National Aeronautics and Space Administration

# G. Capture Mechanism and Capture Process

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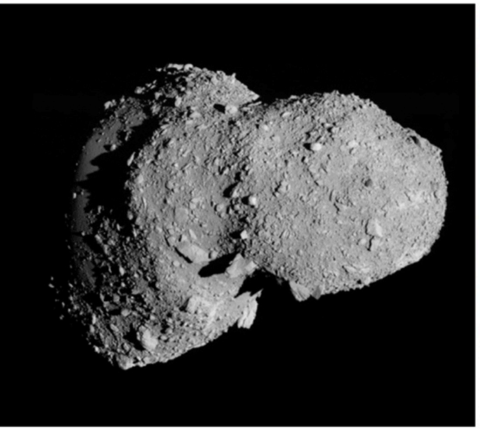
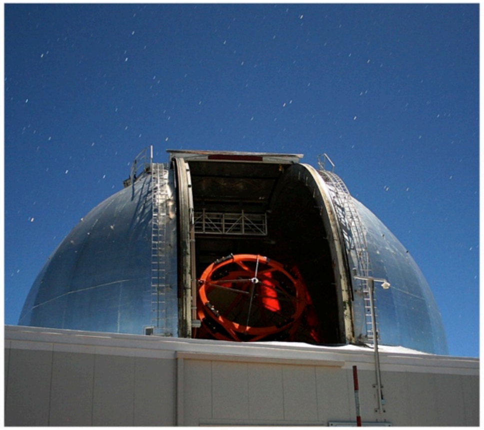



# Capture Mechanism Executive Summary

- Capture implementation is dominated by spin state of target. At low spin-rates (< 0.2 rpm) about all axes the problem is straight forward
  - Forces are small and accelerations reflected back into the spacecraft are < 0.1 g
- ARRM is working to solve the case (at the limit of known objects) of up to ~2 RPM to show robustness
  - Passive and active capture strategies have been studied
  - Two approaches have been identified that appear to meet force limits
  - Strategy is to match spin; quickly inflate air bags to "lock" asteroid to the spacecraft at low contact pressure; force-controlled winches gather and deflate fabric and position center-of-mass; detumble and despin using RCS thrusters
- Uses non-rigidized inflatable capture bag
  - Deals effectively with range of target uncertainties in composition, strength and spin state
  - Can be verified and validated in Earth gravity
- Received industry inputs on concepts and costs that are consistent with concept presented here

# Key Characteristics of Asteroid for Capture

## Composition/Strength

- Rock (>>1PSI)
- Dirt Clod (~1PSI)
- Rubble Pile(<<1PSI)

