# Capturing Non-Cooperative Objects

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# Capturing Non-Cooperative Objects

- Literature
- Spin State
- Modeling
- Grappling
- De-spinning
- Attachment for thrusting

# Non-Cooperative Grappling Literature

- Many have addressed capture of non-cooperative objects in the context of orbital debris removal.
- "Catcher's Mitt" study by DARPA (2010):
  - "*Large object removal generally employs advanced rendezvous and proximity (RPO) operations and sophisticated grappling techniques (other methods of capturing large objects were also proposed: net, inflatable longeron, tethered harpoon, articulated tether/lasso, and electrostatic/adhesive blanket). The significant challenge of grappling a large debris object is further complicated if the object is tumbling…*"
  - *"However, the following positive attributes of articulated arm mechanisms were identified:*
    - *Multi-link robotic arms are the most common and mature means to grapple for servicing satellites or ISS modules, and for docking and assembly; and*
    - *Viable approaches exist for grappling cooperative and non-cooperative (including tumbling) debris in close proximity."*
- European Study (Cranfield Space Research Centre, 2010): *"Grappling and docking mechanism: challenging task for un-cooperative object of unknown condition (fragile?) and state (tumbling?). Autonomy is assumed (but not yet proven)"*

# Tumbling, or just Spinning?

- "Tumbling Asteroids" by Alan W. Harris (JPL, at the time), Icarus, 1993 (http://trs-new.jpl.nasa.gov/dspace/ bitstream/2014/32558/1/94-0304.pdf) says time constant of damping of rotation to align with principal axis is inverse with angular velocity cubed and radius squared. NEA Toutatis (r~2km), a slow-rotator (~7.5 day) is estimated to have damping time constant ~$1.5 \times 10^{12}$ years.
- Under these assumptions, a ~1 m asteroid could have a spin period as slow as 10 minutes and still have a damping time constant as long as the age of the solar system. Small objects have collisional lifetimes much less than the age of the solar system.

# Spin Periods of Near-Earth Asteroids

- Many small NEAs are spinning too fast to be Rubble Piles; no regolith?
- For few-m radius, we need to plan for spin periods of as low as minutes.
- Expect tumbling.
- Figure from "The Rotation Rate Distribution of Small Near-Earth Asteroids" by Desireé Costo Figueroa, Master's Thesis, Ohio University, Nov. 2008.

