Control of a Tether Deployment System For Delivery of a Re-entry Capsule

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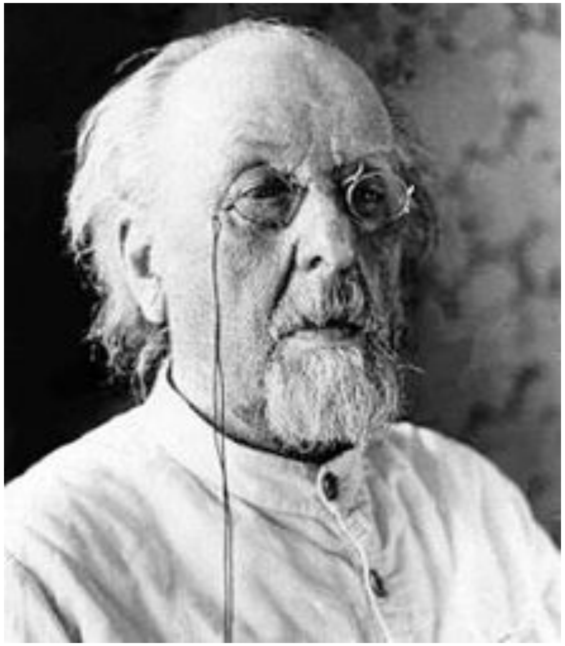
Outline

- Introduction
- Application of space tether systems
- Review of experiment YES2
- The control law
- Mathematical models
- Conclusion

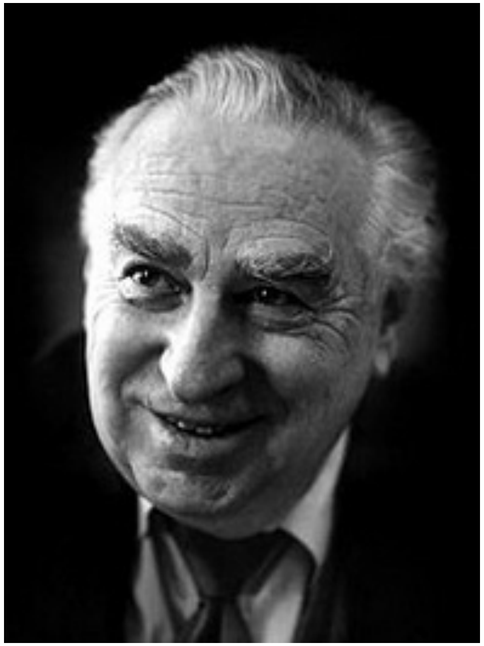
http://spaceports.blogspot.ru

Space tether systems

Space tether system (STS) – mechanical system of rigid bodies moving in different orbits, and the tethers (cables, ropes) that connect these bodies.