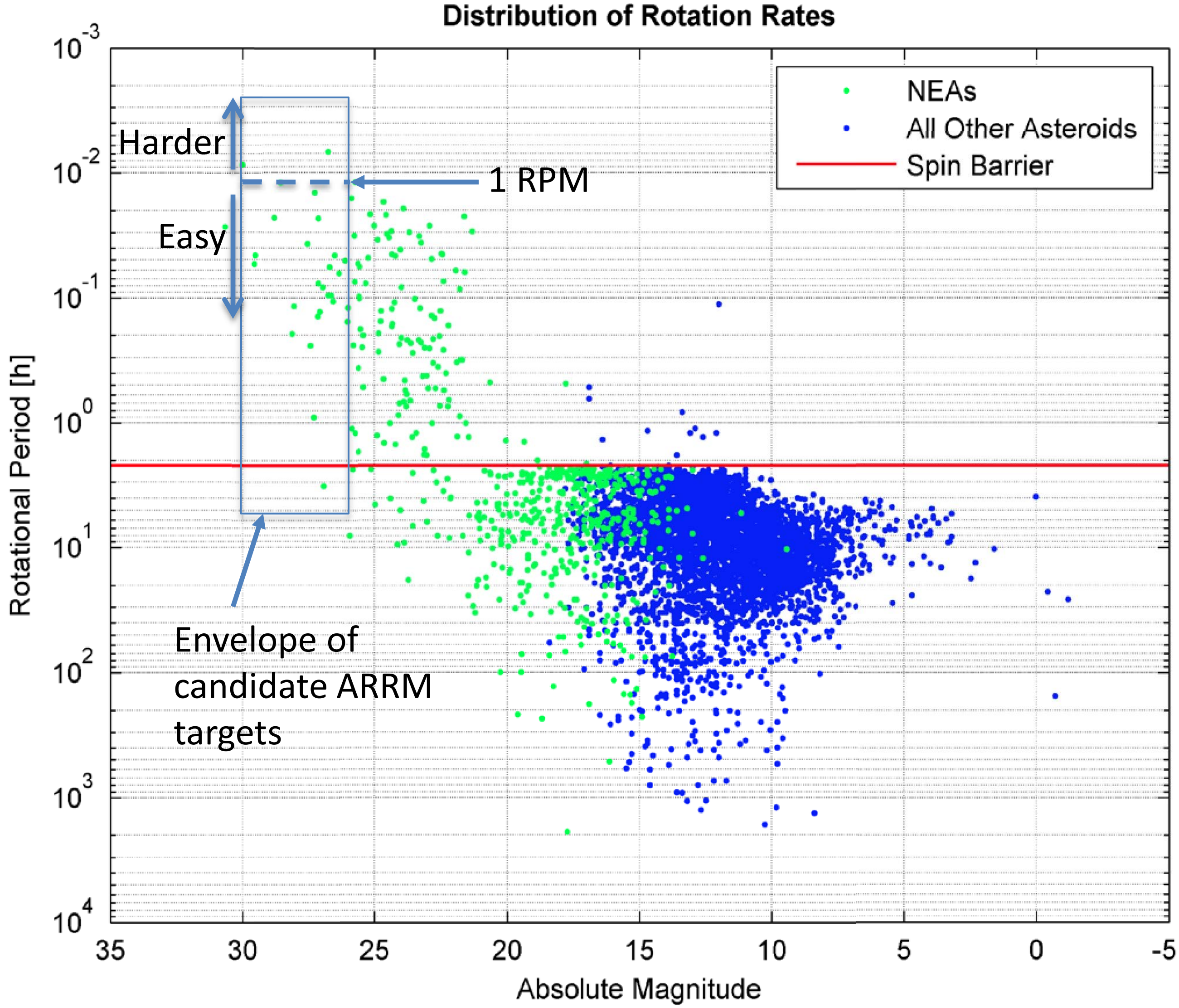
## Spin State

- Slow (<<1RPM), Simple Spin
- Slow (<<1RPM), Tumbling
- Fast (~>1RPM), Simple Spin
- Fast (~>1RPM), Tumbling

- For capture, the primary concerns are composition/strength and spin state
- Have been evaluating passive and active control options that limit forces on the spacecraft/solar arrays to <0.1 g peak for the fast/tumbling state

