Reflectivity Control Device (RCD) Roll Momentum Management for Solar Cruiser and Beyond

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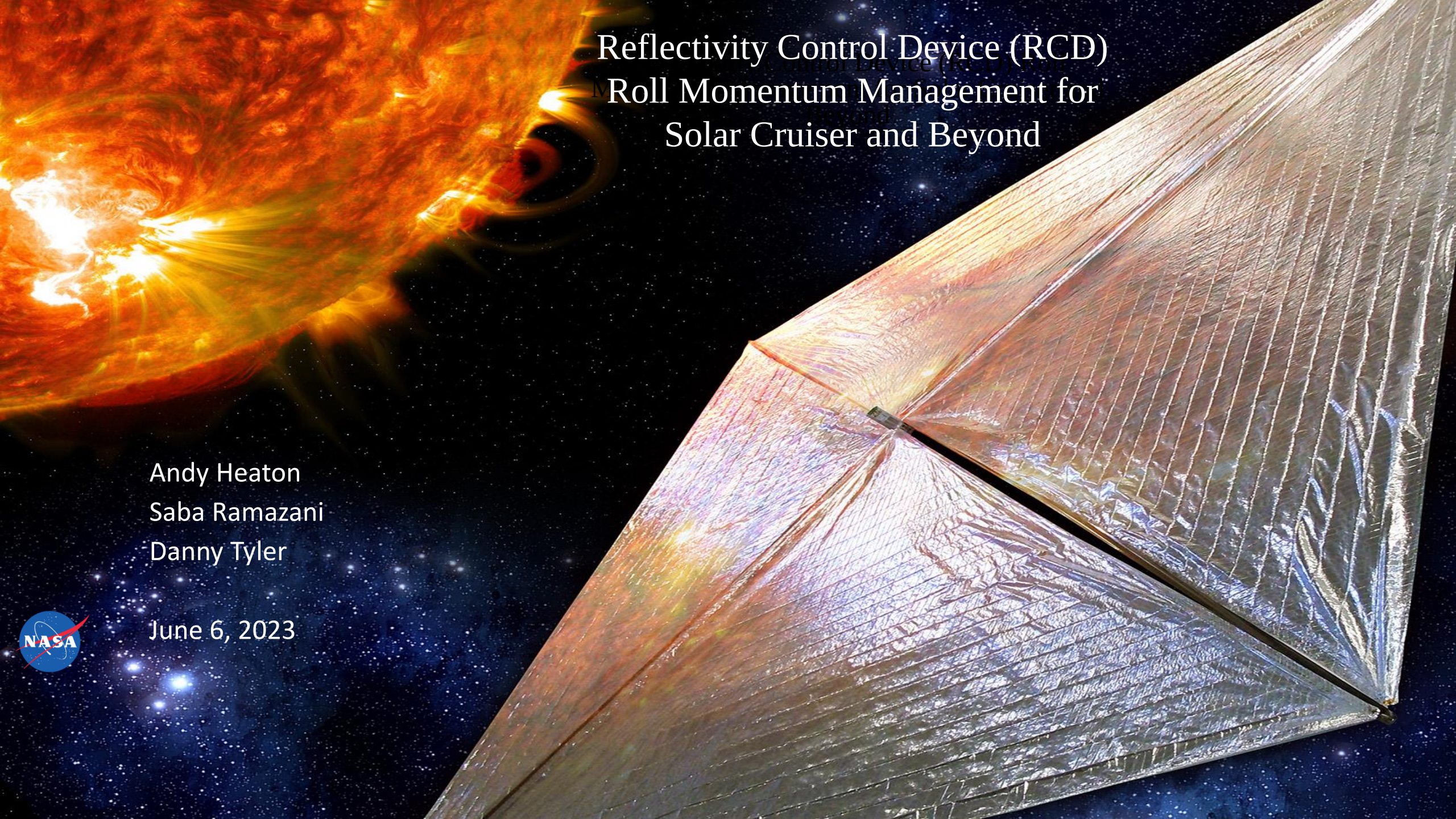