Konstantin Tsiolkovsky



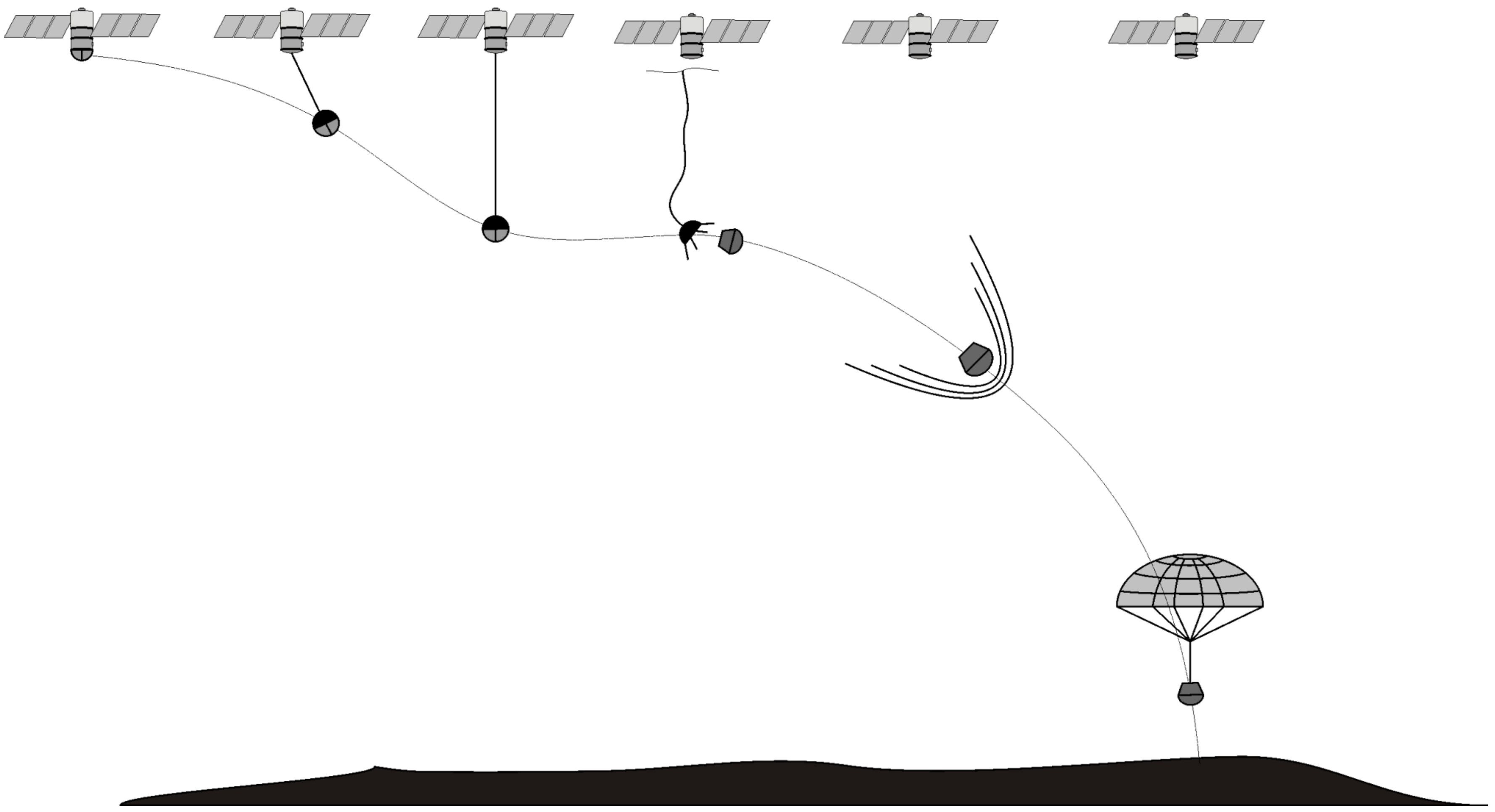
Vladimir Beletskii

Dynamics of STS has been studied by: Beletsky V. V., Levin E. M., Cartmell M.P., Cosmo M.L. , Lorenzini E.C., Misra A.K., Modi. V.J., Williams P., Kruijff M. , Fujii H. A., Edwards B. C., Kumar K. D., Kumar R., McCoy J. E., Sorensen K., Zimmermann F. et al.

