

MAYFLOWER: NEXT GENERATION CUBESAT FLIGHT TESTBED

Talbot Jaeger
Northrop Grumman NovaWorks, Advanced Programs & Technology Division,
One Space Park, Redondo Beach CA, 90278; (310) 813-3098
Talbot.Jaeger@ngc.com

Michael Ciffone, Eric Anden
Northrop Grumman Advanced Concepts RRS, Advanced Programs & Technology Division,
3715 Doolittle Dr, Redondo Beach CA, 90278; (310) 813-0013
Michael.Ciffone@ngc.com, Eric.Anden@ngc.com

ABSTRACT

Northrop Grumman Corporation, in partnership with Applied Minds Incorporated (AMI) and the University of Southern California (USC), completed the “Mayflower” mission as an on-orbit demonstration of CubeSat technologies. Mayflower was one of eight CubeSats launched aboard a Falcon 9 as the rocket’s first commercial payload. The CubeSats were a secondary payload on the COTS-1 flight. Northrop Grumman served as the prime system integrator for AMI’s 2U CubeSat bus and USC’s 1U communication bus.

Planned as a short testbed mission, Mayflower was successful in demonstrating next generation CubeSat bus subsystems such as high power solar arrays and power management as well as advanced thermal rejection and deployable solar arrays. In addition, it assisted in establishing new Northrop Grumman Aerospace Systems (NGAS) development and integration process for CubeSats resulting in over 300% acceleration to previous timelines. Lastly, it led to other innovative ideas for future CubeSats, which are in development for the Plymouth bus.

The demonstration mission reached its end-of-life 12 days after launch and communication was lost. The last received data showed high spin rates, which are believed to be the result of atmospheric disturbances. The design altitude was 325 km and the last recorded space-track data yielded an altitude of less than 180 km. As the orbit decayed, and as analysis predicted, the magnetic torque-coil based reaction control system was eventually overcome by the spacecraft’s high coefficient of drag to achieve 3-axis stabilization. Mayflower utilized two 30 x 40 cm deployed solar arrays to generate a peak power of 48 W, but they also contributed to the large drag coefficient for a CubeSat. Additionally, the solar arrays were directional and, in a tumbling environment, the solar arrays were not able to collect enough solar energy to maintain a positive power budget.

The Mayflower project was the smallest spacecraft built by Northrop Grumman and demonstrated a rapid response space satellite technology build and integration capability. Northrop Grumman designed, manufactured, integrated, and tested the next generation bus subsystems in six-months; a span that is significantly lower than traditional developments.

INTRODUCTION

The CubeSat specification was established by California Polytechnic University in 1999 for use by educational institutions and amateur radio enthusiasts. In recent years the nanosatellite has been used as a testbed for potential future uses by industry. Specifically, the CubeSat specification states that the satellite must be contained within a volume of 10 cubic centimeters, and must weigh less than 1.33 kg.¹ However, this convention can be scaled to lengthen the CubeSat in a single direction.

Northrop Grumman used this nanosatellite convention to create a platform where small satellite technology could be tested. Mayflower was successful in doing just that with the advanced thermal rejection and advanced deployable solar arrays. Nanosatellites, including CubeSats, have been widely accepted as an important part of the development of rapid response space systems.

A PIONEER LAUNCH

The satellite, launched on Dec. 8, 2010, was the first commercial CubeSat deployed into orbit by SpaceX. Also, it was the smallest satellite ever built by Northrop Grumman. Mayflower was launched on a Falcon 9 Dragon test mission and successfully injected into an elliptical orbit with a perigee of approximately 285 km above earth.



The system was designed to test a set of nanosatellite components in space. Following standard specifications, nanosatellites easily combine with one another onto existing rockets, and only require low development costs, making space mission participation more accessible to those outside the industry.

Data gathered from around the world was analyzed, showing all tested systems functioned correctly including a new, previously unproven advanced solar array deployment system. While this first flight collected baseline design data, subsequent flights at higher altitudes will demonstrate unique propulsion, communication and orientation capabilities, and novel payloads.

"Microsatellites are an important part of our future in advancing and maturing technologies," said Paul Meyer, vice president and general manager of Advanced Programs and Technology at Northrop Grumman Aerospace Systems.

Joint Ventures

On the subject of CubeSat partnerships, Paul Meyer said, "We are pleased to be working with Applied Minds to develop the technologies that will make microsatellites successful, and make space mission participation more accessible to nontraditional partners."

Mayflower and other nanosatellites are being jointly developed by Applied Minds and Northrop Grumman, expanding the types of payloads on satellites and,

consequently, the types of missions completed by satellites.

