

Navigation and Alignment Aids Concept of Operations and Supplemental Design Information

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PREFACE

**NAVIGATION AND ALIGNMENT AIDS CONCEPT OF OPERATIONS AND
SUPPLEMENTAL DESIGN INFORMATION**

The International Docking System Standard (IDSS) Interface Definition Document (IDD) provides a specification for a standard set of navigation and alignment aids. This document supplements the IDSS IDD and provides greater insight into the design and usage of the IDSS navigation and alignment aids. The IDSS committee felt that this information would provide additional insight and considered it important to preserve for future IDSS navigation and alignment aids users.

NAVIGATION AND ALIGNMENT AIDS CONCEPT OF OPERATIONS AND
SUPPLEMENTAL DESIGN INFORMATION

CONCURRENCE

OCTOBER 2016

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1.0 INTRODUCTION

The mating of an active and passive vehicle can be achieved through either a space vehicle docking process or space vehicle berthing process.

The space vehicle docking process consists of a rendezvous phase where the active docking vehicle navigates to the passive docking vehicle to align their docking interfaces for the soft capture and a docking phase. The passive docking vehicle should be outfitted with target provisions for middle to long range detection and for relative navigation support up to the point of docking Soft Capture System (SCS) engagement.

The space vehicle berthing process consists of a coarse positioning phase where a robotic manipulator positions the passive vehicle's berthing interface to a standoff position in front of the active vehicle's berthing interface, based on the known geometries of the vehicles and manipulator. The passive vehicle should be outfitted with target provisions for short range detection and relative alignment support up to the point of SCS engagement.

These navigation and alignment aids are detectable by sensors mounted on the active spacecraft and will provide the means to compute a relative position and relative attitude state to support docking or berthing. They can also provide a visual means to determine docking/berthing alignment.

The IDSS IDD provides a specification for a standard set of navigation and alignment aids. This document supplements the IDSS IDD and provides greater insight into the design and usage of the IDSS navigation and alignment aids.

1.1 PURPOSE AND SCOPE

This document contains supplemental navigation and alignment aids information that augment section 3.5, Navigation and Alignment Aids, of the IDSS IDD. It is intended to provide a high level concept of operations of their usage, and design rationale for some of the features of the navigation and alignment aids. While there is some duplication with the IDSS IDD, the information contained herein is intended to be descriptive and non-binding, and the specifications in the IDSS IDD are to take precedence over any information included in this document.

1.2 RESPONSIBILITY AND CHANGE AUTHORITY

Any proposed changes to this information by the participating partners of this agreement shall be brought forward to the IDSS committee for review.

Configuration control of this document is the responsibility of the International Space Station (ISS) Multilateral Control Board (MCB), which is comprised of the international partner members of the ISS. The National Aeronautics and Space Administration (NASA) will maintain this document under ISS Configuration Management along with the IDSS IDD.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. The documents listed in this paragraph are applicable to the extent specified herein.

IDSS IDD (current issue)	International Docking System Standard (IDSS) Interface Definition Document (IDD)
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2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of this document.

None identified

3.0 NAVIGATION AND ALIGNMENT AIDS CONOPS

The IDSS includes three different types of target systems to support docking, as shown in Figure 3.0-1, IDSS Target Systems. They consist of the Perimeter Reflector Targets (PRT), the Peripheral Docking Target (PDT), and the Centerline Docking Target (CDT). These targets work together to support short range as well as longer-range operations while providing overlapping coverage, as described in Figure 3.0-2, Ranges of Applicability of Navigation and Alignment Aids. The target set also allows for different types of sensor systems or technologies that may be available on the active vehicle.

