

Cube Quest Challenge

Ground Tournament Submittal
Requirements and Standardized
Judging Criteria

(Ground Tournament Workbook)

5 June 2015

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Ground Tournaments

Objective

The Ground Tournaments (GTs) are a series of four ground-based activities and reviews, based on tests, engineering data, and analyses supplied by Competitor Teams. The GTs allow NASA to gain or achieve the following:

- Insight into Competitor Team's spacecraft and mission designs;
- Assess technical progress
- Evaluate the likelihood of achieving Challenge goals based on standardized assessments;
- Confirm design compliance with Space Launch System (SLS) and Challenge requirements;
- Incentivize progress with intermediate prize awards.

Judging

A panel of Centennial Challenge-appointed Judges will review the submitted material. Judges may consult with NASA Subject Matter Experts (SMEs), but Judges are the final arbiters for assessments of compliance with Rules and scores in accordance with the Rules. Judging criteria and expected design maturity progressively advance for each successive GT review. All Competitor Teams are judged by the same standardized criteria. After each GT, the Judges will provide Competitors numeric scores based on the standardized assessment criteria in two categories:

- 1) Design maturity and likelihood of achieving Challenge goals – worth 40% of total score
- 2) Compliance with documented Challenge Rules and documented EM-1 safety and interface requirements – worth 60% of total score

Scores will be based on a scale from 1 (low, poor) to 5 (high, superb). Competitor Team composite scores may be posted on the Challenge website after each GT.

Any Competitor Team registered for the Deep Space Derby or the Lunar Derby (or both) may participate in any or all of the GTs. Competitor Teams seeking a NASA launch opportunity on EM-1 must participate in at least the final GT (GT4) in order to be considered for EM-1 integration.

Ground Tournament Instructions

Instructions to Teams

1. Teams are responsible to download and read the current version of the Operations and Rules document, the Ground Tournament Work Book containing the two Judge's Scorecards, the Mission Concept Data Packet definition document, and all other related documents from <http://www.nasa.gov/cubequest/reference>. The Operations and Rules document is the governing document.

2. Teams should refer to the two scorecards included in the Ground Tournament Work Book, titled "Score Card 1 – Likelihood of Success", and "Score Card 2 – IDR & Rules Compliance". Along the top of the evaluation matrix, there are lists of Team Submittals that serve as the inputs for Judge's assessments. The assessment criteria are shown in the matrix - "Likely to Achieve Lunar Orbit", and so on.

The various required submittals are all listed in section "Team Submittals Checklist". Some required submittals have more detailed instructions in the supporting Evaluation Criteria sections of the Ground Tournament Workbook. For example, there is a long list of radio communications data requested in "Communications Evaluation".

3. Each team shall submit documents, analyses, drawings, and other data that the team proposes to be the basis of the score for each Judged Element. The respective supporting Evaluation Criteria Sections list required submittals and other required data details. Teams are not limited to items seen in the supporting tabs. Teams may submit additional documents and data that may enhance their score, per the scoring criteria in the two Judge's Score Cards included in the Ground Tournament Work Book.

Team must also submit documents and information specified in the Mission Concept Registration Data Package.

4. Submittals are due in the format and date specified in the Cube Quest Challenge Operations and Rules document. The current version of the document is available at: http://www.nasa.gov/sites/default/files/atoms/files/revision_b.pdf. Due date and milestones may be repeated in the "Team Submittals Checklist", but in case of any conflict or anything is missing, the Operations and Rules document is the correct definitive reference.

Instructions to Judges

1. Judges will be intimately acquainted with Operations and Rules, the Judge's Score Cards, and all supporting documents.

2. Judges will receive from the Cube Quest Administrator a package of submittals from all participating teams on the date(s) specified in the Operations and Rules document for each ground tournament and/or in-space competition.

3. For each package of submittals received from the teams:

3.1 Judges will fully review the entire collected body of the Team's submittals

3.2 For every element on the two Judge's Score Cards, judges will assess the full collection of submittals. Assessments will be performed in accordance with the following:

- a. Cube Quest Challenge Operations and Rules document (current versions)
- b. Secondary Payload Interface Definition and Requirements Document (IDRD)
- b. Identified elements on the two Judge's Scorecards
- c. Evaluation Criteria identified in the Ground Tournament Workbook

3.3 Judges may consult NASA Subject Matter Experts (SMEs) to perform analysis, simulation, or to advise and interpret the submitted information.

3.4 Judges will insert a numeric score based on the judging criteria of the two Judge's Score Cards: "Score Card 1 – Probability of Success", and "Score Card 2 – IDRD & Challenge Rules Compliance". Numeric score definitions and guidance are given in the Appendix A of this Ground Tournament Workbook, Ground Tournament Success Criteria, for each respective Ground Tournament. The expected degree of progress maturity for team submittals at each ground tournament is defined in Appendix A Ground Tournament Success Criteria.

3.5 Judges will total and average the scores as follows:

a) Score Card 1 – Likelihood of Mission Success (worth 40% of total score)

- 1) In each light green cell in the matrix called "Likelihood of achieving each condition", enter a numeric score. Definitions of numeric scores are found in Appendix A, Ground Tournament Success Criteria.
- 2) Based on Team-selected list of Prizes team intends to attempt to win, which teams submit in their MCRDP Section 2.2, put a "y" in column labeled "Team intends to win this Prize (shown at right)? y/n"
- 3) For each row you marked with a "y", add the values entered in light green colored cells, and enter the average (total divided by number of light green cells in that row) in column labeled "Likelihood of meeting all relevant conditions"
- 4) Transfer the averages of each row (applicable as marked by a "y" in "Team intends to win this Prize", over to the column for the current GT.
- 5) Total the averages in the column for the current GT and average by dividing by the total number of Prizes intended by this team (that is, the number of rows marked "y").

b) Score Card 2 - Compliance with Challenge Rules and IDRD (worth 60% of total score)

- 1) Average the scores for each section as shown on the IDRD Scorecard.
- 2) The cumulative score for Scorecard 2 will be an average of all three sections.

Definitions

Ground Tournament Workbook – this document, called the Ground Tournament Submittal Requirements and Standardized Judging Criteria (aka the “Ground Tournament Workbook”).

Judge's Score Card – Comprised of two parts, the Judge’s Scorecard provides the criteria and evaluation of the Ground Tournament Workbook are the Judge's Score Cards. Part 1 is the Likelihood of Mission Success Score Card; the value on this card comprises 40% of your final Ground Tournament score. Part 2 is the Compliance with Challenge Rules and IDRDR Score Card; the value on this card comprises 60% of your final Ground Tournament score. The Judge's Score Cards tells judges how to numerically score all the team submittals. The Judge's Score Cards don't tell teams what to submit at all.

In-space Prize(s) Achievements - these are the threshold (minimum values) for in-space Prizes as defined in the Cube Quest Challenge Rules. Your "Likelihood of Mission Success" is determined by Judges. Judges determine how likely a team is to achieve all the Prizes that they indicate they intend to compete for. You indicate your intention to compete for which Prizes as part of your Team Submittals.

Team Submittals - these are documents, data, reports, analyses, that are required by: The Cube Quest Challenge Operations and Rules, the Secondary Payload User's Guide, the SLS Interface Definition Requirements Document (IDRD) (to be published later), and as listed in the Judge's Workbook in various tabs. The Judge's Workbook has Workbook has a handy Team Submittals Checklist tab (Tab 4).

Team Submittals Checklist – this section of the Ground Tournament Workbook lists all the expected "submittals" - data, documents, reports, and analyses, the Judges expect to see and the milestones at which they are due.

