Circular-Orbit Maintenance Strategies for Primitive Body Orbiters

Mark S. Wallace and
Stephen Broschart

Jet Propulsion Laboratory
California Institute of Technology

© 2013 California Institute of Technology.
Government sponsorship acknowledged.

Objective

- How to maintain an orbit around a primitive body and avoid secondary interactions with its extended-body gravity field?
- Keep the orbit as circular as possible.

Analytic Perturbation Equations

- Take the analytical equations:

Scheeres, D.J. "Satellite Dynamics About Asteroids" AAS 94-112

$$\dot{\lambda} = -\frac{C_g e}{\sqrt{1-e^2}} \sin\omega \sin\lambda - \dot{N}$$

$$\frac{d}{dt} i = -\frac{C_g e}{\sqrt{1-e^2}} \cos\omega \sin i \sin\lambda$$

$$\dot{e} = -C_g \sqrt{1-e^2} (\sin\omega \cos\lambda + \cos\omega \cos i \sin\lambda)$$

$$\dot{\omega} = -\frac{C_g \sqrt{1-e^2}}{e} (\cos\omega \cos\lambda - \sin\omega \cos i \sin\lambda) - \left(\dot{\lambda} + \dot{N}\right) \cos i$$

$$\dot{a} = 0$$

$$C_g = \frac{3G_1}{2BR^2} \sqrt{\frac{a}{\mu}}$$

- And assume small eccentricities:

$$\frac{d}{dt} i \approx 0 \qquad \dot{\lambda} \approx -\dot{N}$$

- Yields simple near-constant rates in e-ω space:

