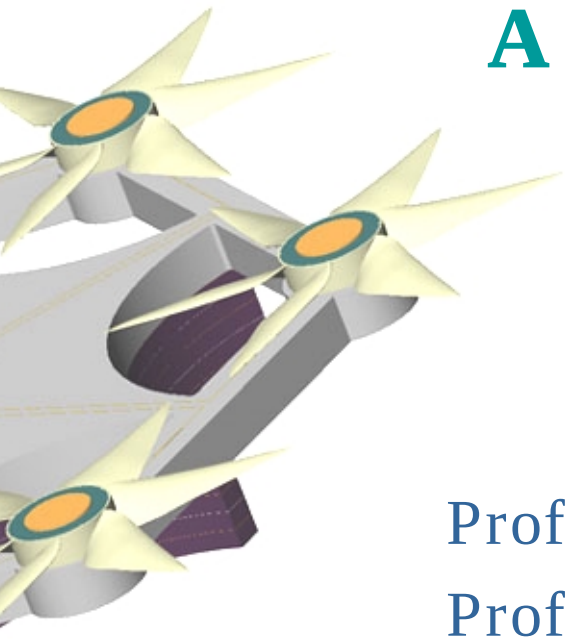
The Mesicopter



A Meso-Scale Flight Vehicle for Atmospheric Research

Stanford University

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Prof. Fritz Prinz, Dept. of Mech. Eng.

Graduate Students:

