Analysis of REXUS12's Suaineadh Experiment:

Centrifugal Force Deployment of Space Web from Sounding Rocket

Huina Mao, Thomas Sinn,
Massimiliano Vasile, Gunnar Tibert

Motivation:
One Step Centrifugal Force Deployment

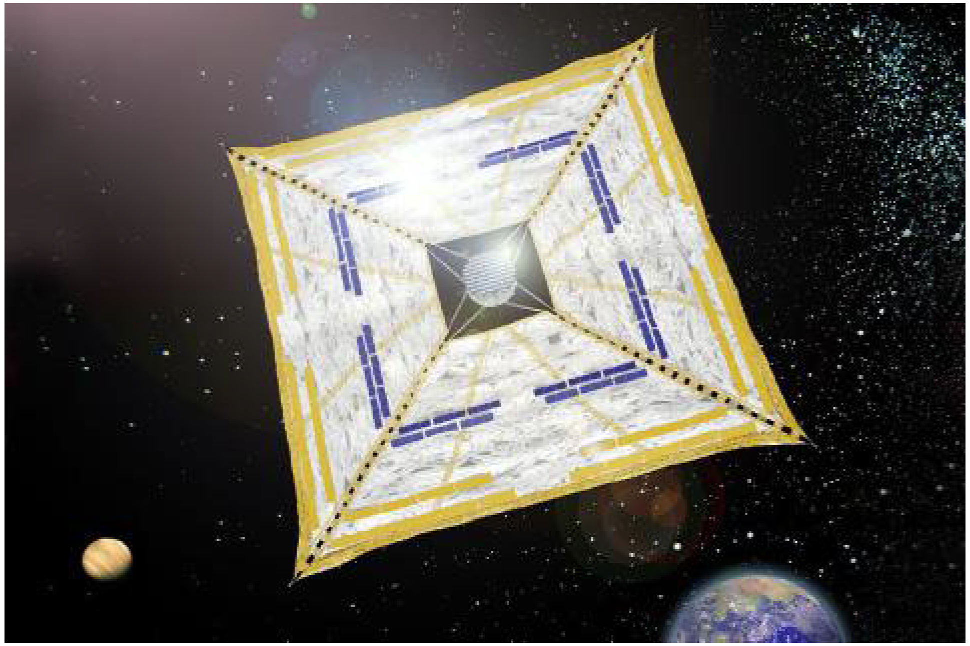


Fig. 1: IKAROS (JAXA About Small Solar Power Sail Demonstrator "IKAROS")

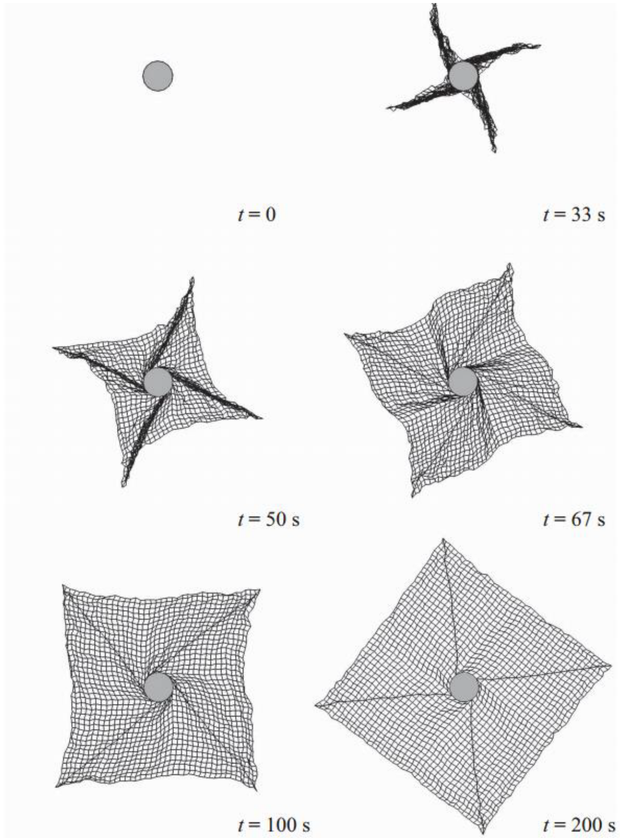
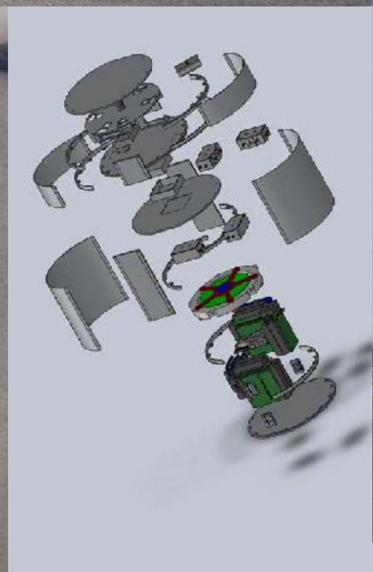


Fig. 2: Controlled one-step deployment of space web. (Mattias Gärdsback)