$$\dot{e_x} = -C_g \cos i \sin\lambda$$

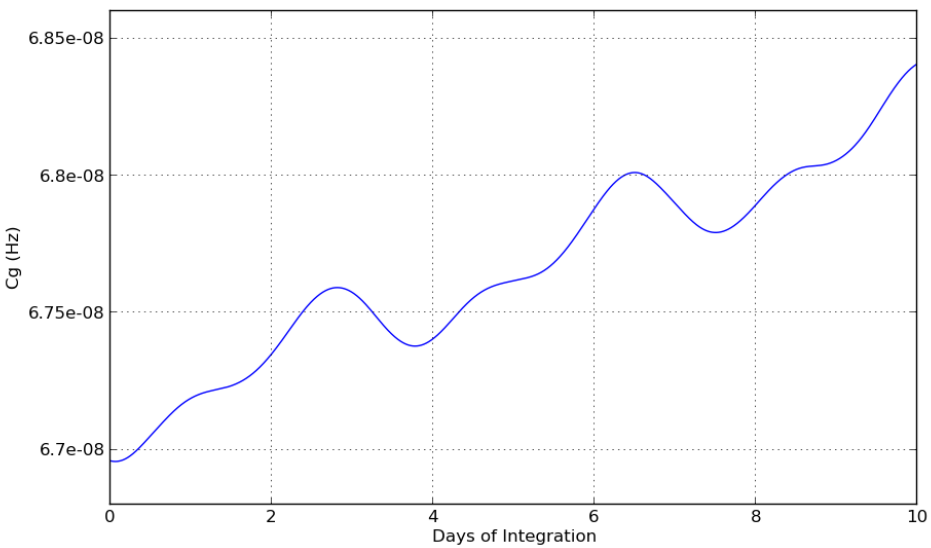
$$\dot{e_y} = -C_g \cos\lambda$$

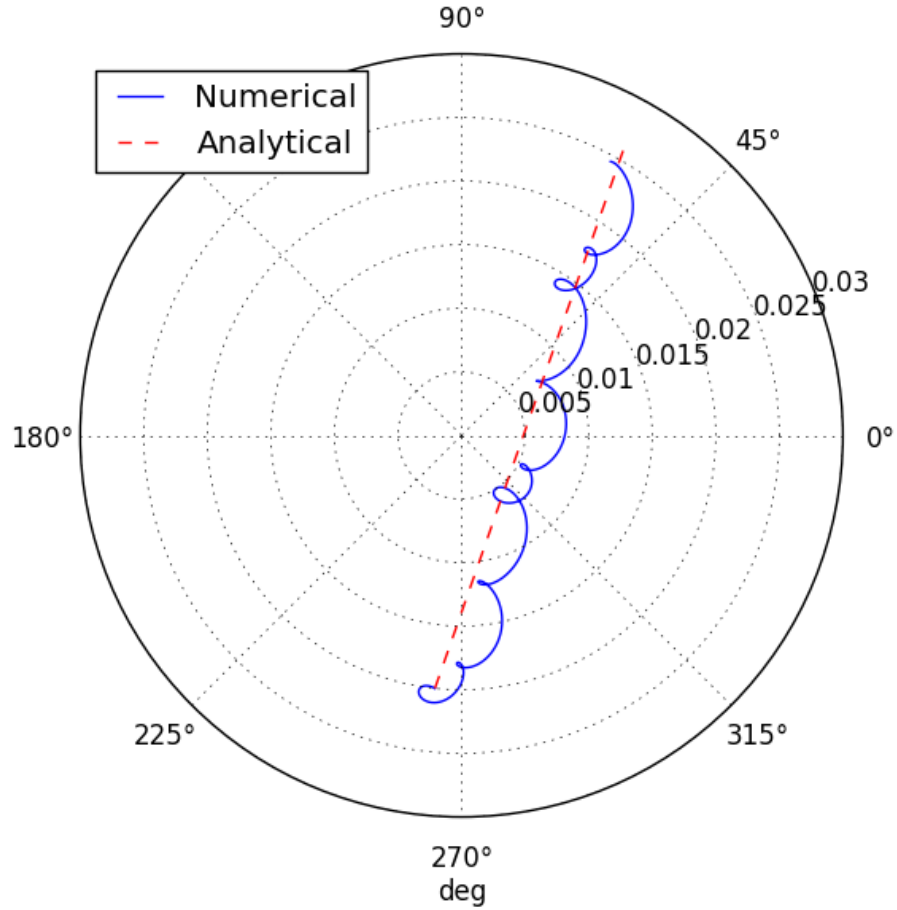
The full paper has the detailed derivation.

Comparison to Numerical Simulation

Parameter	Value (Pole)	Value (Sun-Line)	Unit
Initial Epoch	24 August 2020		TDB
Semi-Major Axis	22.5	22.5	km
Eccentricity	0.02	0.02	
Inclination	75.0	67.2	deg
Argument of Periapsis	255.0	264.0	deg

Tempel 1 begins at ≈ 4.02 AU, dropping to 3.99 AU after 10 days (3% increase in C_g).





Choosing Optimal Initial Conditions

- Select the argument of periapsis to put path through center of e-ω space

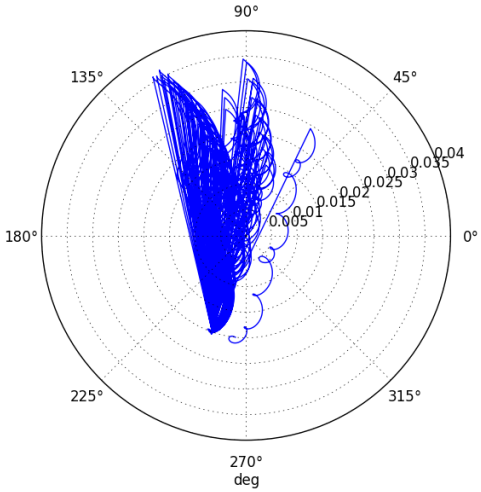
$$\omega_0 = \pi + \tan^{-1}\left(\frac{-C_g \cos\lambda}{-C_g \cos i \sin\lambda}\right) = \pi + \tan^{-1}\left(\frac{-\cos\lambda}{-\cos i \sin\lambda}\right)$$

