Exploring the Advanced Capabilities of WESP Simulation Predictive Rocketry Tool

WARR rocketry

WSPR
WESP SIMULATION PREDICTIVE ROCKETRY TOOL

Aníbal Guerrero Hernández

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WESP

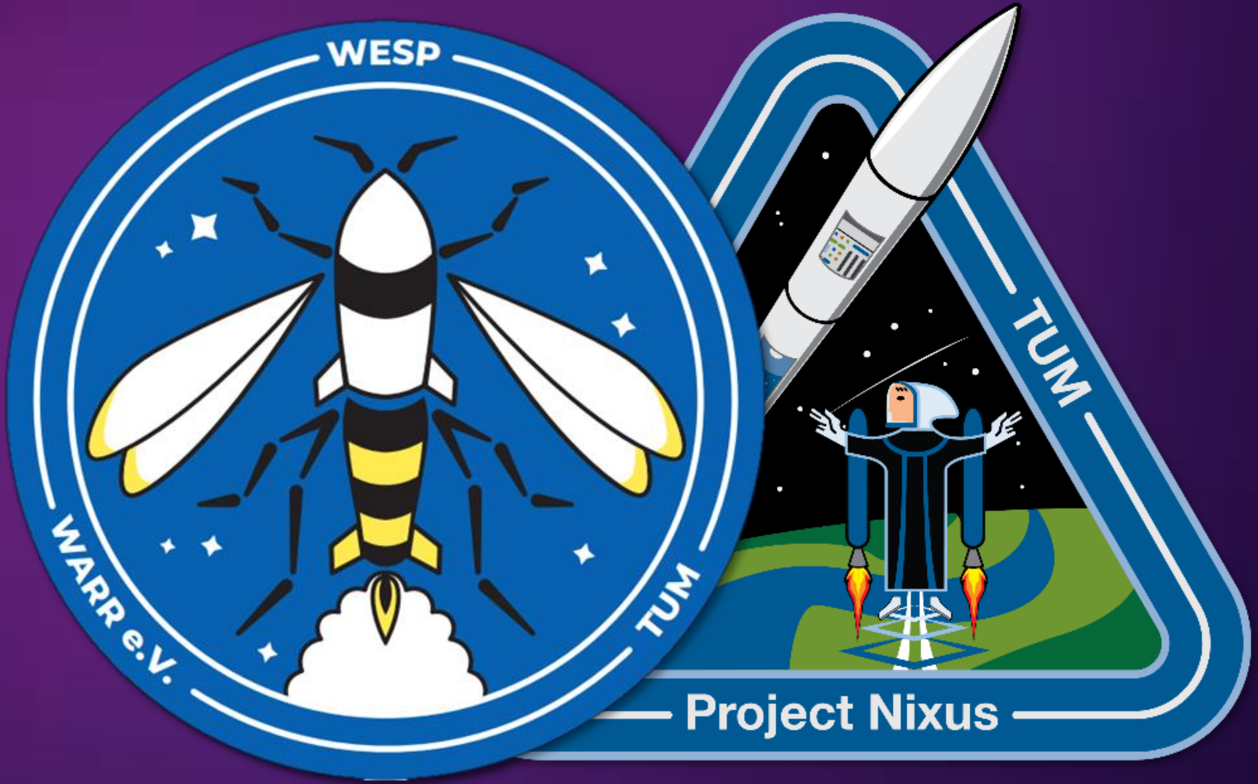
Introduction

ABOUT US

Founded in May 2023
40+ Student Members
25,000+ Engineering Hours

LAUNCHES

EX-3 | 17.07.2023 | FAR, CA, USA
EX-1D | 21.04.2024 | Straubing, Germany
EX-1E | 19.06.2024 | Spaceport America Cup, NM, USA



WARR Rocketry WESP

EX-1D

PARAMETER	EX-1D
Stages	1
Apogee	440 ft
Innovation	- Self-developed flight computer - Maiden flight

WARR Rocketry WESP

EX-1E

PARAMETER	EX-1E
Stages	2
Apogee Target	27,297 ft
Payload Capability	Developed by SpaceLabs – experience with ISS experiments
Innovation	- SRAD wound carbon fiber airframe - Live Telemetry - 2.4GHz LoRa - AM Titanium Motor Mount - WSPR

