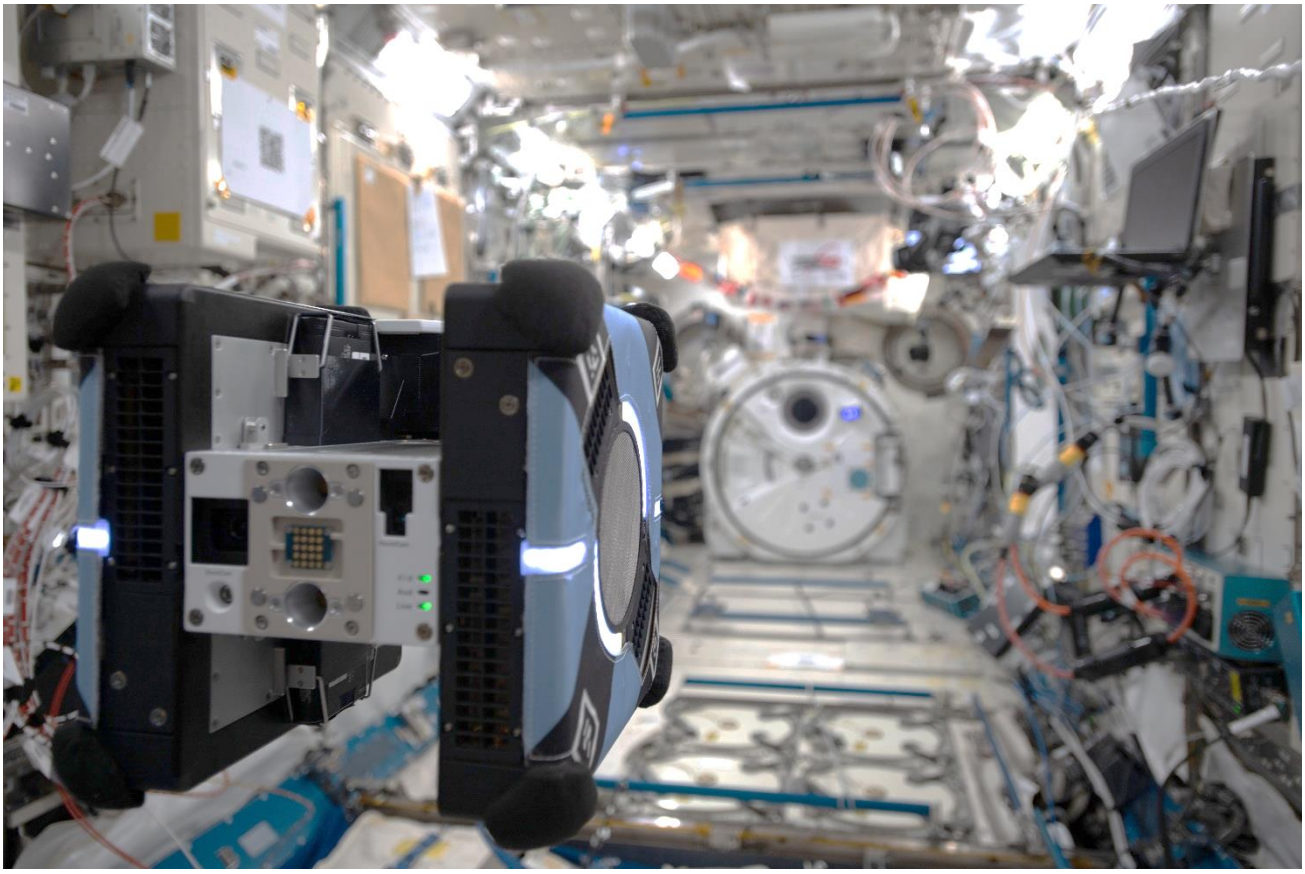
Version 1.1
Released Date: April 28th, 2022

# 3rd Kibo Robot Programming Challenge

## Rulebook



Version 1.1 (Released Date: April 28th, 2022)

**Japan Aerospace Exploration Agency (JAXA)**

# List of Changes

All changes to paragraphs, tables, and figures in this document are shown below.

| Release Date | Revision | Paragraph(s) | Rationale |
|---|---|---|---|
| April 5th, 2022 | 1.0 | All | - |
| April 28th, 2022 | 1.1 | 2.2.2 | Remove information of QR code |
| | | Figure 2.2.4-1 | Remove QR code |

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# 1. Introduction

Let's challenge your program to be the champion of the 3rd Kibo Robot Programming Challenge (Hereinafter referred to as Kibo-RPC)!

In Kibo-RPC, each country/region will first decide its representative in the Preliminary Round using simulators in each country/region in which all participants will participate. The Preliminary Rounds will compete with other participants by your programs developed before The Preliminary Round using JAXA's simulation environment. Refer to Guidebook Section 3 for game content. The Preliminary Round will be based on common scoring factors and game rules across the countries/regions. Since event cases of Preliminary Round vary from country/region to country/region, the details of information such as venues and schedules will be announced by each country's/region's POC. This Guidebook focuses on general rules across all the events.

The winning teams of the Preliminary Round in each country/region are able to participate in the Final Round. In the on-orbit Final Round, the world's best will compete using Astrobee, a free-flying robot installed in the Japanese Experiment Module "Kibo" on the ISS. Please refer to Chapter 4 of the Guidebook for the game details of this Round. Finalist teams compete with each other for the world championship by using free-flyer robots, Astrobee, on the ISS/ Kibo module!

# 2. Preliminary Round

## 2.1. Preliminary Round period

The Preliminary Round is carried out by all countries/regions in the Preliminary Round period. Information of Preliminary Round in each country is described on the Kibo-RPC official web site ( https://jaxa.krpc.jp/ ). Please contact your country's/region's POC for more details.

Note: Participants will not be able to run web simulations from "Preliminary Round" tab. "Preliminary Trial" tab is always available.

APK submission period: June 13th through 27th, 2022

Preliminary Round period: June 28th through July 12th, 2022

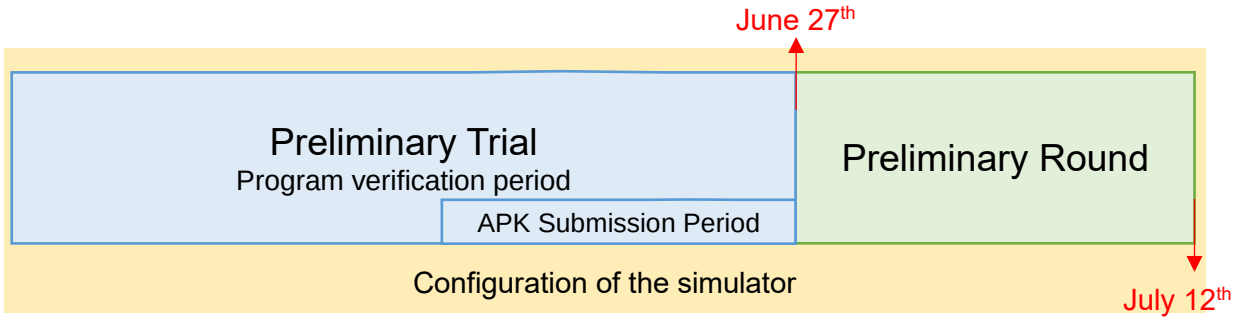



Figure 2.1-1 Preliminary Round Period

# 2.2. Game Rules

## 2.2.1. Game flow

All teams need to create a program such as following points to control NASA's Astrobee in JAXA's simulation environment.

