

Space Program Operations Contract

Star Tracker/Heads-Up Display/Crew Optical Alignment Sight Workbook S TRK/HUD/COAS 21002

Mission Operations Directorate

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Final Version

**This document has been reviewed and updated.
No subsequent updates to this document are anticipated or required due to
the approaching shuttle program closure.**

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S TRK/HUD/COAS 21002

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C-1 – C-4	Rev. B

PREFACE

The Star Tracker/Heads-Up Display/Crew Optical Alignment Sight Workbook was prepared by the United Space Alliance (USA), Mission Operations Directorate.

The primary responsibility is with USA, Space Flight Training and Facilities Operations (SFT&FO) Center, D/4710.

Questions concerning the technical content of this document should be directed to Carla Sugar, 281-244-8487, D/4712.

A Training Materials Evaluation is included at the end of this document. Inputs on this sheet will be used to evaluate the lesson material. You do not need to sign the sheet.

FOREWORD

This training material is part of a series of lectures, handouts, and workbooks for instruction on orbiter Guidance, Navigation, and Control (GNC) systems.

This training package should be studied before you attend any classroom session on this material or take any lesson for which this is a prerequisite.

The orbiter GNC systems lesson sequence chart shows where this lesson fits in the series, the prerequisites for each lesson, and the optimum presentation order. The lesson sequence charts are located in the shuttle Training Program Catalog.

This material is for training purposes only; it should not be used as a source of operational data.

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1.0 INTRODUCTION

The Star Tracker (ST) subsystem is a part of the shuttle navigation system. It consists of two units located just forward and to the left of the commander's +X window (see Figure 1-1) and is used to align the Inertial Measurement Units (IMUs) onboard the shuttle. An additional function of the Star Trackers is to track targets and to provide Line-of-Sight (LOS) vectors for rendezvous calculations. There are two hardware designs of the Star Trackers in use today, the original Image Dissector Tube (IDT) and the Solid State Star Tracker (SSST). The SSST was designed to be interchangeable with the IDT ST.

Alignment of the IMUs is performed as required to maintain the Entry Interface (EI) attitude criteria and to correct IMU drift, within 1 to 2 hours prior to a critical burn, or after a Heads-Up Display (HUD) or Crew Optical Alignment Sight (COAS) IMU alignment. Star alignments are scheduled approximately once per flight day. Alignment of the IMU is accomplished by using the Star Trackers to measure the LOS vector to at least two stars. Using this information, the General Purpose Computer (GPC) then calculates the orientation between these stars and the shuttle to define the shuttle's attitude. Comparing this attitude against the attitude measured by the IMU provides the correction factor necessary to null the IMU error.

The GPC memory contains inertial position information for 100 stars, chosen because they are bright enough for the Star Trackers to acquire and because they provide complete sky coverage.

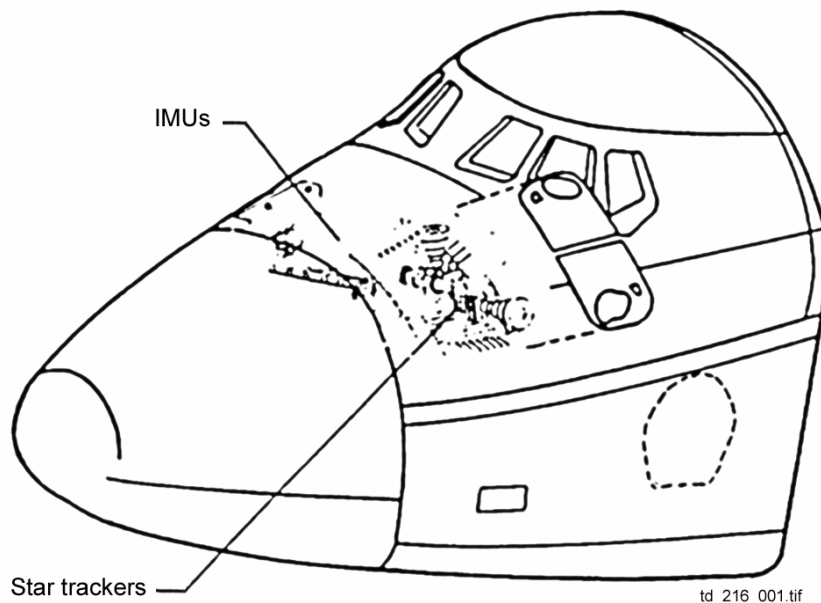
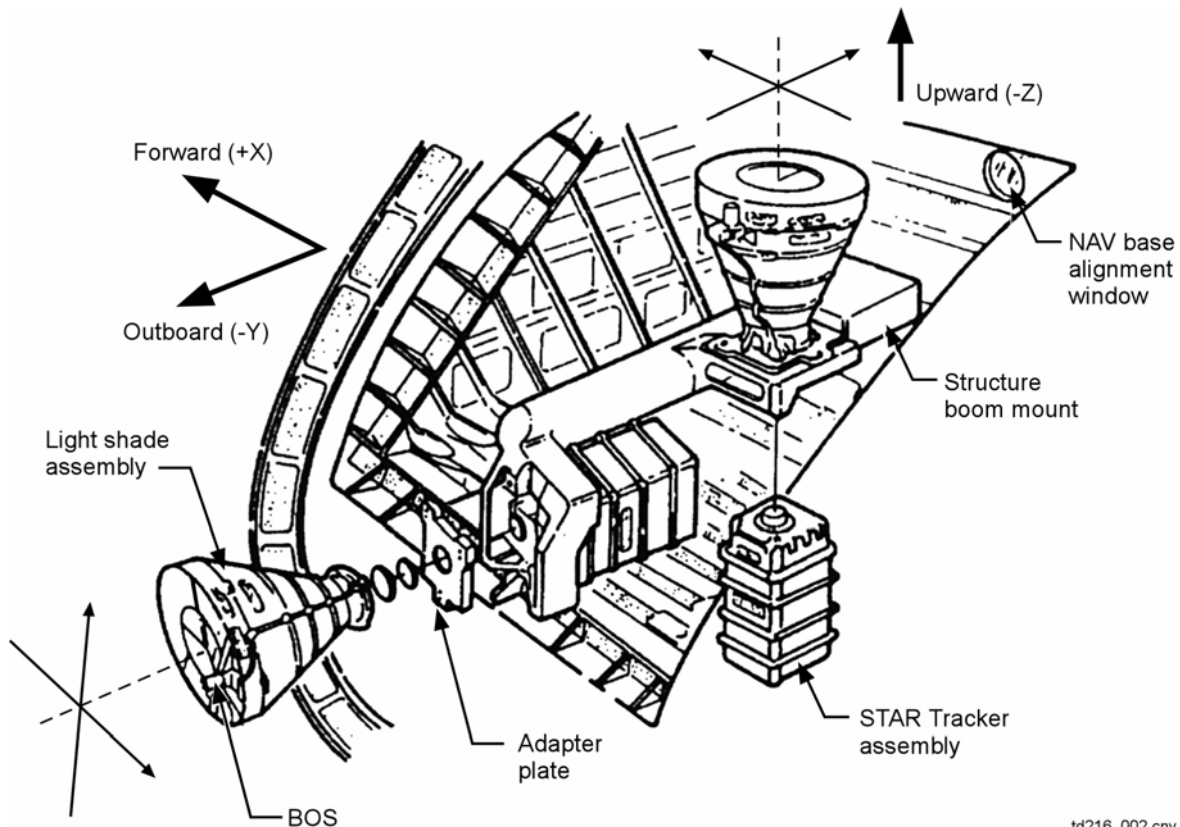


Figure 1-1. Location of Star Trackers onboard shuttle

2.0 EQUIPMENT MOUNTING AND ORIENTATION

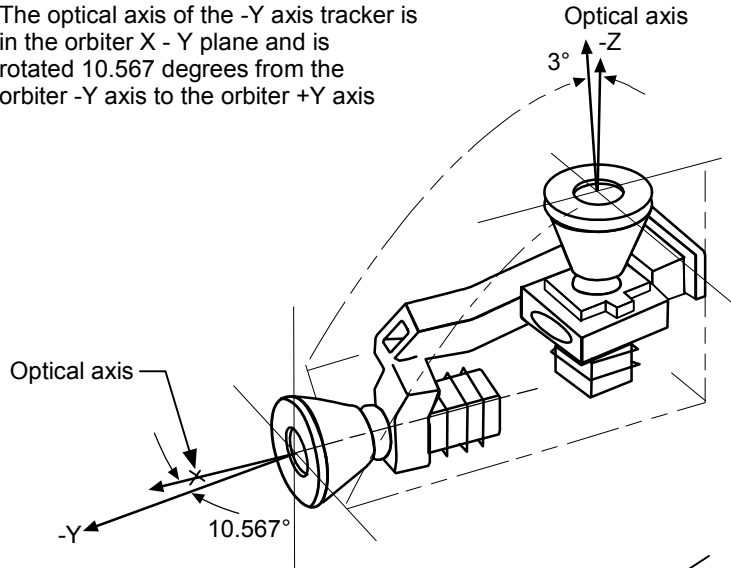
The Star Tracker units are mounted on an extension of the navigation base and are oriented such that the optical axis of the -Z Star Tracker is pointed approximately along the -Z axis of the shuttle and the optical axis of the -Y Star Tracker is pointed approximately along the -Y axis of the shuttle (Figure 2-1). The navigation base is a temperature-stable platform that serves as a focus for the shuttle coordinate system. Since the navigation base provides the mount for the IMUs and the Star Trackers, the Star Tracker LOS is referenced to the navigation base and the shuttle coordinate system; thus the GPC knows where the Star Tracker is pointed and its orientation with respect to the IMUs. See Figure 2-2. The two Star Tracker designs, the IDT and SSST, are interchangeable. The two designs are interchangeable at the mechanical interface and use the same mechanical envelope; however, their weights and centers of gravity are different. The solid state has a heavier Head Assembly because a solid structure was required to sink the heat from the electronic boards to the Navigation Base in order to bypass the temperature sensitive Detector Assembly.



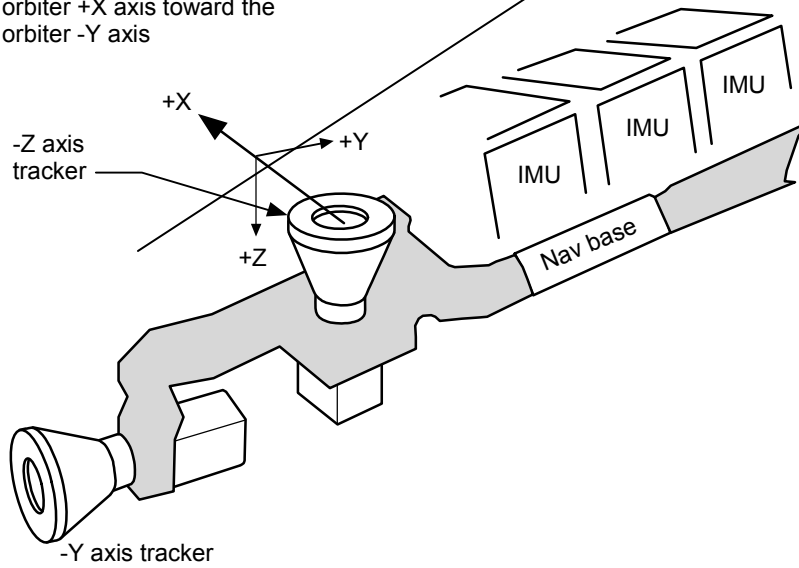
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Figure 2-1. View into Star Tracker cavity

The optical axis of the -Y axis tracker is in the orbiter X - Y plane and is rotated 10.567 degrees from the orbiter -Y axis to the orbiter +Y axis



The optical axis of the -Z axis tracker is inclined 3 degrees in a plane rotated 41 degrees from the orbiter +X axis toward the orbiter -Y axis



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Figure 2-2. Star Tracker orientation

3.0 STAR TRACKER DOORS

The Star Tracker units are enclosed within the shuttle structure and are protected by closed doors during ascent and entry. Each door is opened and closed by two motors operating through a differential gearbox. With both motors operating, the doors are opened or closed in 6 seconds. Should a motor or power to a motor fail, the operating time is increased to 12 seconds. Figure 3-1, Figure 3-2, and Figure 3-3 illustrate the location of these doors. Both doors rotate underneath the outer tile and metal surface of the shuttle.

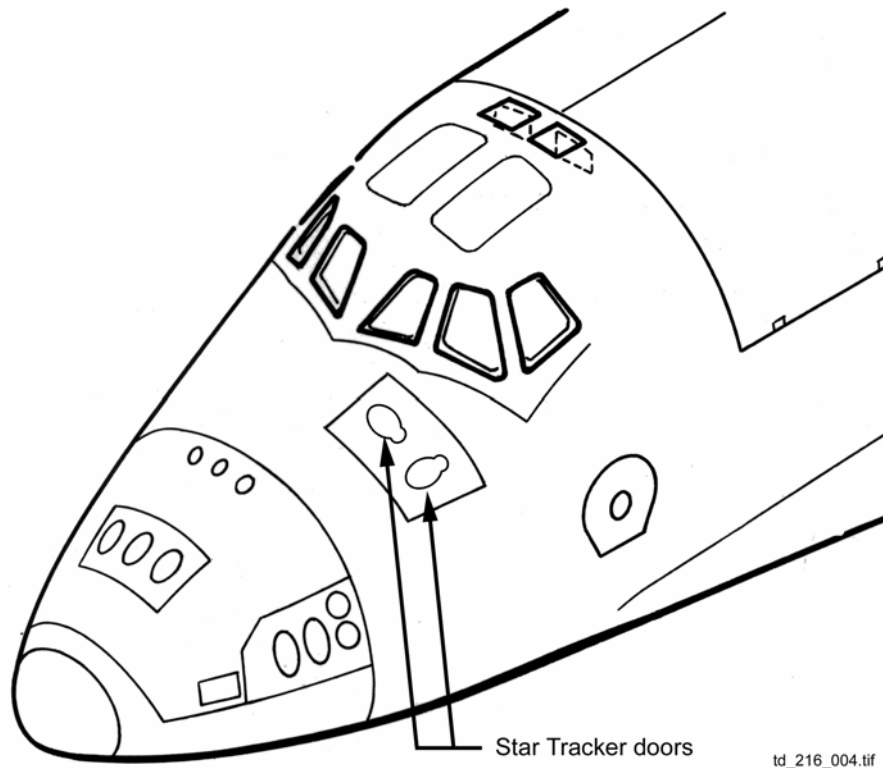


Figure 3-1. Star Tracker door locations

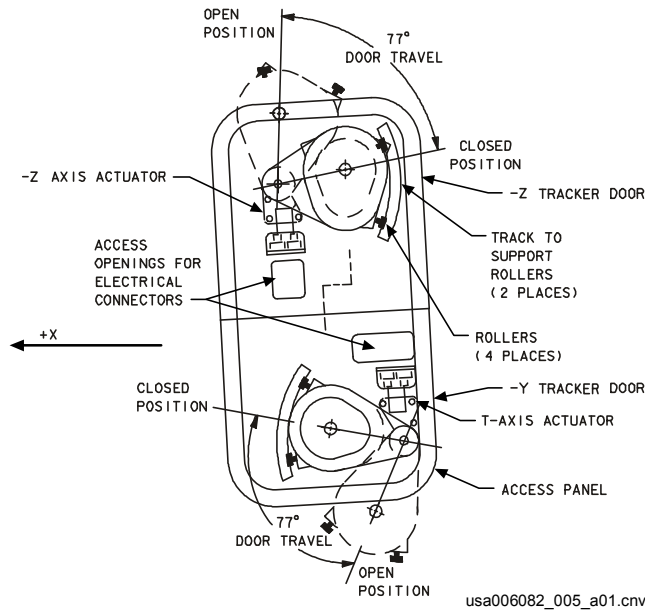


Figure 3-2. Star Tracker door travel directions (viewed from outside)

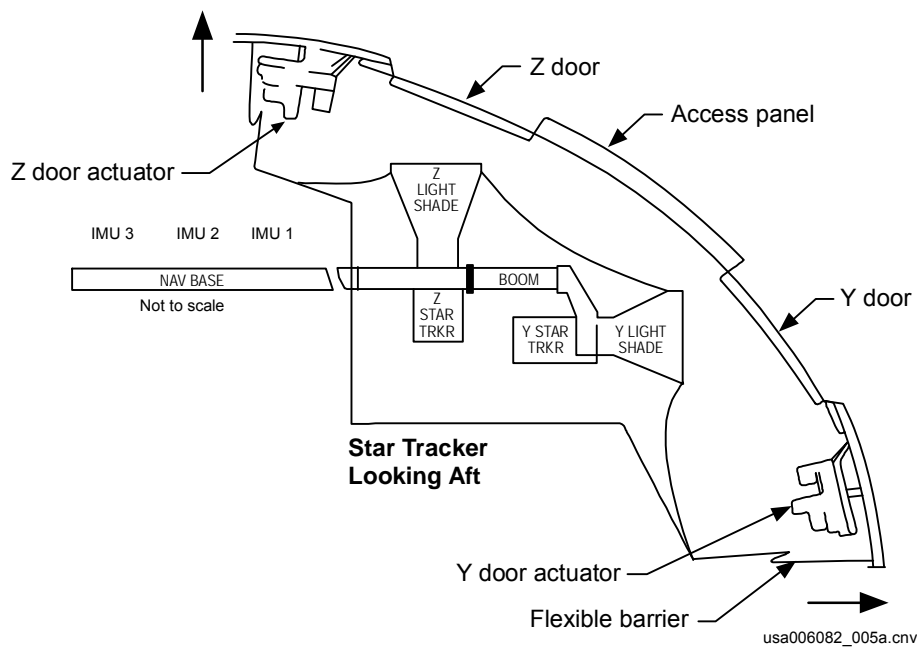


Figure 3-3. Internal view of Star Tracker subsystem (looking aft)

3.2 DOOR CONTROL LOGIC

The three-phase Star Tracker door motors are controlled by the Forward Motor Control Assemblies (FMCAs). Refer to Figure 3-5 while reading the following sequence of operation to open a door.

Assuming that the FMCA LOGIC (Panel (PNL) MA73C) and STAR TRACKER POWER switches are on, the STAR TRACKER DOOR CONTROL switch is set to OPEN. Power is now applied to open drivers in the FMCA and to the open limit switch. Since the doors are closed, the open limit switch is also closed, allowing power to be routed through the limit switch to the open drivers in the FMCA. The open drivers energize two series connected open relays, applying three-phase ac power to the door motor. The door motor continues to run until the door reaches its open position, at which time the OPEN LIMIT switch opens. Power from the OPEN LIMIT switch is now removed from the open drivers, causing the open relays to be deenergized and removing power from the door motor. The SYS 1 and SYS 2 STAR TRACKER DOOR CONTROL switches control a single motor for each door. Therefore, to operate a door in two-motor time (6 seconds), both switches must be used.

