Mayflower:
The Next Generation CubeSat Flight Testbed

2011 Small Sat Conference

9 August 2011

Talbot Jaeger (NG *NovaWorks*)

Mike Ciffone (NG Advanced Concepts – Rapid Response Space)

Next Generation CubeSat (Plymouth) Was Easily Configured For Mayflower Mission

NORTHROP GRUMMAN

	PLYMOUTH Capabilities
Power	>100 W
Propulsion	6DOF; 50 to 1000 m/s ΔV (based on configuration and propellant choice)
Metrology/Control	Precision Pointing/NAV Options: GPS/Star Tracker/ Reaction Wheels
Communications	High Speed Integrated SDR (Uplink, Downlink, Crosslink)
Operations	All Orbits
Bus/Payload	Configurable; From 1.5U
Software	Open Source (pending ITAR restrictions)

Mayflower Mission Configuration
56 W – Split Wing
59 m/s – Cold gas (Single Jet)
GPS/Star Tracker/ Magnetometer/ Torque Coils
Replaced by Payload
325 km Circular
USC CAERUS

MAYFLOWER MISSION: CAERUS+PLYMOUTH
Next Generation CubeSat Flight Testbed

NORTHROP GRUMMAN

Accomplishments:

- <u>Short Timeframe:</u> 6 months to Design, Manufacture, Integrate, and Test Caerus and Plymouth
- <u>Low Mission Cost:</u> IRAD funded Development, Fabrication, Integration, Test and Launch
- Passed NASA Reviews to Launch with COTS-1
- First Commercial Falcon 9 CubeSat Payload
    - Successfully Injected into an Elliptical Orbit with a Perigee of 285 km in December 2010
- Smallest Satellite ever Launched and Developed by Northrop Grumman; First Satellite by USC
- Validated Level 1 Objectives and COTS Design/Test Approach

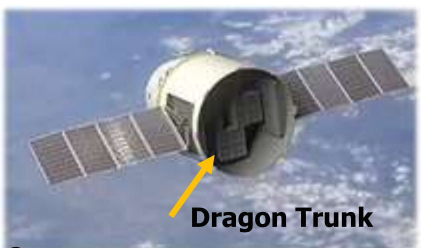
Architecture:

- Cost driven for 325 km orbit with a 34.5 deg Inclination

Concept of Operations:

- CubeSats are Deployed by a P-POD in the Dragon Truck where Future Unpressurized ISS Cargo will be Stored
- ~2 weeks of Operational Demo Mission Before De-Orbiting

P-POD Mounted Inside Dragon Trunk



Stowed in P-POD Launch Adaptor

Program Overview:

- Objectives:
    - Test Next Generation CubeSat Subsystems
    - Demonstrate Northrop Grumman Rapid Response Space Satellite Technology Configuration, Build and Integration Capability
- Top-level Schedule:
    - 4-Month Development (Feb –May 2010)
    - 2-Month Integration and Test (Jun-Jul 2010)
    - 2-week On-Orbit Operation (Dec 8th Launch)
- Workforce Training:
    - University Mission
    - Demonstrate Configurability
    - Student Led System

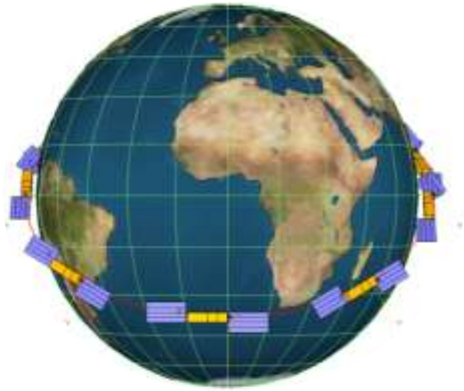
Mayflower Mission Summary

- All systems passed full environmentals and ground ops
- *But autonomous flight S/W and operations ruled the day*
- Mayflower was one of eight CubeSats launched as a secondary payload on the COTS-1 flight aboard Falcon 9
  - Successful automated deployments, activations, execution during challenging tracking period
- Defective part in USC CAURUS command station required autonomous ops early and preloaded ground calibrations to be accurate

- Flights telemetry demonstrated automated ADACS system reacting to early low orbit and successfully providing the major test objectives early via routine high torque/power ops
  - At low altitude, analysis showed that the magnetic torque-coil based reaction control system did not have the control authority to overcome the spacecraft's high coefficient of drag and achieve 3-axis stabilization at perigee so a slow roll was best possible condition based on configuration
    - The design altitude was 325 km and space-track data indicated initial perigee of 285 km and dropping.
    - Plymouth reaction wheel system option, not used to reduced cost, would have handled low orbit torques
    - The last received beacon data showed increasing spin rates, the result of increasing atmospheric disturbances
- Solar arrays were successfully tested, providing power even in the rolling environment but eventually towards its end of life they were not able to collect enough solar energy to maintain a positive power budget
- Demonstration mission terminated when communication was eventually lost but not before successfully satisfying Level 1 objectives (solar array, EPS, thermal, etc)