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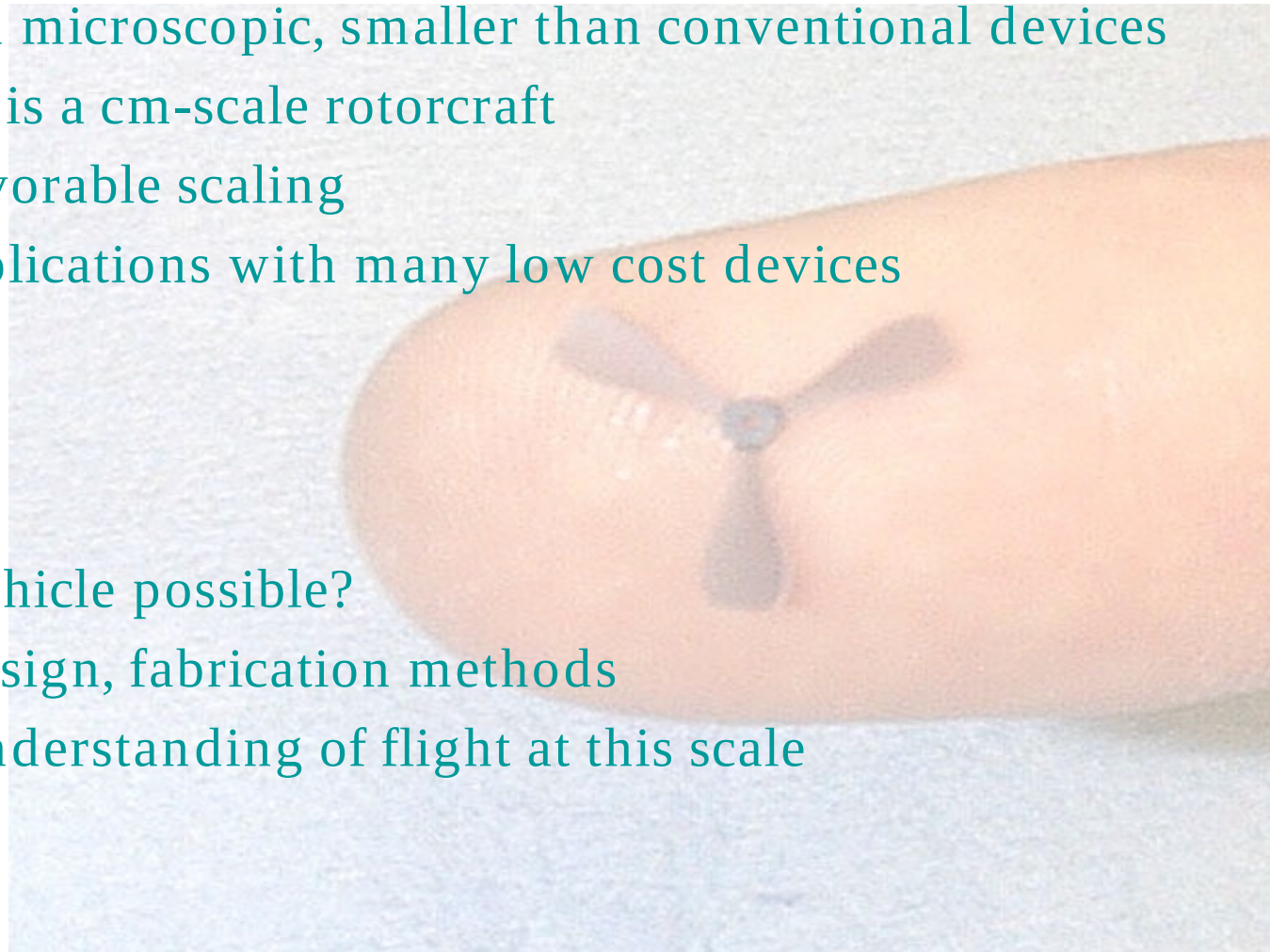
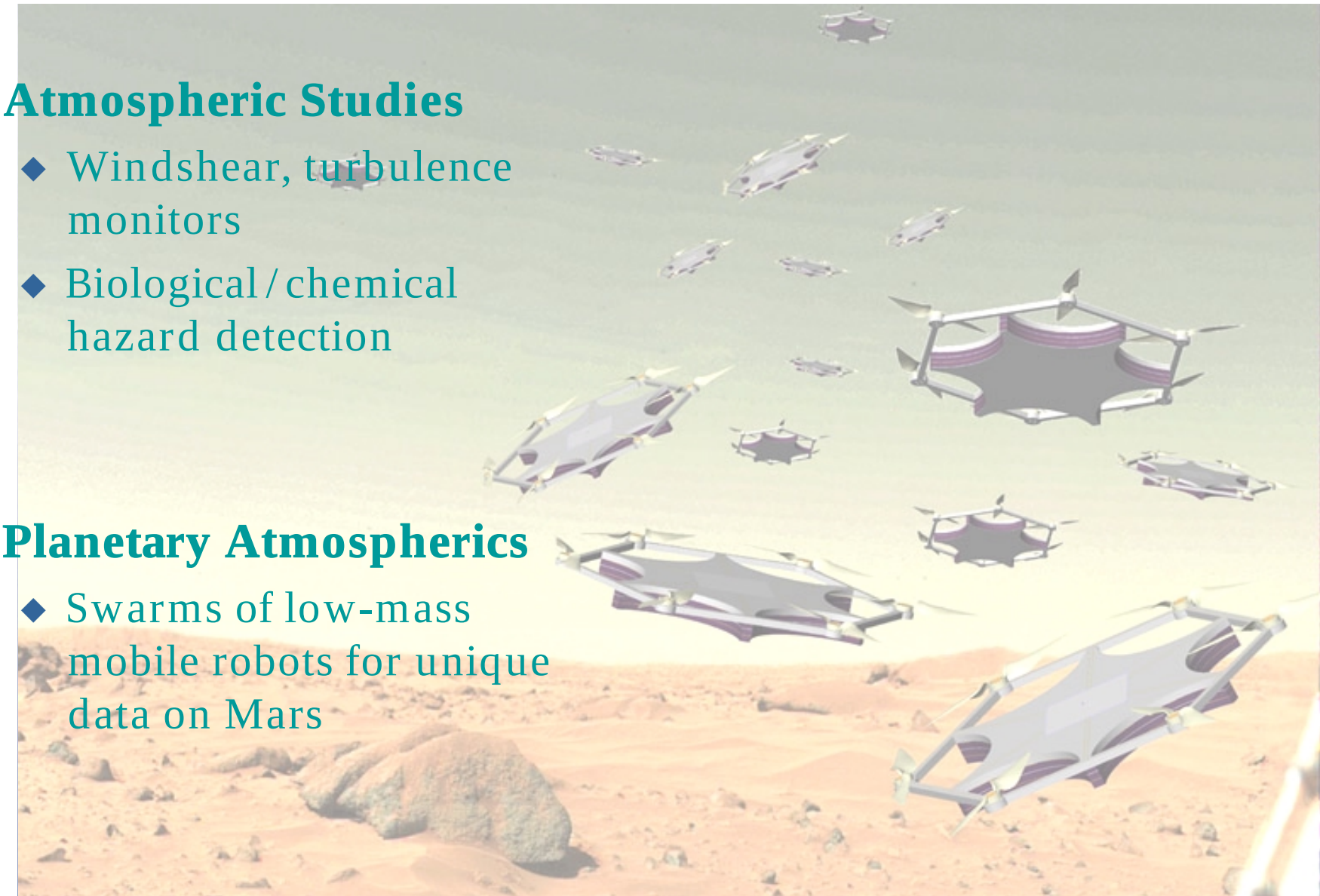
The Concept: Meso-scale Flight

- What is a meso-scale vehicle?
  - Larger than microscopic, smaller than conventional devices
  - Mesicopter is a cm-scale rotorcraft
  - Exploits favorable scaling
  - Unique applications with many low cost devices



- Objectives
  - Is such a vehicle possible?
  - Develop design, fabrication methods
  - Improve understanding of flight at this scale