A similar series of events, using the close drivers, relays, and limit switches, occurs when the STAR TRACKER DOOR CONTROL switch is set to CLOSE. When the STAR TRACKER DOOR CONTROL switch is OFF, power is removed from the drivers in the FMCA. This protects the door motors if a limit switch fails to open after a door has reached its limit. As demonstrated by the door motor control logic, the Star Tracker doors can be closed with the STAR TRACKER POWER switch in the OFF position.

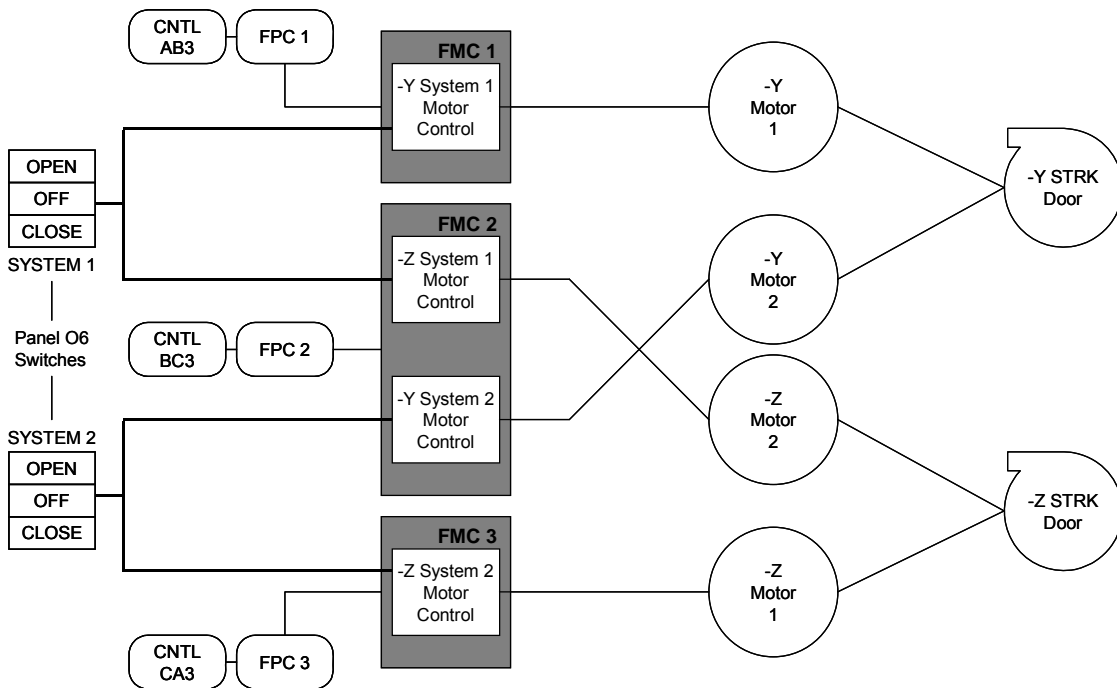


Figure 3-5. Star Tracker door motor logic

3.3 DOOR OPERATIONS

The Star Tracker doors are opened upon achieving orbit during the Post Insertion timeline. The crew procedure for door opening is located in the Post Insertion Checklist, as shown in Figure 3-6.

<u>STAR TRKR ACTIVATION/DOOR OPEN</u> 12	
C	O6 S TRK PWR (two) – ON GNC I/O RESET
	S TRK DR CNTL SYS (two) – OP (start timer) √POS tb (two) – bp
	When both tb – OP (8-24 sec), or either tb – bp for > 24 sec, CNTL SYS (two) – OFF
	* If tb – bp > 8 sec, notify MCC *
	1: GNC 22 S TRK/COAS CNTL
	STAR TRK – ITEM 3,4 EXEC
	1: GNC 21 IMU ALIGN
	RESUME

Figure 3-6. Star Tracker door opening procedure

The Star Tracker doors are usually left open throughout the mission and are closed during the Deorbit Preparation (Prep). An example of the door closing procedure from the Deorbit Prep Checklist is given in Figure 3-7.

<u>DEACT STAR TRKRS & CLOSE DOORS</u> 13	
O6	STAR TRKR PWR (two) – OFF
O14:E, O15:E	cb STAR TRKR –Z,-Y (two) – op
O6	STAR TRKR DR CNTL SYS (two) – CL (start timer) √POS tb (two) – bp
	When both tb – cl (~8-24 sec) or either tb – bp > 24 sec: STAR TRKR DR CNTL SYS (two) – OFF
	* If tb – bp > 8 sec, notify MCC *

Figure 3-7. Star Tracker door closing procedure

4.0 STAR TRACKER HARDWARE

4.1 COMPONENTS

The Star Tracker subsystem comprises the following components (see Figure 4-1):

- Electronics assembly. Contains optics and electronics for converting optical images into digital data
- Adapter plate. Provides common mount for Star Tracker subsystem
- Protective window. Provides a seal that protects and allows electronics assembly to be pressurized
- Light shade assembly. Protects lens from glare. Also provides mount for Bright Object Sensor (BOS) and shutter mechanism.

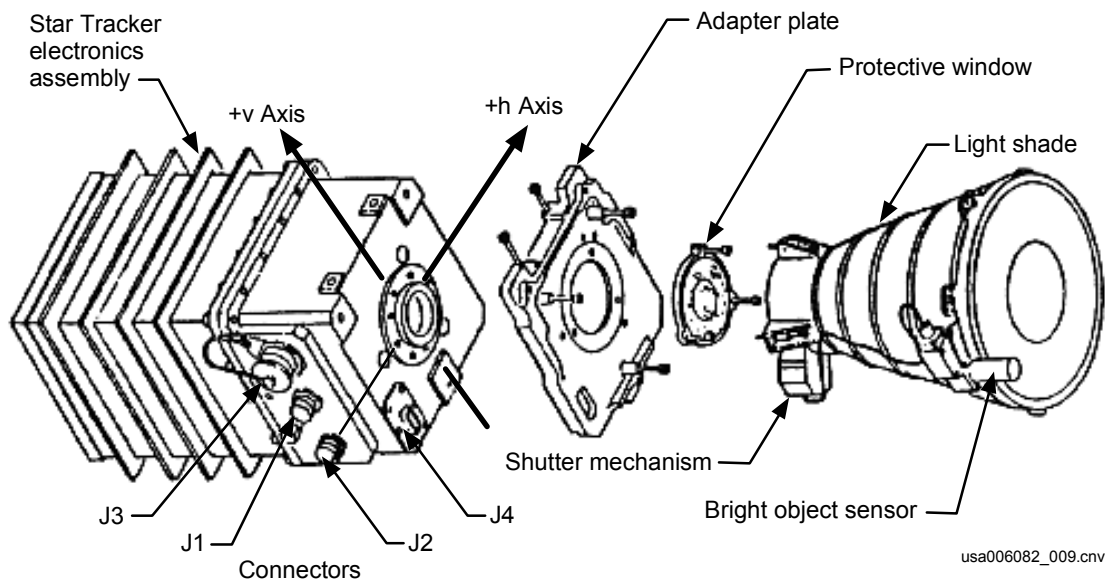


Figure 4-1. Star Tracker components

- IDT

An Image Dissector Tube (IDT) is a type of photomultiplier device in which the sensitive area can be sampled using electronic/magnetic scanning techniques. The image dissector tube is the heart of the ST subsystem (Figure 4-2). It takes the light from the object being scanned (i.e., a star or target) and after it goes through a series of deflections and accelerations, projects it onto an aperture plate.

To properly generate scan sequences for acquisition and tracking raster operation, it is necessary to apply transverse deflection fields in the drift space. These fields cause the complete electron spatial image to shift orthogonally to the field direction, and as this electron image passes over the aperture, the tube signal output varies

directly with the image intensity changes. Thus, the amount of current in the deflection coils required to deflect the beam through the aperture is a measure of the angular offset from the boresight of the optical image. Therefore, by scanning the photocathode in a regular pattern (full field), any optical image within the Field of View (FOV) can be located.

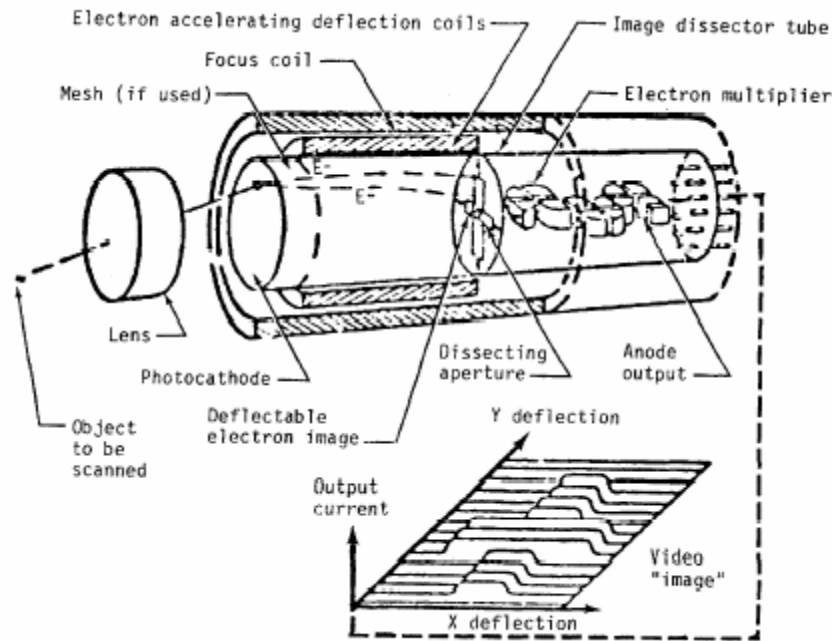


Figure 4-2. Image dissector tube

- SSST

The optics of the Solid State Star Tracker (SSST) reside in the head assembly, where the optics are mechanically controlled. The Star Tracker base is an aluminum structure designed for rigidity, and the lens assembly is heat-fitted into it. The lens contains six doublets with a focal length of approximately 72 mm. The focal plane assembly is mounted to the back of the Star Tracker base and shimmed into alignment and mounted onto the navigation base.

The detector assembly within the focal plane assembly contains the “eye” of the SSST (Figure 4-3). The Charge Coupled Device (CCD) imager is a light-sensing device. Charges accumulate under the image. The accumulation is proportional to the intensity and time interval while the light is present.

The SSST contains six electronic boards: Interconnect, Power Supply (PS), processor, focal plane, Communications Input/Output (CIO), and Tracker Utility Interface (TUI).

The interconnect board serves as an interface between electronic boards in the SSST. It is connected to the CIO, TUI, PS and processor. The processor, in turn,

talks directly to the interconnect board and also to the focal plane board. The processor is actually the brain of the SSST. It uses three types of memory and contains data such as calibration constraints and bit states.

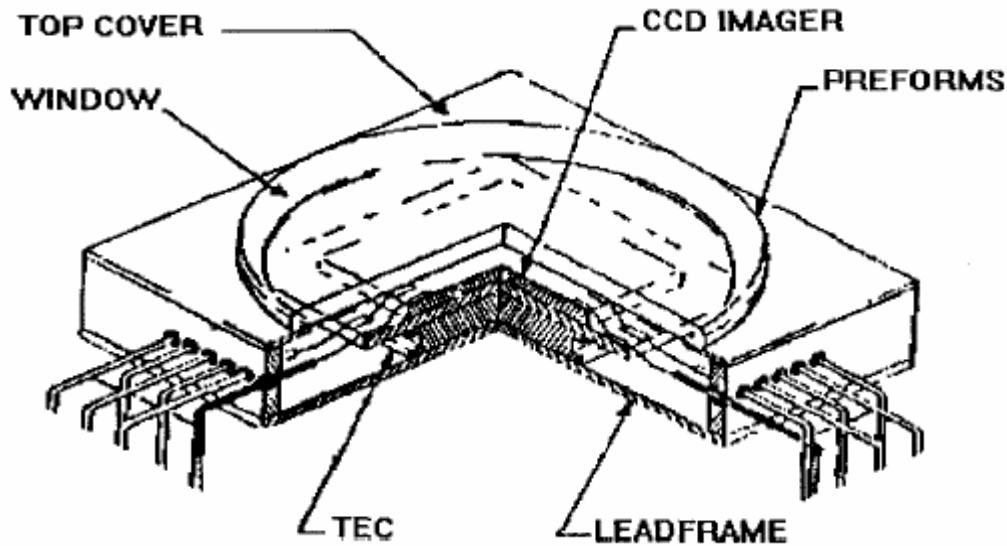


Figure 4-3. SSST detector assembly

4.2 COORDINATE SYSTEM

A right-hand orthogonal system consisting of Horizontal (H), Vertical (V), and boresight axes is used in the Star Tracker (Figure 4-4). The plane of the H and V axes is coplanar with the front face of the Star Tracker. The -Z Star Tracker is mounted such that the +V axis lies in approximately the same direction as the -Y shuttle body coordinate axis, and the +H axis lies in approximately the same direction as the +X shuttle body coordinate axis. These coordinates correspond to those displayed on Specialist Function (SPEC) 22 for -Z COAS use.

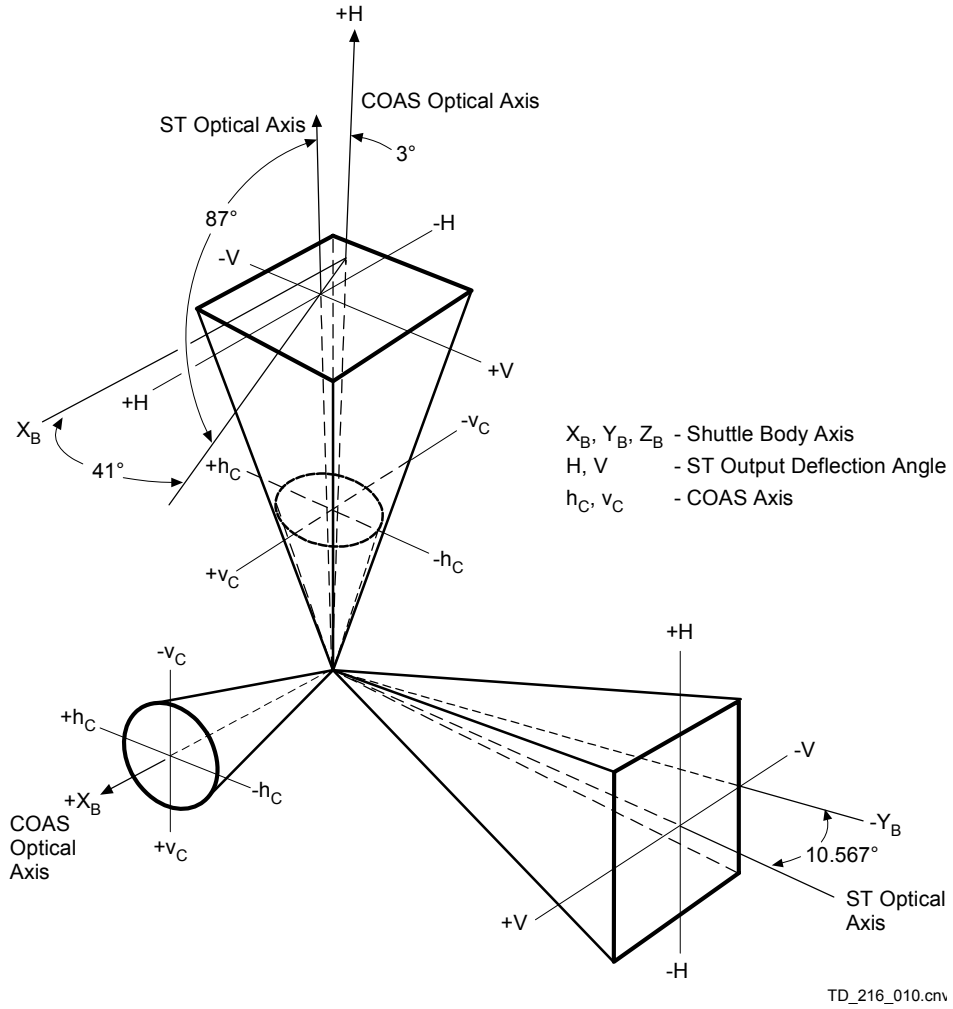
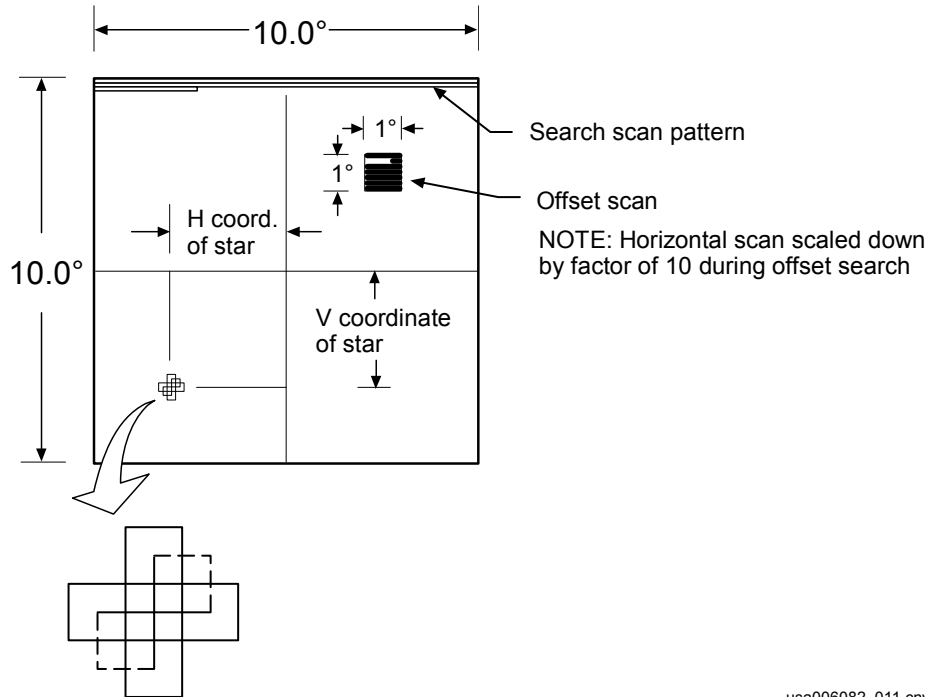


Figure 4-4. Coordinate system

4.3 OPERATING MODES

There are four operating modes of the Star Tracker subsystem.