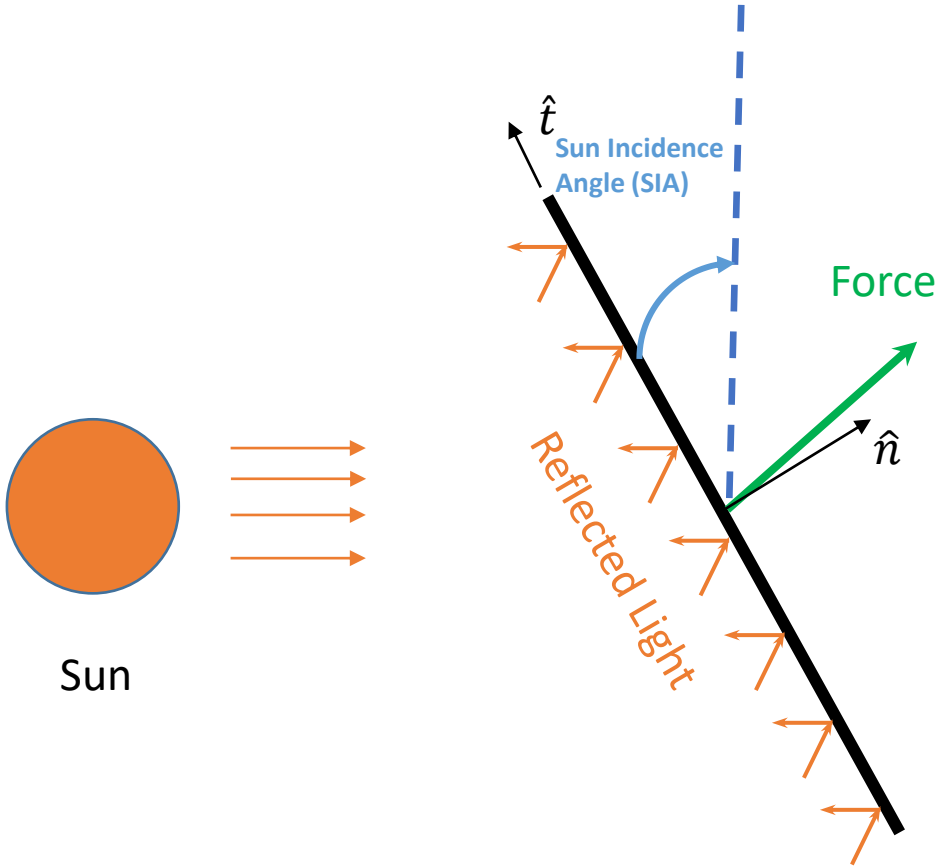
Reflectivity Control Devices (RCDs)