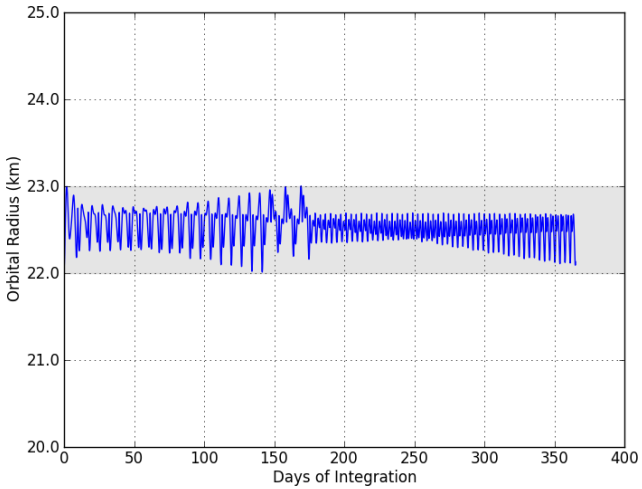
- Choose initial eccentricity to meet some maneuver frequency or choose maneuver frequency based on eccentricity requirements:

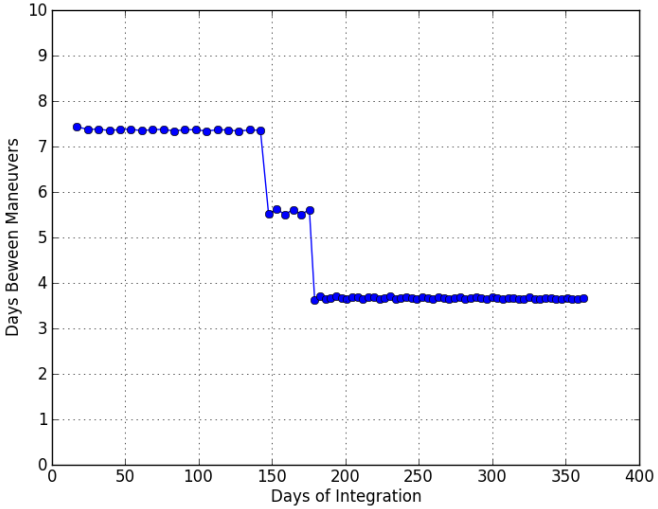
$$e_0 = \frac{t_m C_g}{2}\sqrt{1 - \sin^2\lambda \sin^2 i}$$
$$t_m = \frac{2e_0}{C_g\sqrt{1-\sin^2\lambda \sin^2 i}}$$

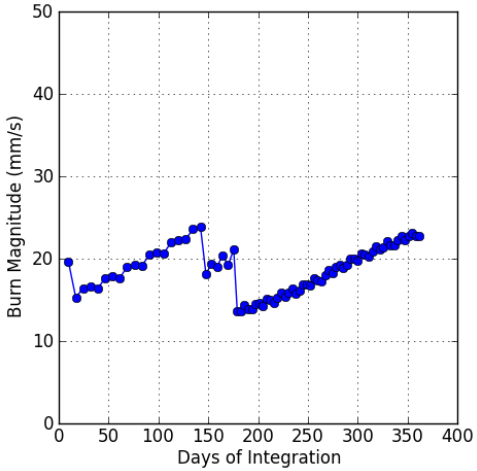
Fixed-Target Controller

- Returns the eccentricity and argument of periapsis to some user-specified point.
- Fails when the maneuver frequency drops below the orbit period

