



Spin Axis Attitude Determination (SAAD) Package

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What's to come...

- Overview of spin axis attitude determination
 - When? Why? How?
- Spin axis attitude determination algorithms
 - Brief intro to those used in SAAD
- Solution of a sample case
 - Data generated, noise and biases added
 - Highlight features of the package from data entry through final solution

Spin Axis Attitude Determination

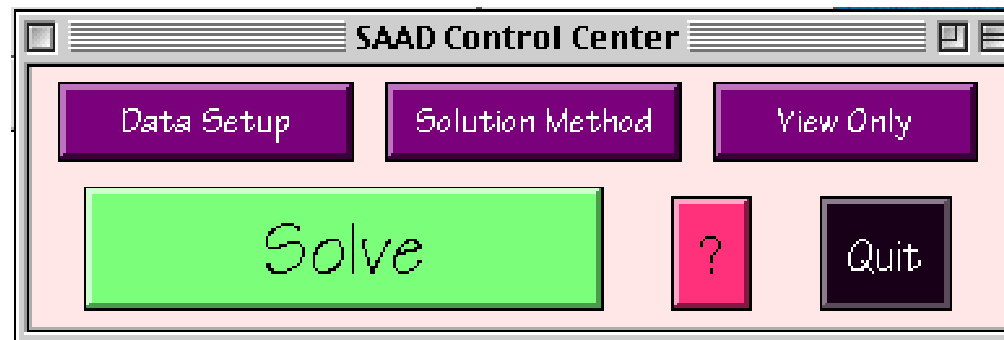
- Used in spinning geosynchronous transfer orbit
- Need to point the spacecraft accurately for the solid rocket apogee firing, which circularizes orbit
- A few tenths of a degree error in declination will have significant effect on the life of the spacecraft
- Measurements taken using sun sensor and horizon sensors
- Typically, very large data sets of noisy data with numerous systematic errors
- Problem is poorly conditioned

SAAD Methods

- Two types of algorithms - closed form and numerical
- Closed Form - solve analytically
 - Single Frame and Batch Shuster
 - Cone Intercept
- Numerical - solve iteratively
 - Differential Corrector
 - Conjugate Gradient
 - Kalman
 - Nelder-Mead

Starting SAAD Package

- Start by typing SAAD at the Matlab prompt
- Main control window (below) gives access to
 - Data entry and setup functions
 - Solution method selection and setup
 - Commands to solve or view the data
 - Help



Data Setup Window

Click **?** to find out more about each option; click **View** to see entered input