European Space Agency

Swedish Space Corporation

Launch in Esrange Space Center



De-spun Rocket

Fig. 3 Suaineadh after launch

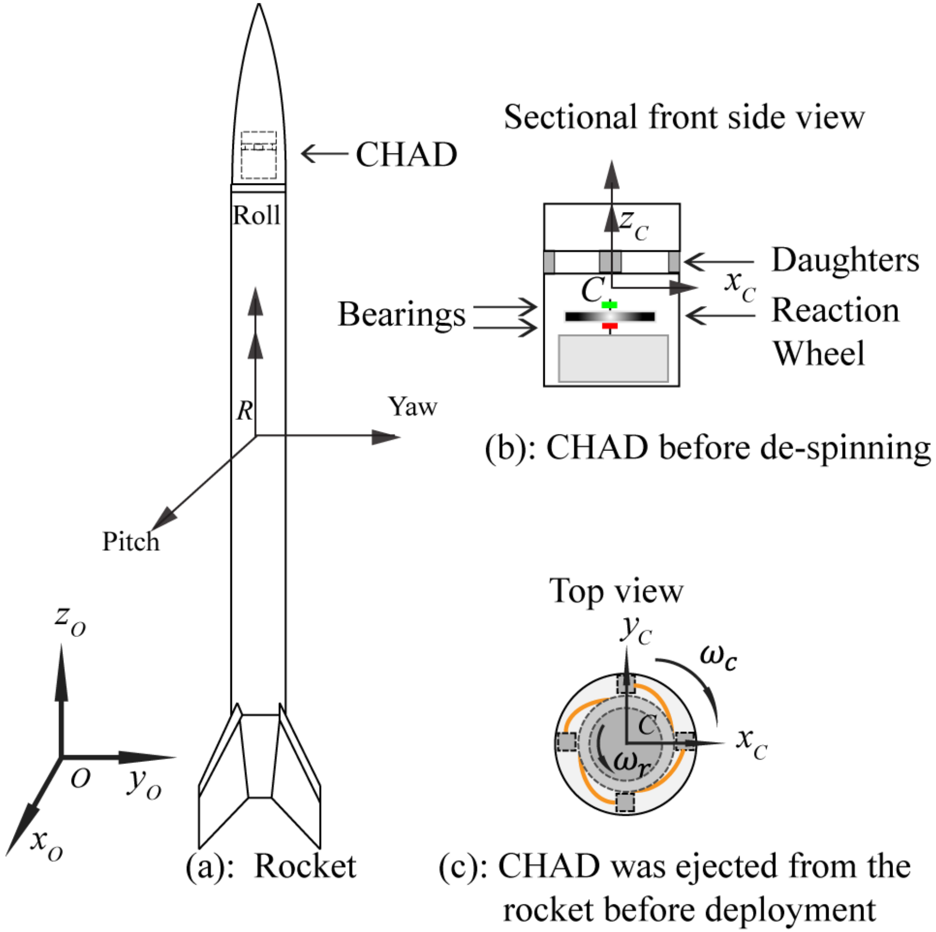


Fig. 4 Space web placed in the Rocket

Wrong Folding Pattern

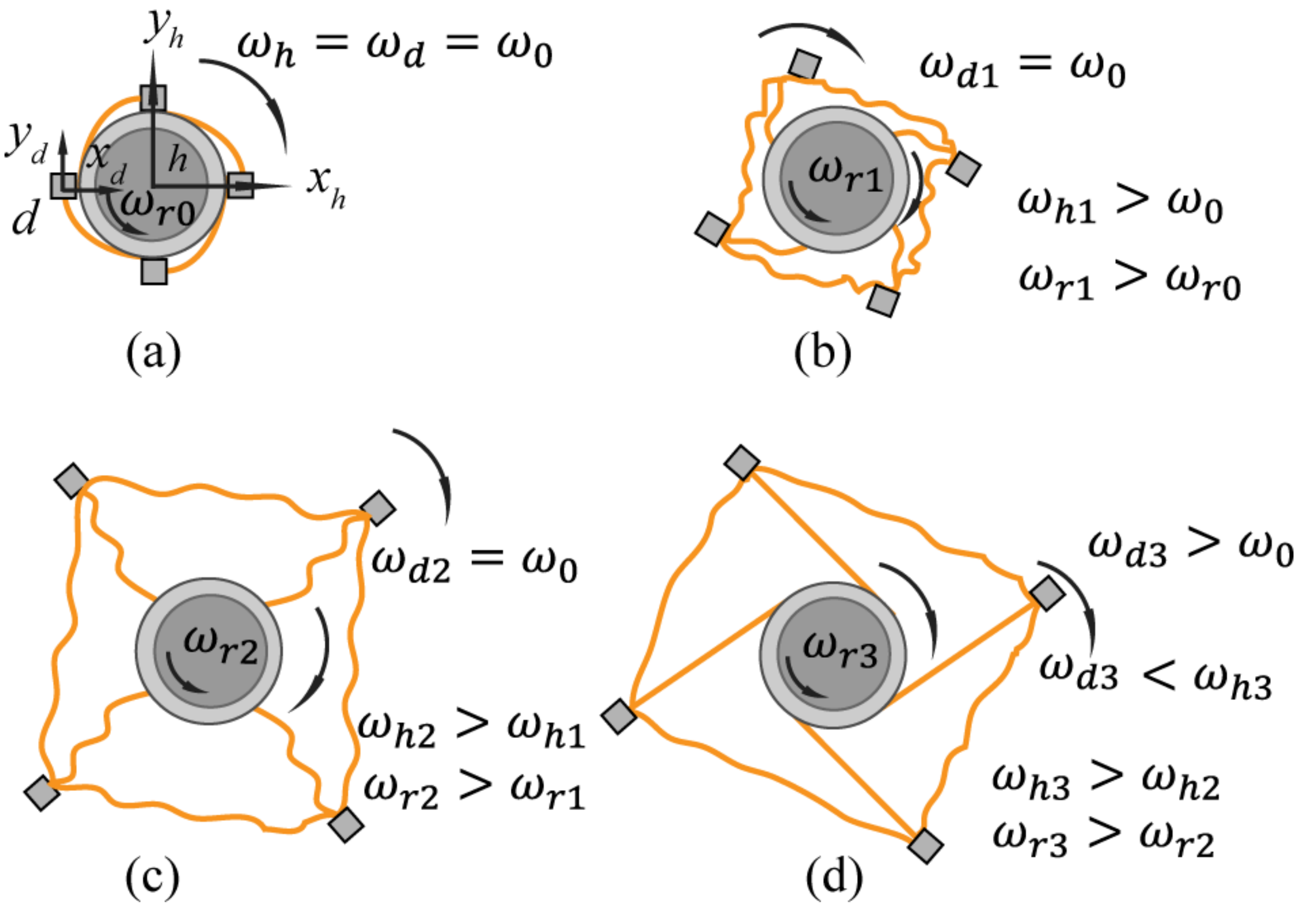


Fig. 5 Space web recoils back with clockwise coiling pattern.