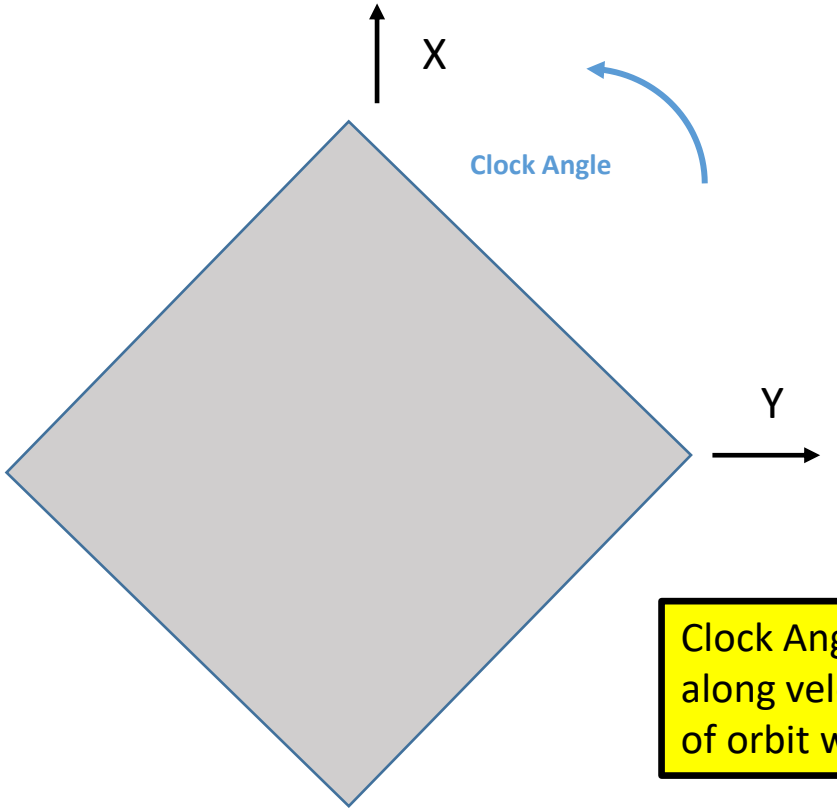
- Reflectivity Control Devices are thin film membranes that can change reflective properties when a voltage is applied to them
- They essentially consist of sail material layers with a Polymer-Dispersed Liquid Crystal Diode (PLCD) layer in between
- They also include a layer to enable application of the voltage
- They are intended to be used for control of solar sails
- RCDs flew successfully on the JAXA IKAROS in 2010

RCD Control of a Solar Sail

- The RCD can be placed near the tip of a solar sail boom for optimal moment arm
- For solar cruiser, we intend to use them for Roll control (axis normal to sail) only, thus they are canted wrt to the sail surface
- Initially the top and bottom layers of the sail were intended to be clear, but analysis showed a reflective bottom layer was more efficient at providing Roll torque