OpenRocket ©

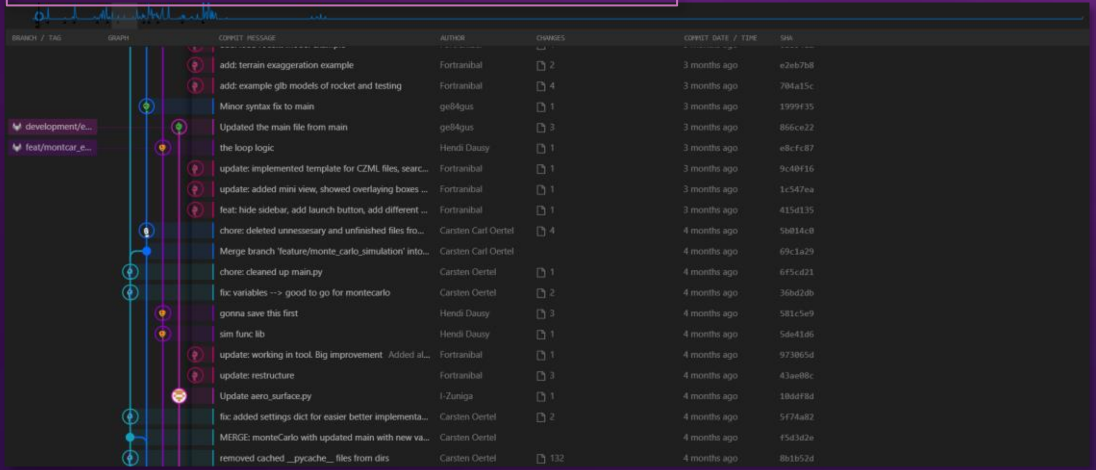
Introduction to WSPR

Our Approach

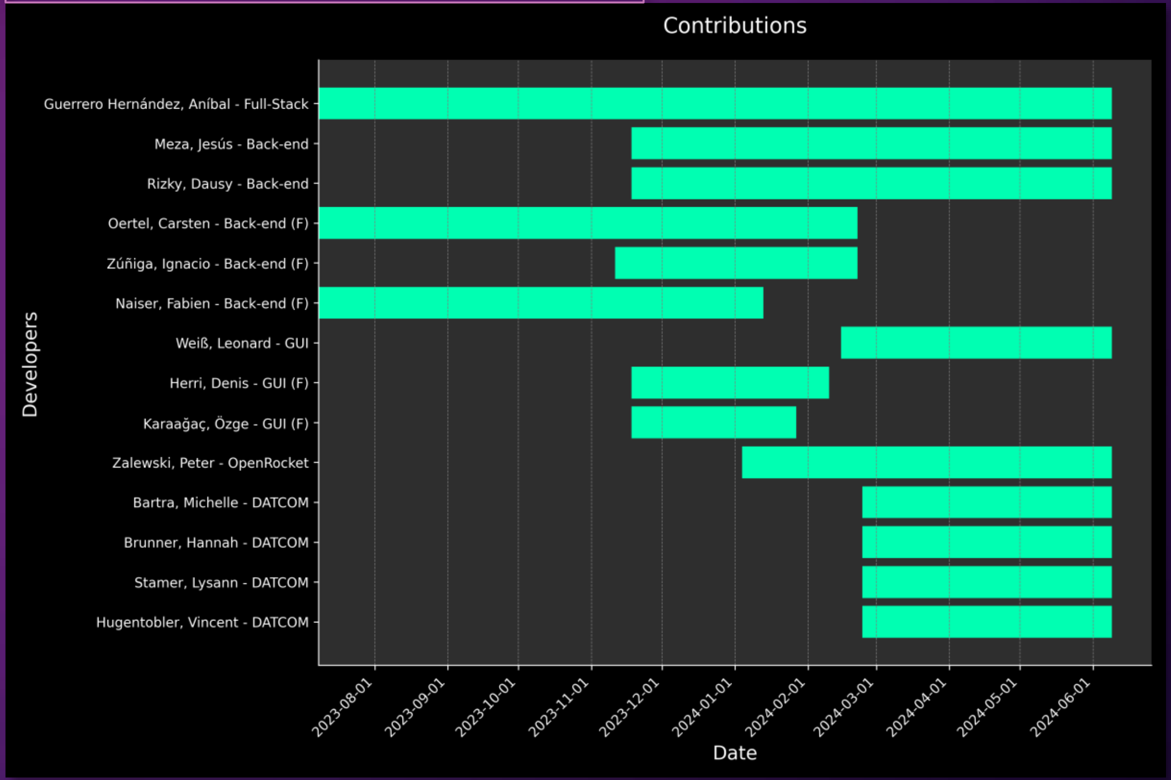
WHAT IS WSPR?

- In-house software to **simulate** 6 DOF trajectories
- Applicable to **all propellant** type motors
- 8 Active Members, 14 Total Developers
- Rapid Iterations, Parallel Developments

PARALLEL DEVELOPMENTS



TEAM MANAGEMENT



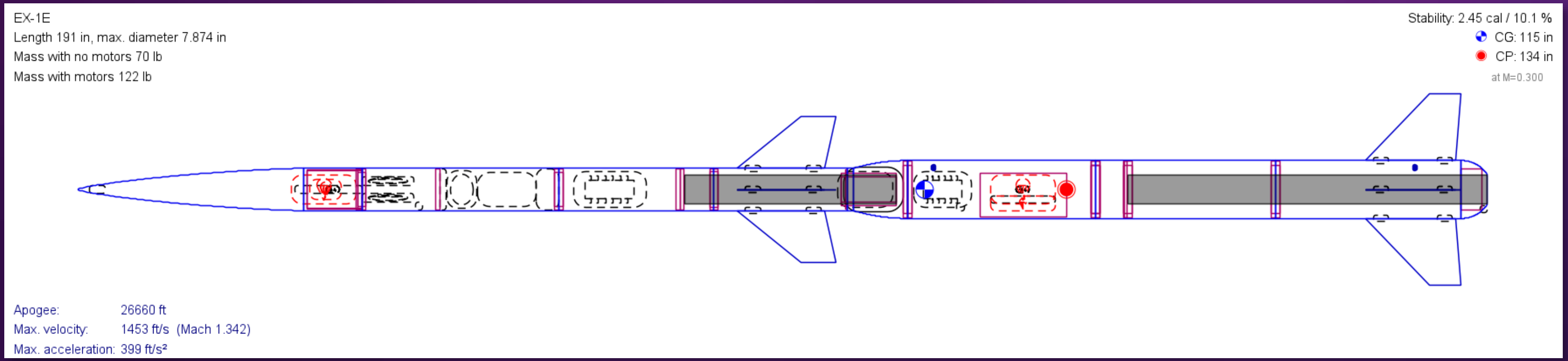
OpenRocket Limitations

Use & Assumptions

Use Cases	Assumptions
• Subsonic Flights • One-stage Rockets • User-friendly Simulation	• Low angle of attack (~0°) • Smooth, continuous rocket body • Boattail drag reduction due to wrong reasons • Rocket body is axially symmetric • Flat plate fins • Nose tip considered as sharp point

LIMITATIONS

- Reduced Accuracy for Supersonic
- **Limited** Adaptability
- **No** Upper Stage Boat tail
- **No** Monte Carlo Iterations



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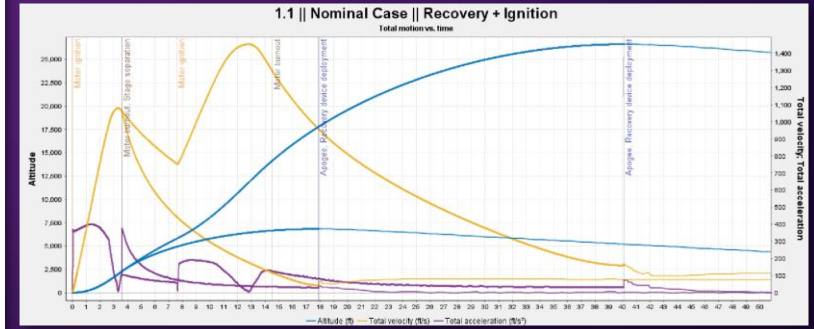


OpenRocket ©

Current Capabilities

Features

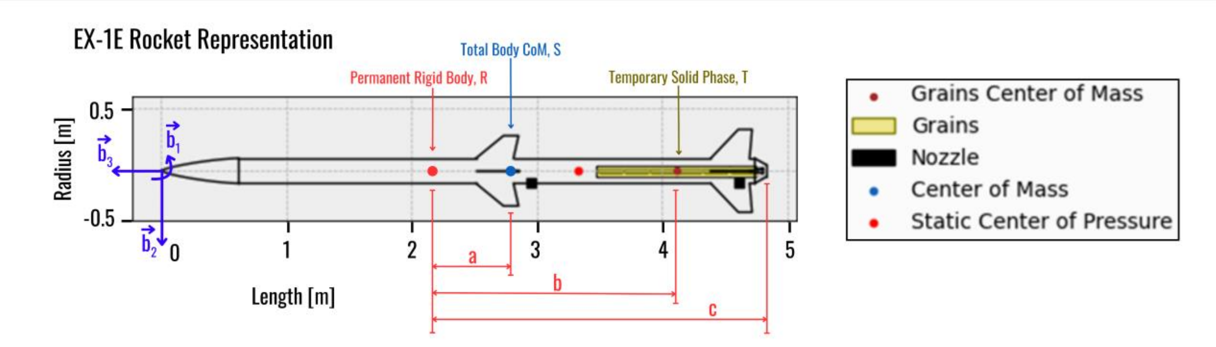
- Dynamic Mass 6 DOF Trajectory Simulation
- DATCOM Corrective Factors Inclusion
- Safety Range Analysis
- Automatic Report Generation
- Web App GUI
- Telemetry Data Analysis
- AR Scenery

6 DOF Simulation

Equations of Motion I - RTT

REYNOLDS TRANSPORT THEOREM

- Complete motion of a variable mass system.
- **Assumption:** Internal gas flow is steady and irrotational relative to the axis of symmetry (**stationary**).