1. Move Astrobee from the starting position to Point 1.
2. Using the surrounding AR tags, the laser is irradiated to the area within the green square of Target 1.
3. Move Astrobee to the area around Point 2 while avoiding the Keep Out Zone (KOZ)*1, which is a no-entry area that looks like an obstacle.
4. Using the surrounding AR tags, the laser beam is irradiated to the center of Target 2 while correcting the position.
   Note: If you want to make minor adjustments to the position for better targeting, please create your program to retry within the time limit.
5. Avoid KOZ and move Astrobee to Goal while facing Airlock direction. *2
6. Using Astrobee's functions, Report "Mission Complete" to Astronaut. *3*4

*1 Keep Out Zone is an area where Astrobee cannot move into. When Astrobee attempts to enter the Keep Out Zone, Astrobee's function denies the move request and it cannot move.

*2 You can make Astrobee turn around to move face forward instead of backward in JAXA's simulation environment. However, the accuracy of Astrobee's self-position recognition in the on-orbit Final Round is differentin the simulation environment, so it increases the risk of failure in self-position estimation. (See Programming Manual for details)

*3 The time limit is 6 minutes for one run. (It ends with the mission completion command and does not include the time to report to the astronauts.)

*4 "Mission Complete" report is done by an API prepared by JAXA and visually displayed in JAXA's simulation environment. It is different from the on-orbit Final Round.

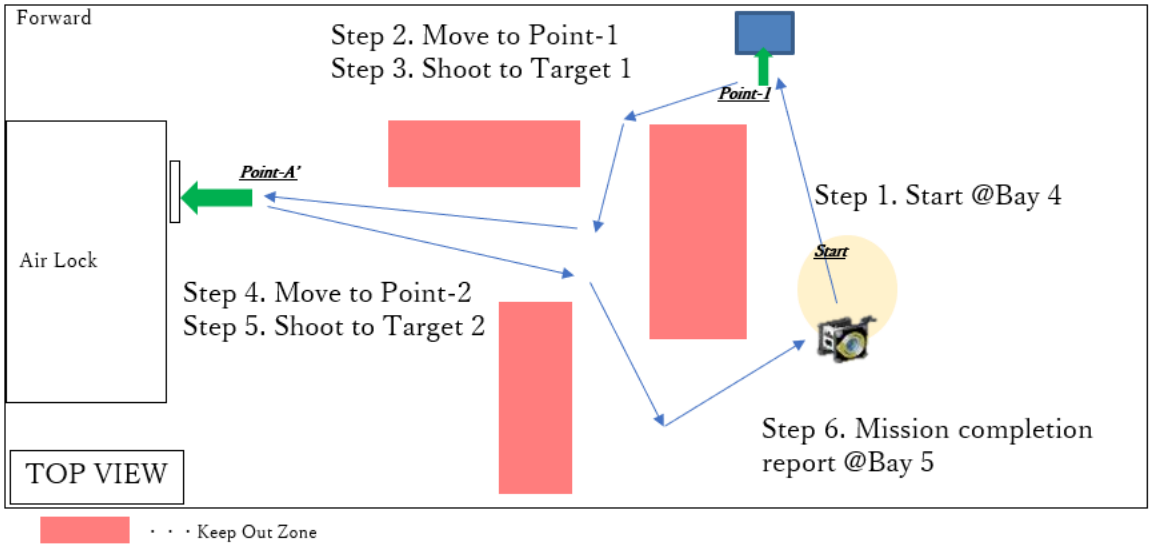



Figure 2.2.2-1 Game Outline of the Preliminary Round

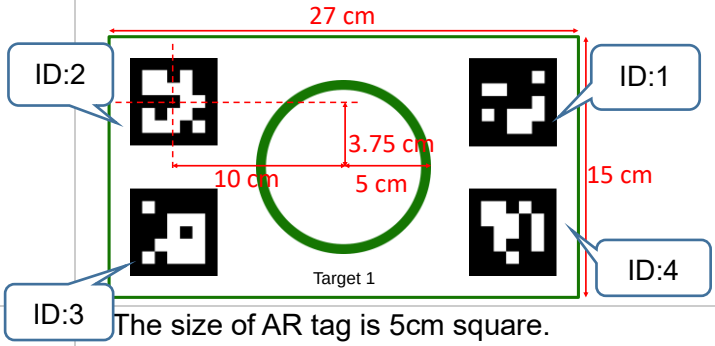
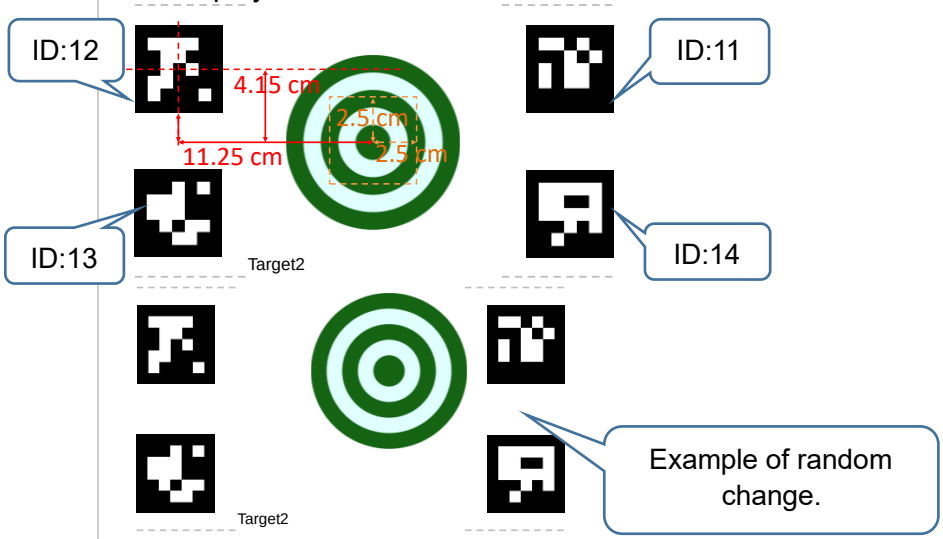
## 2.2.2. Preconditions