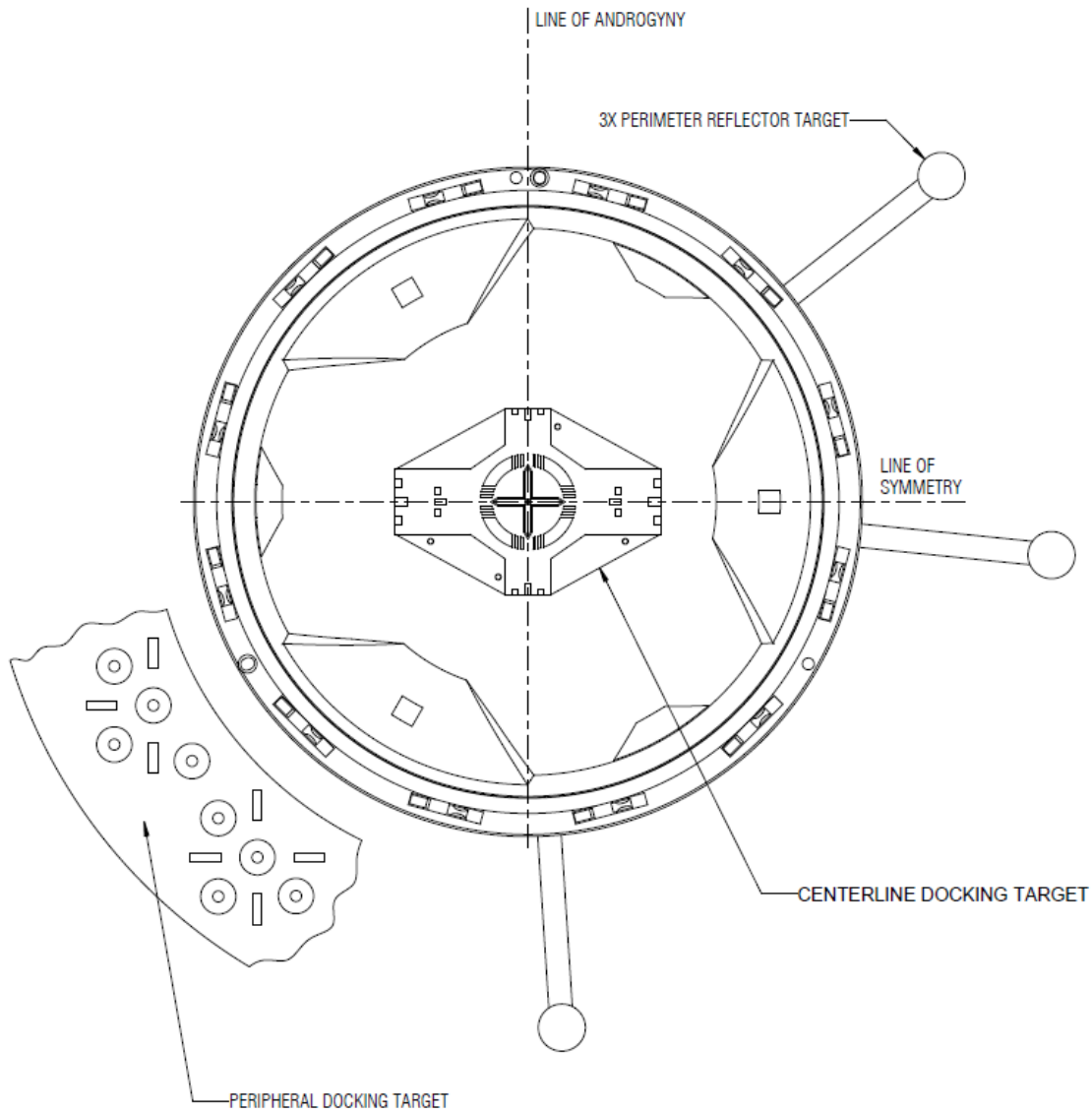


FIGURE 3.0-1 IDSS TARGET SYSTEMS

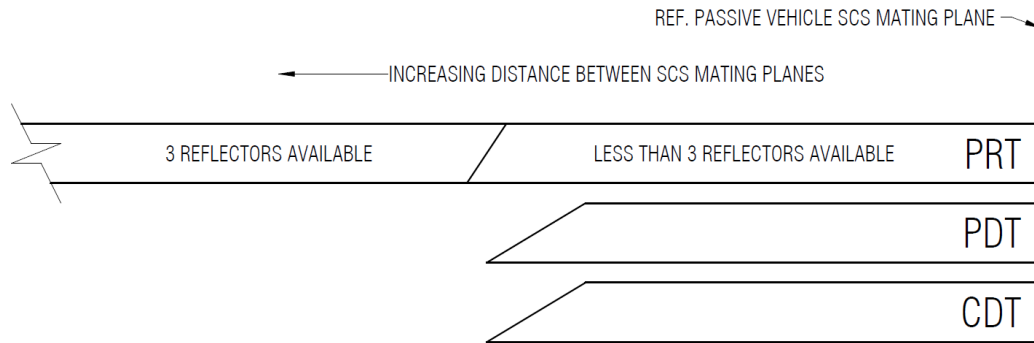


FIGURE 3.0-2 RANGES OF APPLICABILITY OF NAVIGATION AND ALIGNMENT AIDS

The PRTs consist of three retro-reflector assemblies designed to be compatible with laser and optical sensors, and can provide support for estimating relative position and relative attitude while the active vehicle is both on and offset from the docking axis.

The three PRTs have been located around the perimeter of the docking system to allow for unobstructed line-of-sight viewing from longer ranges. Two of the retro-reflector assemblies are hemispherical (that is, they have a hemispherical field of view) and allow for sensor tracking coverage above and below the docking axis to provide support in docking axis acquisition. The third retro-reflector assembly (with a ± 30 degree field of view) provides support for maintaining the docking axis during approach. The fields of view of all the reflective elements are shown together in Figure 3.0-3, Reflector Fields of View. The PRTs can be used either individually or as a set to aid in determining relative position. However, three PRTs are available for three-axis relative attitude determination if desired.

