Near Earth Asteroid Scout Solar Sail Thrust and Torque Model

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Introduction

- A flat plate solar sail model suffices for early design studies
- In the past, NASA used optical coefficients derived in 1978
- The coefficients were reviewed and updated in 2014
- The review indicated that some additional optical tests would be beneficial
- During 2015 detailed structural models of the sail shape became available
- The structural models enabled detailed Attitude Control System design

Optical Model Review

- Standard NASA Optical Coefficients updated in 2014

Coefficient	$\tilde{r}$	s	B_f	B_b	e_f	e_b
Value	0.91	0.94	0.79	0.67	0.025	0.27

Specular fraction coefficient
based on pristine sail material

Wrinkled sail material may not be as specular

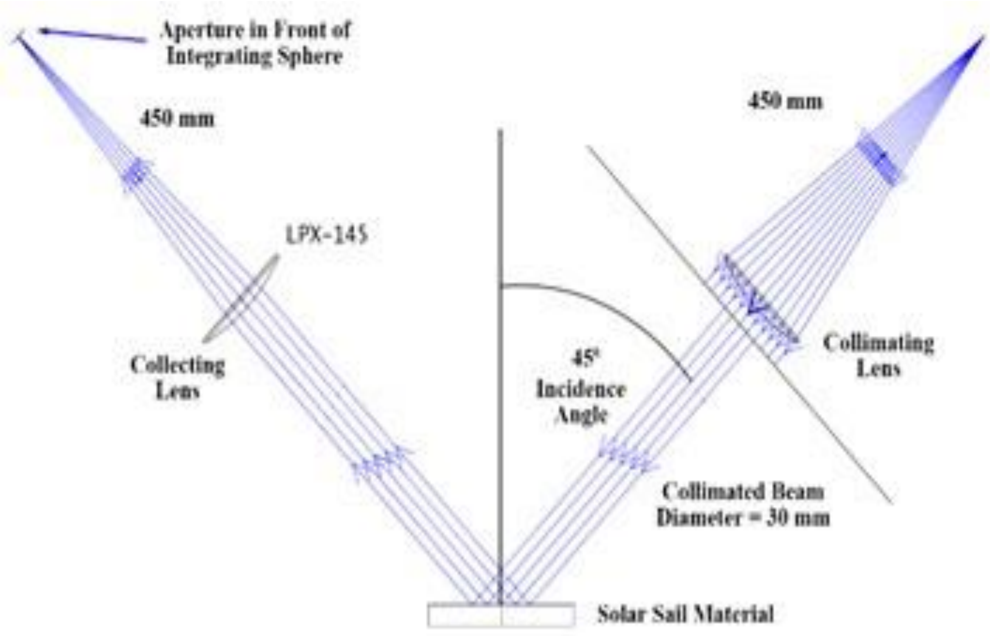
Testing of wrinkled material has been limited in past

Optical Test of Wrinkled Material

A Bi-directional Reflectance Distribution (BRDF) generally is used to determine how specular a reflection is from a given material

However, this test will only determine specular behavior at a microscopic (~ micrometer) level of wrinkles

Specular reflection is defined for this case as light inside a reflected cone of 10 deg

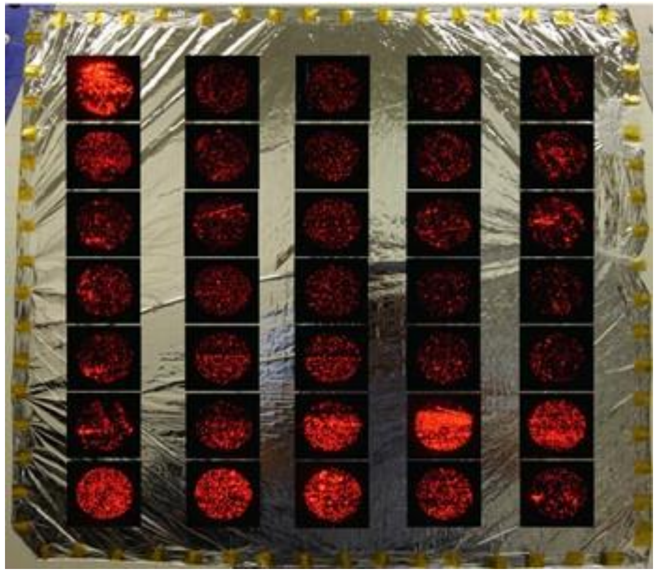


A test was designed to attempt to determine "areal specular behavior"

