Ion Propulsion CubeSat

• Triple CubeSat Lunar orbiter will have one MiXI 1 mN thruster, Specific Impulse about 2,500 – 3,000 seconds

• Xenon propellant of 0.5-0.75 kg

• Power for the xenon ion drive will come from photovoltaic cells on the spacecraft body and eight fold out 30 cm x 10 cm panels
Ion Propulsion System

JPL Miniature Xenon Ion (MiXI) Thruster
Spacecraft

Triple CubeSat Ion Lunar Orbiter with fold outs
Spacecraft Detail

Triple CubeSat Ion Lunar Orbiter Engine & Tanks
NovAtel OEMV-1 GPS Board

16 mm Lens for 1 megapixel Star Tracker
NovAtel OEMV-1 GPS Board

- Currently supplying GPS data for the RAX CubeSat
- The CoCom speed and altitude limits are removed
- The API for the Arm processor is enabled
- We have 4 MB each of RAM & ROM for running the GEONS navigation software on the board
NASA Goddard Spaceflight Center Developed GPS Enhanced Onboard Navigation System (GEONS) Software

- Autonomous navigation
- High performance GPS out to 50 Earth radii
- Celestial navigation for greater distances
- Earth ground transponders (we are not using)
- 20,000 lines of C code
- 60 kB compiled
GPS Enhanced Onboard Navigation System

• Hi fidelity model for satellite navigation (gravity, Earth’s atmosphere, etc.) – can coast through data outages for more than 24 hours
• Kalman filter for computation of corrected position and velocity
• Can process GPS signals from the far side of the Earth
• We will run it on the Novatel OEMV-1 Arm processor
GPS Enhanced Onboard Navigation System

Software Classes

[Diagram showing the software classes and their relationships]
GPS Enhanced Onboard Navigation System
Ion Drive Orbits ala SMART-1
Low Energy Lunar Transfer

Weak Stability Boundary

Ballistic Capture

"Shoot the Moon" Lunar Capture Trajectory (seen in Earth-Centered Inertial Frame)
Spacecraft Celestial Navigation

1. Range and 2. Range rate
3. Chordwidth
4. Angle between landmarks
5. Angle between planes
6. Angle between planet vector and star

Center of Coordinates

Ground Station

Spacecraft
Star Sight Geometry
Control Software

• Control Software written in SPARK/Ada using Adacore’s GNAT Programming Studio & GNAT compiler

• Praxis’ SPARK Toolset used to prove the correctness of the code

• Sofcheck’s AdaMagic compiles it to produce ANSI C intermediate code

• Software run on CubeSat Kit MSP430 CPU
procedure Matrix_2 (J : in Natural)
  --# global in out Upper_Matrix; in In_Matrix, Diagonal;
  --# derives Upper_Matrix from Upper_Matrix, J, In_Matrix, Diagonal;
  --# pre J >= Diagonal'First and J < Diagonal'Last and
  --#     Upper_Matrix'First(1) = Upper_Matrix'First(2) and
  --#     Upper_Matrix'Last (1) = Upper_Matrix'Last (2) and
  --#     Diagonal'First = Upper_Matrix'First(1) and
  --#     Diagonal'Last = Upper_Matrix'Last (1);
  is
    begin
      Upper_Matrix (J, J) := 1.0;
      for I in reverse Natural range Diagonal'First .. J - 1 loop
        Upper_Matrix (I, J) := 0.0;
        for K in Natural range J + 1 .. Diagonal'Last loop
          Upper_Matrix (I, J) := Upper_Matrix (I, J) +
            (Diagonal (K) * (Upper_Matrix (I, K) * Upper_Matrix (J, K)));
        end loop;
        Upper_Matrix (I, J) := (In_Matrix (I, J) - Upper_Matrix (I, J)) / Diagonal (J);
      end loop;
    end Matrix_2;
Navigation Components

• Converting the NASA Goddard GEONS navigation system to SPARK/Ada (about half done) yields about 1% of the error rate of C software

• This process has already found a number of errors in the NASA GEONS software

• Star tracker camera in development at Norwich University

• Attitude control system for a stable platform for the star tracker in development
Remaining Tasks

• Analyze the various low energy transfer paths for delta-v and transit times at University of Vermont

• Choose a flight path

• Model the Van Allen radiation exposure at University of Vermont

• Develop the flight plan
NASA Launch Opportunity

• NASA’s 2010 CubeSat Launch Initiative

• Our project was selected for launch

• A single-unit CubeSat will be launched as part of NASA’s ELaNa IV Falcon 9 flight in March 2012

• It will test the Lunar navigation system in Low Earth Orbit

• Follow our project at www.cubesatlab.org
Our 3m GENSO 2.4GHz Dish
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• AdaCore, Inc. (GNAT Pro)

• Praxis High Integrity Systems (SPARK)

• SofCheck (AdaMagic)

• Applied Graphics, Inc. (STK)
Navigating to the Moon

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