Right Folding Pattern

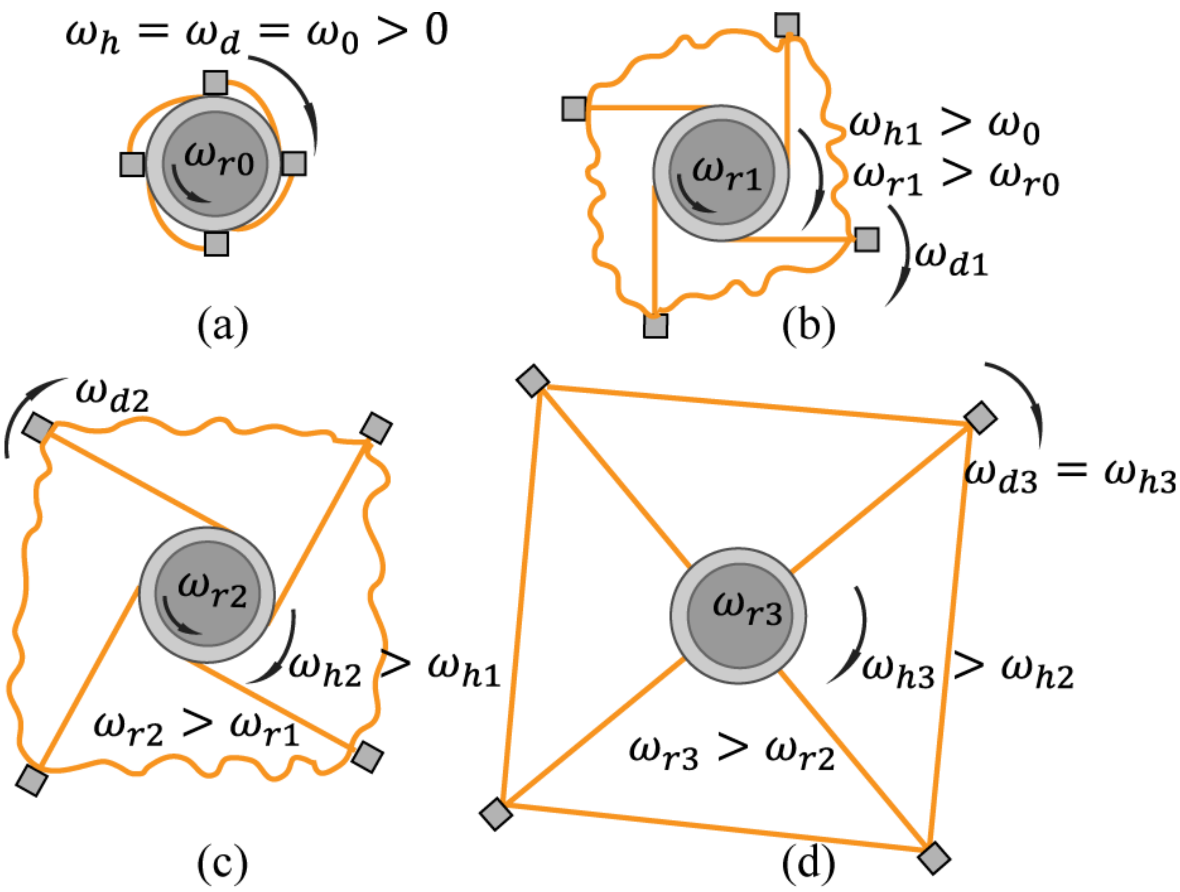


Fig. 6 Space web was stabilized with counterclockwise coiling pattern.

Ground Test

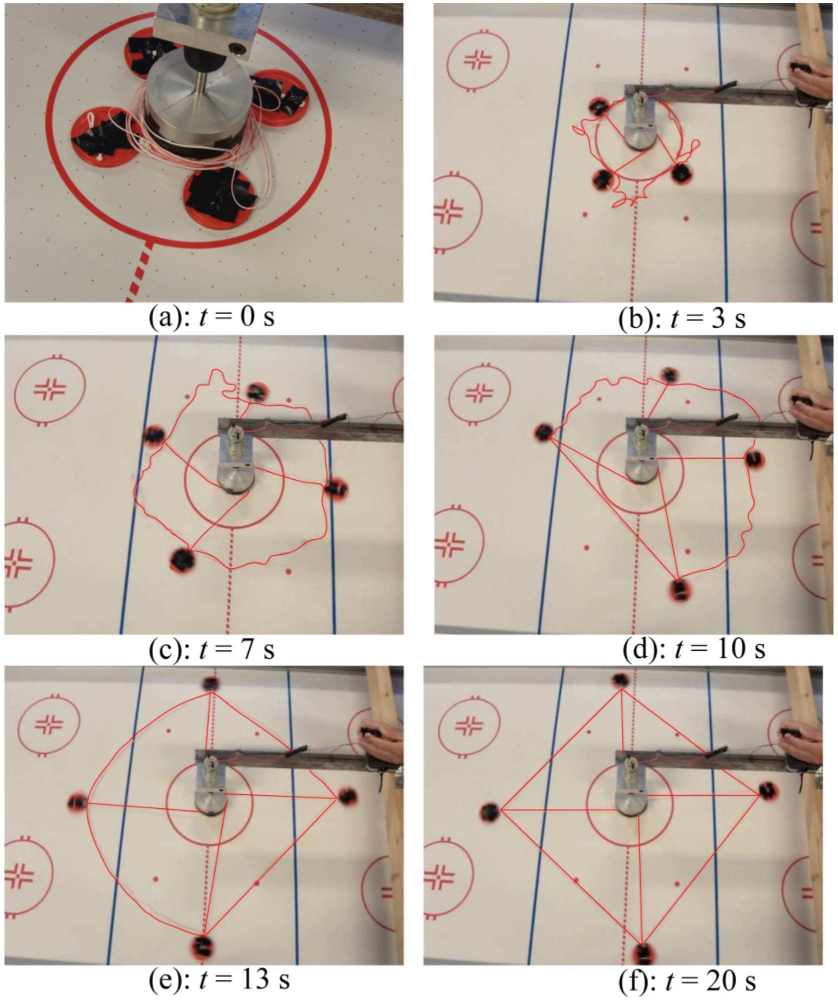


Fig. 7 Ground deployment on a smooth ice hockey table.

