The Potential for Hosted Payloads at NASA

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***Abstract*—The 2010 National Space Policy encourages federal agencies to "actively explore the use of inventive, nontraditional arrangements for acquiring commercial space goods and services to meet United States Government requirements, including...hosting government capabilities on commercial spacecraft". NASA's Science Mission Directorate has taken an important step towards this goal by adding an option for hosted payload responses to its recent Announcement of Opportunity (AO) for Earth Venture-2 missions. Since NASA selects a significant portion of its science missions through a competitive process, it is useful to understand the implications that this process has on the feasibility of successfully proposing a commercially hosted payload mission. This paper describes some of the impediments associated with proposing a hosted payload mission to NASA, and offers suggestions on how these impediments might be addressed.**

Commercially hosted payloads provide a novel way to serve the needs of the science and technology demonstration communities at a fraction of the cost of a traditional Geostationary Earth Orbit (GEO) mission. The commercial communications industry launches over 20 satellites to GEO each year. By exercising this repeatable commercial paradigm of privately financed access to space with proven vendors, NASA can achieve science goals at a significantly lower cost than the current dedicated spacecraft and launch vehicle approach affords. Commercial hosting could open up a new realm of opportunities for NASA science missions to make measurements from GEO. This paper also briefly describes two GEO missions recommended by the National Academies of Science Earth Science Decadal Survey, the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission and the Precipitation and All-weather Temperature and Humidity (PATH) mission. Hosted payload missions recently selected for implementation by the Office of the Chief Technologist are also discussed.

Finally, there are technical differences specific to hosted payloads and the GEO environment that must be considered when planning and developing a hosted payload mission. This paper addresses some of payload accommodation differences from the typical NASA LEO mission, including spacecraft interfaces, attitude control and knowledge, communications, data handling, mission operations, ground systems, and the thermal, radiation, and electromagnetic environment. The paper also discusses technical and programmatic differences such as limits to NASA's involvement with commercial quality assurance processes to conform to the commercial schedule and minimizing the price that makes hosted payloads an attractive option.

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1. INTRODUCTION

The commercially hosted payload approach offers key benefits for government payloads, including lower cost access to space, frequent launch opportunities, and leveraging of existing commercial infrastructure. Attaching a secondary payload to a commercial spacecraft allows the government to pay a fraction of the cost of building and launching an entire spacecraft. The 2010 United States (US) National Space Policy recognizes the benefits of hosted payloads and encourages their use by directing federal agencies to "work jointly to acquire space launch services and hosted payload arrangements that are reliable, responsive to United States Government needs, and cost-effective."[1]

Some obstacles to using commercial hosting for government payloads exist, but these obstacles have been overcome by other government agencies. The programmatic challenges in particular were the focus of a previous study on recent examples of commercially hosted government payloads.[2] Moreover, the technical and programmatic challenges have been overcome by government agencies on successful programs such as the Federal Aviation Administration's Wide Area Augmentation System (WAAS), the US Coast Guard's Automatic Identification System (AIS), the Department of Defense-sponsored Internet Routing In Space (IRIS),[3] and the US Air Force's (USAF) Commercially Hosted Infrared Payload (CHIRP).[4,5,6,7] These programs have provided valuable lessons for future hosted payload programs.

Commercial spacecraft owners and manufacturers see benefits from hosted payloads as well. One of these benefits is the financial advantage that the early government payment provides to offset some of the owner's initial investment in building and launching a new spacecraft. A less quantifiable benefit is that by hosting a government payload, the commercial industry can maximize the orbit locations in Geostationary Earth Orbit (GEO) that remain available for use in the commercial market. The level of commercial interest can be seen in studies that have been performed and the formation of the Hosted Payload Alliance (http://hostedpayloadalliance.org) to create an open dialog between government and industry to address impediments to the use of this space access option.[8]

Many hosted payloads provide communications capabilities for the US military and its allies. These communications payloads are aligned with the core capabilities of the commercial telecommunications industry and therefore fit the hosted payload model well. However, other areas could also realize the benefits of hosted payloads, including technology demonstrations such as IRIS, optical sensor demonstrations such as CHIRP, and Earth-observing sensors that could fit within the mission portfolio of the National Aeronautics and Space Administration (NASA).

For the NASA Science Mission Directorate, commercially hosted payloads offer opportunities for new kinds of science in new orbit locations that are not otherwise readily affordable. Hosted payloads provide opportunities for more missions in a constrained budget environment. NASA technology development can also be accelerated through the use of hosted payloads as a means to advance the Technology Readiness Level (TRL) of new capabilities through on-orbit demonstrations.[4]

In some cases, NASA competitive procurement processes create barriers to commercial partnerships that could be used to formulate science and technology missions. These processes have been focused on traditional government space access models and require some accommodation for the hosted payload strategy, where business cycle timelines are shorter and commercial, firm-fixed price contracts are the norm. Recently, NASA has expanded some of its competitions to enable proposals to include commercial hosting as an accepted means for space access.

As a final introductory note, this paper will focus on commercial hosting to GEO, although opportunities exist for hosting in other orbits. NASA does not operate any science missions in GEO at the time of this writing. However, NASA's future mission plans include the need for certain GEO missions. The commercial telecommunications industry designs, builds, and launches communications spacecraft at a rate over 20 per year. This regular rate of new and replacement satellites provides a steady set of opportunities for hosted payloads.