Acronyms

ADCS	Attitude Determination Control System
cm	centimeter
CQC	Cube Quest Challenge
CY	Calendar Year, January to December
dpi	dots per inch
EM-1	Exploration Mission
FY	Fiscal Year, October to September
GT	Ground Tournament
GNC	Guidance and Navigation Control
GRC	Glenn Research Center
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
ICD	Interface Control Document
IDD	Interface Definition Document
IDRD	Interface Definition and Requirements Document
kg	kilogram
km	kilometer
KPP	Key Performance Parameters
KSC	Kennedy Space Center
MAF	Michoud Assembly Facility
MCR	Mission Concept Review
MCRDP	Mission Concept Registration Data Package
MPCV	Multi-Purpose Crew Vehicle
MSA	MPCV Spacecraft Adapter
MSFC	Marshall Space Flight Center
NASA	National Aeronautical and Space Administration
pdf	portable document format

RF	Radio Frequency
SLS	Space Launch System
SME	Subject Matter Expert
SPDS	Secondary Payload Deployment System
SPIM	Secondary Payload Integration Manager
SPUG	Secondary Payload Users Guide
SRD	System (Subsystem) Requirement Document
SSC	Stennis Space Center
TLI	Trans-Lunar Injection
u	Satellite unit of measure, 1 U = 10 cm x 10 cm x 10 cm (cubic volume)
VAB	Vehicle Assembly Building
W	Watt

Judge's Score Card 1 – Likelihood of Mission Success – 40% of Team Score

Teams Submittals: Teams provide 30 days prior to GT. All required submittals are listed in Submittals Checklist section of GT Workbook.

ConOps	ConOps	CubeSat Architecture	CubeSat Architecture	CubeSat Architecture	CubeSat Architecture	CubeSat Architecture	CubeSat Architecture
Conceptual Mission Design	Conceptual Mission Design	Engineering Drawings (as avail)	Submittals listed in GT Workbook Section Comm	Submittals listed in GT Workbook Section Comm	Conceptual Mission Design	Planned CubeSat Durability & Reliability Approach	Planned CubeSat Durability & Reliability Approach
Planned Orbit/trajectory Design	Planned Orbit/trajectory Design	Planned Durability and Reliability Approach	Submittals listed in GT Workbook Section GNC & ADCS	Conceptual Mission Design	Submittals listed in GT Workbook Section GNC & ADCS	Submittals listed in GT Workbook Section Longevity	Submittals listed in GT Workbook Section Longevity
Submittals listed in GT Workbook Section GNC & ADCS	Submittals listed in GT Workbook Section GNC & ADCS	Submittals listed in GT Workbook Section Longevity		Submittals listed in GT Workbook Section GNC & ADCS			

Judges: Assess Team Submittals per Workbook Evaluation Sections; Evaluate Results Per Workbook Success Criteria, and Follow Judges Workbook Instructions to Assign Numeric Scores for this GT

- 0 - Team submittals are incomplete; do not effectively address how team might achieve team-specified Prize(s); team unlikely to achieve team-specified Prizes.
- 1 - Team submittals just marginally adequate, do little to demonstrate how team will achieve Prize; just possible team will achieve team-specified Prize(s)
- 2 - Team submittals show sufficient progress and demonstrate that team could reasonably achieve specified Prize(s)
- 3 - Team submittals maturing well as planned and expected; are sound basis for expecting good likelihood of achieving specified Prize(s)
- 4 - Team submittals are substantial, ahead of expectations for this milestone; demonstrate very good chance of achieving specified Prize(s)
- 5 - Team submittals are superior and well exceed expectations for this milestone; submittals convincingly demonstrate excellent likelihood to

The expected degree of progress maturity for team submittals at each ground tournament is defined in Appendix A -Ground Tournament Success Criteria of the Ground Tournament Workbook.

Judges receive submittals above; judges assess submittals as described in referenced GT Workbook Sections

Assess above submittals as described in GT Workbook Section GNC and ADCS	Asses above submittals as described in GT Workbook Section GNC and ADCS	Assess above submittals as described in GT Workbook Section Longevity	Assess above submittals as described in GT Workbook Section Comm	Assess above submittals as described in GT Workbook Section Comm	Assess above submittals as described in GT Workbook Section GNC and ADCS	Assess above submittals as described in GT Workbook Section Longevity	Assess above submittals as described in GT Workbook Section Longevity
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Based on assessments from the respective GT Workbook Sections above, Judges determine likelihood of achieving for each condition listed below. Conditions colored light green are considered to be necessary contributors toward achieving associated Prize on far right.

Contributing to Prize Achievement	Likelihood of achieving each Condition								Likelihood of meeting all relevant conditions	Judges assign numeric scores (0-5) per Instructions for each GT				Team intends to win this Prize (shown at right)? y/n	Prize Achievements
	Likelihood of achieving ≥ 1 Lunar Orbit? Likelihood of achieving trajectory, sufficient delta V?	Likelihood of maintaining Lunar Orbit? Likelihood of station keeping, sufficient delta V?	Likelihood of surviving to reach range ≥ 4M km?	Likelihood of closing comm link from range of moon?	Likelihood of closing comm link from ≥ 4M km?	Likelihood of pointing directional elements as necessary? (Perfect score if no directional elements are required to maintain power or close comm link)	Likelihood of surviving ≥ 30 min, including power management, rad tolerance, durability of parts and other factors in GT Workbook Longevity Sect.?	Likelihood of surviving ≥ 28 days, including power management, rad tolerance, durability of parts and other factors in GT Workbook Longevity Sect.?		GT-1	GT-2	GT-3	GT-4		
	N/A	N/A		N/A				N/A	<- Combined likelihood of all light green cells in this row					y/n	Best Burst Data Rate: receives a cumulative volume of error-free data (above the minimum volume of one 1024 bit data block) from their CubeSat over a 30-minute period
	N/A	N/A		N/A					<- Combined likelihood of all light green cells in this row					y/n	Largest Aggregate Data Volume Sustained Over Time: minimum volume of one thousand 1024 bit data blocks from their CubeSat over their best contiguous 28-day (calendar days) period
	N/A	N/A		N/A					<- Combined likelihood of all light green cells in this row					y/n	Spacecraft Longevity: at least 28 elapsed number of competition days, between the date of their first and last, confirmed reception of error-free, 1024-bit data blocks from their CubeSat while maintaining at least the minimum required distance from Earth, and before the "End of Competition" (above the minimum number of 28 elapsed competition days)
	N/A	N/A		N/A					<- Combined likelihood of all light green cells in this row					y/n	Farthest Communication Distance From Earth: at least one, error-free, 1024-bit data block, from the minimum distance of 4,000,000 km), and before the "End of Competition"
		N/A	N/A	N/A	N/A	N/A	N/A		<- Combined likelihood of all light green cells in this row					y/n	Lunar Propulsion: successfully demonstrate their CubeSat has achieved at least one verifiable lunar orbit, as defined in competition Rules
		N/A	N/A	N/A	N/A	N/A	N/A		<- Combined likelihood of all light green cells in this row					y/n	Best Burst Data Rate: cumulative volume of error-free data (above a minimum volume of one 1024 bit data block) from their CubeSat over their best 30-minute operating period
			N/A	N/A					<- Combined likelihood of all light green cells in this row					y/n	Largest Aggregate Data Volume Sustained Over Time: cumulative volume of error free data (above a minimum volume of one thousand 1024 bit data blocks) from their CubeSat over their best contiguous 28-day (calendar day) period
			N/A	N/A					<- Combined likelihood of all light green cells in this row					y/n	Spacecraft Longevity Contest: elapsed number of competition days between the first and last confirmed reception (greater than a minimum number of 28 elapsed competition days), of an error-free, 1024-bit data block from their CubeSat
	Likelihood of Mission Success -->													Total # Intended Prizes	

Likelihood of mission success is sum of all cells in each column divided by number of Prize Achievements the team plans to attempt

Sum of number of number of Prize Achievements that the Team intends to attempt (total number of "y"s)

Deep Space Derby

Lunar Derby

Mission Concept Registration Data Package Sect. 2.2 - Team-selected list of Prizes team

Judges Scorecard 2 – Compliance with Challenge Rules and SLS IDRDR – 60% of Team Score