Solar Sail Angle Definitions





Clock Angle 0 is Y axis along velocity vector of orbit wrt the sun

RCD Force Model

$$P_s = (1 - T_s - R_s)\hat{s}$$

$$P_n = (2R_s(\hat{n} \cdot \hat{s}) + R_d C_{Rd} - T_d C_{Td})\hat{n}$$

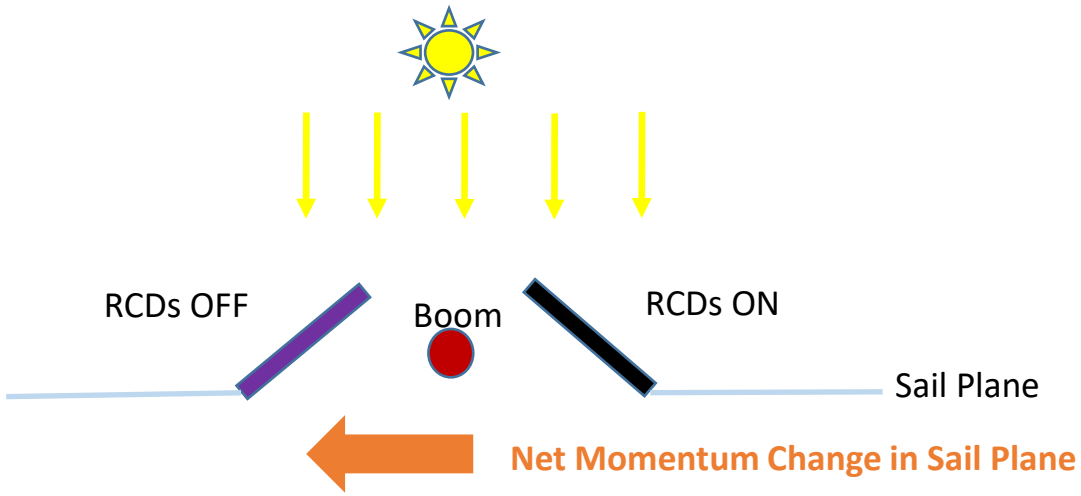
$$P_{sail} = P_0(P_s + P_n)$$

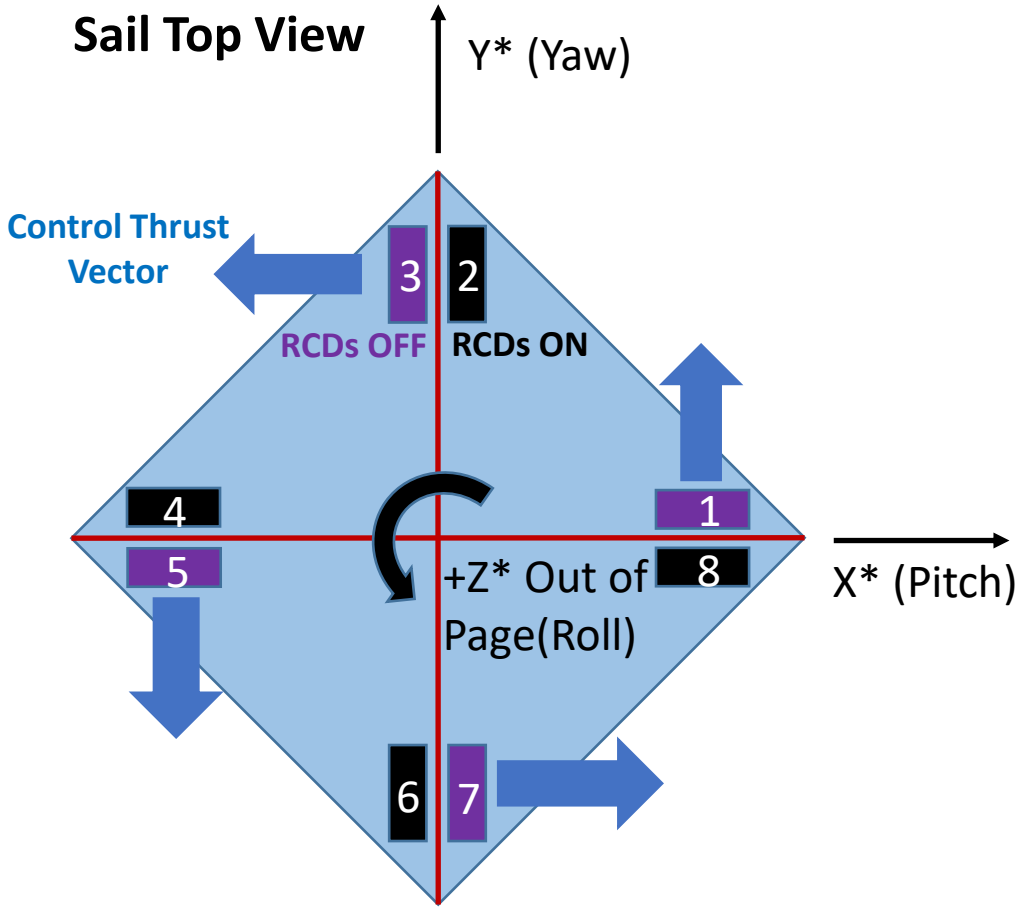
$F = P_{SRP} A(\hat{n} \cdot \hat{s}) P_{sail}$: force on RCD in RCD frame

BRDF Variable Coefficient Model:

- Provides reflection coefficients (R_S, R_d, B_f) as a function of AOI on RCD
- Coefficients change between off and on state, thus providing differential torque between RCDs in differing states