Table 2.2.2-1 Preconditions of the Preliminary Round

| # | Content |
|---|---|
| 1 | The starting position is as follows:<br>Position (x, y, z) = (10.76150, -6.88490, 5.31647)<br>Orientation (x, y, z, w) = (0, 0, -0.707, 0.707) |
| 2 | The Point1 coordinates are;<br>Position (x, y, z) = (10.71000, -7.70000, 4.48000))<br>Orientation (x, y, z, w) = (0, 0.707, 0, 0.707)<br>It must move precisely to this position. |
| 3 | There are AR tags around the Target1. The relative distances between the target and AR tags are always the same. |
| 4 | The position of Point 2 is as follows:<br>Position (x, y, z) = (11.27460, -9.92284, 5.29881)<br>Orientation (x, y, z, w) = (0, 0, -0.707, 0.707) |
| 5 | AR tags exist near Target 2:<br>The position of Target 2 changes randomly within the specified range, and the relative distance between Target2 and the AR tags also changes randomly. |
| 6 | The goal position is as follows:<br>Position (x, y, z) = (11.27460, -7.89178, 4.96538)<br>Orientation (x, y, z, w) = (0, 0, -0.707, 0.707) |
| 7 | About the AR tags and targets, please refer to 2.2.3 Objects. |
| 8 | Keep-Out Zones (KOZ)* simulating obstacles are set somewhere in the path of Astrobee. This KOZ is given as a precondition. About the detail, please refer to 2.2.4 Keep-In-Zone (KIZ) and Keep-Out-Zone (KOZ).<br>* Astrobee cannot move into KOZ. |

## 2.2.3. Objects

Table 2.2.3-1 Objects of the Preliminary Round

| # | Name of object | Method |
|---|---|---|
| 1 | Target1 | The size of AR tag is 5cm square.<br>-It is located on both sides of the Target1.<br>"Aruco.DICT_5X5_250" is used as dictionary.<br>The size of target is 5cm radius, and the distance between the center of AR and center of target is (\|x\|, \|z\|) = (10.00 cm, 3.75 cm)<br>The IDs of the AR tags are 1, 2, 3 and 4, counterclockwise from the upper right.<br>* The text “Target1” will be printed in the Final Round, but it is not displayed in the simulator.<br>* For scoring, a basic point is awarded if the laser beam point hits within the green square, and an additional point is awarded if the laser beam point hits within the green circle.<br>  |
| 2 | Target2 | The size of AR tag is 5cm square.<br>-It is located on both sides of the Target2.<br>"Aruco.DICT_5X5_250" is used as dictionary.<br>The size of target is 5cm radius. The center position of Target2 changes randomly within ±2.5cm.<br>The IDs of the AR tags are 11, 12, 13 and 14, counterclockwise from the upper right.<br>* The text “Target2” will be printed in the Final Round, but but it is not displayed in the simulator.<br>  |

## 2.2.4. Keep-In-Zone (KIZ) and Keep-Out-Zone (KOZ)

Keep-In-Zone (KIZ) is defined as the area where Astrobee can move around, and basically set along the walls of Kibo. It is a preset boundary in Astrobee and if the destination of the moving path of Astrobee is outside the KIZ, that is rejected. You need to design each moving path of Astrobee within the KIZ.

The Keep-Out-Zone (KOZ) are set inside the KIZ as a volumetric zone and used as some obstacles inside Kibo in the Kibo-RPC. You need to design each moving path of Astrobee to avoid the KOZ.
(Figure 2.2.4-1, 2.2.4-2, 2.2.4-3, Table 2.2.4-1)

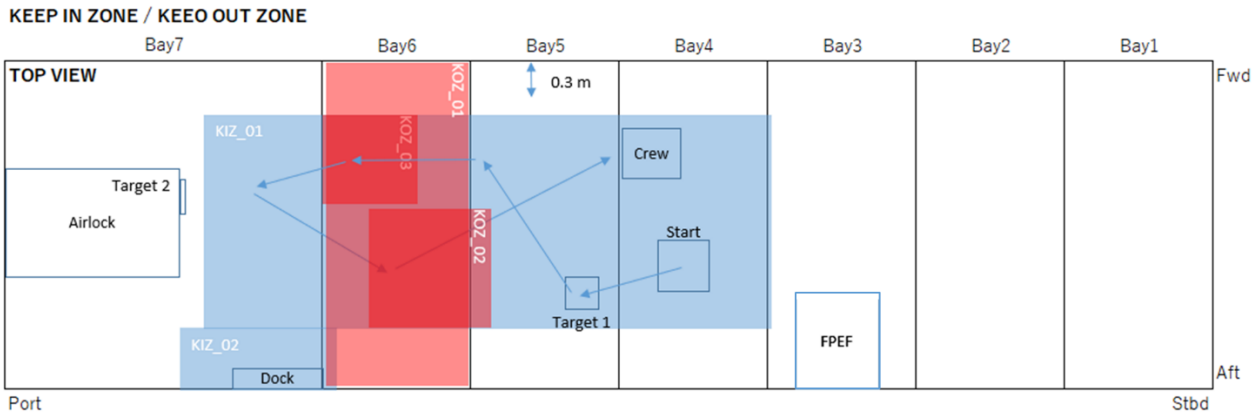



Figure 2.2.4-1 KIZ and KOZ of the Preliminary Round (Top View)

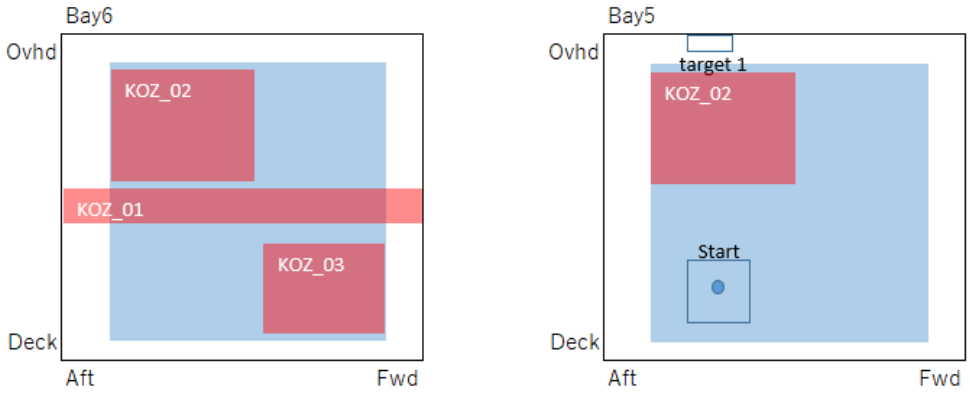



Figure 2.2.4-2 KIZ and KOZ for each country's Preliminary Round (Front View)

Table 2.2.4-1 shows the coordinates of KOZ and KIZ. Definition of the coordinates (x_min, y_min, z_min) and (x_max, y_maxm z_max) are shown in Figure 2.2.4-3.