- a. Full field scan. This is the normal operating mode and the one that will be entered when power is applied to the subsystem, provided no other mode is selected. In this mode the Star Tracker searches a $10^\circ \times 10^\circ$ FOV and acquires and tracks the first object that exceeds the threshold level (Figure 4-5).



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Figure 4-5. Scan geometry

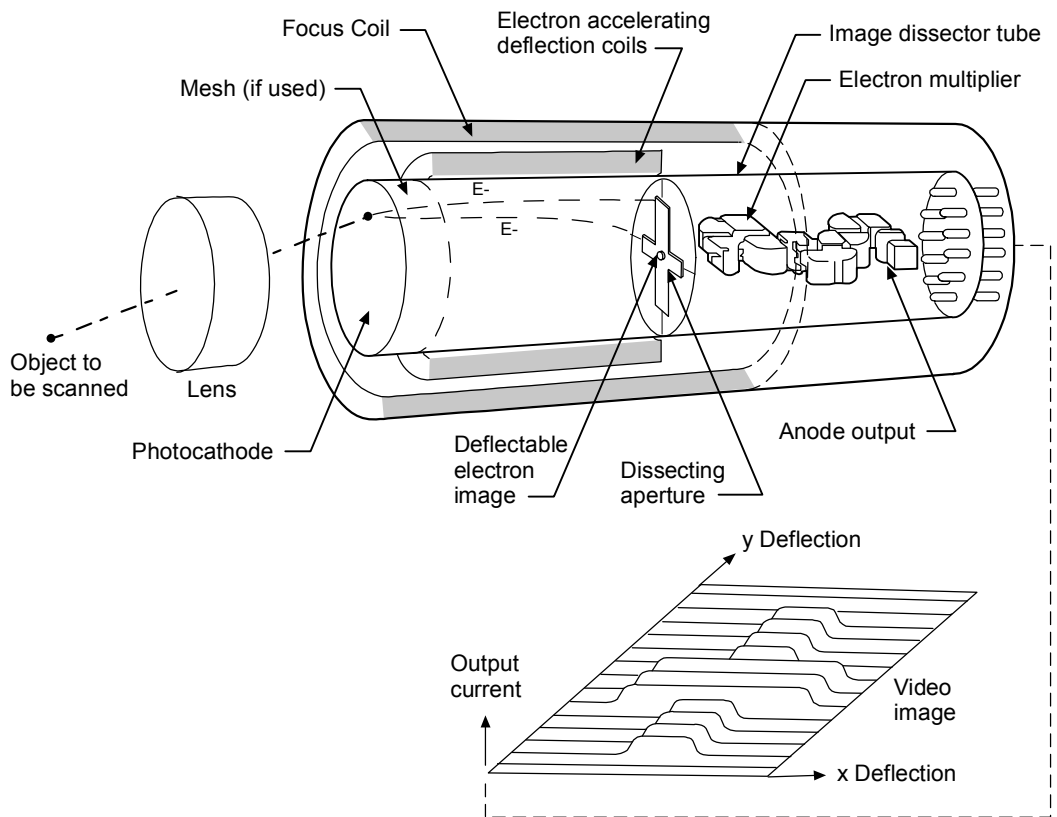
- b. Offset scan mode. When commanded by the GPC, the search area is reduced to a $1^\circ \times 1^\circ$ FOV. Along with the selection of this mode, the vertical and horizontal position of the search area must be specified by the GPC.
- c. Track scan mode. When the Star Tracker locates an object exceeding the threshold level, the vertical and horizontal scan is switched to a cruciform pattern centered on the object (Figure 4-5). The intensity of the object is monitored and the position of the cruciform pattern is altered to keep the pattern centered on the point of highest intensity. Tracking will continue as the object moves across the FOV at up to $0.2^\circ/\text{sec}$ with guaranteed accuracy and up to $0.5^\circ/\text{sec}$ at reduced accuracy.
- d. Self-test mode. In this mode, light from a simulated star is reflected from an aluminized spot on the inner surface of the protective window to a point displaced 4.25° horizontally and vertically. When this mode is selected, the subsystem is automatically placed in the offset mode until the simulated star is located. After acquiring the star, the angular position and magnitude are compared with internally

stored standards to verify subsystem accuracy. Should this internal test fail, an output word to the GPC denotes the failure.

4.4 IMAGE DISSECTOR TUBE

The IDT (Figure 4-6) is the heart of the Star Tracker subsystem. In the IDT, light from an object is focused on a photocathode, causing it to emit electrons. These electrons are focused into a beam and deflected through a hole in the dissection aperture by an electrical current flowing in the deflection coils. The amount of current required in the deflection coils to deflect the beam through the aperture is a measure of the angular offset from boresight of the optical image. Therefore, by scanning the photocathode in a regular pattern (full field), any optical image within the FOV can be located.

After passing through the hole in the dissection aperture, the electron beam enters the electron multiplier, where it is amplified to a usable level at the anode output. Acquisition of an image occurs when the output voltage exceeds a predefined detection threshold level. At this time the scan pattern is changed from a full field or offset scan pattern to a cruciform pattern, and automatic tracking of the object begins. Appendix F contains a generalized block diagram and description of the operation.



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Figure 4-6. Image dissector tube

The detection threshold level can be set to any of four levels by crew input. These levels control the sensitivity of the Star Tracker to star magnitude. Magnitude is a scale of star brightness that is logarithmic and decreases as a star's brightness increases. Visible stars are brighter than 5-6 magnitude. The Sun has a magnitude of approximately -26. A magnitude change of 5 indicates a hundredfold change in brightness. The four levels are defined as follows:

- a. Level 0. Maximum sensitivity level. Acquires objects brighter than +3 magnitude (150 to 153 stars)
- b. Level 1. Detects objects brighter than +2.4 magnitude
- c. Level 2. Detects objects brighter than +2 magnitude
- d. Level 3. Detects objects brighter than +1 magnitude.

The detection threshold level is defaulted to level 0 for normal star tracking operations.

4.5 BRIGHT OBJECT SENSOR

As illustrated previously in Figure 4-1, the BOS is mounted at the forward end of the light shield so that its FOV extends beyond that of the Star Tracker. The purpose of the BOS is to sense objects coming into the Star Tracker FOV that are so bright that they could damage the Star Tracker system. If the BOS detects an object brighter than a magnitude of -12 approaching at rates up to $10^\circ/\text{sec}$, it will close a mechanical shutter that protects the Star Tracker system. As a matter of reference, the Moon between the first and third quarters will close the shutter about 9° from the Star Tracker LOS, while a crescent Moon will not close it at all. A sunlit horizon will close the shutter at 14° to 17° from the LOS. The BOS will not close the shutter for objects dimmer than -8 magnitude. The BOS allows the shutter to open at specified limits from the Star Tracker LOS. The open limits are wider than the close limits, as indicated in Figure 4-7.

The mechanical shutter is spring loaded such that any loss of power to the BOS or to the Star Tracker will cause it to spring closed. In the case of loss of power to the BOS, the shutter can still be manually controlled by crew input.

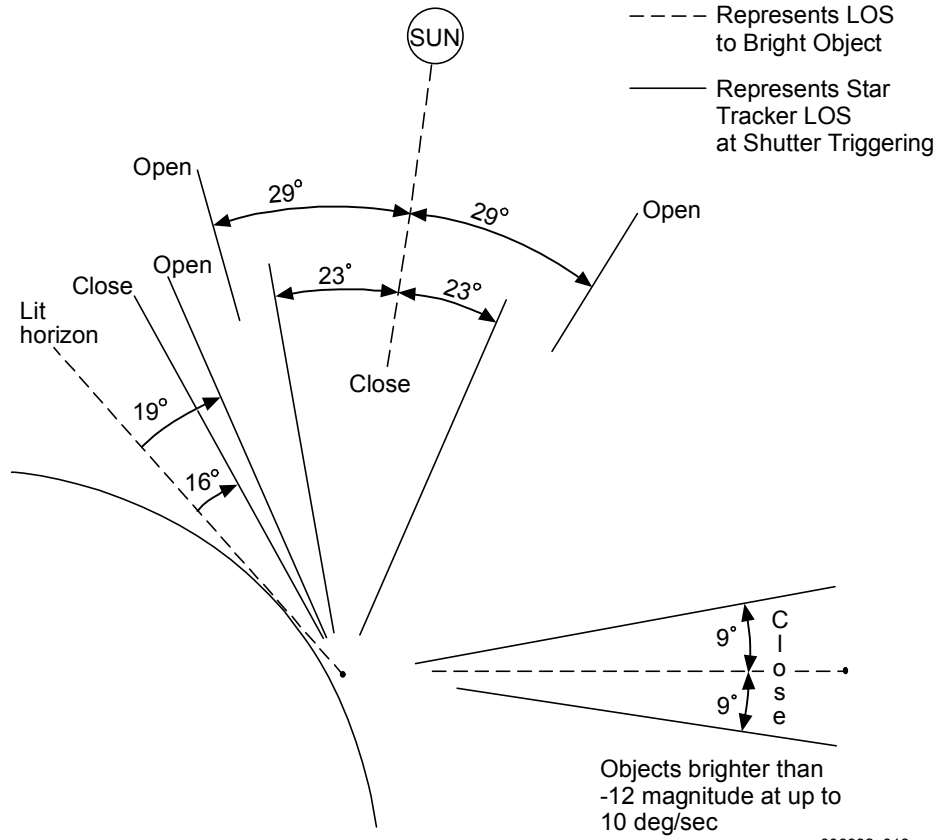


Figure 4-7. BOS operational limits

4.6 QUESTIONS

1. The bright object sensor
 - (a) Looks for bright objects to establish a reference
 - (b) Closes the Star Tracker shutter when a bright object is sensed
 - (c) Changes the gain of the Star Tracker
 - (d) Closes the Star Tracker door
2. How much time does it take to open the Star Tracker doors when both motors are operational?
 - (a) 6 seconds
 - (b) 60 seconds
 - (c) 12 seconds
 - (d) 45 seconds
3. The Star Tracker coordinate system is referenced to the
 - (a) GPC
 - (b) Rate gyro
 - (c) Nav base
 - (d) Accelerometer assembly
4. The desired output from the Star Tracker is
 - (a) Angle from boresight
 - (b) Image dimensions
 - (c) Image and angle from boresight
 - (d) None of the above

5. When commanded to the offset mode by the GPC, which of the following statements is true?
 - (a) The Star Tracker searches a $10^\circ \times 10^\circ$ field of view
 - (b) The Star Tracker searches a 1° square field of view
 - (c) The Star Tracker searches a 2° field of view
 - (d) The Star Tracker will search in this mode for 44 seconds
6. Which of the following statements is true?
 - (a) The crew has no control over the detection threshold level of the Star Tracker
 - (b) The MCC controls the detection threshold level of each Star Tracker
 - (c) There are four levels of detection threshold level control
 - (d) The detection threshold level can be controlled only for targets
7. Loss of Star Tracker power causes
 - (a) The Star Tracker doors to spring closed
 - (b) The shutter to spring open
 - (c) The Star Tracker circuit breaker to pop open
 - (d) The shutter to spring closed

See Appendix B for answers to questions in Section 4.

5.0 STAR TRACKER/COAS CONTROL DISPLAY (STAR TRACKER OPERATIONS)

SPEC 22 provides the control and monitoring capability required to operate and evaluate the Star Tracker and COAS units after the doors are opened and power is applied. It is illustrated in Figure 5-1.

This display is available in GNC Operational Sequence (OPS) 2 and OPS 3, Major Mode 301. It is called up using the keyboard to input SPEC 22 PRO. The lower right side of this display is used for HUD/COAS operations, and the rest, except the sighting table (upper right) depicts Star Tracker operation. The sighting table is shared by the Star Tracker and the HUD/COAS.

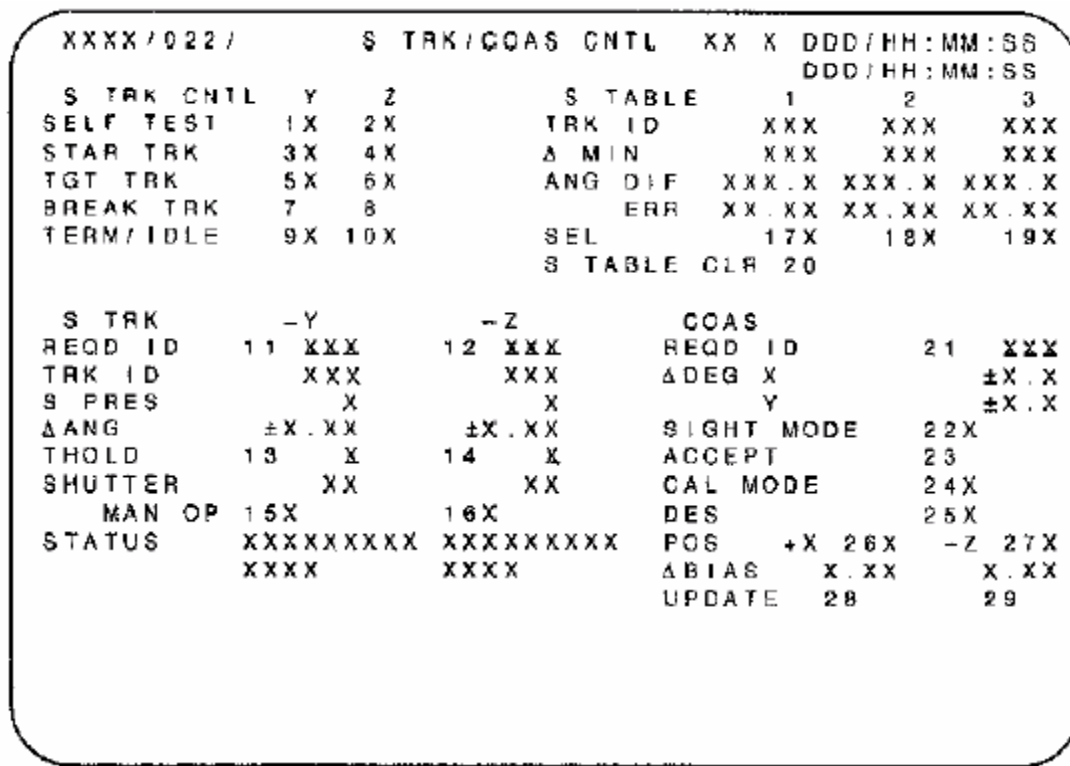


Figure 5-1. S TRK/COAS CNTL display

The upper left portion of the display (Figure 5-2) contains the controls required to select various Star Tracker submodes.

```

XXXXXXXXXX/022/          S TRK
S TRK CNTL   Y   Z
SELF TEST    1X  2X
STAR TRK     3X  4X
TGT TRK      5X  6X
BREAK TRK    7   8
TERM/IDLE    9X 10X
  
```

Figure 5-2. S TRK/COAS CNTL display (upper left portion)

- ITEMS 1 and 2 select the SELF TEST mode for the -Y and -Z Star Trackers.
- ITEMS 3 and 4 select the Star Track (STAR TRK) mode of operation.
- ITEMS 5 and 6 select the Target Track (TGT TRK) submode. The software will provide angular information for rendezvous computations.
- ITEMS 7 and 8 are used to force the Star Tracker to stop tracking (BREAK TRK) the star/target that it is locked on currently and to search the remaining commanded FOV (offset or total) for another star or target. This will be most useful during target tracking operations when an incorrect target is being tracked.
- ITEMS 9 and 10 select the Terminate/Idle (TERM/IDLE) submode. This submode stops all GPC commands to the hardware. The Star Tracker itself will continue to operate, but there will be no return of star data to the GPC. ITEMS 1, 3, 5, 9, and 2, 4, 6, 10 are mutually exclusive items. Both the crew and the GPC control ITEMS 7, 8, 9, and 10. It should be noted that any GNC OPS transition or OPS mode recall will default the Star Trackers to the TERM/IDLE submode. Executing an IMU alignment also modes the Star Trackers to TERM/IDLE to preclude entering star data in the Star Table (S TABLE) during the alignment. Below the submode controls, in the lower left-hand portion of the display, are data and controls to monitor and control Star Tracker functions (see Figure 5-3).

```

S TRK          -Y          -Z
REQD ID      11 XXX      12 XXX
TRK ID              XXX      XXX
S PRES              X        X
Δ ANG        ±X.XX      ±X.XX
THOLD        13 X       14 X
SHUTTER              XX      XX
MAN OP      15X       16X
STATUS      XXXXXXXXX XXXXXXXXX
            XXXX      XXXX

```

**Figure 5-3. S TRK/COAS CNTL display
(lower left portion)**

- ITEMS 11 and 12 are used to input the identification number (Required Identification (REQD ID)) of a star to be tracked. Stars currently in the GPC star catalog are numbered 11-110. The default value is always 0 when SPEC 22 is called. Commanding track with REQD ID equal to 0 results in GPC selection of a star that is currently within the FOV. See Appendix C for the star catalog.
- TRK ID displays the number that identifies the star or target that should be within the FOV.
- S PRES location contains an asterisk (*) when a star is Present (PRES) in the FOV.
- Δ ANG displays the Angle (ANG) between the expected LOS and the actual measured LOS. This angle represents the IMU misalignment error and Star Tracker system errors.
- ITEMS 13 and 14 are control inputs used to enter a magnitude threshold level for star tracking. As discussed earlier, possible inputs are 0, 1, 2, or 3. Default will be 0 when SPEC 22 is called and after the Star Tracker has locked on to the star/target.
- SHUTTER indicates shutter position (OP for open; CL for closed) for each Star Tracker. This does NOT indicate door position.
- ITEMS 15 and 16 inhibit the automatic shutter mode for the appropriate Star Tracker, causing it to be commanded open and to remain open. Reexecution of ITEMS 15 or 16 returns automatic control.

- Below the shutter controls, status information for both Star Trackers is displayed. The status information will be blank or display any one of the following items for the period of time that the condition exists:

ST FAIL	Indicates a SELF-TEST failure.
ST PASS	Indicates a completed SELF-TEST with no detected failures.
OUT FOV	Indicates that the required star is not in the Star Tracker FOV or that it is already in the S TABLE.
HIGH RATE	Indicates that the star/target is passing through the FOV at an excessive rate >0.75 deg/sec).
NO TARGET	Indicates that the desired star/target has not been detected.
FALSE TRK	Indicates that an incorrect star/target has been tracked.