TRANSLATION

$$\overline{R} = m\left(\overline{a_o}^A + \overline{\alpha}^A \times \overline{r_{S-O}} + \overline{\omega}^A \times \left(\overline{\omega}^A \times \overline{r_{S-O}}\right)\right) + 2\int_{\partial C} \overline{\omega}^A \times \rho \cdot \overline{r_{i-O}} \left(\overline{v_i}^R \cdot \overline{n}\right) dS + \int_{\partial C} \rho\, \overline{v_i}^R \left(\overline{v_i}^R \cdot \overline{n}\right) dS$$

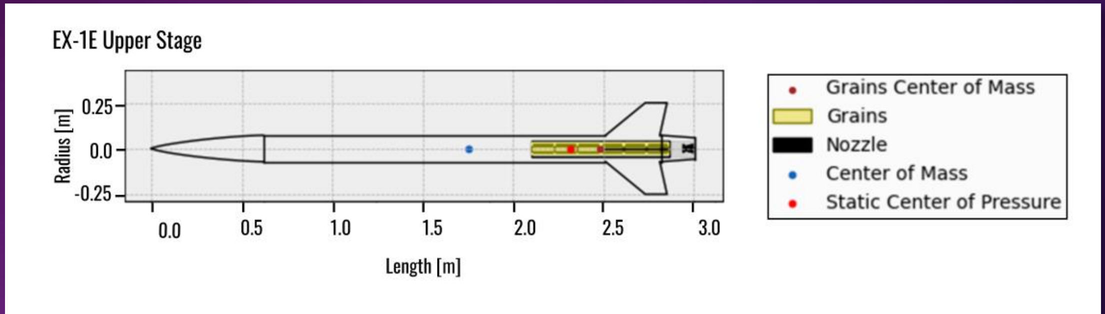
Kinematics of Rigid Body | Coriolis Effect | Thrust

ROTATION

$$\overline{M_S} = I_S \cdot \overline{\alpha}^A + \overline{\omega}^A \times I_S \cdot \overline{\omega}^A + \left(\frac{{}^B dI_S}{dt}\right) \cdot \overline{\omega}^A + \int_{\partial C} \rho \left[\overline{r_{i-S}} \times \left(\overline{\omega}^A \times \overline{r_{i-S}}\right)\right] \left(\overline{v_i}^R \cdot \overline{n}\right) dS$$

6 DOF Simulation

State-Space Representation & Integrator



STATE-SPACE

$$\bar{u} = \begin{bmatrix} x \\ y \\ z \\ v_x \\ v_y \\ v_z \\ e_0 \\ e_1 \\ e_2 \\ e_3 \\ \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix}, \quad \frac{d\bar{u}}{dt} = \begin{bmatrix} v_x \\ v_y \\ v_z \\ a_x \\ a_y \\ a_z \\ \dot{e}_0 \\ \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix}$$

LSODA INTEGRATION SCHEME

- Complex, dynamic system.

Model Requirements:

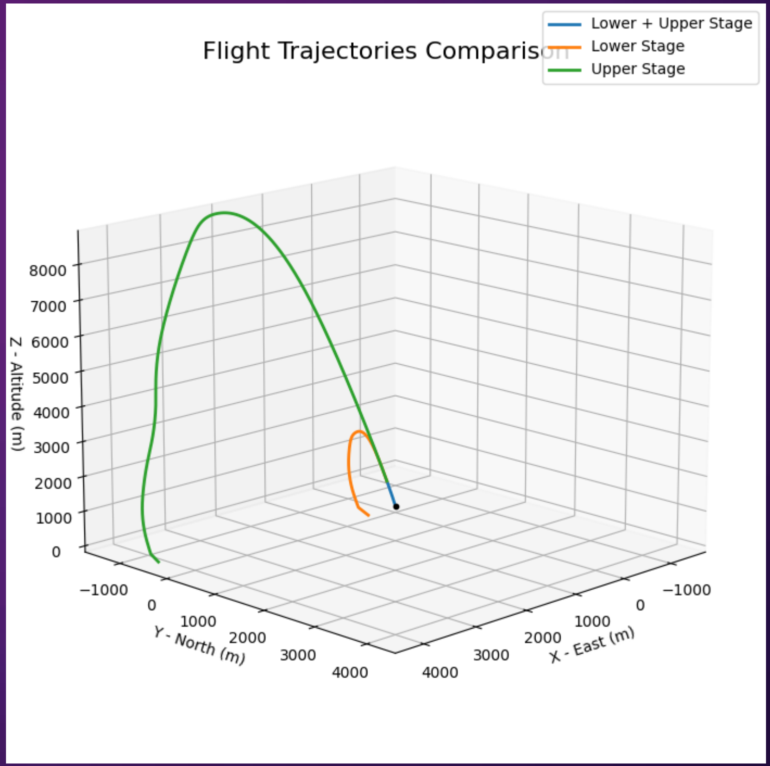
- Robust, efficient solution required.

LSODA vs Runge Kutta:

+ Adaptive step size and methods.

+ **Efficiency** and **accuracy**.

- Computationally expensive.



DATCOM Corrective Factors Inclusion

Applicability

DATCOM REAL FLIGHT DATA

- 3,000+ pages to be **digitalized**.
- **Linear interpolation tables** from real flight data corrects theoretical values for supersonic regimes
- **Corrective factors** for aerodynamic:
  - Lift
  - Drag
  - Normal Force