Data Files

Orbit Data

Sensor Data

Sensor positions and delays

HSA Data Type Angles ▼

1 Lead Trail Mid None

2 Lead Trail Mid None

HSA Processing

1 Lead Trail Mid CW SSA

2 Lead Trail Mid CW Only

Data Repairs

Cull data, permitting sigma deviation from the prediction

Validate dihedral angles

Minimum chordwidth deg

Thin data: Keep 1 of every points

Biases

Chordwidth 1 deg

Chordwidth 2 deg

Dihedral Angle 1 deg

Dihedral Angle 2 deg

HSA Cant 1 deg

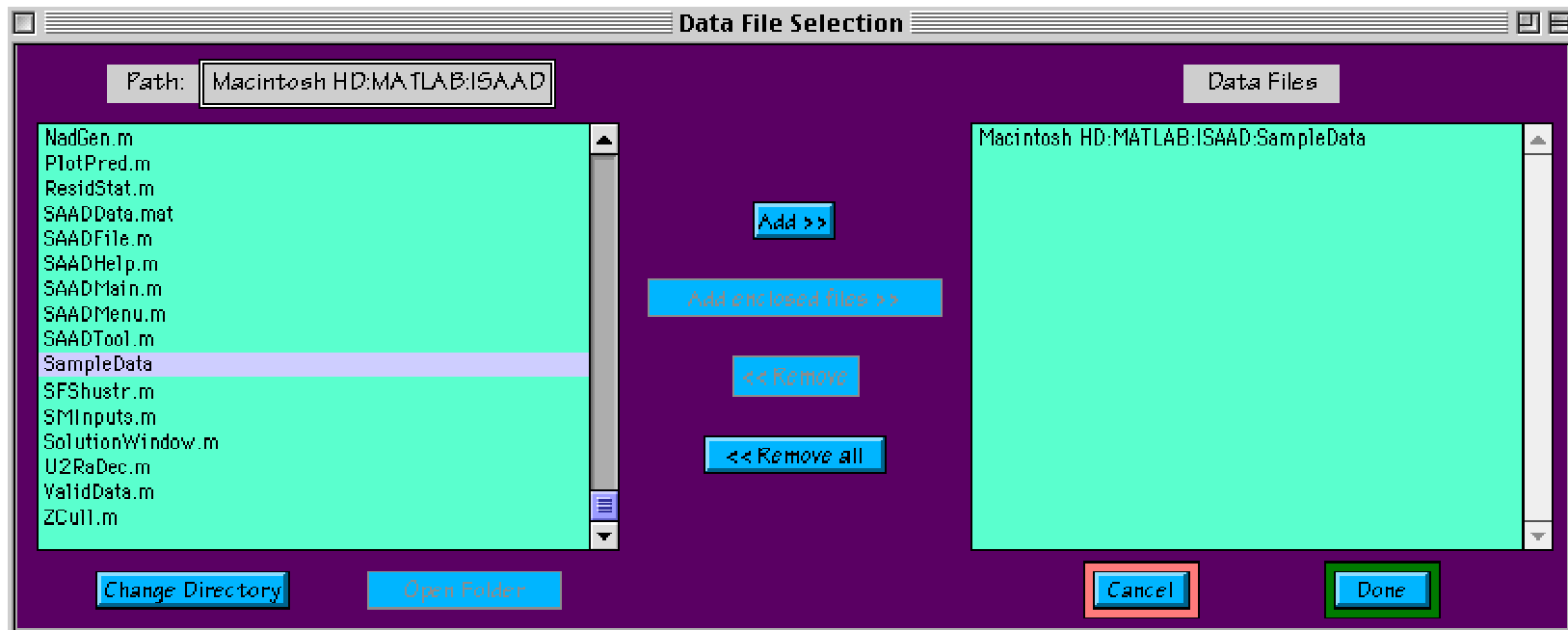
HSA Cant 2 deg

Sun sensor deg

Earth Radius deg

Data File and Loading Function Selection

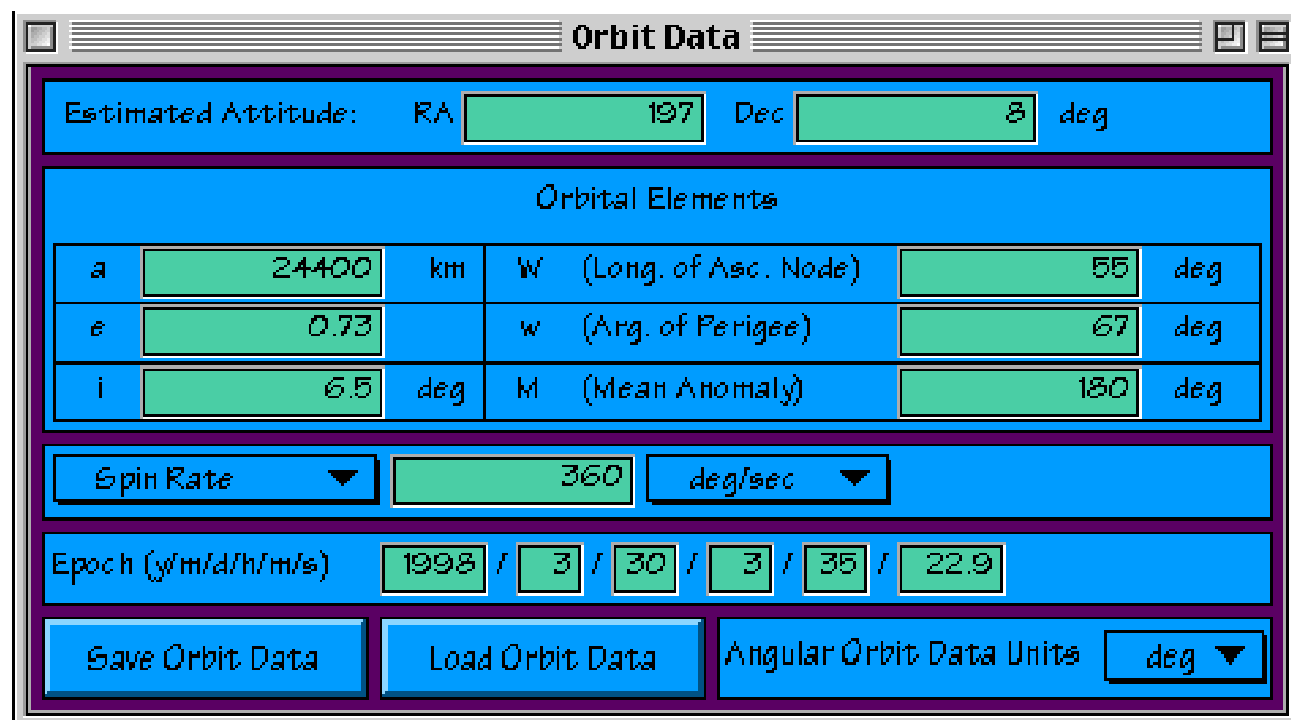
- GUI allows unlimited number of data files



- File dialog used for loading function selection. Loading function is customized for data format.

Load the Orbit Data

- Orbital elements from the current apogee must be used
- Estimated attitude is required



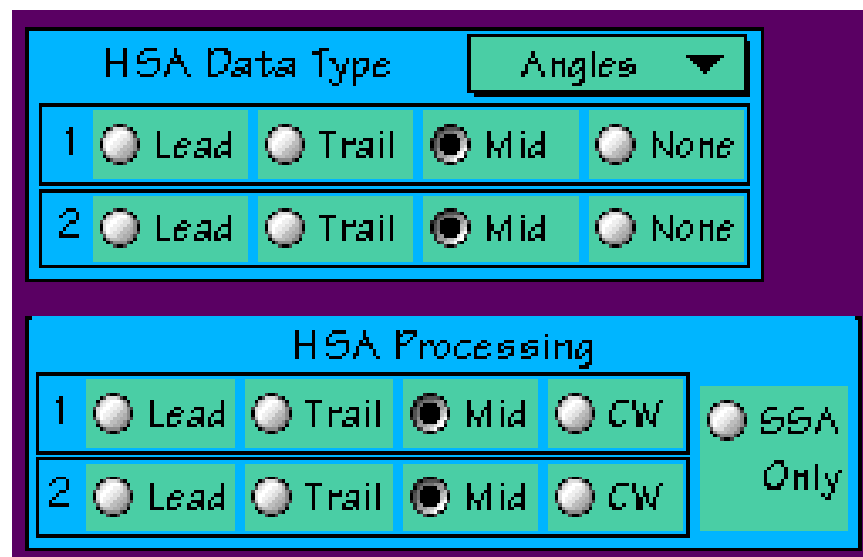
The screenshot shows a software window titled "Orbit Data" with the following fields and controls:

- Estimated Attitude:** RA Dec deg
- Orbital Elements Table:**

a	<input type="text" value="24400"/>	km	W (Long. of Asc. Node)	<input type="text" value="55"/>	deg
e	<input type="text" value="0.73"/>		w (Arg. of Perigee)	<input type="text" value="67"/>	deg
i	<input type="text" value="6.5"/>	deg	M (Mean Anomaly)	<input type="text" value="180"/>	deg
- Spin Rate:** deg/sec
- Epoch (y/m/d/h/m/s):** / / / / /
- Buttons:** Save Orbit Data, Load Orbit Data, Angular Orbit Data Units

HSA Data and Processing

- HSA data can be input in a number of forms
- Processing usually done with midscan dihedral angles
- Other processing options allow attitude solution when full measurements are not available



The image shows two control panels for HSA data. The top panel, titled "HSA Data Type", has a dropdown menu set to "Angles". Below it are two rows of radio buttons for "1" and "2". Each row has four options: "Lead", "Trail", "Mid", and "None". In both rows, the "Mid" option is selected. The bottom panel, titled "HSA Processing", has two rows of radio buttons for "1" and "2". Each row has four options: "Lead", "Trail", "Mid", and "CW". In both rows, the "Mid" option is selected. To the right of these rows is a larger radio button labeled "SSA Only".

HSA Data Type				
1	<input type="radio"/> Lead	<input type="radio"/> Trail	<input checked="" type="radio"/> Mid	<input type="radio"/> None
2	<input type="radio"/> Lead	<input type="radio"/> Trail	<input checked="" type="radio"/> Mid	<input type="radio"/> None

HSA Processing				
1	<input type="radio"/> Lead	<input type="radio"/> Trail	<input checked="" type="radio"/> Mid	<input type="radio"/> CW
2	<input type="radio"/> Lead	<input type="radio"/> Trail	<input checked="" type="radio"/> Mid	<input type="radio"/> CW

SSA Only

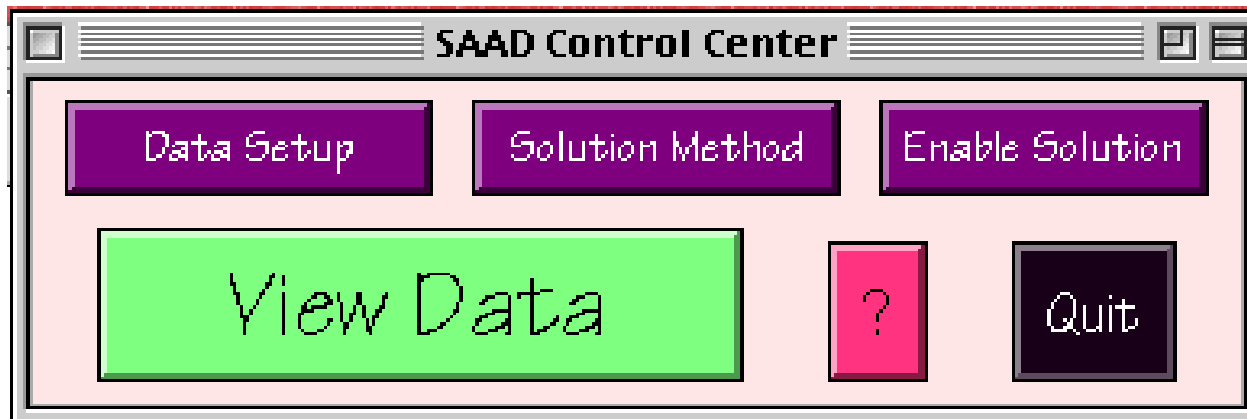
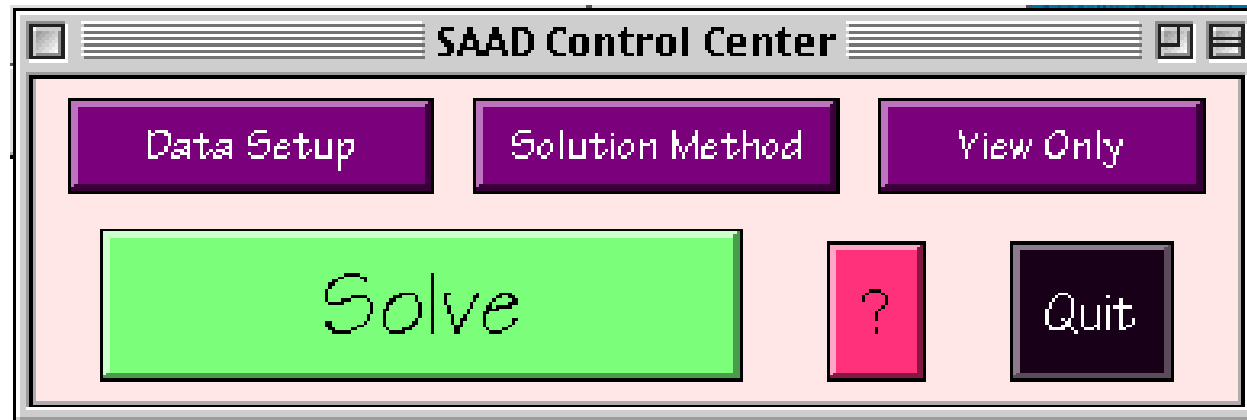
Sensor Data