Pre-launch

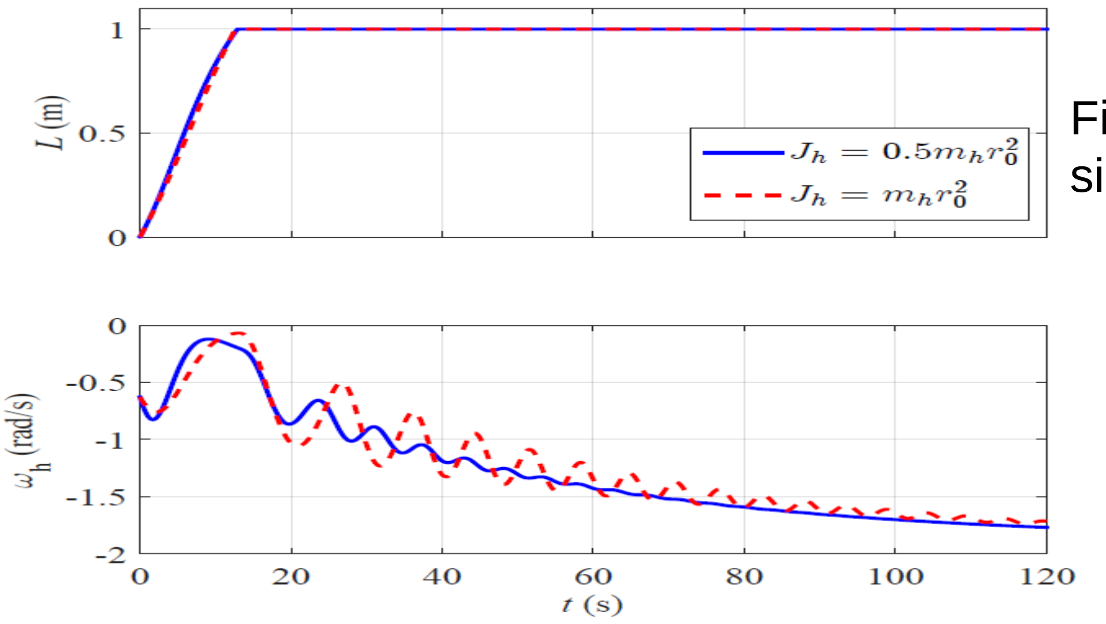


Fig. 8 Pre-launch simulations

Event	Design time (s)	Actual flight time (s)
REXUS ignition	$T+0$	$T+0$
REXUS de-spin	$T+70$	$T+70$
CHAD ejection	$T+80$	$T+80$
Reaction wheel starts	$T+90$	$T+90$
Proper speed of the hub	$T+90+3$	$T+90+15$
Web deployment starts	$T+93+2$	$T+105+2$
Web is fully deployed	$T+95+13$	$T+107+2$
Web stabilization	$T+108+100$	$T+109+168$