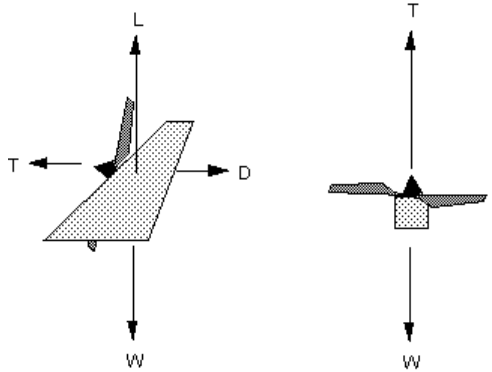
The Concept: Applications

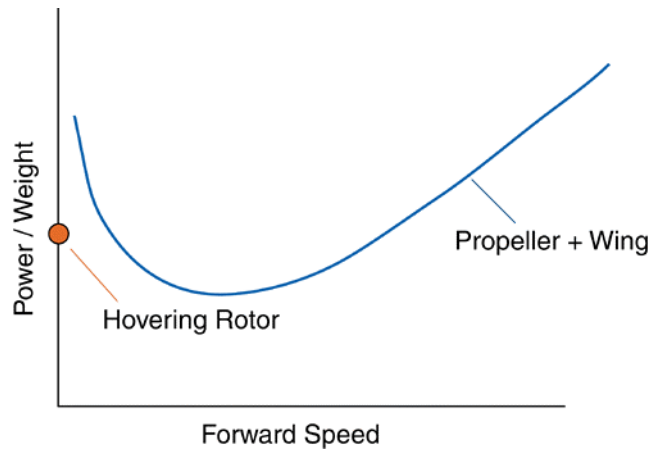


- **Atmospheric Studies**
  - Windshear, turbulence monitors
  - Biological/chemical hazard detection
- **Planetary Atmospherics**
  - Swarms of low-mass mobile robots for unique data on Mars

The Concept: Rotorcraft

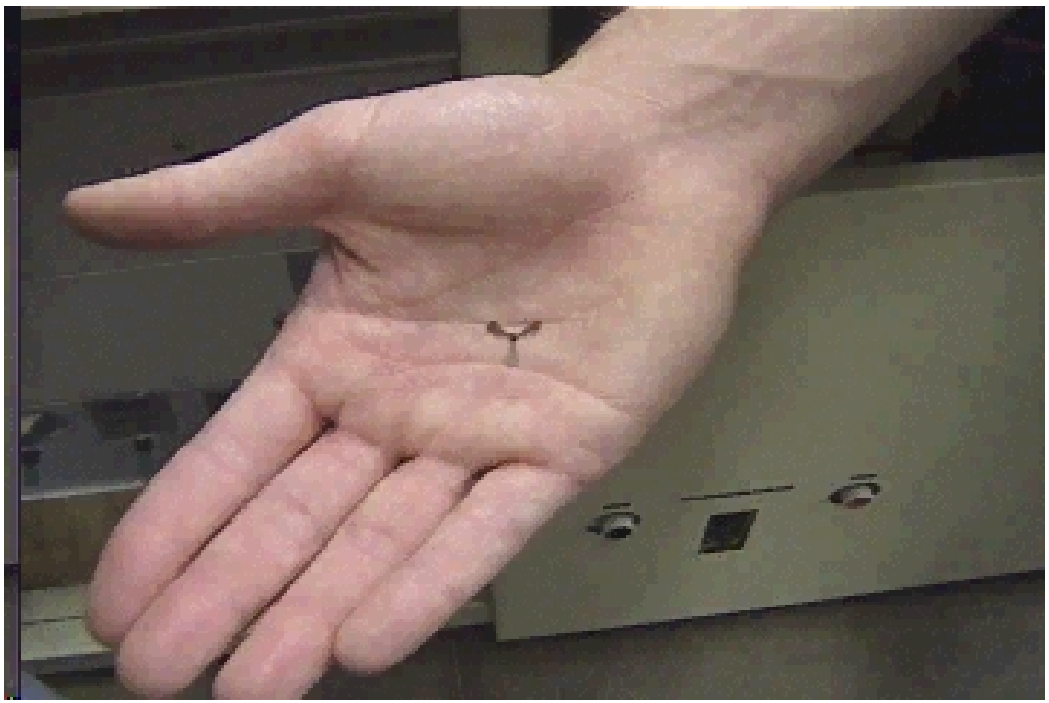
- Why rotorcraft for meso-scale flight?
  - As Reynolds number and lift / drag decrease, direct lift becomes more efficient
  - Compact form factor, station-keeping options
  - Direct 4-axis control