- Need to enter sensor positions on the spacecraft
- HSA time delay will create a dihedral angle bias that varies with spin rate

Sun Sensor Cant Angles	
<input checked="" type="radio"/> Use	
<input type="radio"/>	
Cant 1	90
Cant 2	0
	deg

Horizon Sensor Data	
Cant 1	80
Cant 2	68
Dihedral 1	50
Dihedral 2	50
Delay	0
	sec

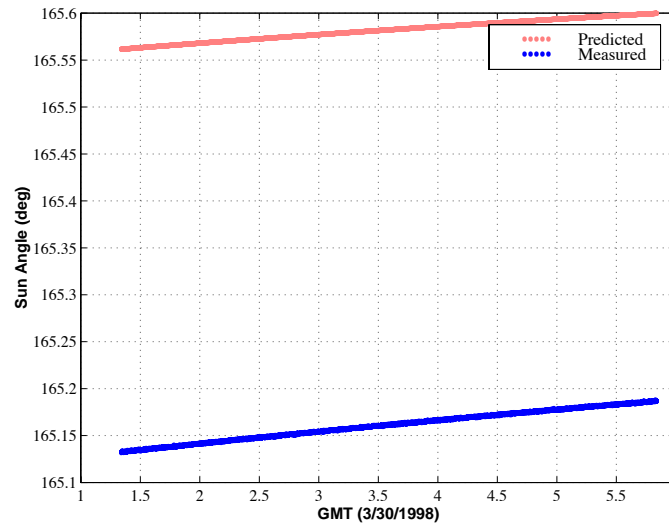
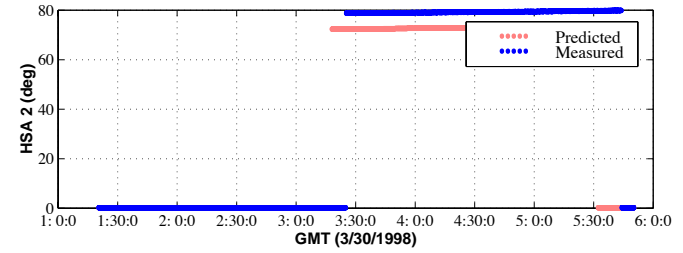
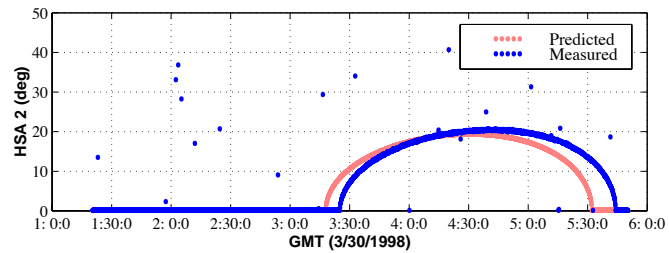
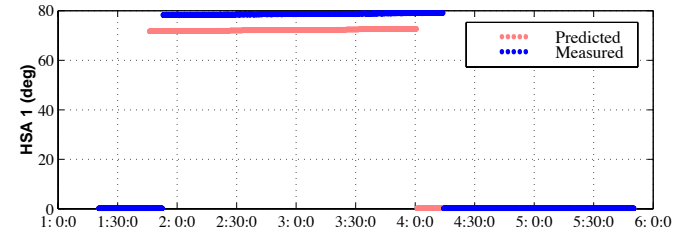
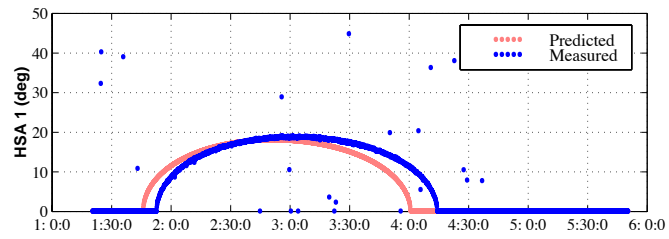
Viewing the Data



The Sample Data

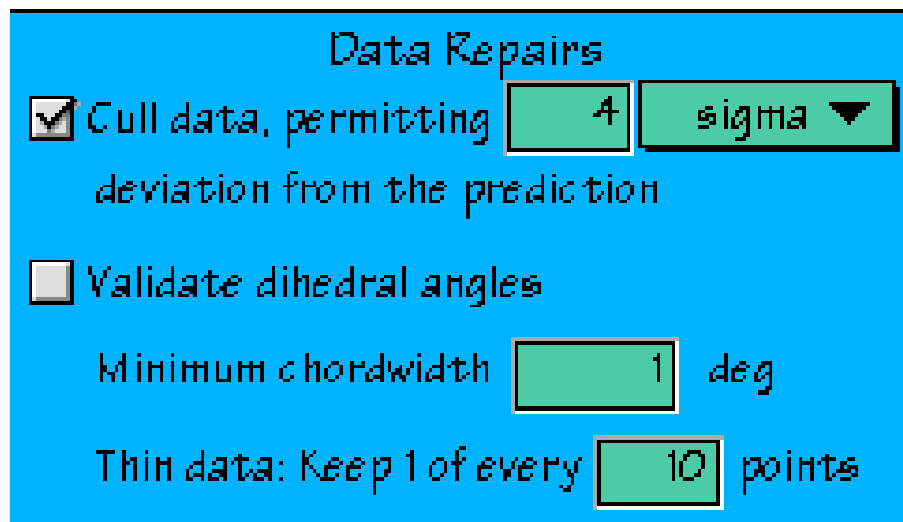
- Viewing the data produces
 - plots of predicted vs. measured data
 - residual plots (measured-predicted) and a
 - residual statistics, consisting of the mean and standard deviation of each measurement. Separate statistics are computed for each HSA.
- Predicted vs. Measured plots for each sensor are shown next.

