

Metrology, attitude, and orbit determination for spaceborne interferometric synthetic aperture radar

Riley Duren, Ed Wong, Bill Breckenridge, Scott Shaffer,
Courtney Duncan, Eldred Tubbs, and Phil Salomon

Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Drive, M/S: 198-B9, Pasadena, CA 91109

ABSTRACT

The Shuttle Radar Topography Mission (SRTM), scheduled for an 11 day Space Shuttle flight in 1999, will use an Interferometric Synthetic Aperture Radar (IFSAR) instrument to produce a near-global digital elevation map of the earth's land surface with 16 m absolute vertical height accuracy at 30 meter postings. SRTM will achieve the required interferometric baseline by extending a receive-only radar antenna on a 60 meter deployable mast from the shuttle payload bay. Continuous measurement of the interferometric baseline length, attitude, and position is required at the 2 mm, 9 arcsec, and 1 m (1.6 sigma) levels, respectively, in order to obtain the desired height accuracy. The Attitude and Orbit Determination Avionics (AODA) subsystem will provide these functions for SRTM. The AODA flight sensor complement includes electro-optical metrology sensors, a star tracker, an inertial reference unit, GPS receivers, plus supporting electronics and computers. AODA ground processing computers will support SRTM system performance evaluation during the mission and baseline reconstruction after the mission. The final AODA data products will be combined with the radar data (range and interferometric phase) to reconstruct the height information necessary for topographic map generation. A description of the AODA system architecture, error budgets, and the major issues involved with measuring large space structures are presented.

Keywords: metrology, attitude determination, orbit determination, spacecraft guidance and control, IFSAR

1. INTRODUCTION

SRTM is a project jointly sponsored by NASA and the National Imagery and Mapping Agency (NIMA) with the goal of generating high accuracy topographic maps on a global scale. SRTM will provide coverage of 80% of the earth's land surface based on data acquired during an 11-day Space Shuttle flight in 1999. SRTM will produce enough data for a digital model of the Earth that will satisfy the NIMA Digital Terrain Elevation Data Level 2 (DTED-2) requirements, which specifies 10 meter relative (over a scene) vertical height accuracy, 16 meter absolute vertical height accuracy, and 30 meter postings.¹ These results will provide significant improvement over existing global topography data sets. Incidentally, all accuracies listed in this paper are at the 90% (1.6 sigma) level unless specified otherwise.

Spaceborne SAR has demonstrated several advantages over conventional imagery, including independence from solar illumination, cloud cover, and forest canopies. Collaborations between NASA and the German and Italian space agencies produced the highly successful Spaceborne Imaging Radar/X-band Synthetic Aperture Radar (SIR-C/X-SAR) instruments which flew twice on the Space Shuttle in 1994.² SIR-C/X-SAR gathered imagery over pre-designated target sites and exercised several experimental SAR techniques. Among the SIR-C/X-SAR experiments were successful demonstrations of repeat-pass interferometry, where imagery of a target was obtained on repeat orbits (the difference in positions on each pass forming the necessary baseline), and ScanSAR, where radar beams were electronically steered in elevation to increase the swath width. These experiments helped pave the way for SRTM. Unlike other spaceborne SAR platforms, SRTM will operate as a fixed-baseline mapping interferometer, which will effectively remove large error sources inherent with the repeat-pass technique, such as temporal decorrelation and baseline uncertainties. SRTM data acquisition is depicted in Figure 1.

The SRTM architecture is based on the existing SIR-C/X-SAR instruments, but has undergone significant changes, resulting in a more complex system. The original SIR-C and X-SAR electronics have been modified and new electronics added to support the IFSAR mode of operation. A new subsystem consisting of a 60 meter mast and supporting mechanisms has

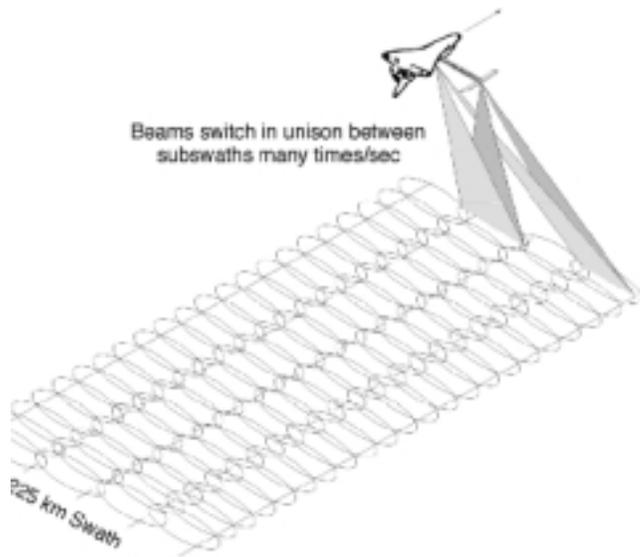


Figure 1 - SRTM Data Acquisition

been added to deploy an “outrigger” radar antenna. New computers and algorithms are being developed to support mission operations and ground data processing. The Attitude and Orbit Determination Avionics (AODA) subsystem is being developed to provide the necessary baseline metrology, attitude, and orbit determination functions for SRTM and is the subject of this paper.