- Below the status display is the Built-In Test Equipment (BITE) output location. During normal operation, BITE is displayed for any of the following conditions:

- Star Tracker depressurization
- Bit count error
- Manchester invalid
- Parity error

During SELF-TEST operation, BITE can be displayed for the following conditions, in addition to the above:

- SELF-TEST mode failure
- SELF-TEST angle error
- SELF-TEST magnitude error
- Bright Object Alert (BOA) failure
- Optics shutter failure
- Star presence indication failure

Refer to Appendix F for a BITE hardware diagram.

Located in the upper right-hand corner of the display is the Star Table (S TABLE) (Figure 5-4). It is used to monitor and control the data available to the GPC for IMU alignments.


```

/COAS CNTL  XX X DDD/HH:MM:SS
                DDD/HH:MM:SS
  S TABLE      1      2      3
TRK ID          XXX   XXX   XXX
Δ MIN           XXX   XXX   XXX
ANG DIF        XXX.X  XXX.X  XXX.X
  ERR          XX.XX  XX.XX  XX.XX
SEL             17X   18X   19X
S TABLE CLR 20

```

**Figure 5-4. S TRK/COAS CNTL display
(upper right portion)**

- TRK ID indicates star ID (11 to 110) associated with each star in the table.
- Δ MIN indicates the age of each input in minutes.
- ANG DIF displays the measured separation angle between two stars in the table. The ANG DIF in column 1 represents the separation angle between stars in columns 1 and 2; in column 2, between stars in columns 2 and 3; and in column 3, between stars in columns 3 and 1.
- ANG ERR is defined as the difference between the actual star separation angle (calculated from the star catalog) and the ANG DIF computed from Star Tracker measurements.
- ITEMS 17, 18, and 19 are controls to select a star pair to be used by the software to compute alignment data.
- ITEM 20 (S TABLE CLR) is used to eliminate all sighting data currently in the table. The S TABLE will automatically clear at the termination of any IMU alignment.

6.0 SOFTWARE PROCESSING

6.1 SELF-TEST

A Star Tracker self-test tests the Star Tracker hardware and BITE. The hardware self-test closes the shutter and activates a Light-Emitting Diode (LED), the light of which is reflected by an aluminized spot on the inner window, producing an optical input at a predefined set of angles and at a given magnitude. The hardware measures these angles and magnitude, compares the measurements against a standard, and outputs a fail or pass status.

SELF-TEST also issues several commands that are checked for proper hardware responses. For instance, during one portion of the test, forced self-test fail output from the hardware causes a BITE indication.

It may take up to 7 seconds to run a self-test on one Star Tracker. If both are commanded to self-test, the first one must finish its self-test before the other can start. Self-testing both units takes approximately 10 seconds. At the completion of the self-test, a status of ST PASS or ST FAIL is displayed.

See Appendix E (Figure E-8) for an ST self-test flow diagram.

Figure 6-1 is an example of the crew procedure for performing a self-test on the Star Trackers. This procedure is located in the Orbit Ops Checklist of the Flight Data File (FDF).

```

S TRK SELF-TEST, GNC 201,202,301

Mnvr to avoid bright objects in both BOSs

GNC 22 S TRK/COAS CNTL
CRT  √S TRK -Y,-Z: STATUS  - (no BITE)
      SHUTTER - OP

      * If SHUTTER - CL          *
      * ITEM 15(16) - EXEC (*)  *
      * ITEM 15(16) - EXEC (no *) *

SELF-TEST - ITEM 1,2 EXEC (*)
√S TRK -Y,-Z: SHUTTER - CL
      S PRES  - (*)
      STATUS  - BITE (mom)
      SHUTTER - OP
      STATUS  - ST PASS

      * If STATUS - ST FAIL, repeat *
      * SELF-TEST                    *
      * If still FAIL, use only if directed *
      * by MCC                        *

STAR TRK - ITEM 3,4 EXEC (*)

```

Figure 6-1. S TRK SELF-TEST cue card

6.2 STAR TRACK

The Star Track software controls the function and inputs to the Star Tracker from initiation of star tracking to completion. As part of the operation, it compares Star Tracker data to preset limits to verify their validity. (See flow diagram in Appendix E.)

There are three modes of star tracking that can be done, based upon the REQD ID:

- a. If no REQD ID is entered, the default value of 0 will remain in the space for each Star Tracker. With initiation of STAR TRK, an automatic star data collection ("star of opportunity") mode will be entered, in which the GPC will continually cycle through the star catalog to determine whether a star is within the FOV. If a star is present, the GPC will track it and enter data into the S TABLE. In this mode, when the table is filled, old data will be dropped as new data are entered. This mode continues until commanded otherwise (crew input, OPS transition, etc.).
- b. If a REQD ID = 0 is entered by the crew, the star catalog will be cycled through once. Any catalog star within the FOV will be tracked and data stored in the table. Upon completion of one cycle through the star catalog, the Star Tracker will mode to TERM/IDLE.
- c. If a REQD ID = "desired star number" is entered by the crew, the GPC checks to see if the star is within the FOV. If it is, the star is tracked, data are stored in the table, and the Star Tracker modes to TERM/IDLE. If it is not, the status message OUT FOV is displayed, and the Star Tracker modes to TERM/IDLE.

Star Tracker software is initiated by commanding the STAR TRK mode. The GPC looks up the vector to the star and compares it with the Star Tracker boresight vector. If the difference exceeds 5° , the requested star is out of the FOV. This is displayed on the status line and the Star Tracker software is moded to TERM/IDLE. If it is within the FOV, the software issues the properly formatted offset commands to the Star Tracker to search a particular portion of the FOV; i.e., where the GPC thinks the star should be, and outputs a TRK ID equal to the REQD ID.

The software waits 4 seconds while the Star Tracker searches a $1^\circ \times 1^\circ$ FOV four times. If it does not acquire a star, the GPC removes the offset command and searches the total FOV, $10^\circ \times 10^\circ$, four times. If it still does not acquire the proper star after 40 seconds, it will output the status message NO TARGET. If the Star Tracker acquires a star in either of the search periods, it outputs the "star present" asterisk. At this time, it also calls a data filter module that develops a horizontal and vertical average angle, timetag, and vertical and horizontal rate information; however, if the shuttle body rates exceed 0.75 deg/sec, the status message HI RATE is output.

If the rates are within tolerance, the GPC checks the relative rates and measured LOS versus calculated LOS. If the star is confirmed, the data go into column 1 and push the first star into column 2. At this time, ANG DIF and ANG ERR will be displayed in column 1 for these two stars. ANG DIF is the separation angle between the two stars, and ANG ERR is the difference between the actual separation angle and the calculated separation angle. The GPC checks the separation angle to see if it is between 35° and 145°. If it is, asterisks are placed beside ITEMS 17 and 18, and ALIGN ENA appears on the IMU ALIGN display (SPEC 21). If a third star is now tracked and confirmed, it will shift into column 1, shifting column 1 data to column 2 and column 2 data to column 3. ANG DIF and ANG ERR are now displayed in all three columns. The ANG DIF and ANG ERR in column 2 are for stars in columns 2 and 3, and ANG DIF and ANG ERR in column 3 are for the stars in column 3 and column 1.

The GPC selects two stars with a separation angle (ANG DIF) closest to 90° by activating an asterisk beside two of the three ITEMS (17, 18, 19). The crew may change this selection by first entering the item number they want to deselect, then entering the item number they want to select.

In the “star of opportunity” mode, the Star Tracker will continue to search for stars. If another star is tracked by GPC command after there are three stars in the table, the new star will be compared to each star in the table to determine whether its separation angle is closer to 90°. If it is, the GPC will save the new star and the one it makes the angle with and delete the older of the two remaining stars. The new star is then entered in column 1 and the data and current star pair selected for IMU alignment are displayed.

The GPC has one additional criterion for determining which stars appear in the S TABLE: If the data on one or more stars are 60 minutes old or older, as shown in the Δ MIN slot, they will be deleted with the next star input. Therefore, the S TABLE will always select the star pair closest to 90° that is less than 60 minutes old.

The previous description of software operation illustrates the need for the capability to clear the S TABLE (ITEM 20). If there is a good angle between two stars, but one or both of them are quite old (45 to 60 minutes), new star data cannot be taken if the old star data are closer to 90°, unless the S TABLE (ITEM 20 EXEC) is cleared and tracking is restarted.

Figure 6-2 is an example of a crew procedure for collecting star data for an IMU alignment. This procedure begins by assuming that the desired stars have been chosen beforehand and that the shuttle has been maneuvered to the proper attitude for tracking by each Star Tracker. This procedure is located in the Orbit Ops Checklist.

IMU ALIGN – S TRK, GNC 201,202,301

1. COLLECT STAR DATA

√In attitude

GNC 22 S TRK/COAS CNTL

S TABLE CLR – ITEM 20 EXEC

√STAR TRK – ITEM 3,4 (*)

√S TRK -Y,-Z: STATUS – (no BITE)
SHUTTER – OP

- * If SHUTTER – CL: *
- * √Attitude, MET correct *
- * Visually verify no bright object in FOV *
- * After data collected and before changing *
- * attitude, return shutter to AUTO *
- * To open shutter: *
- * MAN OP – ITEM 15(16) EXEC (*) *
- * To return shutter to AUTO: *
- * MAN OP – ITEM 15(16) EXEC (no *) *

2. VERIFY STAR DATA

√S TABLE: TRK ID 1,2 correct #s

ANG ERR 1 ≤ 0.08

SEL, ITEM 17,18 – (*)

Wait ~1 min for new IMU ΔANGs

- * If no data after 3 min or bad data: *
- * Repeat step 1 *
- * √Attitude, start, MET correct *
- * √S TRK -Y,-Z: TRK ID: correct #s *
- * ΔANG: < 1.0 *
- * If still no data or bad data: *
- * Perform S TRK SELF-TEST, then: *
- * If both STATUS – ST FAIL: *
- * | Inform MCC before proceeding *
- * If both STATUS – ST PASS: *
- * | Repeat step 1 at new att, stars *
- * If one STATUS – ST PASS: *
- * Perform single tracker steps *

- * Single tracker procedure *
- * √TERM/IDLE, ITEM 9(10) – (*) *
- * Good S TRK, STAR TRK – ITEM *
- * 3(4) EXEC (*) *
- * S TABLE CLR – ITEM 20 EXEC *
- * √S TABLE: TRK ID 1 correct # *
- * Good S TRK, TERM/IDLE – ITEM *
- * 9(10) EXEC (*) *
- * Mnr to second attitude, star *
- * Good S TRK, STAR TRK – ITEM *
- * 3(4) EXEC (*) *
- * Repeat step 2 with good S TRK only *

Figure 6-2. IMU ALIGN procedure

6.3 IMU ALIGN

IMU alignment is accomplished using controls on the IMU ALIGN display (SPEC 21) (see Figure 6-3). This display is available in OPS 2 and OPS 3.

The following items and data in the upper right-hand corner of SPEC 21 are used during IMU alignments using star data.

- ENA will appear to the right of ALIGN if there are good star data (usable for an alignment) in the S TABLE on SPEC 22 and a pair has been selected for use in alignment (asterisk beside two Select (SEL) item numbers).
- ITEMS 10, 11, and 12 allow crew selection of IMU or IMUs to be aligned. Item number execution places an asterisk beside the item number of the IMU selected, indicating selection for alignment.
- ITEM 13 (STAR ALIGN) will appear with an asterisk beside it each time the display is called. This indicates that the IMUs will be aligned using data in the S TABLE.
- ITEM 14 and 15 select other means of aligning IMUs that are explained in the IMU workbook.
- ITEM 16 (EXEC) begins the selected alignment mode for the selected IMUs. An asterisk will appear upon execution of the alignment and disappear upon completion.
- ITEM 17 (TERM) allows crew termination of an alignment at any time. Alignments normally terminate automatically.

In the lower left-hand corner of SPEC 21 are more data of interest during alignment operations.

- ANG ΔX , ΔY , and ΔZ indicate torquing angles through which IMUs must traverse to become aligned. These angles will appear when at least two stars are in the S TABLE and two are selected for use in alignment. The angles will decrease to 0 as the alignment progresses. The torquing rate is 0.022 deg/sec. The IMU with the largest torquing angle will take the longest time, and when completed, ENA will disappear from beside ALIGN at the top right side of the display, as will the asterisk beside ITEM 16. Also, on SPEC 22, at completion of the alignment, the S TABLE will be cleared of all data.

```

XXXX/021/          IMU ALIGN          XX X DDD/HH:MM:SS
IMU                DDD/HH:MM:SS

      1S      2S      3S
STAT XXXX XXXX XXXX          ALIGN XXX
TEMP  XX   XX   XX          IMU 1 10X REF STAR 13X
STBY  21X  22X  23X          2 11X          IMU 14 X
OPER  4X   5X   6X          3 12X TYPE 15 XXXXXX
DES   7X   8X   9X

                                EXEC 16X
                                TERM 17

ACC
      1      2      3
X  ±X.XX ±X.XX ±X.XX          IMU BITE MASK
Y  ±X.XX ±X.XX ±X.XX          1 XXXX 24X
Z  ±X.XX ±X.XX ±X.XX          2 XXXX 25X
                                3 XXXX 26X

ANG
      1      2      3
X  XXX.XX XXX.XX XXX.XX
Y  XXX.XX XXX.XX XXX.XX          NAV ΔV THRESH
Z  XXX.XX XXX.XX XXX.XX          18 XXXXXXXX
ΔX ±XXX.XX ±XXX.XX ±XXX.XX
ΔY ±XXX.XX ±XXX.XX ±XXX.XX          MM READ 19X
ΔZ ±XXX.XX ±XXX.XX ±XXX.XX

```

(XX)

Figure 6-3. IMU ALIGN typical display

Figure 6-4 is an example of a crew procedure for an IMU alignment using star data previously collected. It is located in the Orbit Ops Checklist.

3. CHECK IMU ΔANGs

GNC 21 IMU ALIGN

IMU 1,2,3: STAT – blank

√REF STAR, ITEM 13 – (*)

√TYPE, ITEM 15 – TORQUE

√ANG 1,2,3: $\Delta X, \Delta Y, \Delta Z \leq 0.50$

If no comm, record ΔANGs

* If ANG $\Delta X, \Delta Y, \Delta Z > 0.50$ for two or *

* more IMUs, repeat steps 1,2,3 *

CAUTION

If ANG $\Delta X, \Delta Y, \Delta Z$ still > 0.50 for two or more
IMUs, DO NOT TORQUE PLATFORMS
EXCEPT UNDER MCC INSTRUCTIONS

4. ALIGN IMUs

ALIGN IMU 1(2,3) – ITEM 10(11,12) EXEC (*)

EXEC – ITEM 16 EXEC (*)

√EXEC, ITEM 16 – (no *)

ALIGN IMU 1(2,3) – ITEM 10(11,12) EXEC (no *)

If not deorbit align >>

5. D/O ALIGN VERIFICATION

When D/O align complete, mnvr to VERIF ATT
(FLIGHT PLAN, Detailed Timeline), perform
steps 1,2 using verif stars

√IMU 1,2,3 ANG $\Delta X, \Delta Y, \Delta Z < 0.1$

* If ANG $\Delta X, \Delta Y, \Delta Z \geq 0.1$, √MCC *

* If no comm, repeat steps 1-5 *

Figure 6-4. IMU alignment cue card

6.4 STAR TRACKER PROCESSING CONTROL RULES

Star Tracker software processing control rules are as follows:

- When SPEC 22 is called up in an OPS, releasing the SPEC will not terminate Star Tracker operation. It remains active in the same mode as when released.
- Initial callup during orbit will be in the TERM/IDLE mode. Any subsequent OPS mode transitions or recalls cause the mode to return to TERM/IDLE. Execution of an IMU alignment on SPEC 21, or selecting a COAS submode on SPEC 22, will mode the Star Trackers to TERM/IDLE.
- The software will remain active until termination of the OPS sequence.
- Star Tracker and COAS operations cannot occur simultaneously.
- No ITEM entries or executions may be made on SPEC 22 during an IMU alignment. Attempts to do so will result in an ILLEGAL ENTRY fault message.
- If the current attitude source IMU is misaligned by more than 1.4° , the star tracking software will not accept stars. An alignment using star data collected by the HUD or COAS will have to be done.

6.5 QUESTIONS

1. SPEC 22 (S TRK/COAS CNTL) and SPEC 21 (IMU ALIGN) are available during
 - (a) All of OPS 1 and OPS 2
 - (b) All of OPS 2 and OPS 3
 - (c) All of OPS 2 and 301
 - (d) OPS 1 and OPS 3
2. The “star of opportunity” mode
 - (a) Fills the S TABLE with three stars and modes the Star Tracker to TERM/IDLE
 - (b) Selects any star within the FOV for input to the table
 - (c) Searches through the star catalog once for stars in the FOV
 - (d) Continually cycles through the star catalog searching for stars to track that are within the FOV
3. Δ ANG is the
 - (a) Difference between the measured vector and calculated vector to a star
 - (b) Difference between this star and previous star
 - (c) Angle to be added to star vector
 - (d) Angle to be subtracted from star vector
4. How many stars are in the star catalog?
 - (a) 151
 - (b) 100
 - (c) 60
 - (d) 150

5. What is the REQD ID to command auto star data collection?
 - (a) A crew input of 0
 - (b) 1
 - (c) 11
 - (d) 60
 - (e) A default 0
6. Activating ITEM 15 MAN OP for the shutter causes which of the following?
 - (a) -Y door opens.
 - (b) -Y shutter opens and disables BOS.
 - (c) -Y Star Tracker BITE.
 - (d) Forced manual tracking of stars.
7. The ANG DIF and ANG ERR in column 2 relate to the angles between which stars?
 - (a) Column 1 and column 2
 - (b) Column 2 and column 3
 - (c) Column 3 and column 1
 - (d) Column 2 and a newly collected star not yet in the table
8. ITEM numbers 17, 18, 19
 - (a) Require crew selection to activate
 - (b) Reflect GPC or crew selection of stars
 - (c) Show the two best ANG DIF and ANG ERR
 - (d) Show the two newest stars in the table

9. S TABLE CLEAR, ITEM 20
- (a) Clears the whole table
 - (b) Clears the newest star
 - (c) Clears the oldest star
 - (d) Selectively clears one star

See Appendix B for answers to questions in Section 6.

7.0 HEADS-UP DISPLAY

7.1 INTRODUCTION

The Heads-Up Display (HUD) system is designed to provide the crew with a display of flight-critical information with a minimum of eye movement away from the windows. Its primary use is during the approach and landing phase where runway-related information can be displayed on the HUD to aid the crew in landing. Its function on orbit, however, is as the main backup device to the Star Trackers for performing IMU aligns. There are two HUD systems installed in each orbiter, one on the left, or Commander (CDR) side, and one on the right, or Pilot (PLT) side.

