Kepler’s Orbits BNA’26 Detailed Study Guide

1.Module Introduction

Summary

Welcome to *Kepler’s Orbits*, the Aerospace and Astronomy Module at the Beaconhouse Notion of Academia ‘26. This module is specifically designed to challenge your understanding of aerospace engineering, space technology, and the fundamental principles that govern exploration of the aforementioned domains. The module explores the basic principles that facilitate deeper engagement and further indulgence in these specialized scientific fields. It provides a comprehensive platform for participants to transition from basic theoretical understanding to practical application and complex ideas across three distinct competitive stages, with varying difficulty. The rounds have been designed with problems that relate to real world applications and will thus aid those willing to pursue engineering.

The first round is heavily reliant on an understanding of Fluid Dynamics and airflow principles, with no mathematical modelling required. Knowledge of specific terminologies and ideas however will aid in both design and explanation of your heat shield.

The second round shifts focus towards aeronautical engineering and an understanding of Flight Systems, Flight dynamics, Flight Control Surfaces, Avionics and the fundamentals of flight: lift, drag, thrust et al. Further in this document you will find detailed the exact aircraft to study along with its manual. The objective is to identify the root cause of the failure and reconstruct the sequential chain of events, detailing both the preceding triggers and the resulting consequences.

The final round is a standard model rocket competition but with a twist. You will be required to simulate your design choice in the specified software and obtain theoretical values for vertical and horizontal displacements covered, and then these results will be compared with the actual rocket you have built.

USE OF AI IS NOT PERMITTED AND WILL RESULT IN DISQUALIFICATION.

DELEGATES SHOULD BRING THEIR DEVICES FOR ROUNDS 2 AND 3

2. Round 1

Delegation Cap(2 delegates)

Round Name: Ablative Heat Shield

Overview

In this round, delegates are tasked with constructing a heat shield designed to redirect hot airflow away from a designated payload region while allowing the opposing point to absorb higher temperatures.
The challenge requires applying concepts of airflow manipulation, heat transfer, and geometric shaping to minimise heat conduction toward the protected area. Delegates will complete their prototypes before placing them in the testing station, where temperatures at both ends will be measured to determine the shield’s effectiveness at maintaining the payload below the specified threshold. This round evaluates structural design, thermal performance, and the ability to use limited materials intelligently under realistic engineering constraints. Delegation capacity for this round is limited to **two participants per team.**

The primary objective of this round is to engineer a thermal management system capable of manipulating hot air flow. Delegates must design and construct a prototype that effectively redirects the concentrated hot airflow from a heat gun toward a specific exit point, ensuring that a designated payload- positioned at a distance and away from the direct line of fire, receives the maximum amount of heat from the gun.

Evaluation

Delegates will be evaluated based on the thermal performance and engineering efficiency of their prototypes. The primary metric is the shield's effectiveness at maintaining the payload below the specified temperature threshold while allowing the opposing end to absorb higher heat. Furthermore, the assessment considers the structural design and the team's ability to intelligently manipulate airflow and geometric shaping to minimize heat conduction.

Logistics / Required Tools

Category	Item Description
Provided Resources	Cardboard sheets Standard stationary items Super Glue Aluminum foil
Delegate Requirements	N/A

After Round 1, 40-50% of delegations will be eliminated

3. Round 2
Delegation Cap(3 delegates)

Round Name: Aeronautical Anomaly

Overview

If you have ever watched *Sully, United 93, Flight*, or the Smithsonian Channel's *Air Disasters*; you already have a very good idea of what this round will entail.

Your job as the Go-Team part of the National Transportation Safety board (NSTB) will to analyse flight conditions leading to the crash,and the order of system failure to create a forensic breakdown report of the incident, utilizing provided manual and blueprints.

The aircraft to study will be the ***Airbus A320neo,*** *with the* ***Pratt V Whitney PW1100G-JM*** Geared Turbofan Engine option.