Table. 1 Mission Time lines

During Launch

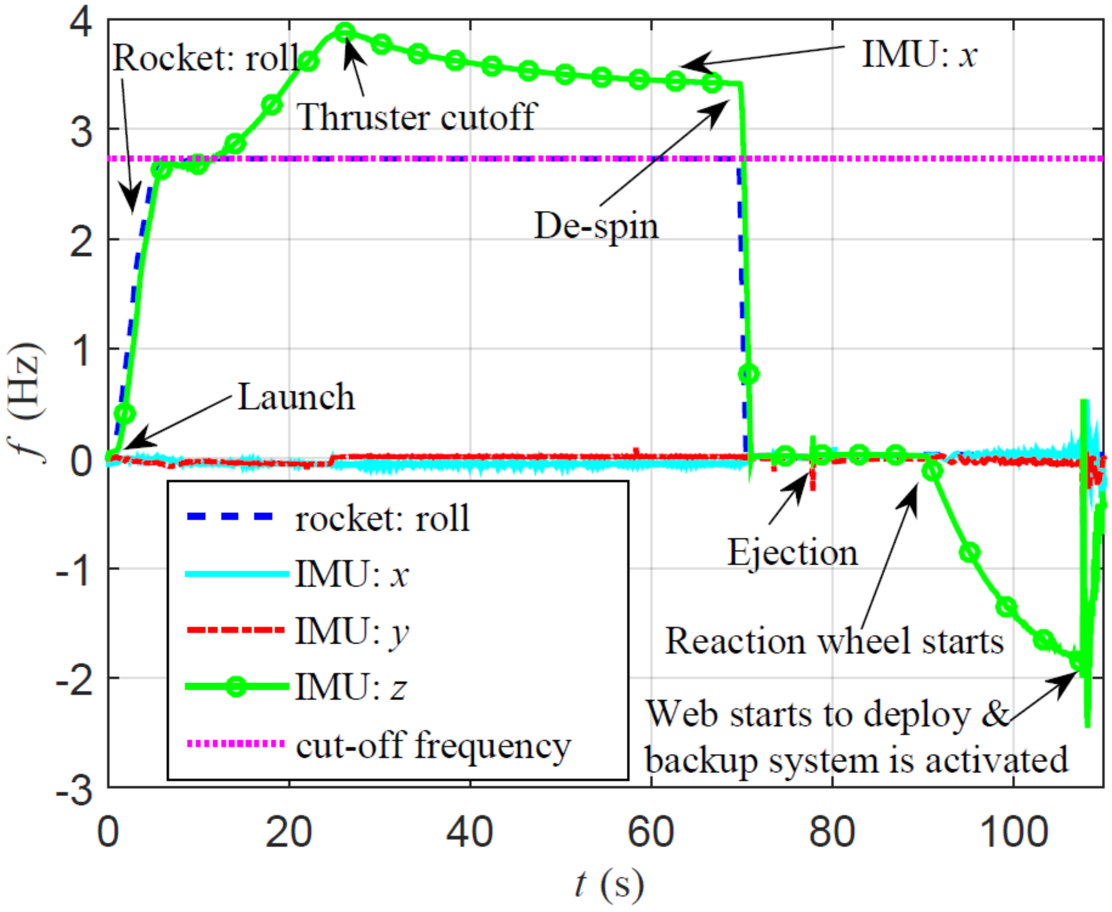
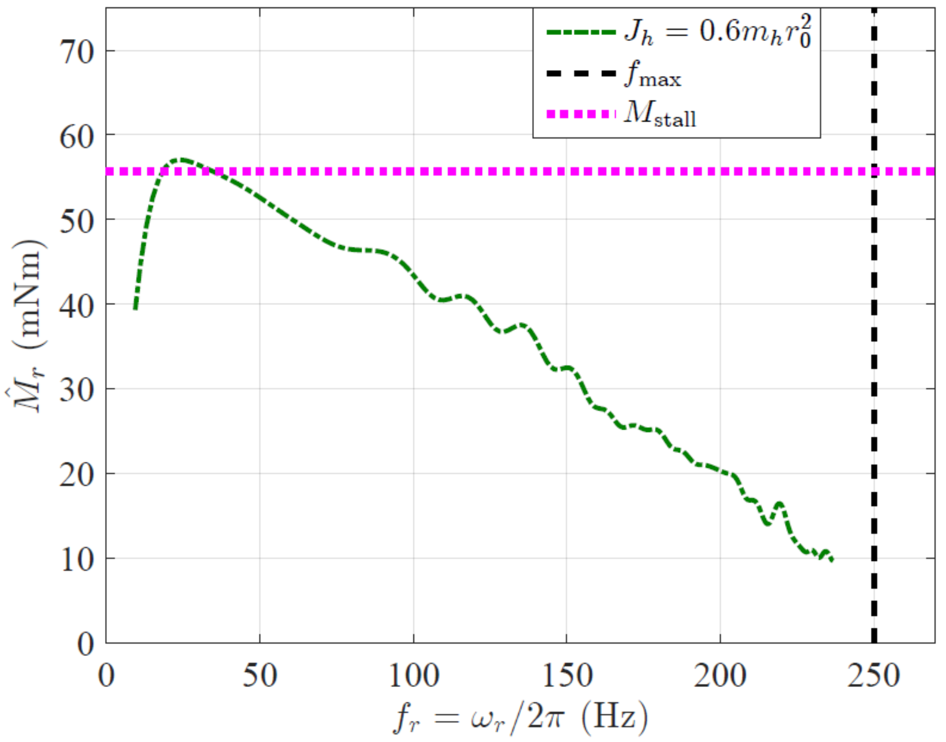


Fig. 9 Acceleration of the CHAD and Rocket

Reconstruction of the Deployment



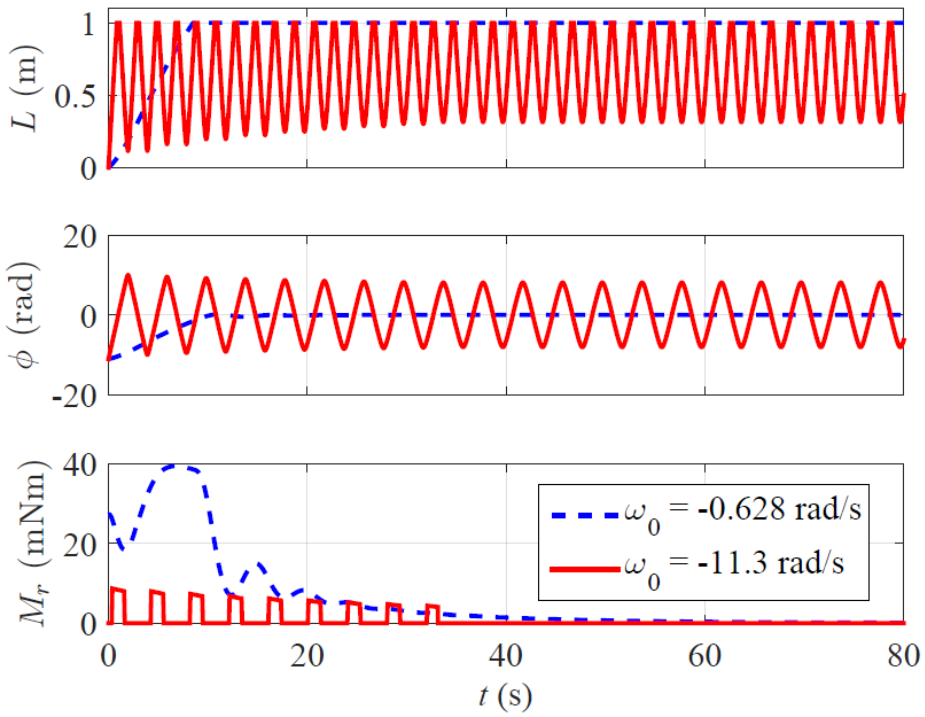


Fig. 10 Nonlinear reaction motor torque calculated from launch data.

Fig. 11 High or proper initial speed deployment.

