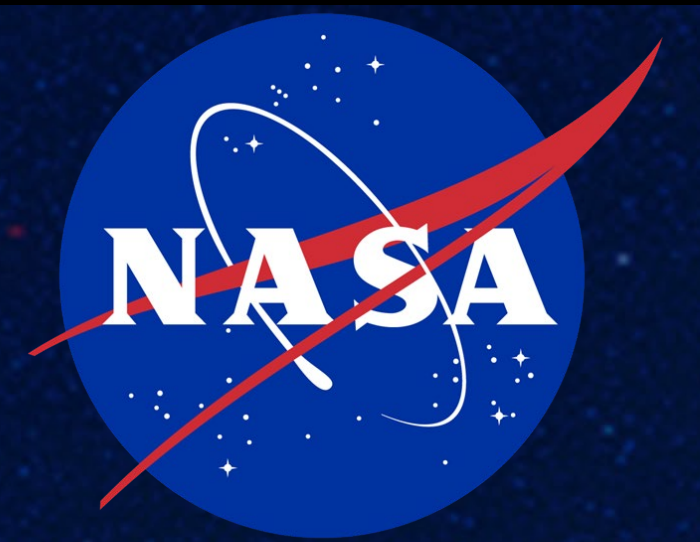


Global Reference Atmospheric Model (GRAM) Suite Upgrades

H. L. Justh¹, S. Dutta², P. Bremner³, K.L. Burns⁴, J. Garland⁵, J. Hoffman⁶, K.M. Sayanagi⁷, C. Walker⁸, and P.W. White⁹.

¹NASA Marshall Space Flight Center, hilary.l.justh@nasa.gov, ²NASA Langley Research Center, soumyo.dutta@nasa.gov, ³NASA Marshall Space Flight Center, paul.m.bremner@nasa.gov, ⁴Jacobs Space Exploration Group, kerry.l.burns@nasa.gov, ⁵Analytical Mechanics Associates, justin.garland@nasa.gov, ⁶Analytical Mechanics Associates, james.hoffman-1@nasa.gov, ⁷NASA Langley Research Center, kunio.m.sayanagi@nasa.gov, ⁸Jacobs Space Exploration Group, corey.d.walker@nasa.gov, and ⁹NASA Marshall Space Flight Center, patrick.w.white@nasa.gov.



Background

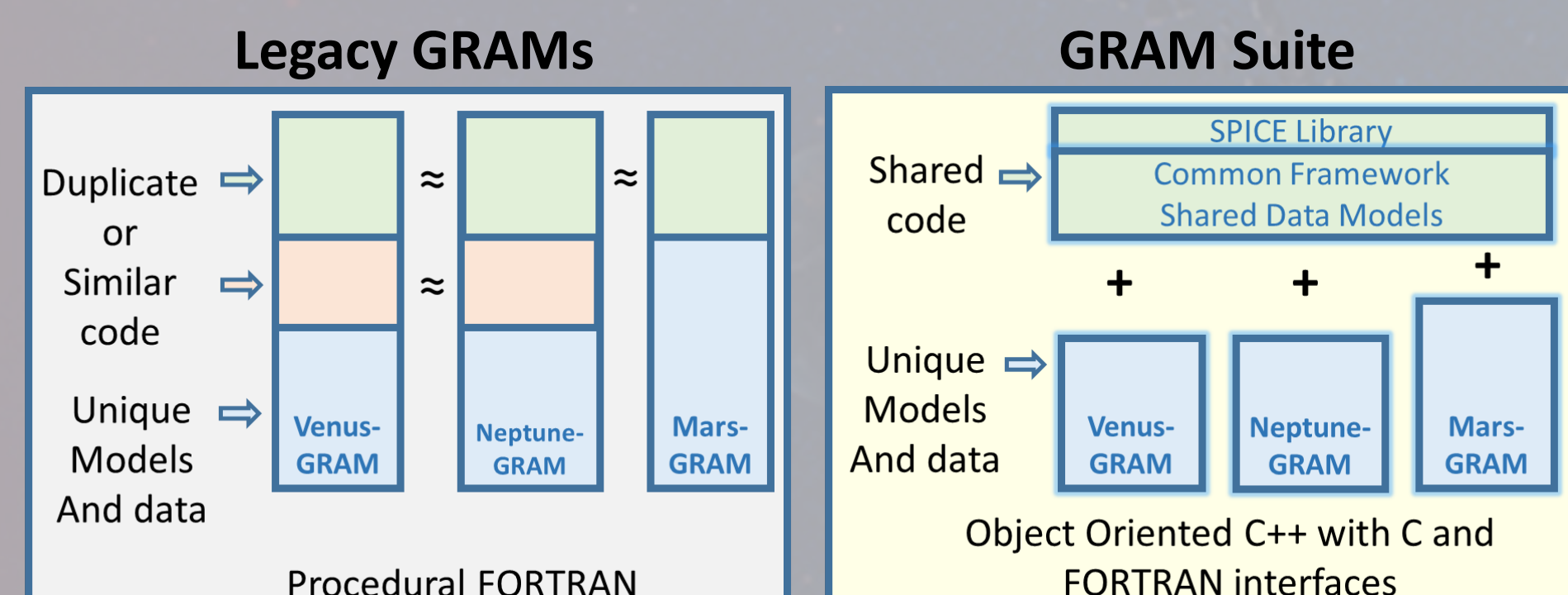
The inability to test planetary spacecraft in the flight environment prior to a mission requires engineers to rely on ground-based testing and models of the vehicle and expected environments. One of the most widely used engineering reference models of planetary atmospheres are the Global Reference Atmospheric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