RCD Array Configuration



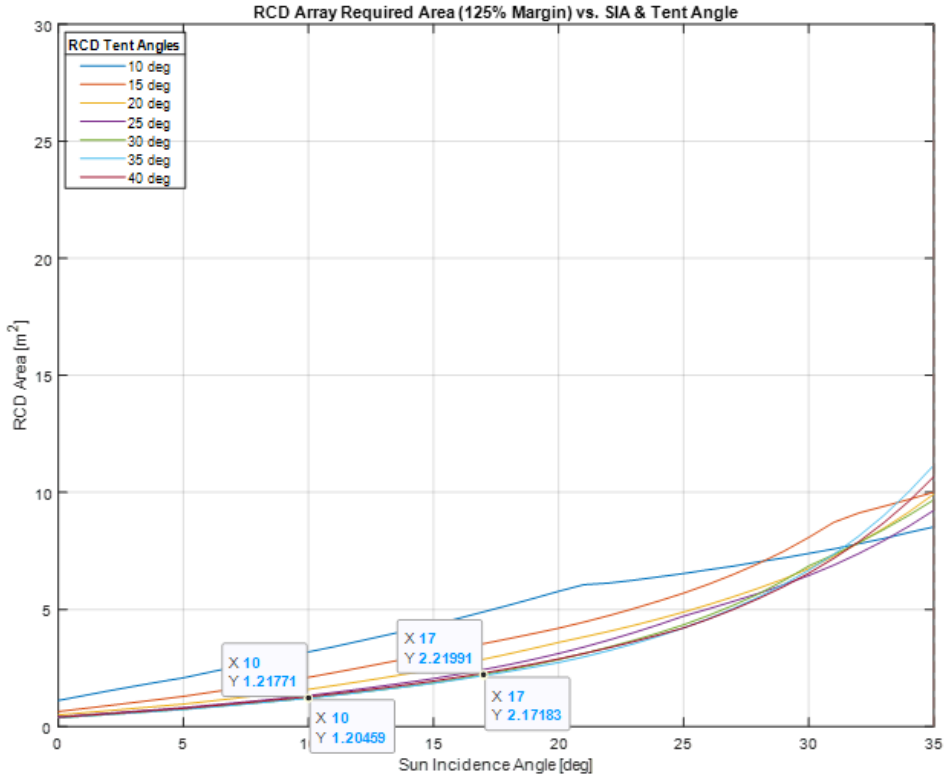


2 States: Clockwise and Counter Clockwise

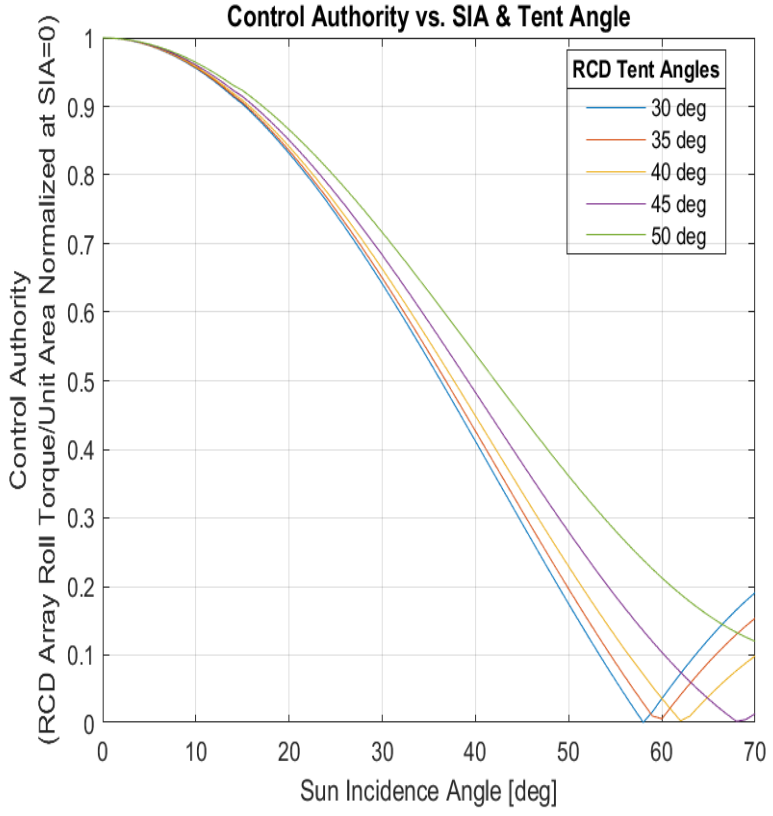
* Sail coordinate system (+Z in sail coordinates is +X in spacecraft coordinates)