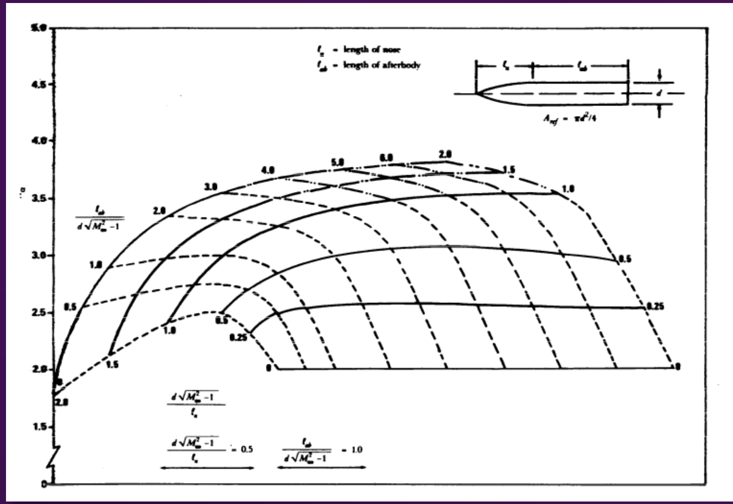
USE CASE

- **Supersonic** Regimes (M>1.5)
- Any flight regime

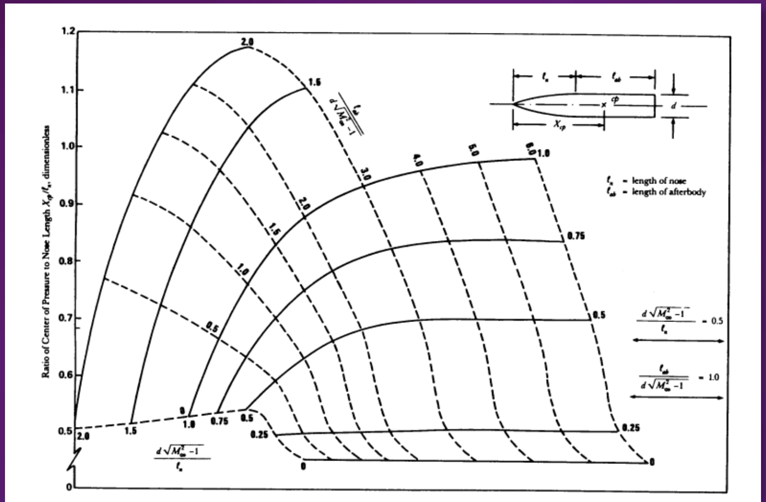
DATCOM Corrective Factors Inclusion

Supersonic C_{N_α} Examples

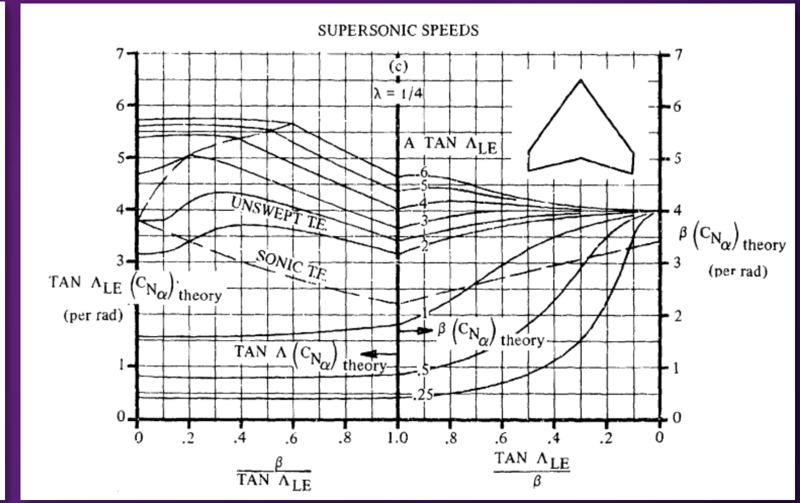
Ogive C_{N_α}



Afterbody C_P



Fin C_{N_α}



$\frac{d\sqrt{M_\infty{}^2-1}}{t_n}$, Coefficient of Compressibility / Nosecone Slenderness

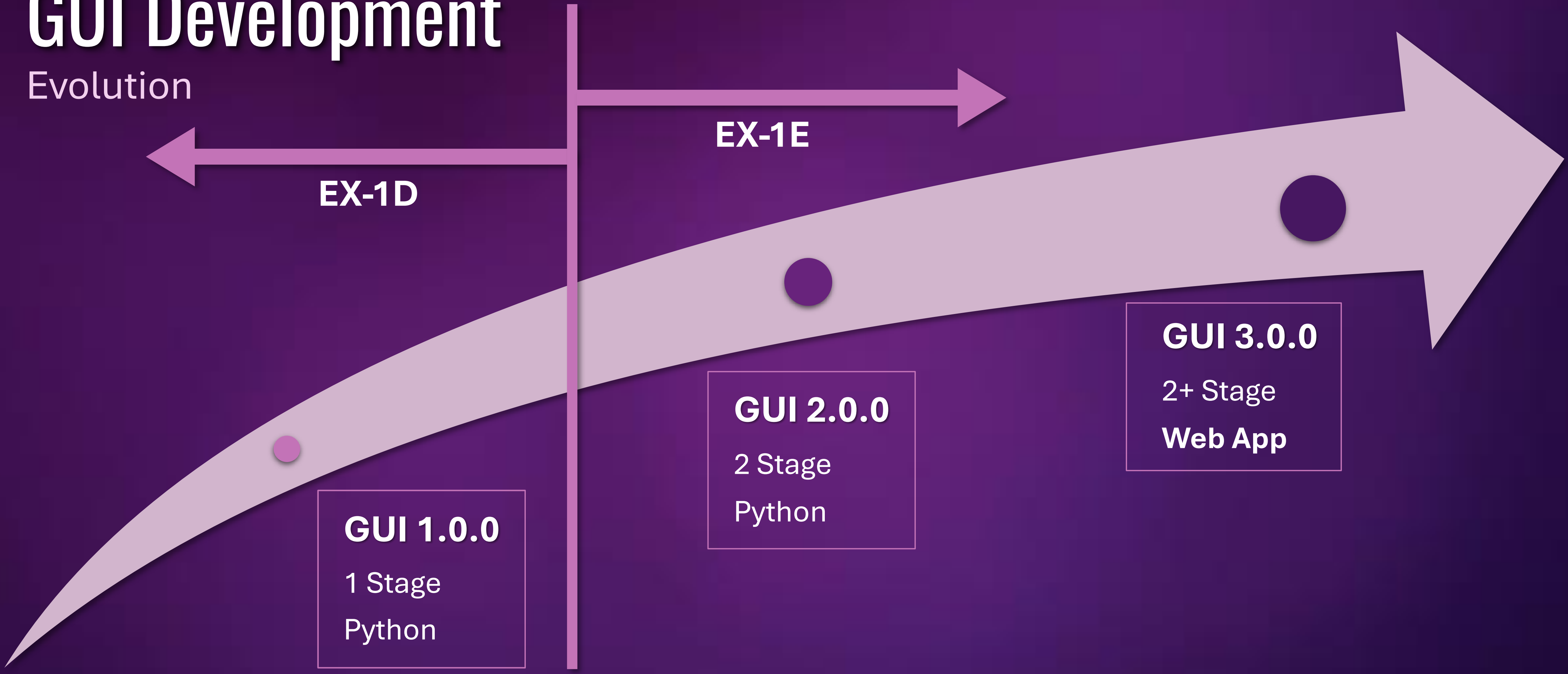
$\frac{t_{ab}}{d\sqrt{M_\infty{}^2-1}}$, Afterbody Slenderness / Coefficient of Compressibility

