Inertial Measurements for Aerobraking Navigation (IMAN)

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Aerobraking Navigation

Navigation Strategy for A/B will be similar to MGS and ODY

- 24/7 OD operations to reconstruct every drag pass, determine density
- Daily strategy analysis to support ABM planning/decision

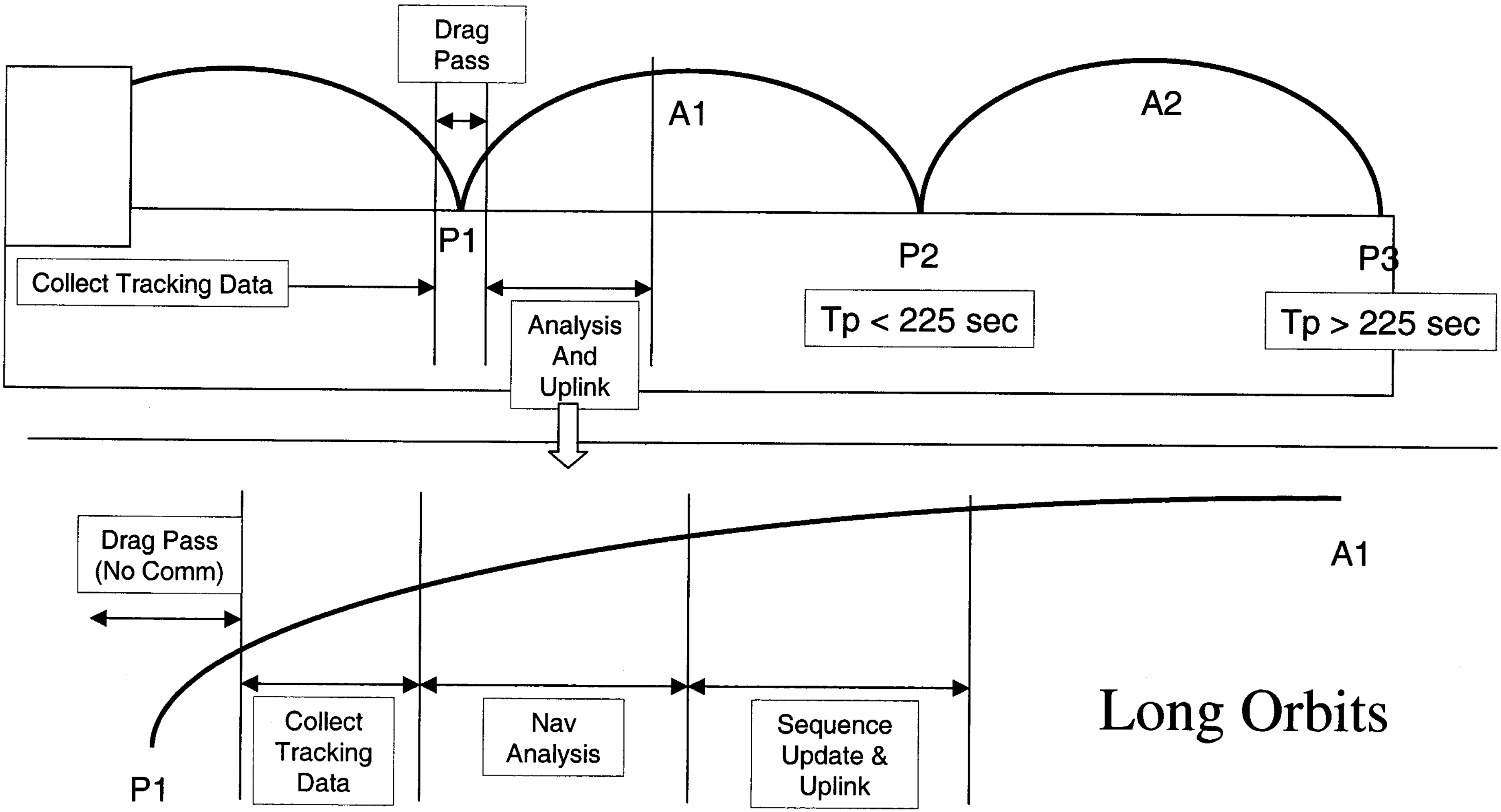
OD Process

- Marshal inputs - ICs from last solution, attitude profile, atmos inputs
- Collect tracking and SMFs after drag pass
- Reconstruct previous orbit(s) drag pass densities using atmos model
- Predict forward using MarsGRAM model with weekly wave determination
- Deliver SPK and OPTG file