Depending on the mounting location of the active vehicle's sensors, the elements of the PRT may pass outside of the sensor's field of view as the active vehicle moves closer to docking. At shorter ranges, the CDT and the PDT are available to serve as a primary focus of the relative navigation sensors. The PDT and the CDT provide references to allow the active vehicle to measure its alignment relative to the docking interface. With the proper placement of the active vehicle's relative navigation sensors, both or either the CDT and PDT can be used through docking/berthing.

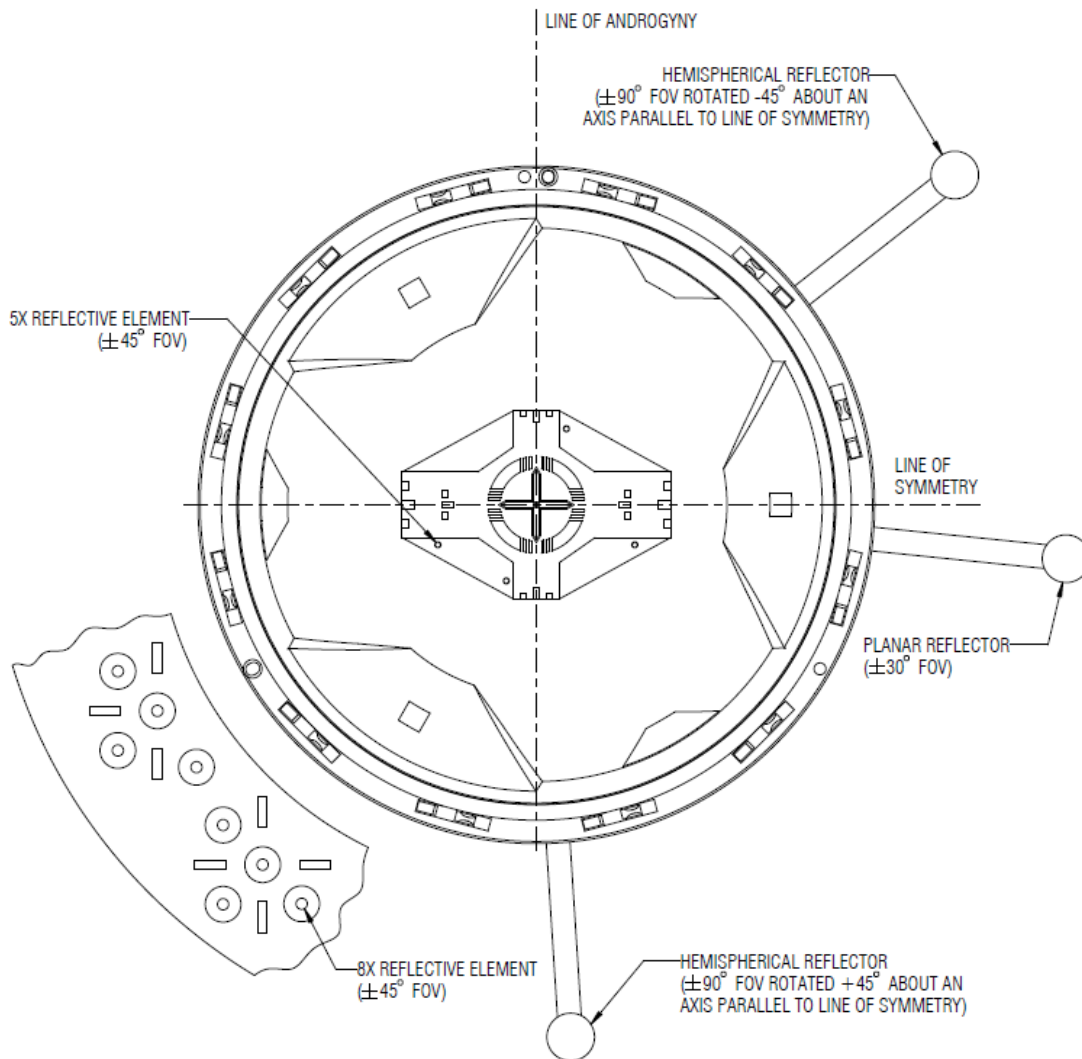


FIGURE 3.0-3 REFLECTOR FIELDS OF VIEW

The CDT is compatible for use with optical and laser sensors. The backplate shown in Figure 3.0-4, CDT Backplate Markings, is printed with markings designed to allow a pilot (aided by a visible light camera or a direct line of sight through a window) to read the lateral and angular alignment cues on the docking target.

