Space Shuttle Star Tracker Challenges

*Star Tracker Overview*

- Location
- System
  - Image Dissector Tube (IDT)
  - Solid State Star Tracker (SS)
- Mission
  - Inertial Measurement Unit (IMU) Alignment
  - Rendezvous Operations

*Star Tracker Fleet Challenges & Solutions*

- International Space Station Tracking Challenges
- Pressurized Case Issue

*Trend Monitoring*

*Questions*
Star Tracker Overview - Location

Shuttle on Pad A at Kennedy Space Center, Florida

Two Star Tracker locations per vehicle.
Star Tracker Overview - System

Two Star Tracker Assembly Models

Old: Image Dissector Tube (IDT)

New: Solid State Star Tracker (SS)

Orbiter Mounting Plate

Light Shade with Shutter Assembly

Bright Object Sensor (BOS)

Protective Window Assembly
HISTORY: Why Two Models?
  • 1970s vintage Original (IDT) Model Issues
    • Cost of Repairs
    • Parts Obsolescence
  • 1992 First flight of Solid State Star Tracker
  • Replace on an attrition basis

Star Tracker Model Similarities
  • Both capable of tracking original catalog of 100 stars
  • Electrical Power and Data interface to orbiter
  • Mechanical mounting on Navigational base interchangeable
  • Software interface to shuttle computer systems

Bright Object Sensor (BOS) Function
  • Removes power to shutter assembly when excessive light is in the
    field of view which causes the shutter to close.
STAR TRACKER DIFFERENCES

Light Collector
- **Original**: Image Dissector Tube (IDT) or magnetic tube
- **Upgrade**: Charge Coupled Device (CCD) or Solid State (SS)
  - Capable of tracking dimmer stars

Effect of Direct Bright Object Exposure (i.e. Sun)
- **IDT** will be irreparably damaged by direct sun exposure.
- **SS** will be temporarily blinded.

Star Tracker Internal Protection
- **IDT** High Background Flag triggers the shutter to closure.
- **SS** has a two level ‘Target Suppress’ Flag
  - Level 1: prevents unreliable data from being accepted by flight software by zeroing data
  - Level 2: closes the shutter
Star Trackers have two primary roles during a shuttle mission:

- Inertial Measurement Unit (IMU) Alignment
- Providing Rendezvous Target Data
Star Tracker Overview – IMU Alignment

- Approximately 2 hours after lift off, the Star Trackers begin tracking.

- When a star is ‘acquired’, the star position and magnitude data is provided digitally to the orbiter computer.

- The horizontal and vertical position of the last three successfully tracked stars are stored in a STAR TABLE. Mission Operations Ground Controllers in Houston, TX review the information prior to using the data to align the Inertial Measurement Units.
Two star position values are used to pinpoint the orbiter attitude in the space coordinate system.

The star positions are compared to the Inertial Measurement Unit (IMU) position and corrections are implemented as required.

A de-orbit star IMU alignment is performed ~165 minutes prior to de-orbit burn.
Navigational solution accuracy is critical to maintain flight path within the entry corridor. The orbiter has structural temperature limits at each position and energy level during entry. One entry constraint is alpha control or Angle Of Attack (AOA).

Successful Entry
Orbiter AOA ~ 40 Deg

Entry Interface

Break Up Low AOA

400,000 ft Altitude

Skip Out

Miss
Rendezvous Operations

- Star trackers are used during the onboard targeting phase of rendezvous.

- Line Of Sight (LOS) tracking provides horizontal and vertical measurements of the target in relation to the orbiter.
There are two timeframes in which star tracker data is acquired during a shuttle rendezvous:

**Contingency ST pass**
- ST used only if radar fails after Transition Initiation (Ti) Burn (< 8 nmi).

**Nominal ST pass**
- (~40 nmi)

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NC  Nominal Correction (closing rate)
NCC Nominal Corrective Combination (tweaks trajectory)
MCx Mid-course Correction (out of plane & phasing)
ST Overview - Rendezvous Operations

- Z Star Tracker
- Orbiter Docking System

ISS Pressurized Mating Adapter

STS128 Separation Photo of the ISS

Orbiter Docking System

First Star Tracker Pass
Second Star Tracker Pass
NCC Burn
NC Burn
Radar & Star Data
Radar & Ti Burn
Final Ground Tracking
INTERNATIONAL SPACE STATION TRACKING CHALLENGES
Fleet Challenges – ISS Tracking


Launched in 1990, the Hubble telescope measures 43.5 ft (4.4m) length x 14.0 ft (4.2m) in diameter.
ST OPERATIONAL MISSION – Rendezvous Operations

Node 1: 18’ L x 15 ft diameter
Zarya: 41’ L x 13.5 ft wide
   Each Solar array is 11 ft wide and extends 35 ft.

