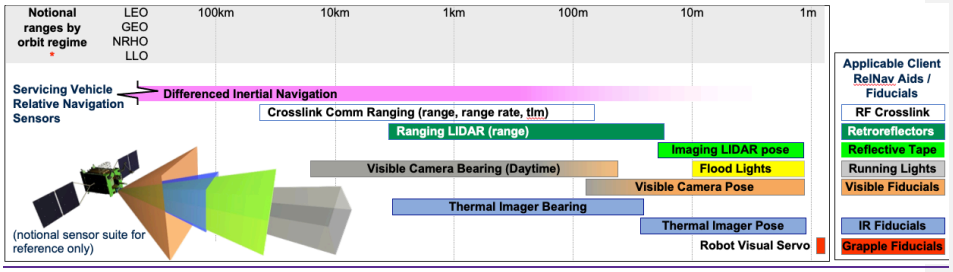

Figure 1. Notional Ranges by Orbit Regime. Courtesy NASA/GSFC.

Figure 1shows notional ranges for different sensors. Spacecraft Fiducial Markers should be applied to support approaching spacecraft sensor suites. The measurement types indicate technical capability associated with different sensing windows: range (1 DOF), bearing (2 DOF), translation (3DOF), orientation(3DOF), pose (6DOF).

4.1 Functional Requirements of Fiducial markers

This is where we describe how these markers will be used

- Tasks: Navigation at various ranges during RPO for GNC, visual servo for free flyer and static capture
-

Functional requirements based on marker user needs and are technology independent.

As described in ISO 24330 Annex B.7, the Rendezvous Phase allows a Servicer Spacecraft to transition into Proximity Operations or Servicing. In the Rendezvous Phase Servicer Spacecraft shall transition in a controlled manner by operating zones. The parametric details, waypoints and/or authorities to proceed are determined by and between the Servicer and the Client.

4.1.1 Remote Survey and Rendezvous

Spacecraft Fiducial Markers shall allow the spacecraft to be seen by other spacecraft attempting remote survey or rendezvous. This type of spacecraft fiducial markers may also be referred to as "far" markers.

4.1.2 Capture and Relocate

Spacecraft Fiducial Markers shall allow the spacecraft to safely capture or be captured by another spacecraft, or for the capture point to be relocated. This type of spacecraft fiducial markers may also be referred to as "near" markers.

4.1.3 Module Replacement

Spacecraft Fiducial Markers shall allow spacecraft modules to safely be replaced. This type of spacecraft fiducial markers may also be referred to as "near" markers.

4.2 Physical Requirements for Fiducial Markers

Fiducial markers with finer resolution shall be used for operations of lesser distance between a Servicer Spacecraft and a Client Space Object.

~~4.2.2~~4.2.1 Remote Survey and Rendezvous

~~4.2.2.1~~4.2.1.1 Visual Fiducial Markers

~~4.2.2.1.1~~4.2.1.1.1 Contrasting Colors

Visual Fiducial Markers shall have colors with high contrast and distinctive from the spacecraft and background (e.g., Earth tones). Black and white is the most common.

Commented [NBJ(53]: Recommended splitting this into two sections: 1) Rendezvous – covers the long range (100s of m to 1s of km) requirements for retroreflectors and lights; 2) Proximity Operations – covers the closer range requirements for visual and IR camera targets and reflectors for close LIDAR use. Can discuss whether Remote survey belongs here at all, it's a service that can be done at lots of different ranges, there may be some specific requirements for fiducials to support it but I can't think of any

Commented [NBJ(54]: By who?

Commented [NBJ(55]: Why is relocate here? No use of fiducials during relocate

Commented [NBJ(56]: By who?

Commented [NBJ(57]: The organization of this section is frustrating because it's so repetitive. I recommend we NOT organize it by phase as you show, but by some other means.

~~4.2.2.1.2~~4.2.1.1.2 Diffuse Surface Finishes
Visual Fiducial Markers shall have diffuse surface (matte) finishes. Glossy surface finishes cause glare and ghosting.