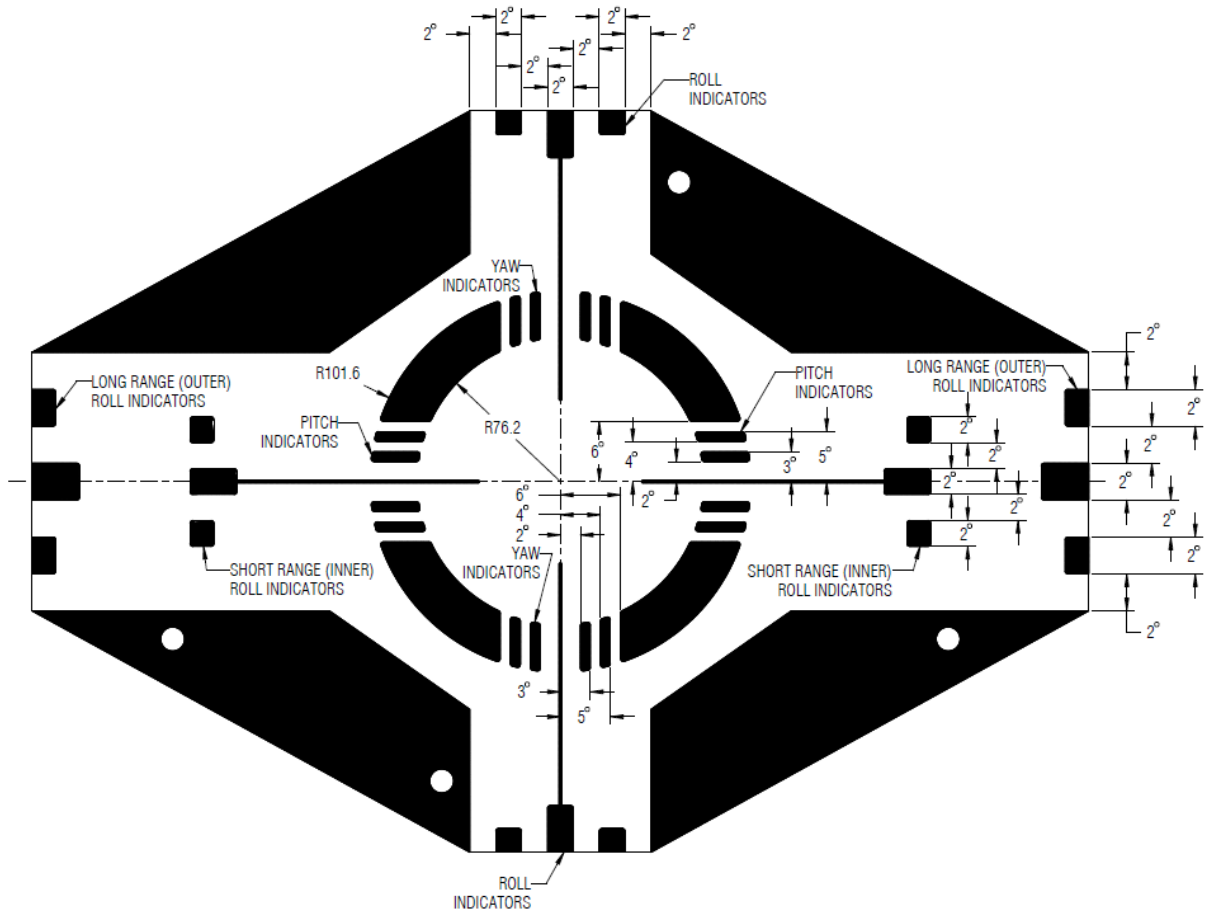


FIGURE 3.0-4 CDT BACKPLATE MARKINGS

Pitch and yaw indicators are to be used with the pointers on the standoff cross as shown in Figure 3.0-5, CDT 2° Pitch Misalignment Indication Example. Both sets of pitch indicator and yaw indicators are sized to give misalignments of 2, 3, 4, 5, and 6 degrees.

