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**NASA Centennial Challenges in Collaboration with Ames Research Center**  
Marshall Space Flight Center, Alabama 35812

**Cube Quest Challenge**  
**Ground Tournaments, Deep Space Derby,**  
**and Lunar Derby**

**Required Navigation Artifacts**

for

Authenticating Claimed Communications Distances, and  
Verifying Achievement and Maintenance of Lunar Orbit for  
Compliance with Cube Quest Challenge Rules

NASA Centennial Challenges – CubeSat Challenge

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**Revision History**

<b>Date</b>	<b>Version</b>	<b>Change Description</b>
6 January, 2015	Draft 1.4	Initial “draft” release
24 March, 2017	Baseline release	No changes to content
11 December, 2020	Rev. A	<ol style="list-style-type: none"> <li>1. Rename the document to “Required Navigation Artifacts”</li> <li>2. Section 4.1.1, 4.1.2, 4.2.1, 4.2.2 Distance between the ground station is changed to 3000 km.</li> <li>3. Deep space derby requirement changed to 3M km</li> <li>4. Added Section 5</li> <li>5. Reorganize the document with section titles and numbers</li> <li>6. Added Table of Content</li> </ol>

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# 1 Overview

## 1.1 Scope and Purpose

The purpose of this document is to describe the required navigation artifacts for Authenticating Claimed Communications Distances, and Verifying Achievement and Maintenance of Lunar Orbit for Compliance with Cube Quest Challenge Rules. The document first provides an introduction to the Cube Quest Challenge, and lists the reference document. Then the two methods of submitting the navigation artifacts are described. In section 4, the rules of generating navigation artifacts and rules of claims/achievements authentication will be discussed. Final section explains the rules for the competition teams obtain their own launch.

## 1.2 Project Introduction

The Cube Quest Challenge (CQC) of the Centennial Challenges Program (CCP) take qualified small satellites to demonstrate their operational techniques and technologies. The spacecrafts will demonstrate meaningful space operations in some manner. After a series of Ground Tournaments (GTs), qualified competitor teams will be offered a secondary payload launching opportunity on NASA’s Artemis I Mission, planned for no earlier than November 4, 2021. These spacecrafts will be inserted into a trans-lunar trajectory for in-space Challenge purposes. Competitor teams may also select a third-party launch provider to participate these Challenges. The Deep Space Derby Challenge will be conducted once competing team CubeSats have achieved, and maintain, a range of 3 million kilometers from Earth. The Lunar Derby Challenge will be conducted once competing team CubeSats have successfully achieved, and maintain, a verifiable lunar orbit as described in the Cube Quest Challenge Operations and Rules (OPSRUL). Prizes will be awarded to the teams who achieve communication, navigation and longevity objectives that have submitted navigation artifacts to authenticate the claimed achievement.

In the Deep Space Derby and Lunar Derby, the Centennial Challenge Program (CCP) Cube Quest Judges will verify that communications achievements eligible for Cube Quest Challenge prizes are performed under the prescribed conditions specified in the Rules. To enable verification, Teams are required to submit to Judges acceptable Navigation Artifacts defined here and according to procedures described here.

Judges use the Navigation Artifacts to ensure compliance with Cube Quest Challenge Rules. CCP Judges use the Navigation Artifacts to authenticate claimed CubeSat communications distances. CubeSat communications must occur from a range beyond 3 million kilometers for eligibility for the Deep Space Derby Prizes. The CCP Judges also

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use Navigation Artifacts to verify claims that CubeSats have achieved and maintain a verifiable lunar orbit, for eligibility for the Lunar Derby Prizes.

This document describes the navigation artifacts required for the following objectives: (1) authenticating claimed Cube Quest communication distances, and (2) verifying the achievement and maintaining of Lunar Orbit for compliance with Cube Quest Challenge rules described in the Cube Quest Challenge Operation and Rules Rev. D.

All of the rules, constraints, and definitions found in the Cube Quest Challenge Operations and Rules (OPSRUL) apply to this document. If any conflicts are found between this document and the ORSUL, then the ORSUL normally takes precedence unless the NASA Cube Quest management office makes a waiver or notification in writing.

## 2 Applicable Documents

This document adheres to the Cube Quest Challenge operation and rules documents listed below.

Document Name	Doc No.	Revision
Cube Quest Challenge Operations and Rules	CCP-OPSRUL-001	Rev. D
Communications Procedure for Both In-Space Challenges	CCP-CQC-COMSPROC-001	Rev. A

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### 3 Navigation Artifacts Submission

Teams participating in one of the two In-Space Derby can submit Navigation Artifacts by one of the following two Approaches.