You should note before proceeding that this round requires extensive knowledge and is not for the faint of heart, despite scenarios being heavily simplified. Delegates are advised to prepare in the following order:

1. Flight fundamentals:
- How does an aircraft generate lift?
- Stall Physics
- Types of drag, its theory and effect.
- While you ***might*** navigate the round without it, we *highly recommend* brushing up on the physics of fluid flow and lift generation. Understanding how air moves over a wing will be your greatest asset in pinpointing exactly why an aircraft lost stability. Eg. Bernoulli's Principle, Pressure differentials, angle of attack (AoA) etc. The best resource for this is Physics by Halliday Resnick and Krane but, videos on youtube may help you understand better.

1. Flight Control Systems
    - **Basic:** Ailerons, Rudders, Elevators and Flaps
    - **Advanced:** (Recommended for standing out) Slats, Trim Tabs, Spoilers THS (Trimmable Horizontal Stabilizer) for Airbus A320 Neo.
    - Aerodynamic Consequences of Landing Gear Deployment and Jamming (BSCU Knowledge is not required)

2. Hydraulic Systems

    For Hydraulic Systems the information listed below should suffice for any explanations in the problem sets you will be provided. *(… but you never know)*

- On the A320neo, no single hydraulic failure should ever cause a total loss of control. The aircraft is designed with **redundancy**, meaning the flight control surfaces are "shared" among the three systems. If one system loses pressure, others are still available to move the remaining surfaces.

  The Green System: It powers the Landing Gear, the brakes, and certain primary surfaces like the left aileron and the rudders. If you lose the Green system, you lose normal landing gear extension and must use the gravity free-fall method

  The Blue System: It powers parts of the elevators and ailerons. Crucially, it is connected to the Emergency Ram Air Turbine (RAT), the windmill that deploys if all engine power is lost to ensure the pilot can still steer the plane.

  The Yellow System: This system powers the right aileron, parts of the elevators, and the flaps. It also allows the ground crew to move surfaces while the engines are off using an electric pump.

  Example Scenario
  Failure: Hydraulic Leak in the Green line.
  Immediate Effect: The Landing Gear cannot be retracted, and the left aileron becomes unresponsive.
  The Result: The plane now has massive Parasite Drag from the gear and an asymmetrical roll because only the right aileron is working.

3. Usage of the Aircraft Flight Manual (AFM), Aircraft Operations Manual (AOM) and the Aircraft Characteristics Manual.

   Aircraft Flight Manual

   The AFM is the legally required document that defines the boundaries and capabilities of the aircraft's performance.
   - Operating Limitations: Participants should look here to find the structural redlines - maximum speeds V$_{mo}$, maximum altitude and weight limits.
   - Emergency Procedures**:** This section details the manufacturer-prescribed steps for handling critical failures, such as a PW1100G engine failure or a total hydraulic loss
   - Certification Standards: It defines the conditions under which the aircraft is safe to fly, helping investigators determine if the pilots operated outside of safety envelopes.

Aircraft Flight Crew Operations Manual

While the AFM tells you what the plane *can* do, the AOM tells you how the crew *should* operate it.

- Standard Operating Procedures (SOPs): Investigators use this to see if the crew followed the correct "chain of command" for the aircraft's systems during the incident
- Normal & Abnormal Checklists: By comparing the pilot's actions to these checklists, delegates can determine if the "chain of events" was worsened by human error or if the mechanical failure was unrecoverable.

Aircraft Characteristics Manual

This manual is often used by airport planners and maintenance teams, but it is a gold mine for crash investigators analyzing physical geometry.

- Geometric Data: Provides exact measurements of the wings, fuselage, and landing gear footprint
- Weight & Balance: Essential for studying Center of Gravity (CoG) anomalies. If a piece of the aircraft was lost, investigators use the ACM to calculate how the balance shifted.
- Ground Clearances: Vital for investigating "gear-up" landings or wingtip strikes, as it provides the exact distance of every component from the ground.

All manuals will be provided to delegates during the round. However, use of AI is NOT permitted and will result in disqualification.

A quick tip is to recognize keywords and abbreviations and use the Find Feature within documents to find them quickly. Additionally there are subsections and indexes to help you navigate the large manuals.