To do so, a laser was spread into a beam that illuminated areas of ~ 10 cm^2

Light is then collected at different cone angles after being reflected

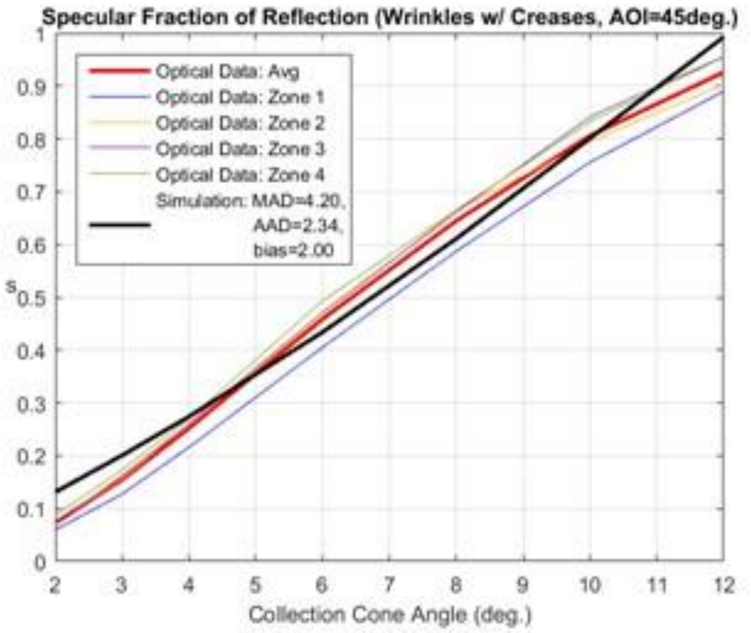
Areal Specular Test



Test regions of 10 cm^2 can be seen to in this photo prior without reflection (they are backlit)

In this photo, the light is shown after reflection

Areal Specular Test Results



By test and analysis, we determined that wrinkles at level of millimeters affect areal specular behavior

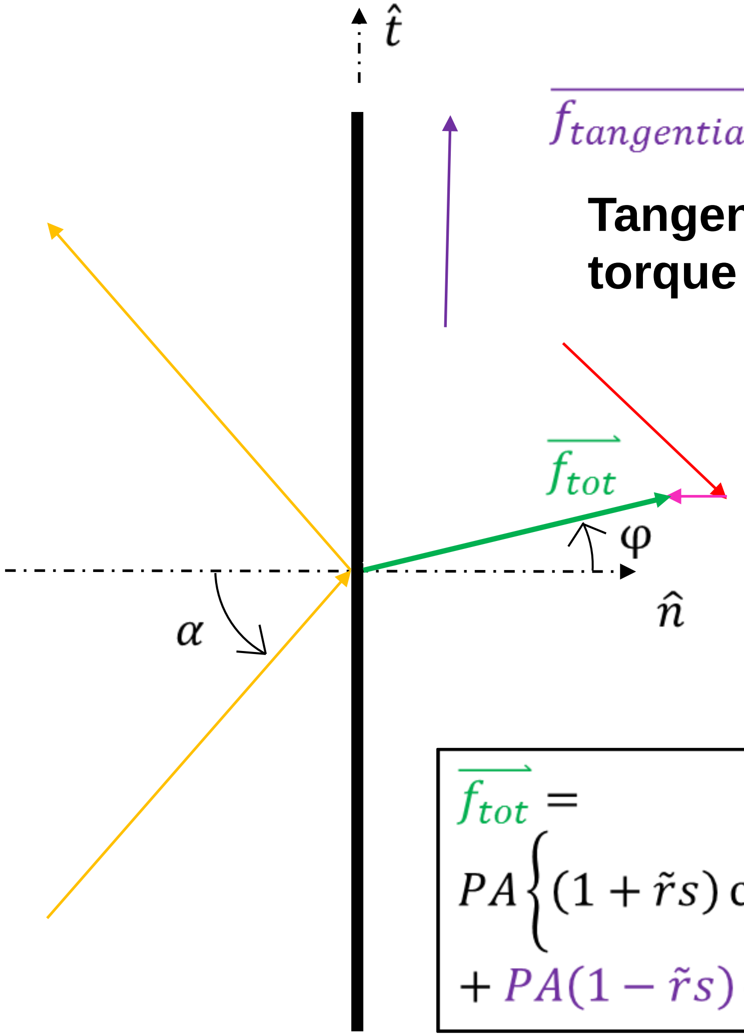
We created an analytical model of wrinkles that included an angular bias and Gaussian noise misalignment for each FEM element