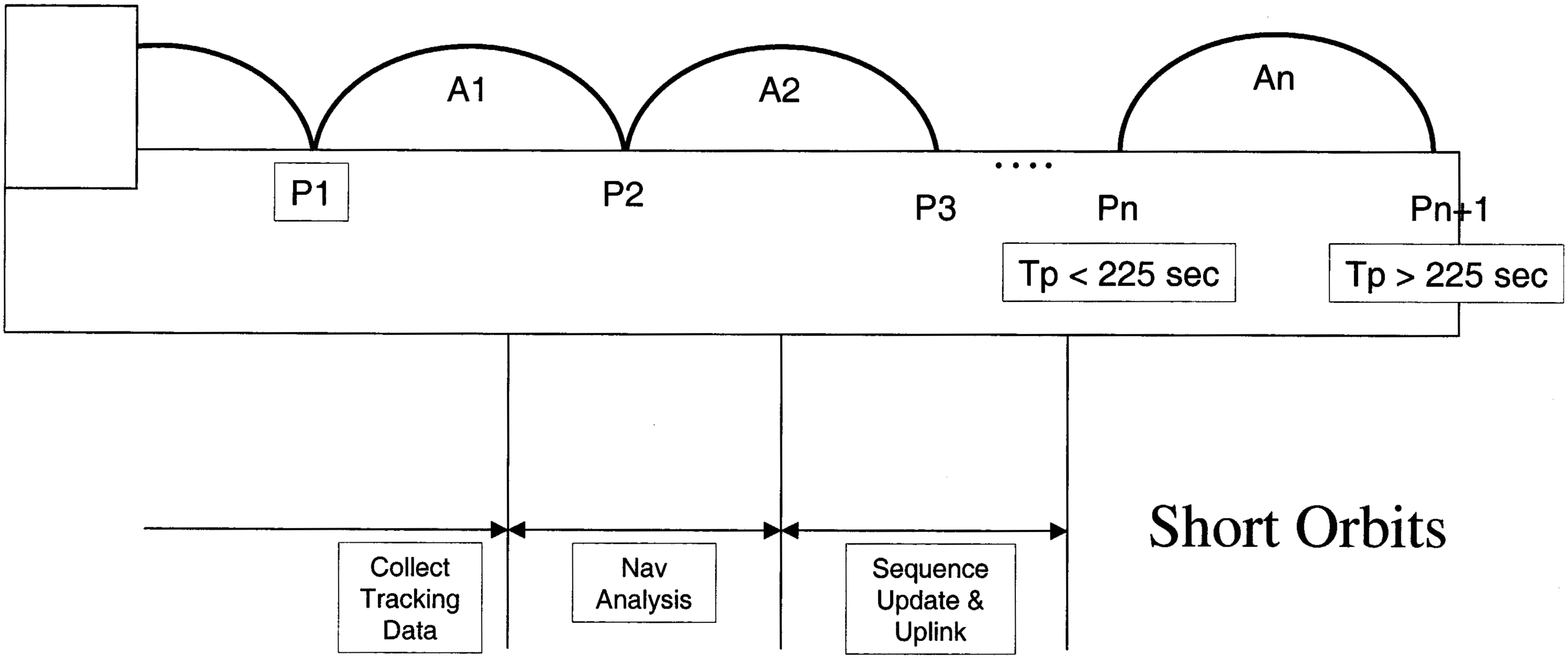
Daily Strategic Process

- Runout deterministic OD solution, Compare to Baseline
- Implement corridor control strategy, NAV recommends ABM decision

Aerobraking Navigation Process



Aerobraking Navigation Process



Short Orbits

Aerobraking Nav Prediction Accuracy

- Requirement
  - Must predict Periapsis Time to within 225 sec
- Capability
  - Timing requirement uncertainty dominated by assumption on future drag pass atmospheric uncertainty
- Atmospheric Variability
  - Total Orbit-to-Orbit Atmospheric variability: 105% (3-σ)
- Periapsis timing prediction
  - To first order, the expected change in orbit period per drag pass will indicate how well future periapses can be predicted
  - This simplifying assumption is supported by OD covariance analysis

Nav Predict Capability

- Example
  - Total expected Period change for a given drag pass is 1000 seconds
  - Atmosphere could change density by 105%
  - Resulting Period change could be off by 105% = 1050 sec
  - If orbit Period is different by 1050 seconds, then the time of the next periapsis will be different by 1050 seconds
  - This fails to meet the 225 sec requirement
- Large Period Orbits
  - Period change per rev is large
  - Therefore can never predict more than 1 periapsis ahead within the 225 sec requirement with any confidence
- Small Period Orbits
  - Period change per rev is small (for example 30 seconds)
  - Therefore can predict several periapses in the future to within the 225 second requirement
  - Example: 105% uncertainty (31.5 sec) will allow ~ a 7 rev predict

JPL

Aerobraking Caveats

- The spacecraft must slew into the aerobraking orientation prior to each drag pass.
  - There is a loss of radiometric tracking precisely when the spacecraft "flies" through the most dynamically changing and unknown portion of its trajectory.
  - This leads to a significant increase in the spacecraft's post-pass state (position and velocity) uncertainty.

- When reconstructing the drag pass, it is assumed that the spacecraft's total change in velocity due to the atmospheric effects is purely due to drag.
  - In practice, the aerobraking orbits do not tend to fit the radiometric data unless residual noise is modeled as artificial dynamic acceleration events.
  - It is likely that the residual noise is due to the lack of modeling of aerodynamic lift and side-force.

- The aerobraking orbit reconstruction process is very time consuming (i.e. lasting several hours for each orbit) and workforce intensive (9 navigators for the Mars Odyssey aerobraking operations).

- All of the spacecraft events occur on a ground-generated timeline (i.e. a sequence of commands). At times, up to 3 sequences must be generated and successfully uplinked to the spacecraft every 24 hours.
  - The personnel required to perform this task constitutes an additional operational cost.

- Spacecraft events take place at times relative to the predicted time of periapse. Any error in this prediction could lead to:
  - aerobraking corridor control maneuver errors and thus inefficient propellant usage.
  - aerobraking drag pass attitude configuration slewing at off-nominal times, capable of inducing inadvertent compensative thruster firings, and thus another source of inefficient propellant usage (inadvertent safe-mode entry triggering is another possible outcome).

The Stage Is Set…

- Questions:
  - Is there a way to avoid the traditional tracking data gap?
  - Is there a way to improve our atmospheric models?
  - Is there a way to be less sensitive to tracking problems after a drag pass?
  - Is there a way to increase our knowledge of the spacecraft state?