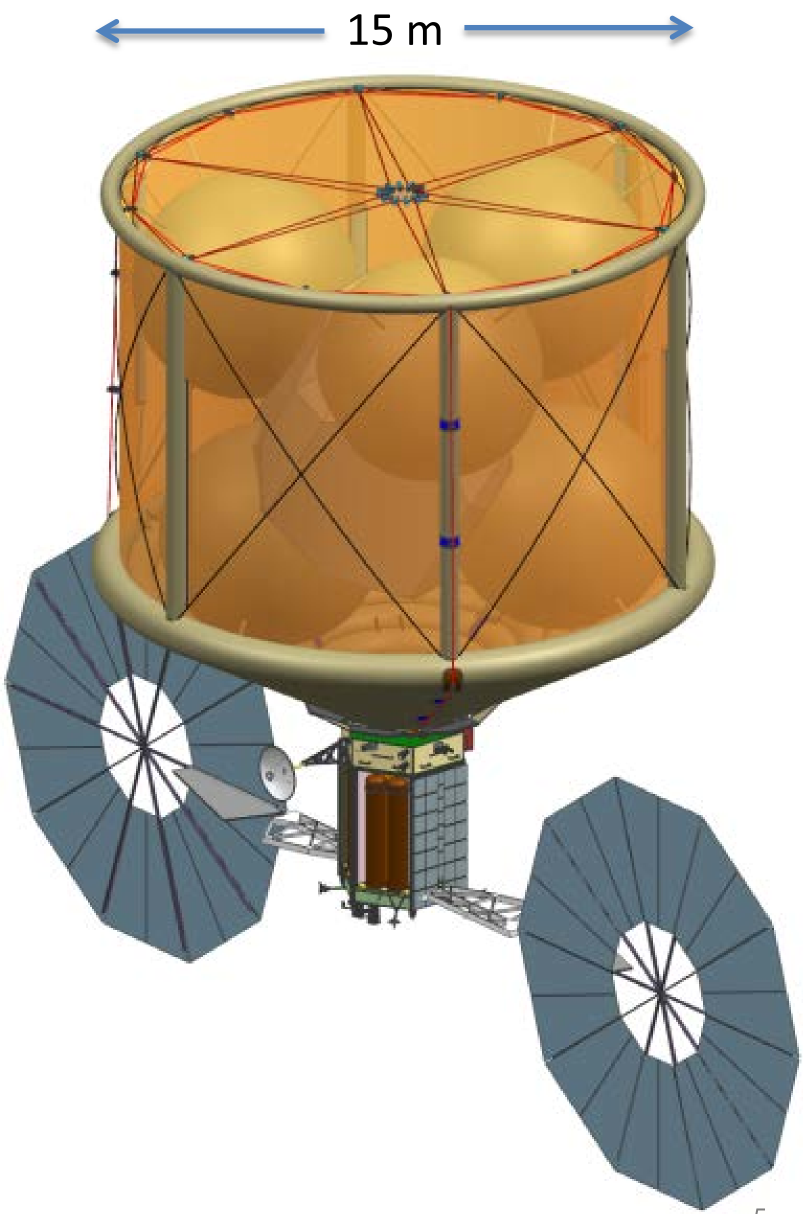
# Spin Periods of Near-Earth Asteroids

- Many small NEAs spin faster than the rubble pile spin barrier, but may be "dirt clods"
- Worst case assumed to be 5-13 m diameter NEA with a spin rate of 2 RPM and tumbling