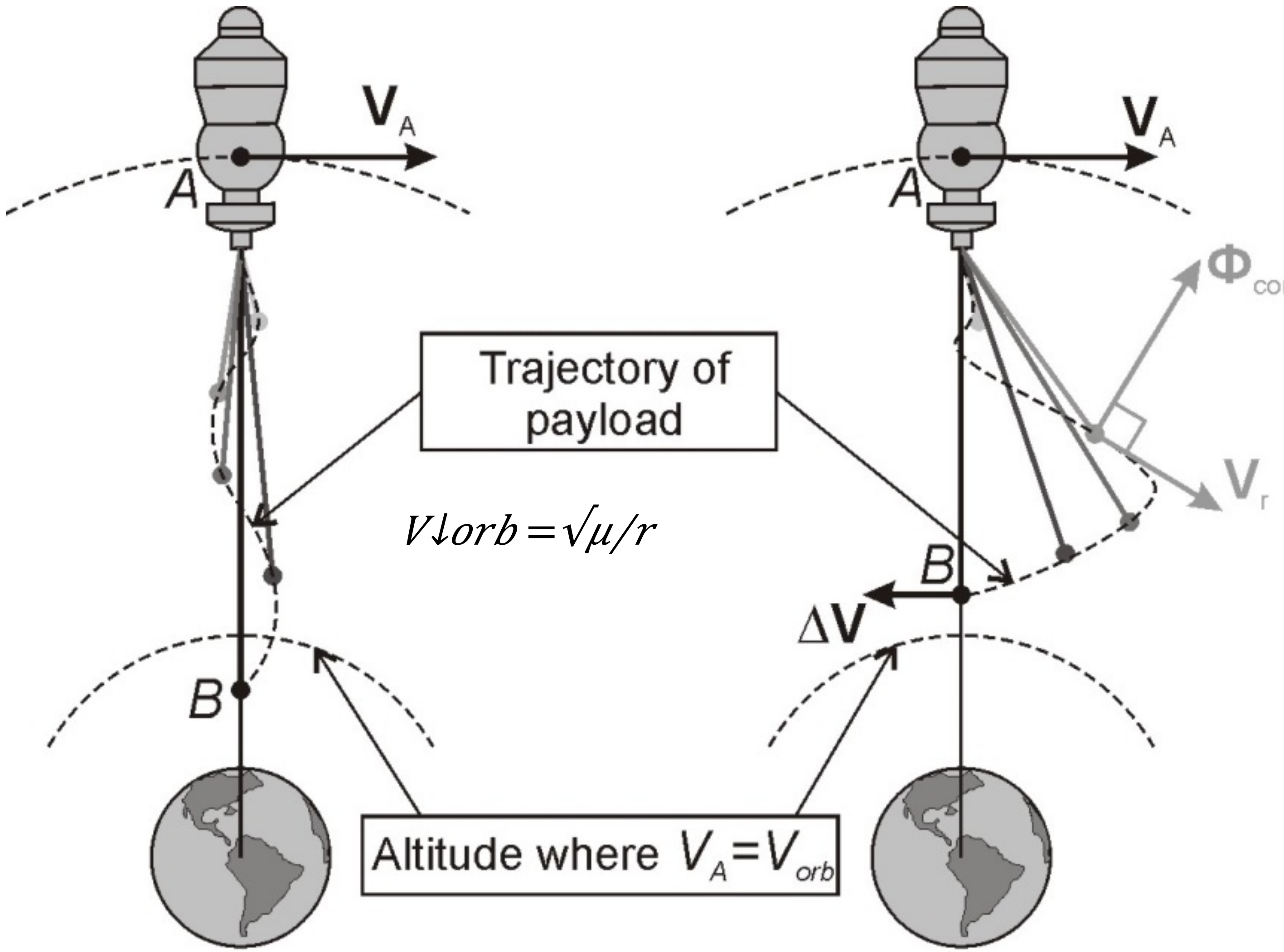
Application of STS

- Creation of an artificial gravity
- Lifting of spacecraft by rotating STS
- Space escalator
- Space elevator
- Interplanetary transfers
- **Lifting and descent of a payload into an orbit**
- Lifting of a space station 's orbit
- Orbital maneuvers without fuel expenditure
- Studying of an upper atmosphere
- Gravity stabilisation of an orbital spacecraft
- Generation of electrical energy by conductive tether
- Use of electrical energy for orbital maneuvers
- Use of electrodynamic tethers for deorbiting
- Et al.

Lifting and descent of a payload



Deployment schemes



$V\downarrow orb = \sqrt{\mu/r}$

a) Static deployment

b) Dynamic deployment

YES-2 (2007)

http://www.esa.int

Young Engineers Satellite 2 :