Before proceeding with a description of the AODA subsystem, a brief discussion of the SRTM mast and disturbance environment is necessary. A section of the SRTM mast structure, including electrical cables, is shown in Figure 2. The mast, developed by AEC-Able, is a composite structure composed of graphite epoxy longerons and battens with stainless steel fittings and titanium cables. When deployed, it forms a rigid structure with primary modal frequencies on the order of 0.1 Hz. The mast is designed to provide minimal thermally-induced distortions, allow quick (20 minute) deployment and retractions, and is capable of being jettisoned in an emergency. The challenges of operating an interferometer with a large deployed mast cannot be overstated. A few of these challenges are:

- (1) The mast alone has very little inherent damping, resulting in the need to add viscous damper struts at the root to prevent resonant instability in response to the Shuttle attitude control system.
- (2) The mast and outboard antenna represent a large moment-arm on the shuttle. Since the SRTM mapping geometry requires that the mast be maintained at a 45° angle with respect to the nadir vector, the resulting gravity-gradient torque is quite significant. A constant-thrust cold-gas propulsion system has been added to the outboard antenna to compensate for this torque and reduce Shuttle fuel consumption.
- (3) Mast pointing is affected by several factors. Gravity unloading, launch shifts, and pre-flight assembly and alignment errors result in a quasi-static pointing bias. In-flight thermal distortions of the mast and antenna structures (bending and twisting) create pointing errors with time-constants of tens of minutes. Finally, the mast will dynamically respond to the shuttle attitude control system thruster firings and astronaut crew activities. Note that mast bending results in relative misalignment between the two antennas (e.g., a 3 cm tip translation results in a 0.1° antenna misalignment).

Although these challenges have been mitigated by the SRTM structural and mechanisms design, mast pointing errors must ultimately be dealt with by AODA and the radar instruments. Pointing errors impact the AODA and radar sensor's capability to both acquire and track targets. The nominal magnitudes and frequencies of these pointing error sources as seen by the AODA sensors are summarized in Table 1. The totals shown include the effects of mast twisting on AODA metrology target displacements. The aft-most AODA metrology target is located 2 meters aft of the mast center-line on the outboard antenna.

2. AODA REQUIREMENTS

The four basic AODA requirements are: 1) provide in-flight measurements necessary to verify successful mast deployment, 2) provide in-flight measurements necessary to guide alignment of the radar antennas, 3) provide updated measurements of mast modal frequencies to guide in-flight optimization of the Shuttle attitude control system, 4) provide data necessary to support post-flight topography processing (height reconstruction).

1) For safety reasons, successful deployment of the mast must be verified before proceeding with the mapping phase of the mission. Although unlikely, failure scenarios exist where the mast is completely extended but one or more latches do not fully engage, making the mast susceptible to collapse in response to shuttle thruster firings. The shuttle will remain in free drift in a stable gravity-gradient attitude during mast deployment and verification. AODA measurements of deployed mast tip position and attitude errors will allow the astronaut crew and ground teams to verify mast integrity before enabling the Shuttle's attitude control system.

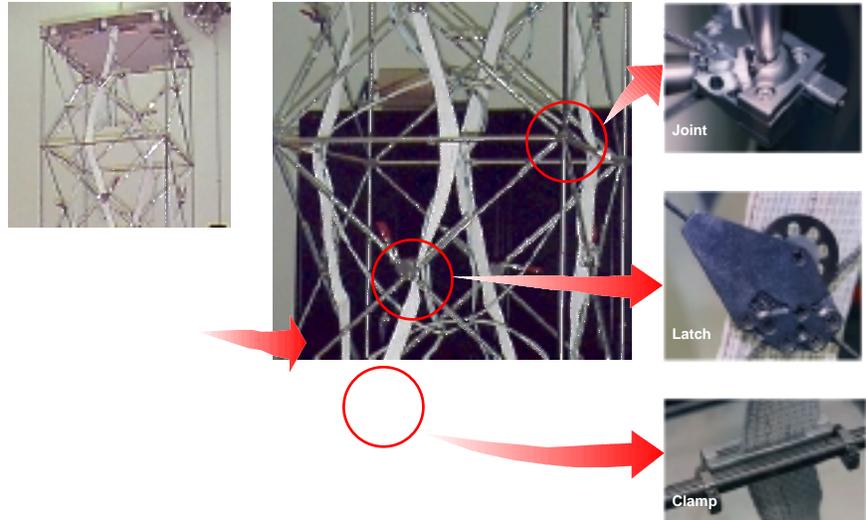


Figure 2 - Mast Cross-Section

2) As mentioned in section 1, errors in mast pointing lead to misalignment between the inboard and outboard radar antennas. The static and quasi-static components of pitch and yaw misalignment must be reduced to 0.3° before the radar instruments can operate properly. Roll misalignment is not critical since the radars can perform significant electronic beam steering about that axis and the antenna pattern is an order of magnitude broader along the roll axis than the pitch or yaw axes. The mast tip is equipped with a two-axis "milkstool" actuator that allows for mechanical adjustment of the outboard antenna pitch and yaw alignment. Following mast deployment, the astronaut crew will use AODA measurements to guide adjustments with the milkstool mechanism. Once the antennas are properly aligned, the radar will compensate for mast dynamics by sensing the returned signal and steering the beam accordingly.