2. New Science Using Hosted Payloads

Most NASA spacecraft operate in Low Earth Orbit (LEO), and most NASA science is conceived and developed with those orbits in mind. Science missions that can be uniquely conducted in GEO face comparatively higher costs for building, integrating, and launching a GEO spacecraft. Due to their orbits, most LEO Earth Science missions provide data for given location on timescales from days to weeks, months or seasons. That data is then aggregated to provide the required monthly, seasonal, or yearly mean measurements. However, many Earth processes require observation of a location on timescales of hours or less. GEO is one solution for more frequent time sampling of a given location from space. Copies of instruments flown on multiple spacecraft in LEO can form a constellation which approaches the temporal revisit capability of GEO, and additionally provides global coverage. However, this constellation approach presents significant expense and operational complexity through, for example, the need for inter-calibration and multiple launches. GEO offers a continuous view of a target domain, enabling measurements on hourly and shorter time scales. The trade-off for these time-resolved measurements, though, is that the GEO spacecraft can only see the portion of the Earth's surface directly under it, rather than the nearly-global coverage eventually provided from LEO spacecraft.

Time-resolved measurements have been identified as a need for NASA in the Earth Science Decadal Survey, which provides a ten-year roadmap for NASA Earth science missions.[9] The Decadal Survey phases its missions in three groups, or tiers, which are to proceed in order. The Decadal Survey has defined two missions that require observations with higher temporal resolution to meet the science objectives: the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission and the Precipitation and All-weather Temperature and Humidity (PATH) mission.[9] The scientific community is evaluating a hosted payload implementation for the GEO-CAPE mission. If such an implementation proceeds to flight, proposals for new types of GEO measurements are likely to emerge that also take advantage of the hosted payload capability.

GEO-CAPE is a Tier 2 Decadal Survey mission focused on air quality and coastal ecosystem science. Air quality measurements of ozone precursor pollutants require high spatial and temporal measurements of atmospheric trace gases that can best be performed from GEO. These measurements will allow better understanding of the rapidly-varying planetary boundary layer and continental-scale pollution transport. Coastal ecosystem science requires measurement of short term dynamics, and the high temporal requirements for ocean color have not been met from LEO observations. These measurements will greatly improve air quality monitoring and forecasting as well as expanding understanding of the interactions between humans, coastal environments, and climate.[9]

The GEO-CAPE mission formulation team is evaluating the option to implement the mission as a series of commercially hosted payloads with overlapping operational lifetimes on orbit, in addition to a more typical implementation option with a single NASA observatory-class spacecraft designed to host multiple instruments. A series of hosted payloads reduces the risk of total mission loss, reduces overall mission cost, and also allows flexibility for the mission development to be phased to fit within future NASA budget profiles. The hosted payload approach allows simpler payloads to be developed and launched as a form of risk reduction and allows technology to be infused in each subsequent payload. In addition to the high-level cost and schedule trades associated with this approach, the GEO-CAPE mission formulation team is studying the ability of the attitude control systems of commercial communications spacecraft to meet the pointing knowledge, control, and stability requirements of the GEO-CAPE instruments. Missions similar to GEO-CAPE are under formulation by the European Space Agency (ESA), the Japanese Aerospace and Exploration Agency (JAXA), and the Korea Aerospace Research Institute (KARI). If implemented during the same time period as these missions, GEO-CAPE would provide a US contribution to an international constellation. As illustrated in Figure 1, this constellation would provide full global coverage for the highly time-resolved measurements and allow unprecedented understanding of global atmospheric processes and pollutant transport. Moreover, it would provide a new capability for quantifying emissions transport into North America and adjacent areas with important implications for air quality policy.

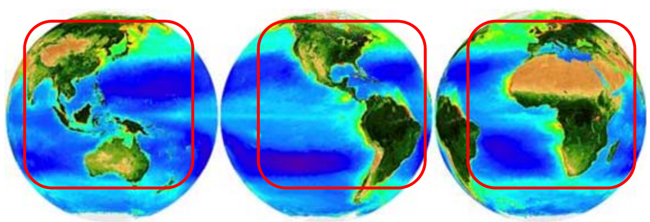

Figure 1: Three GEO missions could provide highly time resolved Earth science measurements with full global coverage, similar to current weather satellites

The PATH mission is a Tier 3 Decadal Survey mission that will provide continuous all-weather measurements of temperature and water vapor profiles in the atmosphere. PATH would also provide sea surface temperature and precipitation measurements several times per hour. These measurements have a significant ability to enhance weather prediction capabilities and models compared to current Geostationary Operational Environmental Satellite (GOES) capabilities. Such measurements also improve capabilities for monitoring and predicting phenomena such as hurricanes or El Niño. The Decadal Survey states that performing this science at the required temporal resolution in LEO would require an "impractically large constellation of platforms" compared to a single GEO mission.[9]

In addition to Earth observations, other areas of NASA science such as space weather measurements and heliophysics could benefit from a hosted payload approach. Real-time applications could be supported in collaboration with meteorological agencies to provide improved weather monitoring and enhanced disaster prediction, observation, and response capabilities.

A subset of planned future NASA missions is appropriate for GEO and for commercial hosting. To fit within NASA mission cost limits, instruments will typically be constrained in mass, power, and volume. Operational constraints suggest that highly autonomous payloads with modest thermal, attitude control, and platform stability requirements are the best candidates to be hosted on commercial spacecraft.