- Answers:
  - There may be if the state is being measured through the drag pass.
  - Perhaps, if we can estimate for atmospheric model parameters of interest during a drag pass.
  - Yes, if the drag pass is measured as it occurs instead of after.
  - Yes, if the drag pass data type used is "strong" enough.
    - Data Noise and Observation/State Partials.

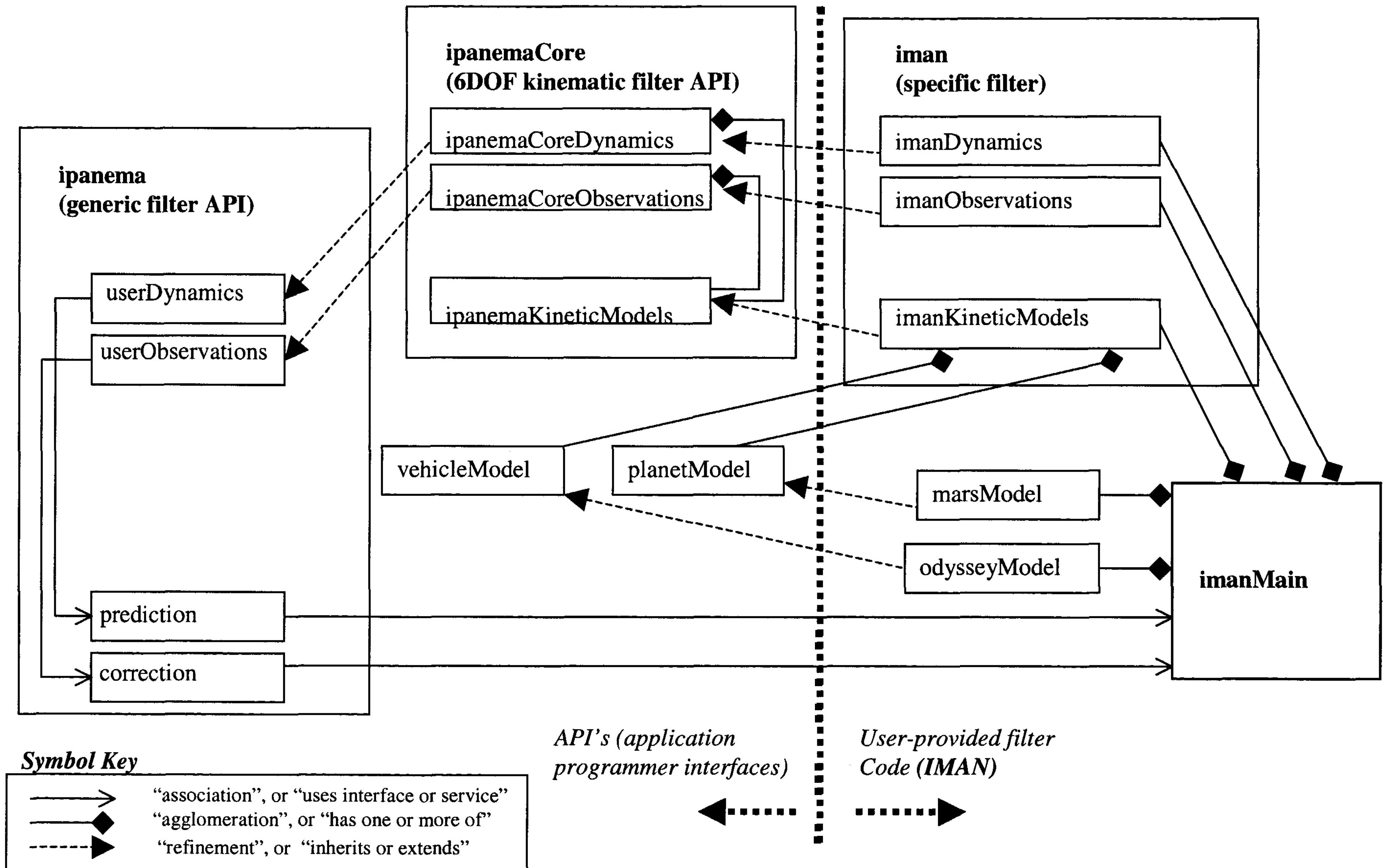
- 6-DOF drag pass reconstruction via IMU data processing could provide the answers.

IPANEMA/IMAN (Jython)

- IPANEMA (Java)
  - 6-DOF Kinematic State Filter with DMC
    - 19 Kinematic States
      - $X = [r,v,a,q,\omega,\alpha]$
    - Capable of ingesting user defined force, torque, spacecraft, and planetary models and state parameters

- IMAN (Java/Python)
  - Aerobraking-tailored force, spacecraft, and planetary atmosphere model with additional state parameters