7.2 HUD ELECTRONICS

The HUD's electronic support units are 16K x 24 Programmable Read-Only Memory (PROM) miniprocessors that are physically located in forward avionics bay 3. These units process data, generate display symbols, and provide deflection voltages for symbol positioning on the display unit. An exploded view of the electronics unit is shown in Figure 7-1.

Dedicated display data used by the HUD display and electronics unit are acquired directly from flight-critical data buses 1 to 4.

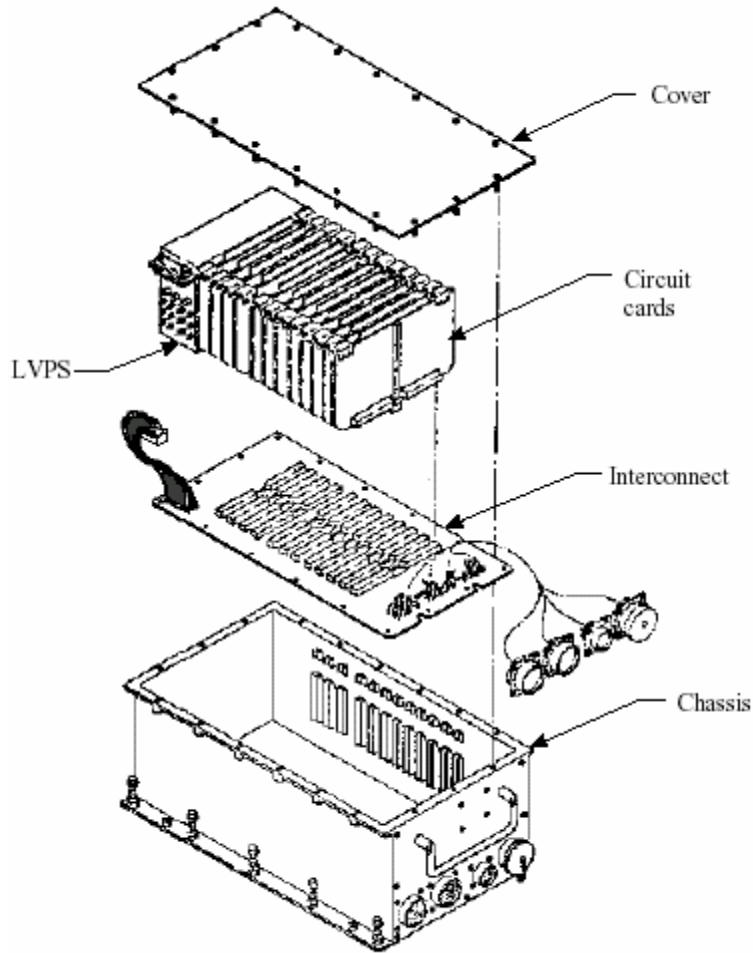


Figure 7-1. HUD exploded view

7.3 DESCRIPTION OF HUD DISPLAY UNIT

The display units themselves are located in the instrument panels in front of the CDR and PLT. They consist of an elongated box assembly, which contains a high voltage power source, X- and Y-deflection amplifiers, a small 4-inch exit diameter Cathode Ray Tube (CRT), and a series of mirrors and lenses. Affixed to the top of the box is a dual combiner lens assembly positioned in the LOS from the pilot's eye through the forward windows. It is shown in Figure 7-2 and Figure 7-3.

Symbols and deflection voltages are used to generate and position the HUD symbology in the CRT. The CRT images are then transmitted through the series of mirrors and lenses that focus them at infinity and project them on the combiner lenses. These lenses reflect the images toward the pilot's eyes while passing outside light rays. Because the images are focused at infinity, head movement does not affect the symbol position with respect to outside light.

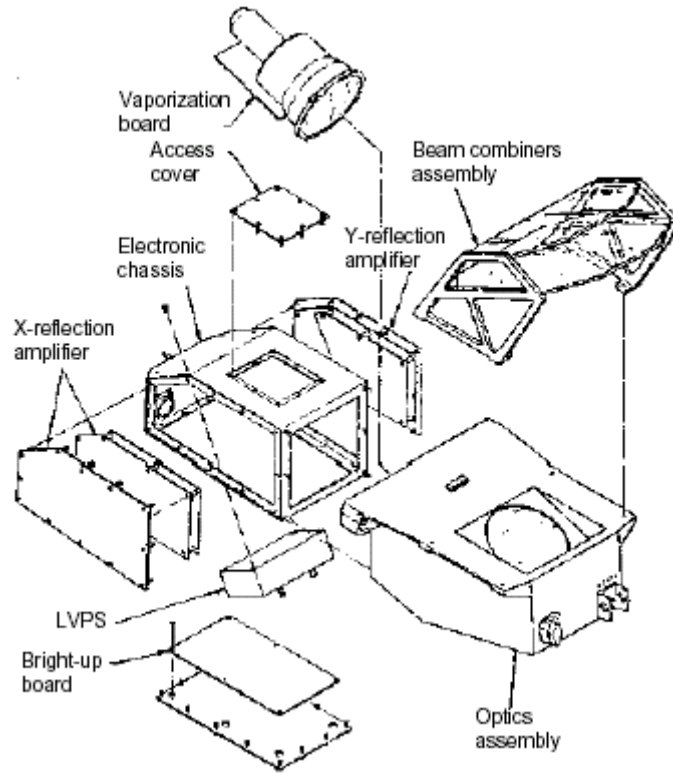


Figure 7-2. Pilot's display unit

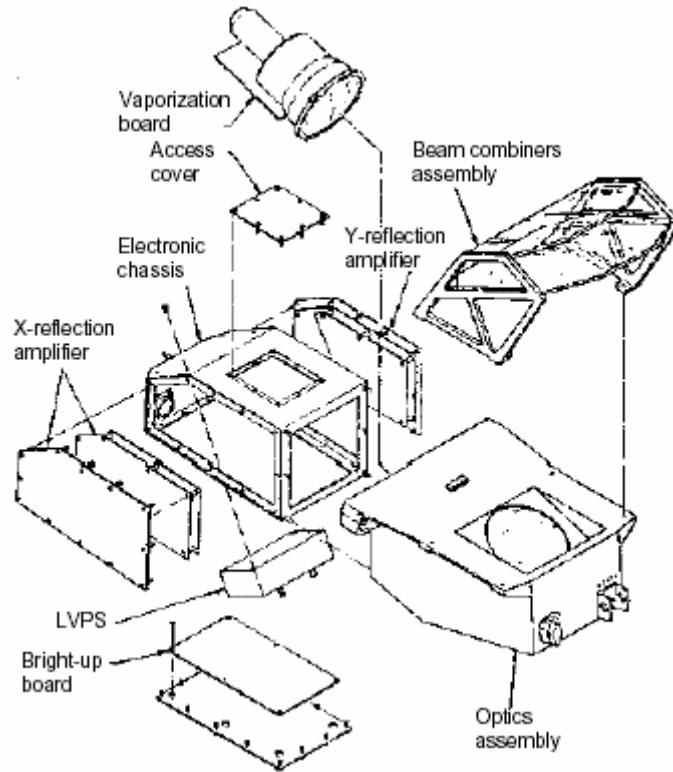


Figure 7-3. Optics chassis

7.4 POWER

HUD system powerup is provided through a switch (Figure 7-4) mounted inboard of the display unit on Panel F3. Power for the CDR's HUD is from Main A through Control Bus AB2. Power for the PLT's HUD is from Main C through Control Bus BC1.

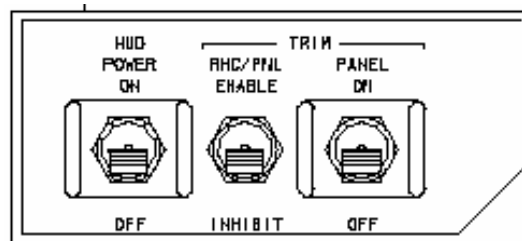


Figure 7-4. HUD POWER switch

7.5 MODES

A three-position mode switch is located on the front of the display unit. Switch positions are: up-TEST, center-NORM, and down-DECLUTTER (DCLT). The DCLT position is a momentary contact; the switch is spring loaded to return from that position. In the NORM position, automatic sequencing of formats and symbology within the formats is provided. In the TEST position, a test pattern is forced up on the display unit (Figure 7-5). This is a series of lines and circles that move and form certain patterns,

breaking and forming up again. When the entire test is over, the word “COMPLETE” appears on the display. It is the word “COMPLETE” in the pattern that is used in performing the HUD calibrations and sightings on orbit.

When the crew has completed the procedure and can see the correct star to be used for a calibration or sighting out the front window of the orbiter, the orbiter is flown to center the star within the “P” in the word “COMPLETE”. This will be used as the boresight for establishing a LOS, which is described in the next section.

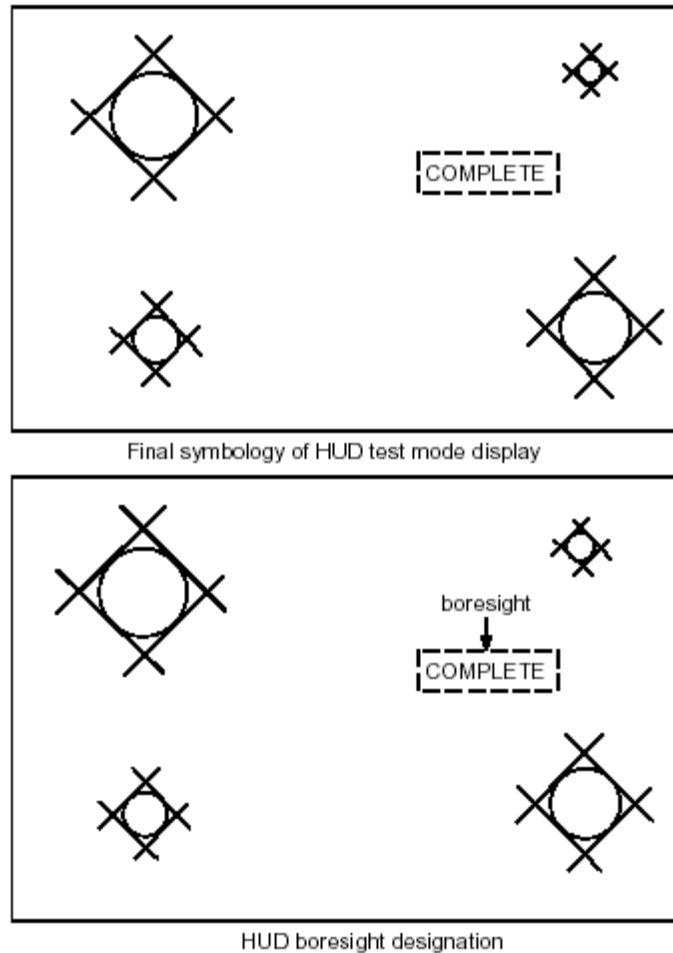


Figure 7-5. HUD test pattern

7.6 ESTABLISHING A LINE OF SIGHT

To establish a LOS to a star, the Attitude Reference (ATT REF) pushbutton is used to inform the GPC software when a star has been correctly sighted. Located on Panels A6 and F6 is an attitude reference pushbutton. One of its functions is to send a discrete to the GPC telling it to snapshot an LOS vector at the current vehicle attitude. These buttons are the ATT REF pushbuttons. The COAS mode must be selected on SPEC 22

for the ATT REF pushbutton to have this function; otherwise, its function is Attitude Direction Indicator (ADI) reference definition.

Each ATT REF pushbutton is within easy reach of a crewmember sighting through a HUD in the +X or -Z position. Each is positioned such that it can be depressed with the left hand while the crewmember sights through the HUD as he maneuvers the shuttle using the RHC with the right hand. The ATT REF pushbutton on Panel F8 can also be used through coordination with another crewmember. While in a COAS mode, the ATT REF pushbutton does not control the ADI. The action of sighting on a star and depressing the ATT REF pushbutton is often referred to as “marking on a star.” When the crewmember has the star correctly positioned within the “P” in the test pattern, he/she will press the ATT REF pushbutton, marking on the star and sending the data to the GPC. This is usually done at least three times to ensure accuracy.

7.7 HUD CALIBRATION

Figure 7-6 is an example of the crew procedure to calibrate the HUD. This requires the crew to sight on a star, incorporate the delta bias into the software, and verify the accuracy by resighting on the same star. This procedure clearly describes how to perform the calibration; it is found in the Orbit Ops Checklist.

Mnvr to center star in HUD boresight:
(Center of 'P' in 'COMPLETE', see HUD
BORESIGHT DESIGNATION, 7-12) |
ATT REF pb – push

Note Δ BIAS value

NOTE

Take minimum three verif marks
to ensure Δ BIAS consistency

If Δ BIAS < 0.12 for at least three marks, go to step 5

DAP: A1/AUTO/VERN
B5/AUTO/PRI (loss of VERNs) |

3. CALIBRATE HUD

Rcd CAL +X Δ BIAS: _____
UPDATE – ITEM 28 EXEC,
Rcd MET ____/____:____

$\sqrt{\Delta}$ BIAS goes to zero

4. CONFIRMATION OF CALIBRATION |

NOTE

DAP in INRTL or FREE as desired for taking
marks. For loss of VERNs, use B5/FREE/PRI

DAP: A1/INRTL(FREE)/VERN (for COARSE CNTL)

Mnvr to locate star

DAP: B5/INRTL(FREE)/VERN (for FINE CNTL) |

Mnvr to center star in HUD boresight:
ATT REF pb – push

Figure 7-6. HUD CALIBRATION procedure (continued)

NOTE

Take minimum three verif marks
to ensure Δ BIAS consistency

$\sqrt{\Delta}$ BIAS < 0.12

* If majority of Δ BIAS > 0.12, repeat *
* steps 3 and 4. If Δ BIAS still > 0.12, *
* \sqrt{MCC} *

5. CLEAN UP

COAS: DES – ITEM 25 EXEC (*)
HUD MODE – NORM
PWR – OFF
FLT CNTLR PWR – OFF

cb DDU L(R) (two) – as reqd

If S TRK(s) to be left in auto star-select mode:

S TRK(s) -Y(-Z) – ITEM 3(4) EXEC (*)

Install L(R) HUD Cover

Reconfig to FLIGHT PLAN DAP

Figure 7-6. HUD CALIBRATION procedure (concluded)

8.0 CREW OPTICAL ALIGNMENT SIGHT INTRODUCTION

The COAS (see Figure 8-1) is used as a backup to the Star Tracker for aligning the IMUs if no HUD is available. The -Z COAS is used for tracking targets during rendezvous, such as ISS, and may also be used to provide visual cues for attitude burns.

As discussed earlier in the Star Tracker section of this workbook, the Star Tracker software will not accept stars for IMU alignments if the stars are more than 1.4° away from where the GPC thinks they should be. Therefore, if the IMUs become misaligned by more than 1.4° , another method of tracking stars is needed. The COAS can be used as an alternate method of star tracking. Like the Star Trackers and the HUD, the COAS is used to establish a line of sight vector to a star, thereby enabling determination of the orientation of the IMUs with respect to the stars. It can serve as a method of coarse alignment with the Star Tracker completing with a fine alignment, or it can be the redundant method in case of failure of both Star Trackers and/or both HUDs.

As with the HUD, using the COAS requires some knowledge of nav star locations in the sky because its application as a contingency method of IMU alignment implies there may be no attitude reference to aid in star sighting. The Flight Maps and Charts of the FDF contain rectangular and polar star charts to aid in nav star location.

The COAS used on the shuttle is a modified unit developed for Apollo. Modifications included changing the reticle dimmer and the mounting so that repetitive mount/demount cycles have little effect on sighting accuracy. Flight experience has shown that this is the case.

The only interface between the COAS and other shuttle systems is an electrical connection to power a light that illuminates a reticle in the barrel.

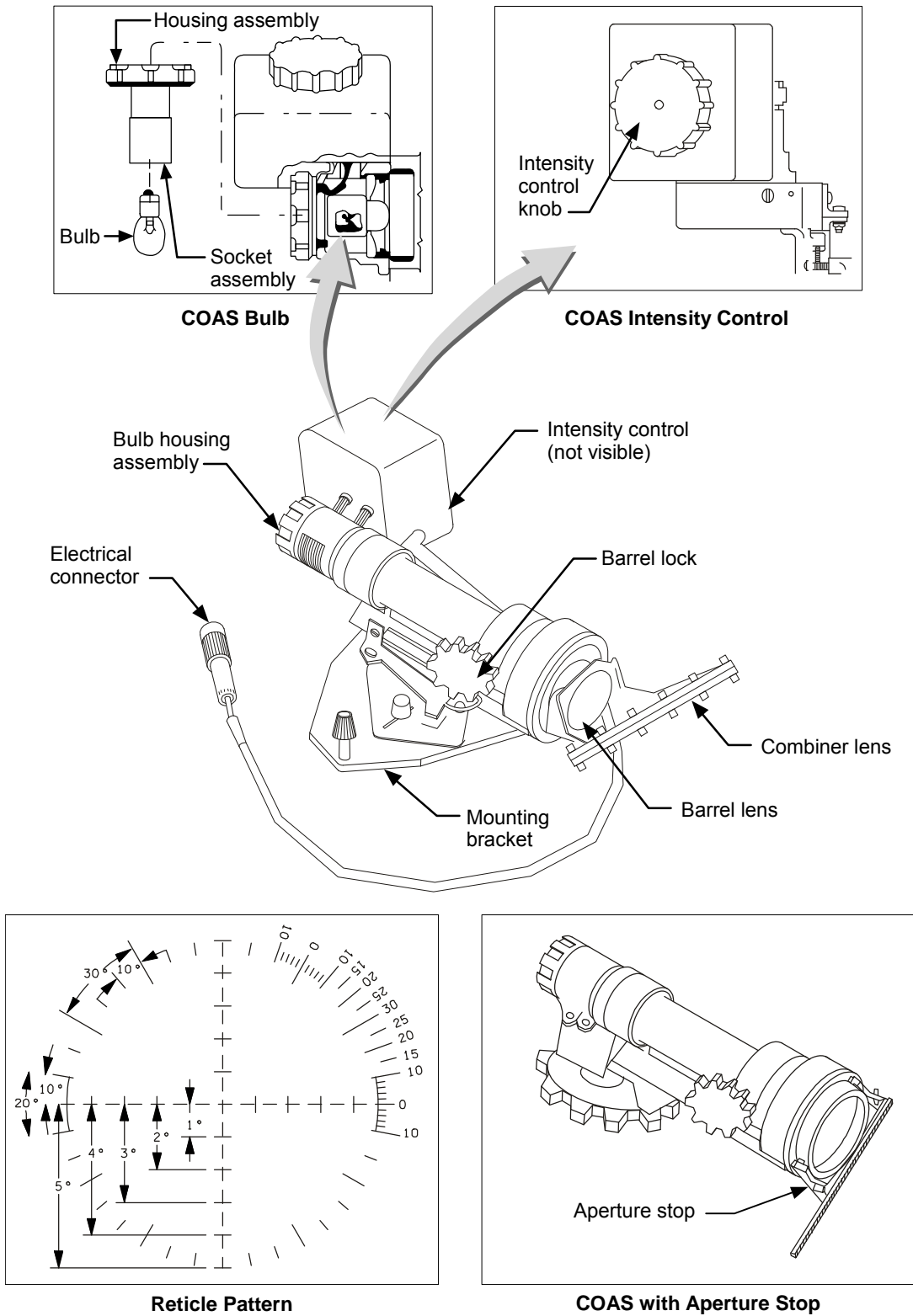


Figure 8-1. Crew optical alignment sight

td216_019.cnv

8.1 DESCRIPTION

The COAS is a cylindrically shaped device about 8 inches long, with a combining glass at one end, a boxlike attachment at the other end (containing a rheostat for light intensity control), and a mounting plate attached to the central portion of the cylinder (see Figure 8-2). Alignment pins are located on the bottom of the mount. Phase self-centering alignment pins maintain the boresight aiming point after many mount and demount cycles. The LOS, as shown, is looking through the combining glass. This is used to project the reticle pattern onto the FOV of the star or target. The knurled knob drives the rheostat, which controls the brightness of the reticle pattern.