The commercial schedule requires some adaptation of NASA project decision making compared to typical NASA science missions. The success of NASA's schedule-driven Mars exploration program, which requires on-time launches within regular launch windows dictated by orbital constraints, demonstrates NASA's ability to perform on a fixed schedule. Operating in a schedule-driven mode constrains mission requirements creep, and places an emphasis on timely decision-making and unchanging mission requirements, similar to commercial projects. Constrained science goals can be realized on time and on budget. The CHIRP program planned to achieve 80% of its objectives for about 10% of the cost of developing a full demonstration mission.[4] For NASA, the commercial project model may meet more overall science objectives than would otherwise be possible for a given budget. As mentioned previously, not all NASA payloads can be hosted, so the hosted payload model will enhance, but not replace, typical dedicated NASA spacecraft missions.

Another way to view the cost benefits of hosted payloads is to examine what can be done for the same total mission cost. A set of 10 Class C and D LEO missions with costs below $200M (real-year) was selected from the NASA Cost Analysis Data Requirement (CADRe) database. The set of missions consists of AIM, CHIPSat, FAST, GALEX, GRACE, IBEX, Jason, TIMED, TRACE, and WIRE. Figure 2 presents an average of the percentage breakdown of costs by mission category for each of these missions. Figure 2 also shows the same information for a comparably-priced example of a commercially hosted payload mission to GEO. For roughly the same total mission cost, considerably more money can be allocated to science and payload development for a hosted payload (54.5%) than for a standard mission (28.5%). It should be noted that the costs for project management, systems engineering, and safety and mission assurance are lower for the commercially hosted payload mission because it assumes reliance on more streamlined commercial processes and efficient production and operations capabilities. Although the CADRe data is for LEO missions, the cost of a spacecraft and launch vehicle for GEO is much higher than for LEO. A GEO mission that includes spacecraft and launch vehicle (not hosted) would be placed in a different mission class altogether, with a significantly higher total mission cost.

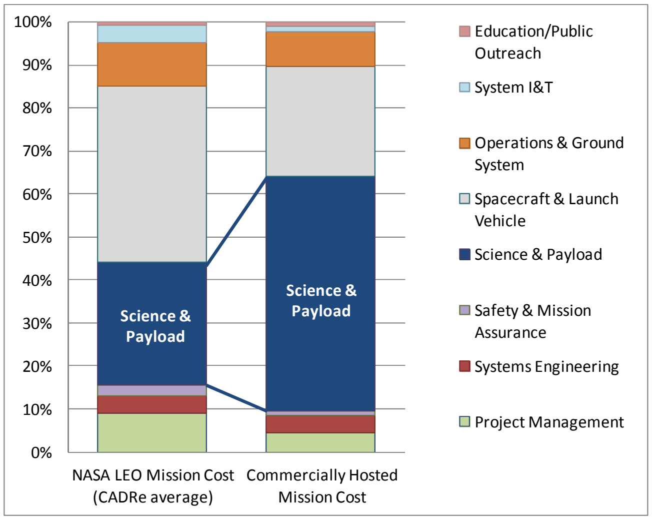

Figure 2: Average cost percentages for NASA Class C/D LEO missions with total mission cost <$200M compared to a NASA hosted payload mission of comparable price

3. HOW NASA SELECTS MISSIONS

Examples of dedicated NASA spacecraft missions include the space observatories that the Science Mission Directorate uses to conduct scientific studies of the Earth, Sun, solar system, and the universe. Likewise, the Human Exploration and Operations Mission Directorate provides dedicated NASA space operations related to human exploration in and beyond low Earth orbit. Consequently, NASA's Science Mission Directorate and Human Exploration and Operations Mission Directorate execute most of NASA's space projects. The Office of the Chief Technologist is also involved in space missions from the perspective of developing and demonstrating advanced space systems concepts and technologies that enable new approaches to achieving NASA's mission. The relationships between these organizations are displayed in the simplified NASA organizational structure in Figure 3. As previously discussed, the Science Mission Directorate is evaluating the use of hosted payloads for a subset of its science missions. The Office of the Chief Technologist recently selected two commercially hosted payload projects for its Technology Demonstration Missions. Hosted payloads also could be used by NASA's Human Exploration and Operations Mission Directorate for making various measurements of a range of space environments, in preparation for human missions beyond LEO.

Science Mission Directorate missions generally fit into one of two categories, directed or competed. NASA assigns a specific NASA Center to lead a directed mission. To date, the Tier 1 Decadal Survey missions have been implemented as directed missions. The other set of Science Mission Directorate missions are selected through competitive processes for various levels of mission funding and payload classifications. The Office of the Chief Technologist has also made use of competitive processes for its technology missions.

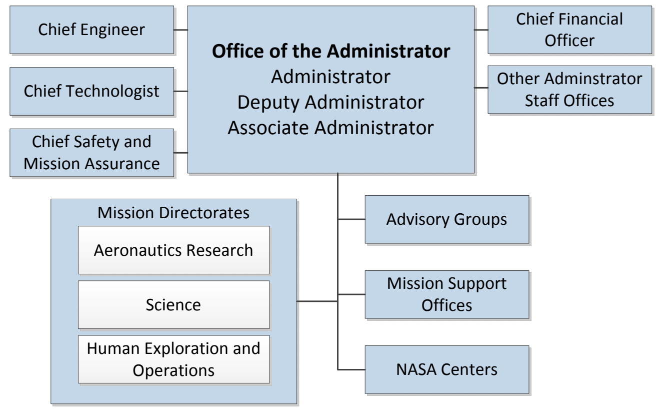

Figure 3: Simplified NASA Organizational Structure

The competitively-selected missions apply the following general model. An initial Announcement of Opportunity (AO) or other type of Broad Agency Announcement (BAA) is posted to the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) site, to solicit proposals that fit a certain mission criteria and budget. After the proposal submission deadline, all the proposals that were submitted are subject to a formal evaluation process. The proposals and their evaluation ratings are delivered to the appropriate selection official, who makes the final mission selection(s) in keeping with the stated solicitation goals and the available budget.

