Venus Atmospheric Entry Simulation Program

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1 Program Overview

Python-based simulation tool for spacecraft entry into Venus atmosphere. Implements aerodynamics, thermal heating, parachute deployment, and airship mass calculations. Features GUI interface, real-time simulation, and visualization.

2 File Structure

- main.py - Application entry point
- gui.py - Tkinter GUI interface
- simulation_engine.py - Core simulation logic
- materials.py - Atmospheric properties
- thermal_calculations.py - Heat flux calculations
- structure_calculations.py - Airship geometry
- plots.py - Matplotlib visualizations
- results_window.py - Results display

3 Installation Requirements

3.1 Python Version

Python 3.7+

3.2 Required Packages

pip install numpy pip install matplotlib pip install scipy pip install tkinter Usually included with Python

4 Usage

Execute the program:

python main.py

4.1 GUI Interface

- Input Parameters: Initial conditions, mass mode, parachutes
- Control Buttons: Run simulation, reset defaults, show plots
- Progress Tracking: Real-time status updates

5 Physical Models

5.1 Atmospheric Model

Empirical data for Venus:

$$\rho(h) = 10^{\text{interp}(\log_{10}(\rho_{\text{data}}),h)}$$

5.2 Drag Force

$$F_d = \frac{1}{2}\rho(h)C_d A v^{n(v)}$$

Variable exponent $n(v)$ with resonance near 340 m/s.

5.3 Heat Flux

$$q = K\rho v^3, \quad K = 10^{-4}$$

5.4 Mass Calculation Modes

1. Specified mass: User-defined constant
2. Airship mode: Buoyancy-based calculation

$$R = \left(\frac{m_{\text{total}}}{\rho_{\text{gas}} \cdot \frac{4}{3}\pi}\right)^{1/3}$$

5.5 Parachute System

- Two-stage: brake chute and main chute
- Velocity-triggered deployment
- Configurable areas and drag coefficients

6 Numerical Integration

Fixed-step Euler method with $\Delta t = 0.001$ s:

$$v_x(t+\Delta t) = v_x(t) + a_x(t)\Delta t$$
$$v_y(t+\Delta t) = v_y(t) + a_y(t)\Delta t$$
$$h(t+\Delta t) = h(t) + v_y(t)\Delta t$$

7 Visualization

Multiple plot types:

- Kinematic: Speed, altitude, trajectory
- Thermal: Heat flux, temperatures, energy
- Orbital: 3D trajectory, polar plots
- Parachute: Deployment events
- Atmospheric: Density profiles

8 Key Algorithms

8.1 Velocity Components

$$v_x = v_0 \cos(\theta), \quad v_y = -v_0 \sin(\theta)$$

8.2 Heat Shield Analysis

1. Calculate total heat load
2. Determine temperature rise
3. Check for melting
4. Calculate melted mass fraction

8.3 Airship Geometry

Iterative radius calculation:

1. Initial estimate: $R_0 = \left(\frac{m_{\text{payload}}}{\rho_{\text{gas}} \cdot \frac{4}{3}\pi}\right)^{1/3}$
2. Calculate envelope mass: $m_{\text{env}} = \rho_{\text{env}} \cdot 4\pi R^2$
3. Update total mass: $m_{\text{total}} = m_{\text{env}} + m_{\text{payload}}$