Ground Tournament Products	Submittal Requirements	Scoring Criteria	Judge's Score
Challenge Rules Compliance			
Compliance with the Cube Quest Challenge Rules	Cube Quest Challenge Operations and Rules	0 - violation of any Rule 1 - compliance with < 75% of Rules marked GT-1 2 - compliance with >75% < 85% of Rules Marked GT-1 3 - compliance with all Rules marked GT-1 4 - compliance with all Rules marked GT-1 and half the Rules marked GT-2-4 5 - compliance with all Rules Marked GT-1 and all Rules marked GT-2-4	
Challenge Rules Compliance Score			
Interface Requirements & Rules			
SPUG Questionnaire Reference: SLS-SPIE-HDBK-005 Secondary Payload User's Guide, Appendix C	Complete/submit questionnaire	1-< 3/4 of form filled out; 3- form filled out but info vague; 5-form filled out & info solid	
CubeSat Overview	Provide description of payload, TRL of systems & ability to mature to TRL6 by GT4, payload unique requirements/goals	1-major gaps in description, TRL not clearly defined, no unique systems defined; 3-basic description provided, TRLs determined & plan mentioned, limited requirements/goals listed; 5-thorough description, clear TRLs w/plans to mature, solid requirements/goals defined	
Concept of Operations Reference: Mission Concept, Registration Data Package	Provide description of mission operation & goals (accomplishments one plans to achieve in flight, process/steps the cubesat will perform during flight, communication plans, and Mission Mode states - forerunner to s/w dev.)	1-provide basic mission goals & description; 3-provide detailed mission steps w/goals at each step; 5-detailed mission steps w/goals & mission mode states	
Hardware Design Reference: Mission Concept, Registration Data Package & IDRDR	Provide system schematic(s) (system/subsystem block diagrams w/high level interfaces), gen. hardware descriptions, initial mass properties, some detail on system w/potential safety issues (i.e. propulsion, power, transmission levels, etc.)	1-rough block diagram, little hardware descript., no mass breakdown, no system details; 3-top level system diag. w/details, mass properties at a system level, some systems w/safety issue identified; 5-top level system diag. & subsystem diagrams, mass properties down to component levels, all systems discussed for safety issues	
Interface Requirements & Rules Score (average of section)			
Verification			
Analysis Reference: IDRDR	Identify planned analysis	1- only mentions analysis; 3-lists analysis w/plans of when performed; 5-all above & provides some initial analysis	
Test/Demonstration Reference: IDRDR	Identify planned testing (development & verification)	1- only mentions testing; 3-lists tests w/plans for development; 5-all above & plans for verification testing	
Inspection Reference: IDRDR	N/A	N/A	
Safety Data Package (SDP) Reference: SLS-RQMT-216 SLSP EM-1 Safety Requirements for Secondary Payload Hardware & SLS-PLAN-217 EM-1 Secondary Payload Safety Review Process	(Reader's Digest version of Hardware Design deliverables w/emphasis on possible hazards) (Presentation to include payload/cubesat design goals/intent, descriptive block diagrams of systems, planned operations, description of possible hazards, etc.)	1-provides a presentation but greatly lacking/needs to be redone; 3-provides a presentation w/minor changes required; 5-presentation is acceptable	
Schedule	Detail plan to GT2 w/milestone events to other GTs	1-provides only top level schedule; 3-provides detailed plan to GT2 & milestones to others; 5-provides details to GT2 & 3 w/milestones to others	
Verification Score (average of section)			
Overall Score (average of all three sections)			

Team Submittals Checklist

<u>Required Submittal & Contents</u> <u>(where applicable)</u>	<u>Where Is The Submittal Defined</u>	<u>When is Submitted Required?</u>	<u>Where/How will it be Used?</u>
Notice of Intention to Compete	Operations & Rules, Rule 2.B and Sect. 5.3	At time of registration and NLT than 30 days before GT-1 or the first GT the team is eligible to complete in	Used to initiate registration; not used in Ground Tournaments
Registration Data Package <ul style="list-style-type: none"> <input type="checkbox"/> Competitor Team Name <input type="checkbox"/> Competitor Team affiliation <input type="checkbox"/> Team Leader Designation <input type="checkbox"/> Team Leader Proof of U.S. citizenship or permanent residence <input type="checkbox"/> Company/organization proof of U.S. incorporation and address of operations <input type="checkbox"/> List of Team Members and proof of eligibility <input type="checkbox"/> All appropriate Competitor Team contact information <input type="checkbox"/> Proof of liability coverage / demonstrated financial responsibility <input type="checkbox"/> Acknowledgement to rules compliance (signature) 	Operations & Rules, Rules 1 and 2, Sect 5.3	At time of registration and NLT than 30 days before GT-1 or the first GT the team is eligible to complete in	Rules Compliance; Team Leader will be the primary point of contact for Cube Quest Challenge Administrator; Ground Tournament Scores will be reported to Team Leader.

<u>Required Submittal & Contents</u> <u>(where applicable)</u>	<u>Where Is The Submittal Defined</u>	<u>When is Submitted Required?</u>	<u>Where/How will it be Used?</u>
Mission Concept Registration Data Package (MCRDP)	Operations and Rules, Rules 3, 8.B and reference document "Mission Concept Registration Data Package Definition" document, on Cube Quest references web page.	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Several GT Workbook Sections use materials from the MCRDP. See details following.
<input type="checkbox"/> Concept of Operations (ConOps)	Mission Concept Registration Data Package Sect. 2.1	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Several GT Workbook Sections
<input type="checkbox"/> Conceptual Mission Design	Mission Concept Registration Data Package Sect. 2.2	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Several GT Workbook Sections
<ul style="list-style-type: none"> List of Deep Space and Lunar Derby Prizes that the teams intend to win 	Mission Concept Registration Data Package Sect. 2.2	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or	Scorecard 1 – Likelihood of Mission Success

<u>Required Submittal & Contents</u> <u>(where applicable)</u>	<u>Where Is The Submittal Defined</u>	<u>When is Submitted Required?</u>	<u>Where/How will it be Used?</u>
		the first GT team is eligible to complete in	
<ul style="list-style-type: none"> Planned CubeSat orbit/trajectory design 	Mission Concept Registration Data Package Sect. 2.2	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	GT Workbook Sect. GNC and ADCS; Sect. Comm; Sect. Trajectory & Propulsion
<ul style="list-style-type: none"> Planned CubeSat durability and reliability approach. 	Mission Concept Registration Data Package Sect. 2.2	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	GT Workbook Sect. Longevity
<ul style="list-style-type: none"> CubeSat architecture description. 	Mission Concept Registration Data Package Sect. 2.2	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	GT Workbook Sect. Longevity
<ul style="list-style-type: none"> Ground systems architecture description. 	Mission Concept Registration Data Package Sect. 2.2	60 calendars days after acceptance of registration data	GT Workbook Sect. Comm

<u>Required Submittal & Contents</u> <u>(where applicable)</u>	<u>Where Is The Submittal Defined</u>	<u>When is Submitted</u> <u>Required?</u>	<u>Where/How will it be Used?</u>
		package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	
<ul style="list-style-type: none"> • Hazards List. 	Mission Concept Registration Data Package Sect. 2.2	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRDR Compliance
<input type="checkbox"/> Conceptual method for CubeSat disposal	Mission Concept Registration Data Package Sect. 2.3; NPR 8020.12 Planetary Protection Provisions for Robotic Extraterrestrial Missions, and NASA STD 8719.14 NASA Technical Standard, Process for Limiting Orbital Debris	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	
<input type="checkbox"/> Satellite Communications Concept	Mission Concept Registration Data Package Sect. 2.4	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	GT Workbook Sect. Comm

<u>Required Submittal & Contents</u> <u>(where applicable)</u>	<u>Where Is The Submittal Defined</u>	<u>When is Submitted Required?</u>	<u>Where/How will it be Used?</u>
☐ SPUG Questionnaire	SLS-SPIE-HDBK-005 SLS Secondary Payload User's Guide, Appendix C, SLS Payload Questionnaire	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRDR Compliance
☐ CubeSat Overview	Scorecard 2 – Rules and IDRDR Compliance	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRDR Compliance
☐ Concept of Operations	Mission Concept Registration Data Package Sect 2.1	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRDR Compliance
☐ Hardware Design	Mission Concept Registration Data Package Sect 2.3 CubeSat Architecture, and IDRDR	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRDR Compliance
☐ Analysis	IDRDR	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRDR Compliance
☐ Test/Demonstration	IDRDR	NLT than 30 days before 1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRDR Compliance