3) Due to the practical difficulties of performing precision modal tests on the integrated system in a 1-g environment, the pre-flight estimates of mast modal frequencies are only accurate to 10-20%. Since notch filter settings in the Shuttle's attitude control system are selected to reduce mast response, uncertainties in pre-flight estimates could lead to inefficient on-orbit performance (resulting in more fuel consumption and larger mast dynamics). Therefore, in-flight modal tests will be performed to improve our knowledge of the mast frequencies and allow for near real-time attitude control system optimization. The modal tests will involve firing shuttle thrusters to excite the mast and use AODA measurements of mast and shuttle dynamics to solve for the modal frequencies (i.e. Power Spectral Density plots based on solutions from the AODA metrology and attitude sensors). The knowledge of the mast frequencies following the in-flight modal test should be good to 5%.

Pointing Error	Resulting AODA Target Displacement (peak-to-peak)	Resulting AODA Target Rate (peak)
Quasi-Static Bending	8.4 cm	-
Quasi-Static Twisting	3.4°	-
Thermal Bending	8.5 cm	4 cm/hr
Thermal Twisting	0.14°	$0.07^\circ/\text{min}$
Dynamic Bending†	6.6 cm	3 cm/s
Dynamic Twisting	0.1°	$0.08^\circ/\text{s}$
(† worst-case Z axis shown)		
Total	36 cm	3.5 cm/s

Table 1 - Expected Pointing Errors

4) There are five primary quantities of interest when using IFSAR to determine the height (h_t) of some target land feature on the earth's surface: range (ρ), interferometric phase (ϕ), baseline roll angle (α), baseline length (B), and platform height (h_p) (see figure 3 for height reconstruction geometry). The expression for target height can be approximated by

$$h_t = h_p - \rho \cos(\sin^{-1}(\lambda\phi/2\pi B) + \alpha) \quad (1)$$

where λ is the observing wavelength³. The baseline is defined as the vector between the phase centers of the inboard and outboard radar antennas. While there are additional error terms involved in solving for the baseline (including electrical phase center shifts due to beam steering and spilling), to first order we can treat the phase centers as being co-located with the mechanical area centroids of the radar phased arrays. For SRTM, the radar instruments provide data necessary to determine ρ and ϕ . AODA will determine α , B , and h_p . After significant ground data processing, a Digital Elevation Model (DEM) is produced based on the SRTM results. The SRTM SAR imagery (obtained concurrently with ρ and ϕ) will be combined with the DEM to generate topographic maps.

The dependence of SRTM height reconstruction performance on various error sources is shown in Figure 4. Errors in baseline angle, baseline length, and platform height have significant impact on total SRTM performance. Baseline roll angle, in particular, is one of the largest error sources (second only to radar phase noise). The allocations shown here represent the primary AODA performance specifications, namely, provide baseline attitude determination at the 9 arcsecond level (includes platform inertial attitude and relative misalignment between inboard and outboard antenna), baseline length determination at the 2 mm level, and platform height determination at the 1 m level. Expected accuracies are also shown.

3. AODA ARCHITECTURE

The AODA system architecture is depicted in figure 5. A detailed description of each component follows. Sensor acquisition and tracking performance is discussed in section 4. Sensor accuracy is presented in section 5 in the AODA error budget.

Orbit (platform position and velocity) determination is provided by an onboard GPS system. It consists of two P-code tracking GPS Receivers (GPSRs) developed as part of JPL's TurboRogue Space Receiver program. Each receiver is connected to two Antennas (GPSAs), one each located on the inboard and outboard radar antennas. Although only one functioning GPSR/GPSA chain is required to provide the necessary orbit determination measurements, the multiple baselines provided by the four GPSAs allows for relative attitude and position determination between the inboard and outboard radar antennas using differential GPS techniques. This capability is only experimental, however, and alone cannot provide the required accuracy for SRTM. It should be noted that the onboard receiver position solution is via "direct GPS" technique

and, if used alone, is limited to 10-100 meter accuracy. For SRTM, pseudorange and phase observables acquired by the onboard GPSRs will be combined with those simultaneously acquired from an existing ground network of globally distributed, well-surveyed GPS receivers to obtain the required 1 meter position determination accuracy (i.e., a "global differential GPS" technique).⁴ This technique provides an additional advantage in that it makes the SRTM GPS system insensitive to Selective Availability.