For many Science Mission Directorate AOs, brief proposals are reviewed and a small number are selected and funded for a Phase A study (i.e. Preliminary Analysis phase). Each funded Phase A team produces a Concept Study Report (CSR). These CSRs are subject to a second round of evaluation and final selection to the mission(s) that will be funded beyond Phase A. This two-step selection process is typically conducted over 18-24 months. Recently, single-step selection processes have been conducted, including the Science Mission Directorate's Earth Venture (EV) opportunities and the Office of the Chief Technologist's Technology Demonstration Missions.

The proposal evaluation process for the Science Mission Directorate involves thorough evaluation by a Science Panel and a Technical, Management, and Cost (TMC) Panel. The evaluations assess criteria in three main categories: scientific merit, scientific implementation merit and feasibility, and TMC feasibility and risk. The weightings between the ratings in these categories are specified in the AO for each opportunity. The AO identifies specific requirements for each of the three categories.

Proposal teams are led by a principal investigator (PI) and generally include partner organizations for the following skill sets: project management, systems engineering, safety and mission assurance, science, instrument design, development, and testing, spacecraft manufacture, integration and test (I&T), launch, operations, and ground systems. NASA Centers are often included as partners in these proposals to provide one or more of these capabilities. NASA Centers may select partners through a competitive process in accordance with Procurement Information Circular 05-15 and NASA Federal Acquisition Regulation (FAR) Supplement 1872.308. NASA typically issues an open announcement of the partnering opportunity through the NASA Acquisition Internet Service (NAIS) Electronic Posting System (EPS) to facilitate partner selection.

Responses to any partnering opportunity that are received by the NASA Center are formally evaluated, and selection(s) made, in order to proceed with the development of a proposal. After selection, the partners participate in the proposal development effort with the applicable NASA Center. If the proposal is selected, the partners named in the selection statement participate in the project without any further competition. This partnering process expedites the initial implementation of the selected mission, while providing an appropriate opportunity for competition.

In the past, the AOs and the selection criteria and processes have been focused on selecting projects using traditional access to space methods and are not necessarily well-suited to hosted payload proposals. Some of the spacecraft and launch vehicle requirements in particular are not necessarily relevant to hosted payload missions because these activities are the responsibility of the spacecraft owner and not the NASA mission team. Imposing spacecraft and launch vehicle requirements hosted payload proposals can improperly increase the perceived risk of those proposals.

4. PROGRESS FOR HOSTED PAYLOADS AT NASA

The recent EV-2 solicitation opened the door for the use of hosted payloads as a space access option for NASA science missions. The EV-2 AO included a provision allowing proposal teams to use hosted payloads as an alternative space access option.[10] This provision represents a major step towards making the use of commercial hosting a reality for NASA.

While significant progress has been made in allowing for lower-cost access to space options, such as hosted payloads, in the proposal process, there are still areas where more can be done to facilitate industry participation. Traditional mission implementation scenarios presume that NASA owns/operates the spacecraft and launch vehicle, consequently it is not unreasonable for NASA to impose requirements on the respective vendors of these items. In contrast, a hosted payload mission implementation scenario presumes that the partner owns/operates the spacecraft and launch vehicle. Since these items are not purchased by NASA, it is not appropriate to impose a standard set of NASA requirements on the spacecraft and launch vehicle. For example, the specific requirement in the EV-2 AO that a hosted payload be launched on a US launch vehicle would be problematic for a majority of industry owner/operators. The requirement is more restrictive than the current US National Space Transportation Policy, which allows secondary payloads on foreign launch vehicles if appropriate approvals are obtained.[11] At present, a majority of commercial GEO launches occur on foreign launch vehicles. For example, of the 108 internationally competed commercial launches from 2006-2010, only 10 US launch vehicles were selected.[12] However, there are indications that the NASA requirement for launch of hosted payloads on US launch vehicles may be relaxed in future AOs.

Complementing its full mission AOs, NASA provides Earth Venture–Instrument (EV-I) opportunities. The EV-Is are planned to have roughly annual releases and selections. NASA will select payloads for development through the EV-I AO. Unlike NASA's full mission solicitations, the EV-I solicitations will not require end-to-end mission definition; consequently, a confirmed host is not required, although suggested partnerships are accepted. Some benefits for commercially hosted payloads arise in this approach. Specifically, the proposal team for a GEO hosted payload can focus on the payload capability only, and is relieved of the responsibility to arrange industry partners for hosting. Such a proposal provides for the instrument to be developed following standard NASA processes over a period of up to 5 years, and postpones commercial hosting arrangements until the instrument is either complete or sufficiently far enough along in its development. This approach meets a major recommendation from the USAF CHIRP program to achieve on-time delivery, which is to contract for hosting after the instrument has been built and is entering the testing phase.[7] There is a potential for difficulty, though, if the instrument is fully developed without a known spacecraft interface, incurring additional cost and schedule to retrofit the payload once a host is identified. For this reason, the authors had previously recommended contracting for hosting when the payload is at a Critical Design Review (CDR) level, but before it had been assembled.[2] The EV-I draft AO indicates that an "appropriate platform" should be identified by the NASA Program Office prior to Preliminary Design Review (PDR), although it is not clear when or how that platform would actually be procured. The EV-I AO requires that cost planning be performed to indicate the yearly cost associated with delays in finding a suitable space access platform for several years after the instrument development is complete.[13]

