Mayflower:  
The Next Generation CubeSat  
Flight Testbed  

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

<table>
<thead>
<tr>
<th>PLYMOUTH Capabilities</th>
<th>Mayflower Mission Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>56 W – Split Wing</td>
</tr>
<tr>
<td>Propulsion</td>
<td>59 m/s – Cold gas (Single Jet)</td>
</tr>
<tr>
<td>Metrology/Control</td>
<td>GPS/Star Tracker/ Magnetometer/ Torque Coils</td>
</tr>
<tr>
<td></td>
<td>Replaced by Payload</td>
</tr>
<tr>
<td>Communications</td>
<td>325 km Circular</td>
</tr>
<tr>
<td></td>
<td>USC CAERUS</td>
</tr>
<tr>
<td>Operations</td>
<td></td>
</tr>
<tr>
<td>Bus/Payload</td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td></td>
</tr>
</tbody>
</table>

**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: CAERUS+PLYMOUTH**

Next Generation CubeSat Flight Testbed

**Accomplishments:**
- **Short Timeframe:** 6 months to Design, Manufacture, Integrate, and Test Caerus and Plymouth
- **Low Mission Cost:** 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**

**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

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

**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 environmental 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
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.

Plug and Play and Rapid Reaction Operations Center with Remote Access Capabilities is a Key Enabler to Responsive Space Demonstrations.
Mayflower Demonstrated the Ability to Integrate CubeSat Telemetry into COTS Ground Systems in Less than 3 Weeks
Operational Relevance

- 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 technology advancements provide for operational relevance to augment the current space architecture**
NORTHROP GRUMMAN
Attitude Determination And Control System (ADACS) Overview

- Using the four torque coils on board, 3 x 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 x 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.