Total Size: 59 ft (~18m) length
   x 15.0 ft (~4.6m) in diameter

First hint of brightness problems began during STS-88 post-undocking operations December 1998.

The –Y solid state star tracker set a ‘target suppress’ flag.

ISS 2A: NODE 1 (Unity) and Zarya
STS-088 --- Dec 1998
International Space Station size increases with each mission.

ISS 3A: Z1 Truss and PMA Added
STS-092 --- Oct 2000
November 2000, the International Space Station is 20 percent complete.

During approach for STS-098, the star tracker set a ‘target suppress’ flag at the later part of the post-Transition Initiation (Ti) tracking window.

This is the first mission with a solid state star tracker in the –Z location.
Fleet Challenges – ISS Tracking

During STS-110 & STS-112 rendezvous, ‘target suppress’ indications occurred after the end of the nominal Star Tracker Pass. Both missions were flown by Atlantis carrying two solid state star trackers.
Solution – ISS Tracking

Post Ti Star Tracker Data

At 8 nautical miles,
  - SS already unable to perform day tracking of the large and bright ISS
  - IDT still tracking successfully

Star Tracker data is required only for contingency scenarios.

Primary tracking provided by radar.

Night time star tracker pass is adequate for relative navigation.
Fleet Challenges – ISS Tracking

Nominal ST Pass Investigation

Multiple Orbit Flight Technique Panel discussions.

Brightness measurements of International Space Station (ISS) during approach.

Manual commanding the shutter open after Bright Object Sensor trip with SSST.

Star Tracker ground testing trials and feasibility studies conducted for enhancing SSST.

Perform an estimation of expected ISS assembly complete size at 40 nautical miles.

<table>
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<th>DATE</th>
<th>STS</th>
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<th>ORBITER</th>
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<td>8A</td>
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NASA analyzed the implications and repercussions to the increasing size of the ISS versus the tracking ability of the two models of star trackers.

IDT = Image Dissector Tube
SS = Solid State Star Tracker
Fleet Challenges – ISS Tracking

ISS

360 ft (110m) End-to-end x 160 ft (48.8m)

48.5 ft length x 14 ft in diameter.
Rendezvous Operations

Nominal Star Tracker Pass

- Star Tracker is primary
- Occurs during day time
- SSST does not handle bright objects as well as IDT

During Sept 2006, STS-115 / OV104 flight, a ‘target suppress’ indication occurred with ~ 7 minutes left in nominal ST pass.

A manual shutter open command was initiated. Final ST update was not taken into navigation state resulting in NCC burn solution being slightly off nominal, but within $3\sigma$ limits.
As the ISS increases in size, solid state ‘target suppress’ indications are expected to occur earlier each mission.

IDTs were still tracking the ISS inside of 8 nmi pass.

International Space Station estimated assembly complete size at 40 nmi is ~7 arcminutes.

Star tracker specification target size limit is 8 arcminutes.
DATE  |  STS  |  ORBITER  |  -Y  |  -Z
---|---|---|---|---
NOV 2006  |  Implement for STS-117  |  ALL ORBITERS  |  SS  |  IDT

Approval obtained to optimize the operational performance by setting the preferred vehicle installation as: –Y = SSST and –Z = IDT.

-Y solid state star tracker due to larger catalog of available stars.

-Z older tube model for International Space Station rendezvous tracking.
CREATED NEW CHALLENGE

- IDT original procurement was only for 11 flight units.
  - 2 lost on Challenger.
  - 1 lost on Columbia.
  - 2 had non-recoverable failures: 1997, 2000

- 6 total available flight units.

- By 2006, the IDT model had no repair capability and only minimal test capability available at the vendor, Ball Aerospace.
Fleet Challenges – IDT Inventory

Fly out the manifest using an IDT to track the ISS

6 Flight IDTs in Inventory
- Orbiters – 1 per vehicle
- Supply – 3 Possible Spares
  - 2 Earlier models
  - Last Powered in 1998 & 2001
  - 1 Pressure Fail

Star Tracker cases are hermetically sealed with inlet and outlet Schrader valves for purge and pressurization with argon.

The argon prevents contamination, especially humidity, from affecting optics.