CORRECTIVE FACTORS

- Corrective factors for the coefficient of normal force different components

GUI Development

Evolution



GUI Development

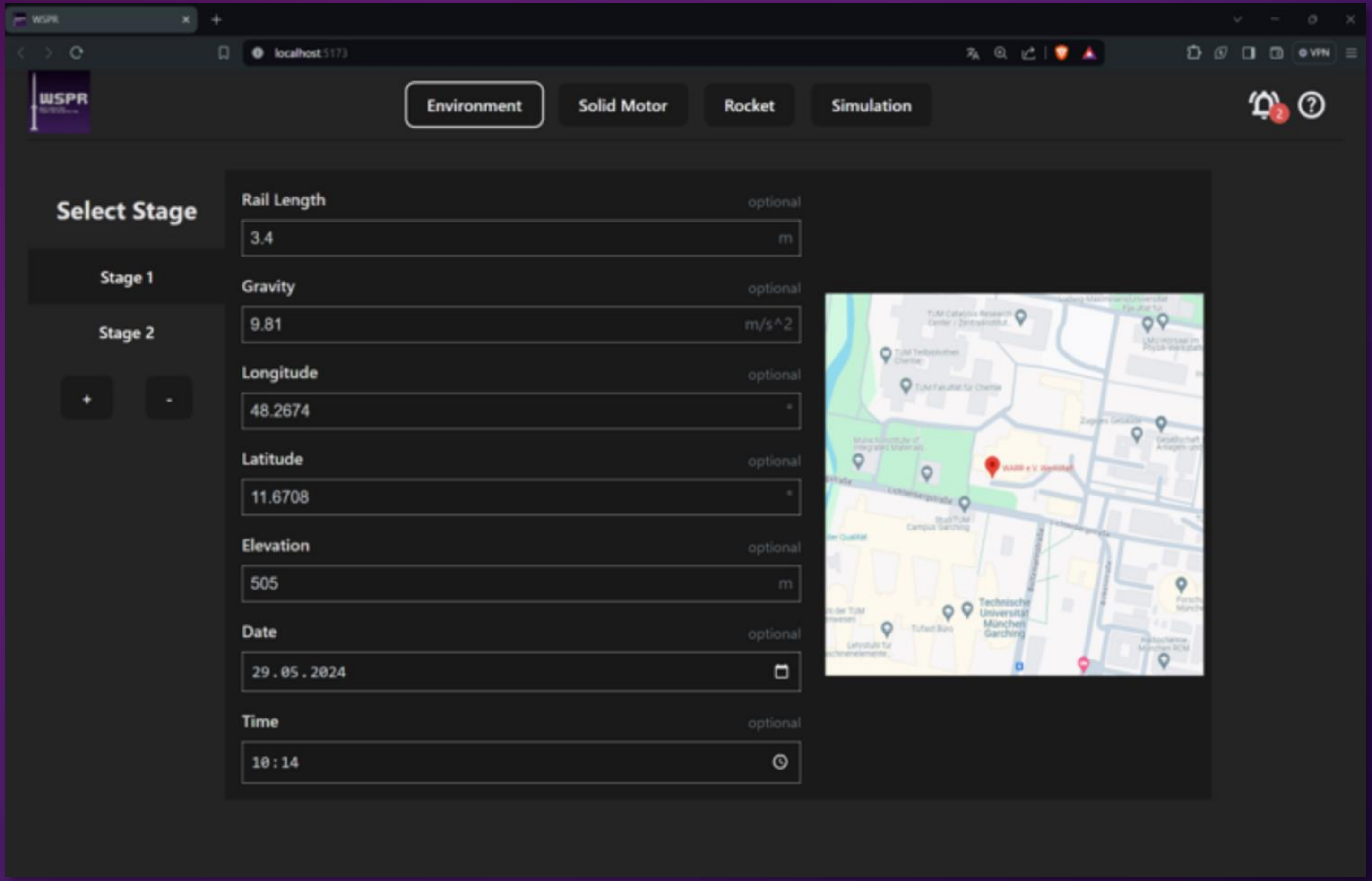
Web App

FRONT-END – WEB APP

- Vue.js - **Lightweight**
- Easier *npm* package management
- **No** steep **learning curve**
- Possible to integrate with AR Scenery

BACK-END – PYTHON

- **Self-hosted server** at TUM supercomputer (WIP)



Safety Range Analysis

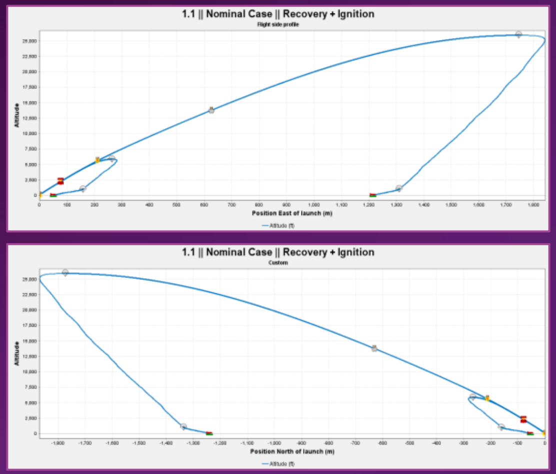
Launch Day #1

DESCRIPTION

- Essential for design optimization and **uncertainty parametrization.**
- **Overnight execution** for extensive results with forecasted conditions as preparation for launch day.
- Comparison between OpenRocket, WSPR and reality.

UNCERTAINTIES ACCOUNTED

- Rocket products of inertia
- Fin misalignments
- Weather conditions
- Motor performance
- Surface roughness and other aerodynamic disturbances (i.e. fin mounts)



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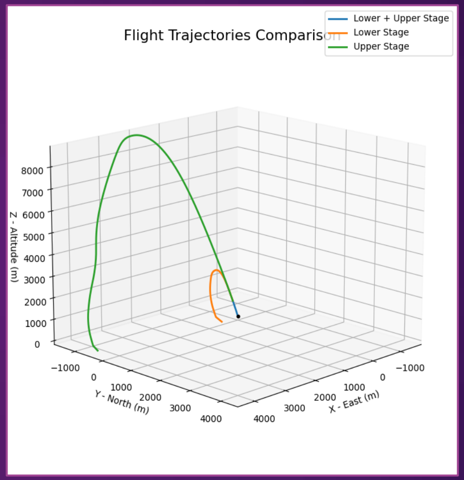
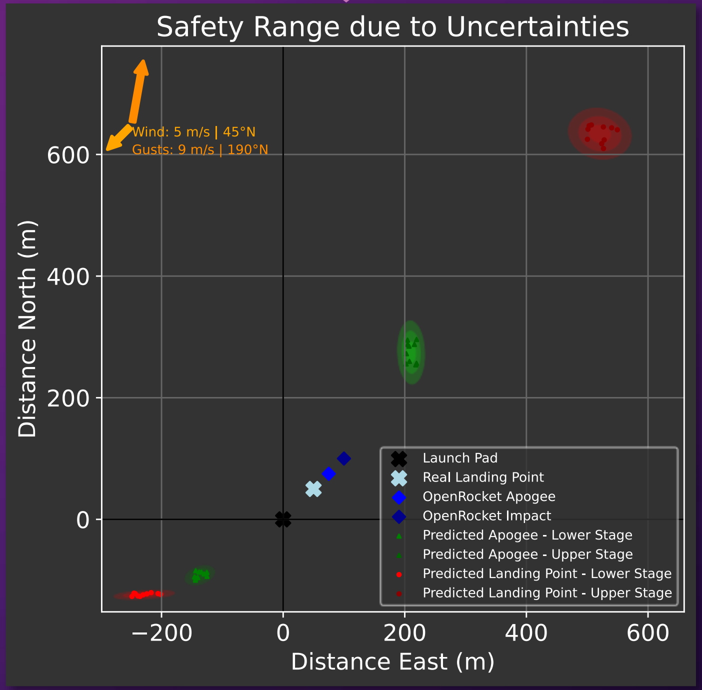




