Ada and SPARK

• The Ada language originally issued in 1983 has been revised in 1995, 2005 and 2012

• Although originally developed at the behest of the Defense Department, Ada has taken over the niche for very high integrity software, as SIGAda says: “When the software really has to work”

• As a result, Ada is used in all commercial airline avionics and all air traffic control systems worldwide, as well as high speed trains and nuclear power plants in Europe
Our ELaNa IV CubeSat

Vermont Lunar CubeSat
Software Controlled Hardware

Clyde Space EPS
Software Controlled Hardware

Astrodev Helium-100 transceiver
Software Controlled Hardware

ISIS AntS crossed dipole antenna
Software Controlled Hardware

IMU, GPS patch, camera & hysteresis board
NovAtel OEMV-1 GPS Board Mounted on University of Michigan Position and Time Board
Follow on Ion Drive CubeSat

Triple CubeSat Ion Drive Propulsion system, Lunar or Interplanetary without fold out PV panel
Follow on Ion Drive CubeSat

Triple CubeSat with CubeSat Kit 56 W fold out PV panel
Follow on Ion Drive CubeSat

JPL Miniature Xenon Ion (MiXI) Thruster
Control Program Architecture
Software Development Process

- Code in SPARK/Ada with GPS
  - Spark Errors
  - Examine with Spark
    - Other Errors
    - Compile in GPS
- MSP430 object code
  - Compile C in Crossworks
  - C intermediate code
    - Compile in AdaMagic
System Design

Diagram showing the system design with the main components including:
- Antenna
- Camera
- Inertial Measurement Unit
- File System
- Radio
- Power Supply
- GPS
- Commander
Subsystems

Superloop

File System

Commander

File Transfer Protocol

Radio
Data Communication

Sends Beacon

- Within Range
  - Receives Request From Ground Control for Telemetry
  - Doesn’t Receive Command

- Out of Range
  - Lock Requested Telemetry Data
  - Enters File Transfer Mode
    - Send Sequence Length Packet Then Send Telemetry

Waits 1 Minute

- File Transfer Success
  - Turn Off File Transfer Mode
  - Turn On Super Loop

- Missing Data
## Subsystems Interfacing

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Interfacing</th>
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<tbody>
<tr>
<td>Antenna</td>
<td>I²C</td>
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<tr>
<td>Radio</td>
<td>RS-232</td>
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<tr>
<td>Camera</td>
<td>SPI</td>
</tr>
<tr>
<td>EPS (Power Supply)</td>
<td>I²C</td>
</tr>
<tr>
<td>Inertial Measurement Unit (IMU)</td>
<td>RS-232</td>
</tr>
<tr>
<td>GPS &amp; GEONS</td>
<td>SPI</td>
</tr>
</tbody>
</table>
Student Participation

2011 (Summer) – Jeremy Audet & Matt Ward started the flight control software
2012 (Summer) – Dan Turner picked up where Matt and Jeremy left off with the flight control software
2012 (Fall) – Michael Collins and Colin Myers started working on the flight control software
2013 (Spring) – India Beauregard helped develop the IMU board, Michael Collins continued
2013 (Summer) – Dan Turner continued with radio and GPS software
Control Software

• Control Software written in SPARK/Ada using Adacore’s GNAT Programming Studio & GNAT Pro compiler
• Praxis’ SPARK Toolset used to prove the correctness of the code
• Sofcheck’s AdaMagic compiles it to produce ANSI C intermediate code
• C code compiled to object code
• Software runs 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;
procedure Get_From_Radio(Ch : out Character; Rx_Success : out Boolean)
--# global in out USCI_A1.State, Utility.Hardware; in Utility.Timer_Done;
--# Ch from USCI_A1.State &
--# Rx_Success from USCI_A1.State &
--# Utility.Hardware from Utility.Hardware &
--# null from Utility.Timer_Done;
is
    Finished : Boolean;
begin
    Utility.Start_B(Utility.Millisecond_Count_Type(20));

    loop
        Finished := Utility.Get_Timer_Finished;
        exit when Finished;
    end loop;

    if USCI_A1.Get_Rx_Buffer_Used > 0 then
        USCI_A1.Eat_Char(Ch);
        Rx_Success := True;
    else
        Ch := ' ';  
        Rx_Success := False;
    end if;
end Get_From_Radio;
Navigation Components

• Converting the NASA Goddard GEONS navigation system to SPARK/Ada yields about 1% of the error rate of C software
• This process has already found a number of errors in the NASA GEONS software
• The GEONS software runs on the GPS board ARM processor
• Celestial navigation camera
• Novatel GPS on University of Michigan Position and Time Board
• Passive magnetic attitude control
• Inertial measurement unit (3 axis magnetometer, gyro and accelerometer)
• Ground based transponder (see LMST, next slide)
Low Mass Radio Science Transponder

- Developed at NASA’s Jet Propulsion Lab
- X band transponder
- Currently 1U size, to be reduced to ½ U
- Will fly on the ELaNa selected LMRST-Sat
- A great addition for an interplanetary flight
NASA Launch Opportunity

• NASA’s 2010 CubeSat Launch Initiative

• Our project was in the first group selected for launch

• Our single-unit CubeSat will be launched as part of NASA’s ELaNa IV on an Air Force Minotaur 1 flight October 30, 2013 to a 500 km altitude, 40.5° inclination orbit

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

• Follow our project at www.cubesatlab.org
X and Y axis Vibration Test
First two stages are Minuteman II first two stages, third and fourth stages are Pegasus second and third stages.
Acknowledgements

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• Altran Praxis (SPARK)
• SofCheck (AdaMagic)
• Applied Graphics, Inc. (STK)
• LED Dynamics (PV boards)
• Microstrain (IMU)