~~4.2.2.1.3~~4.2.1.1.3 Uncluttered Field of Regard
The field of regard shall be uncluttered within a 3" (8 cm) radius around the target.

~~4.2.2.1.4~~4.2.1.1.4 Area Surrounding the Visual Fiducial Marker
The area surrounding the fiducial shall have a non-reflective surface within a 3" (8 cm) radius, colored differently from the primary target.

~~4.2.2.1.5~~4.2.1.1.5 Protection against degradation with exposure
Visual Fiducial Markers shall use inks and finishes that do not degrade with UV or AO exposure to the extent that affects their intended use for the duration of the required life of the target.

~~4.2.2.1.6~~4.2.1.1.6 Edge definition
Visual Fiducial Marker edges shall be crisp and well-defined and are detectable at various angles and under dynamic lighting conditions.

~~4.2.2.1.7~~4.2.1.1.7 Use of Multiple Markers
Visual Fiducial Markers shall be placed at edges of surface of regard for maximum separation, and placed close to the cooperative capture feature

~~4.2.2.1.8~~4.2.1.1.8 Marker Geometry
Visual Fiducial Markers shall have simple geometry distinctive from visual features on the host spacecraft. For example squares, circles, circle outlines, 2D barcode tags.

~~4.2.2.1.9~~4.2.1.1.9 Marker Shapes
Visual Fiducial Markers shall have irregular shapes and/or features that aid in pose estimation (e.g. out of plane features). Symmetrical patterns are not recommended.

~~4.2.2.1.10~~4.2.1.1.10 Marker identification
Visual Fiducial Markers shall contain features that uniquely identify the marker to support multiple targets per mission, multiple targets per image, or targets of different sizes without confusion

~~4.2.2.1.11~~4.2.1.1.11 Marker Degrees-of-Freedom
Visual Fiducial Markers shall allow for the unambiguous estimation of the 6-DOF pose of its host object (3-axes in translation and 3 axes in orientation).

Commented [FS8]: Need more insight as to where this number is coming from. Spacecraft available real estate may prevent this.

Can this requirement be clarified with a generalized diagram? Does it mean there is an 3" (8 cm) radius uncluttered circle that the target fits entirely within, or does it mean that no matter what the size of the physical target is, there is an additional uncluttered region beyond the extent of the target? Sounds like it is the former (i.e. the target fits within an 8 cm radius circle), Agree would be good to know what that size of target is based on for use as a remote survey and rendezvous target.

~~4.2.2.2~~4.2.1.2 IR Fiducial Markers

~~4.2.3~~4.2.2 Capture and Relocation

Capture fiducial markers for berthing or grapple shall be sufficiently different that one location on a spacecraft cannot be mistaken for another.

~~4.2.3.1~~4.2.2.1 Berthing

~~4.2.3.2~~4.2.2.2 Visual Fiducial Markers

~~4.2.3.2.1~~4.2.2.2.1 Contrasting Colors

Visual Fiducial Markers shall have colors with high contrast and distinctive from the spacecraft and background (e.g., Earth tones). Black and white is the most common.

~~4.2.3.2.2~~4.2.2.2.2 Diffuse Surface Finishes

Visual Fiducial Markers shall have diffuse surface (matte) finishes. Glossy surface finishes cause glare and ghosting.

~~4.2.3.2.3~~4.2.2.2.3 Uncluttered Field of Regard

The field of regard shall be uncluttered within a 3" (8 cm) radius around the target.

Commented [FS9]: Same comment as 4.2.1.1.3

~~4.2.3.2.4~~4.2.2.2.4 Area Surrounding the Visual Fiducial Marker

The area surrounding the fiducial shall have a non-reflective surface within a 3" (8 cm) radius, colored differently from the primary target.

