J8.1 Commercially Hosted Payloads: Low-Cost Research to Operations

Carl Schueler[1]
Santa Barbara CA

Abstract

The Commercially-Hosted InfraRed Payload (CHIRP) demonstration launched 21 Sept 2011 was so successful that the Air Force extended the mission for six months to the end of calendar 2012, with an option to further extend the mission. CHIRP is successful in several key ways that demonstrate a low-cost Research to Operations alternative to operational remote sensing from dedicated platforms.

The Air Force estimated that a dedicated geosynchronous earth orbit (GEO) missile-warning demonstration would cost over $500M not including the cost of the sensor. The CHIRP mission cost $82.9M including sensor and spacecraft modifications, integration, launch, development of custom mission operations and data analysis centers, and nine months of on-orbit operations. The Air Force spent $29M upgrading a sensor from another program to fly on CHIRP.

CHIRP integrated the sensor to an independently designed commercial GEO telecommunications spacecraft. Numerous interface risks were overcome, such as electromagnetic, power and data, and dynamic and static mechanical and thermal compatibility. A key challenge was maintaining the sensor focal plane and optics at low temperatures on a spacecraft designed to operate high-temperature communications payloads. Moreover, the spacecraft demonstrated fine pointing stability of a few microradians sufficient for most environmental sensing applications, and provided 70 Mbps continuous data transmittal to the mission operations center. Yet CHIRP was performed under a firm fixed price (FFP) contract, and developed and launched in 39 months from contract initiation.

Environmental monitoring payload Research to Operations transition is an ideal application of commercial hosting because one of the key requirements is availability of a proven payload prior to identification of a commercial host spacecraft. The payload must be delivered for integration no later than 12 months prior to spacecraft delivery. As the commercial spacecraft build cycle is typically 24 months, the payload must be ready for integration within 12 months following spacecraft contract initiation.

Typically a host spacecraft cannot be identified until just shortly before the spacecraft contract is underway. This paper reviews the principal CHIRP successes that demonstrate the applicability of commercial-hosting to reduce the cost of Research to Operations of environmental payloads and provides a hypothetical example of how a specific demonstrated meteorological research payload could be transitioned to operations using the commercial hosting approach.

Nomenclature

AGS = Americom Government Services
AFRL = Air Force Research Laboratory
AIRSS = Alternative InfraRed Surveillance System
ATP = Authorization to Proceed
BOL = Beginning of Life
CDR = Critical Design Review
CHIRP = Commercially Hosted InfraRed Payload
CMAC = CHIRP Mission Analysis Center
CMOC = CHIRP Mission Operations Center
COMS = Communications & Ocean Monitoring Satellite
COMSEC = Communication Security

---

[1] Corresponding author address: Carl Schueler, Schueler Consulting-Santa Barbara, 4546 Via Maria, Santa Barbara CA 93111; email carl@scsb.info

CONUS = Continental United States
C&T = Command and Telemetry
EMC = ElectroMagnetic Compatibility
EOFL = End of Fuel Life
EOL = End of Life
ESD = ElectroStatic Discharge
FAR = Federal Acquisition Regulations
FD-CHIRP = CHIRP Flight Demonstration
FFP = Firm Fixed Price
FPA = Focal Plane Array
GERT = General Environmental Requirements & Test
GEO = Geostationary Earth Orbit
GFE = Government Furnished Equipment
GIS = General Interface Specification
GOCI = Geostationary Ocean Color Imager
HPI = Hosted Payload Interface
HPSD = Hosted Payload Support Deck
I&T = Integration and Test
ITAR = International Traffic in Arms Regulations
MCU = Miniature COMSEC Unit
MEU = Miniature Encryption Unit
MODIS = MODerate resolution Imaging Spectroradiometer
MW = Missile Warning
NASA = National Aeronautics & Space Administration
NOAA = National Oceanic & Atmospheric Administration
NPV = Net Present Value
NSA = National Security Agency
OPIR = Overhead Persistent InfraRed
RR-AIRSS = AIRSS Risk-Reduction
SAIC = Science Applications International Corporation
SeaWiFS = Sea-viewing Wide Field-of-view Sensor
SMC = Space & Missile systems Center
SOC = Spacecraft Operations Center
SPI = Secondary Payload Interface
TRL = Technology Readiness Level
USAF = United States Air Force
WFOV = Wide Field-of-View

INTRODUCTION

There is a big difference between a "hosted payload" and a "commercially hosted payload," such as the successful Commercially Hosted Infrared Payload (CHIRP) illustrated in Fig. 1 [Levi, Newberry, Schueler 2012b]. Any satellite payload is "hosted" on a spacecraft, but a traditionally "hosted" payload is developed in concert with the host spacecraft so that risks of interface issues between the payload and host are minimal.