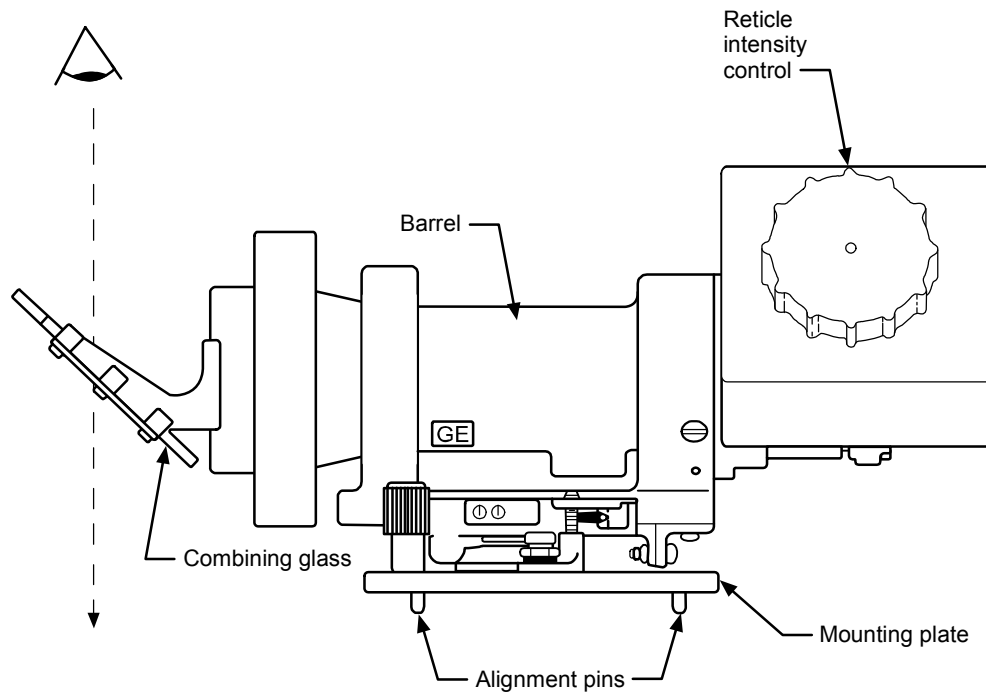
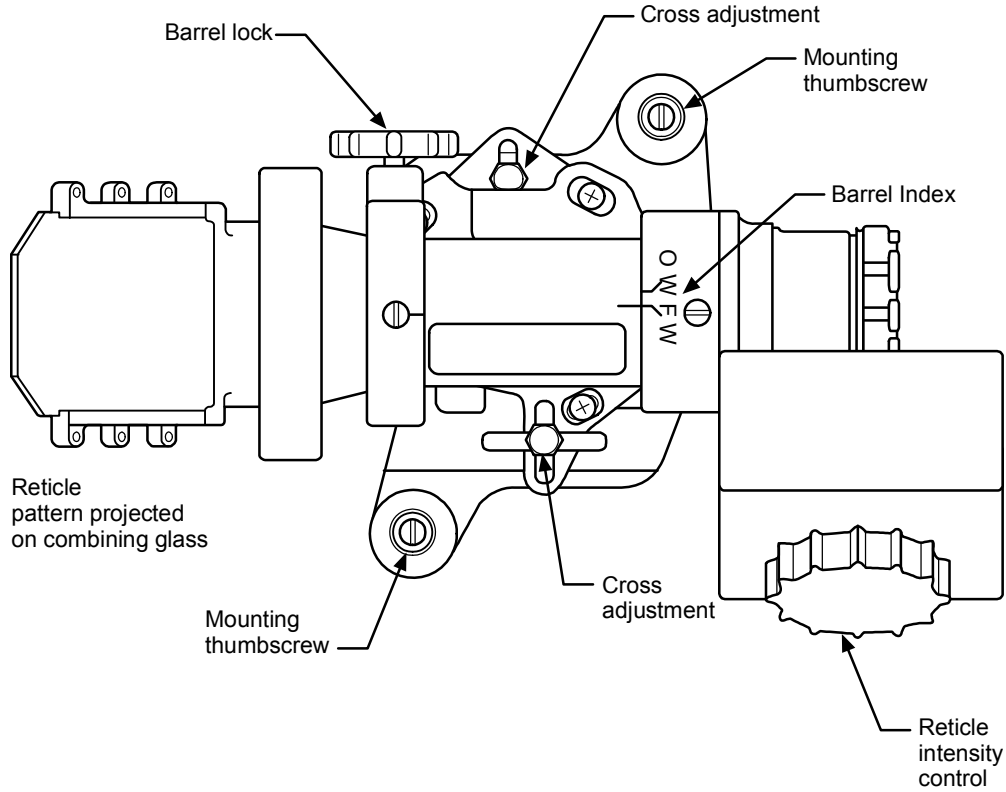


Figure 8-2. COAS side view

Pictured on the combining glass is the reticle pattern as seen when looking through the combining glass at a star or target (see Figure 8-3). Also shown are the two mounting thumbscrews used to lock the COAS into position.

The cross adjustments, which mount the COAS to the mounting plate, are preset prior to ground calibration and should not be moved.

For the COAS to be properly aligned, it must be oriented for the position in which it is mounted. The barrel index allows selection of either Forward Window (FW) or Overhead Window (OW) orientation. This orientation is a rotation of the reticle glass and lower portion of the COAS relative to the upper portion and mounting plate. The rotation aligns the COAS boresight axis with the shuttle body axis associated with the mounting position. The barrel lock fixes the barrel at the correct orientation.

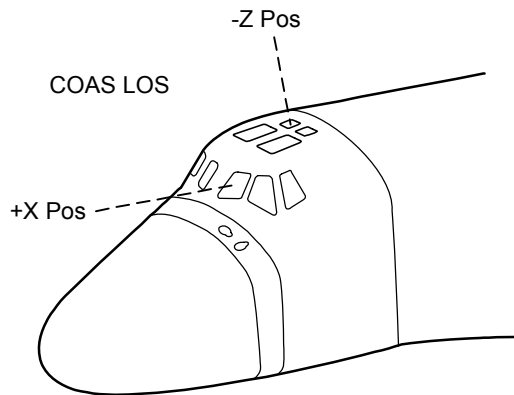


td216_021.cnv

Figure 8-3. COAS top view

8.2 MOUNTING

The COAS has two mounting positions: one above the CDR +X (forward) window (W-3) and one in front of the starboard overhead window (W-7) above the aft flight station. See Figure 8-4 for COAS viewing directions. The +X mount is boresighted parallel to the +X axis and the -Z mount parallel to the -Z axis of the shuttle.

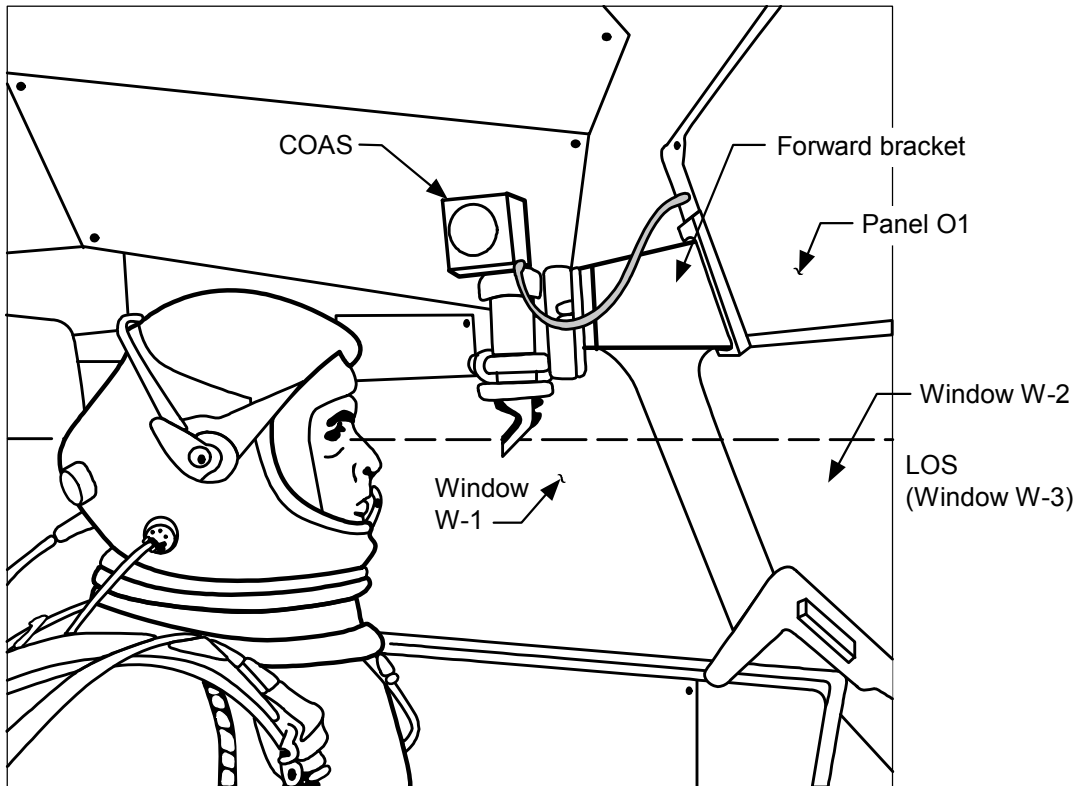


td_216_022.cnv

Figure 8-4. COAS viewing directions

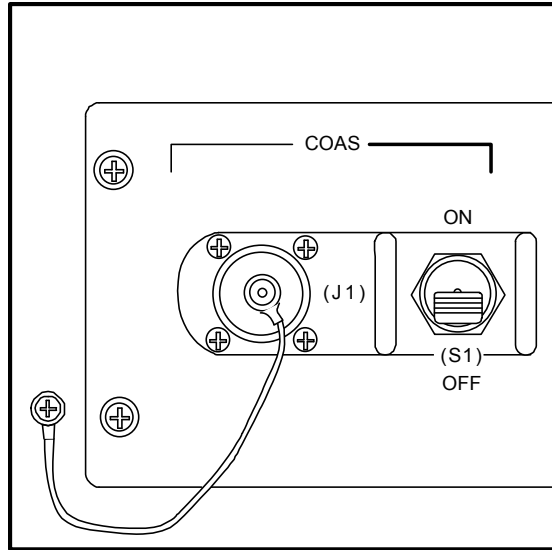
8.2.1 Forward Mounting

When taking sightings along the +X axis (see Figure 8-5), the COAS is mounted on Panel O1 and sighted through window W-3. With the COAS mounted on Panel O1, power to illuminate the reticle is provided from the COAS power switch on Panel O1 (see Figure 8-6). Reticle brightness is controlled by the intensity control on the COAS. A mounting bracket is attached to the COAS prior to mounting it in this position. This bracket is required to lower the unit so that the view through the forward window is unobstructed.



td216_023.cnv

Figure 8-5. Using COAS in forward position

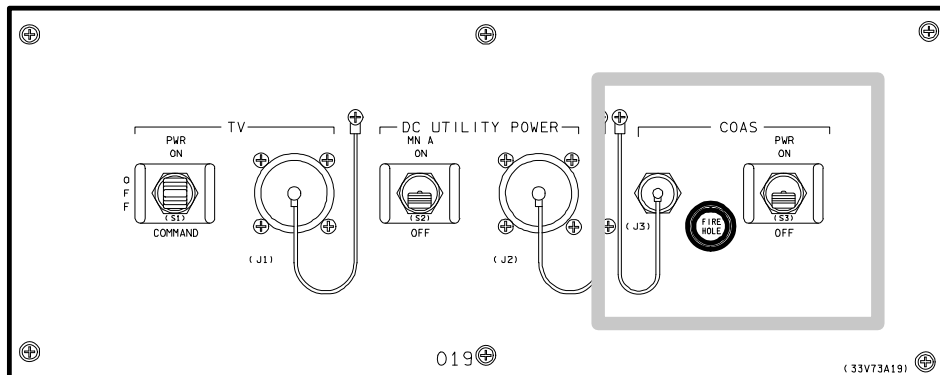


usa006082_052.cnv

Figure 8-6. COAS power switch on Panel O1

8.2.2 Aft Mounting

A COAS mount near the forward edge of the starboard overhead window (W-7) is the aft COAS location for star sighting or rendezvous. Sightings from this position are made in the -Z direction of the shuttle body coordinate system. From this location, the shuttle attitude is controlled using the aft Rotational Hand Controller (RHC). COAS power at the aft mount is controlled by a COAS power switch on Panel O19 (see Figure 8-7). The mounting bracket used at the +X position is not required here and should not be attached. Figure 8-8 illustrates the COAS mounted in the aft position.



td216_030.cnv

Figure 8-7. COAS PWR switch on Panel O19



Figure 8-8. Using COAS in aft position

8.3 COAS POWER

Power for both the forward and aft COAS stations is supplied from Circuit Breaker (CB) 127 (COAS) located on Panel L4. From this CB, power is routed to Panels O1 and O19 (see Figure 8-6, Figure 8-7, Figure 8-9, and Figure 8-10). The state of the COAS power is monitored by flight controllers through the telemetry system. In the event of a COAS power failure, the end of the COAS barrel opposite the reticle can be unscrewed and a flashlight shone through the barrel to illuminate the reticle.

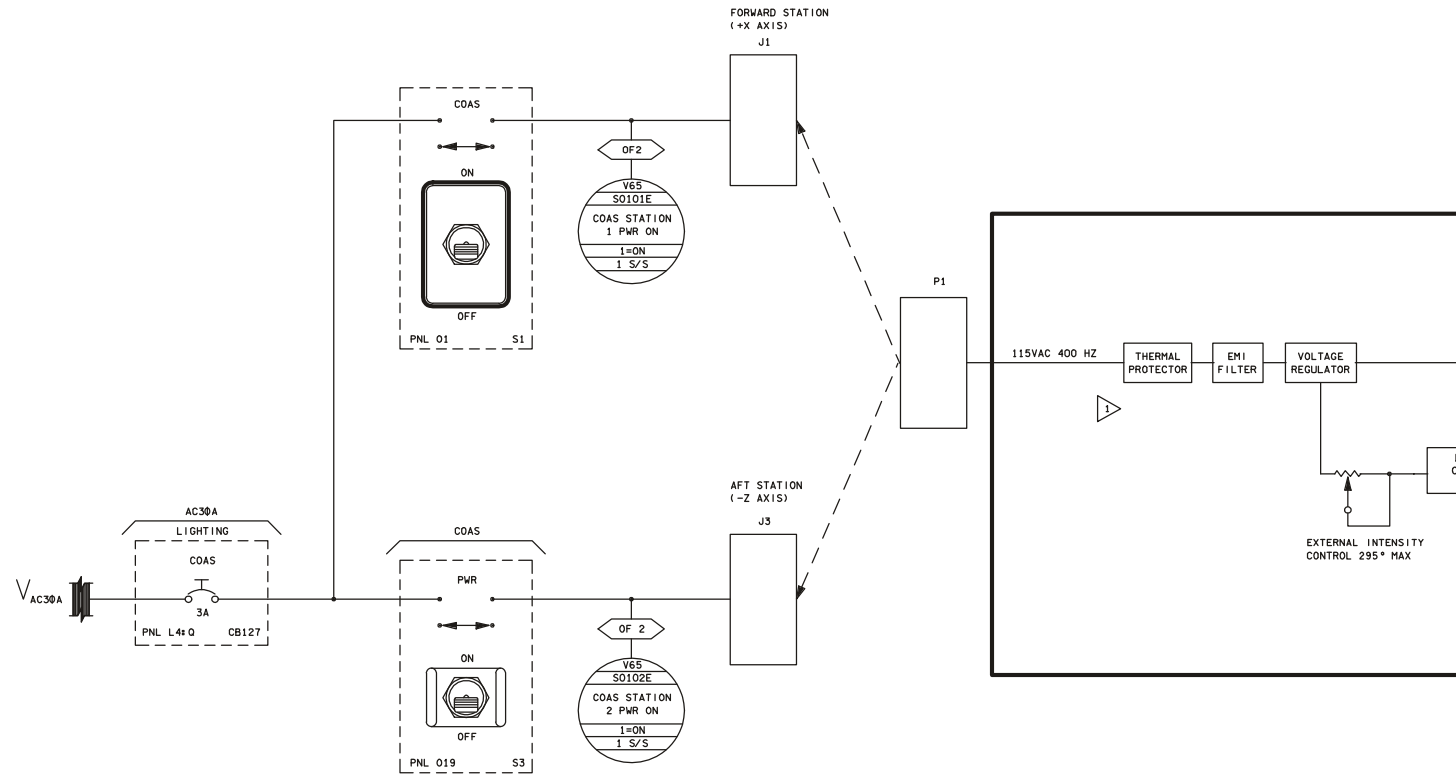
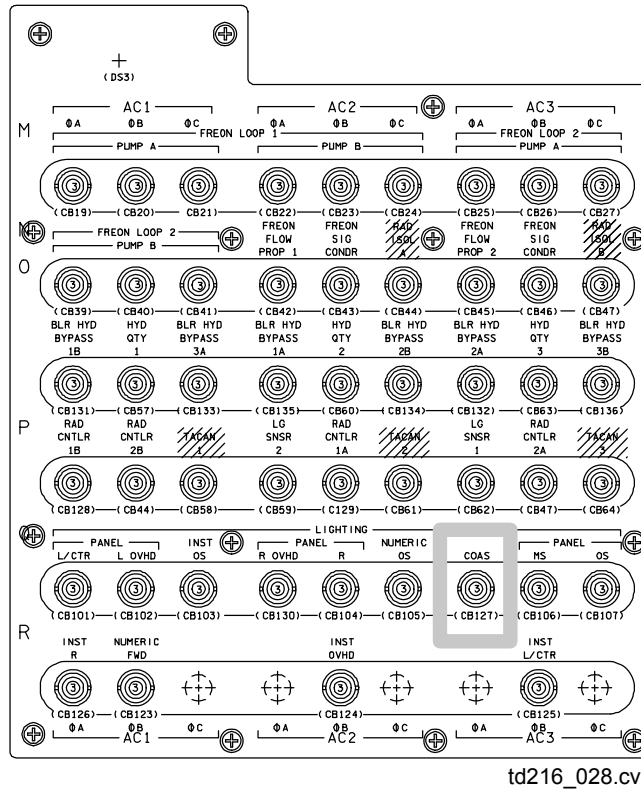