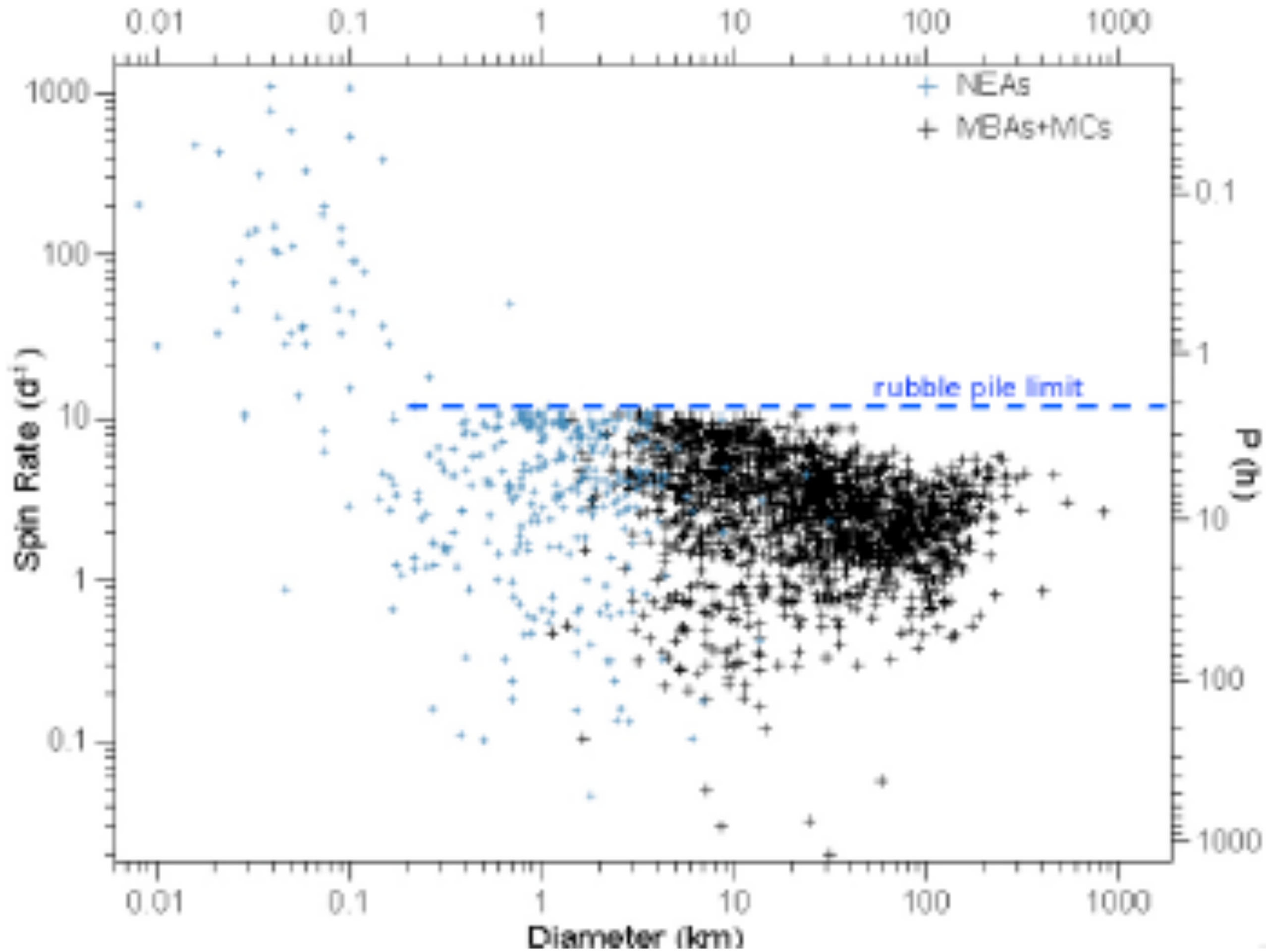



Figure 1.4: The Rotation Rate Distribution for Solar System Bodies. Upper and lower scale indicate approximate diameters. The vertical scale on the right indicates the period in hours. The blue crosses are data from NEAs and the dashed black crosses are data from main-belt asteroids and some main-belt comets. The blue dashed line indicates the rubble pile limit. Modified from Pravec and Harris (2007b).

# Grappling a Spinning Object

- Telerobot Testbed demonstration of grappling a free-spinning gimbaled satellite (1987).
- Demonstrates key ingredients of tracking, synchronized motion, and attachment with compliant grasp.

# Physics of Stopping a Spinning NEA

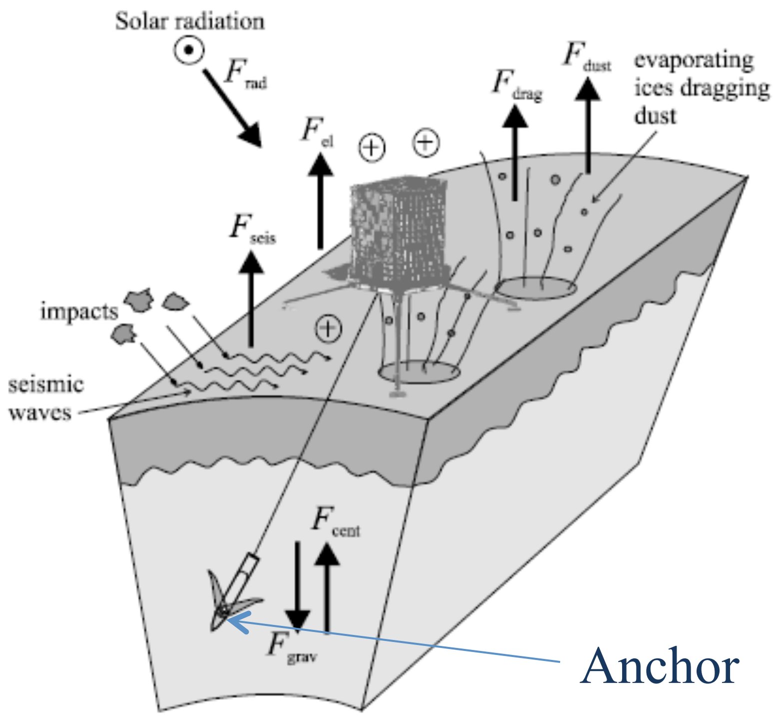
- Using SEP to stop a spinning NEA is simple if it can be grappled effectively.
- A 30 kW SEP system can stop a NEA w/ 2-m radius & 10-minute spin period in 1 revolution.

| | | |
|---|---|---|
| Earth's gravity | 9.81 | m/s2 |
| Gravitational contant | 6.67E-11 | MKS units |
| Solar flux at 1 AU | 1350 | W/m2 |
| density of asteroid | 2500 | kg/m3 |
| spin period | 0.16666667 | hours |
| radius | 2 | m |
| mass | 8.38E+04 | kg |
| moment of inertia | 134041.287 | MKS units |
| angular velocity | 0.01047198 | radians/s |
| angular momentum | 1403.67707 | kg*m/s |
| | | |
| SEP propulsion | | |
| Power | 16,500 | W |
| Isp | 3000 | seconds |
| mass flow rate | 3.8101E-05 | kg/s |
| thrust | 1.12130479 | N |
| torque | 2.24260958 | Nm |
| time to thrust | 625.912366 | seconds |
| total propellant mass | 0.02384772 | kg |

# Modeling

- Custom or commercial stereo vision or laser scanning systems can create precise 3-D model of complex objects:
  - Custom stereo (e.g. MER stereo vision system)
  - Commercial "cloud" multi-image processors (e.g. Microsoft, CAD vendors)
  - LIDAR processing algorithms (custom or commercial)
- Illumination and albedo modeling to compare observed image with prediction at given illumination and viewing angles.