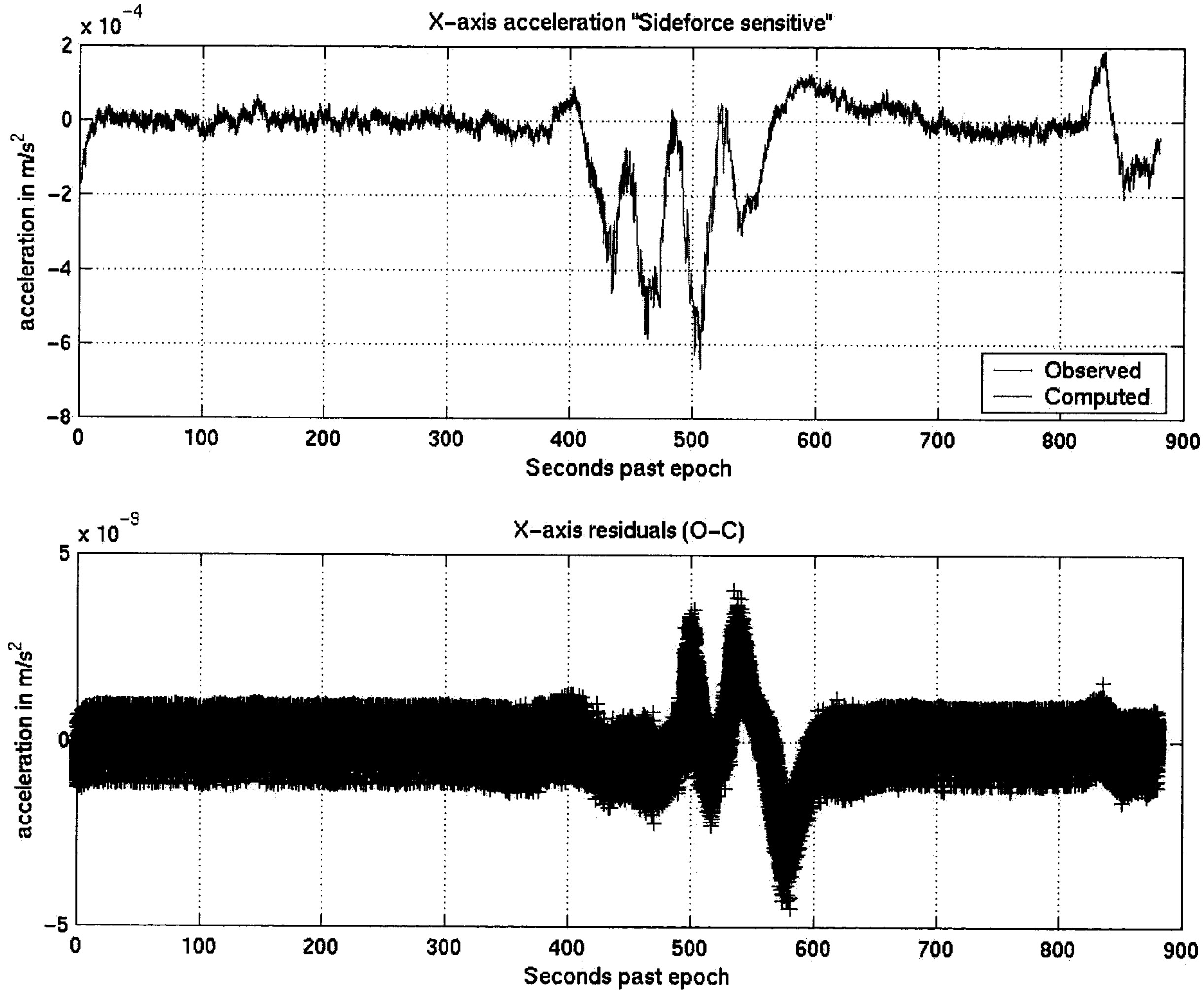
IPANEMA Prototype Software Design



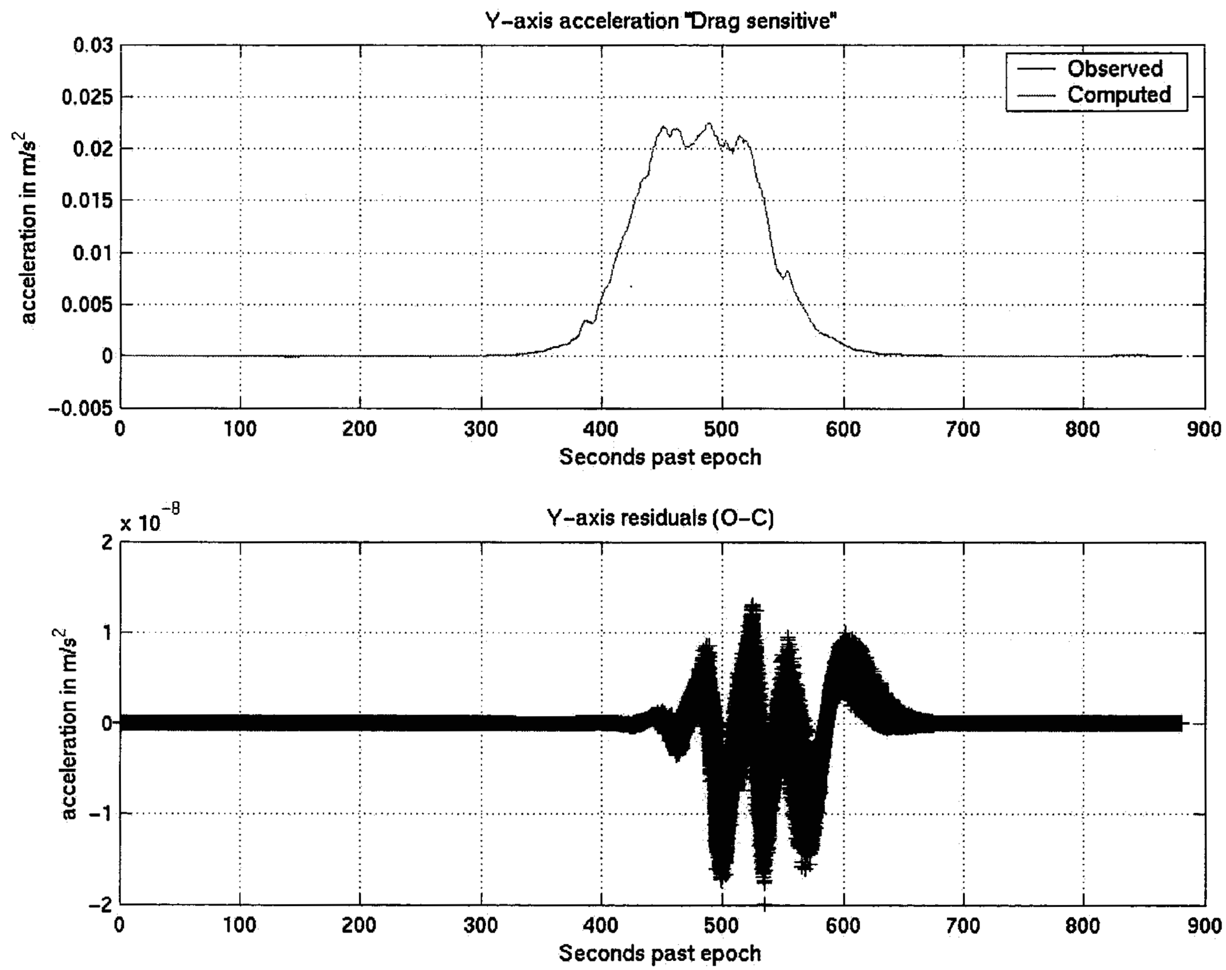
IMAN Operations Process

- Obtain pre drag-pass state and covariance based on best pre drag-pass radiometric fit.
- Generate predicted atmospheric model parameters for upcoming drag-pass.
  - Could be generated based on MarsGRAM.
- Obtain IMU data from telemetry
  - May have to be pre-processed.
- Initialize IMAN with pre drag-pass state and covariance and obtain post drag-pass state and covariance estimate based on 6-DOF fit.