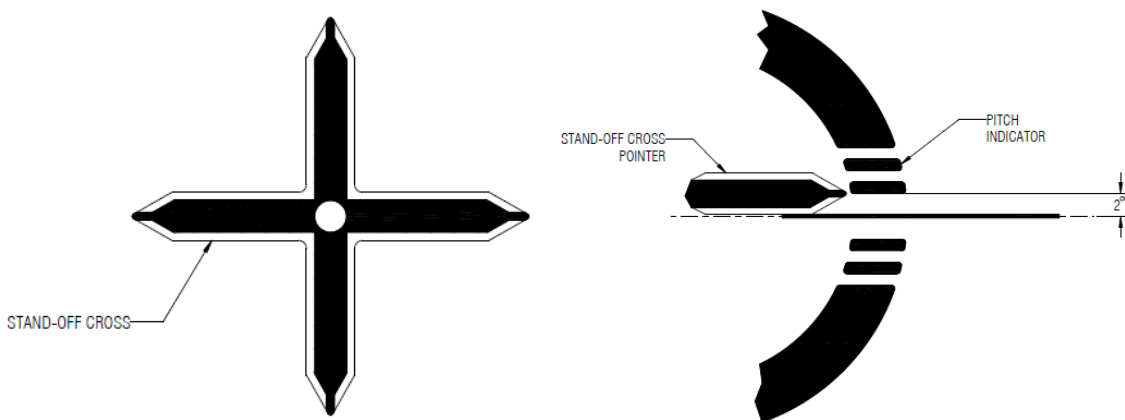


FIGURE 3.0-5 CDT 2° PITCH MISALIGNMENT INDICATION EXAMPLE

Roll indicators are used with vertical or horizontal lines overlaid on a camera image. All six sets of roll indicators are sized to give roll misalignments in increments of 2 degrees. At least two sets of roll indicators on opposite sides of the CDT backplate are required during roll misalignment determination as shown in Figure 3.0-6, CDT 2° Roll Misalignment Indication Example. This example also demonstrates that the roll indicators continue to be useable even when combined with a lateral offset. A short range (inner) and longer range (outer) set of roll indicators are located along the horizontal axis of the backplate. The outer roll indicators should not be used with the inner roll indicators during roll misalignment determination.

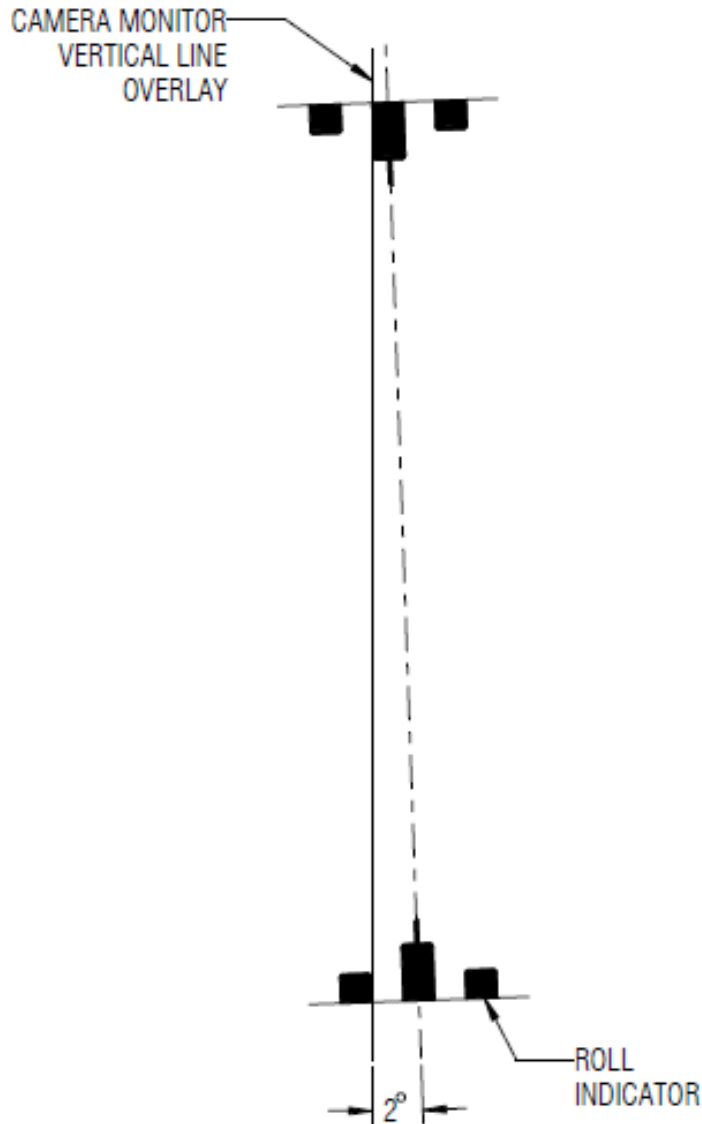


FIGURE 3.0-6 CDT 2° ROLL MISALIGNMENT INDICATION EXAMPLE

The CDT is suitable to be used by a human pilot as an alignment aid for manual docking, or as a way to monitor an automated system. A centerline docking target location is unique in that it eliminates roll alignment error coupling into lateral alignment error at the center of the docking interface.

The CDT also includes reflectors under filter glass that are compatible with optical and laser sensors. The filter glass is used to protect the reflective material from the space environment and to filter out undesired wavelengths. The reflector pattern consisting of five reflectors, four on the backplate and one out-of-plane on the standoff cross, is arranged to provide an unambiguous pattern for estimating attitude.

The PDT is compatible for use with visible light cameras, thermal imagers, and laser sensors and allows for determination of relative pose (position and attitude) with each sensor type. The PDT shown in Figure 3.0-7, PDT Features, consists of six circular features mounted to a backplate, two circular features each mounted out-of-plane on a standoff post, and horizontal and vertical crosshairs. At the center of the circular features are circular reflectors under filter glass that are compatible with optical and laser sensors. As with the CDT, the PDT filter glass is used to protect the reflective material from the space environment and to filter out undesired wavelengths. For the benefit of thermal sensors, the surface properties of the crosshairs and non-glass portion of the circular features are specified to provide a high thermal contrast with the backplate. To increase thermal contrast, the crosshairs are angled to reduce the chance that thermal energy is reflected back from the sensor or active vehicle structure.