Low-Cost / Risk Tolerant Approach Demonstrates Risk Acceptance – Anomalies Did Not Prevent Successful Testing of Major Systems

Achieved vs. Expected Orbit

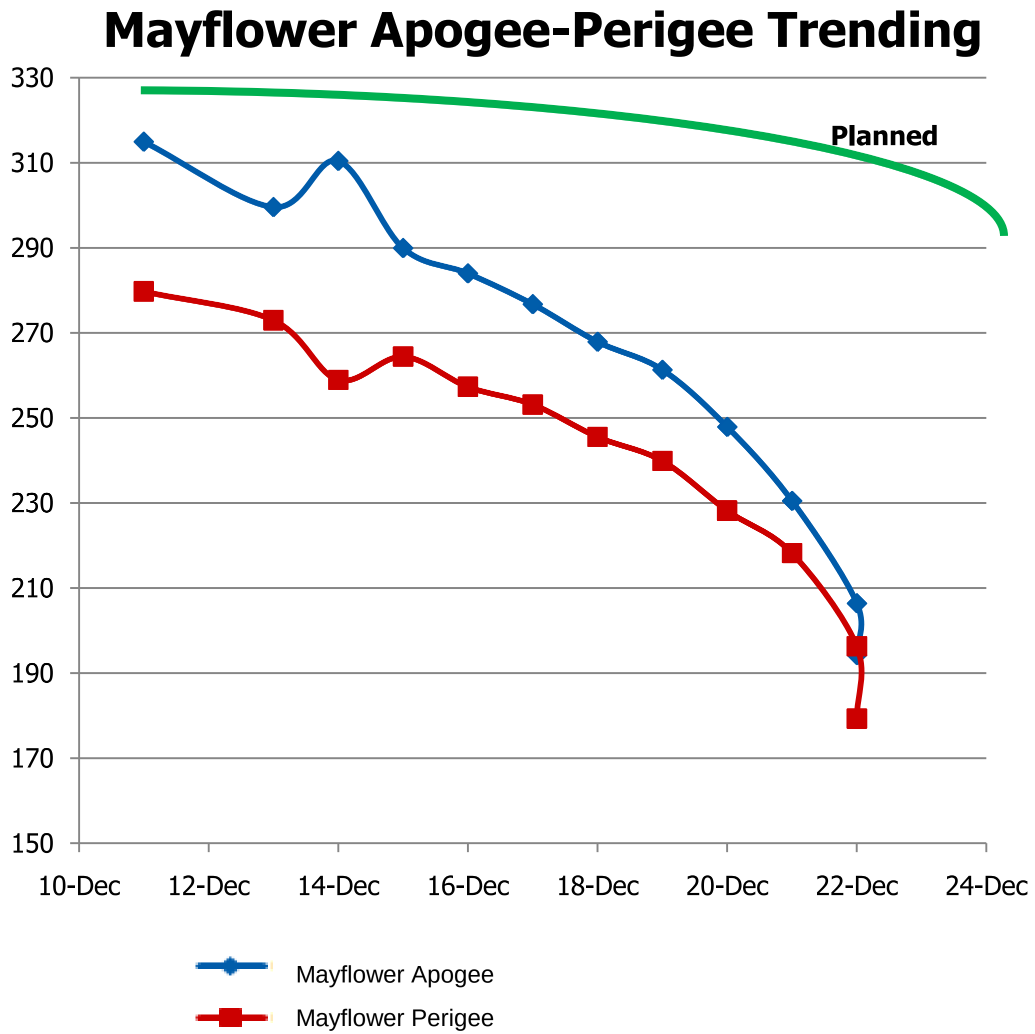


325 km Designed Orbit

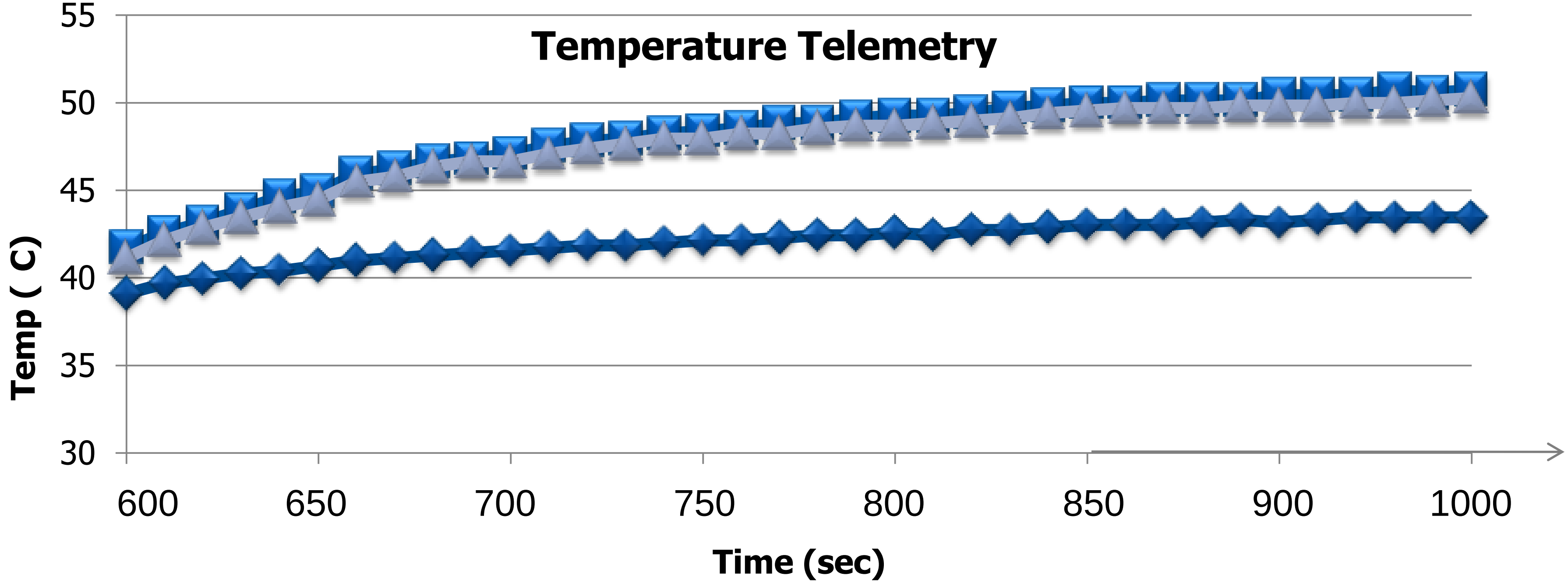
- Pre-launch expected 320 km x 312 km
- 34.5° Inclination

Achieved Orbit

- 310 km x 285 km Elliptical Orbit
- 34.5° Inclination
- Low-altitude increased drag
- Resulted in decreased control
- Increased drag and decreased control create Increased aerodynamic torques
- Decreased mission time



High-capacity Thermal Rejection Design and Solar Array Technology Validated



- Temperature telemetry showed stabilization within operating temperature range, even under worst case conditions while tumbling
  - Tumbling spacecraft: radiator surface less than 25% efficient because of lack of continuous view of deep space
  - Max heat dissipation during tumbling, since torque coils were operating at peak current draw to find 3-axis stabilization
- Deployable solar array technology generated a peak power of 48W, which is the highest wattage achieved by any CubeSat solar array

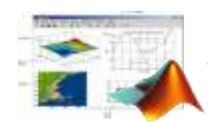
Thermal Rejection Technology Successfully Validated On-orbit