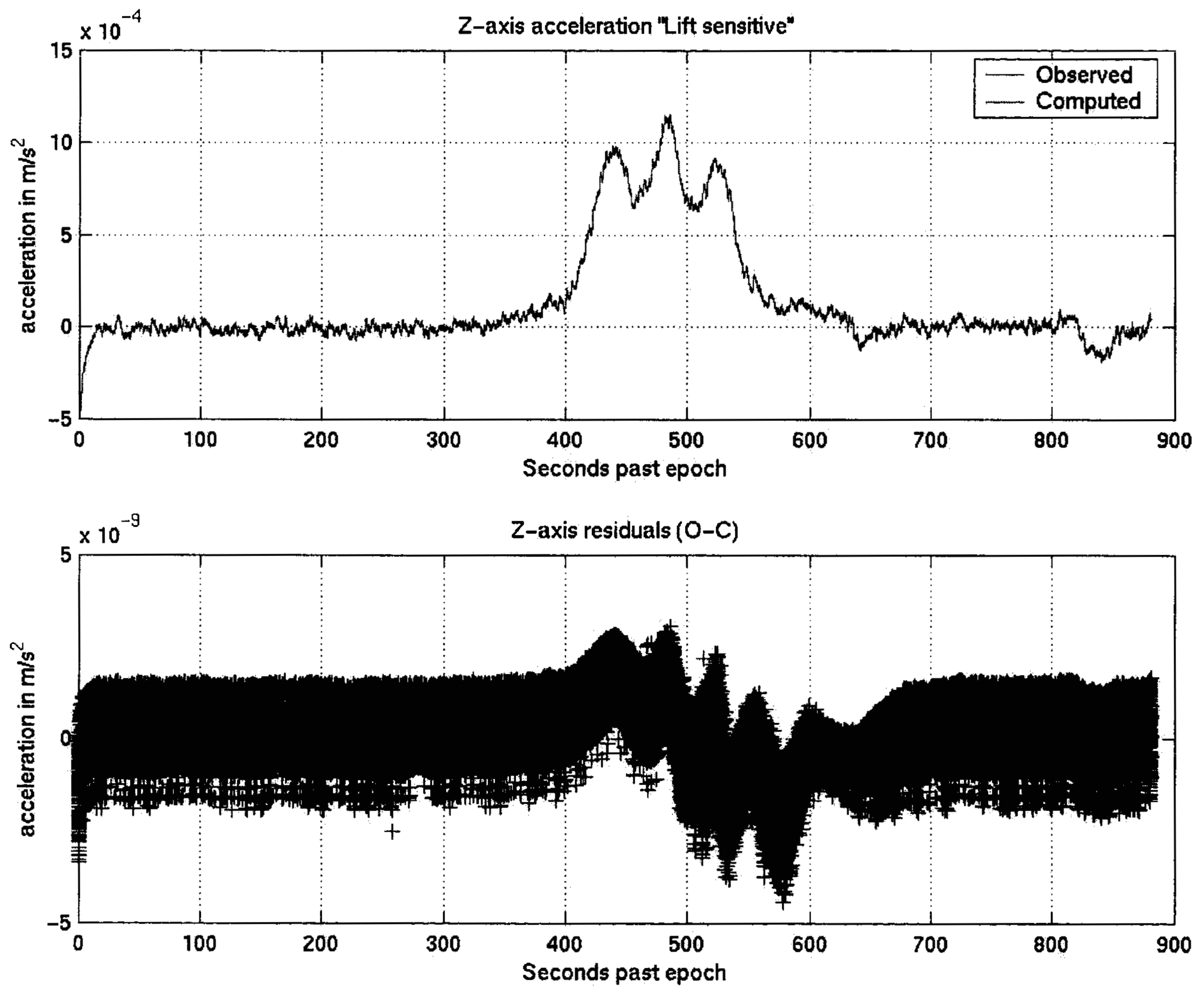
IMAN Results



IMAN Results



IMAN Results



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