The analytical model matched the test results reasonably well

Thus, ~ millimeter level wrinkles can be considered to increase diffusivity of the material (i.e. reduce specular behavior)

One-sigma decrease in fraction of specular reflection is 0.05 (so s = 0.89)

Specular Behavior Effect on Solar Torque



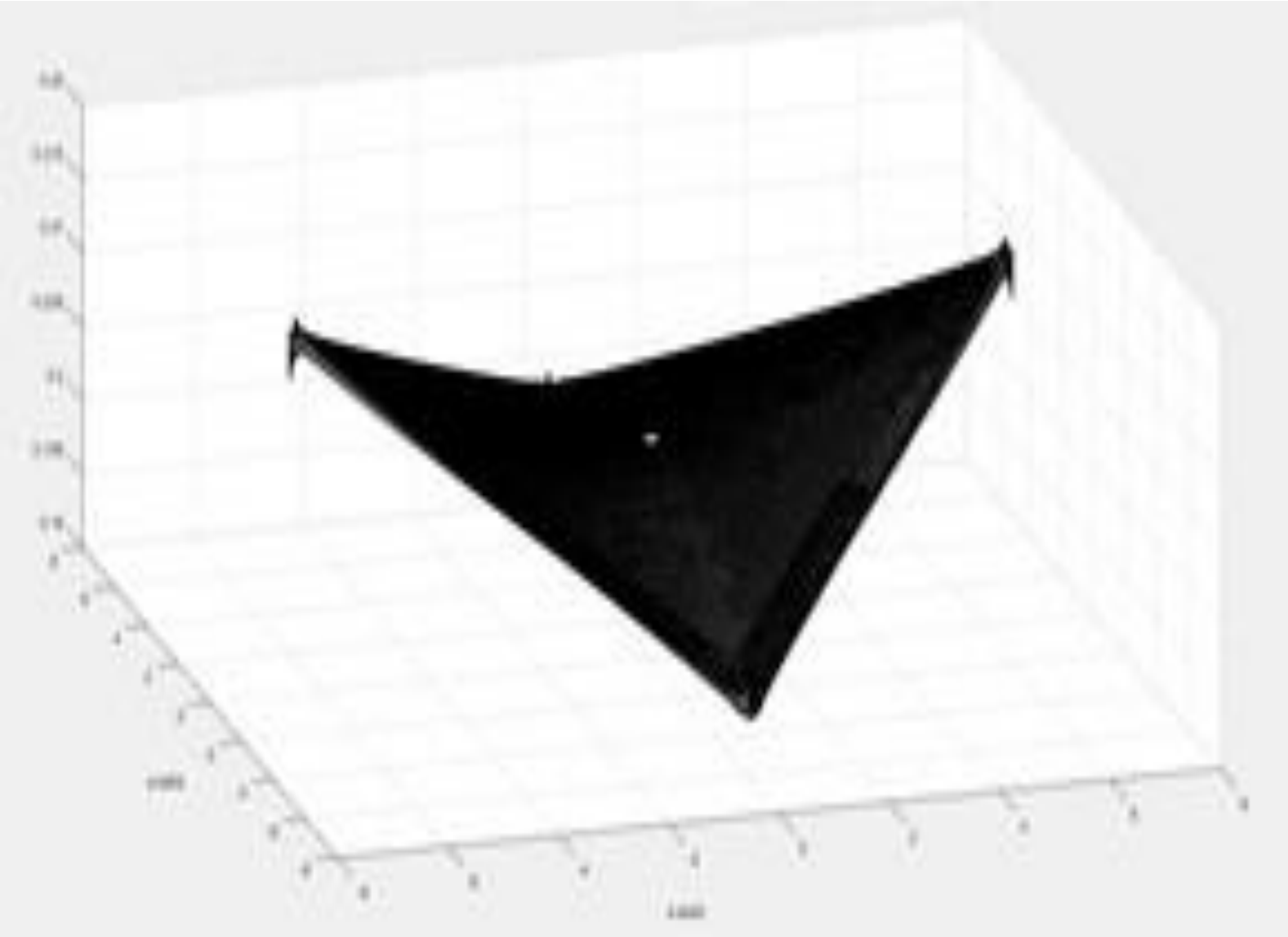
Tangential force is primary driver of solar torque