2007 – YES-2

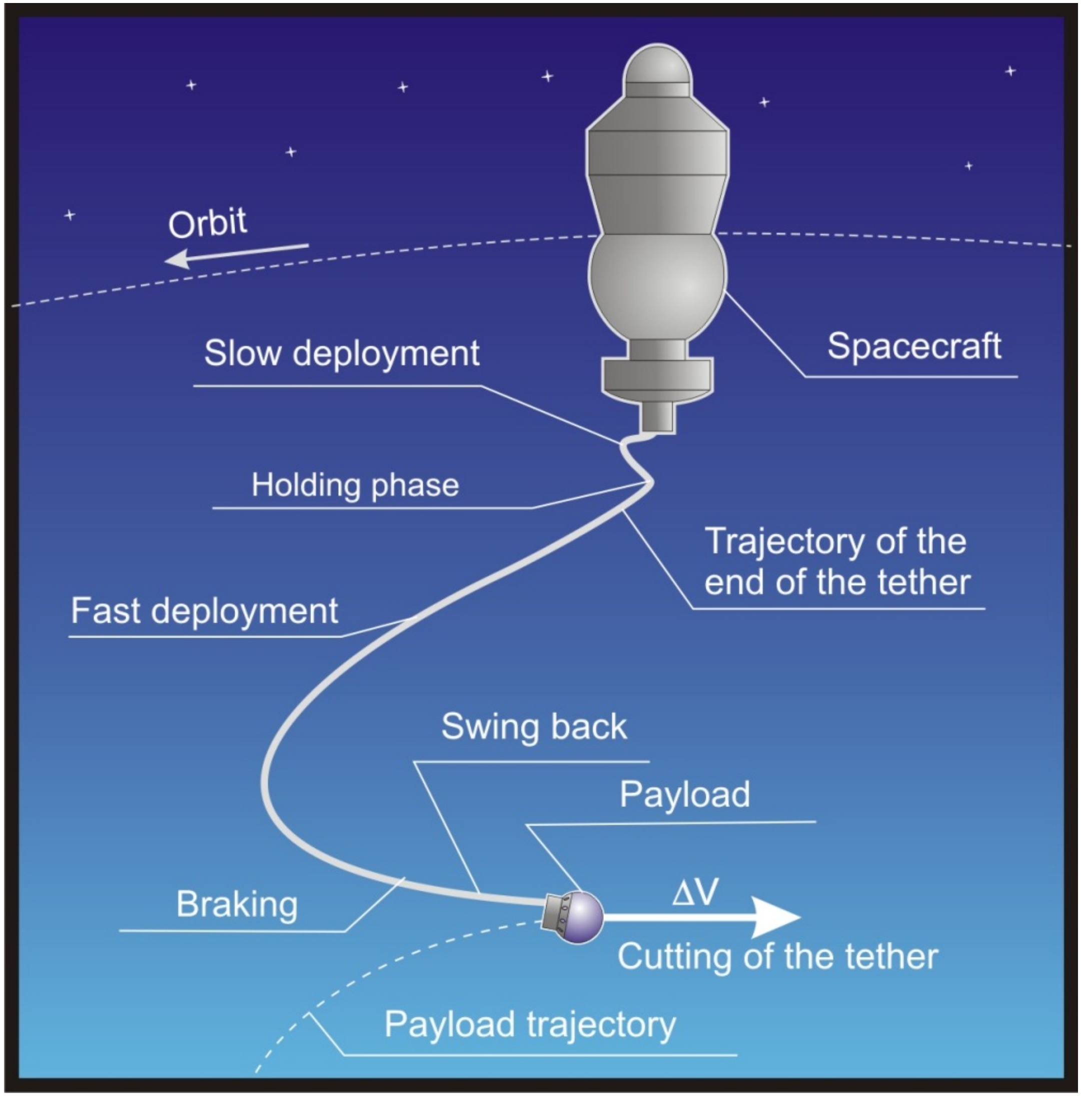
YES2 mission

Foton-M3 parameters:

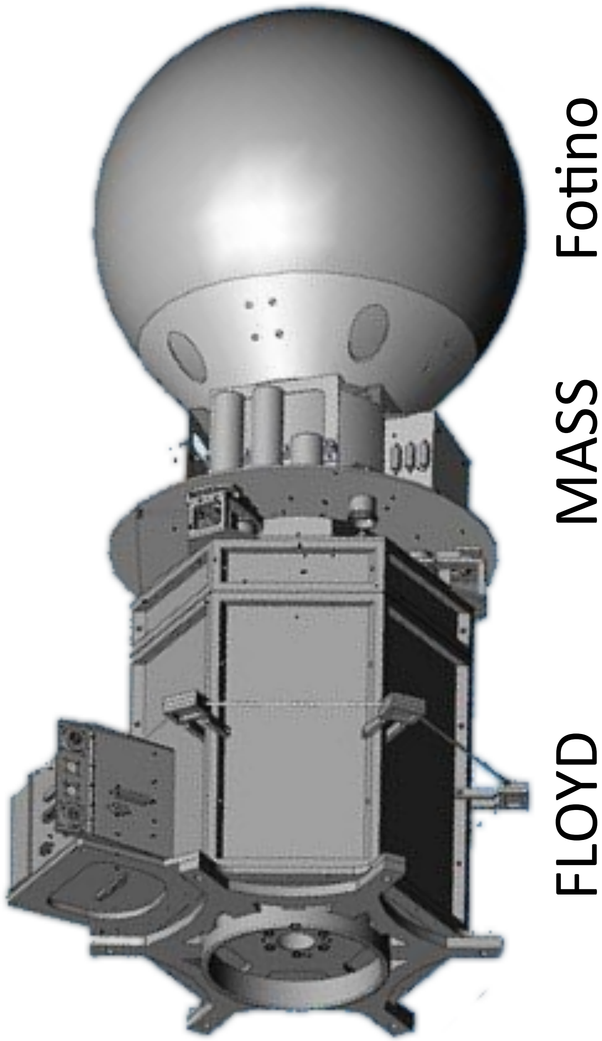
Mass	6530 kg
Ballistic coefficient	0.0123m^2/kg
Inclination	63 deg
Minimum orbital altitude	262 km
Maximum orbital altitude	304 km