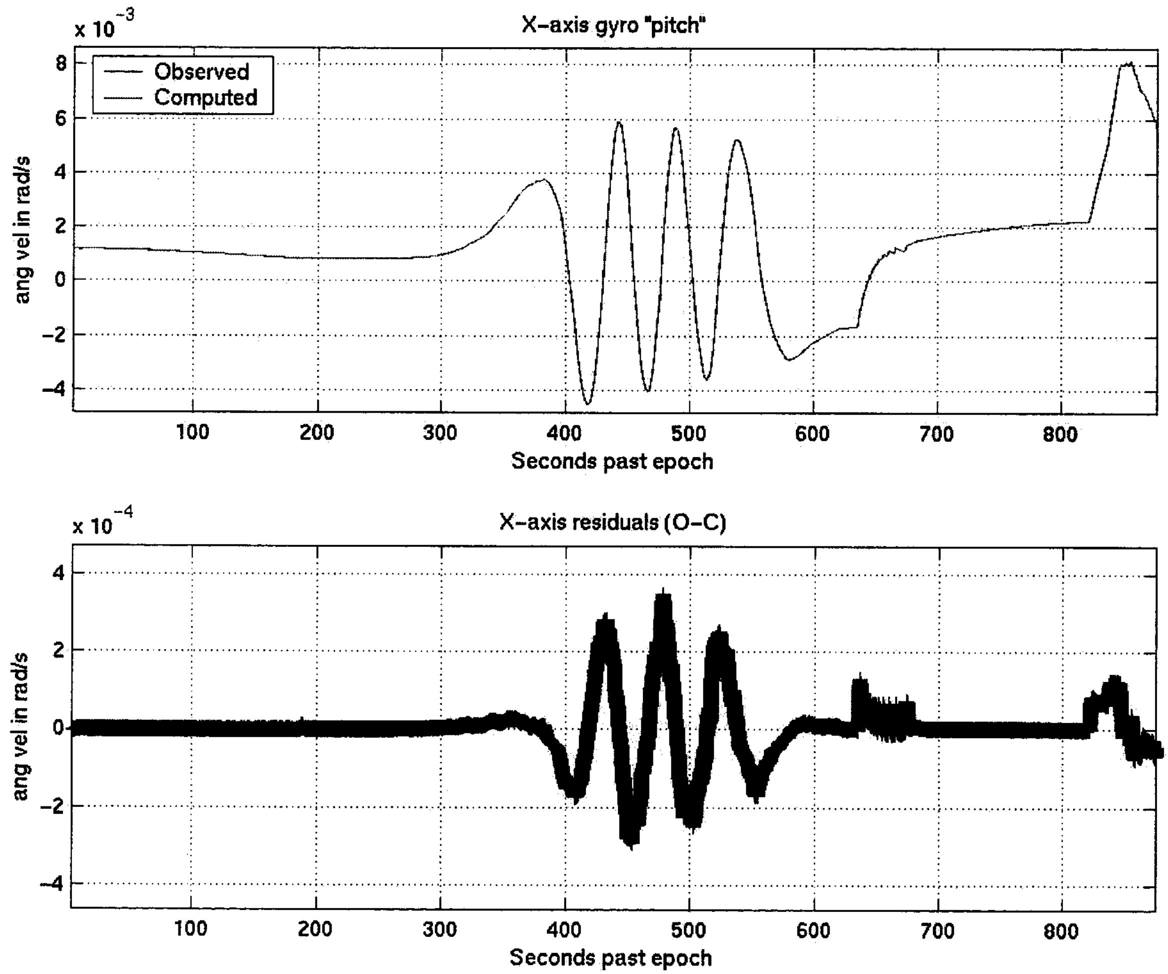

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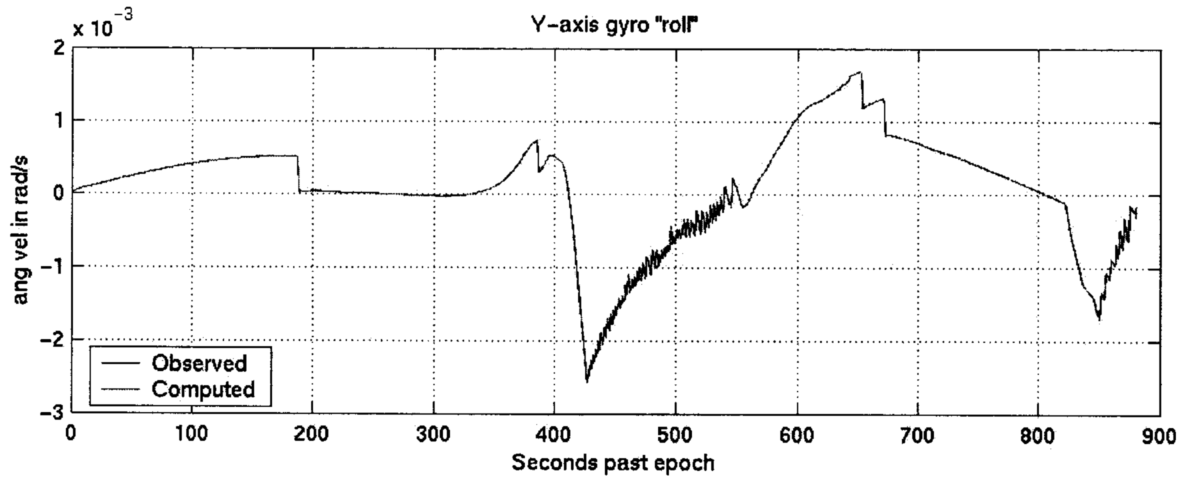