In 1991, the Star Tracker Problem Resolution Team (PRT) authorized a field procedure allowing KSC to perform purge and re-pressurization of installed star trackers.
Fleet Challenges – Pressurized Case

Star Tracker Doors and Carrier Panels Removed

Thermal Blankets Removed
December 2006

- During STS-116 / OV103, the -Z IDT flagged a Pressure Fail Indication (PFI) on orbit.

March 2007, and September 2008

- PFI’s occurred during ground processing between missions.

- Re-pressurizing during each flow was undesirable due to extensive removal of orbiter carrier panels, doors and blankets to gain access to the star tracker.

- Analysis indicated pressure fail would occur during STS-119 mission in March 2009.

- Expected time between re-pressurizations is 7 years.
Fleet Challenges

STAR TRACKER
PRESSURIZED CASE
SOLUTION

*Plan – The vendor, Ball Aerospace, to apply a permanent external sealant to the failing IDT star trackers (OV103 & 1 Spare) at Kennedy Space Center.*
Solution – External Sealing

*Pressure Fail Indication occurred during STS-119 (expected).*

Landing at Kennedy Space Center  \hspace{1cm} \textit{March 28, 2009}

**PLAN ----**

- Remove –Z star tracker from OV103  \hspace{1cm} \textit{April 30, 2009}

- Transport to a clean room laboratory at Kennedy Space Center

- Vendor permanently seal all case seams utilizing a pre-approved epoxy process

- Purge and re-pressurize star tracker

- Transport back to Orbiter Processing Facility

- Reinstall –Z star tracker in OV103

- Perform functional test

\textbf{ALL WITHOUT IMPACTING ORBITER PROCESSING SCHEDULE FOR STS-128!}

\textit{From start of door removal to reinstall – 3 weeks.}
Solution – External Sealing

Ball Aerospace implemented an engineering design change that sealed seams on all faces with epoxy.
Solution – External Sealing

Each side (face) required a minimum four hour cure time prior to moving star tracker.
Solution – Re-pressurization

The final step for the star trackers was a complete 12 cycle purge with argon gas, then re-pressurization to a level equivalent to 17.58 psi at 25 Deg C.

Argon source line from pneumatic test set.

Not Shown: 90 Deg Schrader adapter on purge valve (similar to fill valve) used to open/close valve during 12 purge cycles.
Bonus Leak Test

- How to address SS trackers with pressure case leaks?
- Goal was to first determine source of leak
- Second, perform spot repair
- Bonus, negate possibility of future intrusions into orbiter cavity
- SS trackers were still repairable, therefore complete permanent external sealing was not an option.
- Currently, one SS tracker was not flight worthy due to pressure case leak problems.
Solid State Star Tracker Leak Test

1. Performed sniffer checks with probe to attempt isolation of small leaks.

2. Found the torque on the Schrader cores to be less than recommended by manufacturer.

3. After torque on cores was corrected, the unit was purged and re-pressurized.

4. Subsequent sniff checks were clean.
Fleet Assets Today

All three Orbiters are equipped with

SS in the –Y location for optimal star tracking.

IDT in the –Z location for optimal rendezvous tracking.

Since re-installation into OV103, the IDT has flown flawlessly.

The spare IDT that completed the external sealing process in May 2009, successfully passed ground testing at Johnson Space Center, Electro Optics Laboratory in Dec 2009. No Pressure Fail problems noted.

*The star tracker sub-system is configured to provide optimal support to successfully accomplish the remainder of the shuttle flights.*
Flight Performance
A Built In Test (BITE) simulated star is tracked and the data obtained is compared to factory data stored in memory.

Trend plots are used to track the reported BITE star:
- Horizontal Position
- Vertical Position
- Star Magnitude

Other verifications each ground processing flow include:
- Shutter function
- Bright Object Sensor operation
- Star Tracker door operation
- Optics and Light Shades cleanliness
Credits

• On orbit, pad and launch photographs are furnished courtesy of the National Aeronautics and Space Administration.

• All ground processing and repair photographs were captured by Linda Herrera.

• I would also like to recognize contributions by:

  Phil Perkins, Star Tracker Subsystem Manager
  The Boeing Company

  Jerry Yencharis, Mission Operations Directorate Ground Controller
  Barrios Technology, Incorporated
Additional Links

USA Today link to “International Space Station comes together”

http://i.usatoday.net/tech/graphics/iss_timeline/flash.htm

Downloadable copy of the 2010 NASA International Space Station Calendar

http://www.nasa.gov/pdf/402659main_2010_iss_calendar.pdf

NASA Multimedia Website

http://www.nasa.gov-multimedia/index.html

Astronaut guided tour of the International Space Station