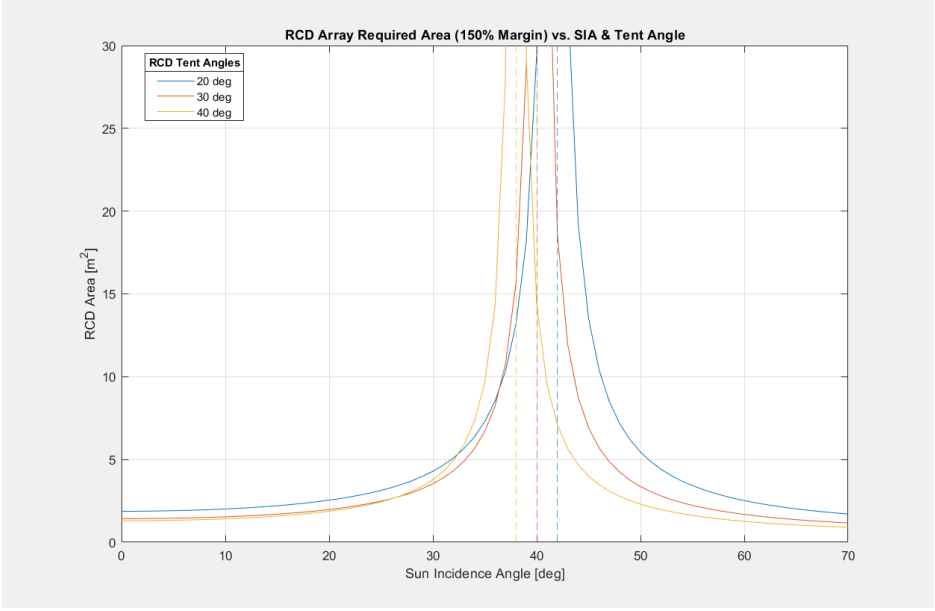
RCD Development for Solar Cruiser

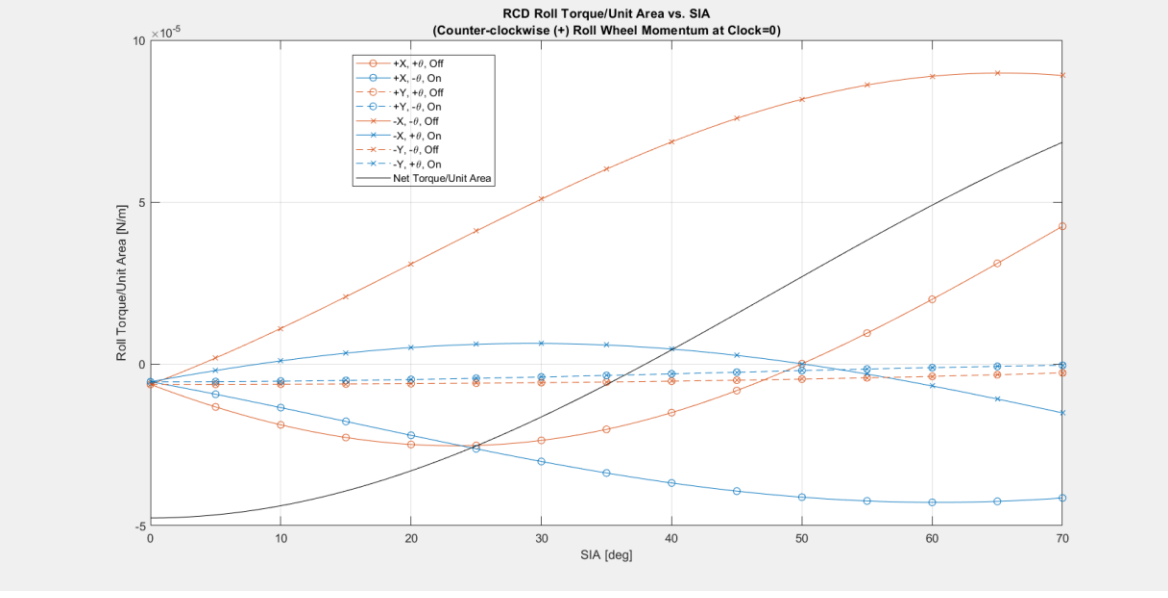
- Development of the RCDs was led by NEXOLVE
- Roll torque requirement is 2.96e-5 Nm
- RCDs designed for control at 17 deg Sun Incidence Angle (SIA)