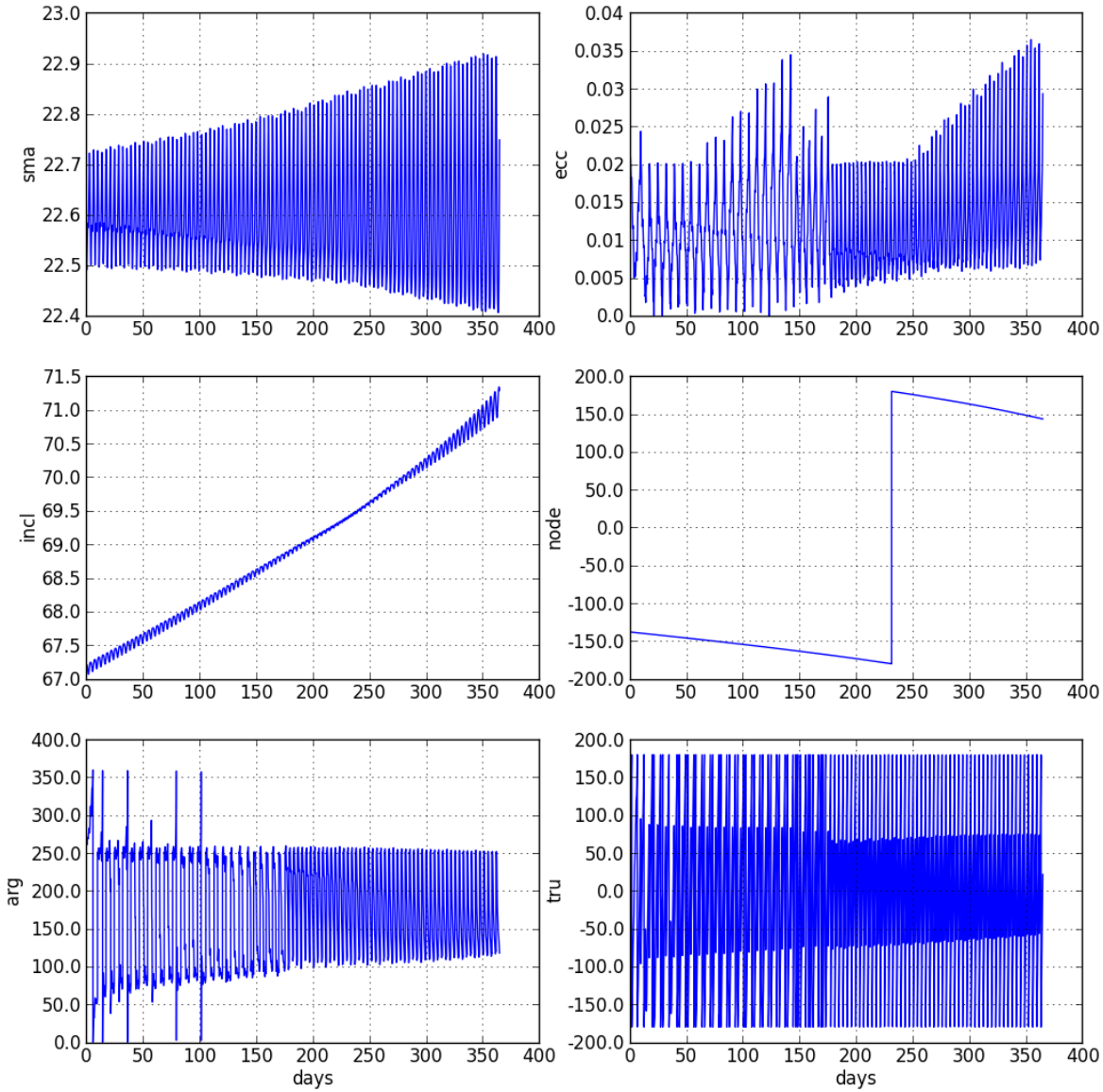






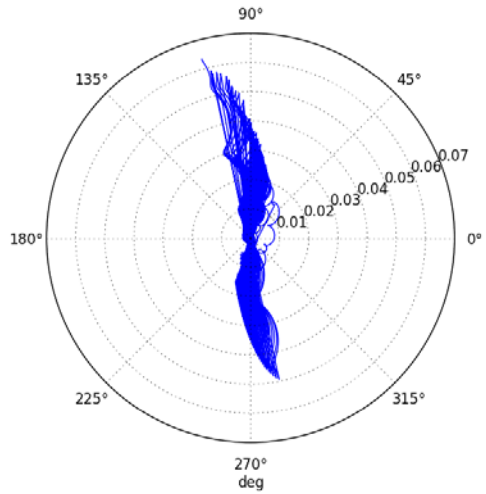


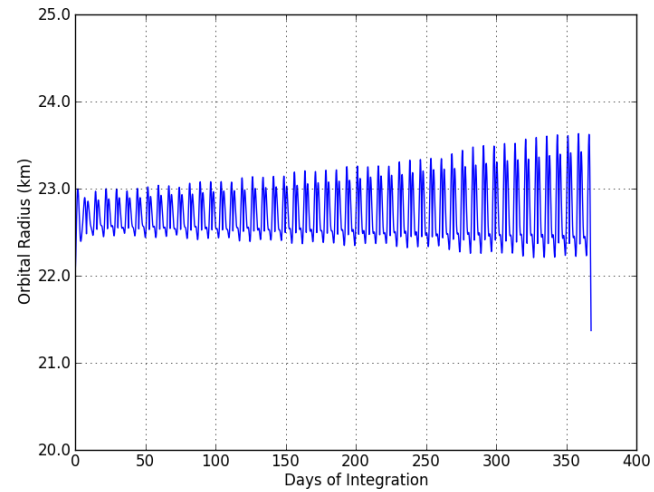
Fixed Target Controller Elements

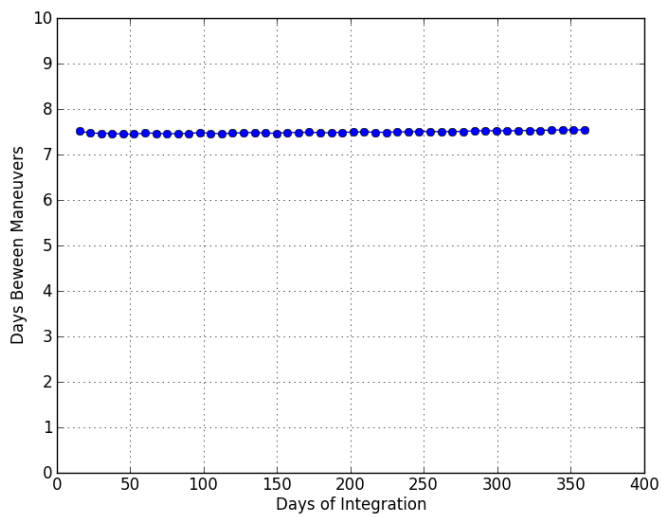


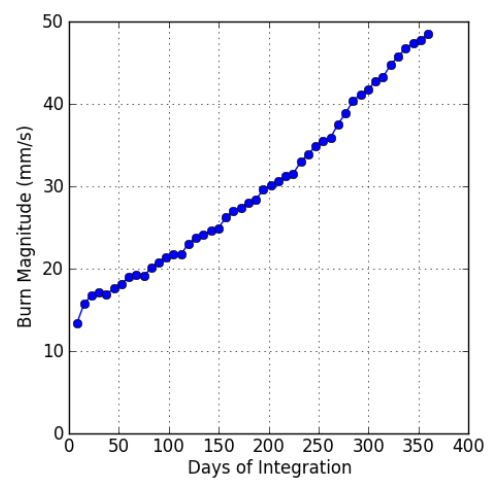
Fixed-Schedule Controller

- Chooses an e-ω target to fit a fixed maneuver frequency.
- Eccentricity grows as C_g increases.