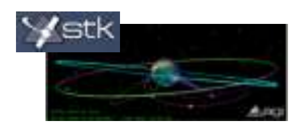
Northrop Grumman
Systems Ops Center
NGSOC

NORTHROP GRUMMAN

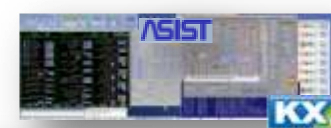
- Northrop Grumman Aerospace Systems (NGAS) has developed its own multi-mission Spacecraft Operations Center (NGSOC)
- The NGSOC reduces risk and cost by using standardized mission operations products development approach
  - Eclipse and Assist Ground Systems
  - Eclipse Telemetry Tracking and Control (TT&C) Software and Misty simulator (Raytheon)
  - ASIST Telemetry Tracking & Control (TT&C) Software (Design America)
  - Multiple workstations
- This operations center is scalable and has adaptable tools and services available to meet program specific needs
  - Visualization, Mission Planning, Data Trending Tools
  - Data Analysis Tools: MatLab, C++, AIG Satellite Toolkit (STK)
  - Remote Telemetry Display Options provide the ability to view real-time telemetry anywhere in the world and provide flexibility in staffing operations center

iPad, iPhone, Blackberry Remote Access





Integrated Ground System Tools



Plug and Play and Rapid Reaction Operations Center with Remote Access Capabilities is a Key Enabler to Responsive Space Demonstrations