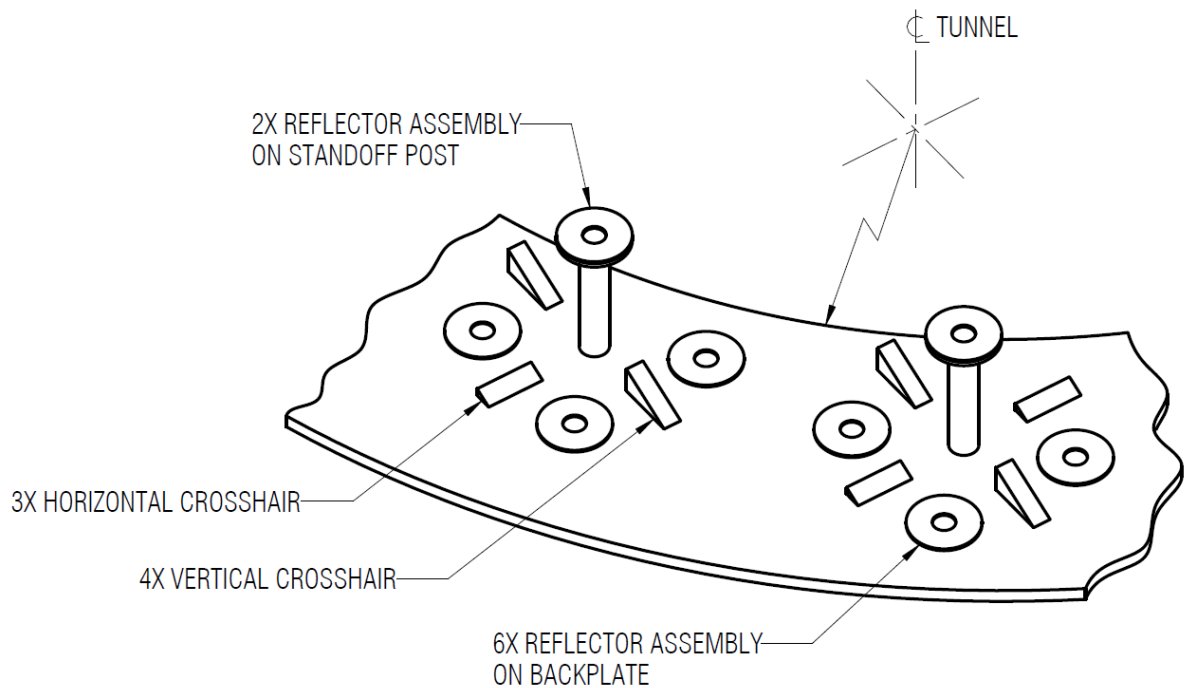


FIGURE 3.0-7 PDT FEATURES

As is common when determining docking sensor applicability, orbital lighting conditions should be considered when analyzing the usability of features on the CDT and PDT. Reflection of thermal energy (either from structure on the passive vehicle, from the active vehicle, from the earth, or from other bright celestial bodies) should be examined when considering using the thermal features on the PDT. In addition, the intensity of the return energy from the reflectors and other features should be considered when specifying the minimum and maximum distance at which a sensor can be used with the PRT, CDT, and PDT.

The combination of the PRT, CDT, and PDT provide navigation support for active vehicle operations at long, mid, and short ranges. These three target systems allow for the use of various relative sensor technologies and therefore provide flexibility in sensor selection. Multiple options exist for sensor redundancy in providing a relative navigation estimate suitable for final approach and docking/berthing operations.

3.1 DESIGN RATIONALE

The following three sections include rationale for a limited set of requirements and design choices made for the PRT, CDT, and PDT. Each section describes details which were identified as being important to preserve for consideration in future modifications of this target set. Where applicable, references to the corresponding IDSS IDD requirement are specified.

3.1.1 PRT DESIGN RATIONALE NOTES

The following notes apply to the PRT.

1. Since a third hemispherical reflector would not offer a big improvement in reflector coverage, a planar reflector, was specified as part of the three reflector pattern of the PRT. See IDSS IDD section 3.5.1.1.4.
2. The PRT was designed with the intent to facilitate automated reflector identification by taking advantage of making each inter-reflector distance unique, subject to the constraint that reflectors would be mounted on a circle centered on the docking centerline. Figure 3.1.1-1, Inter-Reflector Distance and Placement, shows a schematic depiction of the unique inter-reflector distances. The hemispherical reflectors are labeled as point C and point A. The planar reflector is point B. See IDSS IDD section 3.5.1.1.