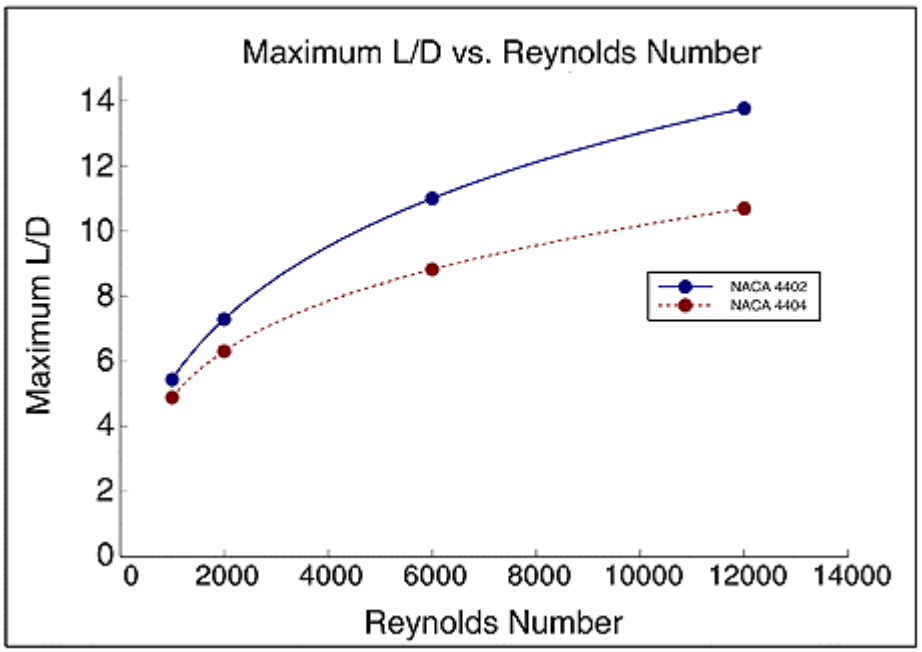
- Scaling laws (and nature) suggest cm-scale flying devices possible.

The Concept: Challenges



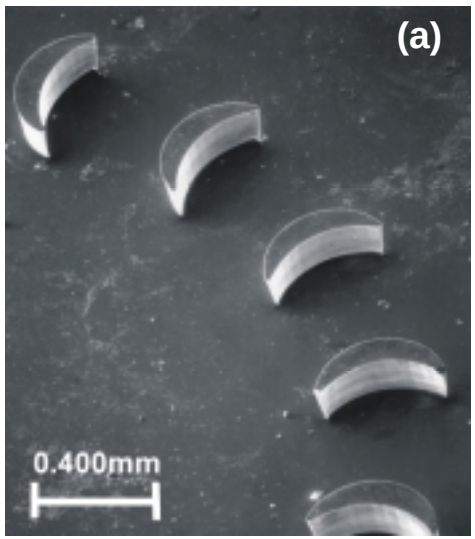
- Insect-Scale Aerodynamics
- 3D Micro-Manufacturing
- Power / Control / Sensors

Challenges: Aerodynamics

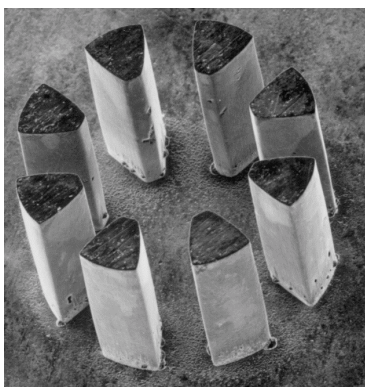


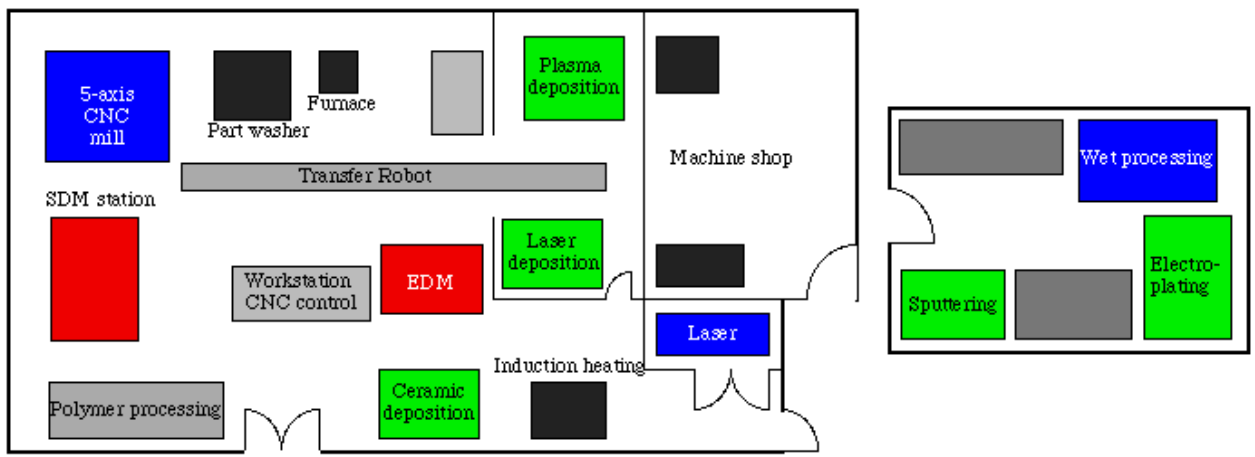
- Insect-scale aerodynamics
  - Highly viscous flow
  - All-laminar
  - Low L / D
- New design tools required