#### 3.1 Submission Approach I

Teams may submit Navigation Artifacts based on telemetric data generated by DSN ground/tracking stations. Note that Teams would not be charged for using DSN communications/tracking services *strictly for the purpose of generating Navigation Artifacts (only)*. (There is, however, a charge for using DSN services as the Team’s primary communications ground station for communications achievements eligible for Prizes. See Cube Quest Rules.)

#### 3.2 Submission Approach II

Teams may submit Navigation Artifacts based on telemetric data generated by their own (or procured) communications ground/tracking stations. Note also that there is no requirement that Teams include a DSN RF-compatible transponder; however, in that case they must use their own ground stations to generate the required Navigation Artifacts for submittal to CQC Administrators.

### 4 Navigation Artifacts Generation and Claim/Achievement Authentication

This section describes the rules of Navigation Artifacts generation using DSN Ground Station and non-DSN Ground Stations. Also, rules of claim/achievement authentication will be discussed.

#### 4.1 Using DSN Ground Stations to Generate Navigation Artifacts

Teams may use NASA DSN services to generate Navigation Artifacts, providing that their CubeSats have DSN RF-compatible transponders. Teams must use X or S band, DSN RF-compatible transponders on their CubeSat. Teams give frequencies for up and down link, and give ephemeris files, in Consultative Committee for Space Data Systems (CCSDS) Orbit Ephemeris Message (OEM) format.

DSN can “shadow track” CubeSat communications with 3<sup>rd</sup> party ground stations, in compatible X- and S-band spectra, by monitoring carrier signals and without needing to demodulate the information on the carrier signals.

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Teams must coordinate with DSN, for review of their shadow track plans with their DSN RF-compatible transponders prior to Ground Tournament 4. In most cases, DSN will waive an RF-Compatibility testing requirement with the Cubesat transponder, if the teams provide a copy of the compatibility test report with their tracking station.

DSN will "shadow track" the downlink carrier signal of the CubeSats and deliver the Doppler data to the Challenge Judges and to JPL MDNAV Section team via Cube Quest Challenge Administrator. The JPL MDNAV Section will authenticate claimed communications distances and verify achievement and maintenance of lunar orbit, and advise Judges accordingly.

**4.1.1 Authenticate Claimed Communication Distance**

For eligibility for Prizes, in conjunction with each communications achievement submitted, Teams must coordinate with DSN so that DSN can obtain one of the following:

1. 8 hours of 2-way Doppler tracking within 1 week of the claimed achievement, or
2. 8 hours of 1-way Doppler tracking within 1 week of the claimed achievement, where frequency stability ( $\Delta f/f$ ) is less than or equal to  $10^{-12}$  over a 24 hour period, or
3. 8 hours of simultaneous 1-way Doppler tracking from stations separated by at least 3000 km within 1 week.

**4.1.2 Authenticate Achievement/Maintenance of Lunar Orbit**

At minimum, competitors must coordinate with DSN so that DSN can obtain at one of the following:

1. 2-way Doppler tracking for one orbital period within 1 week of the claimed achievement of lunar orbit, or
2. 1-way Doppler tracking for one orbital period within 1 week of the claimed achievement of lunar orbit, where frequency stability ( $\Delta f/f$ ) is less than or equal to  $10^{-12}$  over a 24-hour period, or
3. Simultaneous 1-way Doppler tracking for one orbital period from stations separated by at least 3000 km within 1 week (no stringent  $\Delta f/f$  requirement)

The predicted CubeSat trajectory during the tracking interval must be provided in Consultative Committee for Space Data Systems (CCSDS) Orbit Ephemeris Message (OEM) format.

No radiometric ranging data is required.

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NOTE:

1. if the orbit tracking data is not continuous due to lunar occultations of the spacecraft, it should cover most of the orbit that is not occulted, and all of the data should be within 4 revolutions.
2. If the Team’s CubeSat transponder signal is coherent, then it’s possible for DSN to obtain 3-way Doppler if Teams notify DSN of Team’s ground station location and uplink frequency, and notify DSN of transmission dates and times.
3. If the Team’s transponder signal is non-coherent, then it is possible for DSN to obtain 1-way Doppler tracking data. DSN will track with two DSN complexes in parallel and JPL MDNAV will use difference techniques on the 1-way data to generate the information.