<u>Required Submittal & Contents</u> <u>(where applicable)</u>	<u>Where Is The Submittal Defined</u>	<u>When is Submitted Required?</u>	<u>Where/How will it be Used?</u>
☐ Inspection	IDRD	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRD Compliance
☐ Safety Data Package (SDP)	SLS-RQMT-216 SLSP EM-1 Safety Requirements for Secondary Payload Hardware & SLS-PLAN-217 EM-1 Secondary Payload Safety Review Process	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRD Compliance
☐ Schedule	Scorecard 2 – Rules and IDRD Compliance	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	Scorecard 2 – Rules and IDRD Compliance
☐ Submittals specified in GT Workbook Sect. Communications Evaluation (“Comm”)	Specified in Ground Tournament Workbook Sect. Communications Evaluation (“Comm”)	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	As shown in GT Workbook Sect. Comm
☐ Submittals specified in GT Workbook sect. GNC & ADCS Evaluation	Submittals specified in Ground Tournament Workbook sect. “GNC & ADCS”	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	As shown in GT Workbook sect. GNC & ADCS
☐ Submittals specified in GT Workbook Sect. Longevity Evaluation	Submittals specified in Ground Tournament Workbook Sect. “Longevity Analysis”	NLT than 30 days before GT-1 or the first GT team is eligible to complete in	As shown in GT Workbook Sect. Longevity Evaluation

Preliminary

Evaluation Criteria

Rules Verification Evaluation

The Challenge Rules verification will be completed by the Cube Quest Challenge Administrator.

Rule	Rule Title	Meets <input checked="" type="checkbox"/>	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
Eligibility and Registration								
1.A	Team Leader US Citizen		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		
1.B	Foreign National Team Participation		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		
1.C	Designated Countries		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		
1.D	Federal Employee/Entity		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		
1.E	Contractor Employee/Entity		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		
1.F	Prize Award to US Citizen		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		
1.G	Single CubeSat Submission		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		
Competitor Team Responsibilities and Agreements								
2.A	Regulation & Law Compliance for Foreign Students/Employees		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		
2.B	Notice of Intent to Compete		Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package	Confirmed in Registration Data Package		

Preliminary

Rule	Rule Title	Meets ☑	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
2.C	<i>Liability Insurance</i>		Confirmed in Registration Data Package					
2.D	<i>Use of NASA Name and Insignia</i>		Evaluation of websites, submitted materials, etc	Evaluation of websites, submitted materials, etc	Evaluation of websites, submitted materials, etc			
2.E	<i>Compliance w/ existing Laws</i>		Notifications from Law Enforcement or Legal	Notifications from Law Enforcement or Legal	Notifications from Law Enforcement or Legal			
2.F	<i>Monthly Reporting</i>		Monthly Reports Submitted	Monthly Reports Submitted	Monthly Reports Submitted	Monthly Reports Submitted	Monthly Reports Submitted	Monthly Reports Submitted
2.G	<i>Media Rights</i>		Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire
2.H	<i>Purchase/Sales Rights</i>		Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire
2.I	<i>Intellectual Property Rights</i>		Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire
2.J	<i>Delay, Cancellation, Termination</i>		Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire
Mission Concept Registration Data Package								
3	<i>On-time MCRDP</i>		60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in	60 calendars days after acceptance of registration data package and NLT than 30 days before GT-1 or the first GT team is eligible to complete in		
CubeSat Mass, Volume, & Interface Requirements								

Rule	Rule Title	Meets ☑	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
4.A	<i>IDRD Requirements</i>		IDRD Compliance Score > 0					
4.B	<i>SPUG Requirements</i>		SPUG Compliance Score >0					
4.C	<i>Size & Mass Requirements</i>		Concepts and plans for 6U					
4.D	<i>Single Payload</i>		Concepts and plans					
4.E	<i>3rd Party Launch Provider Requirements</i>		Team shows plans for meeting launch service provider requirements	Team shows plans for meeting launch service provider requirements	Team shows plans for meeting launch service provider requirements	Team shows plans for meeting launch service provider requirements	Team shows plans for meeting launch service provider requirements	Team shows plans for meeting launch service provider requirements
4.F	<i>Volume/Mass Precedence – 3rd Party v EM-1</i>		Concepts and plans					
4.G	<i>3rd Party Launch Inspections</i>		Plans to submit					
Radio Frequency Authorization								
5.A	<i>RF in accordance with US and Intl laws/regulations</i>		Concepts and plans					
5.B	<i>Allowable Electromagnetic Spectrum Frequency</i>		Concepts and plans					
5.C	<i>RF Operating Licenses</i>		Concepts and plans					
Monitoring and Inspection								
6	<i>Non-invasive Monitoring any Space-based Communication</i>						Verbal/Written Questionnaire	Verbal/Written Questionnaire

Rule	Rule Title	Meets ☑	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
7	NASA Visits for Inspection		Verbal/Written Questionnaire; Access Provided	Verbal/Written Questionnaire; Access Provided				

Constraints on Ground Tournament Participation

8.A	GT Participation		Mission Concept Registration Data Package					
8.B	Mission Concept Registration Data Package		30 days prior to participation if first GT	30 days prior to participation if first GT	30 days prior to participation if first GT	30 days prior to participation if first GT		
8.C	Intent to Compete – In-space Competitions		Prior to each GT					
8.D	Intent to Compete for EM-1		Prior to each GT up to GT4					
8.E	GT-4 Participate for EM-1 Consideration					Must compete for EM-1 consideration		

Ground Tournament Judging

9.A	Team Submission Requirements		GT-1 Submittals 30 days prior to participation if first GT	GT-2 Submittals 30 days prior to participation if first GT	GT-3 Submittals 30 days prior to participation if first GT	GT-4 Submittals 30 days prior to participation if first GT		
9.B	Site Inspections		Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire		
9.C	Competition Score Public Posting		Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire		
9.D	Scoring Criteria for All Teams		Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire	Verbal/Written Questionnaire		
9.E	Likelihood of Mission Success		Judges Scorecard 1	Judges Scorecard 1	Judges Scorecard 1	Judges Scorecard 1		
9.F	Compliance with IDR and Challenge Rules		Judges Scorecard 2	Judges Scorecard 2	Judges Scorecard 2	Judges Scorecard 2		

Rule	Rule Title	Meets ☑	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
Rules and Requirements for GT-1								
10	GT-1 Participation		GT-1 Submittals per Judge's scorecard, GT workbook, and Operations and Rules					
Rules and Requirements for GT Two								
11	GT-2 Participation			GT-3 Submittals per Judge's scorecard, GT workbook, and Operations and Rules				
Rules and Requirements for GT Three								
12	GT-3 Participation				GT-3 Submittals per Judge's scorecard, GT workbook, and Operations and Rules			
Rules and Requirements for GT Four								
13.A	Final Intention for EM-1 or 3rd Party Launch					GT-4 Submittals		
13.B	GT-4 Participation					GT-3 Submittals per Judge's scorecard, GT workbook, and Operations and Rules		
13.C	EM-1 Compliance Requirements					GT-4 < 3 GT-4 Submittals / SLS Requirements		

Rule	Rule Title	Meets ☑	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
13.D	<i>Team Declaration for EM-1</i>					Prior to entry to GT-4 / Submittals		
Availability of EM-1 Secondary Payload Slots								
14.A	<i>Judges Ranking of GT4 Competitors</i>					Judges Scorecard 1 and 2		
14.B	<i>Top 3 Teams for EM-1 Integration</i>					Judges Scorecard 1 and 2		
14.C	<i>Backfill Competitors for EM-1</i>					Judges Scorecard 1 and 2		
In-Space Competition								
15.A	<i>3rd Party Launch Notification</i>						Team Notification	Team Notification
15.B	<i>EM-1 Deployment</i>						Positive Deployment	Positive Deployment
Competitor Ground Stations								
16.A	<i>CubeSat Communications</i>						No restrictions on quantity of communications	No restrictions on quantity of communications
16.B	<i>Number of Ground Stations</i>						Team Submittals	Team Submittals
16.C	<i>Use of Government Controlled Stations</i>						Team Submittals	Team Submittals
16.D	<i>Monitoring by Government Controlled Stations</i>						Team Submittals	Team Submittals
16.E	<i>Ground Station Operators</i>						Team Submittals	Team Submittals
Planetary Protection								

