A. General Prompt Statement:

In the final on-orbit challenge, the primary goal is to capture a picture of the moon using the satellite whose TLE is given below. To accomplish this, each team is tasked with creating a mission plan that transitions a satellite from a tumbling state to one where it points one of its cameras at the moon. The competitor will be scored on their resulting mission plan as well as how closely they capture an image moon. ***Hint:*** *In the initial tumbling state, all flight software and instruments are off.*

The sample mission plan command format (section B) and list of general commands (section C) can be used to complete the challenge. A compilation of information (section D) and an example quaternion solution (section E) that may be useful for completing the challenge is also provided. Note: Teams should consider limitations provided for certain commands.

Scoring:

This challenge will be evaluated on the following criteria:

1. *Mission Plan Feasibility* – the plan generated by each team contains commands that are executed in the correct order and the image is taken within the window of interest.
2. *Image Capture* – the image of the moon is captured such that the calculated angle, θ_{error}, between the camera boresight and the moon is $< 0.5\ deg$.
    a. This section will be scored using the following relationship:

$$\theta_{error} = \cos^{-1}\left(\frac{U_{camBODY} \cdot U_{veh2moon}}{|U_{camBODY}||U_{veh2moon}|}\right)$$

    where $U_{camBODY}$ is the camera boresight vector and $U_{veh2moon}$ is the vehicle to moon vector.

    b. A submission is accepted when the plan from #1 is valid and $\theta_{error} < 0.5\ deg$.
3. *Extra Condition* – the team generated a commanded quaternion such that the satellite's $-Z$ axis is pointed as close to the Earth's center as possible without violating the θ_{error} requirement in #2. The angle between the vehicle's $-Z$ axis and the vector to the Earth's center will be the score for this condition (a lower score is better).
    a. The team with the best (lowest) score will have their plan uploaded to the on-orbit vehicle to capture an image of the moon.

Window of Interest (UTC): 2020-08-09T00:20:00Z-to-2020-08-09T00:30:00Z

TLE:

DEFCON28 SAT

1 46266U 19031D   20218.52876597 +.00001160 +00000-0 +51238-4 0 9991

2 46266 051.6422 157.7760 0010355 123.0136 237.1841 15.30304846055751

Notes:

- The J2000 ECI frame is the designated inertial frame for the challenge.
- Scoring criteria #2 and #3 should be accomplished with a single slew.
- Incorrect spacing may lead to TLE checksum errors.

B. Mission Plan Command Format:

Using only the available commands listed on the following page, construct a mission plan with the commands listed sequentially in the following format:

1. **[Command Name]**
    a. [Argument Name] = [Argument Value]
    b. [Argument Name] = [Argument Value]
2. **[Command Name]**
    a. [Argument Name] = [Argument Value]
    b. [Argument Name] = [Argument Value]

⋮

6. **[Command Name]**
    a. [Argument Name] = [Argument Value]
    b. [Argument Name] = [Argument Value]

For consistency, all times should be in expressed in UTC as **YYYY-MM-DDThh:mm:ssZ**.

Additional Notes:

- Mission plan submissions should adhere to the numbering scheme shown in the example and the command name and argument format shown in the list of general commands (pg. 3).
- Each command should be sent, at most, once.
- All mission plans must be submitted as text (*.txt) files in UTF-8 encoding. A submission template is provided below:

1. <Command_Name>
a. <Argument_Name> = <Argument_Value>
2. <Command_Name>
a. <Argument_Name> = <Argument_Value>
b. <Argument_Name> = <Argument_Value>
3. <Command_Name>
a. <Argument_Name> = <Argument_Value>
b. <Argument_Name> = <Argument_Value>
c. <Argument_Name> = <Argument_Value>

An example section of a valid mission plan is shown below:

1. Slew to Commanded Quaternion
a. Command Execution Time = 2020-03-25T11:30:00Z
b. ECI-to-Body quaternion = [0, 0, 0, 1]
c. Slew Completion Time = 2020-03-25T11:35:00Z
2. Turn Camera On
a. Command Execution Time = 2020-03-25T12:05:00Z

C. List of Commands:

Unless otherwise specified, provide a gap of at least 5 seconds between commands.