Challenges: Micro-manufacturing



- Efficient aero requires 3-D rotor design with 50 µm cambered blades
- Micro-motor design, construction
- Integrated power, electronics



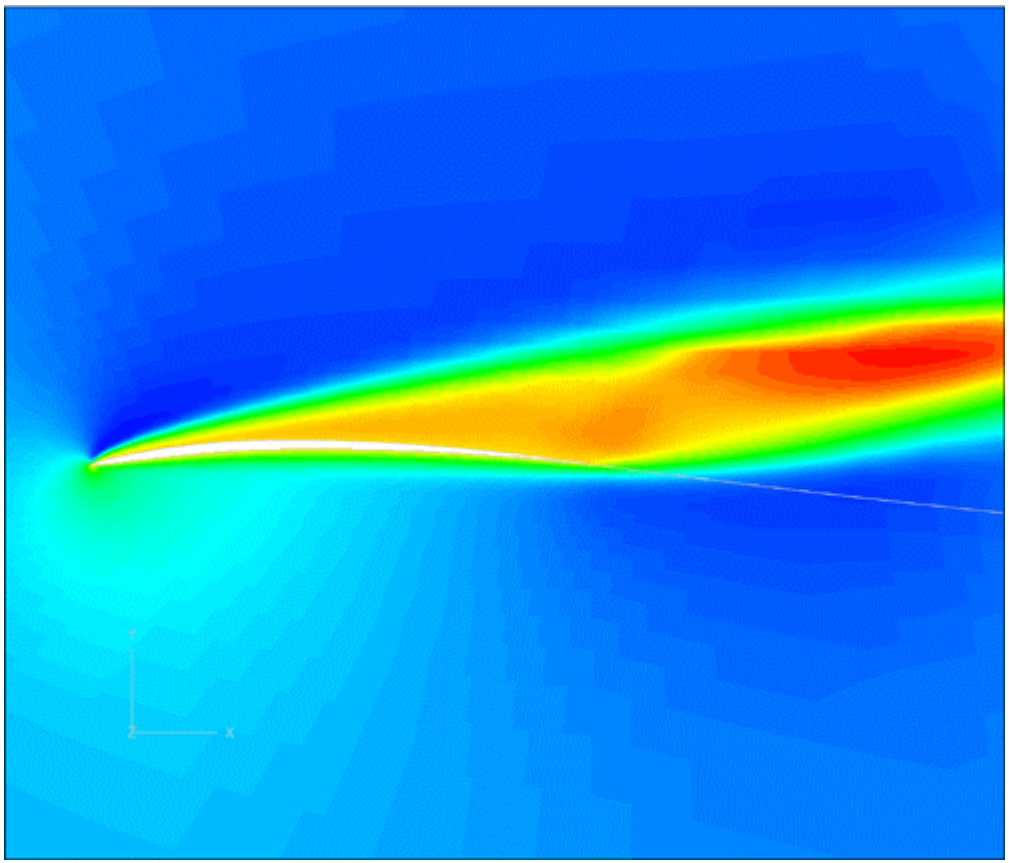


Equipment at Rapid Prototyping Lab

Approach

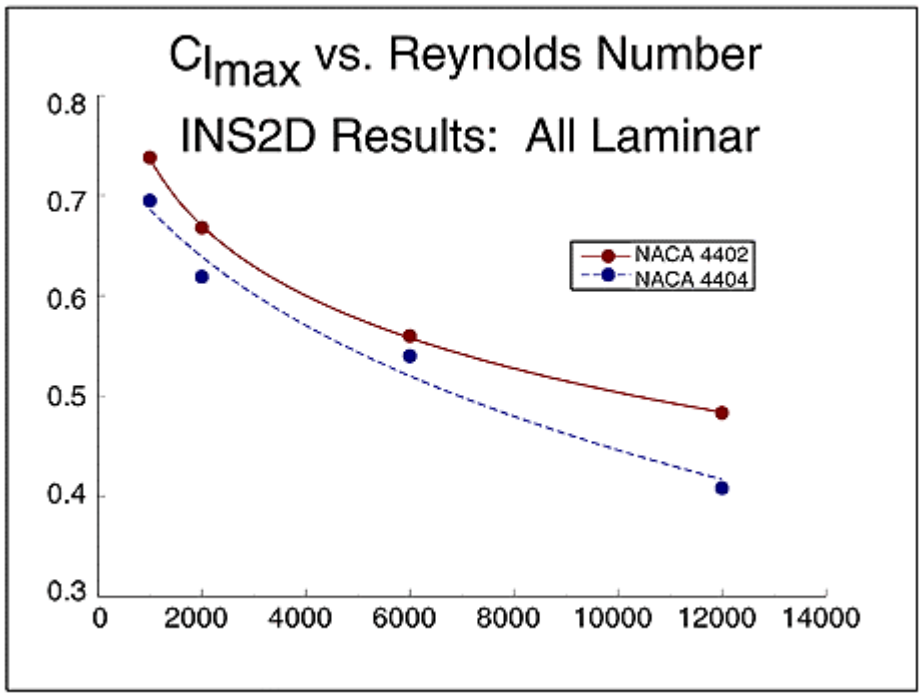
- Advanced aerodynamic analysis and design methods
- Novel manufacturing approaches
- Teaming with industry for power and control concepts
- Stepwise approach using functional scale model tests