The Sample Data (cont.)



Data Validation

- SAAD includes a number of tools for validating and conditioning the data
 - Culling
 - Validating dihedral angles
 - Minimum chordwidth
 - Thinning the data



Data Repairs

Cull data, permitting deviation from the prediction

Validate dihedral angles

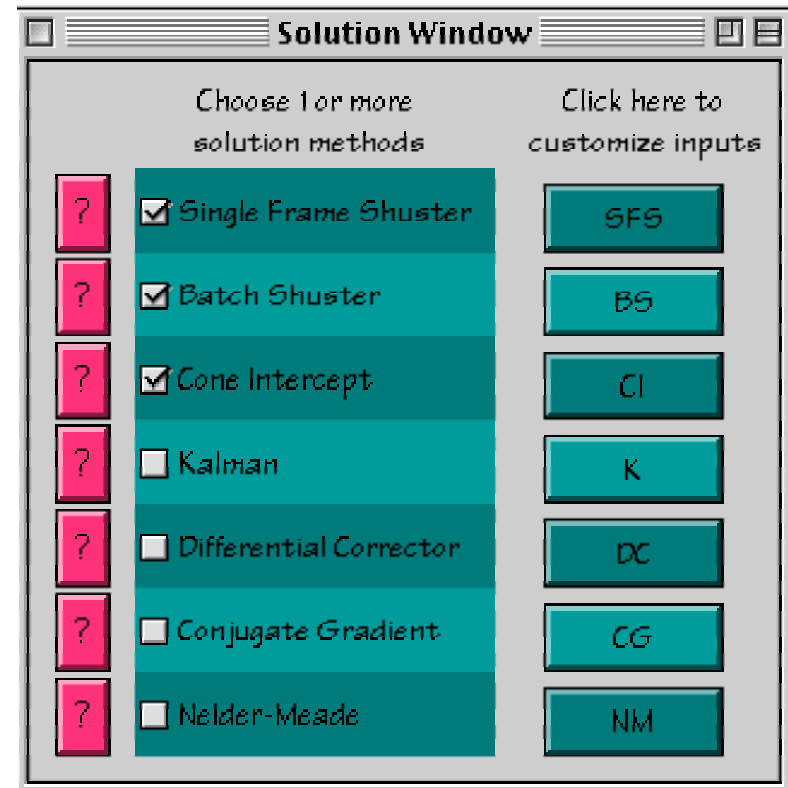
Minimum chordwidth deg

Thin data: Keep 1 of every points

- Accessed through the Data Repairs block of the Data Window

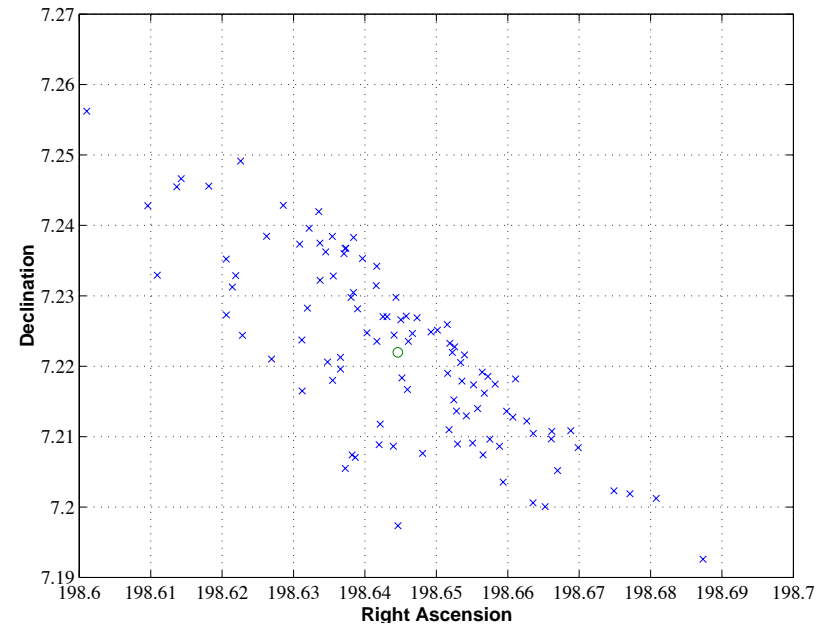
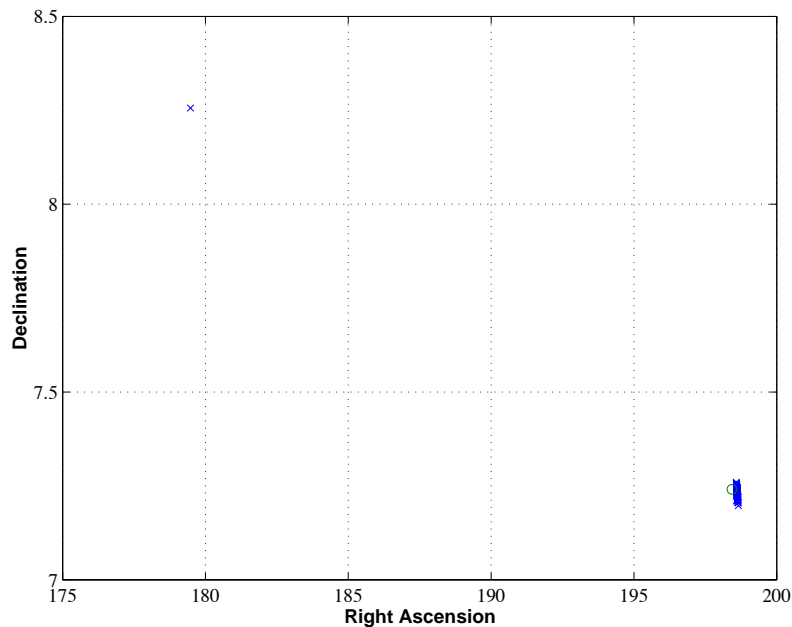
Getting an Attitude Estimate

