Venus Global Reference Atmospheric Model (GRAM) Upgrades

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Background

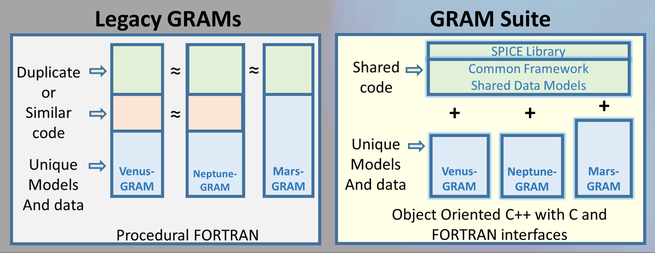
The inability to test planetary spacecraft in the flight environment prior to a mission requires engineers to rely on ground-based testing and models of the vehicle and expected environments. One of the most widely used engineering models of Venus' atmosphere is the Venus Global Reference Atmospheric Model (Venus-GRAM). The Venus-GRAM upgrades are being developed by NASA Marshall Space Flight Center and NASA Langley Research Center.

Venus-GRAM Overview

- Venus-GRAM is an engineering-oriented atmospheric model that estimates mean values and statistical variations of atmospheric properties for numerous planetary destinations
  - Data sources include Venus International Reference Atmosphere (VIRA), Pioneer Venus Orbiter and Probe, Venera Probe, and Magellan
  - Outputs atmospheric density, temperature, pressure, winds, and chemical composition along a user-defined path
  - Provides mean values and variability for any point in an atmosphere
  - Includes seasonal, geographic, and altitude variations
  - Used by engineering community because of the need to simulate realistic dispersions; can be integrated into high fidelity flight dynamic simulations of launch, entry, descent, and landing (EDL), aerobraking, and aerocapture
- GRAMs are not forecast models
- GRAMs are also available for: Earth, Mars, Neptune, Titan, Jupiter, and Uranus
- Available through the NASA Software Catalog https://software.nasa.gov/

Code Modernization - GRAM Suite

- GRAM Suite is common C++ framework that simplifies model updates, integration, testing, and maintenance
  - Common framework that supports all solar system destination models
  - Provides a uniform user interface for all planetary GRAMs
  - Includes C++ library with C and Fortran interfaces that can be incorporated in a trajectory or orbit propagation code
  - First C++ releases of the rearchitected legacy planetary GRAMs are straight conversions from the latest Fortran version; new model updates are being developed as part of future GRAM upgrades



Venus-GRAM Upgrades

- NASA Navigation and Ancillary Information Facility (NAIF) Spacecraft Planet Instrument C-matrix Events (SPICE) toolkit has been incorporated into the GRAM Suite for ephemeris calculations
  - Venus ephemeris values are now computed using the NAIF SPICE library for greater accuracy
- Calculation of the speed of sound has been improved in the GRAM Suite
  - Venus-GRAM computes speed of sound based on a thermodynamic parameterization using density, pressure, and γ, the ratio of specific heats, for a given constituent gas mixture
  - Venus-GRAM previously used a constant γ, which was physically unrealistic
  - Venus-GRAM now uses an improved methodology to compute γ, involving temperature and pressure dependent tables of specific heats evaluated in run-time for the current constituent combination
- Working with VERITAS and DAVINCI+ teams to determine potential mission support by the GRAM team and utilization of collected atmospheric data in Venus-GRAM

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Upgraded Venus-GRAM Release

- GRAM Suite Version 3.0 (Released September 2021) includes:
  - Rearchitected Venus-GRAM (common GRAM framework and Venus specific code)
  - Makefile and Visual Studio solutions for building the GRAM Suite
  - Venus-GRAM User Guide and GRAM Programmer's Manual
  - Examples and tests for successful implementation of Venus-GRAM

Ongoing Venus-GRAM Upgrades

- In Fiscal Year 2020, the GRAM project established contracts with University of Wisconsin and Hampton University to improve atmospheric data in Venus-GRAM
  - University of Wisconsin
    - Reanalysis of the Venus Express radio occultation observations
      - Calculating number density, temperature, and pressure profiles (40-90 km altitude)
    - Analysis of Akatsuki thermal imaging data
      - Calculating temperature values at the limb altitudes as a function of solar time
  - Hampton University
    - Updating Venus global model

Potential Future Venus-GRAM Upgrades

- Solar cycle effect on variability at >100 km altitude
  - Not currently included in Venus-GRAM input data (fixed at solar flux = 150)
  - Define how to utilize the current knobs in Venus GRAM to capture observed solar cycle variability
- Density scale height adjustments
  - Develop an interpolation routine in Venus-GRAM to permit adjustment of both density and scale height at periapsis to make interpolation consistent over a specified altitude range
- Recent mission data incorporation/comparison
  - Compare the results of the University of Wisconsin analysis of Venus Express and Akatsuki to Venus-GRAM
  - Tune Venus-GRAM to match observations in lieu of assimilating them directly into Venus-GRAM
- Global Circulation Model Updates
  - Determine global circulation model data update options for Venus-GRAM that would incorporate more recent mission data and the latest modeling techniques/approaches
- Update topography, solid planet, and high-resolution gravity models
- After completion of the VERITAS mission, update the atmosphere, gravity, and topography models within Venus-GRAM based on data from the mission
- Please contact the GRAM Upgrade Team to provide additional suggestions for future upgrades

Conclusions

- GRAMs are frequently used toolsets and vital in assessing effects of atmospheres on interplanetary spacecraft during the program life cycle process
- Releases of the GRAM Suite, upgrades of the existing planetary GRAMs, and development of new planetary GRAMs are ongoing
- Venus-GRAM atmosphere model upgrades will be included in the next phase of GRAM tasks.

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