Tether system parameters:

Diameter	0.5 mm
Length	30 km
Mass density	0.00018 kg/m
Initial Speed of tether deployment	2.58 m/c
Mass End Load	12 kg

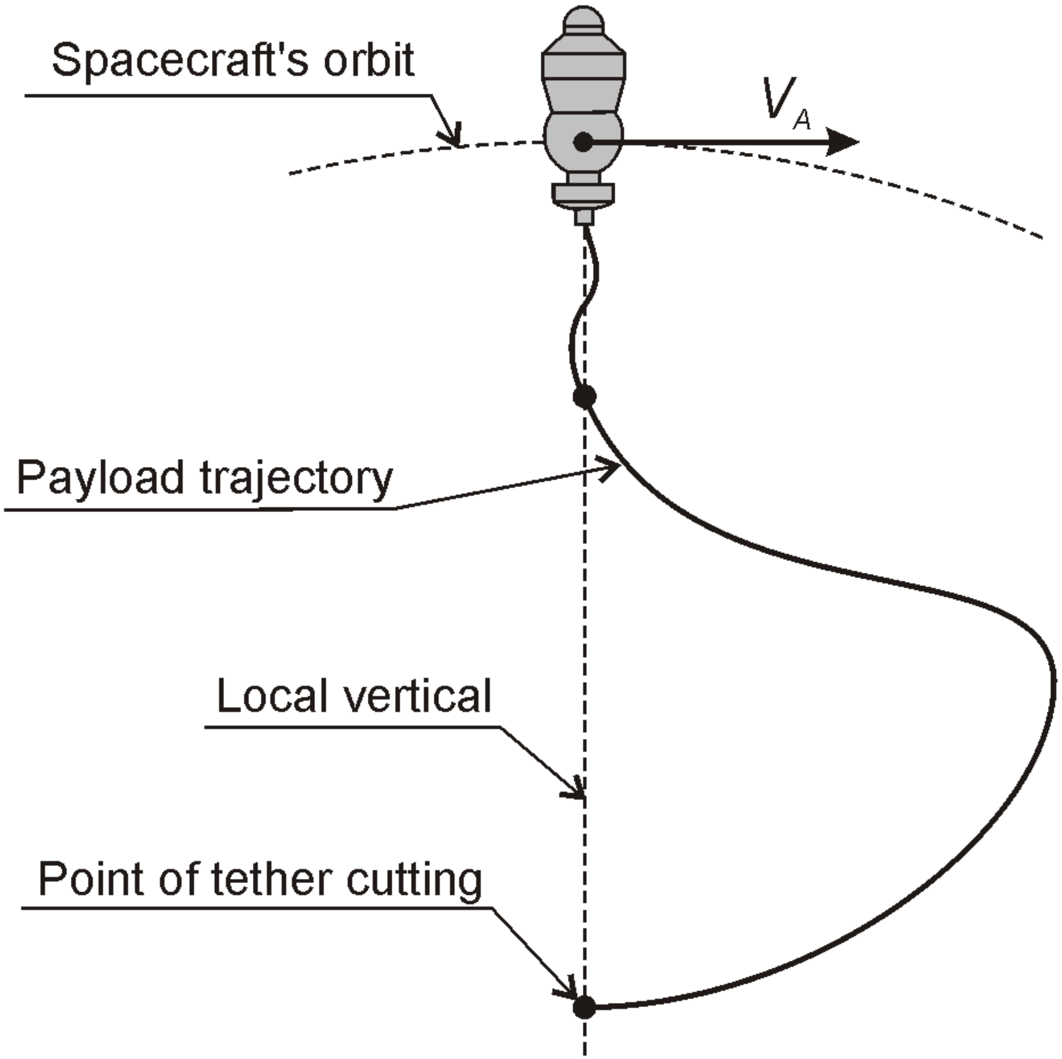


YES2 module



Parameter	Value
Fotino mass	5,5 kg
MASS/Fotino mass	12 kg
Foton-3M mass	6300 kg
Fotino diameter	0.4 m
Tether length	31,7 km
Tether diameter	0,5 mm
Tether mass	5,8 kg
Tether density	0,99 g/cm^3
Tether Tensile strength	3 GPa
Tether Elastic modulus	172 Gpa