Logistics / Required Tools

Category	Item Description
Provided Resources	AFM, FCOM, Manuals, Aviation Abbreviations Kepler's Orbits Round 2 Resources Link For Manuals ***DOWNLOAD RECOMMENDED*** **ACTUAL INVESTIGATION REPORT**

Category	Item Description
	Airbus A320-214 US Airways Flight 1549 Uploaded in the Round 2 Resource Drive
Delegate Requirements	All Delegates are **REQUIRED** to bring their own Devices.

Evaluation

Technical Accuracy and Manual Utilization: Delegates must correctly identify which specific flight control surfaces or systems were compromised based on the provided dataset. High-scoring reports will cite specific sections or diagrams from the **FCOM, AFM, or AOM** to justify why a certain system failed. Failure of the pilot to comply with procedure may be listed as pilot error and a contributing factor to the malfunctions.

Root Cause Identification: The report must pinpoint the primary trigger of the incident - distinguishing between a mechanical failure (such as a **PW1100G** engine anomaly) and a subsequent hydraulic or structural failure.

Analysis of Aerodynamic Consequences: Beyond just naming malfunctioning parts correctly, teams must explain *how* those failures affected the aircraft’s stability. This includes a discussion of the "Flight Fundamentals," such as how a jammed spoiler or unpowered aileron created asymmetric lift or increased drag, leading to the final outcome.

Methodology and Reasoning: Evaluators will look for a structured, forensic approach that maps the sequential chain of events. The justification should be technically sound, moving logically from the initial fault to the final aerodynamic impact, rather than jumping to conclusions without evidence.

Resources:
[Air Disasters | Smithsonian Channel - YouTube]
- Airbus A320 First Flyover Ends in Disaster | Mayday: Air Disaster
- Understanding Aerodynamic Lift
- Understanding Aerodynamic Drag
- Introduction to Glider Flight Physics and Maximizing Flight Distance
- Parasite Drag Force Explained

Please create the investigation report according to conventions, and specify order and cite page numbers and subsections names where relevant.

Good luck.

After Round 2, 10-15 Teams will Remain.

4. Round 3
Delegation Cap(3 delegates)

Round Name: SpaceX Assembly Line

Overview G Significance

Have you ever wondered how scientists were able to send the first human beings to the Moon in 1969? The success of the Apollo missions was not merely a triumph of technology, but a testament to human ingenuity in overcoming immense challenges and making impossible, possible- Earth's gravity, atmospheric resistance, and the limitations of available resources. Through rigorous testing, precise engineering, and coordinated teamwork, these obstacles were transformed into milestones of scientific progress. SpaceX Assembly line is designed to reflect that same spirit of innovation and precision. Delegates who have successfully advanced from the previous rounds will be challenged to apply their technical knowledge, analytical thinking, and team coordination across two dimensions simultaneously. Participants will be required to design and construct two identical rockets: one physical water rocket built in real time, and one virtual rocket developed using the OpenRocket simulation software.

The objective of this round is to evaluate the delegates' ability to translate theoretical designs into practical execution while maintaining consistency between real-world construction and digital simulation. Judging will be based on the accuracy of the design match, engineering efficiency, and overall performance, emphasizing the importance of precision, planning, and collaborative problem-solving - core principles at the heart of aerospace engineering.

Step-by-Step Progression

1. **Team Briefing, Safety, and Fundamental Principles**

Delegates will begin with a formal briefing covering objectives, constraints, safety protocols, and judging criteria. At this stage, participants are expected to understand the foundational physics governing rocket motion, particularly Newton's Laws of Motion, with emphasis on the action–reaction principle that enables rocket propulsion. Basic safety considerations related to pressurized systems and structural integrity must also be acknowledged.