Figure 8-9. COAS power distribution diagram

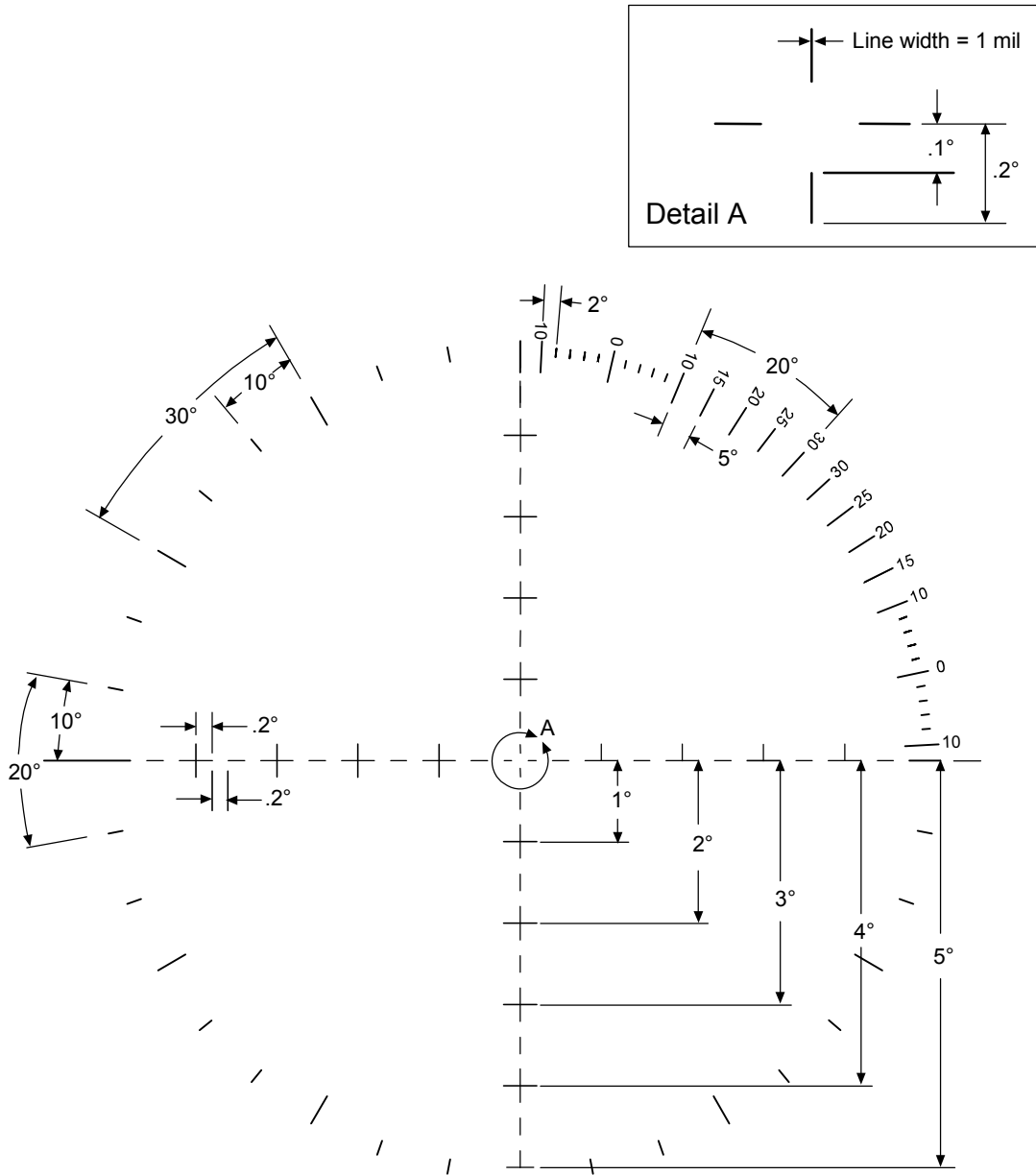


**Figure 8-10. CB 127 on Panel L4
(right portion of panel)**

8.4 RETICLE PATTERN

When using the COAS, the orbiter is slowly maneuvered so that the star or target moves through the center of the cross on the reticle (see Figure 8-11). The desired position of the star is exactly at the intersection of the two perpendicular dashed lines. Once this is achieved, the ATT REF pushbutton, described in the following subsection, is depressed to indicate to the GPC that the star is centered in the reticle.

Refer to Figure 4-4 for COAS coordinate system definition as it relates to the reticle and the Star Tracker coordinate system.



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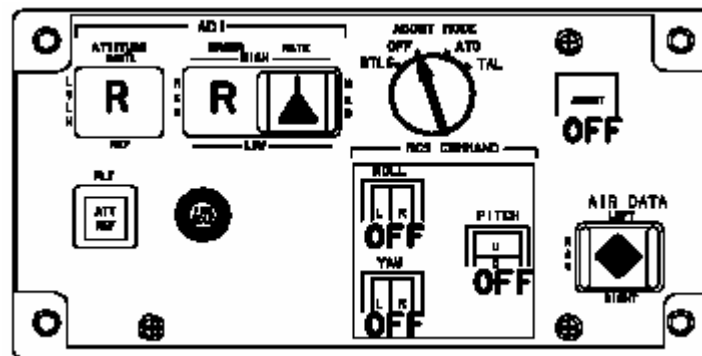
Figure 8-11. COAS reticle pattern

8.5 ATT REF PUSHBUTTON

To establish a LOS vector to a COAS-sighted star, the crewmember needs some method of informing the GPC software when he has a star correctly sighted. Located on Panel and F6 (see and **Error! Reference source not found.**) is an attitude reference pushbutton. One of its functions is to send a discrete to the GPC telling it to snapshot a LOS vector at the current vehicle attitude. These buttons are the ATT REF pushbuttons. A COAS mode must be selected on SPEC 22 for the ATT REF pushbutton to have this function. Otherwise, its function is ADI reference definition.

Each ATT REF pushbutton is within easy reach of a crewmember who is sighting through a COAS in the +X or -Z position. Each is positioned such that it can be depressed with the left hand while the crewmember sights through the COAS as he maneuvers the shuttle using the RHC with the right hand. The ATT REF pushbutton on Panel F8 can also be used through coordination with another crewmember. While in a COAS mode, the ATT REF pushbutton does not control the ADI.

The action of sighting on a star and depressing the ATT REF pushbutton is often referred to as “marking on a star.”



8-12. Forward ATT REF button on Panel F6

8.6 APERTURE STOP AND FILTER

An aperture stop that reduces the FOV is provided to assist in sighting on a star. A filter that facilitates daylight sightings is also provided. The aperture stop and filter both clip on the COAS lens mounting bracket; therefore, they cannot be used simultaneously (see Figure 8-13 and Figure 8-14).

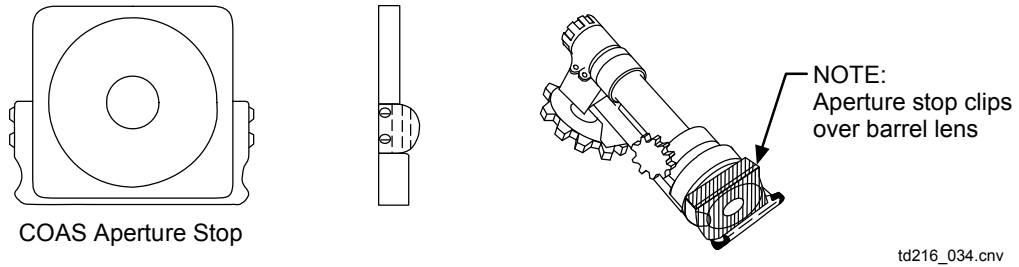


Figure 8-13. COAS aperture stop installation

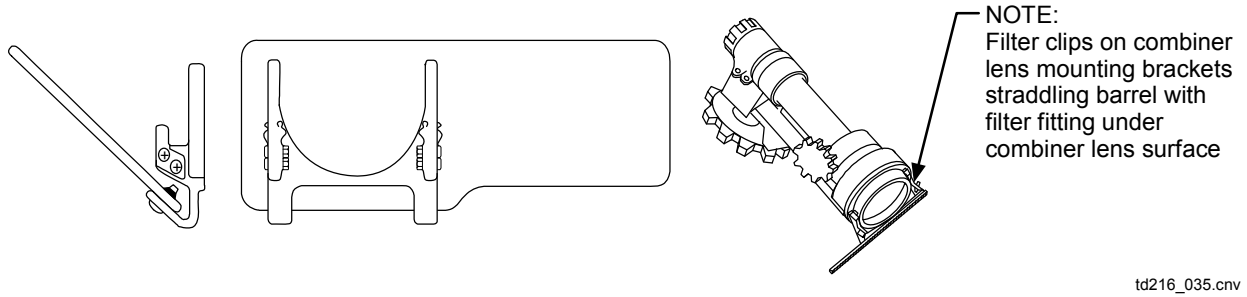


Figure 8-14. COAS filter installation

9.0 STAR TRACKER/COAS CONTROL DISPLAY (HUD/COAS OPERATIONS)

As discussed in the Star Tracker portion of this workbook, SPEC 22 provides crew monitoring and control for Star Tracker and HUD/COAS operations.

These controls are located in the lower right-hand portion of the display (see Figure 9-1).

- a. REQD ID (ITEM 21) allows input of the ID number of the star being sighted.
- b. Δ DEG X and Y display the angular offset of a star/target, tracked by the -Z Star Tracker, from the -Z COAS boresight. X corresponds to the vertical axis of the reticle pattern (parallel to the X body axis of the shuttle) and Y corresponds to the horizontal axis of the reticle pattern (parallel to the Y body axis).
- c. SIGHT MODE (ITEM 22) enables the star tracking software to accept COAS sighting marks on stars to be used for IMU alignments.

```

COAS
REQD ID      21  XX
 $\Delta$ DEG X      ±X.X
      Y      ±X.X
SIGHT MODE  22X
ACCEPT      23
CAL MODE    24X
DES         25X
POS   +X 26X  -Z 27X
 $\Delta$ BIAS  X.XX  X.XX
UPDATE    28    29

```

Figure 9-1. S TRK/COAS CNTL display (lower right portion)

- d. ACCEPT (ITEM 23) allows a star sighting mark to be displayed in the S TABLE.
- e. CAL MODE (ITEM 24) enables software that accepts a star sighting mark for the purpose of HUD or COAS calibration on orbit.
- f. DES (ITEM 25) disables SIGHT MODE or CAL MODE. It restores the ADI definition function of the ATT REF pushbutton and enables Star Tracker operations.
- g. POS allows specification to the software of which HUD or COAS mount position is being used. +X (ITEM 26) specifies either the CDR or PLT HUD positions or the +X COAS mount and -Z (ITEM 27) specifies -Z COAS mount.

- h. Δ BIAS displays compensation computed by software (after a mark on a star) that is needed to calibrate the HUD or the COAS in the position selected by ITEMS 26 or 27. A number will be displayed representing an angular correction (in degrees).
- i. UPDATE (ITEMS 28 and 29) allows a command to incorporate the BIAS into software. ITEMS 28 and 29 represent respectively the +X and -Z positions displayed above. Upon execution, the Δ BIAS returns to zero.

Using the COAS SIGHT MODE or CAL MODE will mode the Star Trackers to TERM/IDLE from any other mode of operation. Only one optical system can be selected at any time.

HUD/COAS-sighted stars will always be inserted into columns 1 and 2 of the S TABLE. The first star sighted will be inserted into column 2, and the second into column 1. However, stars are inserted into the table only after an ITEM 23 (ACCEPT), not after the mark. Column 3 of the S TABLE is not used in HUD/COAS operations. HUD and COAS calibrations do not use the S TABLE. In the sighting mode, data on any number of stars subsequent to the first will always be placed into column 1. To replace data in column 2, the S TABLE has to be cleared first, or the sighting mode deselected and reselected.

10.0 COAS OPERATIONS

10.1 CALIBRATION

The COAS mounting locations are calibrated prior to launch so that the GPC knows the boresighted look angle of each position relative to the navigation base. When the shuttle reaches orbit, the structural forces applied to the vehicle by its environment have changed; therefore, the structural bending of the vehicle may be different than on the ground. Consequently, the GPC may no longer know the correct COAS boresight in orbit. To correct this condition an on-orbit calibration of the COAS is performed.

On-orbit calibration is accomplished by sighting on a nav star while the IMUs are accurately aligned. At this time, the GPC knows the vector to that star. The difference between the two vectors is the error in the COAS look angle, called the “delta bias” (Δ BIAS). The GPC then uses the bias in future COAS sightings to correct for misalignment. Once the COAS is calibrated, subsequent removal and remountings should have no effect on calibration, unless the cabin pressure is changed. Refer to Figure 10-1 for COAS calibration.

In both calibration and star sighting for alignment, the ATT REF pushbutton defines the LOS vector to the star when depressed. In either case, it is possible to depress the ATT REF pushbutton any number of times until there is confidence that an accurate sighting has been performed. The last “mark” is the one that will be used by software when an UPDATE or ACCEPT is executed.

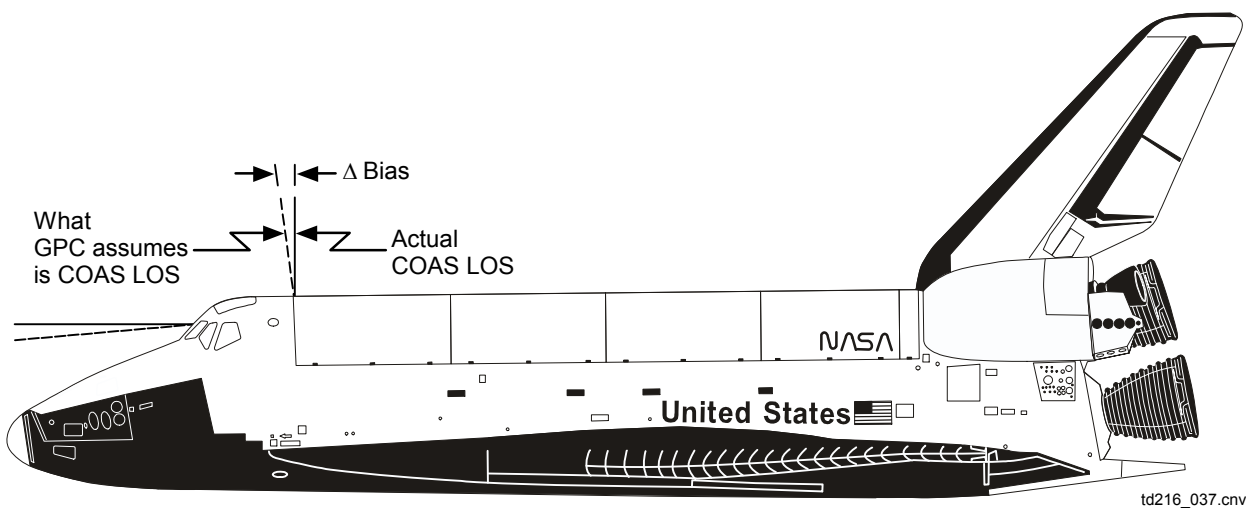


Figure 10-1. COAS Δ BIAS rationale (typical for both COAS positions)

Figure 10-2 is an example of a crew procedure for COAS calibration after achieving orbit. This procedure requires the crew to sight a nav star, incorporate the Δ BIAS into the COAS software, and then verify the sighting accuracy by resighting. It is located in the Orbit Ops Checklist.

COAS CALIBRATION, GNC 201

- O1(O19)
COAS
1. COAS CALIBRATION PREP
COAS – ON
√Barrel Index – FW(OW)
√DAP: A/AUTO/VERN

If -Z COAS CAL,SENSE: -Z

Change DAP A,B to A1,B5
GNC 22 S TRK/COAS CNTL
COAS: REQD ID – ITEM 21 + __ EXEC
POS +X(-Z) – ITEM 26(27) EXEC (*)
CAL MODE – ITEM 24 EXEC (*)
- O14:E,
O15:E,
O16:E
- √cb DDU L(AFT) (two) – cl
- F6/F8
(A6U)
- FLT CNTLR PWR – ON
2. MARK ON STAR
DAP: A1/INRTL(FREE)/VERN (for COARSE CNTL)

Mnvr to locate star

DAP: B5/INRTL(FREE)/VERN (for FINE CNTL)
B5/FREE/PRI (loss of VERNS)

Mnvr to center star in COAS:
ATT REF pb – push
- F6
(A6U)
- NOTE
Take minimum three verif marks
to ensure Δ BIAS consistency
- DAP: A1/AUTO/VERN

Cont next page

Figure 10-2. COAS CALIBRATION procedure

3. CALIBRATE COAS
Rcd CAL +X(-Z) Δ BIAS: _____
UPDATE – ITEM 28(29) EXEC, Rcd
MET ____/____:____
 $\sqrt{\Delta}$ BIAS goes to zero
 4. VERIFICATION
DAP: A1/INRTL(FREE)/VERN (for COARSE CNTL)

Mnvr to locate star

DAP: B5/INRTL(FREE)/VERN (for FINE CNTL)
B5/FREE/PRI (loss of VERNs)

Mnvr to center star in COAS:
ATT REF pb – push

NOTE
Take minimum three verif marks
to ensure Δ BIAS consistency

 $\sqrt{\Delta}$ BIAS < 0.12

* If majority of Δ BIASs > 0.12, repeat *
* steps 3 and 4. If Δ BIAS still > 0.12, *
* \sqrt{MCC} *
 5. CLEAN UP
COAS: DES – ITEM 25 EXEC (*)
COAS – OFF
FLT CNTLR PWR – OFF
- i, cb DDU L(AFT) (two) – as reqd
- $\sqrt{}$ Data transcribed into FLIGHT PLAN
- If S TRK(S) to be left in auto star-select mode:
S TRK(S) -Y(-Z) – ITEM 3(4) EXEC (*)
- Reconfig to FLIGHT PLAN DAP

Figure 10-2. COAS CALIBRATION procedure (concluded)

A software logic flow diagram for the COAS calibration is located in Figure G-1 in Appendix G.