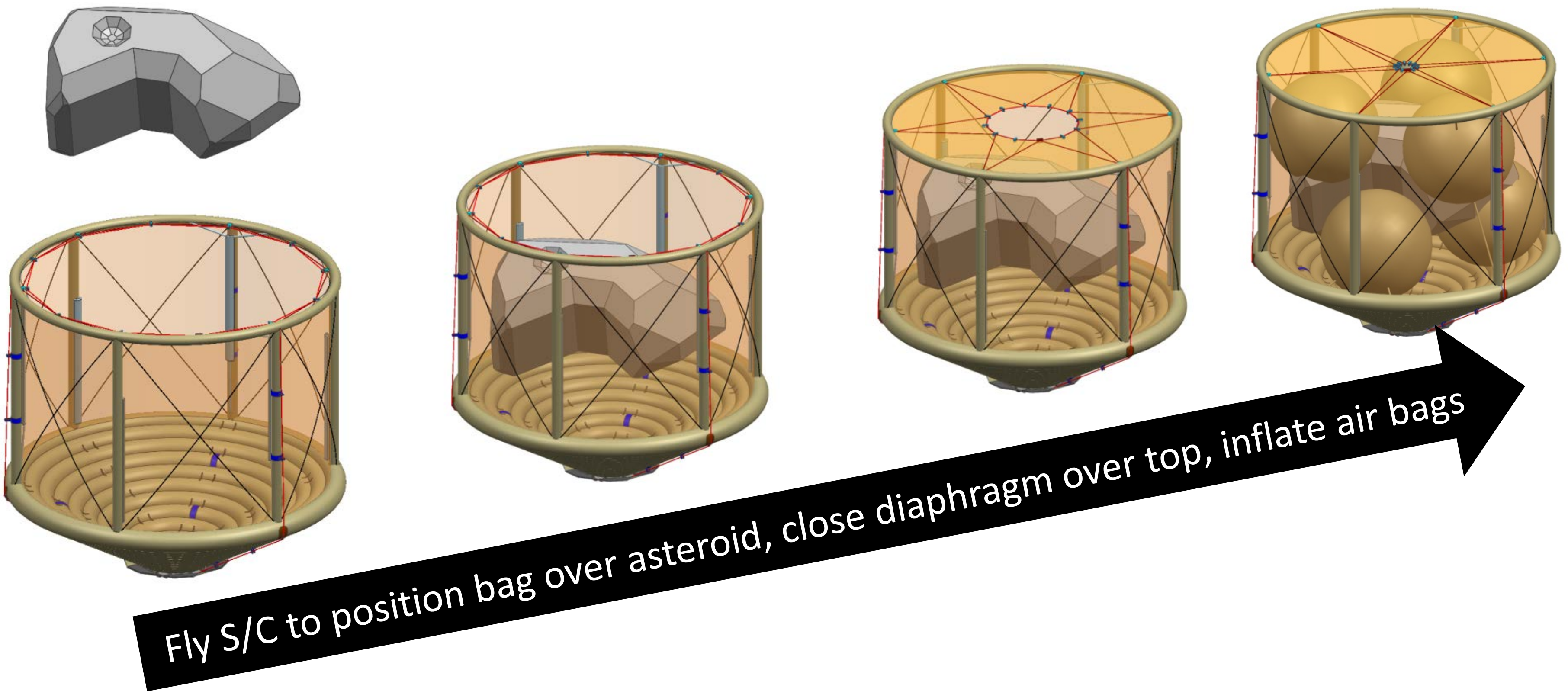


# Capture Mechanism Concept

- Capture bag formed of cylindrical barrel section and conical section attached to S/C
- Inflatable exoskeleton to deploy bag after arrival at asteroid
- Inflatable "stack of torroids" at base of cone to form passive cushion between asteroid and S/C
- Circumferential cinch winches close diaphragm at top of cylindrical section; confine asteroid after deflation
- Air bags quickly immobilize bag in asteroid frame at very low contact pressure (<<1 PSI)
- Axial cinch winches control motion, retrack bag, and position asteroid center-of-mass.