Wind Analysis

Prediction through Windy Forecast

ADVANTAGES

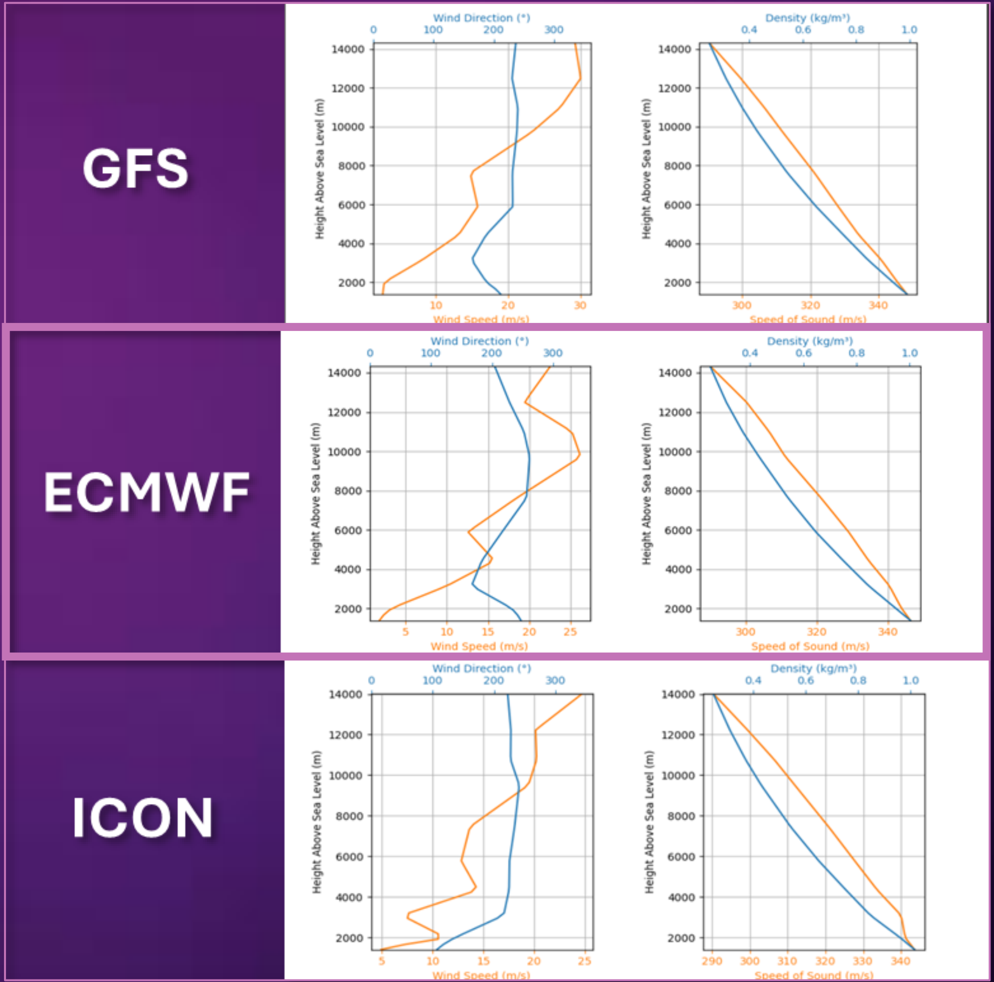
- Automatic **real-time** & **predictive** weather conditions forecasting through API pipeline.
- Launch Rail orientation optimization

WINDY FORECAST

- Most common: **ECMWF** & **GFS**
- Entire **globe coverage**
- Medium-range **10 days forecast**

ECMWF

- **More accurate**, smaller spatial resolution (14km)
- **Hourly forecast**
- 3x **More frequently updated**



AR Scenery

3D Trajectory Visualization

GEOGRAPHIC DATA

- Export trajectory geographic data to GIS file format:
  - Longitude
  - Latitude
  - Altitude

EARTH ENGINE COMPATIBILITY

- Earth Engines can visualize this data to produce animated trajectory.

WEB APP INTEGRATION

Automatic Report Generation

Faster Solutions to Time-Critical Problems

REPORT CONTENT

- Launch Crew & Rocket Information.
- Summary Table with **Launch-Critical Results**.
- Simulated Trajectory summarized.
- **GO/NO-GO** Final Decision.