During Deployment

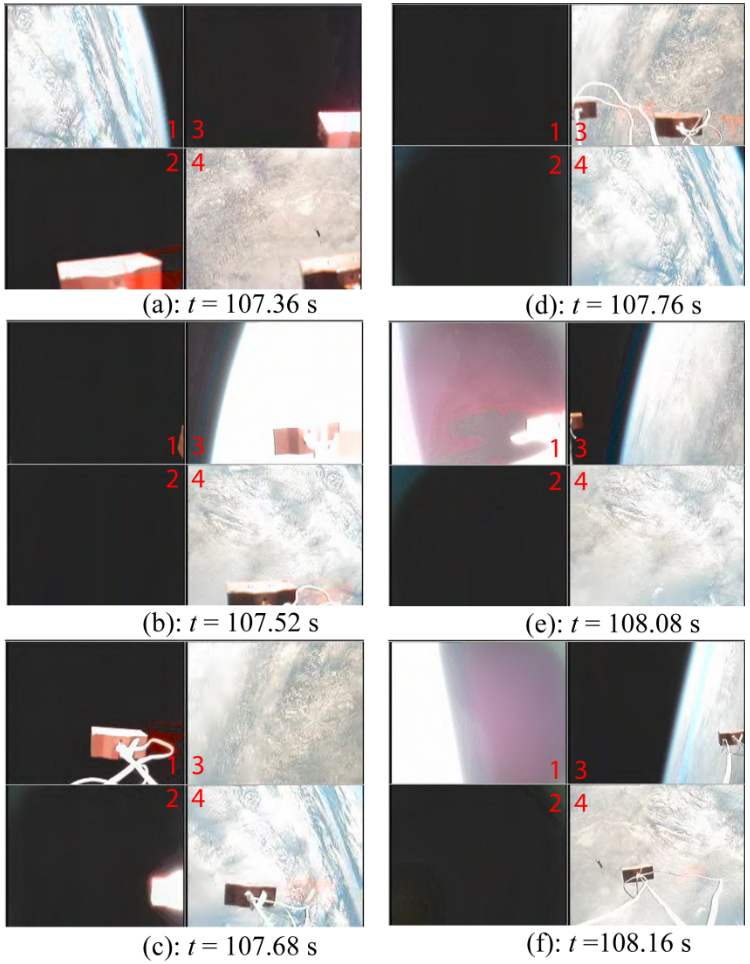


Fig. 12 Deployment images from Camera videos

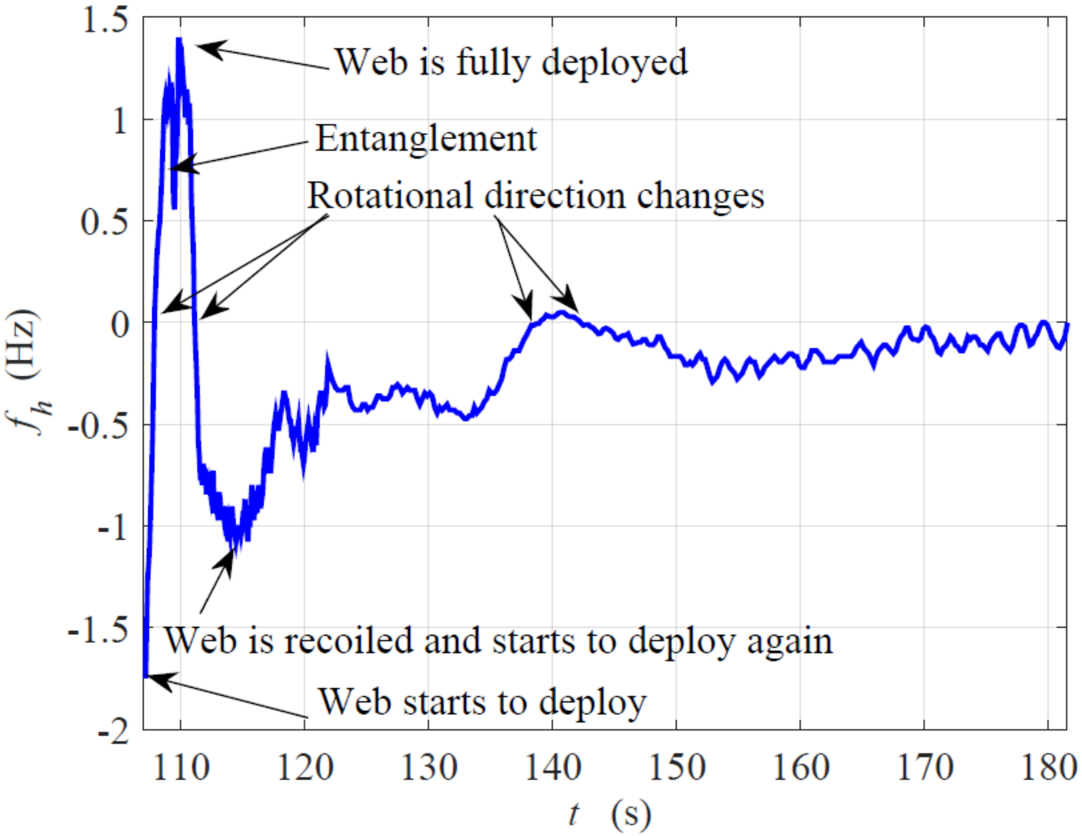


Fig. 13 Angular velocity of the CHAD from video footages

Out of Plane Motion Control

Fig. 14 MAI-400 Micro Reaction Wheel (CubeSat Shop)

MAI-400 Micro Reaction Wheel:

•Momentum storage: 9.35 mNms @ 10,000 RPM
•Maximum torque: 0.635 mNm
•Weight: 90 g
•Dimensions: 3.3 cm x 3.3 cm x 3.84 cm

Out-of-plan Control Method:

$$M_1 = \hat{M}_t \mathrm{sign}(\omega_1) \min\left(1, \lambda_1 \left|\frac{\omega_1}{\omega_{10}}\right|\right)$$

$$M_2 = \hat{M}_t \mathrm{sign}(\omega_2) \min\left(1, \lambda_2 \left|\frac{\omega_2}{\omega_{20}}\right|\right)$$

$$M_3 = \lambda_3 \hat{M}_r \mathrm{sign}(\omega_{3p}) \max\left(0, \min\left(1 - \frac{\omega_3}{\omega_{3p}}, 1\right)\right)$$