Approach: Aerodynamics



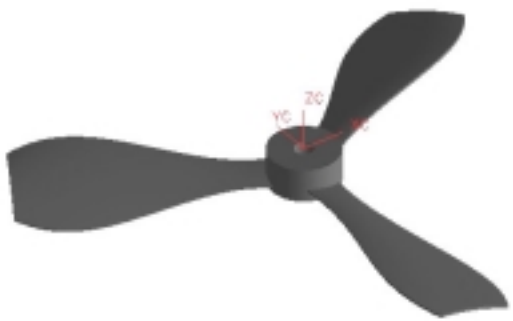
- Navier-Stokes analysis of rotor sections at unprecedented low Reynolds number
- Novel results of interest to Mars airplane program
- Nonlinear rotor analysis and optimization code

Approach: Aerodynamics



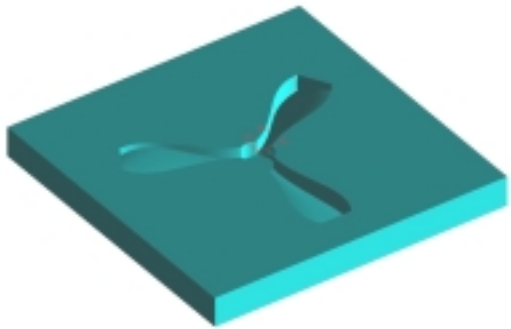
- New results for very low Re airfoils
- Very thin sections required
- Maximum lift increases as Re decreases below 10,000

Approach: Rotor Optimization

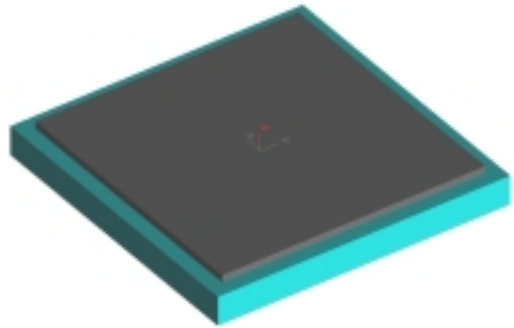


- Chord, twist, RPM, blade number designed using nonlinear optimization
- 3D analysis based on Navier-Stokes section data
- Rotor matched with measured motor performance