The baseline attitude has two primary components: the inertial platform or inboard antenna attitude and the (primarily) mast-induced relative motion between the two radar antennas. The inertial platform attitude is measured by a Star Tracker Assembly (STA) and an Inertial Reference Unit (IRU). The STA consists of the Lockheed Martin Autonomous Star Tracker (AST-201). The STA will output quaternions representing its boresight's inertial attitude at 1 Hz. IRU measurements will further refine the attitude

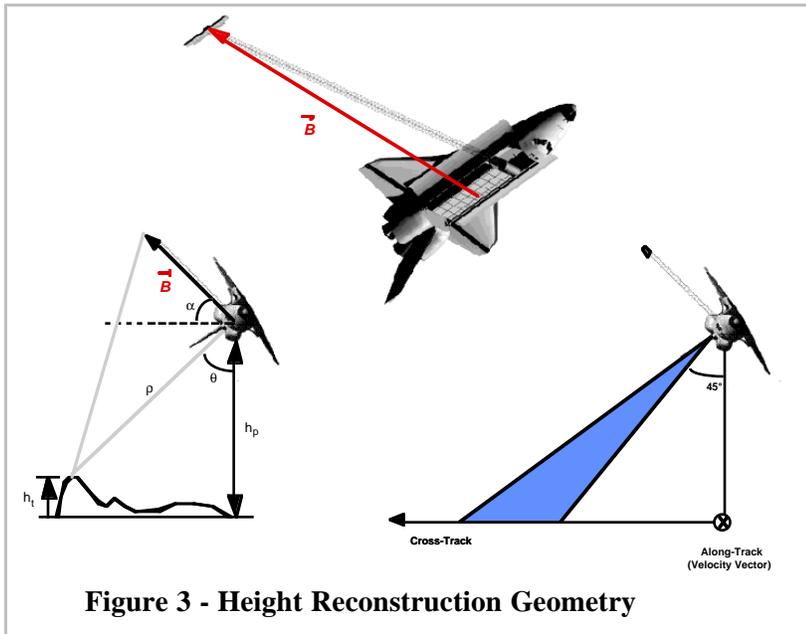


Figure 3 - Height Reconstruction Geometry

estimate during post-flight ground data processing. The IRU is a Teledyne Dry Rotor Inertial Reference Unit (DRIRU-II). Developed as the NASA Standard IRU in the mid-1970's, the DRIRU-II has an excellent record of precision attitude rate sensing.⁵ This particular unit has flown twice on the space shuttle and will not be modified for SRTM. Incidentally, the

AODA GPS, STA, and IRU sensors are necessary because the Shuttle guidance and navigation systems cannot provide the required accuracy and because significant thermal distortions exist between the shuttle guidance platform and the SRTM inboard antenna.

The sensors used for performing the AODA platform position and inertial attitude determination were specifically designed for use in guidance and navigation applications. However, due to cost and schedule constraints, the baseline metrology sensors required substantial use of inherited and commercial hardware with unique modifications.

The ASTROS Target Tracker (ATT) is critical for meeting all four AODA requirements: baseline determination, antenna alignment support, mast deployment verification, and mast modal ID. The Advanced Stellar and Target Reference Optical Sensor (ASTROS) was developed by JPL in the 1980's to serve as a high precision star tracker for pointed applications.⁶ It has flown on the shuttle twice and has demonstrated sub-arcsecond accuracy in-flight. However, since it was designed to operate as a star tracker on a gimbal-pointed platform, it required significant modifications for AODA. A corrective lens has been added to change the focal length to 60 m. A neutral density filter and narrow passband interference filter have been added to allow target acquisition in the presence of bright backgrounds. Additional modifications have been made to the electronics and firmware to improve tracking performance. The ATT, located on the inboard antenna, will track three red (635 nm) LED targets located on the outboard antenna. The LEDs will be mounted on hollow graphite-epoxy "stalks" and separated by 1 meter both laterally and in line of sight (see Figure 5). A redundant LED array is also included. This assembly is called the Optical Target Assembly (OTA). The ATT will output centroid information (CCD line and column coordinates) on all OTA three targets at 4 Hz. This arrangement will allow AODA software to determine the outboard antenna's relative attitude and position based on the ATT centroid data.

Although the ATT provides very good accuracy in determining 5 of the 6 outboard antenna degrees of freedom, it has poor accuracy in determining the line-of-sight component. This is due to the geometrical limitations imposed by the size of the outboard antenna, which constrains the separation of our metrology targets. Therefore, it was necessary to add additional metrology instruments capable of measuring the largest component of baseline length (range to outboard antenna) to high accuracy. Rather than develop a precision metrology instrument (perhaps based on a laser interferometer), we took a novel approach and acquired a commercially-available surveying rangefinder, known in the industry as an Electronic Distance Meter (EDM). The Leica-Wild DI2002 EDM actually exceeds our performance requirements (1 mm versus 3 mm relative accuracy). It operates on a time-of-flight principle (amplitude modulating an infrared carrier in a progression of frequencies up