RCD Loss of Control Authority at High SIA





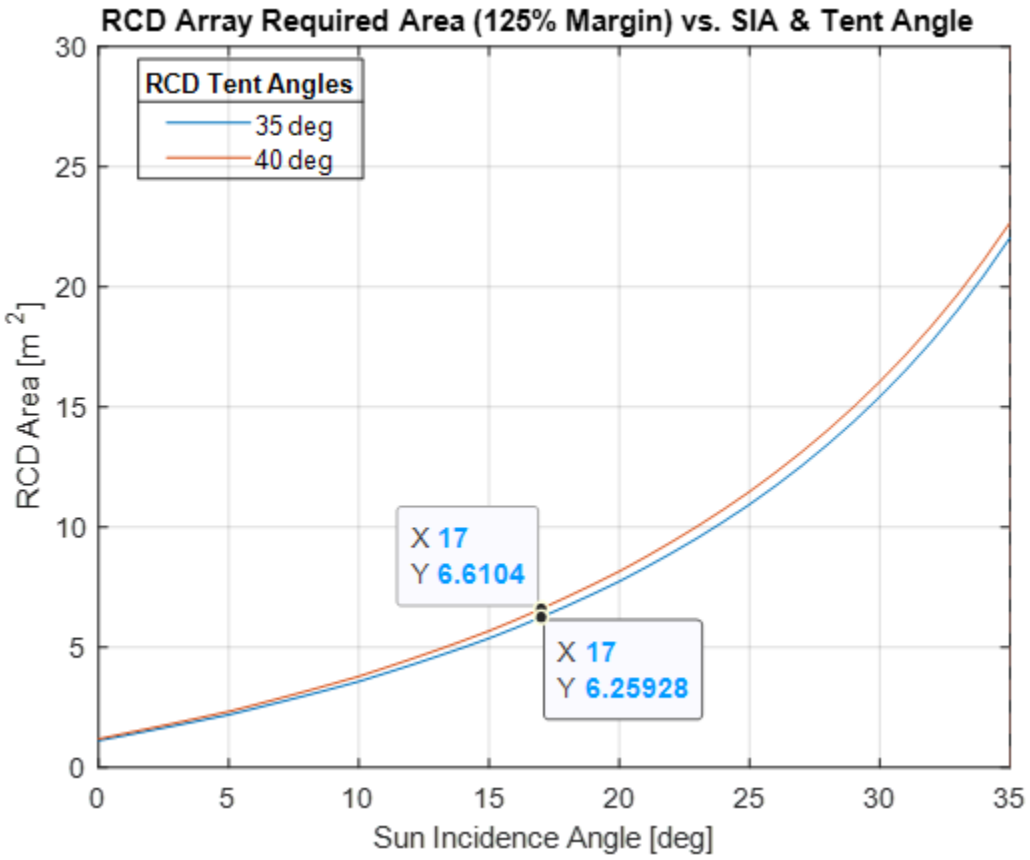


Trades for Solar Cruiser RCDs

- The following parameters were primary drivers in the trade space:
  - Area of RCDs
  - Tent angle (angle wrt to sail normal surface)
  - Voltage applied to RCDs
  - Thickness of material (i.e., mass of RCDs)
- RCDs also designed with 125% margin
- We also traded control logic to attempt to avoid bad combinations of SIA and Clock but were largely unsuccessful