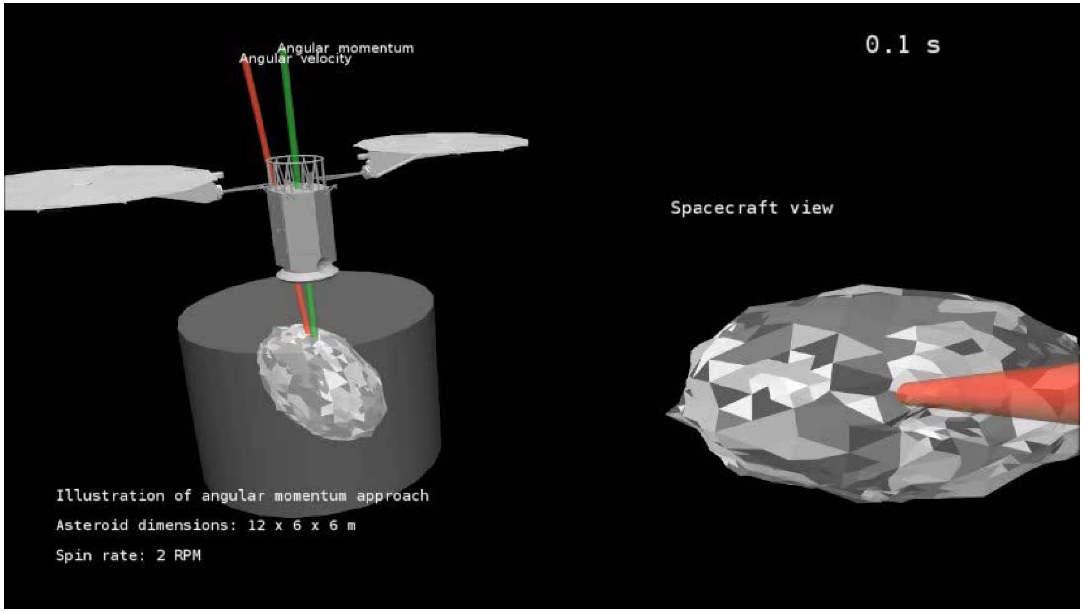
# Capture Sequence




- Spacecraft approaches and matches spin along projected asteroid spin vector a short time in the future.
- When asteroid is centered in the bag, close top diaphragm, and at the moment spin is matched, inflate air bags w/pressure <<1 PSI to limit loads on surface of asteroid, achieving controlled capture quickly; cinch asteroid tight to S/C while venting.
- Mechanism provides elasticity to control loads to solar arrays.

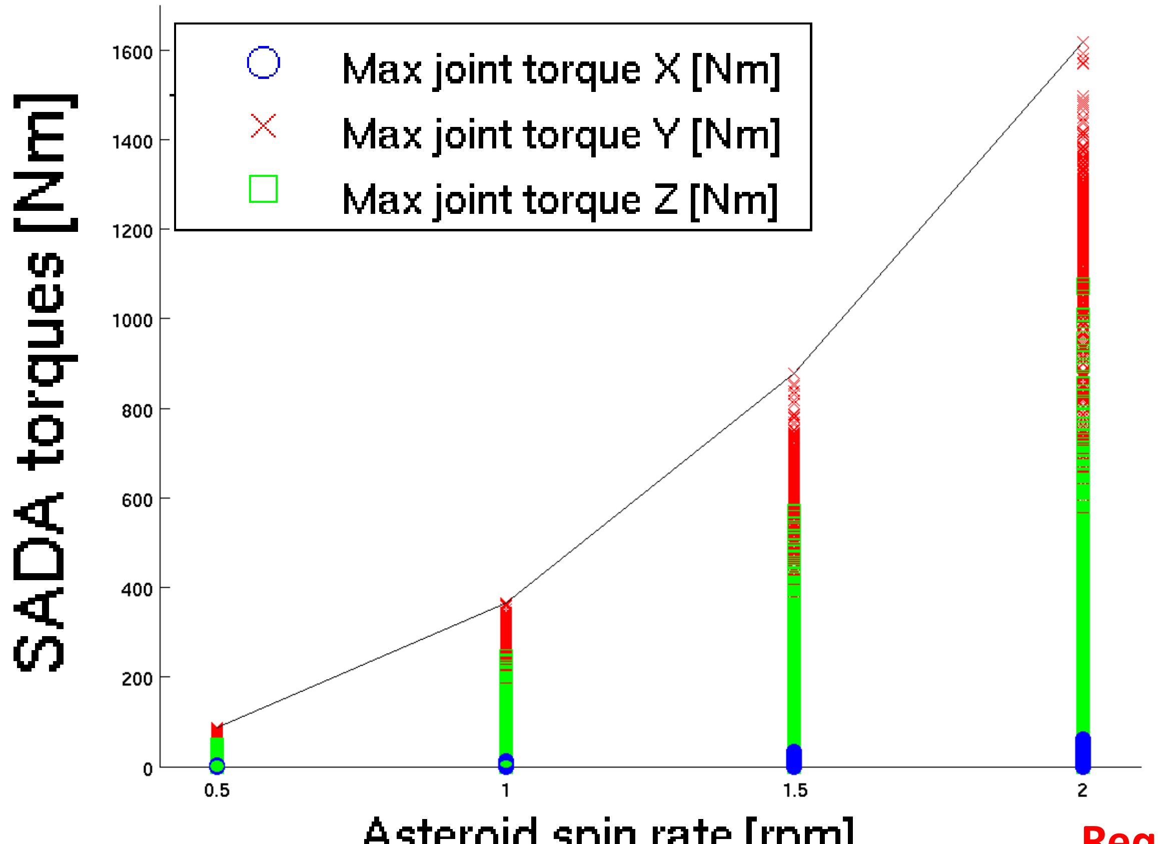
# Passive Capture, Matched Instantaneous Spin Vector