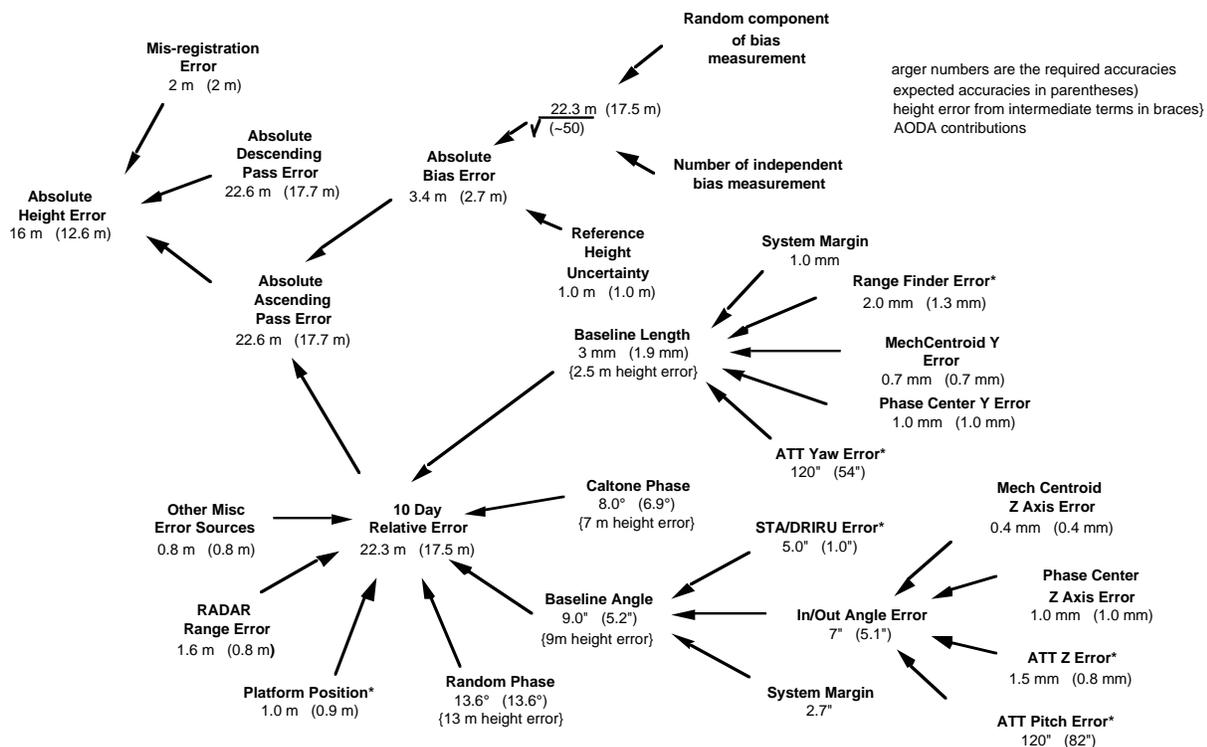


Figure 4 - SRTM Height Error Budget

to 50 MHz and comparing the phase of the return from a cube-corner reflector with that of the outgoing beam). A series of performance and environmental tests demonstrated that this off-the-shelf unit will meet our needs. Work is proceeding to flight-qualify four of these instruments (two redundant units for measuring range to outboard antenna and two other units to measure displacements between the inboard C- and X-band arrays). Modifications include external lens assemblies to increase the EDM field of view, external conversion of the RS-232 communications port to RS-422 (for improved noise immunity), minor thermal conduction improvements, replacement of a few radiation-intolerant parts, and some ruggedization. Otherwise, there is no need to modify the internal workings of the EDMs. The EDMs will undergo a rigorous environmental and burn-in test program.

The unorthodox-looking structure in Figure 5 called the AODA Sensor Panel (ASP) supports the STA, IRU, ATT, and EDMs. The ASP is kinematically mounted to the inboard antenna structure and is designed to keep all of the components isothermal through the use of thermal blanketing, conductive straps, and two “cold plates” located under the panel. This is necessary to minimize the amount of in-flight thermally-induced shifts between the sensor boresights.

Sensor command, power, and data handling is provided by the Sensor Interface Unit (SIU), a smart mux/demux developed at JPL specifically for AODA. It contains the necessary electronics and firmware for supporting the diverse suite of sensors. The SIU, together with the GPSRs, provides precision time-tagging of sensor data to allow post-flight correlation of AODA data with radar data.