10.2 STAR SIGHTING

Use of the HUD or COAS for actually aligning IMUs occurs only when the IMUs become so badly misaligned that the Star Tracker cannot be used or when both Star Trackers

have failed. In either event, a HUD or COAS-based IMU alignment is a contingency procedure and, as such, is located in the GNC section of the Flight Data File Malfunction Procedures book as a Failure Recovery Procedure (FRP).

The procedure in Figure 10-3 is a typical part of the FRP. It is assumed that any IMU failures/problems have been corrected and at least one IMU is available for alignment.

GNC FRP-3 IMU RECOVERY WITH AT LEAST ONE IMU AS GOOD REFERENCE

- NOTE
Procedure must be accomplished in GNC OPS 2 or GNC OPS 3
1. Deselect IMUs being recovered
GNC 21 IMU ALIGN
 ✓IMUs: DES – ITEM 7(8,9) EXEC (*)
 - O14:A,
O15:A,
O16:A 2. Ensure pwr applied to all IMUs
 If not, ACTIVATE IMU(s) GNC SSR-1
 3. Ensure all IMUs in OPERATE mode
GNC 21 IMU ALIGN
 ✓IMUs: OPER – ITEM 4,5,6 EXEC (*)
- NOTE
If ITEMS 4,5, or 6 executed, wait for asterisks to appear (~90 sec)
4. Enable serial data link
 GNC I/O RESET
- NOTE
Possible erroneous IMU BITE/T 1(2,3) msg
after GNC I/O RESET. Ignore msg unless
MCC advises otherwise, or if no comm
5. Reestablish skew between IMUs. Choose IMU with good reference and align other two IMUs with IMU to IMU ALIGN. Use good IMU as reference for align – IMU to IMU ALIGNMENT (ORB OPS, GNC)
- NOTE
Both nonreference IMUs should be aligned to preclude possibility
of IMU RM FAIL (RM threshold reset following any align)
6. Reselect IMUs previously deselected
GNC 21 IMU ALIGN
 DES – ITEM 7(8,9) EXEC (no *)

Figure 10-3. GNC FRP-3 procedure

A software logic flow diagram for the HUD/COAS sighting procedure is located in Figure G-1 in Appendix G.

10.3 QUESTIONS

1. The COAS is used to sight stars through which of the following windows?
 - (a) CDR +X window and the starboard overhead window
 - (b) CDR +X window and the port overhead window
 - (c) PLT +X window and the port overhead window
 - (d) Starboard overhead window and the -X aft window
2. The COAS is locked into place by
 - (a) Alignment pins
 - (b) Mounting thumbscrews
 - (c) Barrel lock
 - (d) Electrical connectors
3. The HUD/COAS “mark” capability is a secondary function of
 - (a) GAIN ENA switch on the Panels F2 and R10
 - (b) ADI ATT REF Pushbutton Indicator (PBI) on A6 and F6
 - (c) ENTER SW on Panels A8 and F5
 - (d) None of the above
4. COAS power for both stations is supplied from
 - (a) Single CB and individual switches
 - (b) Single switch and individual CBs
 - (c) Separate CB and switch for each
 - (d) CB for each

5. In the SIGHT MODE, where do the data go in the S TABLE?
 - (a) First star goes into column 1; second star goes into column 2.
 - (b) First star goes into column 1; second star forces column 1 into column 2 and inserts second star into column 1.
 - (c) First star goes into column 3; second star goes into column 2.
 - (d) First star goes into column 2; second star goes into column 1.
6. CAL MODE operations require activation of the following item numbers for complete calibration (use SPEC 22 display):
7. Star sighting with the HUD or COAS is
 - (a) The nominal method of IMU alignment
 - (b) Its only function
 - (c) A backup method of IMU alignment
 - (d) Done to calibrate the Star Trackers for IMU alignments
8. The Δ BIAS acquired during calibration
 - (a) Can only be computed with the first "mark"
 - (b) Should be repeated to ensure consistency after ITEM 28(29) EXEC (UPDATE)
 - (c) Can never be expected to be less than 0.12°
 - (d) Should be repeated to ensure consistency before ITEM 28(29) EXEC (UPDATE)
9. Which one of the following statements is true?
 - (a) The COAS SIGHT MODE must be deselected between sightings.
 - (b) A COAS calibration of the -Z position will not be good at the +X position.
 - (c) HUD/COAS sighted stars for an IMU alignment must be between 85° and 95° from each other.
 - (d) In the HUD/COAS auto star select mode, no REQD ID input is required.

See Appendix B for answers to questions in Section 10.

APPENDIX A
ACRONYMS AND ABBREVIATIONS

A	Aft
ADI	Attitude Direction Indicator
ANG	Angle
ATT	Attitude
ATT REF	Attitude Reference
AUTO	Automatic
BITE	Built-In Test Equipment
BOA	Bright Object Alert
BOS	Bright Object Sensor
BP, bp	Barberpole
BRT	Bright
C&W	Caution and Warning
CAL	Calibration
CB, cb	Circuit Breaker
CCD	Charged Coupled Device
CDR	Commander
CIO	Communications Input/Output
CL	Close
	Clear
CLR	Clear
CMD	Command
CNTL(R)	Control (Controller)
COAS	Crew Optical Alignment Sight
COORD	Coordinate
CRT	Cathode Ray Tube
D/O	Deorbit
DAP	Digital Auto Pilot
DCLT	Declutter
DDU	Display Driver Unit
DES	Deselect
DIF	Difference
DR	Door
EI	Entry Interface
ENA	Enable
ERR	Error
EXEC	Execute

FDF	Flight Data File
FMCA	Forward Motor Control Assembly
FOV	Field of View
FPC	Forward Power Controller
FRP	Failure Recovery Procedure
FW	Forward Window
FWD	Forward
G	Gravity Gravitational Unit
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer
H	Horizontal
HUD	Heads-Up Display
HW	Hardware
I/O	Input/Output
ID	Identification
IDT	Image Dissector Tube
IMU	Inertial Measurement Unit
INH	Inhibit
INRTL	Inertial
LED	Light-Emitting Diode
LOS	Line of Sight
LVPS	Low Voltage Power Supply
M50	Aries Mean of 1950
MAG	Magnitude (D-1)
MAN	Manual
MCC	Mission Control Center
MET	Mission Elapsed Time
MIN	Minute
NAV, nav	Navigation
O	Overhead
OP	Open Operate
OPER	Operate
OPS	Operational Sequence Operations
OW	Overhead Window

PB, pb	Pushbutton
PBI	Pushbutton Indicator
PLT	Pilot
PNL	Panel
POS	Position
Prep	Preparation
PRES	Present
PROM	Programmable Read-Only Memory
PS	Power Supply
PWR	Power
RCD	Record
REQD	Required
RHC	Rotational Hand Controller
S	Star
S TRK	Star Tracker
SEL	Select
SEP	Separate
SFT&FO	Space Flight Training and Facilities Operations
SPEC	Specialist Function
SSST	Solid State Star Tracker
ST	Self-Test
	Star Tracker
STAT	Status
STBY	Standby
SW	Software
SYS	System
TB, tb	Talkback
TEC	Thermal Electric Cooler
TEMP	Temperature
TERM	Terminate
TGT	Target
TRK	Track
TRKR	Tracker
TUI	Tracker Utility Interface
USA	United Space Alliance
V	Vertical
VERN	Vernier

**APPENDIX B
ANSWERS**

Answers for Section 4

1. The bright object sensor
(b) Closes the Star Tracker shutter when a bright object is sensed.
2. How much time does it take to open the Star Tracker doors when both motors are operational?
(a) 6 seconds
3. The Star Tracker coordinate system is referenced to the
(c) Nav base
4. The desired output from the Star Tracker is
(a) Angle from boresight
5. When commanded to the offset mode by the GPC, which of the following statements is true?
(b) The Star Tracker searches a 1° square field of view.
6. Which one of the following statements is true?
(c) There are four levels of detection threshold control.
7. Loss of Star Tracker power causes
(d) The shutter to spring closed

Answers for Section 6

1. SPEC 22 (S TRK/COAS CNTL) and SPEC 21 (IMU ALIGN) are available during
(c) All of OPS 2 and 301
2. The “star of opportunity” mode
(d) Continually cycles through the star catalog searching for stars to track that are within the FOV
3. Δ ANG is the
(a) Difference between the measured vector and calculated vector to a star.
4. How many stars are in the star catalog?
(b) 100
5. What is the REQD ID to command auto star data collection?
(e) A default 0
6. Activating ITEM 15 MAN OP for the shutter causes which of the following?
(b) -Y shutter opens and disables BOS.
7. The ANG DIF and ANG ERR in column 2 relate to the angles between which stars?
(b) Column 2 and column 3
8. S 17, 18, 19
(b) Reflect GPC or crew selection of stars
9. S TABLE CLEAR, ITEM 20
(a) Clears the whole table

Answers for Section 10

1. The COAS is used to sight stars through which of the following windows?
(a) CDR +X window and the starboard overhead window
2. The COAS is locked into place by
(b) Mounting thumbscrews
3. The HUD/COAS MARK capability is the secondary function of
(b) ADI ATT REF PBI on A6 and F6
4. COAS power for both stations is supplied from:
(a) Single CB and individual switches
5. In the SIGHT MODE, where do the data go in the S TABLE?
(d) First star goes into column 2, second star goes into column 1.
6. CAL MODE operations require activation of the following item numbers for complete calibration (use SPEC 22 display):
21, 26 or 27, 24, 28 or 29, 25
7. Star sighting with the HUD or COAS is
(c) A backup method of IMU alignment
8. The Δ BIAS acquired during calibration
(d) Should be repeated to ensure consistency before the ITEM 28(29) EXEC (UPDATE)
9. Which of the following statements is true?
(b) A COAS calibration at the -Z position will not be good at the +X position.

APPENDIX C SHUTTLE STAR CATALOG AND CHART

This section contains the parametric data associated with 100 predefined navigation stars that have been selected for use with the shuttle Star Tracker. The parameters listed for each star include: (1) star number, (2) star common name, (3) star unit vector components, i.e., Right Ascension and Declination, (as of 1 January 1975) in M50 coordinates, and (4) approximate visual magnitude. Star data for the catalog stars (unit vectors) are required whenever S TRK software processing functions are being performed. Note: Star Catalog data are preliminary. The 100 star unit vector coordinates are premission loaded and will be updated as required. The star catalog contains 60 entries, currently ordered as follows:

1. OTHER ORBITING VEHICLE
2. CENTER OF EARTH
3. EARTH RELATIVE TARGET
4. CENTER OF MOON
5. CELESTIAL TARGET
- 6-10. UNASSIGNED
- 11-60. NAV STARS, (MISSION INDEPENDENT, OPS 2, 3, AND 8)
- 61-110. NAV STARS, OPS 2 AND 8

The non-nav star entries are used to support the Universal Pointing SPEC functions and target tracking operations.

Also included is a star chart from which nav star identification and location can be determined.

Celestial Target ID	Name	Right Ascension	Declination (N/S)	Mag
11	SIRIUS	101	17 S	-1
12	CANOPUS	96	53 S	-1
13	RIGEL	78	8 S	0
14	VEGA	279	39 N	0
15	HADAR	210	60 S	1
16	ACHERNAR	24	57 S	0
17	ACRUX	186	63 S	1
18	CAPELLA	78	46 N	0
19	SPICA	201	11 S	1
20	ARCTURUS	213	19 N	-0
21	PROCYON	114	5 N	0
22	ALTAIR	297	9 N	1
23	BETELGEUSE	88	7 N	0
24	BELLATRIX	81	6 N	2
25	REGULUS	151	12 N	1
26	FOMALHAUT	344	30 S	1
27	DENEK	310	45 N	1
28	AL NA'IR	331	47 S	2
29	ALKAID	206	50 N	2
30	ANTARES	247	26 S	1
31	CASTOR	113	32 N	2
32	ALDEBARAN	68	16 N	1
33	PEACOCK	305	57 S	2
34	MIAPLACIDUS	138	70 S	2
35	NUNKI	283	26 N	2
36	KAUS AUSTRALIS	275	34 S	2
37	ALPHERATZ	1	29 N	2
38	NAVI	13	60 N	2
39	ALHENA	99	16 N	2
40	MIRFAK	50	50 N	2
41	DENEBOLA	177	15 N	2
42	ALPHECCA	233	27 N	2
43	RASALHAGUE	263	13 N	2
44	MERAK	165	57 N	2
45	POLARIS	27	89 N	2
46	PHECDA	178	54 N	2
47	GIENAH	183	17 S	3
48	ZUBENESCHEMALI	229	9 S	3
49	KOCHAB	223	74 N	2
50	AVIOR	125	59 S	2
51	ATRIA	251	69 S	2
52	HAMAL	31	23 N	2
53	MENKENT	211	36 S	2
54	DIPHDA	10	18 S	2

Celestial Target ID	Name	Right Ascension	Declination (N/S)	Mag
55	ALPHARD	141	8 S	2
56	AL SUHAIL	137	43 S	2
57	ACAMAR	44	41 S	3
58	DENEK ALGEDI	326	16 S	3
59	SCHEAT	345	28 N	2
60	ENIF	325	10 N	2
61	ALNILAM	83	1 S	-2
62	EL NATH	81	29 N	2
63	NAOS	120	40 S	2
64	SAIPH	86	10 S	2
65	ALIOH	193	56 N	2
66	MENKALINAN	89	45 N	2
67	ETA CENTAURI	218	42 S	2
68	REGOR	122	47 S	2
69	ALGOL	46	41 N	2
70	MUHLIFAIN	190	49 S	2
71	ZETA CENTAURI	208	47 S	3
72	ALUDRA	111	29 S	2
73	ACRAB	241	20 S	3
74	THETA CARINAE	160	64 S	3
75	ZETA OPHIUCHI	249	10 S	3
76	EPSILON CENTAURI	204	53 S	2
77	ALGENIB	3	15 N	3
78	GAMMA LUPI	233	41 S	3
79	MARKAB	346	15 N	2
80	EPSILON PERSEI	59	40 N	3
81	PHACT	84	34 S	3
82	SABIK	257	16 S	2
83	THETA AURIGAE	89	37 N	3
84	ALPHA ARAE	262	50 S	3
85	KAPPA VELORUM	140	55 S	2
86	ALDERAMIN	319	62 N	2
87	ZOZCA	168	21 N	3
88	ZETA CANIS MAJORIS	95	30 S	3
89	ARNEB	83	18 S	3
90	ZETA PERSEI	58	32 N	3
91	ALPHIRK	322	70 N	3
92	MIRACH	17	35N	2
93	ICEN	199	36 S	3
94	COR CAROLI	193	39 N	3
95	BETA GRUIS	340	47 S	2
96	DELTA CYGNI	296	45 N	3
97	ALMACH	30	42 N	2
98	ZUBENELGENUBI	22	16 S	3

Celestial Target ID	Name	Right Ascension	Declination (N/S)	Mag
99	GAMMA GRUIS	328	38 S	3
100	GAMMA TRI AUSTRALE	229	68 S	3
101	IZAR	221	27 N	3
102	ELTAMIN	269	51 N	2
103	ARICH	190	1 S	3
104	ZETA AQUILAE	286	14 N	3
105	EPSILON CYGNI	311	34 N	2
106	ANKAA	6	43 S	2
107	RHO PUPPIS	121	24 S	3
108	BETA TRIANGULI	32	35 N	3
109	PI SAGITTARII	287	21 S	3
110	ZETA HERCULIS	250	32 N	3

Training Materials Evaluation

Please answer the following questions regarding the lesson you just completed. Your feedback will allow us to produce more effective training materials. When complete, mail to: **Space Shuttle DPS/Navigation Department, DS24.**

**TITLE/CODE OF LESSON: Star Tracker/Heads-up Display/Crew Optical Alignment
Sight workbook/S TRK/HUD/COAS 21002**

SIZE OF AUDIENCES/CLASS:

1. How well did this lesson meet its purpose?

For each statement below, mark one box on the scale:

- | | Strongly Disagree | | | | Strongly Agree | | | |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| a. The lesson objectives are clearly stated. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| b. The lesson objectives are clearly defined. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| c. The lesson effectively teaches skills and information. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| d. The lesson meets its purpose and objectives. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

2. How satisfying is the content of this lesson?

For each statement below, mark one box on the scale:

- | | Strongly Disagree | | | | Strongly Agree | | | |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| a. The information is structured in a logical flow. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| b. The content is clear. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| c. The content is complete. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| d. The level of detail is correct for this information. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| e. The amount of information is effective. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| f. The graphics contribute to my understanding. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

3. How appealing was the presentation of this lesson?

For each statement below, mark one box on the scale:

- | | Strongly Disagree | | | | Strongly Agree | | | |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| a. The overall presentation is appealing. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| b. The visuals chosen are appropriate for the lesson. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| c. The visuals make the information more interesting. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| d. The graphics are legibly reproduced. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| e. The audio/visual or print quality is good. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

4. How valuable is this information?

For each statement below, mark one box on the scale:

- | | Strongly Disagree | | | | Strongly Agree | | | |
|--|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| a. The lesson teaches skills and information I need. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| b. The lesson meets my expectations. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| c. This information is useful for later reference. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| d. I would recommend this lesson to others. | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

**PLEASE WRITE YOUR COMMENTS/QUESTIONS ON THE BACK OF THIS FORM.
EXPLAIN ANY NEGATIVE ANSWERS IN SPECIFIC TERMS.
THANK YOU IN ADVANCE FOR YOUR ASSISTANCE!**