Approach: Rotor Manufacturing

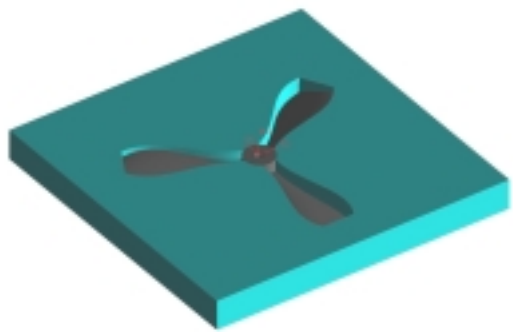


1. Micro-machine bottom surface of rotor on wax



2. Cast epoxy

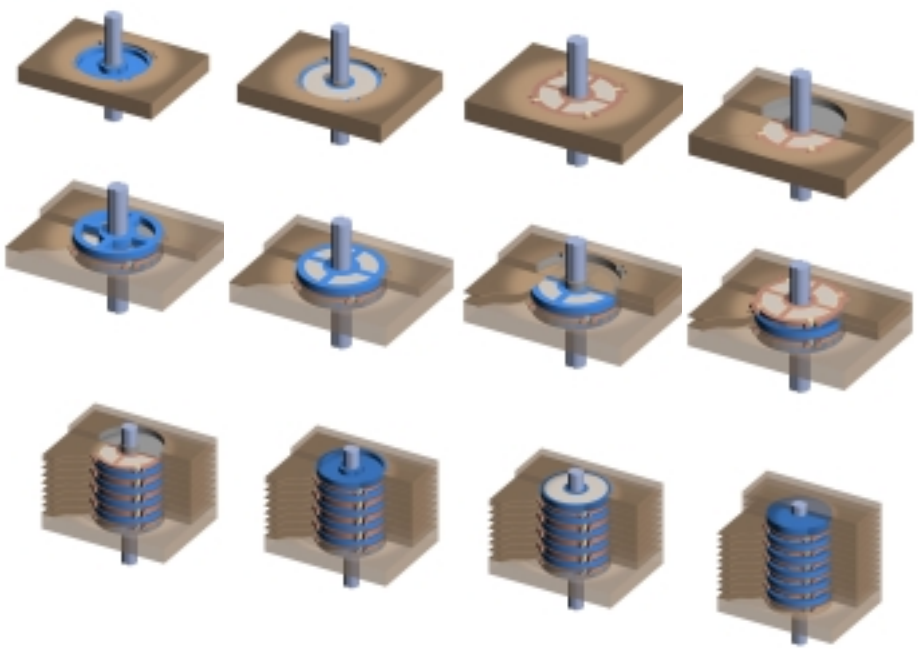
3. Remove excess epoxy



4. Machine top surface of rotor

5. Melt wax

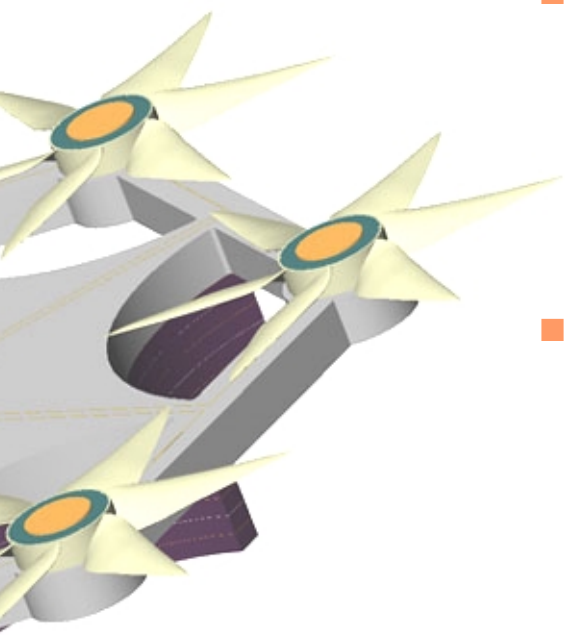
Approach: Micro-Motor Development



Steps in micro-motor fabrication

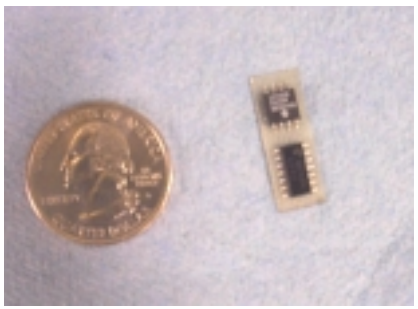
- 1mm diameter micro-motor constructed using SDM
- Fabrication complete, first spinning tests underway
- Initial rotor tests use 3mm brushless DC motor

Approach: Battery Technology



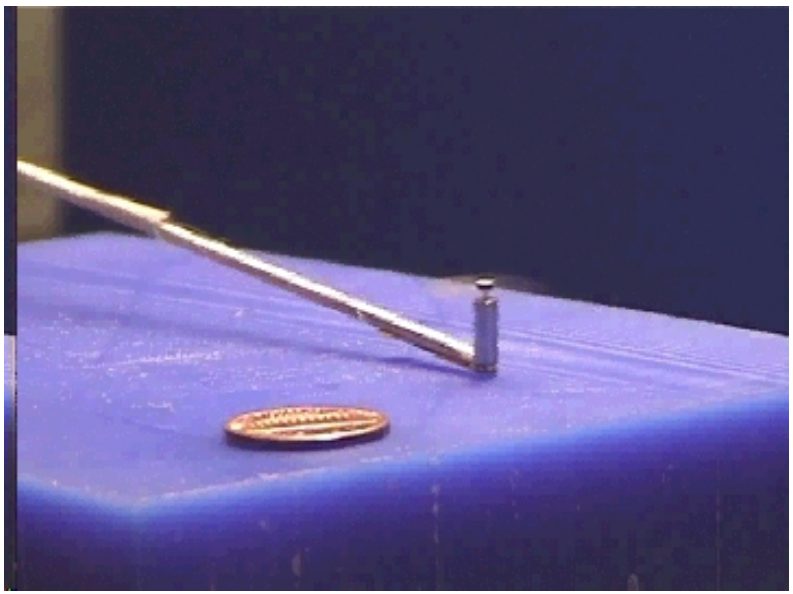
- New lithion-ion technology provides 130 mW hr/g -- will power prototype mesicopter for 30 min of flight.
- SRI partners developing “direct-write” battery under DARPA program. High energy density system integrated with small-scale structure.