- **Initialize ACS**
  - *Arguments*:
    - Command Execution Time = YYYY-MM-DDThh:mm:ssZ
  - *Notes*:
    - Minimum time to next command must be $\geq \mathbf{2100}\ s$
    - Initializing ACS de-tumbles the vehicle.
- **Slew to Commanded Quaternion**
  - *Arguments*:
    - Command Execution Time = YYYY-MM-DDThh:mm:ssZ
    - ECI-to-Body quaternion = $[q_1, q_2, q_3, q_0]$
      - q_0 is the scalar element.
      - The J2000 ECI frame is the designated inertial frame.
    - Slew Completion Time = YYYY-MM-DDThh:mm:ssZ
  - *Notes*:
    - ECI-to-Body quaternion must be provided as a unit quaternion and in brackets (as shown in the example above).
    - (Slew Completion Time – Command Execution Time) $\geq \mathbf{180}\ s$
- **Turn Camera On**
  - *Arguments*:
    - Command Execution Time = YYYY-MM-DDThh:mm:ssZ
- **Turn Camera Off**
  - *Arguments*:
    - Command Execution Time = YYYY-MM-DDThh:mm:ssZ
- **Set Camera Exposure**
  - *Arguments*:
    - Command Execution Time = YYYY-MM-DDThh:mm:ssZ
    - Set exposure time = Exposure_Time
  - *Notes*:
    - Camera exposure time must be given in μs and be within $20\ \mu sec \leq$ Exposure_Time $\leq 3000\ \mu sec$
- **Capture Target Image**
  - *Arguments*:
    - Command Execution Time = YYYY-MM-DDThh:mm:ssZ
  - *Notes*:
    - The image will be taken at the command execution time with no delay

Additional Notes:

- Commands listed in the mission plan should adhere to the argument format shown.

D. Additional Information Relevant to Challenge:

- Satellite ephemeris propagation should be generated via the TLE obtained in the previous step. Consider using open-source propagators such as PyEphem.
- For quaternions, we define
  - ECI-to-Body quaternion = $[q_1, q_2, q_3, q_0]$
    - q_0 is the scalar element.
    - The J2000 ECI frame is the designated inertial frame.
- ECI-to-Body quaternion takes a vector from J2000 ECI frame and places it in the Body frame.
- The imaging camera's boresight vector in its body-fixed frame is:
  - $U_{cam,BODY} = \begin{bmatrix} 0.0071960999264690 \\ -0.999687104708689 \\ -0.023956394240496 \end{bmatrix}$
- Although there are no wrong answers when it comes to the exposure time, historical records show a good exposure time lies within 300 μsec and 1 $msec$ with the moon at 12% visibility.

E. Example Quaternion Solution

An example window of interest and TLE are provided below. It should be noted that this example challenge is provided as an exercise and its inputs should not be used to solve the on-orbit challenge. The final mission plan submission for the on-orbit challenge must use the window of interest and TLE provided in section A.

Inputs:

Window of Interest (UTC): 2020-07-29T10:20:00Z-to-2020-07-29T10:21:00Z

TLE:

DEFCON28 SAT

1 46266U 19031D   20208.40655026 .00001349 00000-0 57626-4 0 9995

2 46266 51.6412 206.4482 0010395 88.8118 271.4054 15.30274909 54207

Solution:

Time of image = 2020-07-29T10:20:00Z

ECI-to-Body quaternion = [0.227708109495010, 0.292329517797394, -0.188961693387362, 0.909387677685778]

Results:

Angular Error from Camera Boresight to Moon Center: 0.000000 deg

Angular Error from -Z Panel to Earth Center: 1.844374 deg