Rule	Rule Title	Meets ☑	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
17.A	Submission of ODARS & EOMPS		Team Submittal	Team Submittal	Team Submittal	Team Submittal		
17.B	OARD and EOMP Submission		No later than GT-4	No later than GT-4	No later than GT-4	No later than GT-4		
17.C	Lunar Orbit End of Mission					Team Submittal		Team Submittal
17.D	Missions Designs & Planetary Protection					Team Submittal	Team Submittal	Team Submittal
17.E	Planetary Protection Plans		Team Submittal	Team Submittal	Team Submittal	Team Submittal	Team Submittal	Team Submittal
Communications Competition: In-space Challenges								
18.A	Start of Operating Period						Team Notification	Team Notification
18.B	Communications Methodology						Team Submittals	Team Submittals
18.C	Communications Log						Team Submittals	Team Submittals
18.D	Protocol for Transmission						Team Submittals	Team Submittals
18.E	Data Block Receipts						Team Submittals	Team Submittals
18.F	Data Block Delivery for Judging						Team Submittals	Team Submittals
18.G	Transmission Achievement Evidence						Team Submittals	Team Submittals
Competition End: In-space Challenges								
19.A	3rd Party Launches						365 days from EM-1 Launch	365 days from EM-1 Launch
19.B	EM-1 Launch						365 days from EM-1 Launch	365 days from EM-1 Launch

Rule	Rule Title	Meets ☑	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
19.C	Activity after Competition Days						365 days from EM-1 Launch	365 days from EM-1 Launch
19.D	3 rd Party Longevity Competitions						Team Submittal	Team Submittal
EM-1 Deployment								
20	Failure to Deployment from EM-1						Ineligible for Prizes	Ineligible for Prizes
NASA Rights to Share Team Information								
21	NASA Rights to share Competitor Accomplishments and Progress							
Deep Space Derby: Verifiable Minimum Distance								
22.A	Achieve and maintain 4M km distance						Team Submittal / Independent Verification	
22.B	Evidence of Spacecraft Distance						Team Submittal	
22.C	No verifiable minimum distance / end of contest						365 days of EM-1 Launch	
Deep Space Derby: Prizes								
23.A	Best Burst Data Rate						Team Submittal / Independent Verification	
23.B	Largest Aggregate Data Volume						Team Submittal / Independent Verification	
23.C	Spacecraft Longevity						Team Submittal / Independent Verification	

Rule	Rule Title	Meets <input checked="" type="checkbox"/>	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
23.D	<i>Farthest Comm distance from earth</i>						Team Submittal / Independent Verification	
Lunar Derby: Verifiable Lunar Orbit								
24.A	<i>Verifiable Lunar orbit</i>							Team Submittal / Independent Verification
24.B	<i>Lunar orbit definition</i>							Team Submittal / Independent Verification
24.C	<i>Evidence of lunar orbit</i>							Team Submittal / Independent Verification
24.D	<i>Evidence for minimum altitude</i>							Team Submittal / Independent Verification
24.E	<i>Evidence of maintaining lunar orbit</i>							Team Submittal / Independent Verification
24.F	<i>No verifiable / end of contest</i>							Team Submittal / Independent Verification
Lunar Derby: Prizes								
25.A	<i>Lunar Propulsion</i>							Team Submittal / Independent Verification
25.B	<i>Best Burst Data Rate</i>							Team Submittal / Independent Verification
25.C	<i>Largest Aggregate Data Volume</i>							Team Submittal / Independent Verification
25.D	<i>Spacecraft Longevity</i>							Team Submittal / Independent Verification

Rule	Rule Title	Meets <input checked="" type="checkbox"/>	GT One Information for Judges to Consider	GT Two Information for Judges to Consider	GT Three Information for Judges to Consider	GT Four Information for Judges to Consider	Deep Space Derby Information for Judges to Consider	Lunar Derby Information for Judges to Consider
Rules Modification								
26	<i>Additional Challenge Rules</i>							

Preliminary

Preliminary

Communications Evaluation

<the submittals required in this section have to be cross-walked against the MCRDP Satellite Communications Concept submittals>

Judges and their subject matter experts will utilize the data requested below to run simulations and perform analyses to determine each team's communication link margin, its estimated error-free 30-minute burst data rate performance and its estimated error-free 28-day aggregate data volume, from average lunar range or from 4M km range, as applicable. All data inputs are mandatory for each GT. Incomplete data will result in downgraded score. If an optical communications system is proposed, the teams will need similar link budgets but with the relevant optical equivalent data.

Submittals for judging should include the following data and be based on the noted criteria for each GT:

GT1: Estimates based on manufacturer and ground station information, estimates, and user guides, etc.

GT2: Estimates based on preliminary design documents

GT3: Estimates based on final design documents, analyses and available tests

GT4: Estimates based on test results

For the in-space competitions, the additional criteria must be submitted:

Lunar Comm: Have to know how many times they listened, how many min's the moon is visible (worst case), nominal attenuation. In ConOps specify (on one page) they have to tell you how many ground stations,

Deep Space Comm: trajectory, range of ranges. Earth-centered coordinates trajectory of satellite.

General Requirements
Orbit Dynamics
Mission Geometry
Comm System Details
Frequency up/down
Data rate up/down
Error rate
Ground station
Antenna characteristics
Radio details
Communication link margin

<i>For Transmitting CubeSat:</i>	
P	Transmitter power (including High Power Amplifier)
Ll	Transmission Line loss
Gt	Transmit Antenna gain
Theta	Antenna half power beam width angle
Lambda	Carrier frequency
Pointing loss	
Implementation loss	

Preliminary

Preliminary

Spacecraft Antenna Polarization

For Receiving Station:

Ar Effective receive antenna aperture area

Gr Receive antenna gain

System Noise Temperature (including all contributions - antenna elevation, atmosphere, sun, hot bodies, cosmic background)

G/T

Ground Station Pointing Loss

Polarization Loss

Required Total Power / Noise Spectral Density

Ground station elevation angle

Path Parameters

data rate

BER Bit Error Rate

Eb/No required

Eb/No Received

modulation

coding

n Receive station number of 30-minute blocks during 28-day window (used to estimate aggregate data volume)

Antenna pointing

Expected view time of ground station

Carrier loop bandwidth

Distance between satellite and ground station

Path Loss

Telemetry modulation Index

Ranging modulation Index

carrier suppression by telemetry mod index

carrier suppression by ranging mod index

data channel suppression by telemetry mod index

data channel suppression by ranging mod index

Ground Station Antenna Polarization

Preliminary

Preliminary

Guidance, Navigation and Control Systems (GNC) and Attitude Determination and Control System (ADCS) Evaluation

- 1) Explain how your CubeSat determines its position and its attitude (using whatever chosen coordinate system with the precision you need to accomplish your in-space objectives (including capture and maintenance of lunar orbit, if applicable)).
- 2) Explain how you control your CubeSat's position (if necessary) and its attitude with precision sufficient to accomplish your objectives (including the insertion into lunar orbit and maintenance of lunar orbit, if applicable to your in-space objectives.)
- 3) Provide analysis to show how you determined the required precision and margin for your position and attitude determination and control.
- 4) You'll need to explain your knowledge (determination) accuracy requirements, and your control accuracy requirements, and also your hardware and software components necessary to achieve each of the above.

Preliminary

Longevity Evaluation

The team should demonstrate how CubeSat elements with finite operating life will survive transport, launch, and the space environment and continue to perform their required functions.

Examples of CubeSat elements with limited life or that can be adversely impacted by the transport, launch and operating environments:

Mechanical mechanisms, structures, pressure vessels, batteries and battery capacity, solar array efficiency, etc.