Scheme of payload descent (YES2)



Change in altitude in the perigee

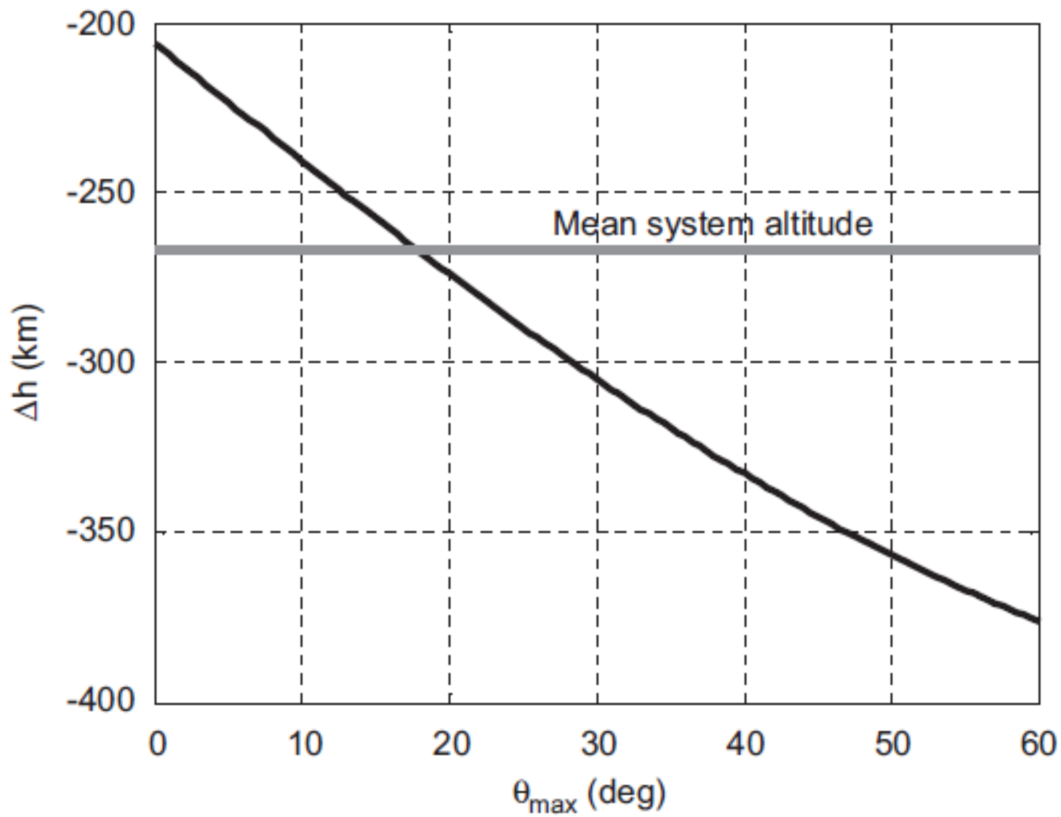


Fig. 5. Change in altitude of payload vs tether libration amplitude.

P. Williams et al. / Acta Astronautica (64) 2009

Change in altitude in the perigee

The change in altitude in the perigee of the capsule after the separation from the tether in the point A