Commented [FS10]: Same comment as 4.2.1.1.3

~~4.2.3.2.5~~4.2.2.2.5 Protection against degradation with exposure

Visual Fiducial Markers shall use inks and finishes that do not degrade with UV or AO exposure to the extent that affects their intended use for the duration of the required life of the target..

~~4.2.3.2.6~~4.2.2.2.6 Edge definition

Visual Fiducial Marker edges shall be crisp and well-defined and ~~are~~ be detectable at various angles and under dynamic lighting conditions.

~~4.2.3.2.7~~4.2.2.2.7 Use of Multiple Markers

Visual Fiducial Markers shall be placed at edges of surface of regard for maximum separation, and placed close to the cooperative capture feature

~~4.2.3.2.8~~4.2.2.2.8 Marker Geometry

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~~4.2.3.2.9~~4.2.2.2.9 Marker Shapes

Visual Fiducial Markers shall have irregular shapes and/or features that aid in pose estimation (e.g. out of plane features). Symmetrical patterns are not recommended.

~~4.2.3.2.10~~4.2.2.2.10 Marker identification

Visual Fiducial Markers shall contain features that uniquely identify the marker to support multiple targets per mission, multiple targets per image, or targets of different sizes without confusion

~~4.2.3.2.11~~4.2.2.2.11 Marker Degrees-of-Freedom

Visual Fiducial Markers shall allow for the unambiguous estimation of the 6DOF pose of its host object (3-axes in translation and 3 axes in orientation).

~~4.2.3.3~~4.2.2.3 Grapple

~~4.2.3.4~~4.2.2.4 Visual Fiducial Markers

~~4.2.3.4.1~~4.2.2.4.1 Contrasting Colors

Visual Fiducial Markers shall have colors with high contrast and distinctive from the spacecraft and background (e.g., Earth tones). Black and white is the most common.

~~4.2.3.4.2~~4.2.2.4.2 Diffuse Surface Finishes

Visual Fiducial Markers shall have diffuse surface (matte) finishes. Glossy surface finishes cause glare and ghosting.

~~4.2.3.4.3~~4.2.2.4.3 Uncluttered Field of Regard

The field of regard shall be uncluttered within a 3" (8 cm) radius around the target.

Commented [FS11]: Same comment as 4.2.1.1.3

~~4.2.3.4.4~~4.2.2.4.4 Area Surrounding the Visual Fiducial Marker

The area surrounding the fiducial shall have a non-reflective surface within a 3" (8 cm) radius, colored differently from the primary target.

Commented [FS12]: Same comment as 4.2.1.1.3

~~4.2.3.4.5~~4.2.2.4.5 Protection against degradation with exposure

Visual Fiducial Markers shall use inks and finishes that do not degrade with UV or AO exposure to the extent that affects their intended use for the duration of the required life of the target..

~~4.2.3.4.6~~4.2.2.4.6 Edge definition

Visual Fiducial Marker edges shall be crisp and well-defined and ~~are~~ be detectable at various angles and under dynamic lighting conditions.

~~4.2.3.4.7~~4.2.2.4.7 Use of Multiple Markers

Visual Fiducial Markers shall be placed at edges of surface of regard for maximum separation, and placed close to the cooperative capture feature

~~4.2.3.4.8~~4.2.2.4.8 Marker Geometry

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~~4.2.3.4.9~~4.2.2.4.9 Marker Shapes

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~~4.2.3.4.10~~4.2.2.4.10 Marker identification

Visual Fiducial Markers shall contain features that uniquely identify the marker to support multiple targets per mission, multiple targets per image, or targets of different sizes without confusion

~~4.2.3.4.11~~4.2.2.4.11 Marker Degrees-of-Freedom

Visual Fiducial Markers shall allow for the unambiguous estimation of the 6DOF pose of its host object (3-axes in translation and 3 axes in orientation).

~~4.2.4~~4.2.3 Module Replacement

Module replacement fiducial markers shall be sufficiently different that one module or location on a spacecraft cannot be mistaken for another.