Table 2.2.4-1 Installed Coordinate of Obstacles

| Type | No. | x_min | y_min | z_min | x_max | y_max | z_max |
|---|---|---|---|---|---|---|---|
| KOZ | 01 | 9.8673 | -9.18813 | 3.81957 | 10.7673 | -8.28813 | 4.81957 |
| | 02 | 9.8585 | -9.4500 | 4.82063 | 12.0085 | -8.5000 | 4.87063 |
| | 03 | 11.1067 | -9.44819 | 4.87385 | 12.0067 | -8.89819 | 5.87385 |
| KIZ | 01 | 10.3 | -10.2 | 4.32 | 11.55 | -6.4 | 5.57 |
| | 02 | 9.5 | -10.5 | 4.02 | 10.5 | -9.6 | 4.8 |

*The origin of the coordinate axis is set outside of Kibo

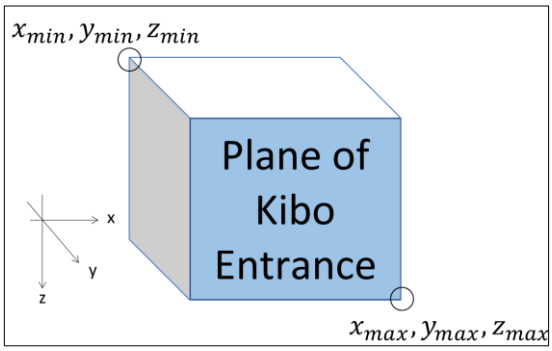



Figure 2.2.4-3 Definition of the coordinates

## 2.2.5. 10 automatic runs per APK

In the Preliminary Round, 10 runs are automatically executed for one APK to keep the fairness against the random elements included in the simulation. In these 10 runs, the conditions such as the position of the Target2 and other random elements are all different.

This method avoids the accidental results (good and bad results by accidents) and also prevent to rank by the environmental and disturbance conditions. All participants can challenge in the same condition.

Note: In the "Preliminary Trial," the user can choose from two patterns of simulation: one which the position of Target 2 changes randomly, and the other which the position of Target 2 is fixed at a certain position.

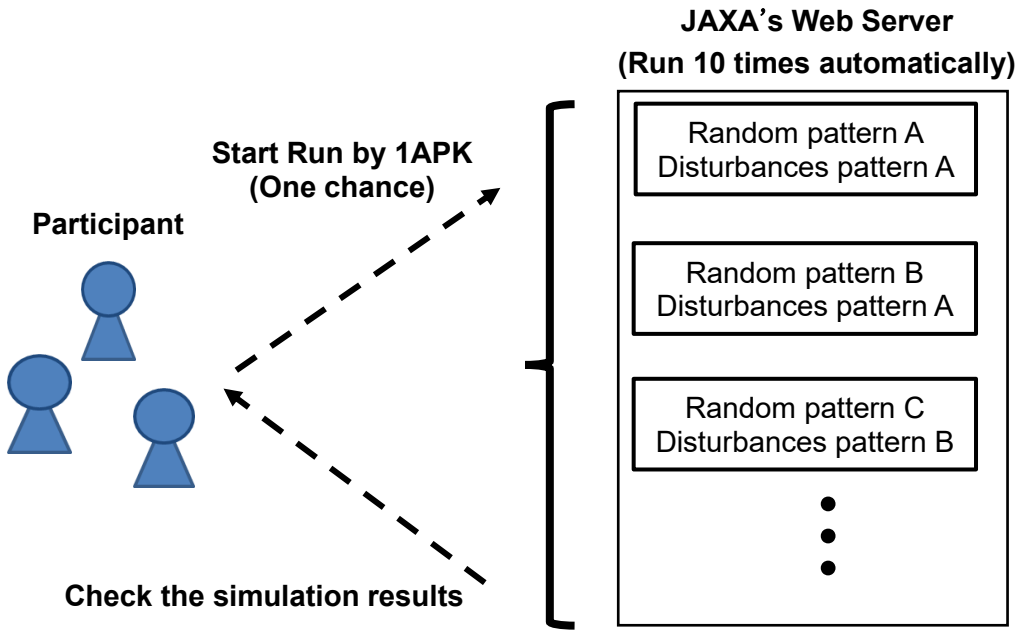



Figure 2.2.5-1 10 times run

## 2.2.6. Ranked by the worst result of 10 automatic runs

The ranking will be determined by the worst score in 10 runs.

Space missions are performed under very severe conditions, such as one failure is not allowed, and malfunctions cannot be recovered directly by human hands. This mission scenario is also an important mission that cannot be failed to help the astronaut's life in the ISS crisis, so it is necessary to complete the mission even with the worst result. Therefore, in order to evaluate participant's programming that can perform well under any conditions, the worst result is used for ranking.

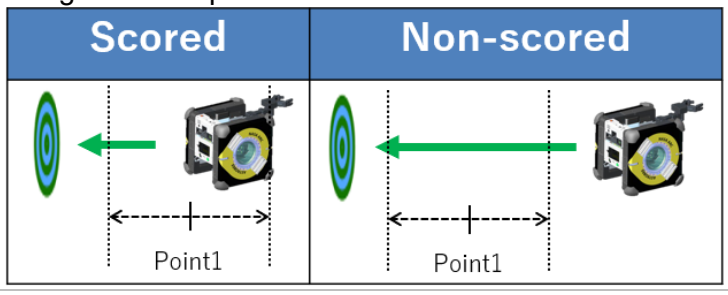
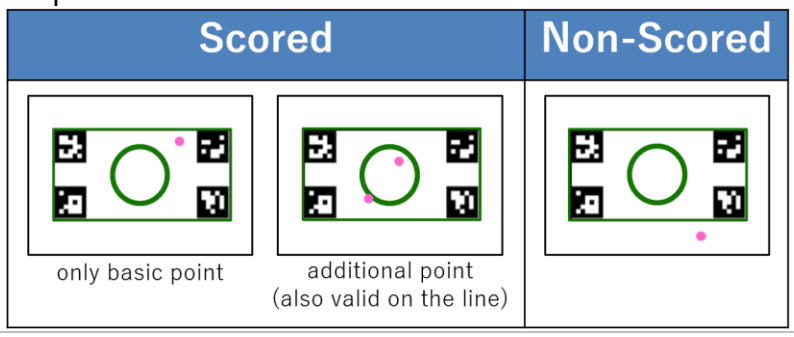
Detailed scoring criteria are provided in Section 2.3.

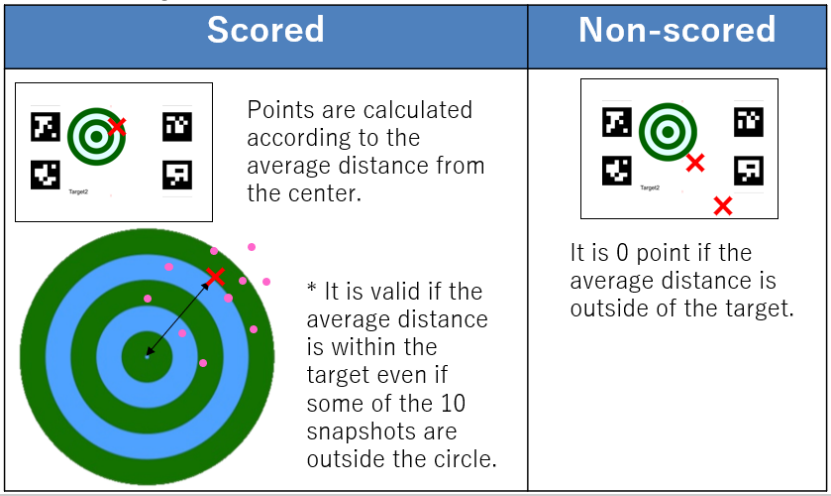
# 2.3. Scoring

## 2.3.1. Factors

Your class and score are calculated by the following factors.

