The use of NASA GSFC Modular, Reconfigurable, Rapid (MR^2) Small Satellite for the Measurement of Greenhouse Gases

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Abstract: The Small Rocket/Spacecraft Technology (SMART) is an existing microsatellite prototype bus that provides the ability to accommodate focused science (and technology validation) missions without the need to spend large resources typical of high-performing spacecraft. SMART represents the sum value of GSFC's long tradition of developing systems that find efficient application in a series of missions, exemplified by two successful major programs: the Multi-mission Modular Spacecraft (MMS), and the Small Explorer Program (SMEX). SMART is based on an evolutionary architecture based drawn from these two experiences: the Modular, Reconfigurable, Rapid (MR^2) architecture. This paper shows a SMART-derivative spacecraft (with re-sized structure) used to accommodate the Abundance of Methane via Interferometric Glint Observation (AMIGO) instrument. The principal objective of AMIGO is to map and quantify the abundance of the major greenhouse gases (particularly methane) and to identify and quantify their sources and sinks on a global basis. In addition, a Laser retro-reflector instrument of opportunity is included, to add to the constellation of spacecraft relevant to the definition and regular update of the International Terrestrial Reference Frame (ITRF).

1. INTRODUCTION

A NASA GSFC Internal Research and Development (IRAD) project has focused on identifying the Small Rocket/Spacecraft Technology (SMART) prototype applications from within Space Science, Planetary Science, and Technology Validation mission areas. SMART represents the sum value of two successful GSFC programs: the Multi-mission Modular Spacecraft (MMS), and the Small Explorer Program (SMEX). The MMS was a standard, three-axis stabilized spacecraft design conceived to accommodate the largest number of missions, whether in low Earth, or in geosynchronous orbits, with six spacecraft successfully flown under its umbrella. On the other hand, the SMEX program executed at GSFC included a small team that worked across several mission boundaries, with overlapping mission developments. This staggered approach allowed satellite launches once every 12 to 18 months. Structures, thermal designs, and attitude control systems were designed per mission needs, whereas other subsystems were taken from an inventory of spacecraft designs that were developed for the initial three SMEX missions (SAMPEX, FAST, and SWAS). Two additional in-house spacecraft, for a total of 5 vehicles were flown from GSFC under this mantra. SMART is based on an evolutionary architecture drawn from these two experiences: the Modular, Reconfigurable, Rapid (MR^2) architecture (sometimes with "Adaptive" added to its mix).

With a limited budget and long gaps between existing NASA science and engineering flight programs, SMART can fill the "in-between" projects where focused objectives can lead to simple systems and reduced costs. In itself SMART, as a particular instantiation of the MR^2 architecture, is not intended to be the "do all, be all" system. As it stands, its original size had to be enlarged for this mission in order to accommodate AMIGO. What is most important is the adaptation of an architecture and process that enable the production of cost-effective, reconfigurable (re-sizing in this case) space systems. Other cost-effective spacecraft and systems have been developed within industry. Nonetheless, NASA continues to explore and expand the possibilities that these new class of systems can bring to the table to accomplish world-class science. It is not the intent here to show the full benefits of MR^2 as there is enough information in the open literature to this effect (see References 1, 2, and 3 for a more detailed description and analysis), but to illustrate one particular Earth Science application based on SMART.

2. ABUNDANCE OF METHANE VIA INTERFEROMETRIC GLINT OBSERVATION (AMIGO)

AMIGO employs a series of differential radiometers based upon the Fabry-Perot (FP) interferometer, and measures atmospheric absorption spectra for several greenhouse gases (including the three most active greenhouse gases: water vapor, carbon dioxide, and methane) in solar glints over ocean and from small bodies of water over landmasses. The need to understand the behavior of greenhouse gases as they contribute to climate change is increasing rapidly both for scientific understanding as well as for regulatory control, as international protocols are developed to help moderate the release of these into the atmosphere. Space borne measuring systems are needed because of the global nature of the problem, but the identification of release sites from space is difficult because the measurement of a surface phenomenon is masked by the presence of the entire atmosphere between the sensor and the source. This has led to a precision requirement on the order of 400:1 for the measurement of carbon dioxide column from space, a challenge that applies in some measure to all space borne searches for surface sources and sinks. In spite of the measurement challenges, the need remains to provide more frequent access to space, with spacecraft that can be cost-effectively produced in higher numbers than traditional stove-pipe systems. This is where spacecraft like SMART come into play.

AMIGO can operate from a range of altitudes between 350 and 1000 km, preferably at a near-polar orbit in order to observe at high latitudes. The orbit must also afford the opportunity to view glint at low Solar Zenith Angles (i.e., near noon rather than dawn/dusk). A sun-synchronous orbit is advantageous for regular sampling, but not required since methane is long-lived and diurnal changes in column are not large. Any orbit with lower inclination or further from noon would limit coverage; the threshold for orbit inclination is the ISS orbit of 51.6°. This orbit would cover the majority of anthropogenic sources and processes. All these orbits are serviced by SMART's built-in capabilities.