# Forces on a Small Body Lander

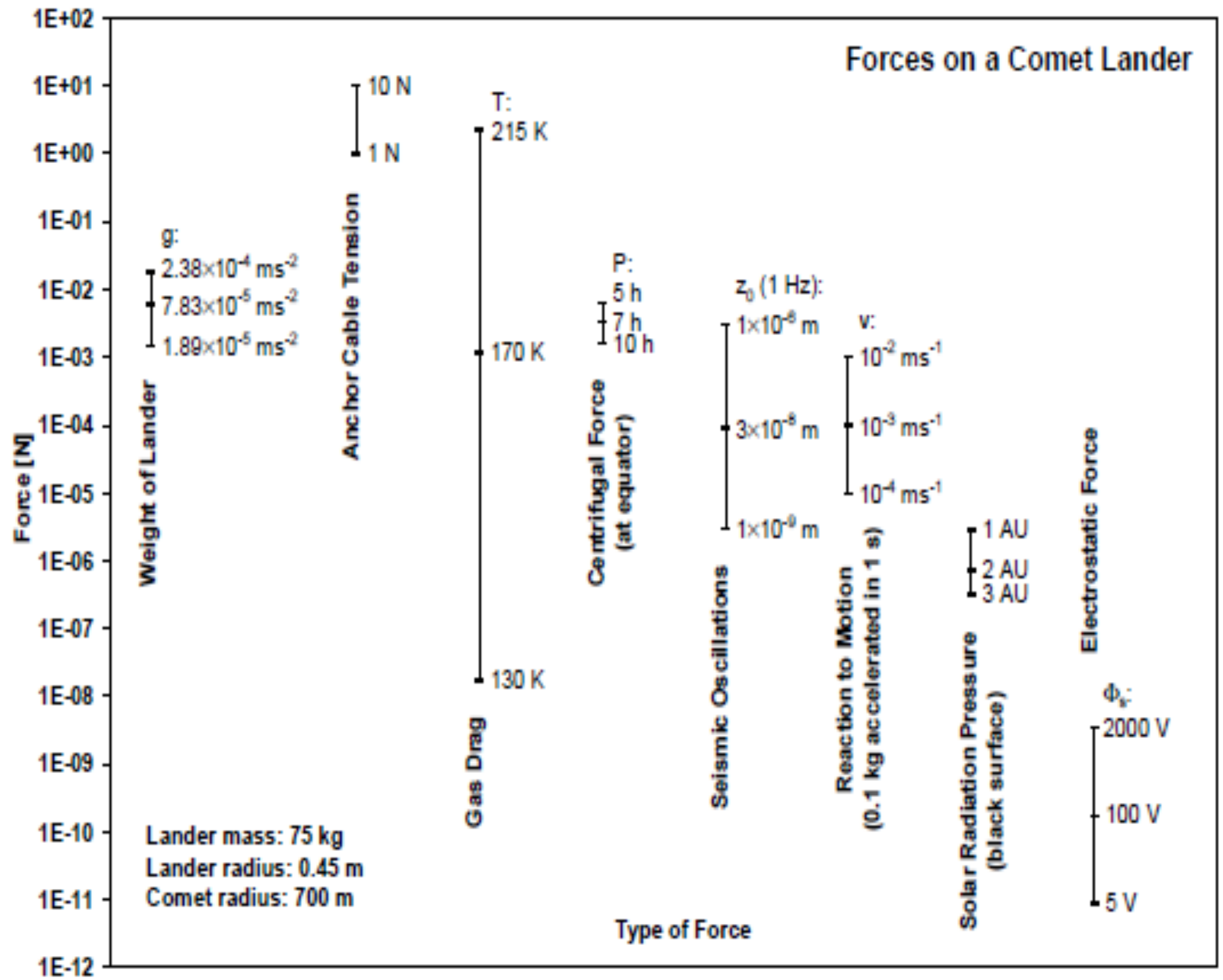



"Measuring Physical Properties at the Surface of a Comet Nucleus" Andrew J Ball, Ph.D thesis 1997, University of Kent, Canterbury, UK.