Expected Team submittals: Longevity Analysis

Teams should show concepts, designs and test data that demonstrate mechanisms will survive the loads of launch, and will continue to operate correctly in the actual operating environment.

Show that the elements will continue to operate correctly.

Identify margin used in the analysis.

Environments:

Describe the environments that the CubeSats are designed to survive, during transport, launch, and operations in-space.

References:

Teams are recommended to refer to NASA Goddard Space Flight Center's General Environmental Verification Specification (GEVS) (GSFC-STD-7000) as an excellent resource for understanding environmental test and margin analysis.

Teams are recommended to refer to Goddard Space Flight Center Rules for the Design, Development, and Operation of Flight Systems (GSFC-STD-1000) for guidance on design and test of systems to withstand and operate in the space environment, including recommendations for margin at each phase of design and test.

"Judges and their subject matter expert consultants will use the recommended input listed below to evaluate s/c length of survival. They will determine each team's likelihood of lasting at least 28 days in lunar orbit or lasting long enough to reach > 4M km. For GT1 an acceptable level of detail will include a description of the approach and methodology used. For GT2-4, supporting data to validate the approach should be provided."

Background

This section will address the scoring criteria for the test plans for CubeSats entering into the Cube Quest competition. Additionally this section will assure that judges will be able to assess spacecraft longevity, both as far as ability to survive launch and ability to survive the space environment in order to complete the mission.

General Guidelines

Overall, the Testing and Verification plan is not required for the first two ground tournaments, but is a required input for the last two.

Documents used in consideration for evaluating teams in this section should include: GSFC-STD-7000A-General Environmental Verification Standard (GEVS) for Goddard Space Flight Center Flight Programs and Projects, SLS-

Preliminary

Preliminary

SPIE-HDBK-005SLS-Secondary Payload User's Guide (SPUG), NASA/SP-2007-6105-NASA Systems Engineering Handbook

The following describes what requirements would satisfy a score of "3" on the judge's scorecard for each milestone

Methodology GT-1 (MCR)

Teams are expected to have completed a well-defined mission concept, as well as any necessary technological development. There is no specific testing requirement for GT-1. At a mission concept review the SLS SPUG questionnaire should be completed.

Methodology GT-2 (PDR)

Teams are expected to have completed a preliminary design. There is no specific testing requirement for GT-2. At a preliminary design review no test plan is required for a score of 3.

Methodology GT-3 (CDR)

Teams are expected to have completed final design. By this milestone every team is required to have a completed test plan. This test plan should include a plan for meeting all of the Secondary Payload User's Guide requirements, including but not limited to: dimensional testing, center of mass, mechanical shock and vibration, thermal, EMI/EMC, off-gassing, and end-to-end mission simulation.

Methodology GT-4 (FRR)

Teams are expected to have completed system assembly, integration and test. The flight unit should be completely ready for launch. All procedures outlined in the test plan required at GT-3 should be completed, and any associated verifications should be closed out. Test reports are required for vibration testing, off-gassing testing, and EMI/EMC testing.

Preliminary

Trajectory and Propulsion Evaluation

<The required submittals of this section have to be cross-checked against the MCRDP submittals>

Deep Space Methodology Orbit analysis

GT-1 (MCR)

Competitors should demonstrate available launch opportunity for escape orbit if not on EM-1. If there will be any station keeping or correction maneuvers, there should be large dry mass margin (>30%) to account for >10% deterministic dV margin and future design iterations (statistical dV). The SC-Earth range/angle over mission lifetime should be considered and may affect communication requirements. Depending on the sensitivity of the payload, any lighting/thermal constraints that will be predisposed during orbit should be addressed (SC-sun range/angle or solar exclusion zone). Depending on desired heliocentric orbit, collision analysis may need to be performed to assure no potential harm to SC or an orbiting body. SC orientation (spinning, body fixed, aligned, etc.) will also affect thermal constraints and should be illustrated that this will not perturb payload/power requirements.

If SC will flyby or rendezvous with an orbiting body, the SC approach velocity/angle needs to be understood for maximum approach velocity. For impact, flyby or rendezvous trajectories, B plane (incoming declination/right ascension asymptote) should be utilized as a target parameter. If impact is desired, competitors need to comply with planetary protection needs. The impact angle should also be optimized for required maximum impact velocity. For flyby trajectories, closest approach altitude should be low enough for payload to carryout science, simultaneously a safe altitude to ensure there will be no impact.

Orbit environment can be illustrated in STK, GMAT or another trajectory design program where advanced propagation is established (using gravity fields, not point masses, as well as varying solar flux) to simulate realistic effects.

For judging, candidates will submit an ephemeris file (via STK or GMAT) during each time step that orbit is defined to ensure design meets MCR requirements. If STK or GMAT is not available, time and state vectors (epoch, position and velocity) in a determined reference system at each time step will be required for orbit validation.

Resources:

Trajectory Browser

Trajectory Design with STK/Astrogator: Mars Orbit Mission Tutorial

Design of Round-Trip Trajectories to Near-Earth Asteroids Utilizing a Lunar Flyby by Sonia Hernandez and Brent Barbee

Interplanetary Trajectory Analysis for 2020-2040 Mars Missions including Venus Flyby Opportunities by Takuto Ishimatsu, Jeffrey Hoffman, and Olivier de Weck

Deep Space Methodology GT-2

Orbit optimization/Mission design (PDR)

Orbit design meets all requirements of mission design and ConOps is satisfied. If any risks are associated with initial orbit design, the orbit is optimized to reduce number of risks. Candidates will provide a 'Day in the Life' of the mission to illustrate how everything will work in orbit; when critical trajectory events will be performed on a timescale to guarantee orbit design. At this stage there should be around 20-30% dry mass margin, including 10% deterministic dV margin.

Preliminary

Preliminary

Preliminary

In addition, an ephemeris file for each time step of orbit simulation will be provided to judge orbit design specifics.

Resources:

Deep Space Methodology GT-3

Orbit Validation/Verification (CDR)

All science and mission requirements are met and there are no uncertainties in trajectory environment; orbit design closes, including all subsystem trades. Error simulation (Monte Carlo) is performed to ensure accuracy of orbit design (characterization and correction). Pointing uncertainty (thrust vectors, impact position vectors) is established to determine accuracy for either impact or flyby. Any TCMs (Trajectory Correct Maneuvers, statistical dV) will be determined from error simulations and may affect total dV budget. Dry mass margin should remain around 30% margin to account for this.

Competitors should simulate orbit environment in thermal vacuum chamber to ensure SC health during flight, as well as in-orbit testing to ensure orbit design.

Resources:

Contingency Planning and Mission Performance Impacts: A Novel Approach to Launch Error Simulation, Characterization and Correction by Emmet Fletcher

There are various in-orbit test systems info online via Intelsat testing site, SED, Redu Space Services, etc. (<http://www.intelsat.com/wp-content/uploads/2013/01/ds-satellite-services-in-orbit-testing.pdf>)

Deep Space Methodology GT-4

Flight Ready (FRR)

Orbit will be demonstrated by flight dynamics team via flight software. SC characteristics will demonstrate no issues during flight simulation, and the use of orbit determination tools (ODTBX, ODTK) for high-fidelity trajectory propagation should be performed.

Resources:

<http://opensource.gsfc.nasa.gov/projects/ODTBX/>

<http://odtbx.sourceforge.net/>

Lunar Orbit Maintenance

Methodology GT-1

For low lunar orbits, teams need to show orbit propagation results that meet lifetime requirements. Orbital elements of the chosen orbit have to be listed: initial altitude, inclination, Right Ascension of the Ascending Node (RAAN) and argument of periapsis. They need to show that the orbit is achievable and that lunar perturbations over time do not compromise mission safety. If the proposed mission requires orbital elements to be constant, they need to address the implementation of a lunar frozen orbit. If the orbit requires station keeping, the propellant mass allocation has to consider it and maneuvers have to be properly addressed and comply with mass allocation constraints for propellant and orbit determination. Perilune altitude should not be less than 30 km during mission lifetime, for safety issues. Ideally, perilune altitude should be within 20% of the nominal initial altitude in order to have a safe stable orbit (extra points).