Northrop Grumman Systems Ops Center NGSOC

CubeSat Supportability

NORTHROP GRUMMAN

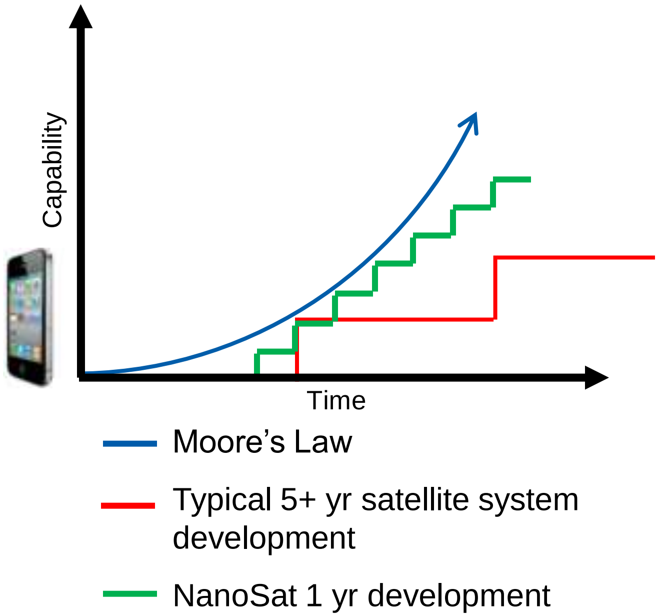
Mayflower Demonstrated the Ability to Integrate CubeSat Telemetry into COTS Ground Systems in Less than 3 Weeks

Operational Relevance

NORTHROP GRUMMAN

- Mayflower showed that NanoSats provide an opportunity to rapidly experiment and demonstrate high-end hardware and software use in space
  - Typical space programs can take more than 5 years, as opposed to less than 1 year for Mayflower
  - This progress keeps our space assets on pace with Moore's Law

- Plymouth provides scalable, rapidly deployable, and resilient architectures
  - Scalable cost/capability meets community's needs
  - Allows for development flights as easily as proliferated high-tech architectures that are resilient to events
    - Loss of a single asset does not cripple a system
  - CubeSat standard launch utilizes low-cost launch opportunities



Plymouth's unique approach to thermal management and its short development spans enables it to incorporate commercial advances and deploy them responsively

Plymouth technology advancements provide for operational relevance to augment the current space architecture

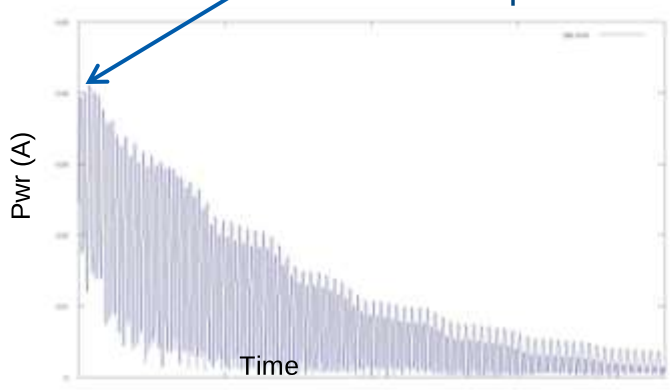
NORTHROP GRUMMAN

Attitude Determination And Control System (ADACS) Overview

NORTHROP GRUMMAN

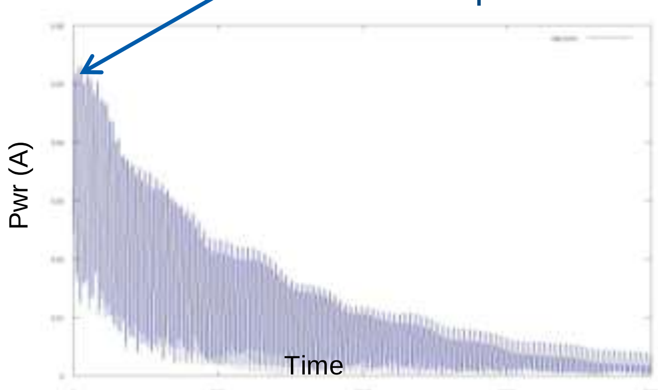
- Using the four torque coils on board, 3×10^{-5} N-m peak torque was generated and available to stabilize the spacecraft
- Exponential increases in aerodynamic torques were experienced as altitude decreased
  - Max aerodynamic torque experienced at 275 km reached over 3.0×10^{-5} N-m, which was enough to destabilize the spacecraft
- These torques were too great for the spacecraft to recover from recorded spin rates
  - System designed for spin rates of 5.7 deg/s, with a margin that allows for 12.0 deg/s
  - Initial spin rates were recorded at 10 deg/s, peak spin rates were recorded 13.5 deg/s
- When the aerodynamic torques reached a 2-fold increase on the spacecraft, one more order of magnitude of power to torque coils was required to stabilize the system

Peak: 0.04 amps



300km Altitude (1.58×10^{-5} N-m)

Peak: 0.5 amps



275 km Altitude (3.0×10^{-5} N-m)