3. SMART (ModE) BRIEF DESCRIPTION

As a low-cost "class-D" micro-satellite prototype, SMART has a mix of heritage and ruggedized Commercial Off-The-Shelf (COTS) components chosen judiciously and tested extensively [4]. Its modular functionality follows a similar philosophy to the old MMS approach, with "core" and mission-specific components. Unlike MMS however, components are non-standard, but replaceable depending on requirements and technical evolution. Instead, emphasis is placed on *interface* standards, as these generally change slower (than components) over time. Key to SMART is an internally reconfigurable structure. For the purpose of the present application however, this structure is resized from its original form to accommodate AMIGO, but maintains the exact same architecture (form and function). A straight 2.25X scaling of the original vehicle diameter is used, which requires structural analysis to be carried out to verify integrity, but no lengthy or detailed re-design. A "SMART-ModeE" (for "Earth-Mode") version of the bus is hence envisioned, applicable to this and many Earth Science missions. SMART Functional Modules and their components are as follows:

1. Base Bus Module: Structure, Command, Telemetry, and Data Handling, Attitude Control Subsystem, Power Conditioning and Distribution Unit, Passive Thermal Control.
2. Propulsion Module and/or Power Conversion Module.
3. Active thermal control.

The original vehicle uses a momentum bias attitude control subsystem. The larger structure may require a larger wheel, but it may be chosen from a wide selection of components already available in the market. Again, the changes are kept manageable (and available) without the need for lengthy re-design.

3. INSTRUMENT ACCOMMODATION

The instrument accommodation in SMART-ModeE is shown in Figure 1. AMIGO occupies the +Z nadir deck on the "top" of the spacecraft. Support subsystems are internally located within the core bus structure, whereas the deployable, single-axis arrays are on the power service module at the opposite end. A 6-cube Laser retro-reflector instrument of opportunity is included on the nadir deck. The spacecraft weighs about 150 kg, and fits within a Pegasus fairing with 97cm diameter interface. With a Pegasus performance of 375 kg to a 500 km orbit, there is more than enough margin left for any orbit of interest to AMIGO.

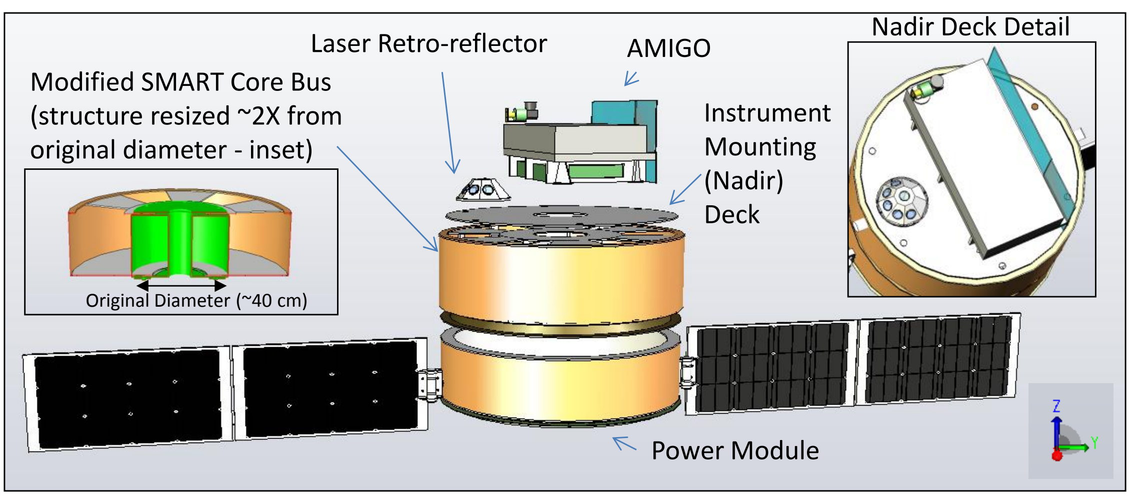

Figure 1: SMART Modular design provides flexibility in capabilities

4. CONCLUSION

SMART is a flexible system derived from a modular, reconfigurable, rapid architecture. Its application to this particular Earth Science mission necessitated a larger structure (SMART-ModeE), and ensuing attitude control subsystem modifications. Nonetheless, a complete system re-design is not necessary since the architecture allows for internal and external re-configurability. Its low-mass, use of carefully selected and screened COTS components, standard interfaces, modular, reconfigurable architecture, and capability of launching in a small vehicle (or as a secondary in a larger one), makes this system relatively less expensive than traditional Earth Science missions. SMART-ModeE and AMIGO are a good example of how the MR^2 architecture may be used to reduce mission costs, whilst obtaining science data critical to understanding the Earth system and the effects of green-house gases. Instruments of opportunity are easily accommodated in an architecture that is designed to accept changes.

5. REFERENCES

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