NASA's CubeQuest Challenge – From Ground Tournaments to Lunar and Deep Space Derby.

The First Flight of NASA's Space Launch System will feature 13 CubeSats that will launch into cis-lunar space. Three of these CubeSats are winners of the CubeQuest Challenge, part of NASA's Space Technology Mission Directorate (STMD) Centennial Challenge Program. In order to qualify for launch on EM-1, the winning teams needed to win a series of Ground Tournaments, periodically held since 2015. The final Ground Tournament, GT-4, was held in May 2017, and resulted in the Top 3 selection for the EM-1 launch opportunity. The Challenge now proceeds to the in-space Derbies, where teams must build and test their spacecraft before launch on EM-1. Once in space, they will compete for a variety of Communications and Propulsion-based challenges. This is the first Centennial Challenge to compete in space and is a springboard for future in-space Challenges. In addition, the technologies gained from this challenge will also propel development of deep space CubeSats.

I. Introduction – CubeSats and Government Challenges

A. CubeSats – Where are they now?

While CubeSats have been around for many years, they have stayed in the Low Earth Orbit (LEO) regime. Now that they have been established at the LEO level, and Commercial Off The Shelf (COTS) solutions have been successful both on the hardware and launch side of the mission, the next logical step is to take CubeSats beyond LEO. A successful Deep Space CubeSat mission will take more than just launching a LEO CubeSat into deep space, however. Two key technology areas that can be improved for deep space missions are communications and propulsion. For LEO CubeSats, propulsion is usually only necessary for attitude control functions (which can also be accomplished by other means). Radios also don't need to be terribly powerful, and often run on amateur frequencies. Many companies and startups have been working on propulsion solutions and Deep Space Network (DSN) compliant radios, but have yet to actually fly them. With NASA's Space Launch System (SLS) launching 13 6U sized CubeSats into cis-lunar space in 2018, the time to prove out Deep Space CubeSats has come.

B. Government Challenges and NASA's Centennial Challenges

Government or corporate sponsored technical "challenges" have been around since the pre-industrial age. More recently, challenges have rewarded accomplishments in aerospace, including Charles Lindbergh's flight across the Atlantic in 1927, and Scaled Composite's Ansari X-Prize win in 2004. In 2005, NASA started the Centennial Challenge Program (CCP) as a way to incentivize development of relevant technologies in the private sector. Unlike large contracts with large overhead, the CCP focuses on technology and goals that student groups, startups and independent investors can participate in. Since its inception, the CCP has rewarded groups and individuals for developments in Astronaut Gloves, Regolith Excavation and 3D Printed Habitats, among others.

II. A Brief History of the CubeQuest Challenge

With past Challenges being in the realm of rocketry and rovers, having a spacecraft design challenge centered on CubeSats seemed like a natural fit. With an industry ready for deep space launch

opportunities, and with NASA's own deep space launch vehicle in development, the time for investment into deep space CubeSat technologies had come.

A. The Roots of CubeQuest

How the CubeQuest challenge was created, in terms of goals, judging criteria, etc.

B. Ground Tournament 1

Ground Tournament 1, held in the summer of 2015, was the first graded round of the Ground Tournaments. Along with $20,000 in prize money, teams were competing for a Top 5 slot, which would help them in qualifying for a potential EM-1 launch slot. In terms of mission timeline, GT-1 represented what a Mission Concept/Systems Requirements Review (MCR/SRR) would be in the NASA realm. GT-1 was also the opportunity for teams to make their first impressions, and for judges to see where the competition was going. Out of the 13 teams that participated in GT-1, the Top 5 teams were:

1. Team Miles, Tampa, FL
2. MIT KitCube, Cambridge, MA
3. Cornell CisLunar Explorers, Ithaca, NY
4. Novel Engineering, Coca Beach, FL
5. Ragnarok Industries, Wilmington, DE

C. Ground Tournament 2

Ground Tournament 2 was held in the spring of 2016, and graded teams both on their improvement from GT-1, as well as making sure the missions were at a Preliminary Design Review (PDR) level of maturity. At stake was $30,000 in prize money for each of the Top 5 finishers, as well as more eligibility for an EM-1 launch slot (for those teams not in the Top 5 for GT-1). The Top 5 of the 10 teams that participated in GT-2 were:

1. Cornell CisLunar Explorers, Ithaca, NY
2. MIT KitCube, Cambridge MA
3. SEDS Triteia, La Jolla, CA
4. University of Colorado CU-E3, Boulder, CO
5. Team Miles, Tampa FL

D. Ground Tournament 3

Nearly a year and a half separated GT-2 from GT-3, giving the teams ample time to improve their designs. GT-3 had no relevance when it came to EM-1 launch eligibility, but did offer a $30,000 price to the Top 5 finishers. GT-3 was analogous to a Critical Design Review (CDR) in NASA parlance, and teams had to show significant effort and confidence in their mission designs. This level of development brought the competition down to seven participating teams, the Top 5 being:

1. Team Miles, Tampa, FL
2. Cornell CisLunar Explorers, Ithaca, NY
3. University of Colorado CU-E3, Boulder, CO
4. MIT KitCube, Cambridge, MA
5. SEDS Triteia, La Jolla, CA

E. Ground Tournament 4

Ground Tournament 4 was the final on-earth tournament - the team's final opportunity to show off their designs before launch. Teams that were in the Top 5 for either GT-1 or GT-2 must finish in the Top 5 for GT-4 to be eligible for an EM-1 launch opportunity. The Top 5 teams also received $20,000 in prize money. GT-4 was situated a year before delivery to SLS (for EM-1 teams), placing the tournament between a CDR and FRR in the traditional timeline. In terms of project schedule, many teams were in the middle of integration and testing activities, but nevertheless had data to show the judges, who had to project the likelihood of team's progress until hardware delivery. The Top 5 team were:

1. Announced June, 2017
2. Announced June, 2017
3. Announced June, 2017
4. Announced June, 2017
5. Announced June, 2017

III. What Comes Next – The Teams and their Missions

Now that the Ground Tournaments are over, the remainder of the Challenge will happen in space. For 365 days after the launch of EM-1, the winning Ground Tournament teams (and any other teams that have acquired their own launch) will seek to fulfill their propulsion, communication, and longevity goals.

A. Winning Team 1

Mission description, including mission ConOps, and hardware descriptions.

B. Winning Team 2

Mission description, including mission ConOps, and hardware descriptions.

C. Winning Team 3

Mission description, including mission ConOps, and hardware descriptions.

D. Other teams – 3rd party launch opportunities

Mission description, including mission ConOps, and hardware descriptions.

IV. Conclusions

Input from competitor teams about pros/cons to this particular challenge. Lessons learned from Project Management side of the Challenge, and the path forward.