Table 2.3.1-1 Scoring Factors for the Preliminary Round

| # | Factor | Detail |
|---|---|---|
| 1 | Reaching Point1 | Scoring is based on the coordinates when Astrobee arrive at Point 1.<br>If the arrival coordinates are within a specific distance, you can get a basic point.<br>  |
| 2 | Laser irradiation to Target 1 | If the laser irradiation point is within the specified square frame, you can get a basic point.<br>In addition to a basic point, you can get an additional point if the laser hit within a circle frame close to the center of the target.<br>The laser irradiation position is determined from a single snapshot.<br>  |

| # | Factor | Detail |
|---|---|---|
| 3 | Laser irradiation to Target 2<br>(After laser irradiation, a snapshot is taken by calling the snapshot API.) | The distance from the point of laser irradiation to the center of Target 2 is an average of 10 snapshot.<br>Additional points are given depending on the average distance from the Target 2 center.<br>  |
| 4 | Reaching the Goal | Scoring is based on the coordinates when Astrobee reach Goal.<br>If the arrival coordinates are within a specific distance , you can get a basic point. |
| 5 | Reporting “Mission Complete” to Astronaut | Elapsed time from Start to Report |

* Taking snapshots

- During irradiating the target with the laser, Astrobee takes 10 snapshots at intervals of a second. Score is evaluated by the average of distance from irradiating point to the center of target of 10 snapshots. Taking snapshots is possible only once in each Run, for Target 1 and Target 2 respectively.
- If you program automatic re-trial for fine adjustment of Astrobee position, you can retry aiming and laser irradiation until taking the snapshots after finalizing the laser irradiation. (Refer to Figure 2.3.1-1) It might be better to consider a unique strategy such as using image processing to assess the accuracy.

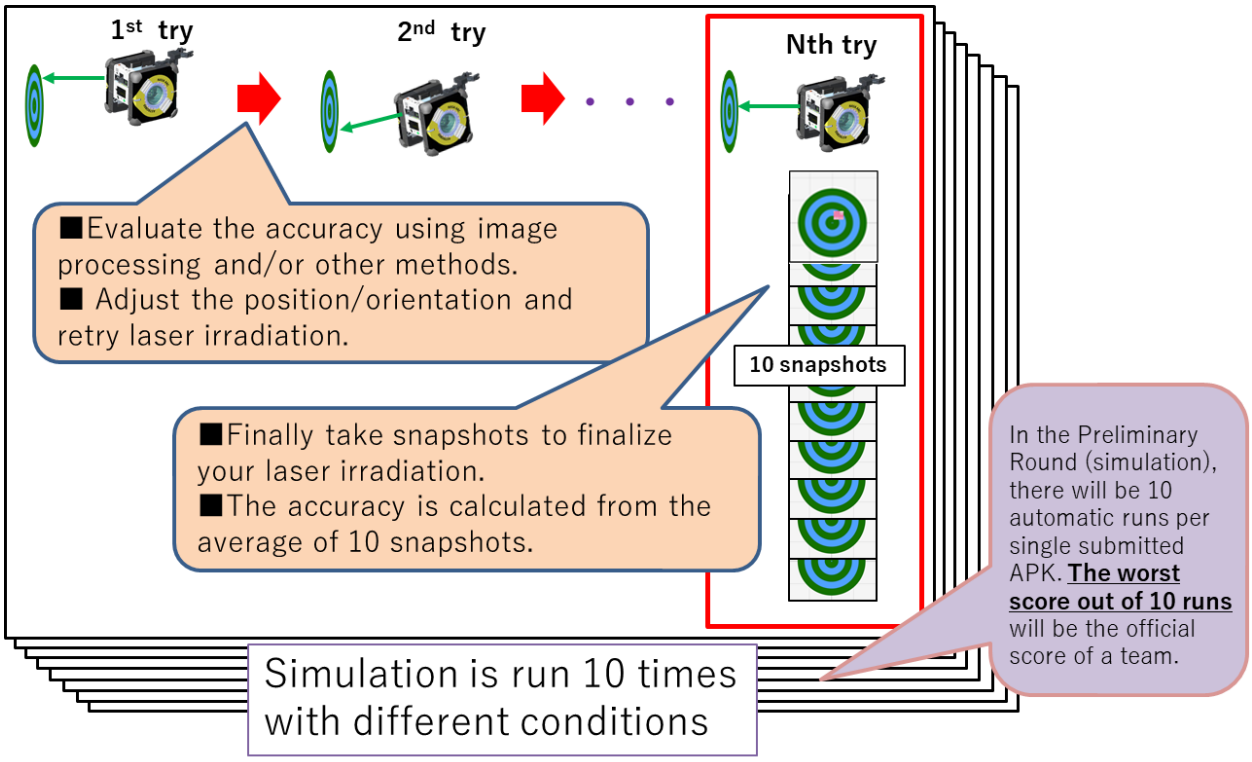



Figure 2.3.1-1 Method of repeating 10 times and scoring

## 2.3.2. Ranking method

In the Preliminary Round, all teams are rankedby the worst score out of 10 runs. Therefore, even if 9 runs have completed the mission, it is ranked by the worst score when you cannot reach to Goal within the time limit even once. In other words, the result of the run that you could not reach Goal is the team's evaluation.

It is important to create a program that can accomplish missions under any random conditions.

| | Random pattern | Level | Score |
|---|---|---|---|
| 1 | Random pattern A<br>Disturbances pattern A | Mission completed | 70 |
| 2 | Random pattern B<br>Disturbances pattern A | Mission completed | 89 |
| 3 | Random pattern C<br>Disturbances pattern B | Mission completed | 90 |
| 4 | Random pattern D<br>Disturbances pattern F | Target1 Laser irradiation time out | 10 |
| 5 | Random pattern A<br>Disturbances pattern C | Target2 Laser irradiation time out | 60 |
| 6 | Random pattern C<br>Disturbances pattern E | Mission completed | 75 |
| 7 | Random pattern G<br>Disturbances pattern G | Mission completed | 88 |
| 8 | Random pattern F<br>Disturbances pattern A | Mission completed | 65 |
| 9 | Random pattern E<br>Disturbances pattern C | Mission completed | 77 |
| 10 | Random pattern B<br>Disturbances pattern G | Mission completed | 68 |

Figure 2.3.2-1 Method of evaluating team scores

# 2.4. Joining Preliminary Round

## 2.4.1. How to participate in Preliminary Round

Participants need to submit the APK for the Preliminary Round by the submission deadline. (All figures below are screen shots in 2nd Kibo-RPC.)

## 2.4.2. Submission of Preliminary Round APK

Participants create and submit a program for Preliminary Round by the submission deadline to participate in the Preliminary Round. You may resubmit another APK as many times as you wish, even after you have submitted one APK, as long as it is within the submission deadline.