$$\Delta h = R_p - R_0$$

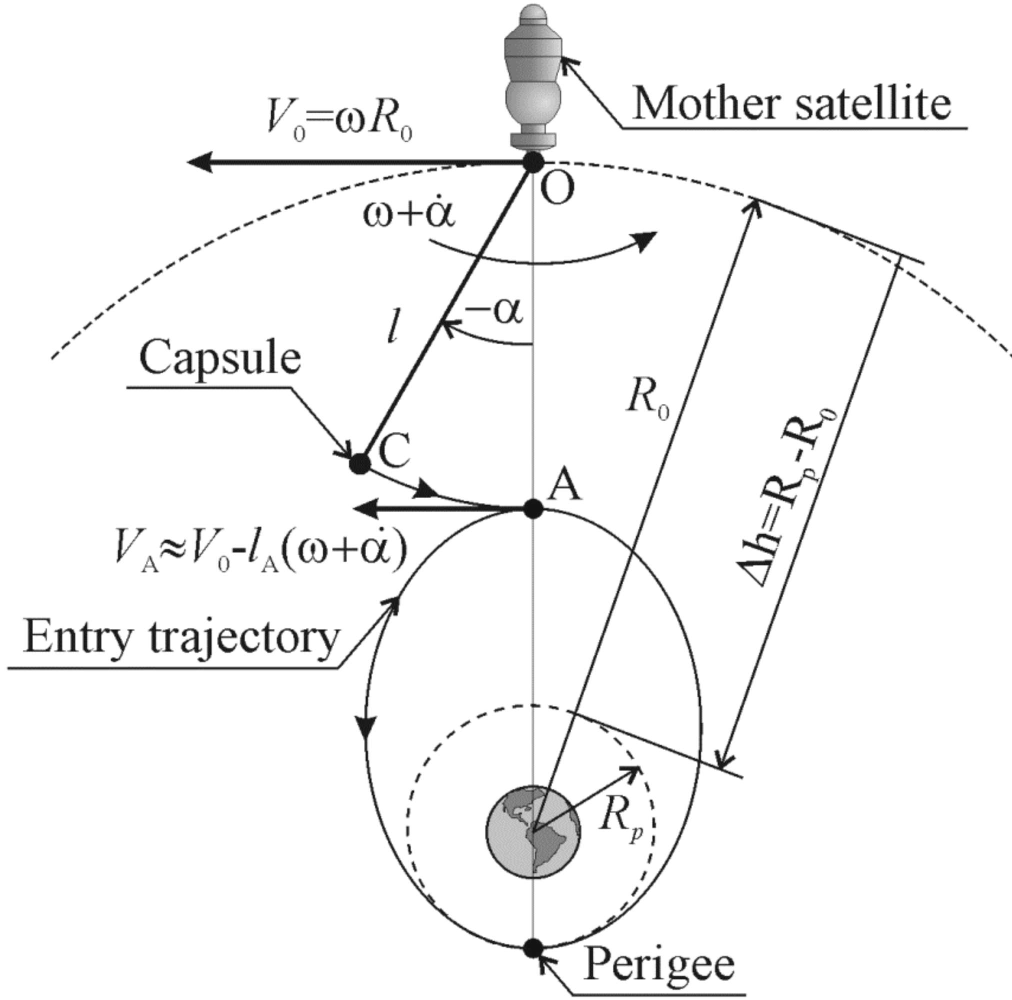
$$= \frac{\left[\left(R_0 - l_A\right)V_A\right]^2}{2\mu - \left(R_0 - l_A\right)V_A^2} - R_0$$

For the tether length (YES2)

$$l = 30\,km$$

Occurs

$$\Delta h_{YES2} \approx -330\,km$$



P. Williams et al. / Acta Astronautica (64) 2009

The control law

The control law is based on the principle of a swing with variable rope

$$\frac{dl}{dt} = -\lambda \frac{d\alpha}{dt} \qquad (1)$$

λ is a constant coefficient

The Coriolis force $\Phi_C = 2m_c\dot{\alpha}\dot{l} = 2\lambda m_c\dot{\alpha}^2$ (2)

results in an increase in the amplitude of oscillations tether

if $\lambda > 0$

results in a decrease in the amplitude of oscillations tether

if $\lambda < 0$

The basic assumptions

1. Mass of the capsule significantly less mass of the mother satellite

$$m_c << m_m$$

2. The tether is weightless

$$m_t = 0$$

3. The tether length is always much smaller than the mother satellite orbital radius

$$l << R_0$$

Tethered system model

Equation of motion for the inextensible tether

$$\alpha'' + \frac{3}{1+e\cos\theta}\sin\alpha\cos\alpha - 2\left(\frac{\lambda\alpha'}{l} + \frac{2e\sin\theta}{1+e\cos\theta}\right)(\alpha'+1) = 0 \qquad (3)$$

where $\left(\ \right)' = d\left(\ \right)/d\theta$

Then the tether tension force is

$$T = m_c\left[N^2(1+e\cos\theta)^4\left(\lambda\alpha'' + \frac{2e\lambda\alpha'}{1+e\cos\theta}\sin\theta + \alpha'^2 l\right) + \frac{2g_0 l}{R_0}\cos^2\alpha\right] \qquad (4)$$