| Force | Direction(s) | Magnitude |
|---|---|---|
| Weight of the lander (gravitational force) | Towards centre of mass of nucleus | $F_{grav} = M \cdot \frac{4}{3}\pi R_c \rho_c G$ |
| Centrifugal force | Outwards from nucleus rotation axis | $F_{cent} = M \cdot \frac{4\pi^2 R_c \cos\delta}{P^2}$ |
| Drag from evolved gas | Mostly radial away from nucleus, possibly some tangential component (wind) | $F_{drag} = 4R^2 C_D a e^{-\frac{b}{T}}$ |
| Impact of dust particles | Complex (mostly radial) flux, partially coupled to gas flow | $F_{dust}$ = momentum transferred per unit time; related to gas flow |
| Solar radiation | Anti-solar direction (day only) | $F_{rad} = \frac{\pi R^2}{c} \cdot \frac{1371\,[\mathrm{Wm}^{-2}]}{(d\,[\mathrm{AU}])^2}$ |
| Passage of seismic waves | Many | $F_{seis} = \frac{4\pi^2 M z_0}{\tau^2}$ |
| Electrostatic | Normal to nucleus surface (repulsive) | $F_{el} = \pi R^2 \cdot \frac{e n_e \Phi_s}{2}$ |
| Reaction from moving parts (e.g. drill & deployable experiments) | Many (upwards for devices lowered to surface or drilling into it) | $F_{reac}$ = mass of moving part × velocity / acceleration time |
| Anchor cable tension | Downwards | $F_{anc}$, determined by harpoon rewind motor |

# Forces on a Small Body Lander – cont.

- Anchoring force should overcome other forces acting on lander
- Anchoring force needed:
  75 kg lander - 10N anchor force
  750 kg lander - 100N anchor force

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# Definitions of cohesion and friction angle

- τ = c + tan ($\phi_f$) , where $\phi_f$, is known as the friction angle (or internal-angle-of-friction), and the zero normal-stress intercept, c, is known as the cohesion (or cohesive strength) of the soil. Sample values for lunar soil are shown.

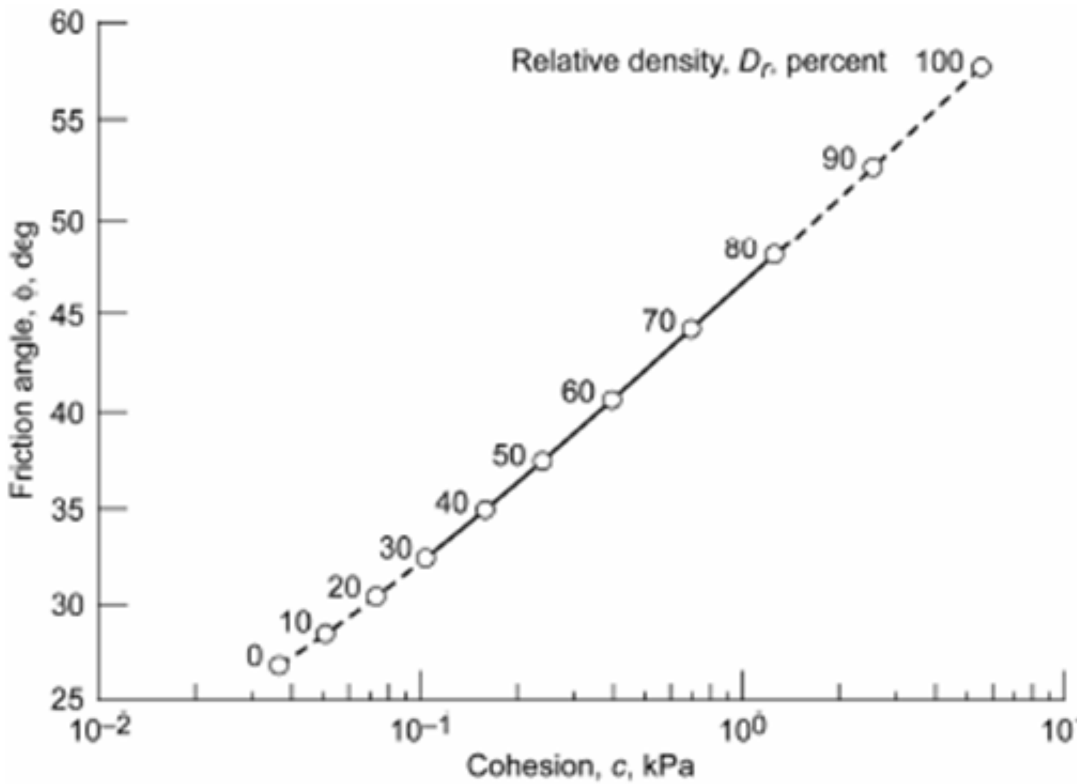



Figure A1.—Measured shear strength of a basaltic simulant of lunar soil, showing the friction angle (verticle axis) and cohesion (horizontal axis) for different relative densities (after Mitchell et al. [1972 and 1974]). Taken from Heiken et al. [1991].