- Use closed form methods
- Methods are selected using the Solution Window
- Results should be nearly the same from each, differences may indicate dihedral and/or earth radius biases
- Single Frame Shuster and Cone Intercept produce plots of the algorithm results



Single Frame Shuster Results

- Results show each of the Shuster solutions for HSA 1 (left) and HSA 2
- Notice the spurious data point on the HSA 1 plot



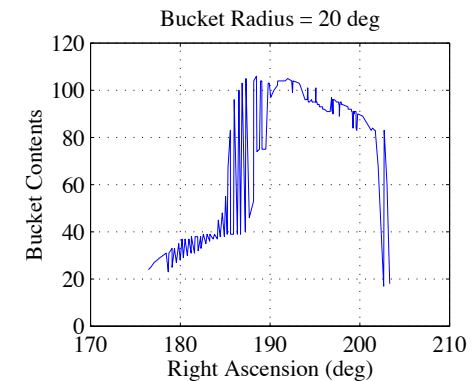
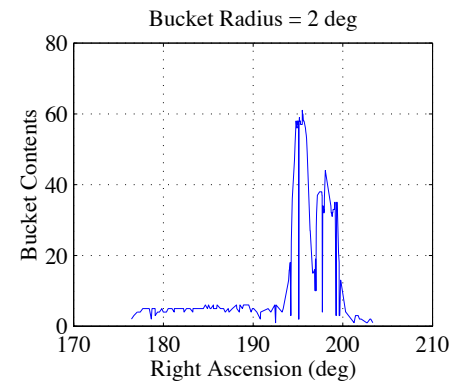
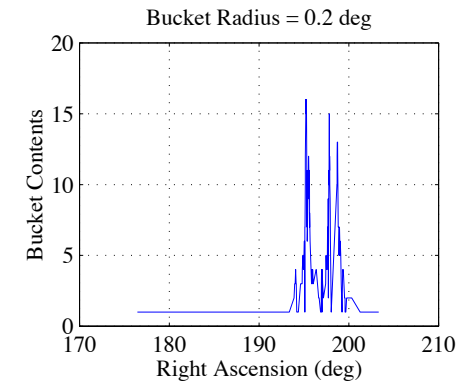
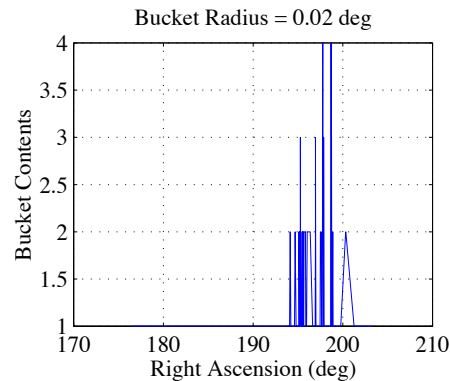
Numerical Results

Solution Method	HSA	Right Ascension	Declination
Single Frame Shuster	1	198.43	7.24
	2	198.64	7.22
Batch Shuster	1	198.41	7.25
	2	198.65	7.22
Cone Intercept	1	195.49	-16.79
	2	197.84	7.89

- Difference between Shuster and Cone Intercept indicates likely dihedral and/or earth radius biases
- Cone intercept 1 result indicates possible problem

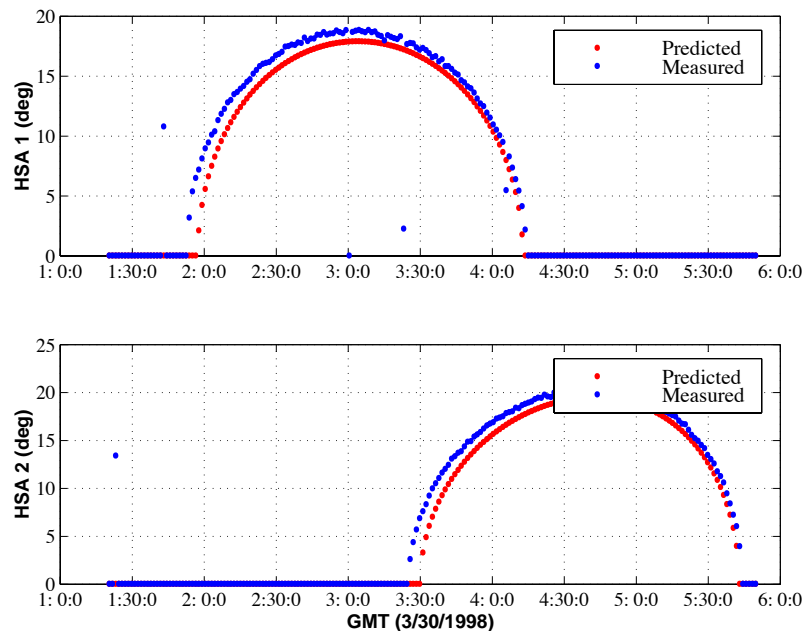
Cone Intercept Results

- Plots show a tie in the 0.02° buckets (upper left).
- Algorithm moves to next larger bucket to break the tie, in this case an error results.
- Possibly too little data being used.