Stabilize the Out-of-plane Motions before Deployment

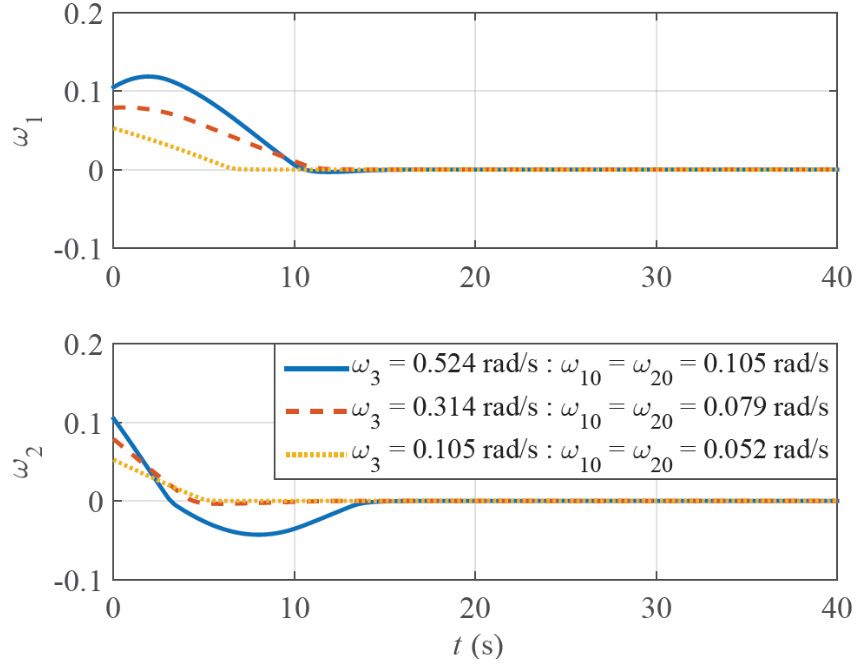


Fig. 15 Stabilize the out-of-plane Motions before deployment without changing ω_3.

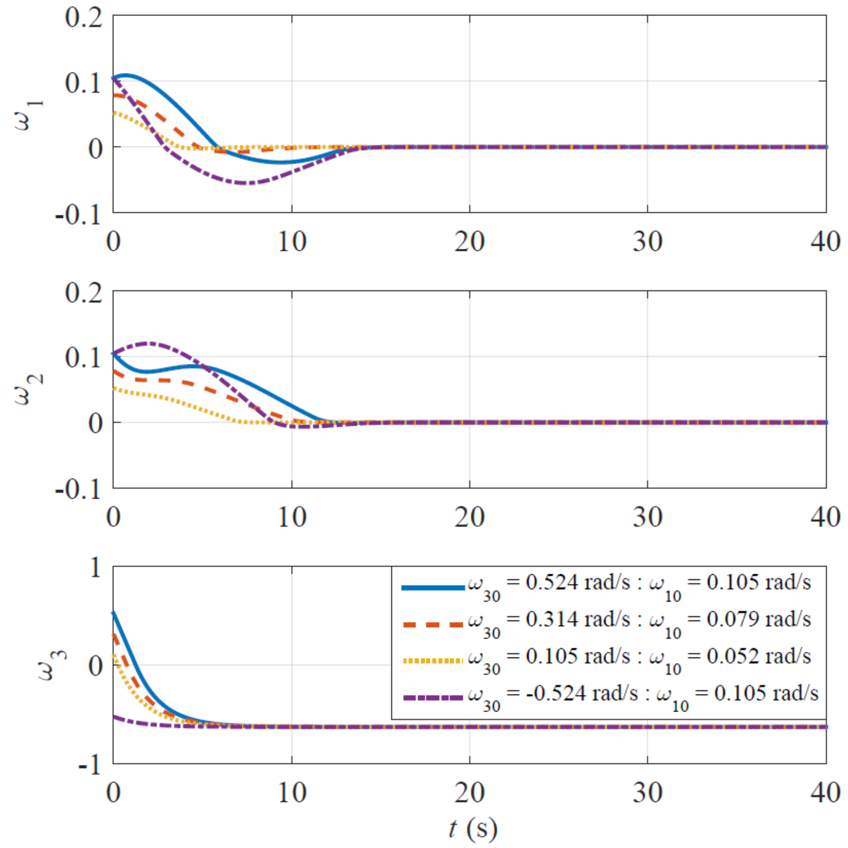


Fig. 16 Stabilize the out-of-plane motions and accelerate before deployment with changing ω_3.