•Cohesion is ~40 Pa at loosely packed conditions and increases to 10 kPa at 100% relative density. Friction angle also increases monotonically from 25 deg to ~60 deg.
•Rosetta Lander design takes advantage of this effect of greatly increased cohesion by local compression of the cometary regolith under the landing pods during landing.

Reference: Bulk Powder Physical Properties (Cohesion, Cohesivity, Flowability) from "Adhesion of Lunar Dust" by Walton in NASA/ CR-2007-214685

# Inflatable Anchor

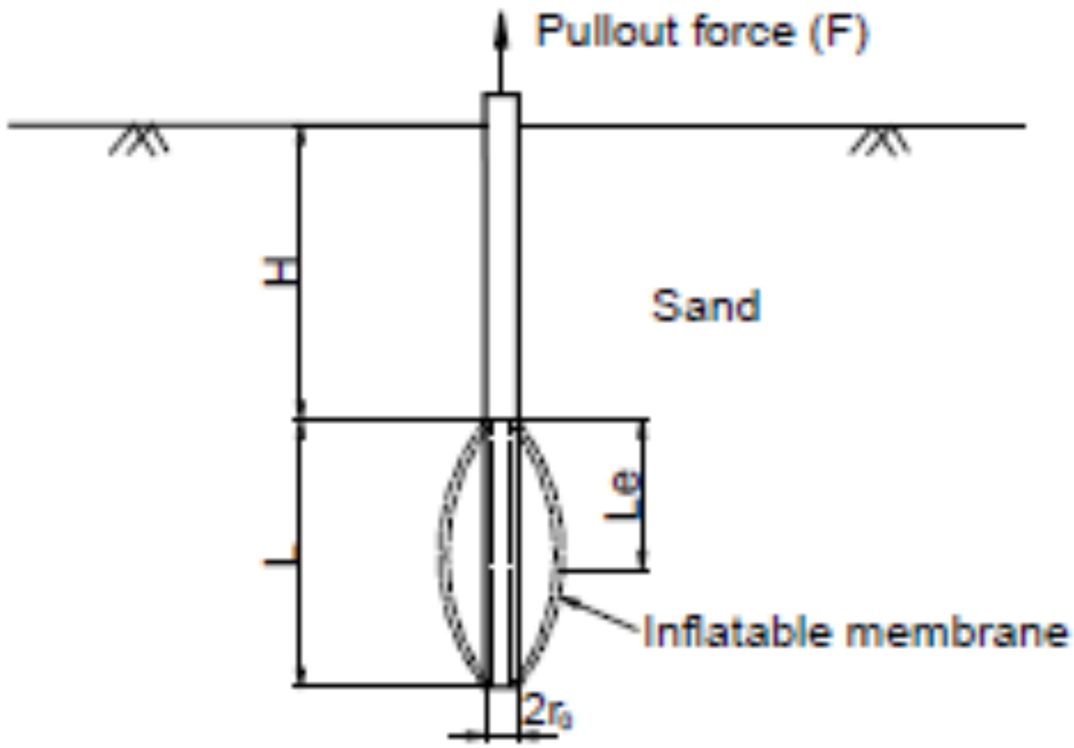



Fig. 1. Inflatable anchor.

Example: with $\mu = 0.6$

50 kPa = 7.3 psi

H = L

$$L := \begin{pmatrix} 10 \\ 20 \\ 30 \end{pmatrix} \cdot \text{cm} \quad r := \begin{pmatrix} 1.7 \\ 2 \\ 4 \end{pmatrix} \cdot \text{cm} \quad P := \begin{pmatrix} 50 \\ 50 \\ 50 \end{pmatrix} \cdot \text{kPa}$$