Commented [FS13]: Suggest reword to:

Module replacement fiducial markers shall contain features that uniquely identify the marker to support multiple targets per mission, multiple targets per image, or targets of different sizes without confusion

Discussion?

4.3 Operational Requirements for Fiducial markers

Remote survey and rendezvous spacecraft fiducial markers shall not be operated an any way that creates interference on any telecommunications assigned frequencies.

4.3.1 Remote Survey and Rendezvous

4.3.1.1 Remote survey and rendezvous trajectory shall not result in uncontrolled collision and generation of space debris.

~~4.3.1~~4.3.2 Capture and Relocation

~~4.3.2~~4.3.3 Module Replacement

Annex A Volumes and Zones

Current Terms and Users

Term	ISS	IRSIS	Space Logistics	Astroscale	Clearspace	CONFERS
Transfer		X				
Rendezvous	X	X				
Rendezvous Sphere		X				
Approach Sphere		X				
Approach Ellipsoid	X					
Proximity Operations	X	X				
Keep Out Sphere	X					
Waypoints			X			
Approach Corridor	X					
Departure Corridor	X					
Collision Avoidance Maneuver	X					
Mating	X					
Docking	X					
Capture	X					

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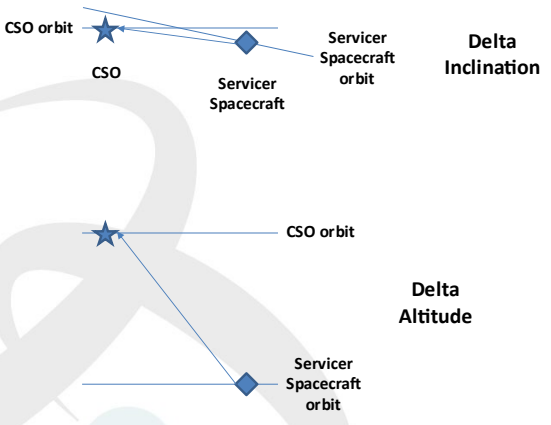
05/18/2021

Transfer: From One Orbit to Another



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Defined Envelopes Around or Near CSOs

- Approach ellipsoid — 4 km x 2 km x 2 km around center of mass
- Keep Out Zone / sphere — 200 m around center of mass
- Rendezvous Sphere — 10 km radius around center of mass
- Approach Sphere — 1 km radius around center of mass
- Waypoint 1 — 80 m
- Waypoint 2 — 15 m
- Waypoint 3 — 1 m
- Approach corridor — 10° cone centered on docking port

2

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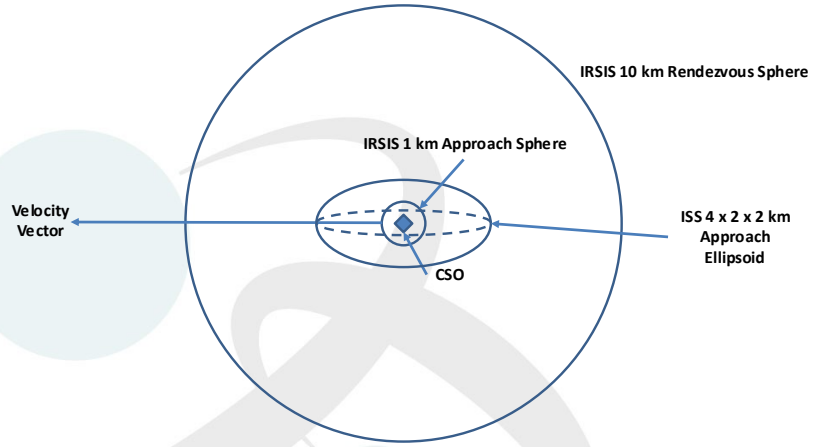
Rendezvous and Prox Ops Control Zones – 1