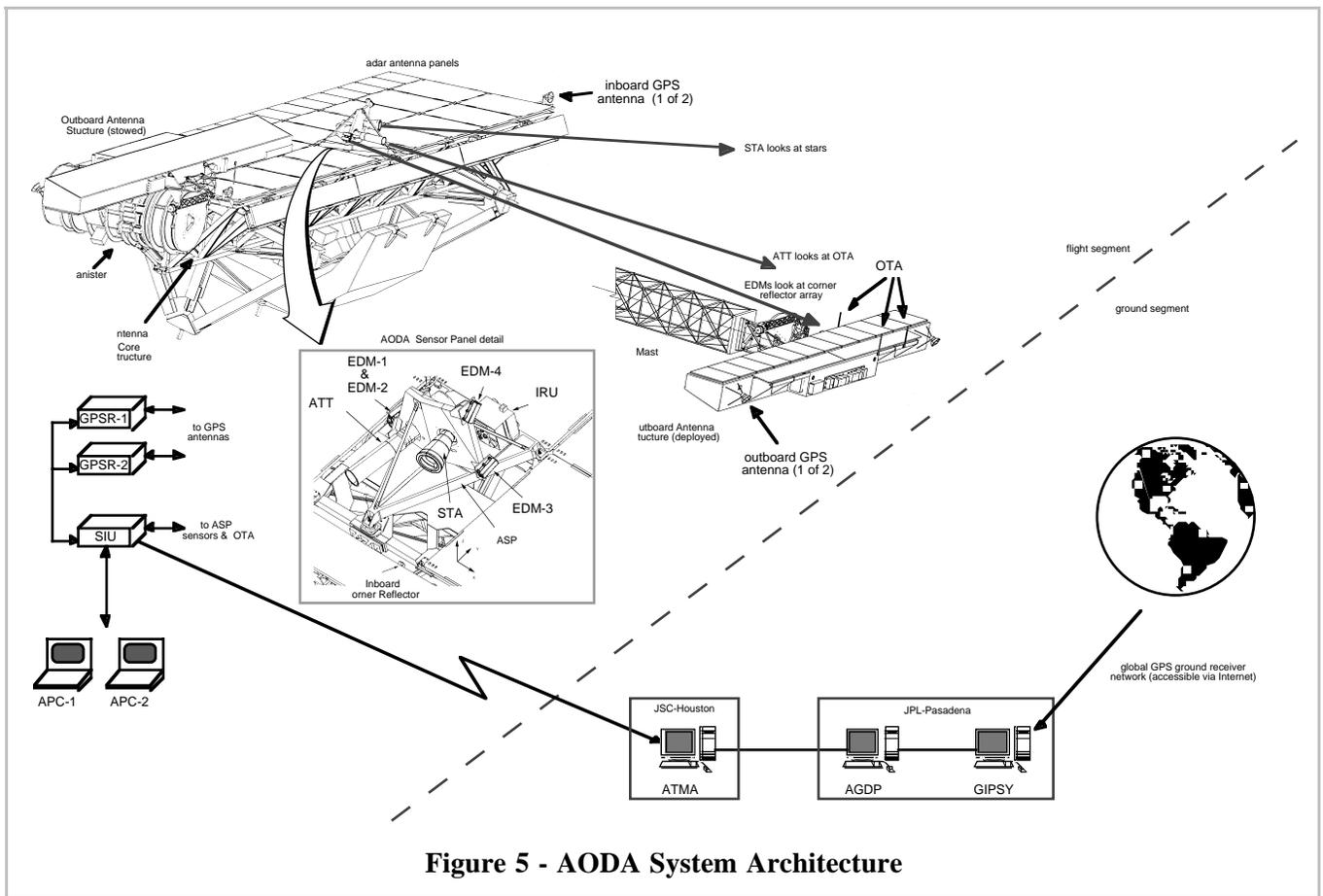


Figure 5 - AODA System Architecture

Two laptop computers with JPL-developed software will function as onboard AODA Processing Computers (APCs). Located in the Shuttle’s crew cabin, they will provide automated control loops for the operating the ATT and EDMs, an attitude estimator and associated display to guide antenna alignment, and additional AODA status displays and command interfaces for the astronaut crew. They also provide the primary AODA data archive to be recovered post-mission. The AODA data is also downlinked in real-time.

The AODA ground segment consists of the previously described global network of ground GPS receivers, the GPS Inferred Positioning System (GIPSY), the AODA Ground Data Processor (AGDP), and the AODA Telemetry Monitor/Analyzer

(ATMA). The ground segment will be used during the mission to support quick-look height reconstruction, antenna alignment, and mast modal ID. However, the primary use will be during several weeks of post-flight data processing. The ATMA will serve as the front-end of the ground segment and is used to acquire the raw telemetry data and display the processed results. The AGDP will take the raw data from the ATMA (or APCs, following post-flight recovery), pass the onboard raw GPSR data to GIPSY (where it will be combined with ground receiver data), perform the attitude and baseline determination processing, recombine the GIPSY output data, and present the radar ground segment with a single time-tagged data archive.

During the first 12 hours of the SRTM mission, the AODA operations will be very closely linked with the deployment of the mast, alignment of the antennas, and optimization of the shuttle attitude control system. Intensive interaction with the astronaut crew (via the APC laptop computers) is expected during this period. However, the AODA system is designed to operate autonomously once the mapping phase of the mission begins. Automatic control loops running in the onboard software will trigger re-acquisition attempts if target lock fails. Error checking software will alert the astronaut crew and ground teams in the event of malfunctions.

4. ACQUISITION & TRACKING PERFORMANCE

The STA has a $8.8^\circ \times 8.8^\circ$ Field Of View (FOV) and employs a guide-star catalog covering 16,000 stars. It will perform autonomous acquisition and begin tracking within 10 seconds of activation (with no a priori attitude knowledge). Acquisition starts with the STA scanning its CCD for guide stars. It then uses a pattern-recognition technique to match the guide star pattern with the database. Upon successful match, it moves into track mode and proceeds to generate ECI-to-boresight quaternions. The STA typically tracks 30-50 stars. It is capable of full accuracy for rates of $0.5^\circ/\text{s}$ and degraded accuracy for rates as high as $2^\circ/\text{s}$. The STA will autonomously reacquire in the event of a failed guide star identification or in the case of bright objects in the FOV. The STA runs internally at 2 Hz but only outputs data at 1Hz (the 1 Hz output includes the quaternion plus incremental angles representing any rotation between it and the previous frame). This allows for 2Hz post-flight attitude estimation.