Preliminary

Teams can simulate their own orbits with tools such as STK or other orbit propagation software. They can use available literature to target stable regions of low lunar orbits in the initial phases of the contest (see references). They need to address end of life requirement to comply with planetary protection. Lunar orbit crash has to be controlled and they need to specify ConOps to perform an impact at a suitable and safe location.

References:

D. Folta and D. Quinn, "Lunar Frozen Orbits," AIAA 2006-6749, AIAA/AAS Astrodynamics Specialist Conference and Exhibit, Keystone, CO, 21-24 August, 2006.

Ely T., Lieb E. 'Constellations of Elliptical inclined lunar orbits providing polar and global coverage'. AAS 05-343. Fundamentals of Astrodynamics and Applications [David A. Vallado, Wayne D. McClain]

Methodology GT-2

Simulation results from orbit propagation need to be submitted. They need to be performed with high accurate gravity models with degree and order of at least 50x50. They need to include solar radiation pressure for the defined area to mass ratio of the spacecraft and also count on third body perturbations from the Sun and the Earth. Simulation need to address lifetime and perturbations on the main orbital elements of the proposed orbit. They need to address also the same parameters for initial orbits that are similar to the proposed one in order to account for deviation at Lunar Orbit Insertion (LOI). Perturbations that perform an evolution that do not comply with science requirements need a well-defined station-keeping strategy.

Methodology GT-3

Orbital determination needs to be perfectly addressed. A detailed description of contact times/strategies and telemetry needs to be explained and nailed down. Covariance matrix in both position and velocity has to be included in the analysis and results need to be consistent with proposed operations. Orbit analysis needs to include analysis of the interactions with other lunar orbiters in order to minimize risk of collisions or communications interference.

Methodology GT-4

TBD

References for margins

"Rules for the Design, Development, Verification and operation of Flight Systems" GSFC-STD-1000, rev C.2, December 12, 2006"

"Mass Properties Control for Space Vehicles", TOR-2005(8583)-3970, Prepared for the Space and Missile Systems Center, Air Force Space Command by Aerovance Corporation, 2005

"Space Systems - Mass Properties Control for Space Systems", S-120-2006e, AIAA.

"Mass Properties Control for Space Vehicles", SRP 11 Rev B, SAWE.

Propulsion

General guidelines

3- Main thruster characteristics and performance parameters need to be listed: specific impulse, thrust, efficiency, propellant type, and total impulse and duty cycle specifications. All of the parameters have to be consistent with

the proposed mission maneuvers and limitations. Physics behind thrust generation have to be defined and validated. Propellant storage has to be described and propellant mass has to be consistent with required ΔV . Propellant characteristics such as density and state of matter should be explained. The propulsion system needs to comply with power, mass and volume constraints, giving some margins. Maneuvers and procedures have to be explained.

If the spacecraft has two separate propulsion units for main ΔV applications and ADCS, both need to follow these guidelines. Redundancy and safety guidelines have to be addressed for hazardous propellant and to ensure thruster performance. The propulsion system needs to show robustness and be able to pass tests in relevant conditions: vibration, vacuum, thermal.

References:

“The Physics of electric propulsion”. Robert G. Jahn.

“Fundamentals of Electric Propulsion: Ion and Hall Thrusters”. Dan M. Goebel and Ira Katz.

“Rocket Propulsion Elements”. George P. Sutton, Oscar Biblarz

“Rocket and spacecraft Propulsion”. Martin J.L.Turner

Methodology GT-1

Teams can use data and information from available literature regarding existent propulsion systems that complies with the guidelines. Teams need to address performance calculations based on verified thruster characteristics. Propellant mass and power required have to be nailed down by showing calculations. This has to be explained for all phases of the mission. Power budget needs to meet requirements for propulsion system consistently as well as mass and volume constraints.

If the propulsion system is self-designed, they need to show the design process and extensive testing, as well as a detailed explanation of the physics behind thrust generation. Maneuvers have to take into account thrust vector direction and can be calculated using orbital mechanics software such as STK to obtain extra points.

Mass growth allowance need to be 18% for propulsion system dry mass and 3σ for propellant mass.

Methodology GT-2

Teams need to provide verified results from thrust stand tests that show a robust performance. In addition they need to prove that performance meet thruster characteristics. The thrust provided has to be consistent with the proposed trajectory and maneuvers. Specific impulse needs to be measured and comply with propellant mass allocation. Tests have to show functionality of the propulsion system and thrust has to be measured previously in valid experiments.

Thruster location in the spacecraft needs to be consistent with addressed thrust maneuvers. A description of thrust alignment needs to be presented for each maneuver.

For determined propellants, storage/handling constraints as well as operating pressure and internal/external leakage avoidance need to be described. For bipropellant systems, the oxidizer/fuel mixture ratio needs to be included in the calculations. Gas volume in the propellant tank should be at least 5%. For certain chemical propulsion systems, pressurant mass and pressurant gas tank configuration (dimensions, shape and pressure) needs to be included.

Efficiencies need to be verified by extensive testing, especially propulsive efficiency and electrical efficiency of the power electronics in the case of electric propulsion and combustion efficiency for chemical.

Propulsion system cannot interfere with any other subsystem in the spacecraft. A detailed analysis of potential interactions between thruster operation and other subsystems (example: backflow and thermal exchange) needs to be presented. A COMSOL or similar software detailed analysis to address these challenges would obtain extra points. Three levels of redundancy have to be implemented in the propulsion system in order to address failure modes.

Mass growth allowance needs to be 12% for propulsion system dry mass and 3σ for propellant mass.

Methodology GT-3

Propulsion system has to go through extensive environmental testing. Teams need to prove that all the different parts of the propulsion system can support: vibration, thermal, vacuum and other relevant tests such as lifetime tests. All safety issues have to be perfectly addressed: propellant feed systems, abort control. All subparts of the propulsion system such as chambers, tanks or valves need to be explained in detail and tested under relevant conditions.

Software has to be tested and control procedure explained. Telemetry constraints for commanding thrusters have to be assessed. For critical maneuvers, communications and ranging to obtain spacecraft position and perform maneuvers have to be nailed down.

Mass growth allowance needs to be 4% and 3σ for propellant mass.

Methodology GT-4

Propulsion system is ready for flight. All tests and integration have been completed and thruster must have shown a robust performance. All details from GT-3 are perfectly addressed.

TBD (continue)

Actual mass has to be measured accurately, therefore there is no mass growth allowance.

Preliminary

Appendix A Ground Tournament Success Criteria

Success Criteria - Ground Tournament One (GT-1)

GT-1 Purpose:

Given the team's proposed in-space Prize(s) they intend to compete for, demonstrate the team's CubeSat and ground systems design approaches and operations concepts for meeting those Prize achievements; determine if the architecture and the concept are likely to accomplish the minimum threshold achievements for Prize(s) as defined in the Rules; and to assess plans and progress toward compliance with Challenge Rules, required SPUG inputs, and SLS interface requirements as documented in the SLS IDR.

Judges Evaluation Criteria for GT-1:

- Team in-space Prize(s) objectives are clearly defined and stated.
- Accomplishment of minimum Prize achievements, as defined in Operations and Rules for each in-space Prize selected by the team is, or appears, to be feasible per Judge's assessment of submitted materials. A solution has been identified by the team that is, or appears, to be technically feasible.
- System and subsystem design approaches and operational concepts exist and are consistent with the requirements.
- Development schedule estimate is credible.
- Planning is sufficient to proceed to the next phase.
- Major risk and mitigation strategies have been identified and are acceptable based on technical risk assessments
- Requirements definition is complete with respect to top-level mission requirements; interfaces with external entities and between major internal elements have been defined.
- Requirements allocation and flow down of key driving requirements have been defined down to subsystems.
- Preliminary approaches have been determined for how requirements will be verified and validated down to subsystem level.