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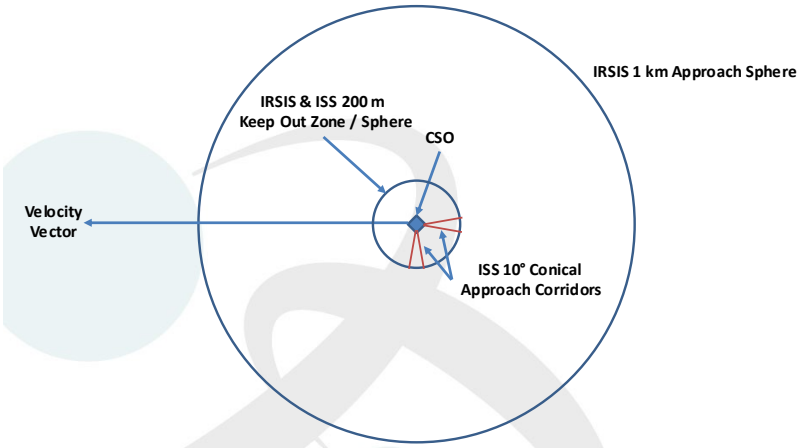
Rendezvous and Prox Ops Control Zones – 2



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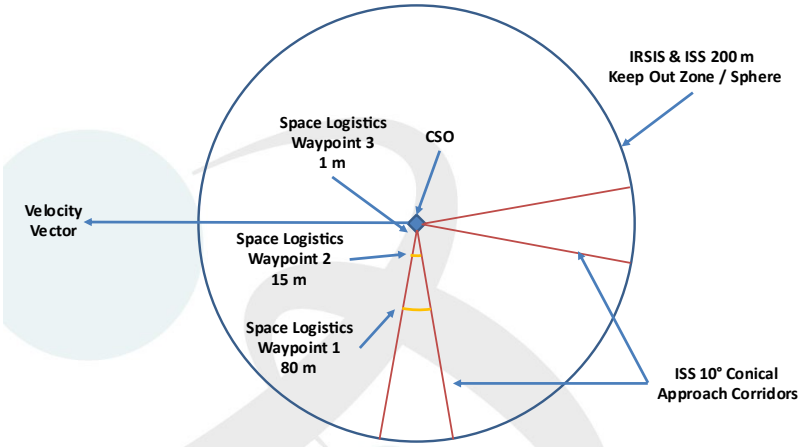
Rendezvous and Prox Ops Control Zones – 3



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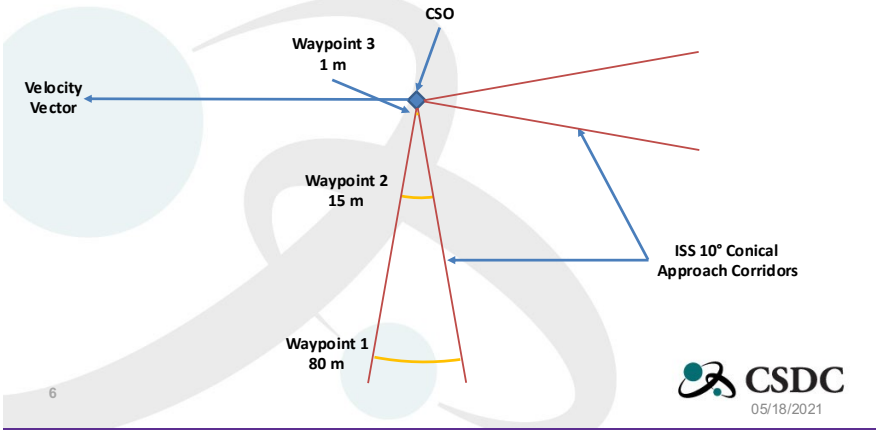
Rendezvous and Prox Ops Control Zones – 4



Annex B , etc. Informative ~~Clauses~~ Annexes

- Introduction to space relative navigation sensors and systems (GNC) and visual servo sensors and systems (robotic manipulators)
- Introduction to computer vision approaches
- Indentification (do we want to capture this? Not sure anyone's used this for RPO, probably have for space robotics

Bibliography

IRSIS