$$\alpha = Sun\ Incidence\ Angle$$

$$\varphi = Center\ Line\ Angle\ (Thrust\ Angle)$$

$$\overrightarrow{f_{tot}} = PA\left\{(1+\tilde{r}s)\cos^2\alpha + B_f(1-s)\tilde{r}\cos\alpha + (1-\tilde{r})\frac{\varepsilon_f B_f - \varepsilon_b B_b}{\varepsilon_f + \varepsilon_b}\cos\alpha\right\}\hat{\boldsymbol{n}} + PA(1-\tilde{r}s)\cos\alpha\sin\alpha\,\hat{\boldsymbol{t}}$$

Three Dimensional Sail Model

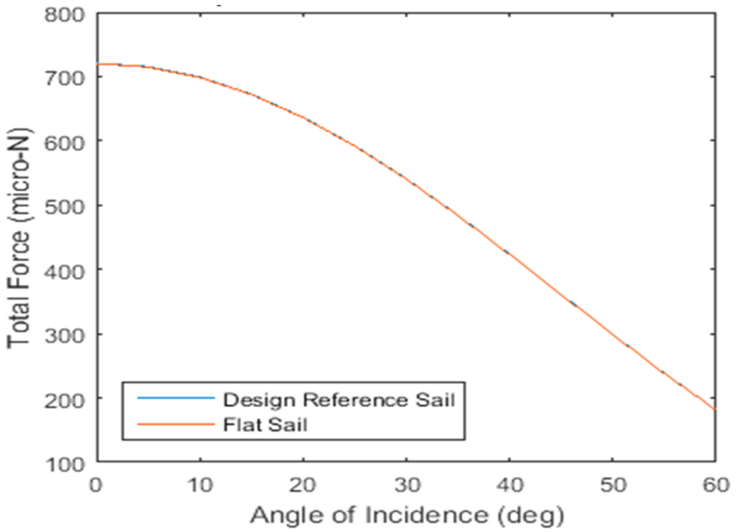


LaRC created a ~66,000 element FEM in Abacus that includes realistic tension and thermal effects

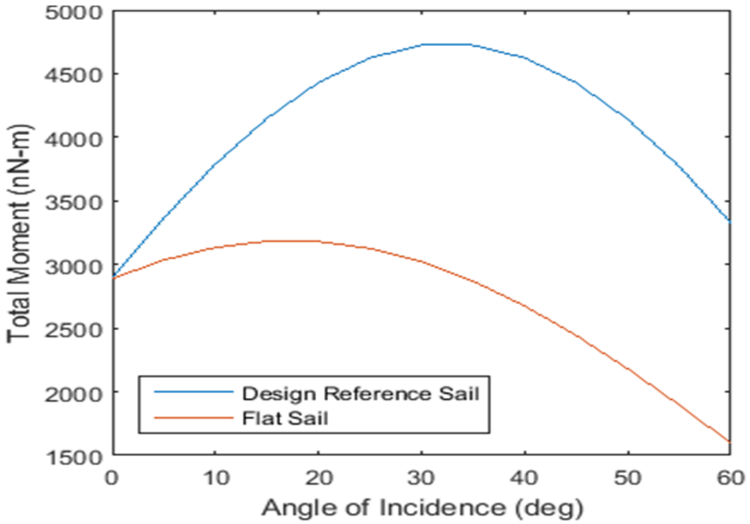
We used the GSM developed by U. of Michigan to reduce this model to 84 coefficients

CPU savings are considerable

Sail Thrust and Torque



Sail thrust magnitude is not affected much by shape



Sail torque is strongly affected by shape

Sail torque is important to ACS design

Conclusions and Forward Work

Conclusions

- The effect of ~ millimeter scale wrinkles can be modeled as a global decrease in specular behavior
- For NEA Scout, shape has an important effect on torque but not on thrust magnitude

Future Work

- Continue to refine results of optical testing
- Carefully select off-nominal thrust/torque cases for study given resource limitations