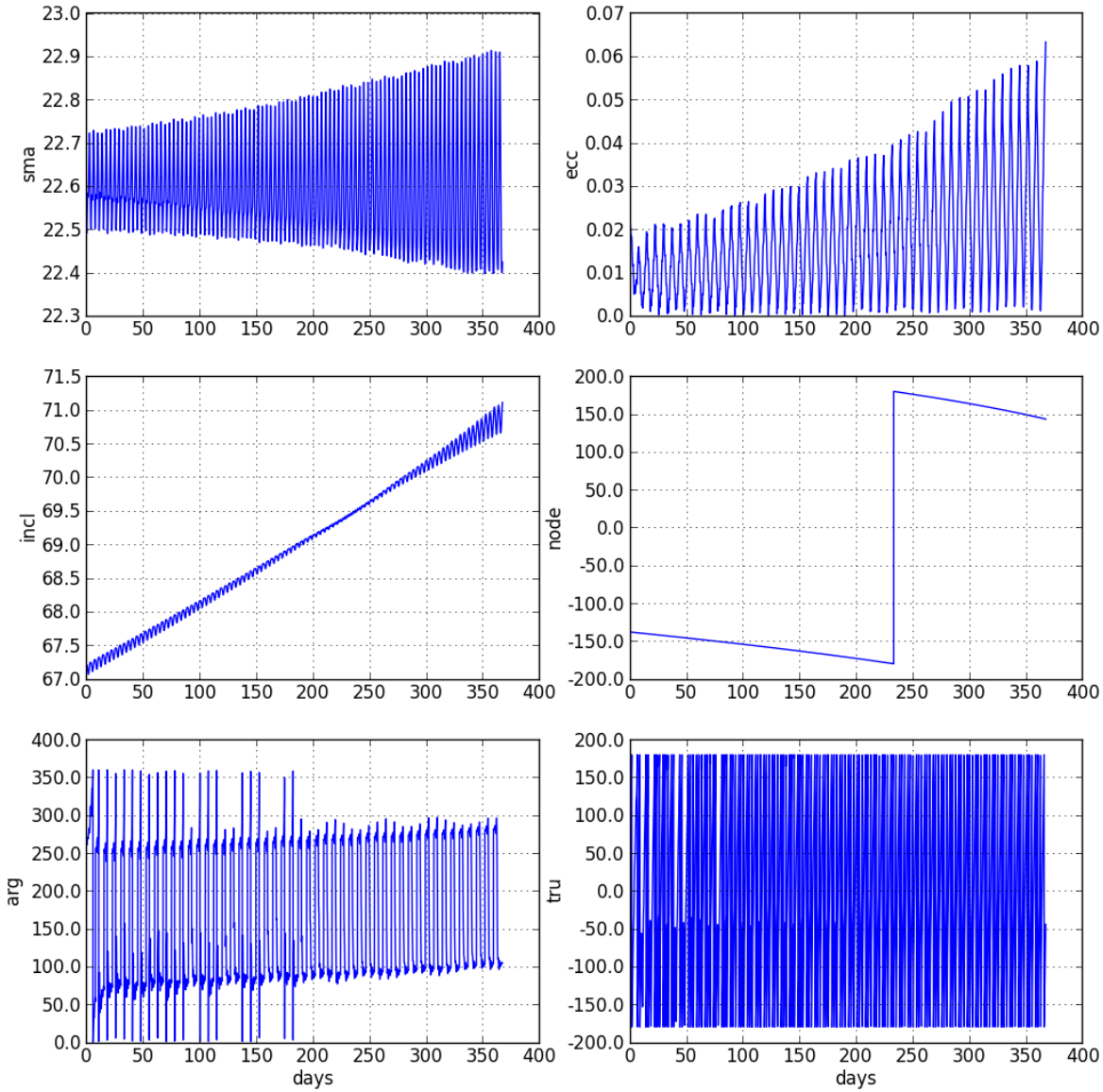








Fixed Schedule Controller Elements



Conclusions

- Computationally simple controllers.
- Numerically powerful and stable.
- Other options to implement the equations:
  - Fixed eccentricity target with variable initial argument and schedule
  - Complement e-ω controller with ascending node control to maintain constant hour-angle.

Any Questions?