To address these concerns about unspecified payload-spacecraft interfaces, in concert with the EV effort, a Common Instrument Interface (CII) effort is underway at NASA. CII intends to provide standard interface guidelines for both LEO and GEO EV-I payloads. Draft LEO interface guidelines are currently available on the EV-I solicitation program library, along with a draft payload opportunity database.[14] Prospective commercial GEO hosts have suggested that standard interfaces for hosting payloads are unlikely without significant changes to their business model, with attendant cost increases for hosting.

The CII draft payload opportunity database lists all of the commercial GEO hosting opportunities as "implausible/unknown." This guidance may reduce chances of a GEO hosted payload being selected through the EV-I process and is at odds with the demonstrated interest of the industry and with commercial GEO replacement cycles. However, future guidance on GEO interfaces and opportunities is still in development and may prove more amenable to GEO hosted payloads.

The Science Mission Directorate's Earth Science Division is taking steps to create opportunities for commercially hosted payloads, and the Office of the Chief Technologist has made significant progress in this area as well. The Office of the Chief Technologist's BAA for Technology Demonstration Missions solicited proposals to advance the TRL of various capabilities from at least TRL 5 to TRL 7 or higher. This BAA was written generically to allow any form of space access to be proposed for demonstrations requiring access to orbit. The Office of the Chief Technologist selected two hosted payload Technology Demonstration Missions from this solicitation.[15] The Laser Communications Relay Demonstration (LCRD), shown in Figure 4, will demonstrate high-speed laser communications capabilities. The LCRD mission will be hosted on a commercial GEO communications spacecraft.[16] The Deep Space Atomic Clock (DSAC), shown in Figure 5, will demonstrate a highly stable timing capability to enhance and reduce costs for spacecraft navigation and tracking. The DSAC mission will be hosted on a LEO spacecraft in the Iridium constellation.[17]

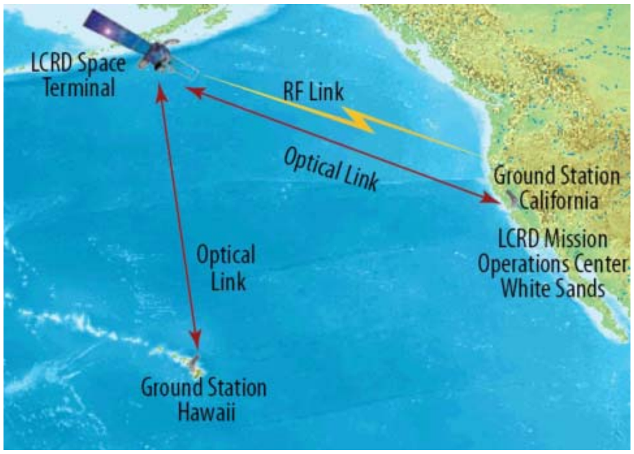

Figure 4: The LCRD mission will be hosted on a commercial GEO spacecraft[15]

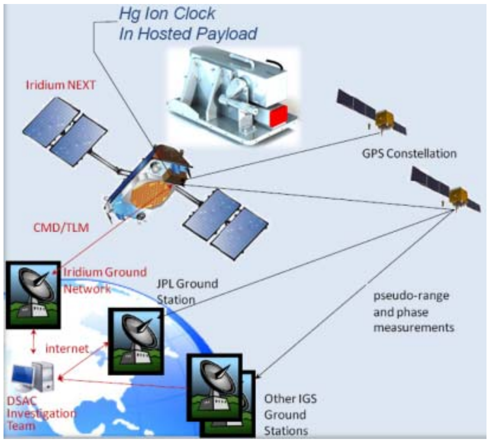

Figure 5: The DSAC mission will be hosted by an Iridium spacecraft in LEO[15]

5. PROPOSING A HOSTED PAYLOAD TO NASA

Hosted payloads have been proposed to Science Mission Directorate opportunities in the past, but thus far none have been funded by NASA.[2,18] During the recent EV-2 full mission AO, the authors proposed a GEO hosted payload, addressing a number of barriers associated with proposing a hosted payload through an AO process. The EV-2 AO for a full mission was cost-capped at $150M. The EV-2 AO is a single-step selection, after which the selected mission will be funded to begin implementation at Phase A, without a second round of proposals and evaluation for final selection.

The authors invested over 12 months in understanding the business models of commercial GEO enterprises and building relationships with all of the US spacecraft manufacturers and owner/operators in order to assure responses to partnering opportunities offered by NASA. These activities were performed through conferences such as the Satellite Conference and Exhibition, and through hosted payload forums such as the former Hosted Payloads Working Group and the Hosted Payload Summits organized by the Hosted Payload Alliance. Because of these efforts, the authors received a significant number of responses to their partnering opportunity19], including one that fully met the needs with a satellite manufacturer and an owner/operator team. The commercial owner/operator generally selects the manufacturer in the competitive market 2-3 years before launch, while the authors developed their EV-2 proposal 5-6 years before launch. Committing to a commercial partnership so far in advance of the fully-developed business case is not typical for satellite owner/operators or manufacturers, and should not be expected for NASA hosted payload proposals in the future. A more flexible AO process could be developed that would accommodate a proposal to NASA with only an owner/operator or manufacturer as a partner. In either case, the terms of the AO could require that the remaining partner be contractually bound by the NASA payload's CDR.