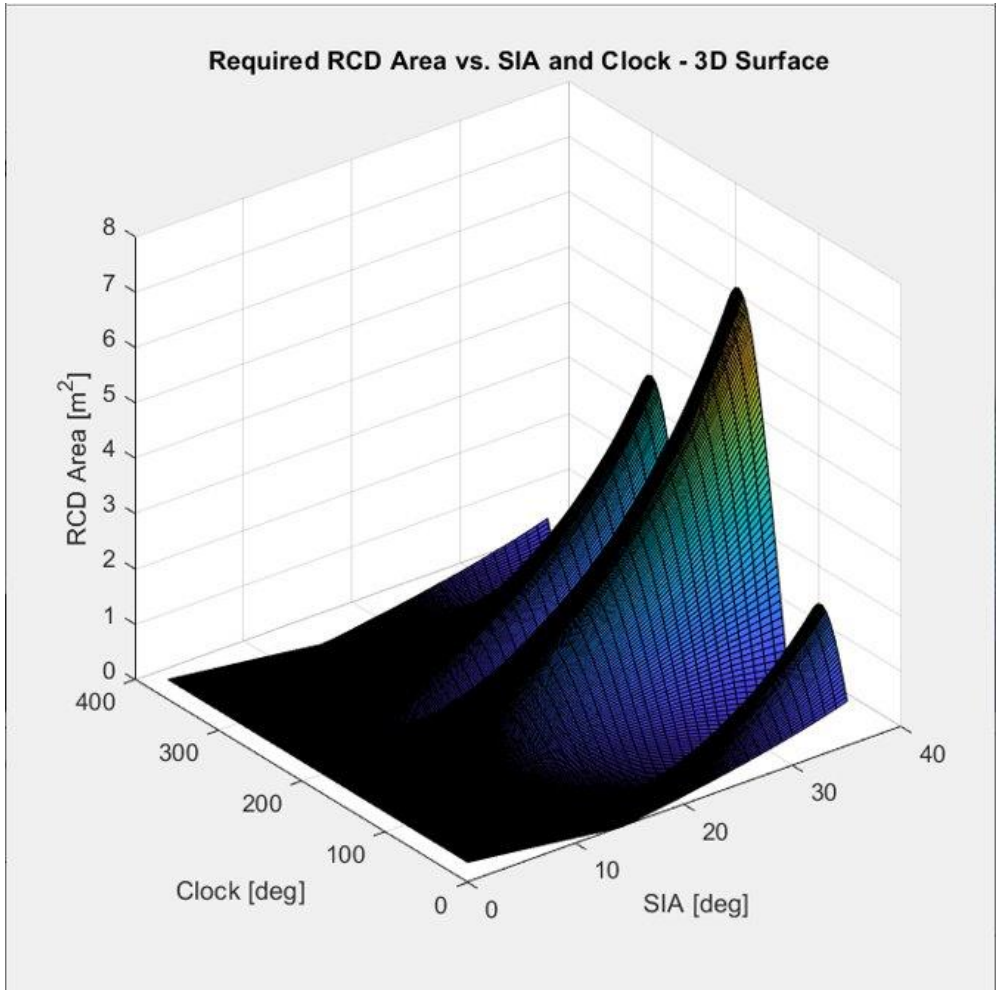
RCD Development Progress

- We obtained results that closed the design space



Additional RCD Development Results

We can predict performance over an arbitrary range of operational attitudes



RCDs Trade Well vs. Other Actuators

- Magnetic Torque rods do not work in deep space
- Moving masses require moving parts and weigh more
- Power requirements for RCDs are relatively modest compared to other actuators
- RCDs have much lower mass than other actuators

Conclusions and Future Work

- We have made great progress in developing RCDs for use on Solar Cruiser and other future solar sail missions
- Work remains to further develop RCDs to survive in the harsh space environment, but progress has been made in this area as well
- For Solar Cruiser and future solar sail missions, RCDs offer great promise as low mass and reasonable power requirements trade well compared to other Attitude Control System (ACS) solutions, particularly for Roll control