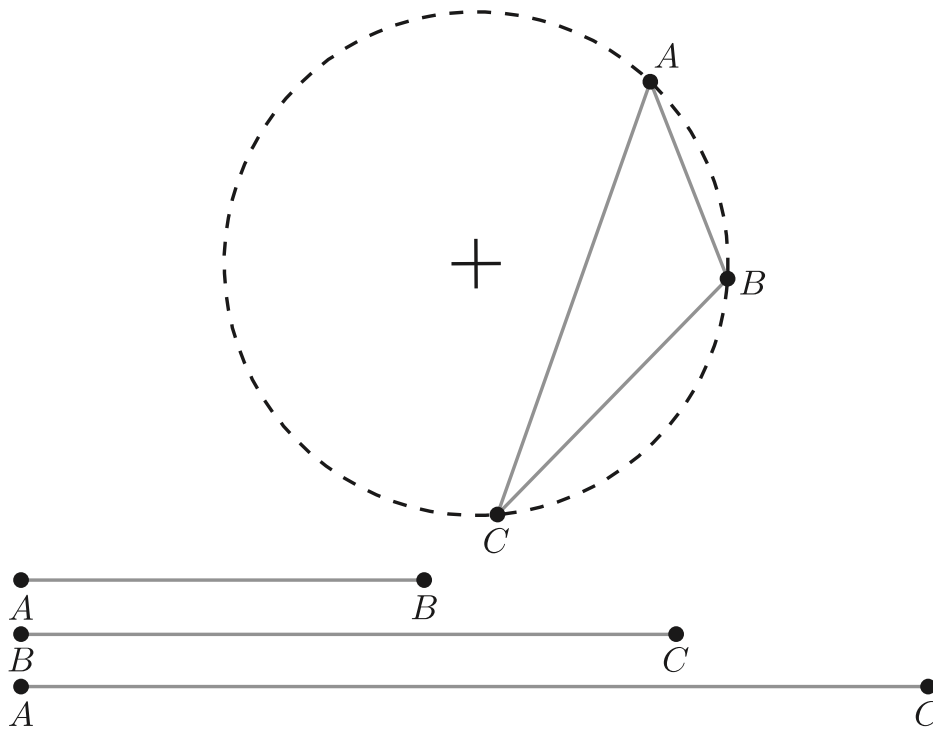


FIGURE 3.1.1-1 INTER-REFLECTOR DISTANCE AND PLACEMENT

3.1.2 CDT DESIGN RATIONALE NOTES

The following notes apply to the CDT.

1. Tight mounting tolerances of the standoff cross with respect to the backplate are required since a small positional misalignment between the mounting of the standoff cross and backplate centerline will result in a bias in the pitch or yaw reading of the visual markings. For example, a mounting misalignment of 1.0 mm represents a pitch or yaw bias of approximately 0.2 degrees. See IDSS IDD section 3.5.2.2.5.
2. The reflective element clear aperture size was determined, in sensor testing, to be the appropriate size to provide sufficient return energy for a laser sensor for the final 15 m of the approach to docking. In the testing, a flash Light Intensification Detection and Ranging (LIDAR) was able to reliably detect all five CDT reflective elements from 15 m to docking. See IDSS IDD section 3.5.2.3.3.

3. The CDT provides visual piloting cues to give the active docking vehicle's pilot the ability to estimate lateral position misalignments as well as angular misalignments in three axes. The markings on the backplate allow a human to estimate the misalignments to within ± 1 degree per axis. The CDT is designed to provide alignment cues when viewing the target in the visible wavelengths. See IDSS IDD sections 3.5.2.2.4 and 3.5.2.2.10.
4. The backplate roll, pitch, and yaw markings along with the standoff cross height was sized to enable a crewman to determine the presence of angular misalignments of greater than 1 degree when viewing the CDT with a National Television Standards Committee (NTSC) camera zoomed to a 10 degree horizontal field-of-view from a range of approximately 10 meters. See IDSS IDD sections 3.5.2.2.4 and 3.5.2.2.10.

3.1.3 PDT DESIGN RATIONALE NOTES

The following notes apply to the PDT.

1. The apparent position of a Standoff Post over a marked backplate can visually provide approximate pitch and yaw attitude and lateral alignment information. Two standoff posts are specified to provide sensor mounting location flexibility while also allowing sensor tracking of required features at close ranges through docking. See IDSS IDD section 3.5.3.7.
2. Maintaining a minimum border around each visual navigation feature will improve the performance of some visual recognition algorithms. This buffer must be maintained even in the presence of transition areas from light to dark where the raised backplate features meet the backplate. See IDSS IDD section 3.5.3.8.
3. The circular navigation features are required to be of a known and consistent size to be compatible with some visual recognition algorithms. See IDSS IDD section 3.5.3.9.
4. The reflective element clear aperture size was determined to be the appropriate size to provide sufficient return energy for a sensor during the final approach to docking. See IDSS IDD section 3.5.3.10.
5. The placement of the reflective elements such that they form concentric circles with the PDT circular features allows them to be used simultaneously as visual and reflective features. See IDSS IDD section 3.5.3.11.
6. The circle feature thickness should be less than 25 mm so as to reduce the possibility of the post mounted circle obscuring other features on the backplate when there is a misalignment between the PDT and an active docking vehicle's sensors. See IDSS IDD section 3.5.3.12.