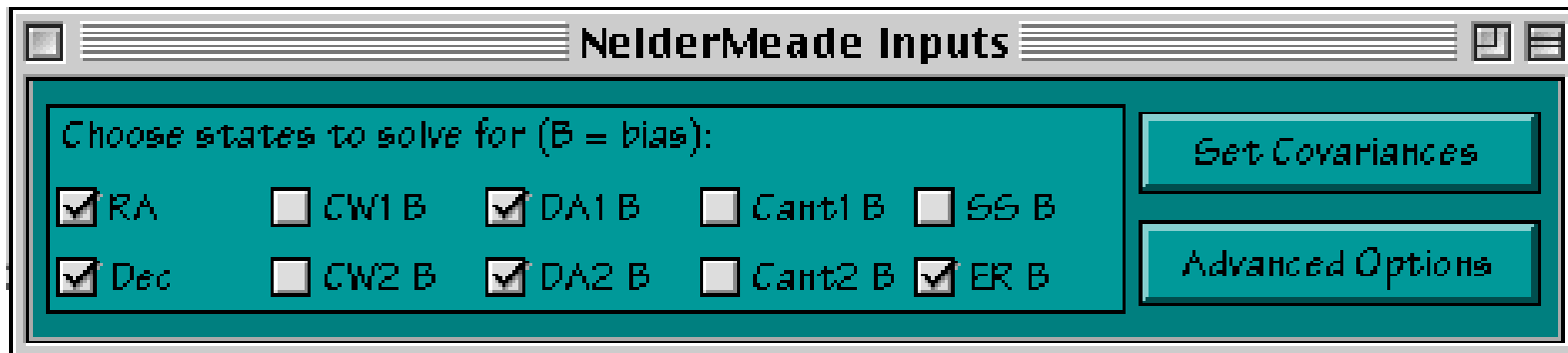
Adjust Estimated Attitude

- Enter new attitude in orbit window: RA = 198.5, Dec = 7.23
- View data again
- “Fat” chordwidths indicate earth radius bias



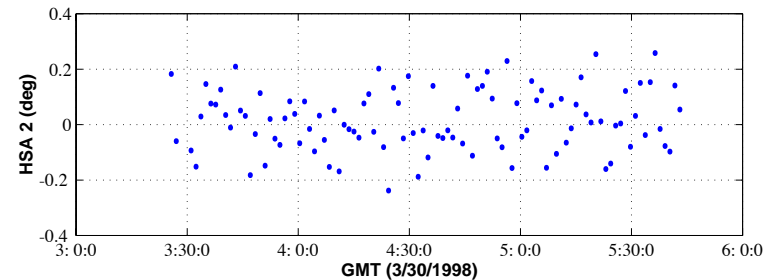
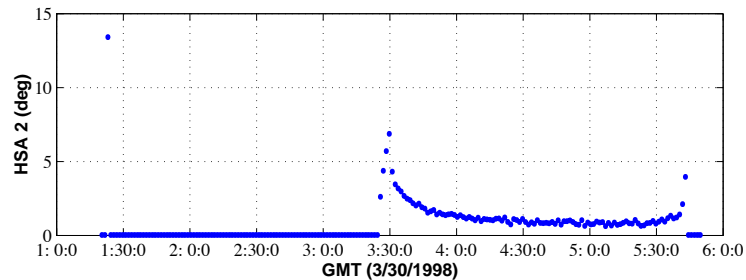
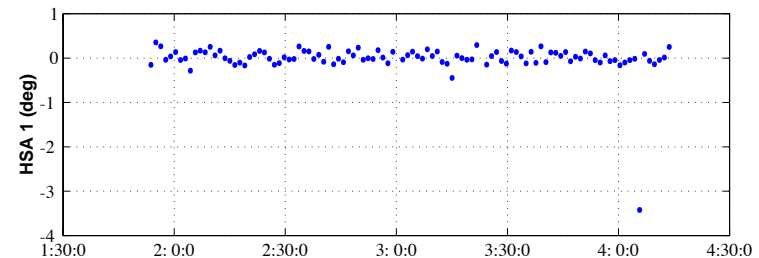
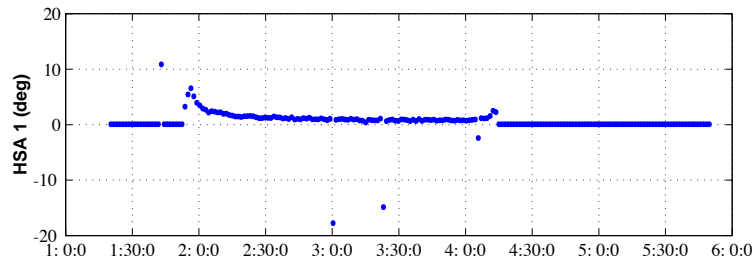
Least Squares Solution

- Start with Nelder-Mead
- Deselect closed form methods in the solution window, select Nelder-Mead
- Select states to be solved for



Nelder-Mead Results

- Residual statistics and plots indicate a much improved solution
- Chordwidth residuals before and after