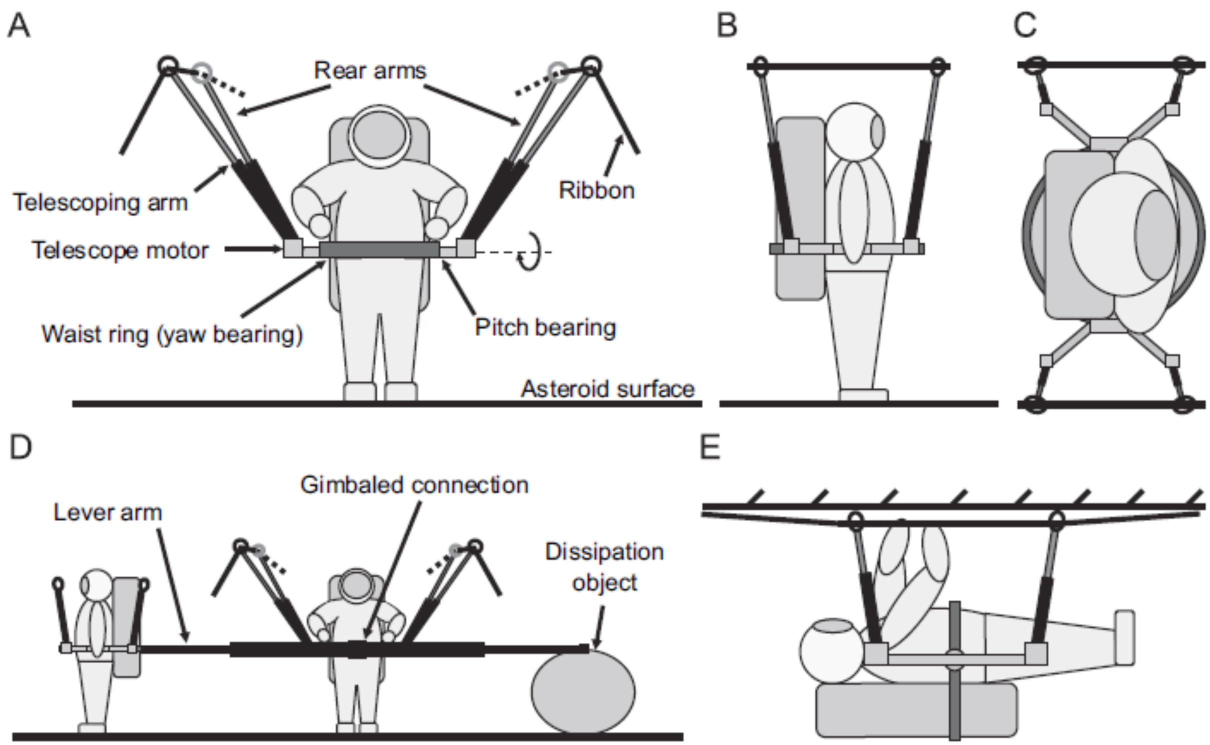
$$F := \overrightarrow{(2 \cdot \pi \cdot r \cdot L \cdot \mu \cdot P)}$$

$$F = \begin{pmatrix} 320.4 \\ 754 \\ 2.3 \times 10^{3} \end{pmatrix} \text{N}$$

"Non-linear analysis of pullout tests on inflatable anchors in sand" by Y. Yang, S. D. Hinchberger, and T.A. Newson, Geotechnical Research Centre, Dept of Civil Eng, The University of Western Ontario, London, Ontario, Canada N6A 5B9.

# Circumferential Rope Tether

- The ropes have to be reeled out around body before landing on the asteroid
- Feasible for very small bodies (<10km)




Ian Garrick-Bethell, Christopher E. Carr "Working and walking on small asteroids with circumferential ropes" Acta Astronautica 61 (2007) 1130-1135.

# Helical Anchor

- Requires torque counterbalance during deployment
- Used commercially in terrestrial applications
- Load Q can be positive or negative