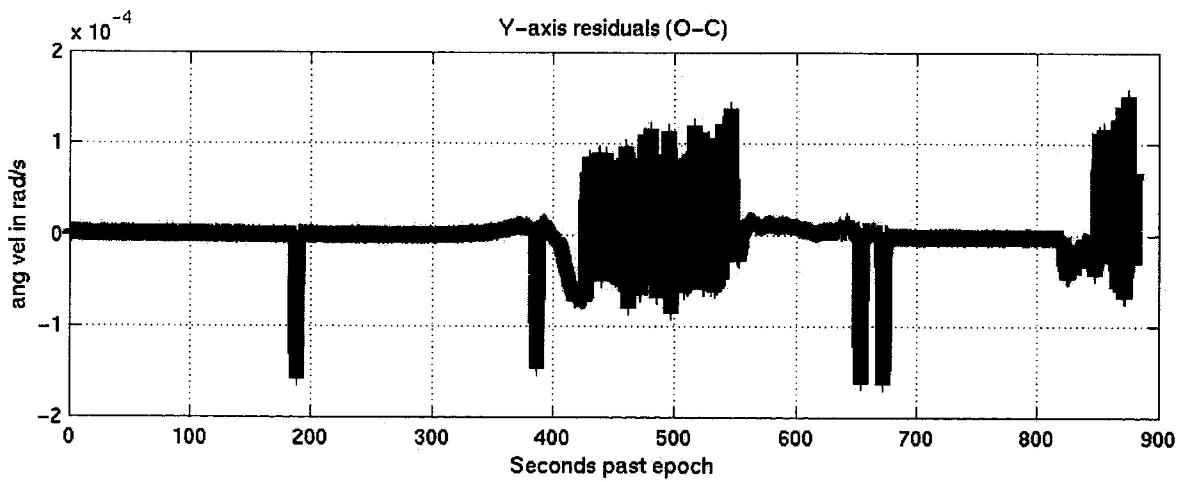

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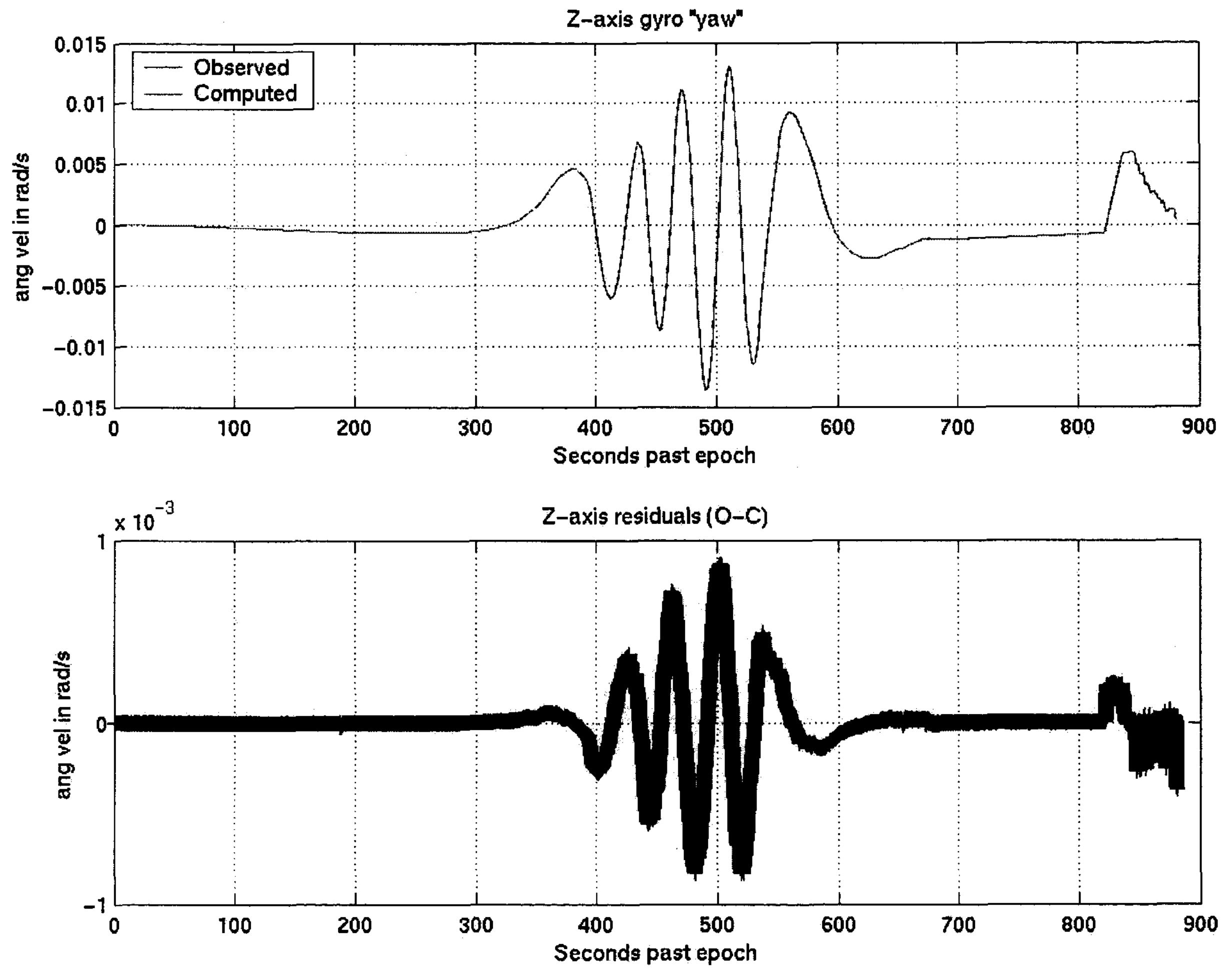