Built at Applied Minds in 2010, Mayflower and a payload, designed by the University of Southern California, were integrated and tested at Northrop Grumman, and then integrated into the Falcon 9 Dragon test mission by California Polytechnic State University, San Luis Obispo.

Communications from Mayflower were received at numerous locations around the world and collectively analyzed by NovaWorks, an innovation center for development and operations at Northrop Grumman. Mayflower serves as the technology development forerunner for other space products at NovaWorks.

"This was an exciting mission for us, and we are proud to be SpaceX's first nongovernment customer," said Danny Hillis, co-founder of Applied Minds. "We hope to launch many more satellites with them in the future."

Applied Minds invents, designs, creates and prototypes high technology products and services for a broad range of commercial and government applications including aerospace, transportation, education, architecture, distance collaboration, advanced visualization, electronics and software.

RAPID RESULTS

The development of the Mayflower program began in February 2010, and the satellite's design, manufacture, integration, and testing occurred within the next six months. This clearly demonstrates the Northrop Grumman rapid response space satellite technology build and integration capability. Also, this gave significant time to prepare for the December launch. The total mission cost was under \$2 million, and all parts were Commercial Off-The-Shelf (COTS) validated.

Mayflower also passed the NASA review to launch with COTS-1 as the first commercial Falcon 9 payload.

In Orbit

After launch, Mayflower was deployed among other CubeSats from the SpaceX Dragon trunk using the standard Poly Picosatellite Orbital Deployer (P-POD) module that is frequently used with CubeSats.

Although it was planned for the satellite to be launched into approximately a 325 km orbit at 34.5 degree inclination, the orbit that was achieved was a 310 by 285 km elliptical orbit with a 34.5 degree inclination. This orbit shortened the life of the testbed due to the

low perigee but still sufficed to complete the necessary payload test that the satellite was carrying.

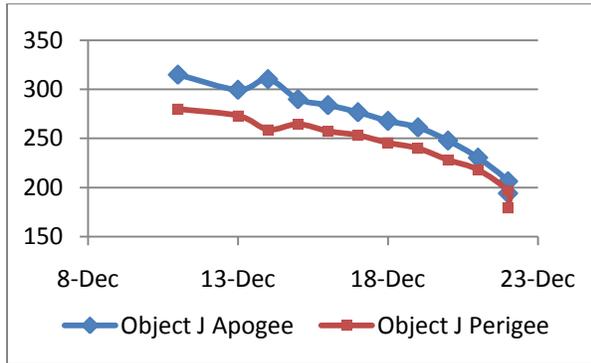


Figure 1: Object J Apogee-Perigee Trending

Using the four torque coils on board, N-m peak torque was generated and available to stabilize the spacecraft as aerodynamic torques increased. However, aerodynamic torques increased exponentially as altitude decreased, at 300 km the system experienced N-m of torque and at 275, the CubeSat experienced N-m. This meant that torques on the system were too great to recover from recorded spin rates once the spacecraft lost altitude towards its end-of-life. The system was designed to recover from a 5.7 deg/s spin rate, and the margin allows for a 12.0 deg/s spin rate. The spin rates recorded peaked at 13.5 deg/s prior to loss of communication at the end of life.

To put into perspective the impact of aerodynamic disturbances, when the aerodynamic torques generated a 2-fold increase on the spacecraft, an order of magnitude more power to torque coils was required to stabilize the system. This destabilization of the spacecraft is what eventually led to the end of its mission.

Test Validation

Although Mayflower ended its mission due to external effects on the stability of the system, the high-capacity thermal rejection design was still fully tested and validated while on orbit. Results showed that the highest power of a CubeSat solar array deployed on orbit reached a 48 W peak. Also, temperature telemetry showed stabilization within operating temperature range under worst case conditions.

Worst case conditions occurred while the spacecraft was tumbling at the end of its mission, and the radiator surface was less than 25 percent efficient, since there was no continuous view of deep space present. Also, while the spacecraft was attempting to reach stabilization during the tumbling stage, the torque coils

were operating at peak current draw (maximum heat dissipation).

End of Mission

The Mayflower demonstration was terminated when communication was eventually lost. The last received beacon data showed high spin rates believed to be the result of atmospheric disturbances. At this 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 to achieve 3-axis stabilization. As mentioned before, the design altitude was 325 km and the last space-track data indicated an altitude of 180 km and dropping.

This risk tolerant approach to development, integration and testing resulted in many lessons learned. A more robust attitude control system would reduce mission risk for future builds.