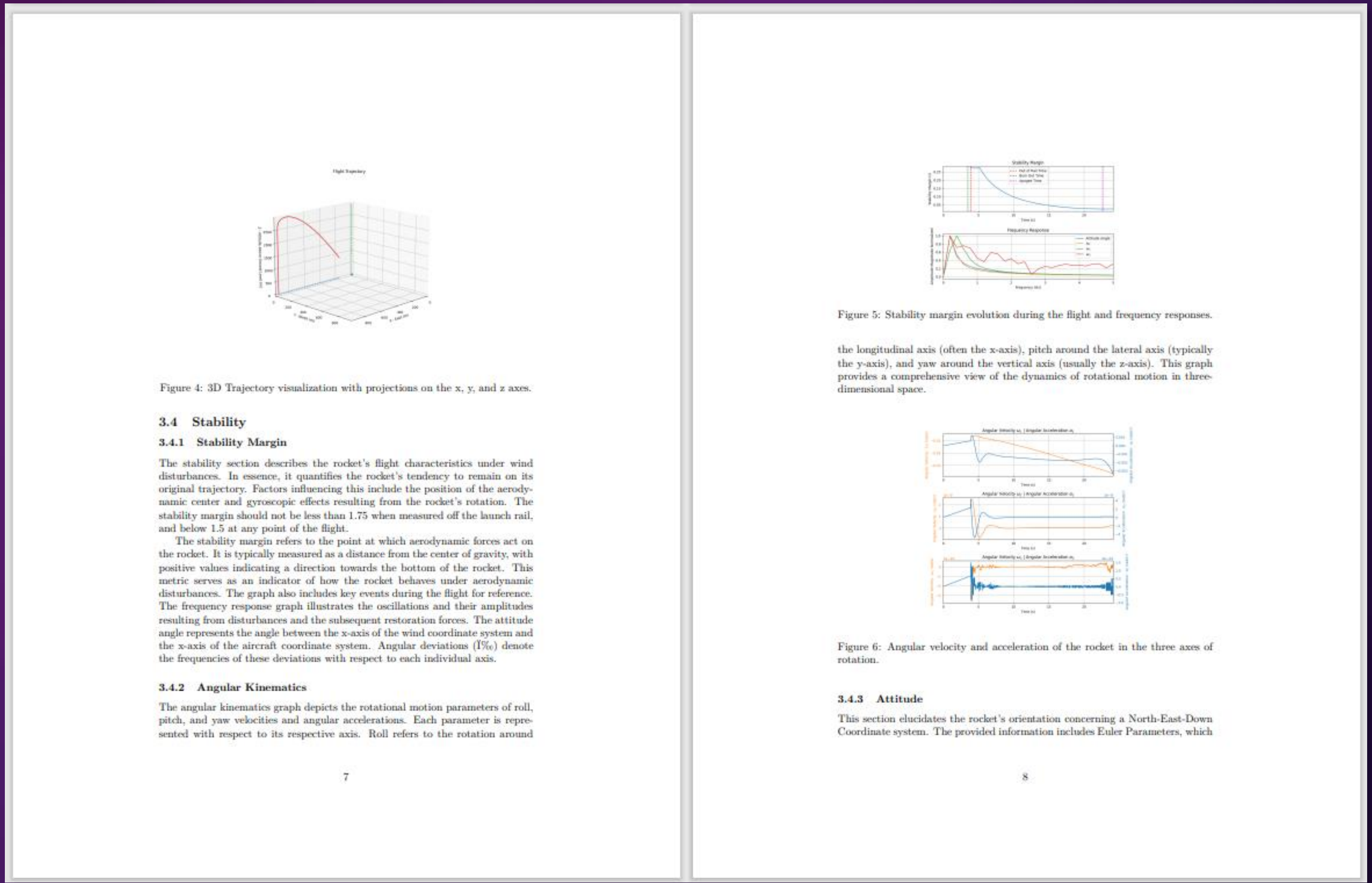


Figure 4: 3D Trajectory visualization with projections on the x, y, and z axes.

3.4 Stability

3.4.1 Stability Margin

The stability section describes the rocket's flight characteristics under wind disturbances. In essence, it quantifies the rocket's tendency to remain on its original trajectory. Factors influencing this include the position of the aerodynamic center and gyroscopic effects resulting from the rocket's rotation. The stability margin should not be less than 1.75 when measured off the launch rail, and below 1.5 at any point of the flight.

The stability margin refers to the point at which aerodynamic forces act on the rocket. It is typically measured as a distance from the center of gravity, with positive values indicating a direction towards the bottom of the rocket. This metric serves as an indicator of how the rocket behaves under aerodynamic disturbances. The graph also includes key events during the flight for reference. The frequency response graph illustrates the oscillations and their amplitudes resulting from disturbances and the subsequent restoration forces. The attitude angle represents the angle between the x-axis of the wind coordinate system and the x-axis of the aircraft coordinate system. Angular deviations (Ï‰) denote the frequencies of these deviations with respect to each individual axis.

3.4.2 Angular Kinematics

The angular kinematics graph depicts the rotational motion parameters of roll, pitch, and yaw velocities and angular accelerations. Each parameter is represented with respect to its respective axis. Roll refers to the rotation around

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Figure 5: Stability margin evolution during the flight and frequency responses.

the longitudinal axis (often the x-axis), pitch around the lateral axis (typically the y-axis), and yaw around the vertical axis (usually the z-axis). This graph provides a comprehensive view of the dynamics of rotational motion in three-dimensional space.

Figure 6: Angular velocity and acceleration of the rocket in the three axes of rotation.

3.4.3 Attitude

This section elucidates the rocket's orientation concerning a North-East-Down Coordinate system. The provided information includes Euler Parameters, which