Stabilize the Out-of-plane Motion during Deployment

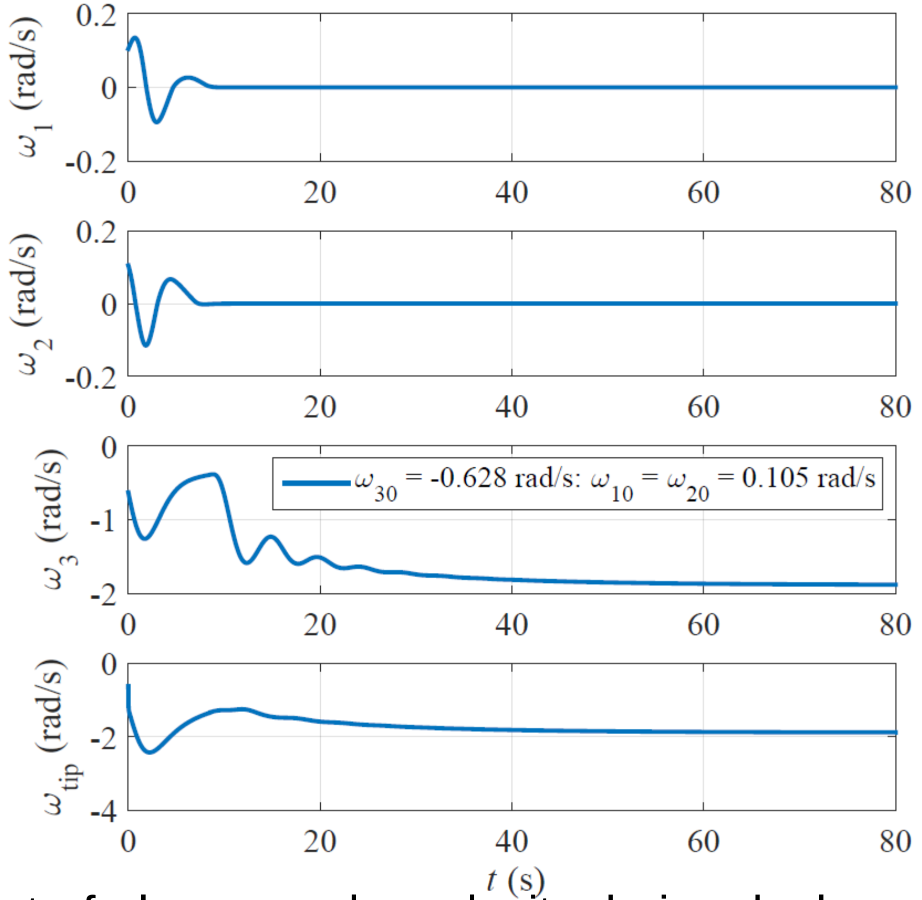


Fig. 17 Stabilize the out-of-plane angular velocity during deployment: the space web started to deploy from the specified proper initial angular velocity $\omega_{30} = 0.628\, rad/s$

Tape-spring Arms Space Web/Solar Sail

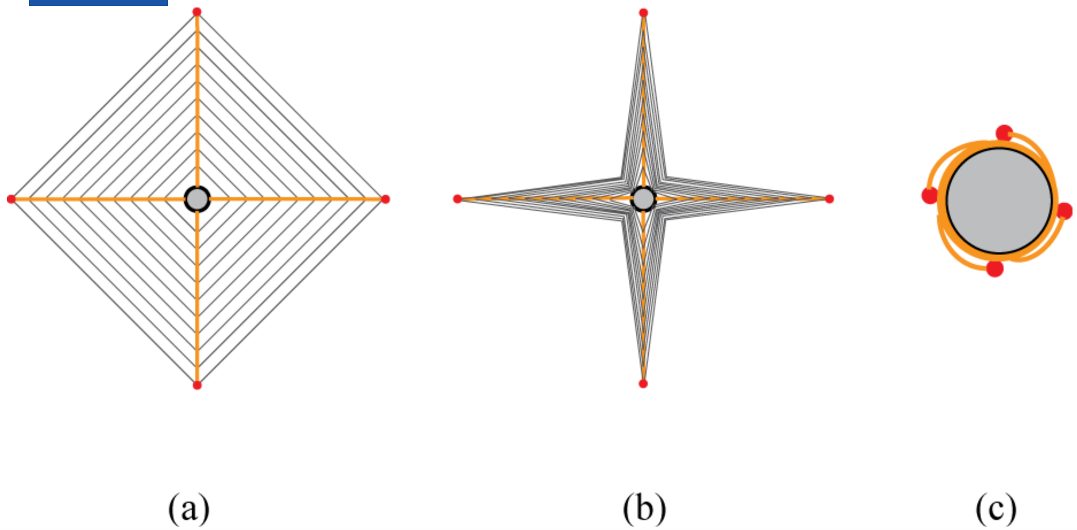


Fig. 18 Folding sequence for a quadratic space web with neutral stable tape spring arms.

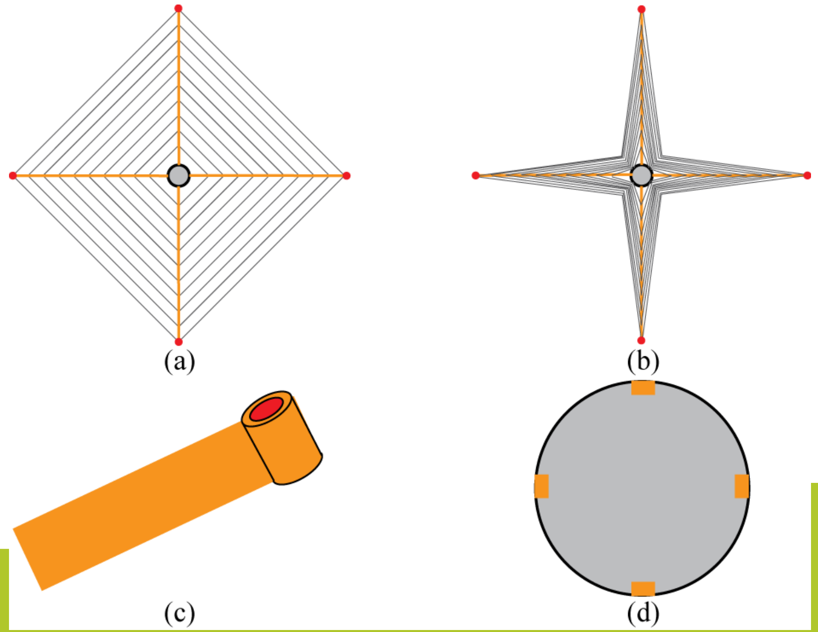


Fig. 19 Folding sequence for a quadratic space web with self-deployable bi-stable tape spring arms.

Conclusion

- The Suaineadh space web design was presented from structures, folding patterns and coiling directions.
- Ground test and simulations are used and indicate the web deployment is controllable.
- During launch, the space web did not deploy at the correct angular velocity due to some unclear problems, e.g. broken sensor, controller.
- Reconstruction of the dynamics by simulations: if the deployment had started from the correct initial angular velocity, the motor used in the experiment would most likely be able to produce a stable deployment.
- Out-of-plane motions stability method is studied and simulated.
- Two new tape spring arms pace web designs are discussed.