Analytical solution

To find an approximate analytical solution of the equation (3) should introduce additional assumptions

The mother satellite moves in a circular orbit

$$e = 0$$

The control coefficient is always much smaller than the tether length

$$\varepsilon = \lambda / l_0 << 1$$

The approximate analytical solution in implicit form $\theta = \theta(\alpha_m)$

or

$$4a\varepsilon(\theta - \theta_0) = \left[\left(\sqrt{a} - a\right)\ln\left(\sqrt{a} + 1 + x\right) - \left(\sqrt{a} + a\right)\ln\left(\sqrt{a} - 1 - x\right) + 2\ln(x) \right]_{\sin^2\alpha_{m0}}^{\sin^2\alpha_m}$$

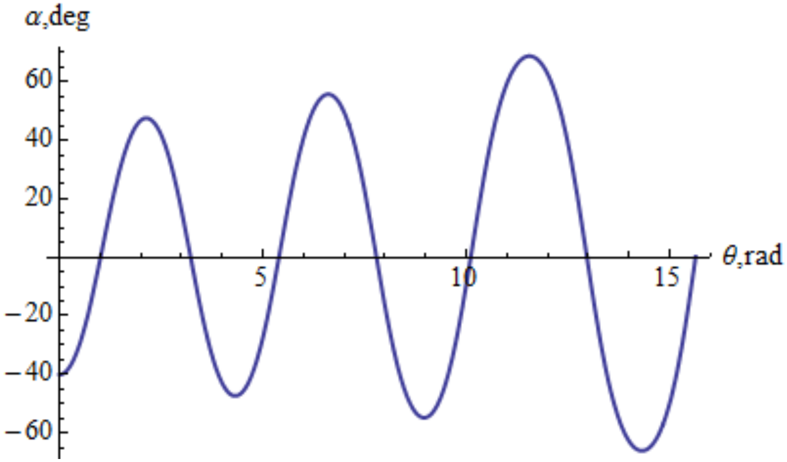
where $a = 17,\ \alpha_{m0} = \alpha_m(\theta_0)$

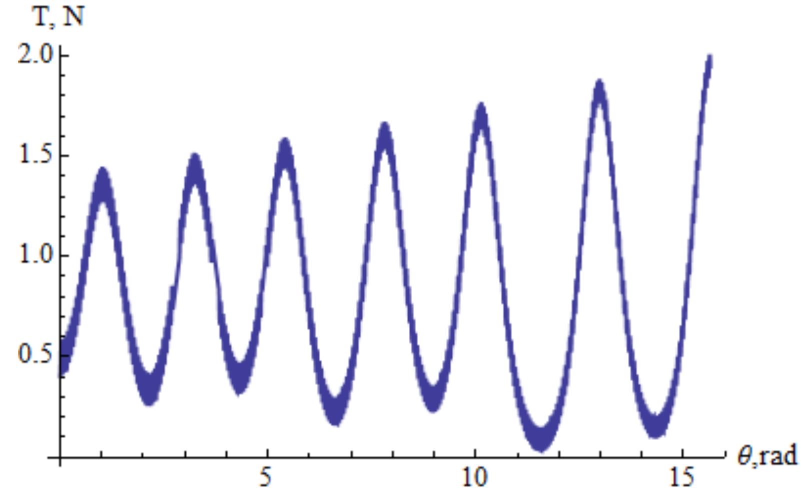
Simulation results

The control law (1) is activated after the deflection tether $a_m = -40\deg$

Parameters STS similar to YES2 $(e = 0.0027)$ and $\lambda = 750\,m$

The dependences of the deflection angle and of the tether tension from true anomaly





The tether length ranged $l \in (23.6,\ 25.4), km$

The change in altitude $\Delta h = -335 km < \Delta h_{YES\,2}$

Conclusion

The results of this study suggest that a possible way to reduce the perigee altitude is to swinging motion of the tether

The proposed control law may be applicable in cases when the initial deployment is realized as static or as dynamic

It can be assumed that the control law can be used for stabilization Of the tether relative to the local vertical if we take negative coefficient control $\lambda < 0$

Further research on the subject should verify the tether dynamics in more detail

Thank you

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