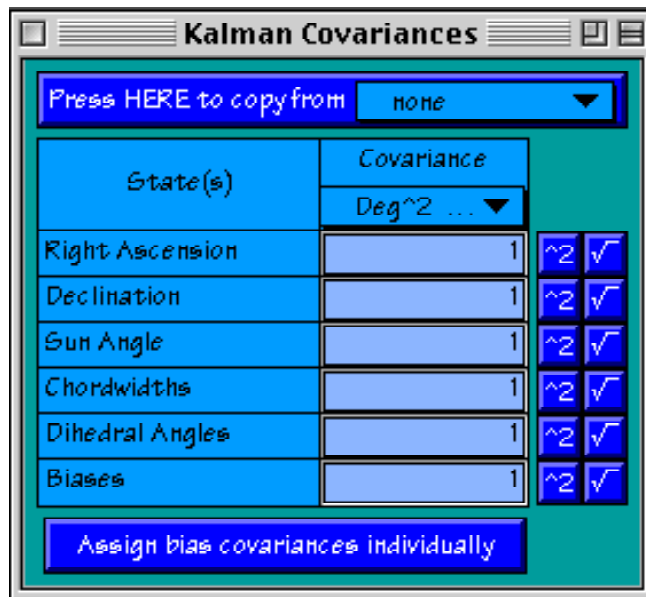
Further Refinement of the Solution

- Enter biases and attitude solution and rerun Nelder-Mead
- Run other numerical methods
- Solve for additional, or fewer, biases
- Adjust data thinning value
- Adjust culling threshold

Biases		
Chordwidth 1	<input type="text" value="0"/>	deg
Chordwidth 2	<input type="text" value="0"/>	deg
Dihedral Angle 1	<input type="text" value="1.36"/>	deg
Dihedral Angle 2	<input type="text" value="1.35"/>	deg
HSA Cant 1	<input type="text" value="0"/>	deg
HSA Cant 2	<input type="text" value="0"/>	deg
Sun sensor	<input type="text" value="0"/>	deg
Earth Radius	<input type="text" value="0.40"/>	deg

Advanced Input Options

- All numerical methods use initial state covariance values
- A flexible covariance entry window exists for each method
- Other advanced options include maximum iterations and ending tolerances

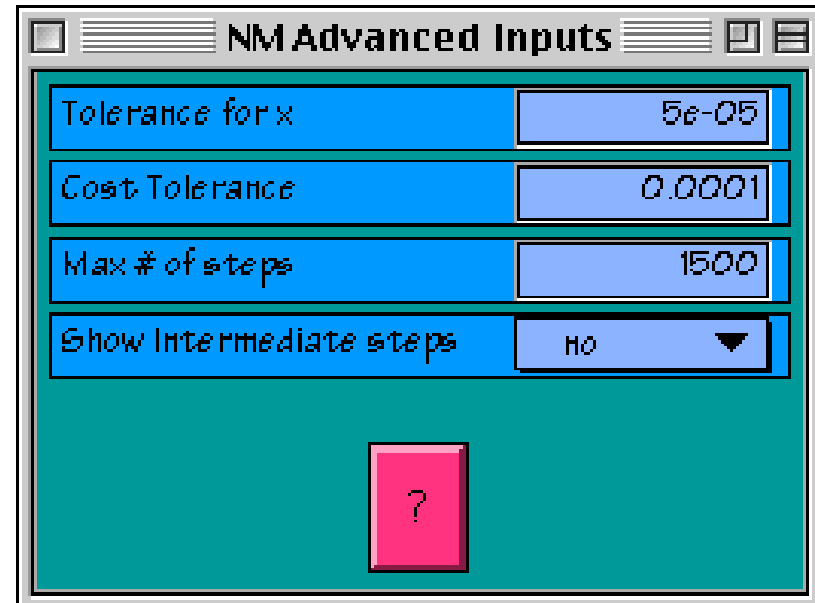


Kalman Covariances

Press HERE to copy from none

State(s)	Covariance		
	Deg ² ...		
Right Ascension	1	$\sqrt{2}$	✓
Declination	1	$\sqrt{2}$	✓
Sun Angle	1	$\sqrt{2}$	✓
Chordwidths	1	$\sqrt{2}$	✓
Dihedral Angles	1	$\sqrt{2}$	✓
Biases	1	$\sqrt{2}$	✓

Assign bias covariances individually



NM Advanced Inputs

Tolerance for x 5e-05

Cost Tolerance 0.0001

Max # of steps 1500

Show intermediate steps NO

?

Final Attitude Solution

- To reach the final solution
 - Reran Nelder-Mead with new attitude and biases
 - Added sun sensor bias
 - Reduced culling threshold from 4 sigma to 3° (~1.6 sigma)
 - Ran all other method using results from above, which are shown at right

State	Value (deg)
Right Ascension	198.29
Declination	7.48
Dihedral Angle Bias (HSA 1)	1.42
Dihedral Angle Bias (HSA 2)	1.42
Earth Radius Bias	0.40
Sun Sensor Bias	-0.02

Final Attitude Solution (cont.)

Solution Method	HSA	Right Ascension	Declination
Single Frame Shuster	1	198.29	7.48
	2	198.29	7.48
Batch Shuster	1	198.29	7.48
	2	198.29	7.48
Cone Intercept	1	198.31	7.46
	2	198.29	7.49
Kalman	Both	198.30	7.48
Differential-Corrector	Both	198.30	7.48
Conjugate Gradient	Both	198.29	7.48
Nelder-Mead	Both	198.30	7.48
True Attitude		198.30	7.50

Conclusion

- GUI features make SAAD much easier to use
- Tools allow visual and numeric validation and conditioning of data
- Variety of algorithms enhances reliability of the solution
- Bias calculation and use made much simpler
- Advantages in speed because data is only read from file once, but can be processed an unlimited number of times