CUBESAT EVOLUTION

Mayflower, as the Next Generation Flight Testbed, well demonstrated advanced CubeSat technologies such as electronics integrated into the structural design, autonomous 3-axis stabilization, large deployable fixed solar arrays with sun-tracking, and cold-gas propulsion. This demonstration proved useful in validating research in developing the Next Generation CubeSat Bus – Plymouth.

Next Steps

The Plymouth Next Generation CubeSat Bus is currently in development to create high-precision integrated Attitude Determination and Control System (ADACS), high-power generation, and integrated S-band communication. The ADACS on the Plymouth will have a less than 0.5 degree pointing accuracy with more than 50 m/s, and up to 300 m/s, delta-v capability. The high-power generation will include a 100 W deployable solar array, and Electrical Power Subsystem (EPS) optimized to provide more than 50 W to the payload. The S-band communication will include a tunable 0.3 to 3 GHz S/W defined radio, with greater than 1 Mbps data rates.

Given that the Plymouth is tested and validated, responsive space systems would be opened up to a multitude of future rapid demonstration and validation of commercial hardware and software approaches. Some of these approaches include smart phone hardware, Central Processing Units (CPUs) and solid state storage, miniature optics, Inertial Measurement Units (IMUs), Global Positioning System (GPS), and Plug and Play (PnP) avionics integration.

Also, other future opportunities would include on-orbit demonstrations of distributed/sparse architecture technologies. These would include Beyond Line-Of-Sight (BLOS) communication, data exfiltration, Intelligence Surveillance and Reconnaissance (ISR), and Space Situational Awareness (SSA).

All of these opportunities will require that proper tests are validated, which is the reason for why the Mayflower testbed and Plymouth CubeSat bus are so important.

Operations Center

In addition to the demonstrations made in orbit, Northrop Grumman has also developed its own multi-mission spacecraft operations center (NGSOC). The NGSOC reduces risk and cost by using a standardized mission operations products development approach. This approach includes Eclipse and Assist Ground Systems, Eclipse Telemetry Tracking and Control (TT&C) software, Eclipse Telemetry Tracking and Control (TT&C) simulator (provided by Raytheon), ASIST TT&C software (provided by Design America), as well as multiple workstations.

This operations center is scalable and has adaptable tools and services available to meet program specific needs. Some of the tools that the center uses are visualization, mission planning, and data trending tools. Also, this includes some data analysis tools such as MatLab, C++, and AIG Satellite Tool Kit (STK). Remote Telemetry Display Options provide the ability to view real time telemetry anywhere in the world and provides flexibility in the staffing operations center.

PnP and rapid reaction ground with remote access capabilities is a key enabler to responsive space demonstrations such as Mayflower, and will be used for the Plymouth CubeSat bus and other future uses. The Mayflower mission demonstrated the ability to integrate CubeSat telemetry in COTS ground systems in less than 3 weeks.

CONCLUSION

The Mayflower Next Generation Flight Testbed showed that nanosatellites provide an opportunity to rapidly experiment and demonstrate hardware and software use in space. As opposed to typical satellite system development which can take more than five years, nanosatellites only take up to one year to develop. This keeps space assets on pace with Moore's Law which predicts exponential growth in computing processing power.

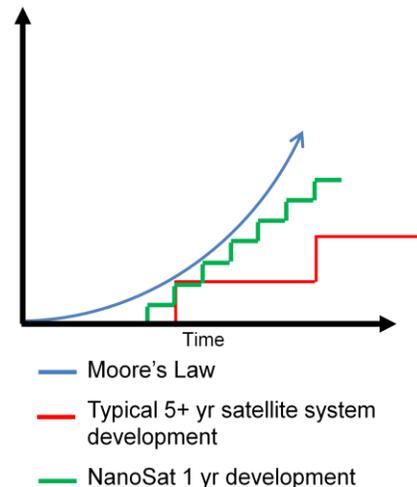


Figure 2: Moore's Law Comparison with Nanosatellites

Nanosatellites shorter development spans enable them to incorporate commercial advances and deploy them in a responsive way.

Also, NGSOC's multi-mission, standardized, modular ground system approach enables the cost-effective demonstrations that have already been made with Mayflower, and which will be continued in the future.

The Mayflower testbed is a pioneering step in the direction to take commercial technology to space, and to demonstrate and validate new technologies as they come along. New technologies will further push the industry in the direction that it's already headed, with Northrop Grumman and its CubeSat development partners leading the way in development, integration, and testing of CubeSats.

References

1. *CubeSat in the News*. 2011. Web. 01 June 2011. <<http://www.cubesat.org>>.