Deployment of space aerodynamic tether system

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Samara

Est. 1586

1 300 000 inhabitants
3 000 000 in Samara region

A city of aviation and space-rocketry construction
Samara State Aerospace University

- One of the leading Russian universities
- Founded in 1942 with the purpose of the preparation of engineers for the aircraft industry
Samara State Aerospace University

- about 17000 students
- 5 institutes and 16 faculties
- 110 undergraduate and postgraduate educational programmes
- 32 specialities of post-graduate training
- 9 doctoral dissertation councils
What is space aerodynamic tether system?

- a spacecraft and
- an aerodynamic stabilizer – a light metal or inflatable part

What for?

- aerodynamic stabilization of a spacecraft’s motion on Earth or other planet orbit
- fast deceleration and descent of a no longer operational spacecraft on predictable small landing area of a planet surface
- stabilization of launcher’s detached parts
- atmospheric probes based on tether system
Deployment process assumptions

- Both spacecraft and stabilizer are considered as material points
- Tether is massless
- Geocentric fixed coordinate system
- Tether stretchability as well as inertness of placed on spacecraft tether deployment device are taken into consideration
- Tether stretchability law is one-side - tether does not receive compression.
- Tether deployment device works only for deceleration purposes and cannot pull the tether in.
- Motion of a spacecraft and a stabilizer around there centers of mass is stable that is provided by proper parameters choice

\[ m_i \frac{d^2 \vec{r}_i}{dt^2} = \vec{G}_i + \vec{T}_i + \vec{R}_i \]
Deployment process perturbations

- Atmosphere density
- Ballistic coefficients of bodies in the system - up to 40%
- Changes in inertness of deployment control device
- Mistake of detachment direction in direction of flight – 45°
- Detachment velocity -25%
Deployment stage

Dynamic law

- Realizes control force by a break (deceleration) device with and without inverse connection (feedback) principle

\[
F_{tt} = \begin{cases} 
F_{\text{min}}, & \text{if } t < t_1 \\
F_{\text{min}} + (F_{\text{max}} - F_{\text{min}}) \sin^2 \left[ k_p(t - t_1) \right], & \text{if } t_1 \leq t \leq t_2 \\
F_{\text{max}}, & \text{if } t > t_2 
\end{cases}
\]

- Strikes after achieving maximum length of a tether

45° mistake of detachment direction in direction of flight

Tether length and tether tension force
Deployment stage

**Kinematic law**

- Based on a program of velocity change
- Described as a harmonic function
  \[ V_L(t) = V_{\text{max}} \cos^2(\omega t + \varphi) \]
- More accurate achievement of final motion conditions of a stabilizer despite of possible uncertainty in initial conditions and other parameters

Figure a: Tether tension force, control force

Figures b,c: Velocity and tether length processes
Deployed tether aerodynamic system

- Aerodynamic stabilization on various stages:
  - low planet orbit,
  - top layers of the atmosphere (about 100-200 km altitude for Earth) for preliminary stabilization before descent,
  - dense layer to maintain steady motion before landing.
- Allows to lower the requirements of spacecraft aerodynamic characteristics and their deviations
Tether system

- Equations derived by using a theorem on kinetic moment variation for each body and a theorem on the motion of the center of mass.
- Gravitation moment is not taken into consideration, the magnitude of gravitational acceleration is invariable within the system size.
- Dynamic equations are complemented by kinematic equations for the SC, AS, and tether
Stability conditions

**Static**
- For statically and dynamically balanced bodies under constant dynamic velocity pressure (velocity and density).
- Absence of other perturbations (dissipation and geometric and mass asymmetry).
  \[ \alpha_k = 0 \ (k = 1, 2, 3) \]
- Necessary conditions for the stability of motion.

**Dynamic**
- Determine the slow decrease in the amplitudes of vibrations of the variables about the unperturbed solution.
- Can be treated as sufficient conditions for the stability of the system.
- The sufficient stability conditions are usually verified by applying various perturbations (slow variations in the system parameters and the action of dissipative terms) to the system.
Parameter choice – cylinder + semi-sphere

Proton launcher, 2\textsuperscript{nd} stage

![Graph and image of rocket launch]
Parameter choice – cylinder + cylinder

**Soyuz launcher – 2nd stage**

- Mass - 6625 kg, length - 27 m, radius - 1.5 m.
- Impossible to achieve stable motion
- If sizes are equal or close, it is impossible to achieve static stability by mass redistribution only
- If masses are equal, it is impossible to achieve static stability by changing cylinders’ lengths
- If stabilizer is longer than spacecraft than mass redistribution does not lead to static stability
- If stabilizer is shorter than spacecraft, it is possible to achieve stability by reducing its mass to critical value (approx. 450 kg).
Parameter choice – cone + cone

- Spacemail based on YES-2 ideas
- Light capsule without engines
Conclusion

- Deployment based on kinematic laws has advantages compared to dynamic laws.
- These advantages are based on more accurate achievement of final motion conditions of a stabilizer despite of possible uncertainty in initial conditions and other parameters.
- Kinematics laws can be used with feedback principle, but it is necessary to add that the regulator model here is ideal, without taking into consideration discrete regulator work, possible measurement mistakes etc.

- Choice of parameters allows to achieve stability of a system even if spacecraft and stabilizer are statically unstable.
Thank you!

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