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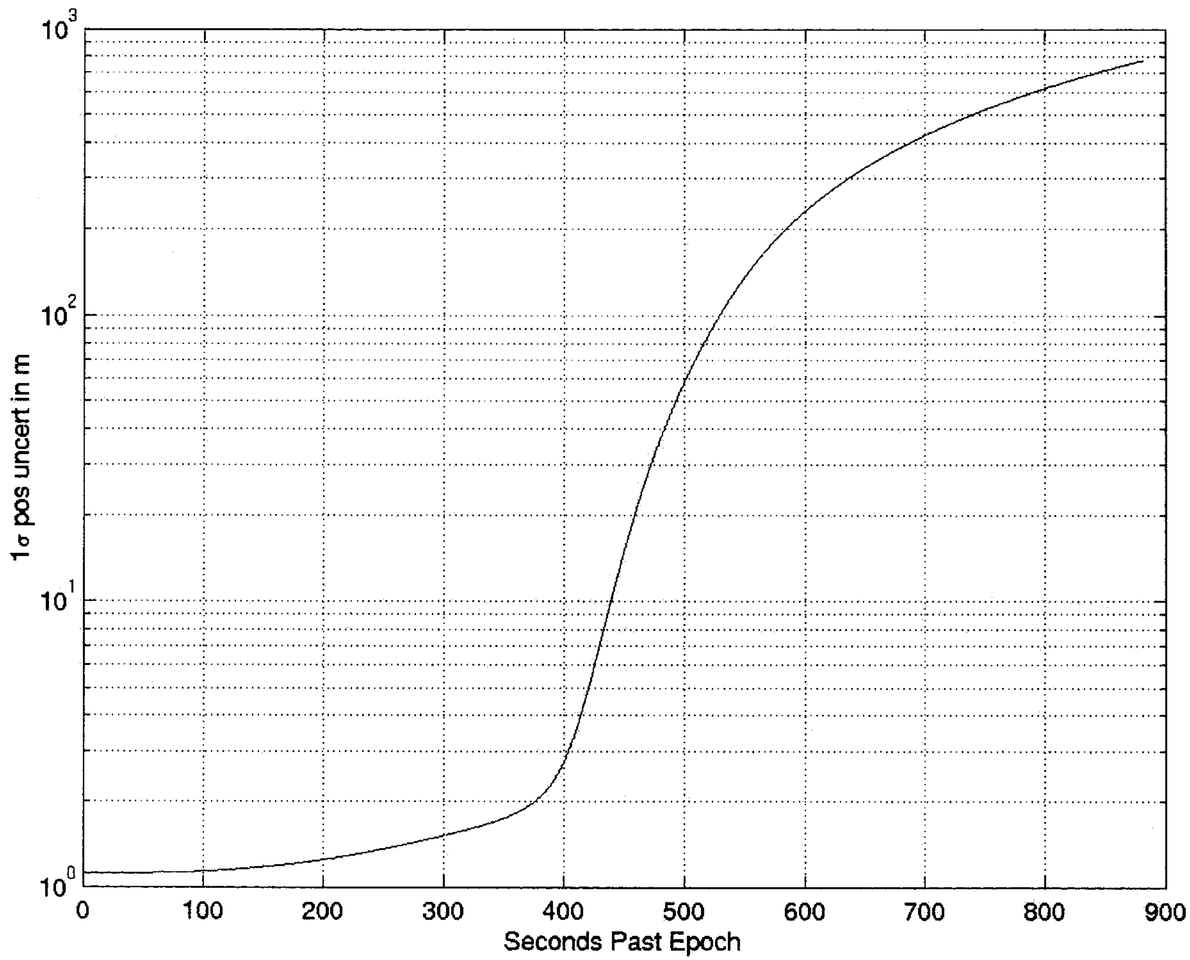

Conclusions

- The results thus far show:
  - It is possible to fit an aerobraking trajectory in a 6-DOF sense, by using IMU data as a navigation measurement.
  - A pure kinematic state covariance shows realistic uncertainties in the state given some nominal atmospheric model.

- Things to be done (next steps):
  - add in a higher fidelity gravity model (perhaps up to a 4x4 field).
  - add in observation model states, namely estimate for things like base density and scale height.
  - perform more filter tuning.
  - compare results against navigation team solutions.
  - fit representative aerobraking orbits of various orbital periods (e.g. 16 hour, 6 hour, 3 hour).
  - determine sensitivity to *apriori* covariance
  - try various measurement compression rates (i.e. 50 Hz, 20 Hz, 10 Hz, 1 Hz)