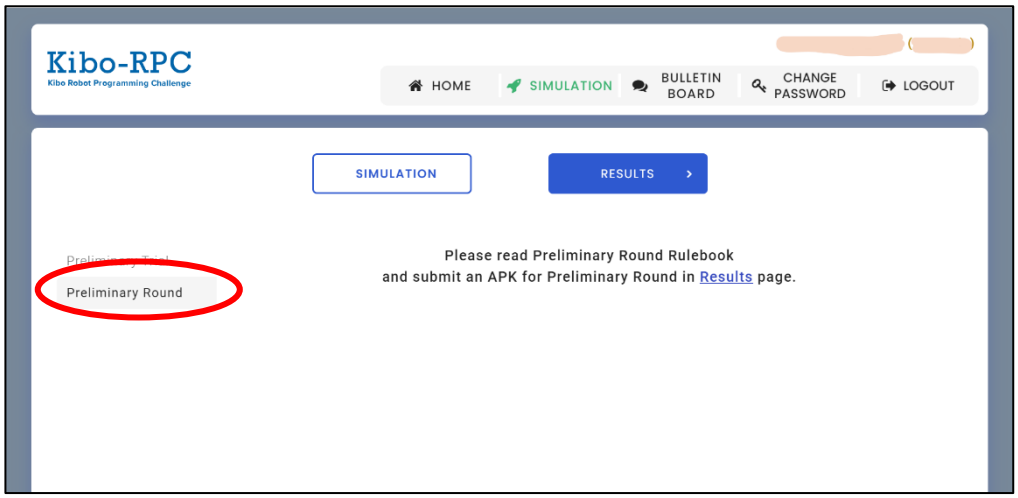



Figure 2.4.2-1 Preliminary Round

Before the Preliminary Round period, the web simulation result screen will be changed as shown in Figure 2.4.2-1. Before submitting your APK, please evaluate the performance of your program using Preliminary Trial simulator. After that, you select your best program from the result list of “Preliminary Trial” on “RESULTS” screen, and press the "SUBMIT" button that is newly added. And then the APK is submitted. Once press the “SUBMIT” button, it is changed to the “CANCEL" button. Therefore, you can resend the other APK by clicking the “CANCEL” button before the deadline.

Note: “SUBMIT” button can only be pressed when you subumit the APK that is “Finished” status in the “Preliminary trial”. If you have only “Failed” APK, you cannot participate in the Preliminary Round. Please make sure to create an APK that is “Finished” in the “Preliminary trial”.

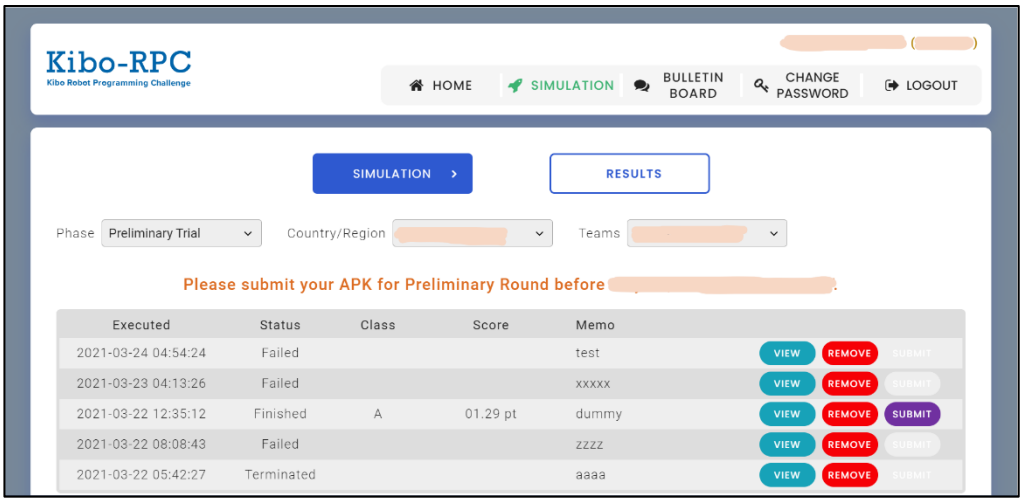



Figure 2.4.2-2 Preliminary Trial after change

The submitted APK can be confirmed from the "Preliminary Round" tab as shown in Figure 2.4.2-3. You can cancel to submit the APK on RESULTS screen, but be careful about the submission deadline because you cannot press the “SUBMIT” and “CANCEL” button over the deadline

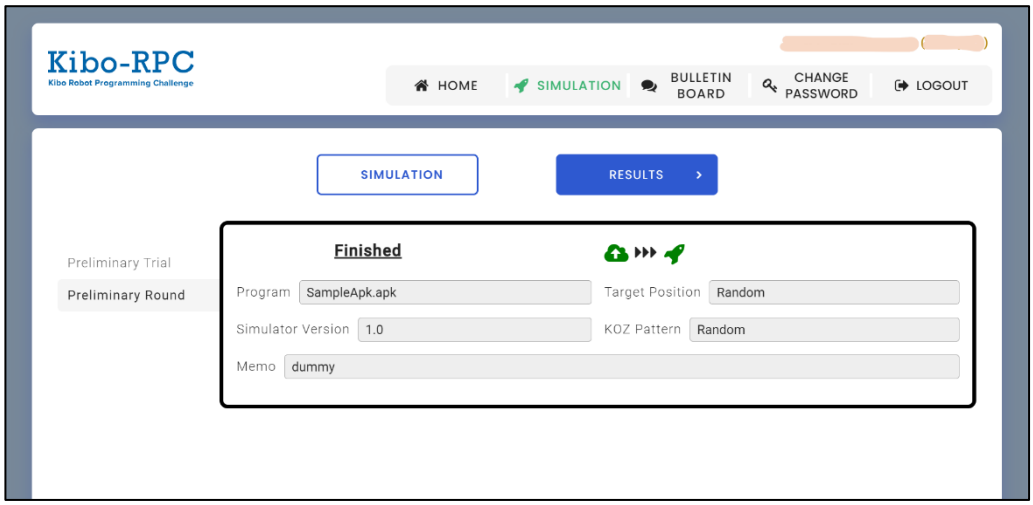



Figure 2.4.2-3 Preliminary Round

## 2.5. Event methodology

This section explains three typical Preliminary Round styles which are carried out in each country/region. Please confirm how Preliminary Round event will be held at the ACTIVITY tab on the Kibo-RPC official web site or contact your country's/region's POC.

### 2.5.1. Real Event

Real Event means the Preliminary Round event is held at a venue in your country /region. Participants must submit the APK on the web by the deadline and go to the venue on the day. If it is difficult to go to the venue, each team's leader should talk to your country's/region's POC and participate in an alternative way (typically through Social Media). Figure 2.5.1-1 shows the general flow.