The commitment of appropriate hosting partners far in advance of the usual commercial business cycle is a challenge for proposing a hosted payload to NASA's full mission AOs. The AOs generally have specific technical requirements for the instrument, spacecraft, ground systems and operations, as well as requirements for guaranteeing placement of the host spacecraft in the desired orbital slot. Meeting all of these requirements for a hosted payload requires the spacecraft owner/operator, manufacturer, and launch services provider to be identified in the proposal. The owner/operator provides orbit slot ownership/guarantee and pricing, satellite operations, and may also provide commercial ground systems. The manufacturer provides the technical design of the spacecraft, interfaces, I&T, and associated pricing. The commercially-selected launch services provider determines the launch loads and requirements for the NASA payload. Additionally, the specific manufacturer or launch provider selected can affect the owner's business case for a specific commercial mission, which can further influence the price for payload hosting.

The owner of a commercial communications spacecraft generally does not select the spacecraft manufacturer or launch provider until 2-3 years prior to launch. Current NASA proposal processes would require the commercial owner to select these partners 5 years or more prior to the desired launch date. This requirement introduces risk to the spacecraft owner that must project spacecraft replacement rates and their associated slot locations up to 2 years in advance of their normal business cycle. Forcing the hosted payload partnership so early in the business cycle also affects the proposed mission by requiring that the science goals adapt to possible changes in final orbit location or launch date. Research of industry methods indicates that the appropriate synchronization between NASA payloads and a commercial satellite mission may occur at the payload's CDR, approximately 30 months prior to the host launch.[2]

Recently, the Science Mission Directorate selected the Global-scale Observations of the Limb and Disk (GOLD) mission for Phase A study as part of its latest two-step Explorer solicitation. The GOLD mission was selected for the first step of funding with only the spacecraft owner identified as a partner. The Office of the Chief Technologist also recently selected the LCRD mission with only the spacecraft manufacturer as a partner. These two selections demonstrate that the spacecraft and launch vehicle requirements in a solicitation can be relaxed enough to accommodate either of these proposal teaming arrangements.

NASA's present implementation of the US Space Transportation Policy creates difficulty for proposed hosted payloads, although there are indications that this implementation could become more accommodating to hosted payloads in the near future. In particular, for payloads hosted on commercial GEO spacecraft, the majority of these spacecraft are launched on foreign launch vehicles. According to a Defense Industrial Base Assessment report on the US Space Industry, "the U.S. Expendable Launch Vehicle industry has declined significantly in the international market since the 1990's – U.S. industry is down to 20% of the market during the 2002-2006 time frame versus a 40% market share for U.S.-manufactured vehicles from 1996-2000. This is attributable primarily to price competition and a shift back to GEO payloads," which are predominantly launched on foreign launch vehicles.[20] It should be noted that new market entrants have the potential to shift the competitive landscape in GEO in the future.

The current US Space Transportation Policy includes an exception allowing a secondary government payload to be launched on a foreign launch vehicle if approval is obtained.[11] In September, 2011, the USAF CHIRP payload and its host spacecraft were launched from Kourou, French Guiana on a French Ariane V launch vehicle. NASA also may need to work through this approval process for Future AOs that require proposed commercially hosted payloads to launch on US launch vehicles will significantly limit the field of potential responders. Furthermore, the requirement to launch on US launch vehicles could also alter the processes by which commercial owners select their launch providers and disadvantage them in the commercial marketplace. One option is for the government customer to pay the cost difference between the owner's selected foreign launch provider and an available US launch provider. However, this would reduce the cost benefit of commercial hosting to the government and reduce the attractiveness of the hosted payload option. Additionally, this would not address another potential concern of commercial industry: since the US launch vehicles are launched on government-controlled ranges, government launches would likely have priority over a commercial launch, resulting in costly delays for the commercial owner.

6. OTHER CONSIDERATIONS FOR PROPOSING GEO HOSTED PAYLOADS

Science instruments to be hosted on a commercial GEO should be adapted for a variety of technical differences compared to a standard LEO NASA mission. These differences include a space radiation environment that differs from that in LEO, with less radiation from trapped protons, but more exposure to solar flare protons/ions and galactic cosmic rays, as well as increased potential for electrostatic discharge on the spacecraft surfaces and electromagnetic interference differences.[21,22] These differences are well understood in the technical community, and commercial spacecraft manufacturers are experienced at designing, building, and operating systems in this environment. The considerations of the radiation environment (both total dose radiation and surface charging) should guide the sensor design, as has been done for the GOES and other meteorological instruments.

Other payload differences are driven by the nature of the host commercial communications satellite. Commercial spacecraft operate with surfaces at much higher temperatures than those on typical NASA spacecraft, which drives the development of different thermal interfaces, tolerances, and heat management and rejection systems for the science payload. From an operations perspective, the hosted instrument should be designed to operate with minimal commanding from the ground, to avoid impacting the standard commercial operations practices. However, it is also useful to take advantage of existing spacecraft resources, to include paying for the use of the existing commercial communications payloads (transponders) for command and telemetry capabilities. NASA's free and open data policy requires no changes to the commercial communications system with regard to data security. NASA has a requirement for securing the payload command uplink, but this requirement should generally be met by standard commercial practices.