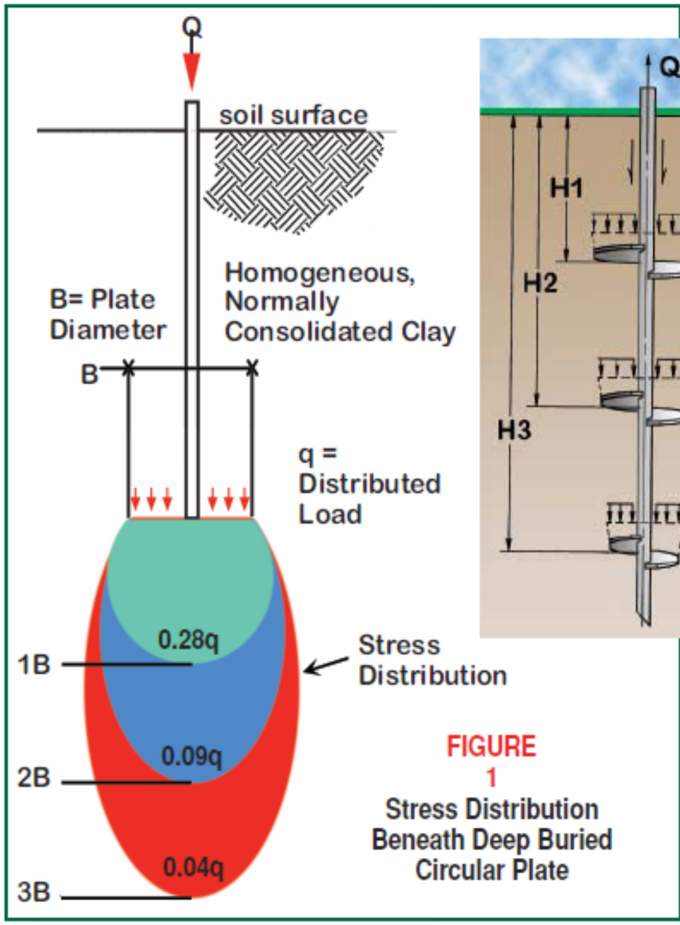



FIGURE 1 Stress Distribution Beneath Deep Buried Circular Plate

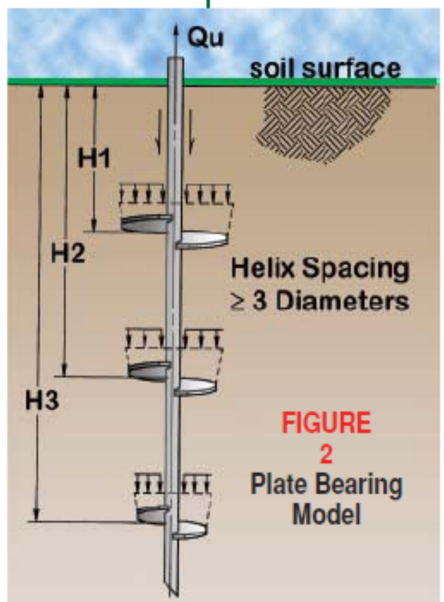



FIGURE 2 Plate Bearing Model

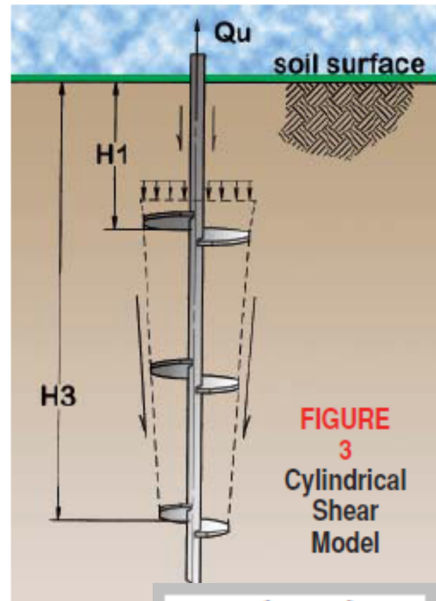



FIGURE 3 Cylindrical Shear Model

Cohesion $c := \begin{pmatrix} 70 \\ 2000 \end{pmatrix} \cdot Pa$ ← loose regolith, ← compacted

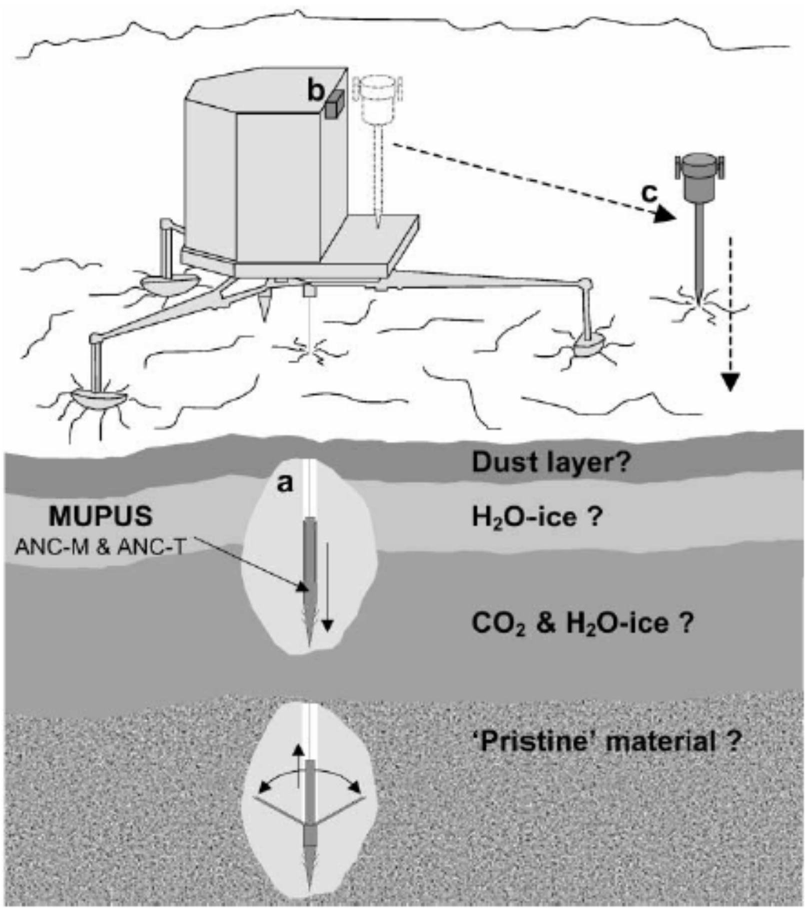
Area $An := 0.1 \cdot m^2$

Equation for force $Qn := An \cdot (9 \cdot c)$

Normal force value $Qn = \begin{pmatrix} 63 \\ 1.8 \times 10^3 \end{pmatrix} N$ ← loose regolith, ← compacted