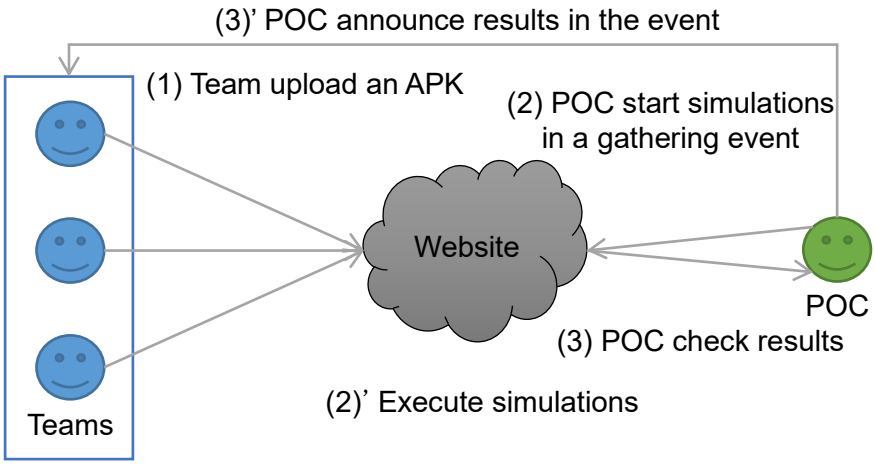



Figure 2.5.1-1 Real Event flow

### 2.5.2. Virtual Event

Virtual Event means the participants take part in the Preliminary Round through Social Media. Therefore, participants can participate from your school and home. The basic Preliminary Round procedure is the same as in Section 2.5.1. Participants must submit the APK on the web by the deadline.

### 2.5.3. E-mail Notification

E-mail Notification is a method that done without gathering with other participants, and the result is notified by e-mail from your country's/region's POC later. Therefore, participants do not need to participate in the Preliminary Round on a particular day. However, as in 2.5.1 and 2.5.2, participants must submit the APK on the web by the deadline.

*Please confirm with the POC in each country/region which style they will carry out.

# 3. Bonus Round

## 3.1. Submission for Bonus Round

Bonus Round is a preliminary round held after the completion of each country's Preliminary Round and is open to Worldwide Teams only. For details on the Worldwide Teams and how to form a team, please refer to the Entry Description. In addition, if the Worldwide Teams win the Preliminary Round in each country/region, that Worldwide team cannot participate in the Bonus Round.

## 3.2. Result

The Bonus Rounds will be held after the completion of each country/region's Preliminary Round, but no special events will be held. After the Preliminary Round in each country/region, the Kibo-RPC Secretariat will re-rank the results of the Preliminary Rounds in each country/region for only teams that meet the requirements, and select one representative team. Therefore, participants do not have to resubmit your program for the Bonus Round. As soon as a representative team is selected, the Kibo-RPC Secretariat will notify the team concerned by e-mail.

# 4. Final Round

## 4.1. Preparation for Final Round

Only each representative team can participate in the Final Round. In the Final Round, the participants will be able to refine your program from the Preliminary Round. Please create a program for the Final Round and submit an APK and source code by the submission deadline. Refer to "Submission of Final Round APK" in Section 4.4.

**1) Draft Source Code Submission Deadline: TBD (your time zone)**

**2) Final Round Program Submission Deadline: TBD (your time zone)**

* For 1), JAXA will check your source code in advance whether there is any code that adversely affects Astrobee on ISS. If necessary, JAXA will ask the participants to modify the code.

## 4.2. Game Rules

### 4.2.1. Game Flow

In the Final Round, each team will create a program to move Astrobee on the ISS from starting position to the target point while avoiding KOZ, irradiate lasers to two targets, and report back to the astronauts. Basically, the same game flow with the Preliminary Round, but please note that “Mission Complete” report is a little different from the Preliminary Round. “Mission Complete” report is done by playing a pre-recorded audio file submitted by the finalist teams. When the “Mission Complete” API prepared by JAXA is issued by APK, Astrobee will automatically play the audio file. Please refer to the Programming Manual for the detailed information about audio files.

## 4.2.2. Preconditions

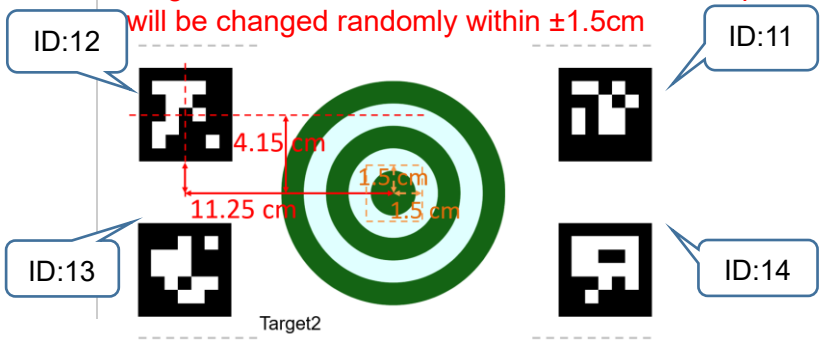
Table 4.2.2-1 Preconditions of the Final Round

| # | Content |
|---|---|
| 1-4 | The starting position, the Point1 position, and the Point2 position are the same as the Preliminary Rounds.<br>See Table 2.2.2-1 for details. |
| 5 | Different from the Preliminary Round, the position of Target 2 will not change, but the participants will not be notified of Target 2 position. |
| 6 | For AR tags and targets, please refer to 4.2.3 Objects. |
| 7 | Information of KOZ/KIZ is the same as the Preliminary Round in each country/region.<br>See 2.2.4 Keep-In-Zone (KIZ) and Keep-Out-Zone (KOZ) for details. |

Since the environmental conditions are different from the simulation and on-orbit, it is important to create a program that can show high performance even in the real environment.

## 4.2.3. Objects

Table 4.2.3-1 Objects in the Final Round

| # | Object name | Method |
|---|---|---|
| 1 | Target 1 | The objects of Target1 are the same as those in each country/region's Preliminary Round.<br>See Table 2.2.3-1 for details. |
| 2 | Target 2 | It is basically the same as the Preliminary Round.<br>The part that differs from the Preliminary Round is that the size of Target2. It will be 6 cm in radius and the center position of Target2 will be changed randomly within ±1.5cm<br>  |

## 4.2.4. Mission Complete Report

The supported formats of the audio files are described at following URL;
https://developer.android.com/guide/topics/media/media-formats

Please create an audio file within 20 sec. You need to record your voice and place it in the specified folder to report mission completion on the ISS. The detail is written in Section 3.1

on the Programming Manual. The Crew Award will be presented to the team whose mission completion report impress the astronauts.

Details of the mission completion report will be updated at a later date.

## 4.2.5. Keep-In-Zone (KIZ) and Keep-Out-Zone (KOZ)

Information on KIZ/KOZ is the same as the Preliminary Round in each country/region. See section 2.2.4 for details.

## 4.2.6. Only one APK, only one run

Each team submits one APK like the preliminary round. However, it only runs one-time on ISS. Since we will use Astrobee in the Final Round on ISS, you cannot be redone or interrupted. It is a one-time shot.

However, if the Astrobee itself stop due to a malfunction, the participants will be offered the opportunity to re-run your program according to the rules described in 4.2.10.

## 4.2.7. The Time limit 6 minutes per team

If it exceeds time limit, APK will automatically shut down. Please make sure that you have to complete the mission within time limit. And even before the time limit, if Astrobee gets stuck or its self-position is lost, it is automatically judged as a game-over. The system may also terminate without waiting for the time limit when it is judged that no further operation can be expected, such as when Astrobee stop for a long period of time for reasons other than image processing for laser irradiation of the target.