Instrument complexity, mass, power, volume, and data rate are primary drivers in finding a suitable host spacecraft at a suitable price. Smaller and simpler payloads will generally be easier to host. Hosting is also more likely and affordable when the payload interfaces are less invasive and less prescriptive to the commercial mission, and integration processes are minimized. For example, a specific lesson from the CHIRP program is that the payload should be designed to avoid contact with the primary payload antennas in both their deployed and launch configurations. One way to address this is to sign the hosting contract for a specific host spacecraft near the payload CDR, so that both designs are mature enough to define interface control documents to avoid interface changes late in the project. Availability of hosting opportunities also depends on how the instrument operations affect the spacecraft. For example, yaw-flip or other maneuvers common on GOES spacecraft are not permitted during normal commercial operations. In some cases, the instrument may have a steerable mirror to target its measurements, but significant movement of massive instrument components could impact the primary commercial mission. Any of the limitations discussed in this paragraph are generally negotiable with commercial vendors, but ultimately, more complexity will result in a higher price for hosting the instrument.

NASA generally continues operating its science missions for as long as the spacecraft and instrument are still functioning and capable of making a useful measurement. For a hosted payload, this flexibility is at least somewhat altered by the addition of the spacecraft owner, who has their own commercial priorities, into the decision process. For example, the hosted payload is generally making use of available power margin at the beginning-of-life of the spacecraft. The solar array-produced power decreases over the 15 year lifetime of the spacecraft, and after many years it may not support both the spacecraft's primary commercial mission and the NASA payload. At this point, the NASA activity may not be extended even if the payload is still otherwise functional. The spacecraft owner will also evaluate their own economic factors when considering the extension of a hosted payload beyond the originally contracted life.

Both a benefit and a challenge for hosted payloads at GEO is the capability for significantly higher volumes of science data. Since the spacecraft is able to downlink data to its ground station continuously for its entire lifetime, and since commercial transponders are capable of rates around 70-80 Mbps, the spacecraft can deliver far more science data than a LEO mission that is only in view of its ground stations for a few minutes per orbit. The continuous high data throughput of commercial communications satellites allow for significantly larger focal plane array instruments or more frequent measurements, thereby improving spatial and/or temporal resolution. The data can also be inherently provided at near real time.

The high data rates and volumes need to be addressed for the ground segment of the mission. Systems that are capable of transferring, processing, and storing such high data rates and volumes are required. NASA does not currently operate science missions from GEO, so it does not have existing ground systems in place that are well-positioned to support such a mission. Although NASA could certainly develop and operate such systems, it is possible that a cost/benefit analysis would recommend the use of existing commercial ground systems as a paid service rather than designing and building an equivalent NASA system.

The authors submitted a request for information (RFI) to commercial industry to survey its capability to support such a data rate with the system illustrated in Figure 6. Responses to the RFI indicated that high data rates could be supported by commercial ground systems with no issues for data latency, transmission, or storage. Some responses recommended assessing the option of a dedicated ground antenna for the mission compared to using the existing commercial teleports for the lowest cost.

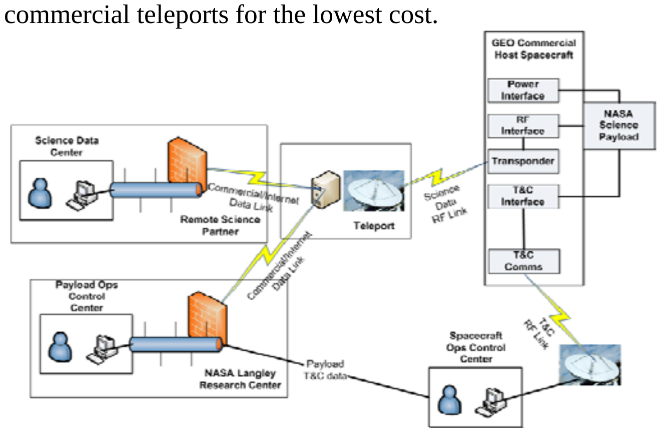

Figure 6: Potential ground system from commercial communications RFI

Mission assurance and mission review processes require appropriate tailoring for a hosted payload mission, where NASA is not purchasing the spacecraft or the launch vehicle. Standard levels of NASA oversight may add significant cost or may not be permitted on a commercial mission, where commercial processes provide the foundation for the reliability and success of the vendor. Commercial decisions are made more quickly and by fewer people than in typical NASA activities. The commercial manufacturers and owner/operators indicate that one or two government representatives can be accommodated within the cost and schedule constraints of the commercial marketplace, but the large numbers of personnel normally employed for mission assurance and mission reviews would be a cost item if imposed. Tailoring the mission assurance and management requirements for a hosted payload project would serve to better align the expectations of the government and commercial partners, and may improve the likelihood of successful project execution.[7]

Programmatic adjustments are necessary to successfully propose and implement a hosted payload mission at NASA. Instrument development and testing must be completed with sufficient time to allow integration with the host spacecraft before it launches. The mission must be managed to the schedule, a paradigm shift from the NASA model of maximizing the science and allowing scope changes that extend the schedule. Rather than seeking to expand performance throughout instrument development, the project team must agree early on the requirements that meet the commercial schedule in order to access its selected flight opportunity. There is precedence for operating in this schedule-driven mode at NASA. For example, all of the missions that NASA sends to Mars must be launched within specific and predictable windows of opportunity. With few exceptions, these missions routinely meet their targeted launch window and demonstrate NASA's ability to operate in a schedule-driven manner.