2. **Assignment of Standardized Booster and Constraints**

All teams will be assigned an identical booster configuration within the OpenRocket software. This booster cannot be modified and establishes uniform propulsion conditions across all teams. Delegates must recognize the importance of controlled variables in experimental and engineering comparisons. Delegates should know the role of boosters in rocket propulsion, Importance of standardization in engineering evaluation and stay within the fixed-boundary design constraints

3. Conceptual Rocket Design and Stability Planning

Teams will plan the overall geometry of their rocket, including body length, diameter, fin number and placement, and nose cone design. At this stage, delegates must ensure that the rocket is aerodynamically stable and structurally feasible using water bottles and cardboard. Knowledge areas required for this area include Center of Mass (CM) and Center of Pressure (CP**)** concepts, Stability margin and its effect on flight behavior and Aerodynamic drag reduction through shape optimization

Teams will plan the overall geometry of their rocket, including:

- Body length and diameter
- Number, size, shape, and placement of fins
- Nose cone shape and

design In OpenRocket, delegates must:

- Use the software's stability indicators to verify CM–CP separation
- Adjust mass distribution and geometry to achieve stable flight

4. Digital Modeling and Simulation in OpenRocket

Teams will create a detailed digital model of their rocket using OpenRocket, incorporating accurate dimensions, mass estimates, and materials. Delegates must run simulations to analyze flight trajectory, stability, apogee, and descent characteristics, refining the design based on data-driven outcomes. Skills required by delegates in this area include translating physical designs into simulation parameters, understanding drag, thrust curves, and gravity losses and Interpreting simulation outputs such as stability and translating real-life dimensions and materials into OpenRocket components

- Correctly assigning:
  - Body tube dimensions
  - Fin geometry
  - Nose cone parameters

    - Mass and material properties
- Understanding thrust curves, drag, and gravity losses

Delegates must run simulations to analyze:

- Flight trajectory
- Maximum altitude (apogee)
- Stability margin
- Descent behavior

Simulation results should be used to refine and optimize the design.

5. Parallel Physical Construction of the Water Rocket

While finalizing the digital design, teams will construct the physical rocket using approved materials. Accurate fin alignment, secure joints, and balanced mass distribution are essential to ensure real-world performance matches the simulated model. Things to be noted during its construction are its structural mechanics and material strength, effects of mass distribution on flight stability, practical limitations of low-cost materials in aerospace design and its accuracy to the simulation design in OpenRocket software.

The physical rocket must closely match the OpenRocket design in:

- Dimensions
- Fin configuration
- Mass distribution

Any deviation must be corrected in both the physical and digital models.

6. Design Validation and Iterative Refinement

Teams will cross-verify the physical rocket against the OpenRocket model. Any deviations in dimensions or mass must be corrected in both versions. This step highlights the iterative nature of engineering and the need for validation between theory and practice, model–reality correlation and Error analysis and design refinement

7. Final Submission and Technical Documentation

Teams will submit their completed physical rocket along with the finalized OpenRocket simulation file and relevant performance data. Delegates should be prepared to justify their design choices using scientific reasoning and simulation evidence. This will include technical documentation standards, engineering justification and design rationale and data-supported decision-making

8. Evaluation, Performance Review, and Judging

- Consistency between the physical rocket and OpenRocket simulation
- Correct application of physics and aerospace principles
- Simulation accuracy and design reasoning
- Overall engineering execution

Knowledge Evaluated:

- Integrated understanding of propulsion, aerodynamics, and stability
- Ability to perform comparative analysis between simulated and real-world designs
- Systems-level thinking and problem-solving

Final Note to Delegates

This is the **final round of the module** and is designed to simulate real-world aerospace engineering workflows. Delegates are expected to arrive fully prepared, having reviewed:

- This study guide
- The OpenRocket tutorial video
- Fundamental physics and stability concepts

Precision, consistency, and scientific reasoning will be critical to success.

Logistics / Required Tools

Category	Item Description
Provided Resources	Cardboard Plastic bottle

Category	Item Description
	Cutter Tape *Water Rocket Launcher* Chart Paper
Delegate Requirements	Laptop downloaded with OpenRocket software

Resource Links:
https://openrocket.info/
OpenRocket Tutorial Part 1: Basic Rocket Design
OpenRocket Tutorial Part 2: Installing Motors and Running Simulations
Open Rocket Tutorial
How to Make a Water Rocket

5. Preparation / Study Resource Hub

All resources can be found attached within their respective subsections. In case of queries you may reach out here:

Module Heads

Shayaan Ilyas: +92 309 5199629
Abdullah Muhammad: +92 315 5999781