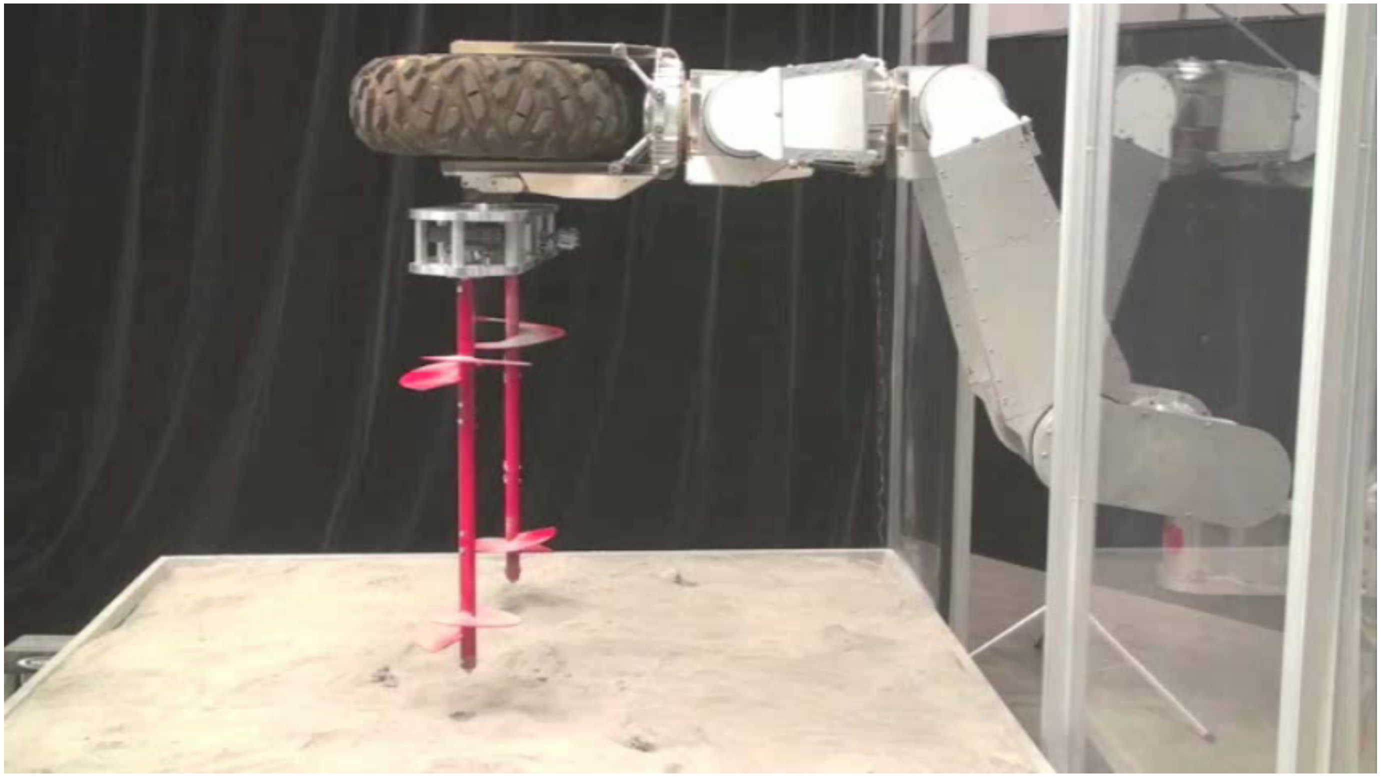
# Harpoon Anchor

- Possibly Simple & light-weight
- An instrumented harpoon probes the media during its passage
- Deceleration curves can be inverted to yield mechanical properties
- Cohesion can be calculated




During penetration the flaps are closed; following penetration, tensioning of the cable by the rewind motor causes a partial opening of the flaps, depending on the strength of the material. From "Impact penetrometry..", Komle et al. [www.elsevier.nl/locate/planspasci](www.elsevier.nl/locate/planspasci)

# Augering into Regolith



- Counter-rotating helical augers have no net torque reaction. Separation between flutes reduces friction without reducing pull-out force compared to continuous flute.

# Conclusions

- Small NEAs may be fast-spinners of solid rock (no regolith) or slower spinning with regolith,
- Spin of NEAs is easily zeroed with ~1N force for ~10 minutes, if one can "grab hold",
- Anchoring to nickel-iron would be done with magnet; anchoring to rock would be with rotary-percussive "bootstrapping" drill requiring axial force of ~10N for ~1 minute to start pilot hole; anchoring in regolith might be with counter-rotating augers,
- Nets or lassos deserve further study.