The typical NASA science mission accommodates changes late into a project because NASA absorbs the costs of configuration changes and launch delays in pursuit of maximum science return. A well-planned payload project, supported by management decisions to limit mission creep and execute on schedule, should be able to realize the cost and schedule benefits afforded by the commercial business cycle.

For contracting, NASA would utilize a FAR Part 12 "Commercial Items" contract for a hosted payload mission. These contracts are fixed-price (the only other option is time and materials), and to the maximum extent practicable, should be "consistent with customary commercial practice" (48 C.F.R. 12.301(a)(2)). It is likely that NASA and its commercial partner will have differing expectations or opinions on what "consistent with customary commercial practice" means in the context of a hosted payload contract. For example, although indemnification is a standard commercial term, it is the exception in Government contracts, as the Government cannot indemnify a contractor without express statutory authority to do so. Government also has restrictions or specific requirements with regard to insurance coverage, multi-year contracts, assignment, progress or "milestone" payments, contract termination and dispute resolution. In addition, because the contract will be firm fixed-price, it is important that the parties allocate risk and quantify potential liability for unexpected but nonetheless foreseeable events, such as launch delay or failure, spacecraft operational degradation or reduction of operational life, interference with the primary payload, late delivery by the Government of the hosted payload instrument, and movement of the satellite to a different orbital slot. For the Government, the late delivery of the payload poses a significant risk, which is complicated by the fact that there will likely be no direct contractual privity between the instrument builder and payload integrator. As a result, the Government will need to ensure that there is consistency regarding liability terms among different contractual instruments. As stated previously, many if not all of these issues have been successfully addressed on prior hosted payload missions; however, to foster greater understanding as well as to facilitate more efficient and effective contract negotiations and business relationships, it would be helpful if the Government and commercial sector could agree on standard terms and conditions for hosted payload contracts.

Finally, a proposed hosted payload may create concerns in the NASA community through the use of commercial services in place of those that are traditionally provided by NASA for its missions, such as ground systems, communications, and launch. While the National Space Policy promotes the use of commercial infrastructure where appropriate, there may be concern over supplanting traditional NASA services with commercial ones. However, these concerns are unfounded. As stated previously, NASA does not have any science missions operating in GEO. In addition, since only a small subset of planned NASA missions can be executed as hosted GEO payloads, NASA will still require its launch, operations, and ground system services for the majority of its missions. As a result, NASA can leverage the existing commercial infrastructure when appropriate, and avoid making the investment required to build and maintain its own, essentially redundant, capabilities.

This strategy of leveraging commercial infrastructure and capabilities to accomplish NASA missions is already being implemented for transportation of cargo and crew to and from LEO and the International Space Station (ISS). However, because there is currently no capability in the commercial sector for LEO/ISS delivery for NASA to leverage, NASA is making an initial investment to develop and mature commercial infrastructure and capabilities through its Commercial Orbital Transportation Services and Commercial Crew Development initiatives. As a result, when compared to NASA's LEO/ISS delivery strategy, hosted payloads are even more attractive because mature commercial infrastructure and commercial capabilities already exist and require no investment from NASA.

7. CONCLUSION

Commercially hosted payloads present an opportunity for NASA to meet identified strategic needs and to expand NASA science capabilities into new endeavors at low cost. Hosted payloads also provide a path for NASA to do more science and technology development in a time of fiscal constraints. While there are still some impediments to proposing a hosted payload to the AO-driven competitive selection processes, the recent expansion of the NASA Earth Venture opportunities to include hosted payloads represent a significant step forward. There are also indications that future opportunities will be even more accessible for hosted payload proposals. Likewise, the Office of the Chief Technologist's selection of two hosted payloads for its Technology Demonstration Program will be pathfinders for NASA in aligning and tailoring its processes to fit the hosted payload approach.

ACRONYMS

AIS	Automatic Identification System
AO	Announcement of Opportunity
BAA	Broad Agency Announcement
CADRe	Cost Analysis Data Requirement
CDR	Critical Design Review
CHIRP	Commercially Hosted Infrared Payload
CII	Common Instrument Interface
CSR	Concept Study Report
EPS	Electronic Posting System
ESA	European Space Agency
EV	Earth Venture
EV-I	Earth Venture – Instrument
FAR	Federal Acquisition Regulation
GEO	Geostationary Earth Orbit
GEO-CAPE	Geostationary Coastal and Air Pollution Events
GOLD	Global-scale Observations of the Limb and Disk
GOES	Geostationary Operational Environmental Satellite
I&T	Integration and Test
IRIS	Internet Routing In Space
ISS	International Space Station
JAXA	Japanese Aerospace and Exploration Agency
KARI	Korea Aerospace Research Institute
LaRC	Langley Research Center
LEO	Low Earth Orbit
NAIS	NASA Acquisition Internet Service
NASA	National Aeronautics and Space Administration
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
PATH	Precipitation & All-weather Temperature and Humidity
PDR	Preliminary Design Review
PI	Principal Investigator
RFI	Request for Information
RFP	Request for Proposal
TMC	Technical, Management, and Cost
TRL	Technology Readiness Level
US	United States
USAF	United States Air Force
WAAS	Wide Area Augmentation System

ACKNOWLEDGEMENTS

The authors would like to thank Patrick McCaffery, Brad Gardner, Steve Hall, and Tony Tyler, as well as other members of the GEO-CAPE hosted payload study team for their support on various technical, procurement, legal, cost, and program management aspects of commercially hosted payloads.

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