Approach: Sensors / Controls



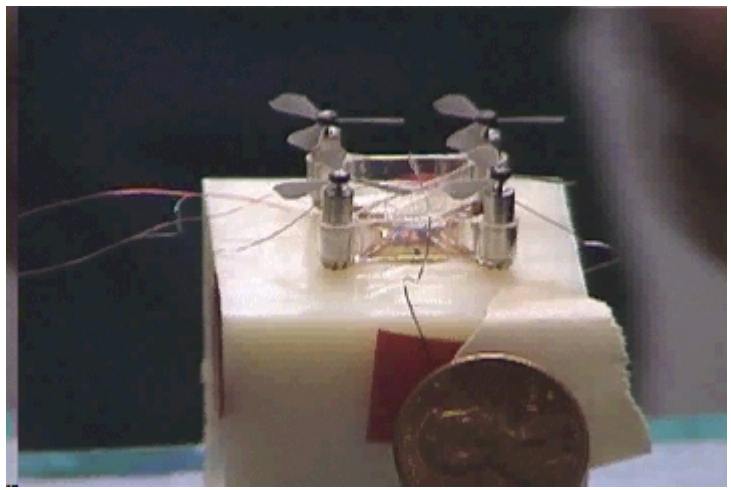
- Innovative passive stabilization under test at larger scale
- Micro-motor controllers in development
- Inter-chip communication concept studied by industry partner

Status



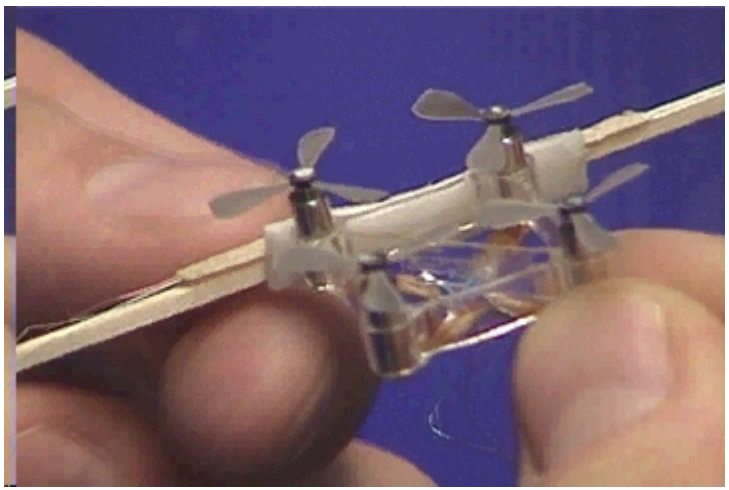
- 1.5 cm rotors designed, tested
- 4-Rotor concept constructed, initial tests complete
- Single rotor performance characterized using 3mm, 325mg motor, external power

Status: Initial Prototypes



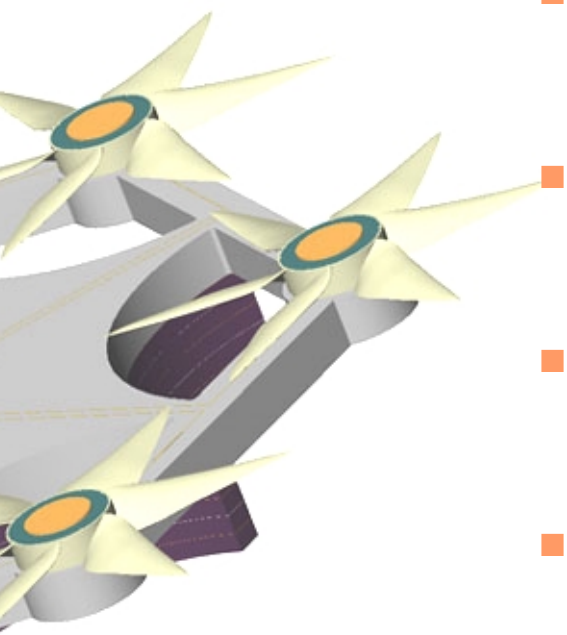
- 4-Rotor design fabricated, assembled 3/18/99
- Initial tests successful

Status: Initial Prototypes



- Initial tests stabilized on pivot arm
- Weight excludes power and controller
- Current estimates suggest 1.5cm mesicopter can lift batteries, controller as well

Current Work



- Rotor testing, optimization
- Micro-motor development
- Integration of power / motor controls
- Discussions with SRI, Intel, NASA on batteries, communications, sensor options

Continuing Work / Future Visions

- First flight of world's smallest free-flight powered aircraft imminent

- Program will lead to:
  - New manufacturing approaches and design tools for miniature devices
  - Fundamental understanding of small-scale flow for terrestrial or Mars aircraft
  - New generation of flight vehicles that act in concert to provide an unprecedented sensor platform