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WARR rocketry

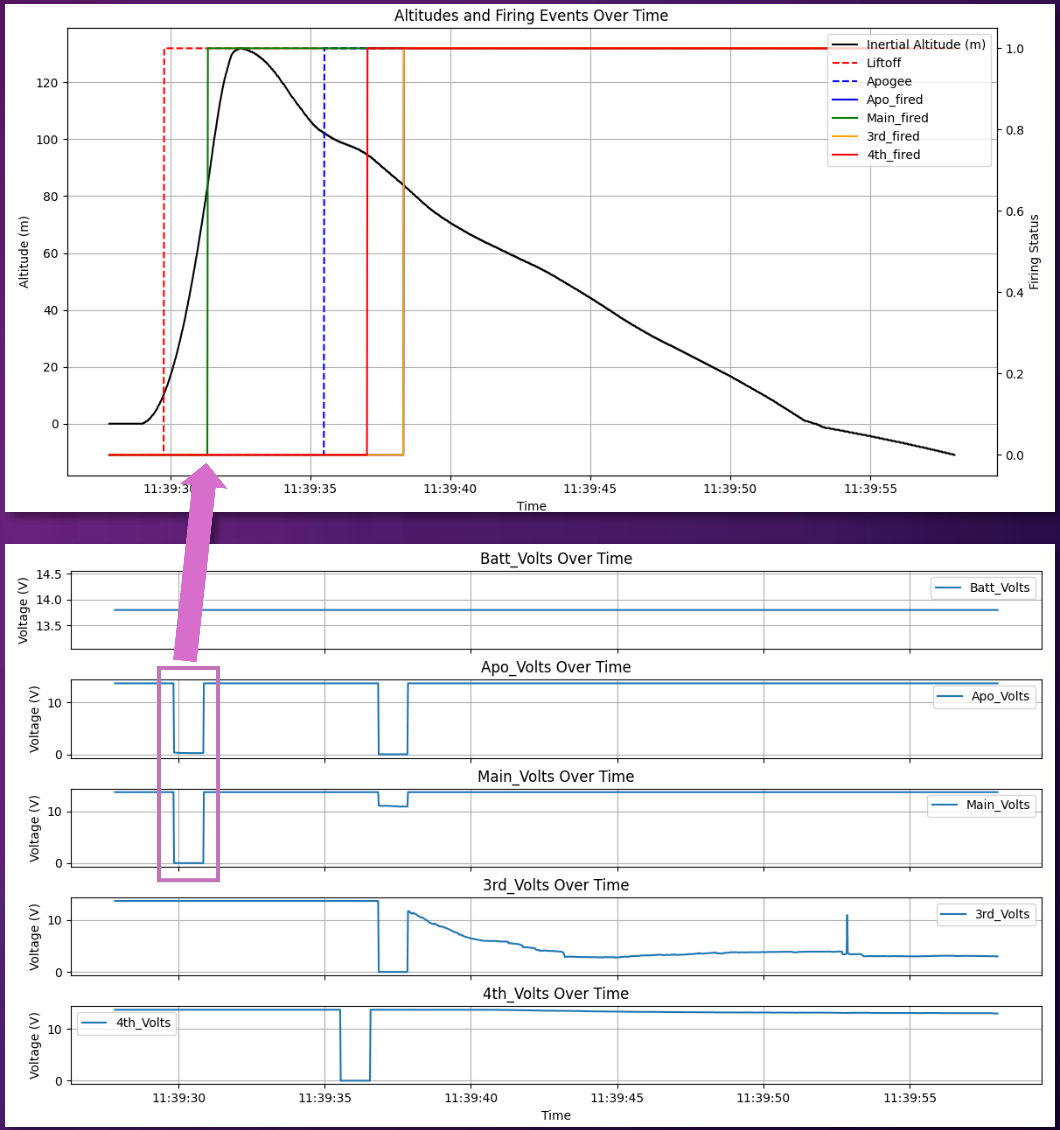
Telemetry Data Analysis

EX-1D, Straubing Launch

FLIGHT COMPUTER TELEMETRY DATA

- **Failure Analysis** in case of failed recovery & **FC anomaly detection.**
- Highest Shock Force: Drogue & Main simultaneous deployment.
- **Hardware** & **Logic Test.**

Channel	TIme	Updwards Velocity [m/s]	Altitude (AGL) [m]
NC Drogue	2024-06-15 11:39:38:347	-8.5344	85.4964
NC Main	2024-06-15 11:39:38:347	67.056	99.1819
SW Main	2024-06-15 11:39:38:347	-8.5344	85.4964
SW Drogue	2024-06-15 11:39:38:347	-6.7056	95.3414



Data Validation

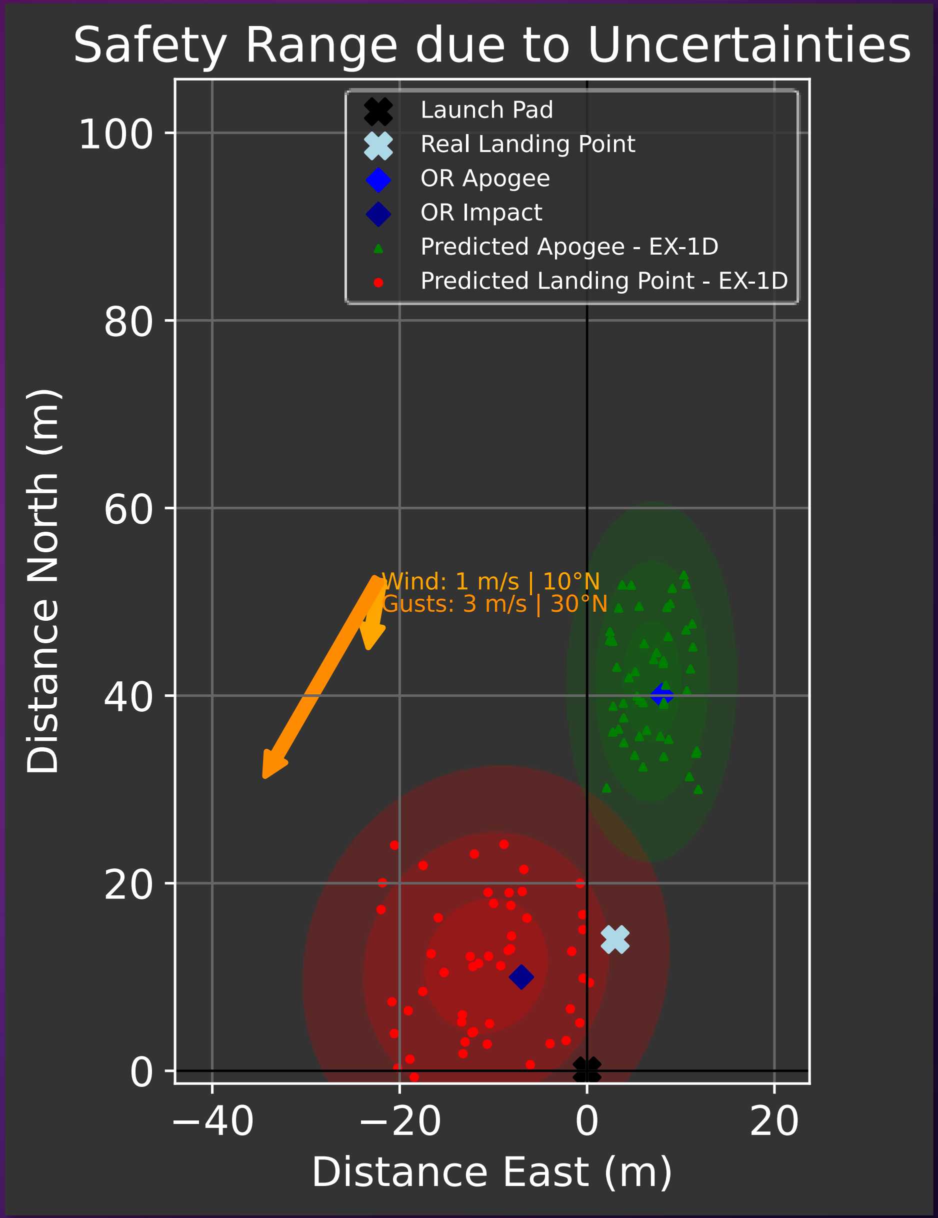
Launch Data Analysis

WSPR PERFORMANCE

- Openrocket vs WSPR vs Reality.
- Safety Range Analysis through Monte Carlo Iterations.

SAC24 GOALS

- Validate for:
    - Higher apogee
    - Supersonic flight
    - Two-staged rocket



Future Developments

What's Next?

MODEL VALIDATION

Real flight data used to validate 6DOF Simulator for high apogees.

DATCOM VALIDATION

Aerodynamics improvements in trajectory simulation for supersonic and transonic regimes.

RockIT INTEGRATION

Design phase level in-house software for liquid propulsion system design.

WARR rocketry RockIT

Design Tool for Liquid Propulsion Systems

LIQUID PROPULSION DESIGN OPTIMIZATION

- Preliminary Design Phase tool for liquid propellant sounding rockets.
- Outcome: **KARA, ROTA, Brunhilde**

INTEGRATION WITH WSPR

- Integration as conceptualization of propulsion system with RockIT into WSPR.

Liquid Design

Pre-Launch

Post-Processing

RockIT

WSPR

WSPR

Design Phase

Launch Campaign

Rocket Launch

Q&A Session

Thanks for your attention!