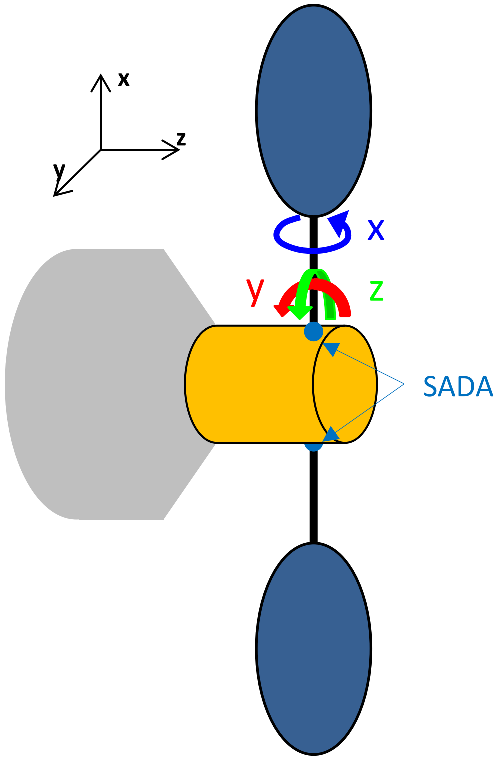
- Asteroid inertial and spin properties determined by observation and state accurately projected into the future by many minutes to hours
- Asteroid instantaneous spin vector circulates around angular momentum vector
- Spinning S/C approaches along projected instantaneous spin vector and grabs when vector matches S/C location to minimize bag scuffing



# Monte Carlo Simulation Results

- 5,472 samples (4 spin rates, 36 shapes, and 38 fully nutated states)
- Grab uses optimized generalized 6-DOF spring-loaded joint
- Spring parameters are derived from an optimization within the base-line toroidal isolation device design constraints




**Requirement: ≤1,765 Nm**

# Capture Testbed

- Questions that will be answered by scale model and full scale testing (not likely answerable by physics-based simulation) include:
  - Cinch cords behavior and control of bag fabric, demonstrating full closure of the bag?
  - Characterizing snagging of the bag by the asteroid, forces on the bag, and general control of the bag
  - Determining the best cinching and GN&C algorithms to manage the asteroid motion in the bag

- Initial 1/8 scale capture testbed has inflatable exoskeleton with winches suspended from gantry over asteroid on end of 8-DOF robot arm that can spin and tumble the asteroid in the S/C (lab) reference frame.

# Summary and Conclusions

- Continuing to explore options to capture asteroid under a wide range of initial conditions while limiting forces on the spacecraft
  - Inflatable exoskeleton deploys fabric capture bag; air bags inflate at the moment of capture to "lock on" when the spacecraft spin matches that of asteroid.
- Have evaluated two classes of capture using separate strategies and models: passive and active
- Two passive approaches appear to meet constraints
  - Match primary spin rate and let flexibility of bag mechanism accommodate capture forces of other axes, works up to 1 rpm transverse rate
  - Match instantaneous spin vector and initiate capture at moment instantaneous relative spin rates are ~ zero, works for up to 2 rpm
- Monte Carlo simulations starting to be applied for wide range of asteroid inertial, spin and tumble states and indication are that asteroids can be safely captured at ~2 rpm