7. The circular navigation features need to be very sharp as they are the key to visual recognition. Any distortion in the circularity of the features can result in navigation error in relative attitude algorithms. See IDSS IDD section 3.5.3.14.
8. In order to present enough of a flat indicating surface with good thermal reflection and still be wide enough to show up on a thermal imager at short range, the radius of the edge of the circular navigation features cannot be too rounded. See IDSS IDD section 3.5.3.15.
9. In order to present enough of a flat indicating surface with good thermal reflection and still be wide enough to show up on a thermal imager at short range, the radius of the edge of the crosshairs cannot be too rounded. A maximum radius of 2 mm allows the vertical crosshairs to have at least the center half of the width to remain flat. See IDSS IDD Figure 3.5.3.16-1, PDT Crosshair Details.
10. The crosshairs can be used to indicate the center of the standoff post and should be placed such that their intersections indicate the center of the standoff post as closely as possible. See IDSS IDD section 3.5.3.18.
11. The crosshairs need to be closely aligned with the “vertical” and “horizontal” directions of the PDT coordinate system for monitoring purposes. See IDSS IDD section 3.5.3.19.
12. A smooth, uninterrupted surface of each circular navigation feature and crosshair is required so that there is no interference with visual navigation. See IDSS IDD section 3.5.3.20.
13. Two separate target patterns are specified to provide sensor mounting location flexibility while also allowing sensor tracking of required features at close ranges through docking. For a single pattern, three planar and one out-of-plane fiducial is needed for target acquisition, recognition, and solving for roll ambiguity. Therefore, a total eight fiducial elements are specified for the PDT. See IDSS IDD section 3.5.3.21.1.
14. The filter glass must transmit all the visible wavelengths greater than 380 nm to be compatible with visible light cameras, and have a wavelength band from 850 nm to 1600 nm in order to accommodate many laser sensors currently in use. See IDSS IDD section 3.5.3.21.8.
15. The filter glass needs to be relatively parallel to the backplate to ensure that any specular reflections off the surface of the glass from any docking lights are predictable and consistent from one circular feature to another. See IDSS IDD section 3.5.3.21.9.
16. An out-of-plane reflective element is necessary to accurately measure relative pose (position and attitude). See IDSS IDD section 3.5.3.21.10.

17. In order to provide thermal contrast, PDT features need to be either highly emissive or highly reflective. To maximize contrast, the crosshairs are angled such that little thermal energy is reflected towards the infrared sensor. Otherwise, reflected thermal energy would not provide enough contrast with the highly emissive portions of the PDT. Field of view analysis should be performed to ensure that the crosshairs do not reflect thermal energy from the structures of either the target vehicle or the approaching active vehicle. The angle specified in this requirement may be adjusted to account for the structural design of the target and active vehicles, so long as the angle falls within the specified range. See IDSS IDD section 3.5.3.22.
18. A standoff element is necessary for determination of spacecraft attitude. Length of element was determined based on maintaining non-interference between the visual marking on the standoff element and any markings on the backplate. See IDSS IDD section 3.5.3.23.
19. Surface characteristics were selected to provide the necessary thermal contrast to be compatible with thermal imaging technology and visual contrast to be compatible with feature recognition algorithms. See IDSS IDD section 3.5.3.24.
20. Limiting surface reflection is desirable to reduce interference with feature recognition algorithms. See IDSS IDD section 3.5.3.25.

APPENDIX A - ACRONYMS AND ABBREVIATIONS

CDT	Centerline Docking Target
CONOPS	Concept of Operations
FOV	Field Of View
IDD	Interface Definition Document
IDSS	International Docking System Standard
ISS	International Space Station
LIDAR	Light Intensification Detection and Ranging
m	Meter
MCB	Multilateral Control Board
mm	millimeter
NASA	National Aeronautics and Space Administration
nm	Nanometer
NTSC	National Television Standards Committee
PDT	Peripheral Docking Target
PRT	Perimeter Reflector Target
R	Radius
REF.	Reference
SCS	Soft Capture System
TBD	To Be Determined
TBR	To Be Resolved

APPENDIX B - GLOSSARY <RESERVED>

APPENDIX C - OPEN WORK <RESERVED>

Table C-1 lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBD item is numbered based on the section where the first occurrence of the item is located as the first digit and a consecutive number as the second digit (i.e., <TBD 4-1> is the first undetermined item assigned in Section 4 of the document). As each TBD is solved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

TABLE C-1 TO BE DETERMINED ITEMS

TBD	Section	Description

Table C-2 lists the specific To Be Resolved (TBR) issues in the document that are not yet known. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBR issue is numbered based on the section where the first occurrence of the issue is located as the first digit and a consecutive number as the second digit (i.e., <TBR 4-1> is the first unresolved issue assigned in Section 4 of the document). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

TABLE C-2 TO BE RESOLVED ISSUES

TBR	Section	Description