Scoring:

0 - insufficient information to determine likelihood of achieving Prize

1 - Little consideration in how to achieve; not likely to achieve Prize

2 - Some considerations in some aspects of achieving; might achieve Prize

3 - Considerations into many aspects; reasonable likelihood of achieving Prize

4 - Substantial thought into plans; most aspects needed to achieve are considered; good plans to achieve Prize

5 - Very detailed plans; concepts and trades thoroughly evaluated, significant analysis performed, and very likely to achieve Prize

Preliminary

Preliminary

Preliminary

Success Criteria - Ground Tournament Two (GT2)

GT-2 Purpose:

Given the team's proposed in-space Prize(s) they intend to compete for, demonstrate that teams will achieve stated in-space Prize(s) with reasonable technical risk and within schedule constraints and are ready to proceed to detailed design and GT-3. Teams can show that appropriate design options have been selected, interfaces have been identified, and verification methods have been described. Teams show acceptable progress and plans for complying with Cube Quest Rules and with the SLS interface requirements.

Judges Evaluation Criteria for GT-2:

- The top-level requirements - including Derby success criteria, TPMs and Rules and IDR constraints are agreed upon, finalized, stated clearly and are consistent with the preliminary design.
- Preliminary design is expected to meet the requirements at an acceptable level of risk.
- Definition of the technical interfaces is consistent with the overall technical maturity and provides an acceptable level of risk.
- Adequate technical interfaces are consistent with the overall technical maturity and provide an acceptable level of risk.
- Adequate technical margins exist with respect to TPMs.
- Team risks are understood and have been credibly assessed, and plans, process and resources exist to effectively manage them.
- SLS safety have been adequately addressed in preliminary designs and any applicable system safety analysis could be approved.
- The operational concept is technically sound, includes (where appropriate) human factors, and includes the flow down of requirements for its execution.

Scoring

0 - insufficient information to determine likelihood of achieving Prize

1 - Preliminary design, requirements, risk plans, operating concepts, interface definition, test plans do little to demonstrate how team will achieve Prize; not likely to achieve Prize

2 - Preliminary design, requirements, risk plans, operating concepts, interface definition, test plans demonstrate team might achieve Prize; might achieve Prize

3 - Preliminary design, requirements, risk plans, operating concepts, interface definition, test plans demonstrate reasonable likelihood of achieving Prize

4 - Preliminary design, requirements, risk plans, operating concepts, interface definition, test plans are substantial and demonstrate most aspects needed to achieve Prize are considered; good chance to achieve Prize

5 - Preliminary design, requirements, risk plans, operating concepts, interface definition, test plans demonstrate excellent likelihood to achieve Prize

Preliminary

Success Criteria - Ground Tournament Three (GT3)

GT-3 Purpose:

given the team's proposed in-space Prize(s) they intend to compete for, demonstrate that the Team's design maturity is appropriate to proceed with fabrication, assembly, integration and test; determine that the technical effort is on track to complete the CubeSat and ground system development and in-space operations, to achieve selected in-space Prize Achievements, and be completed in time to deliver for integration with SLS. Demonstrate good progress and plans for compliance with Cube Quest Challenge Rules, and with the SLS interface requirements as documented in the IDRD.

Judges Evaluation Criteria for GT-3:

- The CubeSat and Ground Segment detailed designs are expected to accomplish selected Prize achievements with adequate margins.
- Interfaces (CubeSat, Ground, SLS, Environmental) control documents are sufficiently mature to proceed with fabrication, assembly, integration, and test, and plans are in place to manage any open items.
- The team schedule estimates are credible to achieve the next GT and CubeSat delivery dates
- High confidence exists in the CubeSat/Ground Segment baseline, and adequate documentation exists or will exist in a timely manner to allow proceeding with fabrication, assembly, integration, and test.
- The CubeSat/Ground Segment verification and product validation requirements and plans are complete.
- The testing approach is comprehensive, and the planning for system assembly, integration, test, and launch site and Cube Quest operations is sufficient to progress into the next phase.
- Adequate technical margins (e.g., mass, power, memory) exist to complete the development within schedule, and known technical risks.
- Risks to achieving selected Prizes are understood and credibly assessed, and plans and resources exist to effectively manage them.
- Durability and longevity (e.g., reliability, quality, and parts) have been adequately addressed in system and operational designs (e.g., PRA, and failure modes and effects analysis) meet requirements, are at the appropriate maturity level for this phase of the team's life cycle, and indicate that the team reliability residual risks will be at an acceptable level.
- The team has demonstrated compliance with applicable NASA and implementing Center requirements, standards, processes, and procedures.
- TBD and TBR items are clearly identified with acceptable plans and schedule for their disposition.
- Engineering test units, life test units, and/or modeling and simulations have been developed and tested per plan.

Preliminary

Preliminary

Preliminary

- Material properties tests are completed along with analyses of loads, stress, fracture control, contamination generation, etc.
- Appropriate parts have been selected, and planned testing and delivery will support build schedules.
- The operational concept has matured, is at a GT-3 level of detail, and has been considered in test planning.

Scoring

0 - insufficient information to determine likelihood of achieving Prize(s)

1 - CubeSat and Ground System detailed designs, plans and procedures and other submittals do little to demonstrate how team will achieve Prize; not likely to achieve Prize(s)

2 - CubeSat and Ground System detailed designs, plans and procedures and other submittals demonstrate team might achieve Prize; might achieve Prize(s)

3 - CubeSat and Ground System detailed designs, plans and procedures and other submittals demonstrate reasonable likelihood of achieving Prize(s)

4 - CubeSat and Ground System detailed designs, plans and procedures and other submittals are substantial and demonstrate good chance to achieve specified Prize(s)

5 - CubeSat and Ground System detailed designs, plans and procedures and other submittals demonstrate excellent likelihood to achieve specified Prize(s)

Preliminary

Preliminary

Preliminary

Success Criteria - Ground Tournament Four (GT4)

GT-4 Purpose:

given the team's proposed in-space Prize(s) they intend to compete for, verify the completeness of the CubeSat and ground systems and to assess compliance with all Challenge Rules and IDR requirements; to examine the CubeSat, ground systems, documentation and test data and analyses that support verification; ensure that CubeSat is ready for shipment to the SLS; verify that the Team has complied with all Cube Quest Challenge Rules; verify the team has complied with all SLS interface requirements per the SLS IDR. The top-performing teams will be offered the opportunity to fly on SLS EM-1 mission.

Judges Evaluation Criteria for GT-4:

- Required tests and analyses are complete and indicate that the CubeSat and Ground Segment will perform properly in the expected operational environment.
- Risks are known and manageable.
- CubeSat and Ground Segment meet the established acceptance criteria.
- The team has demonstrated compliance with Challenge Rules and SLS IDR requirements.
- TBD and TBR items are resolved.
- Technical data package is complete and reflects the final CubeSat and Ground Segment design
- The CubeSat and Ground Segment, including all enabling products, is determined to be ready to be placed in an operational status.
- Systems hardware, software, personnel, and procedures are in place to support operations.
- Operations plans and schedules are consistent with selected team Prize achievements/objectives.
- Team risks have been identified, planned mitigations are adequate, and residual risks are accepted by the team
- Testing is consistent with the expected operational environment.

Scoring

0 - insufficient information to determine likelihood of achieving Prize(s)

1 - CubeSat and Ground System test results, demonstrations, analyses, operating plans, and procedures and other submittals do little to demonstrate how team will achieve Prize; not likely to achieve Prize(s)

2 - CubeSat and Ground System test results, demonstrations, analyses, operating plans, and procedures and other submittals demonstrate team might achieve Prize; might achieve Prize(s)

3 - CubeSat and Ground System test results, demonstrations, analyses, operating plans, and procedures and other submittals demonstrate reasonable likelihood of achieving Prize(s)

4 - CubeSat and Ground System test results, demonstrations, analyses, operating plans, and procedures and other submittals are substantial and demonstrate good chance to achieve specified Prize(s)

Preliminary

5 - CubeSat and Ground System test results, demonstrations, analyses, operating plans, and procedures and other submittals demonstrate excellent likelihood to achieve specified Prize(s)

Preliminary

Preliminary