The GPSRs power up with no a priori knowledge of position, velocity, or time. They begin to search over the expected Doppler range of ± 4 KHz from the L1 GPS frequency (1575.42 MHz) for signals from the GPS satellites, searching for up to 16 simultaneously. When a signal is detected, the GPSR acquisition algorithm locks on and switches to tracking mode. Once 4 or more satellites are being simultaneously tracked, the ranging data from the independent tracks is used to calculate the antenna state vector and time. P-code and phase data from the ongoing tracks constitute the GPS observable. This information is also used in real-time to predict future GPS tracks and lock onto them directly as the GPS satellites become visible. Up to 16 satellites may be tracked simultaneously by each receiver. Once time and position solutions are complete, the receiver internal clock is synchronized to GPS Time (traceable to UTC) and provides sub-microsecond time measurements necessary for correlating GPS observables to radar events.

The ATT has a $2.2^\circ \times 3.5^\circ$ FOV but is pointed to minimize the amount of bright antenna structure in the FOV (resulting in a tolerance for ± 25 cm of mast tip displacement before losing one of the targets). ATT target acquisition and tracking is directed by executive software running on the APC laptops. Low-level control functions are implemented in ATT and SIU firmware and hardware. An automated control loop is started by user command. Acquisition starts with the ATT performing analog threshold scanning of its CCD. Bright pixel information is gathered and centroid information for up to three targets is output. The ATT will track 1-3 targets, although the default APC setting will continue to attempt acquisition until 3 targets are found. Once in track, the ATT maintains track windows about each centroid on the CCD. This allows faster tracking than that achievable by full-CCD readouts every sample. Track window position is updated every frame. The ATT runs at 8Hz in order to follow worst-case mast tip velocities of 60 mm/s. However, due to Shuttle telemetry bandwidth limitations, the data is only read-out by the SIU at 4 Hz (every other frame is discarded). This is more than adequate to Nyquist sample the mast dynamics.

The EDMs do not actively "acquire" their targets. They have a fairly small FOV (approximately 1.7 mrad). Provided sufficient signal strength is returned from the target, they will continue to operate independently of the target motion. The target is a large (40 cm diameter) array of cube-corner reflectors located on the inboard edge of the outboard antenna. This will allow the two outboard-looking EDMs to still acquire enough signal in the event of large mast excursions. Rotations of the outboard antenna produce some errors in range solution, but when coupled with the ATT data, the resulting range accuracy is still better than 2 mm. A single cube-corner reflector is located on the inboard X-band radar antenna. This reflector will be deployed into the spots of the two associated EDMs along with the antenna itself (via a tilt motor). Once the

X-band antenna is deployed, it will remain in place throughout the mission with only small (1 cm level) thermally-induced excursions.

Integrated testing of the ATT and EDMs is crucial to verifying the robustness of the system and will be accomplished using a dynamic Mast Motion Simulator (MMS). The MMS consists of a set of three LEDs and corner reflector array mounted on a servo-driven two-axis translation stage. The translation stage and controller box are of the type commonly used in “pick and place” manufacturing applications and were procured from a commercial vendor. Our unique application required us to develop special data files based on predictions of on-orbit mast dynamics. Some of the data files are direct outputs from the combined SRTM/Shuttle dynamic model at NASA’s Johnson Space Center. The files are downloaded into the MMS via a desktop computer and used to drive the two-axis translation stage with the LEDs and corner reflectors. The MMS will be located on a rooftop 60 meters distant from the windows of the AODA testbed. This allows full-motion, end-to-end dynamic testing to be performed with the AODA flight hardware. Nominal and contingency scenarios will be simulated and integrated ATT/EDM data will be acquired for end-to-end checkout of the AODA ground data processing algorithms. Astronaut training will also be performed in this environment.

Pre-launch alignment verification is also very important to the success of SRTM. The relatively small FOVs of the ATT and EDMs, in particular, place stringent constraints on the total amount of misalignment that can be tolerated. The goal of ground alignment verification is to identify and remove most of the systematic error terms prior to launch in order to allow maximum margin for on-orbit excursions. An important phase of alignment verification involves powered-up testing with the AODA flight sensors to confirm the as-built pointing geometry is correct. This will culminate with a final end-to-end alignment test at the Kennedy Space Center prior to launch. Although the mast cannot be fully deployed once it is integrated with the rest of SRTM (it will be deployed several times before leaving the vendor’s facility), we plan to project a line representing the nominal mast center-line and deploy a set of targets at 60 meters. The ATT and EDM lens covers will be removed and powered-up measurements will verify the targets appear in the proper area on the ATT CCD. The EDM spot will be examined with an infrared camera to confirm it falls on the correct location on the corner reflector array.