**4.2 Using Non-DSN Ground Stations to Generate Navigation Artifacts**

The navigation data described below must be submitted for every CubeSat transmission submitted for purposes of the in-space competitions. Date and time stamps must be included as directed in the Rules. Ground station operators employed by the Team must affirm by their signature, the accuracy of all information submitted.

CCP reserves the right to assign a NASA-designated inspector to witness any operations. Teams will notify Cube Quest Administrators in advance of dates and times of ground stations operations, so that NASA-designated inspectors may travel for on-site witness.

**4.2.1 Authenticate Claimed Communication Distance**

At minimum, competitors must provide at least one of the following to Cube Quest Administrators, who will forward to JPL’s MDNAV Section:

1. 8 hours of 2-way Doppler tracking within 1 week of the claimed achievement, or
2. 8 hours of 1-way Doppler tracking within 1 week of the claimed achievement, where frequency stability ( $\Delta f/f$ ) is less than or equal to  $10^{-12}$  over a 24 hour period, or
3. 8 hours of simultaneous 1-way Doppler tracking from stations separated by at least 3000 km within 1 week, or
4. 10 astrometric measurements spanning at least 2 days (e.g. collected over 3 nights) within 1 week.

Some additional specifications on these tracking artifacts are:

1. The predicted CubeSat trajectory during the tracking interval must be



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- provided in Consultative Committee for Space Data Systems (CCSDS) Orbit Ephemeris Message (OEM) format.
2. The tracking data must be provided in CCSDS Tracking Data Message (TDM) format.
  3. Transmit/receive frequencies may be provided instead of Doppler shift data.
  4. No radiometric ranging data is required.
  5. If using Doppler data, it should have an accuracy of 1 mm/sec over a 60 second compression period; a minimum of one data point per minute must be provided. 2-way Doppler may be reconstructed using telemetry instead of using a transponder.
  6. Astrometric measurements should be accurate to 1 arc-sec (5  $\mu$ rad) or better, which can be done with a 30 cm telescope if the CubeSat has a laser. Use of the Table Mountain Observatory could provide better accuracy if available. Astrometric measurements should be roughly equally spaced, if possible.

Teams may provide additional data that they feel strengthens their case at their discretion.

#### 4.2.2 Authenticate Achievement/Maintenance of Lunar Orbit

At minimum, competitors must provide at least one of the following to Cube Quest Administrator, who will forward to JPL's MDNAV Section:

1. 2-way Doppler tracking for one orbital period within 1 week of the claimed achievement of lunar orbit, or
2. 1-way Doppler tracking for one orbital period within 1 week of the claimed achievement of lunar orbit, where frequency stability ( $\Delta f/f$ ) is less than or equal to  $10^{-12}$  over a 24 hour period, or
3. Simultaneous 1-way Doppler tracking for one orbital period from stations separated by at least 3000 km within 1 week (no stringent  $\Delta f/f$  requirement), or
4. At least 20 astrometric measurements covering at least one orbital period within 1 week.

NOTE: if the orbit tracking data is not continuous due to lunar occultations of the spacecraft, it should cover most of the orbit that is not occulted, and all of the data should be within 4 revolutions. Astrometric measurements should be roughly equally spaced, where possible.

#### 4.3 Additional Specifications for Artifacts Tracking

Some additional specifications on these tracking artifacts are:

1. The predicted CubeSat trajectory during the tracking interval must be provided in

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CCSDS OEM format.

2. The tracking data must be provided in CCSDS TDM format.
3. Transmit/receive frequencies may be provided instead of Doppler shift data.
4. No radiometric ranging data is required.
5. If using Doppler data, it should have an accuracy of 1 mm/sec over a 60 second compression period; a minimum of one data point per minute must be provided. 2-way Doppler may be reconstructed using telemetry instead of using a transponder.
6. Astrometric measurements should be accurate to 1 arc-sec (5  $\mu$ rad) or better, which can be done with a 30 cm telescope if the CubeSat has a laser. Use of the Table Mountain Observatory could provide better accuracy if available.

Teams may provide additional data that they feel strengthens their case at their discretion.

## 5 Teams Use Third-Party Launchers

Competing teams may use third-party launchers to enter the In-Space Challenges. If the teams use NASA DSN services to generate navigation artifacts, all the requirements described in section 4.1 will be applicable. If the teams use non-DSN ground station to generate navigation artifacts, the data submitted shall meet the specification described in section 4.2. Additional specifications described in section 4.3 are applicable to both methods. All the navigation artifacts shall be submitted to Cube Quest Challenge Administrator.