

The Application of Miura Folding Concept in Solar Sail Membrane Deployment

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Abstract

Solar sail is a form of spacecraft propulsion using radiation pressure exerted by sunlight on large area membrane with extremely high reflectivity. With the advantage of no propellant cost combined with long operating lifetimes, solar sails can potentially be used in a variety of future space exploration missions. To achieve large thrust for continual acceleration in interstellar voyage, at least hundred-meter membrane with μm class thickness is needed. To deploy such large thin membrane in orbit, the fold and deploy method is one of the most important technology in solar sail engineering.

Miura-Origami is a very basic origami method, which is very similar with the leave unfolding pattern. By learning the Miura-origami analogy with the leave pattern, a 3-demention outward combined system which called a skew leaf-out folding pattern is put forward. This folding pattern is applied in designing the folding process of large-scale triangle sail membrane. Each triangle sail membrane was firstly folded with this skew leaf-out pattern, then wind on to the rotation coil in centre shaft. Most mission take the Z pattern to fold the membrane which release the full hypotenuse at the beginning, when the IKAROS take the horizon Z fold which release the hypotenuse at last by an unlock device with a big impact. By analysis compared with these Z fold patterns, the deploy procedure in our design is more uniform with the skew leaf-out folding pattern. Also numerical analysis is done in stress distribution, crease length and stability during deploying. Numerical analysis results are also used as a reference in design of solar sail deployment system.



Figure 1: Skew leaf-out folding pattern.

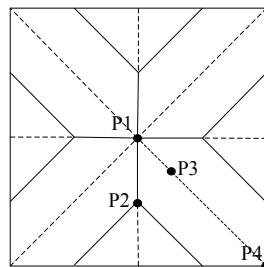


Figure 2: Picked points position.

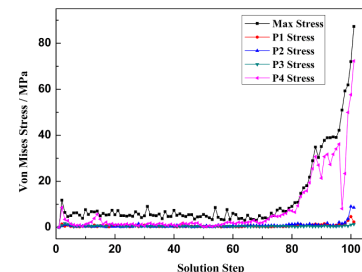


Figure 3: Stress curve.

The single sail deployment experiment without booms is done to verify the feasibility of the skew leaf-out pattern. The deploy speed under different driven load is studied, by loading four sets of weight. From the result we can tell that, only under 1kg load, the sail can't deploy

completely. Under 2.5kg, 2.0kg and 1.5 kg, the deploy time don't reflect obvious difference, the sail can complete the deploy procedure successfully. Under 2.5kg load the two right edges go first, then the parallel part of the sail deployed leading by the edges gradually, the whole process was symmetry. Also the deploy process was well-proportioned without serious accumulation, the deploy speed was also uniform.

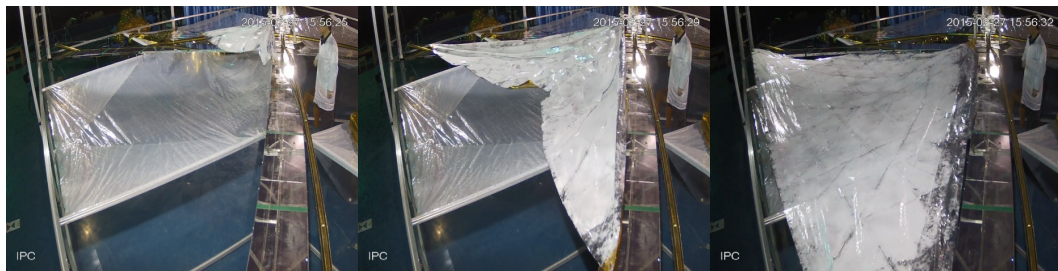


Figure 4: Deploy process under 2.5kg loads

Aiming at main belt asteroid exploration mission, a $160 \times 160\text{m}$ solar sail concept is proposed by CAST. The deployment system design is done based on previous analysis, also the structure and mechanism design of center shaft. In order to verify the folding procedure design, fold-deployment ground test of whole solar sail in skew leaf-out folding pattern is conducted on an $8 \times 8\text{m}$ principle prototype which the sail is driven by four inflatable booms. The full prototype deployment ground test shows that the sail deploys uniformly, the prototype operates well and the folding design can insure the sail deploy smoothly and synchronize leading by the inflatable booms.

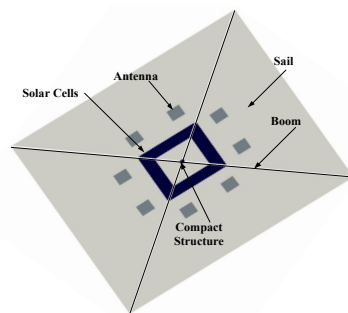


Figure 5: Solar sail configuration from CAST **Figure 6:** Prototype ground test preparation



Figure 7: Prototype ground test deployment experiment

From the ground tests, the skew leaf-out folding concept turn out to be a very potential application in solar sail deployment, which shows better reliability.