5. AODA FINAL ACCURACY

The AODA Error Budget, representing expected performance, is shown in Figure 6. It is important to note that all of the AODA requirements specify *relative* accuracy as opposed to absolute accuracy. This is because large systematic error biases, such as sensor-to-platform misalignment (due to pre-flight buildup and alignment errors and launch shifts), can be removed post-flight by calibrating the data. SRTM calibration is accomplished by performing radar data-takes periodically during the mission to establish independent measurements of the interferometric baseline attitude and length. A few calibration data-takes are scheduled over well-surveyed ground sites but the majority will take place over the ocean. Only a few such calibration tie-points should be necessary to remove the large systematic biases. In other words, AODA only needs to provide sufficient measurement accuracy to propagate the baseline attitude and length between calibration sites. The only exception to this is the GPS-derived platform position solutions, which do not require calibration.

A variety of coordinate systems are used by AODA. In the error budget, the term “platform” refers to the SRTM inboard antenna coordinate system. Solutions for baseline length and attitude are given relative to this coordinate system. All platform position solutions are given relative to World Geodetic Survey 1984 (WGS-84), an earth-centered-earth-fixed coordinate system. Initially, the platform attitude solutions are given in Earth Centered Inertial (ECI) coordinate system then, using GPS position data, are transformed to the Tangential Cross Normal (TCN) coordinate system, an SRTM-centered-SRTM-fixed coordinate system which maintains one axis normal to the WGS-84 ellipsoid.

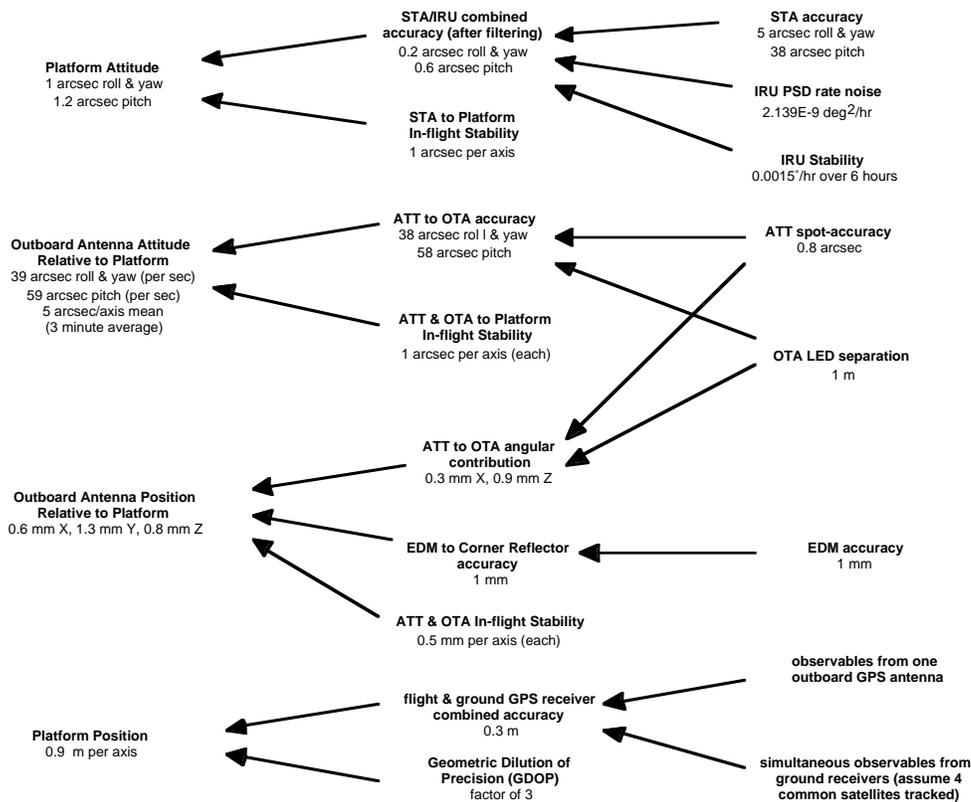


Figure 6 - AODA Error Budget

Initial AODA sensor test results are promising. The ATT, IRU, and EDM accuracies have been verified through test. GPS performance is expected to be consistent with that obtained on TOPEX/Poseidon (except we expect 1 meter performance on a one second basis as opposed to centimeter performance over long arcs). Preliminary results from testing at the vendor's facility indicate the STA should perform as indicated here. Additional STA testing at JPL's Table Mountain Observatory is planned for April 1998. Additional insight into integrated system performance will be gained over the coming months.

6. CONCLUSIONS

SRTM will provide unprecedented, near-global topographic coverage of the earth's land surface in a single 11 day shuttle mission. In addition to being a practical application of long-baseline interferometry, SRTM will be executed much faster and cheaper than alternative schemes. The AODA subsystem will demonstrate the application of traditional spacecraft attitude determination techniques to interferometric baseline reconstruction, "global differential GPS" for use in a fully-operational application, and novel modifications to existing sensors, converting them into space-qualified metrology instruments. The use of large space structures is becoming more commonplace, particularly for use in remote-sensing and astronomy. SRTM and AODA are among the first of these new systems to become operational. While the goal of SRTM is to produce a specific data product, it is also likely to provide some practical lessons-learned on developing and operating a space interferometer.

7. ACKNOWLEDGMENTS

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