Outer Planet Global Reference Atmospheric Model (GRAM) Upgrades

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Background

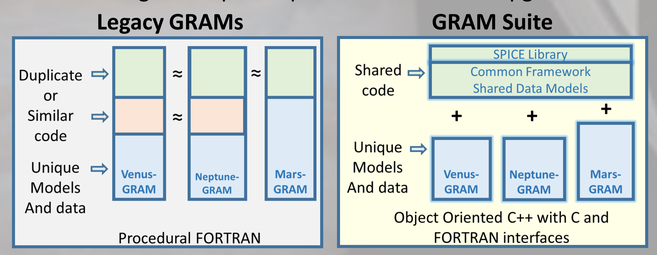
The inability to test planetary spacecraft in the flight environment prior to a mission requires engineers to rely on ground-based testing and models of the vehicle and expected environments. One of the most widely used engineering models of planetary atmospheres is the Global Reference Atmospheric Model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

GRAM Overview

- GRAMs are engineering-oriented atmospheric models that estimate mean values and statistical variations of atmospheric properties for numerous planetary destinations
  - Currently available for Earth, Mars, Venus, Titan, Neptune, and Uranus
  - 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 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



Outer Planet GRAM Upgrades

- GRAM ephemeris has been upgraded to the NASA Navigation and Ancillary Information Facility (NAIF) Spacecraft Planet Instrument C-matrix Events (SPICE) toolkit
- Calculation of the speed of sound has been improved in the GRAMs
  - GRAMs compute speed of sound based on a thermodynamic parameterization using density, pressure, and γ, the ratio of specific heats, for a given constituent gas mixture
  - GRAM legacy codes used a constant γ, which was physically unrealistic
  - GRAM Suite uses an improved methodology to compute γ in run-time for the current constituent combination
- In Fiscal Year 2020, the GRAM project established a contract with Hampton University to develop empirical global models for Jupiter, Saturn, Uranus, Neptune, and Titan
  - Work is ongoing to develop models that will be used in future GRAM updates
  - Will incorporate latest data available for each destination
- Titan-GRAM atmosphere model upgrades will be included in the next phase of GRAM tasks

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Upgraded Outer Planet GRAM Releases

- GRAM Suite Version 1.0 (Released May 2020) includes:
  - Rearchitected Neptune-GRAM (common GRAM framework and Neptune specific code)
  - Makefile and Visual Studio solutions for building the GRAM Suite
  - Neptune-GRAM User Guide and GRAM Programmer's Manual
  - Examples and tests for successful implementation of Neptune-GRAM
- GRAM Suite Version 1.1 (Released September 2020) added:
  - Rearchitected Titan-GRAM (common GRAM framework and Titan specific code)
  - Titan-GRAM User Guide
  - Examples and tests for successful implementation of Titan-GRAM

New Outer Planet GRAM Release – Uranus-GRAM

- Released in GRAM Suite Version 1.2 (July 2021) which adds:
  - Common GRAM framework and Uranus specific code
  - Uranus-GRAM User Guide
  - Examples and tests for successful implementation of Uranus-GRAM
- Uranus-GRAM atmospheric data is from the NASA Ames Research Center (ARC) Uranus Atmospheric Model [1,2]
  - Based on Voyager radio science, Infrared Interferometer Spectrometer and Radiometer (IRIS), and Ultraviolet Spectrometer (UVS) data from the Voyager 2 fly-by of Uranus that occurred on January 24, 1986[3,4,5]
  - Includes atmospheric density, pressure, temperature, and chemical composition (helium, hydrogen, and methane)
  - Does not include wind data

Upcoming New Outer Planet GRAM Releases

- Jupiter-GRAM:
  - Based on Galileo probe Atmospheric Structure Instrument (ASI) data from Seiff et al.[6]
  - Includes atmospheric density, pressure, and temperature
  - Does not include chemical composition or winds
- Saturn-GRAM is currently under development
- Jupiter-GRAM and Saturn-GRAM will be released in a future version of the GRAM Suite

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 outer planet GRAMs, and development of new outer planet GRAMs are ongoing

References

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