* The time limit for the on-orbit finals is currently the same as for the Preliminary Round, but it will be changed from now on. Any changes will be announced.

## 4.2.8. Operation of the APK on the day of the Final Round

Participants may NOT operate the APK on the day of the Final Round.

The submitted APKs are code-reviewed by the technical team of JAXA / NASA and uplinked to Astrobee on ISS in advance. The APKs are started with the execution command sent from ground operators.

## 4.2.9. Judging method

On the ISS, the speed and accuracy of the mission are judged by the following methods. Details of the scoring criteria are written in Section 2.3.

Speed: Time from APK execution start to send Finish command (Mission Complete Report) is recorded as the time stamp in Astrobee, which is available to the ground as telemetry.

Accuracy: Judged by the exact movement to the Point1 position and the position of laser irradiation to Targets1 and 2. The moving position is recorded on the ground as telemetry. Irradiations are recorded in Astrobee on the ISS and accuracy is determined by snapshot images. Target 1 has two snapshots (one is used for judging and one is a spare). Target 2 is calculated with 11 snapshots (10 are used for judging and 1 is a spare).

Besides, the level of mission achievement is judged with the same way as the Preliminary Round, using APIs (startMission, reportMissionCompletion, etc.). See also the Programming Manual.

## 4.2.10. Final Round run order

In the Final Round, the teams are divided into 3 tiers according to the Preliminary Round results, and the runs are performed in this order. The results of the Preliminary Round in each country/region are summarized and the representative teams are listed in order of their scores. An example of a team assignment in a Tier is shown in Table 4.2.9-1. Tier divisions in the 3rd Kibo-RPC will be announced as soon as possible.

Table 4.2.9-1. Team Allocation Example (2nd Kibo-RPC assignment)

| Tier in the Final Round | Preliminary Round results |
|---|---|
| 1st Tier | 1st Place |
| | 2nd Place |
| | 3rd Place |
| | 4th Place |
| 2nd Tier | 5th Place |
| | 6th Place |
| | 7th Place |
| 3rd Tier | 8th Place |
| | 9th Place |

The run order in the Final Round is prioritized in the order of tier.
If a team gets stuck due to Astrobee's failures on ISS, that team will run again before moving to the next tier, as long as there is enough time. No re-runs will be performed by stacks caused by the participant's APK. Please note that the time to conduct the competition in orbit is limited, so the lower-ranked teams in the Preliminary Round may not be able to run the program in the on-orbit Final Round. See Figure 4.2.9-1 for details.

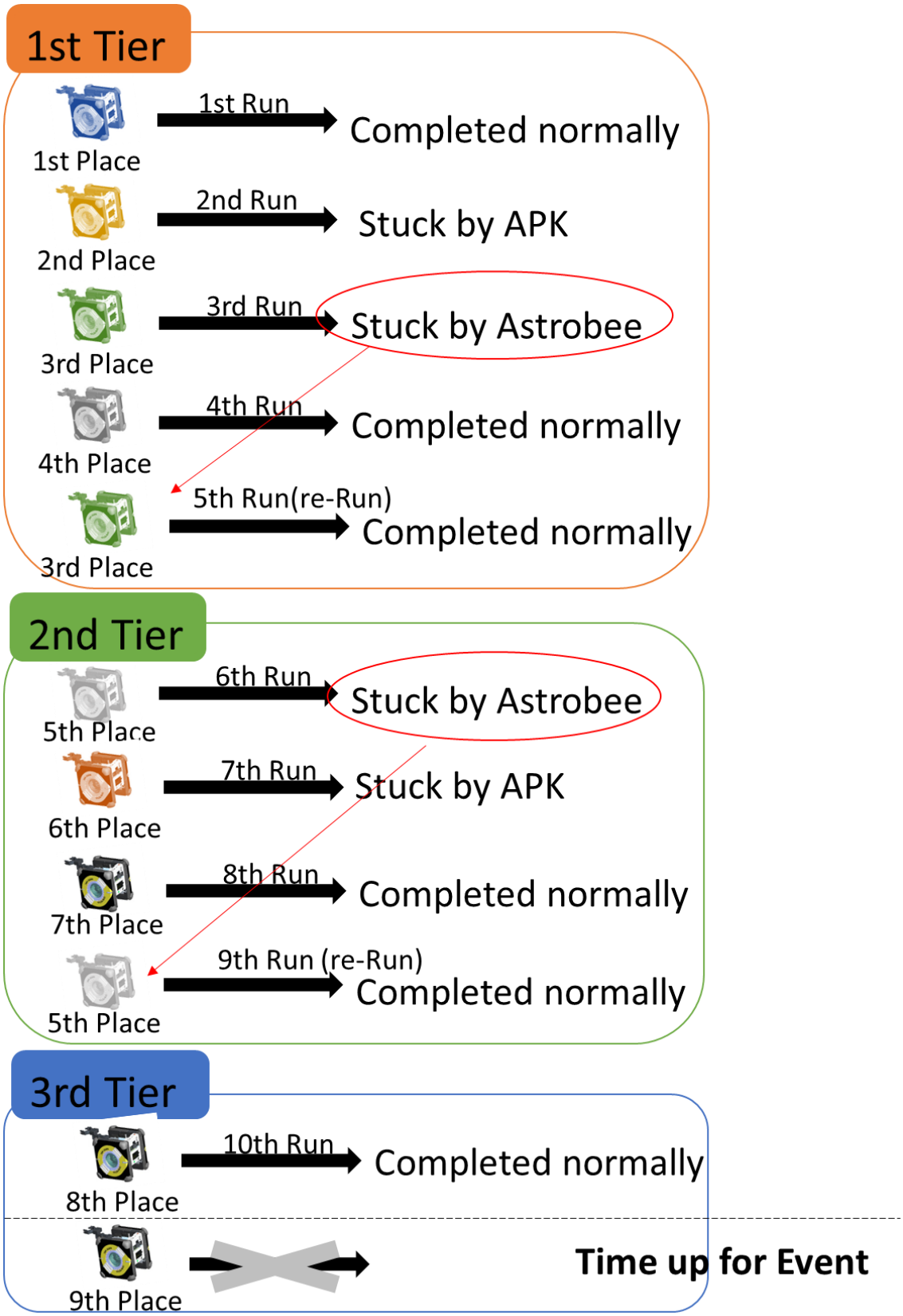



Figure 4.2.9-1 Example of the Final Round run order

## 4.3. Scoring

### 4.3.1. Factors

The scoring factors are the same as the Preliminary Round. See 2.3.1 for detail. However, in the Final Round, your APK will be run only once on ISS.

### 4.3.2. Ranking Method

Only one run is performed in the Final Round. Therefore, the one result is the team's score. Your voice message of “Mission Complete” will be evaluated for Crew Award as well.

## 4.4. Joining the Final Round

What the finalists need to do is followings. Details will be released at a later date.

(1). API updates
(2). Change APK application ID and APK name
(3). Create and place of audio files
(4). Send APK, source code, audio files, and message text files
(5). Confirm that everything is complete.

## 4.5. Event methodology

This section explains the plans of the Final Round.
Information will be updated as soon as the content is determined.