GRAM Overview

- Engineering-oriented atmospheric models that estimate mean values and statistical variations of atmospheric properties for numerous planetary destinations
- Currently available for Venus, Earth, Mars, Jupiter, Titan, Uranus, and Neptune
- Outputs include atmospheric density, temperature, pressure, chemical composition, radiative fluxes (for Mars-GRAM), and wind components along a user-defined path
- Includes seasonal, diurnal, geographic, and altitude variations when such data are available
- Widely used by the engineering community because of their ability to create realistic atmospheric dispersions
- Can be integrated into high fidelity flight dynamic simulations of launch, entry, descent and landing (EDL), aerobraking and aerocapture
- Not a forecast model
- Available through the NASA Software Catalog <https://software.nasa.gov/software/MFS-33888-1>

GRAM Suite

- Common object-oriented C++ framework that simplifies model updates, integration, testing, and maintenance
 - Supports all solar system destination models
 - Provides a uniform user interface for all GRAMs
 - Includes C++ library with C and Fortran interfaces that can be incorporated in a trajectory or orbit propagation code
 - All future GRAM Upgrades will be released in the GRAM Suite



Initial GRAM Suite Upgrades and Improvements (May 2020-April 2023)

- Rearchitected the legacy GRAMs (Venus, Mars, Titan, and Neptune-GRAM), rearchitected and updated Earth-GRAM, and added new GRAMs (Jupiter¹ and Uranus-GRAM²) to the GRAM Suite
- GRAM ephemeris upgraded to the NASA Navigation and Ancillary Information Facility (NAIF) Spacecraft Planet Instrument C-matrix Events (SPICE) toolkit (version N0067) for increased accuracy
- Topography model based on Magellan data³ added to Venus-GRAM
- 2019 Range Reference Atmosphere database added to Earth-GRAM
- Calculation of the speed of sound was improved in the GRAM Suite
- Renamed input parameters to be more descriptive and reformatted output files have been reformatted
- User Guides for all GRAMs have been published as NASA Technical Memos

NASA Marshall Space Flight Center

Planetary Atmosphere Specialist
Hilary Justh

Earth-GRAM Developer
Patrick White

GRAM Developer
Lee Burns

Jacobs Space Exploration Group

Data Implementation

Paul Bremner

Corey Walker

Jacobs Space Exploration Group

NASA Langley Research Center

Project Manager

Soumyo Dutta

Code Architect

James Hoffman

Analytical Mechanics Associates

Outer Planet GRAM Developers

Kunio Sayanagi

Justin Garland

Analytical Mechanics Associates

Latest GRAM Suite Release

- GRAM Suite Version 2.0.0 (Released November 2023) included:
 - Addition of Python Application Program Interface (API)
 - Earth-GRAM Modern Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) Update
 - Earth-GRAM Bug Fixes
 - Updated Earth-GRAM User Guide⁴
 - Updated GRAM Programmer's Manual

Upcoming GRAM Suite Release

- GRAM Suite Spring 2024 release will include:
 - Earth-GRAM gridded forecast upgrade
 - Mars-GRAM topography data upgrade
 - Venus-GRAM gravity data upgrade
 - Uranus-GRAM input model data upgrade
 - Updated Earth, Mars, Venus, and Uranus-GRAM User Guides
 - Updated GRAM Programmer's Manual

Future Planned GRAM Suite Upgrades

- Addition of MATLAB API
- Earth-GRAM gridded forecast upgrade
- Gravity data upgrades for all GRAMs
- Mars, Venus, and Titan-GRAM input model data upgrades
- Addition of Saturn-GRAM

Conclusions

- GRAMs are frequently used toolsets and vital in assessing effects of atmospheres on spacecraft during the program life cycle process
- GRAM Suite Version 2.0 is available via the NASA Software Catalog <https://software.nasa.gov/software/MFS-33888-1>
- Upgrades of GRAM Suite are continuing
 - Updating the inherent data in the GRAMs to reflect current best estimates
 - Next GRAM Suite release in Spring 2024
- Ongoing discussions with:
 - Modeling groups within NASA and academia regarding status of their models
 - Planetary mission teams (VERITAS, DAVINCI, Dragonfly, MAV, MAVEN, etc.) to determine potential mission support by the GRAM team, utilization of collected atmospheric data, and needed GRAM upgrades
- Feedback regarding the GRAMs is encouraged and welcomed



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