A commercially hosted payload, however, is placed on a "standard commercial bus" designed with minimal consideration for the hosted payload or interfaces to it [Andraschko]. Moreover, the spacecraft is typically launched within 30 months of contract initiation, and the hosted payload must be delivered for integration no less than 12 months before spacecraft delivery for launch as suggested in Fig. 2. Therefore, the commercially hosted payload must typically be designed before spacecraft contract initiation. This means the hosted payload must be designed without knowledge of the spacecraft on which it will be carried or the launch system to be employed. Those realities create potential for interface discrepancies and payload mechanical/thermal inadequacies that risk damage to the hosted payload and the spacecraft during launch and in-orbit. In addition to technical risks, the commercially hosted payload approach requires that the hosted payload be funded in advance of identification of a host and launch opportunity, making commercial hosting a contracting challenge compared to traditional dedicated ("hosted" but not "commercially hosted") missions.

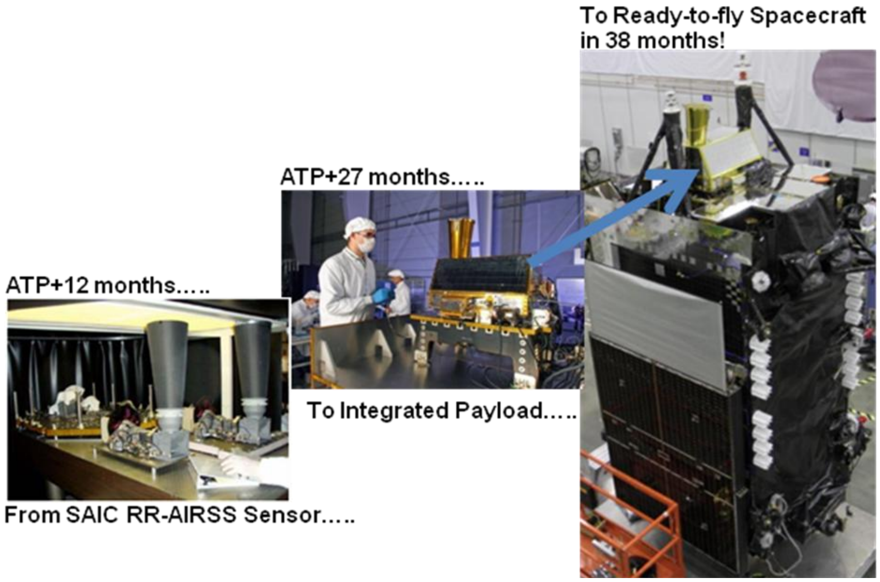

Figure 1. CHIRP launched 39 months from contract authorization to proceed (ATP). *A single quadrant of the SAIC RR-AIRSS sensor was integrated to the SES-2 commercial GEO spacecraft delivered 38 months from ATP and launched a month later.*

The CHIRP flight demonstration was the first commercially-hosted Overhead Persistent InfraRed (OPIR) mission [Schueler 2012c] and has been lauded for demonstrating dramatic cost savings compared to dedicated missions [Baddeley, Baker, Buxbaum, Foust, Ledbetter, Levi, Morring, Neil, Newberry]. The genesis of CHIRP was the Alternative Infrared Surveillance System (AIRSS) risk-reduction (RR-AIRSS) program initiated in FY06 to produce staring Wide Field of View (WFOV) Missile Warning (MW) sensors for potential geostationary earth orbit (GEO) demonstration [AFRL]. RR-AIRSS was conducted by the Air Force Research Laboratory (AFRL) out of Kirtland Air Force Base in Albuquerque NM under the sponsorship of the Air Force's Space & Missile-systems Center (SMC) at Los Angeles Air Force Base in El Segundo CA. Raytheon Space & Airborne Systems in El Segundo CA and Science Applications International Corporation (SAIC) Electro-Optics Division in San Diego CA won the two sensor contracts.

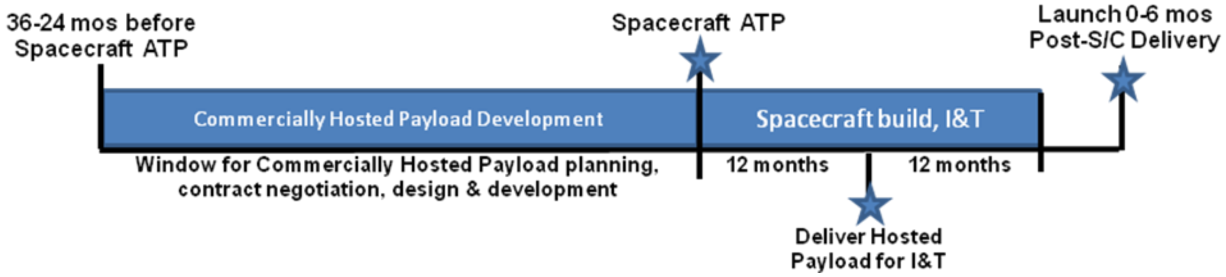

Figure 2. Typical commercial spacecraft timeline and hosted payload schedule implications

In 2006, sensor development efforts were proceeding towards 2007 Critical Design Review (CDR) and Engineering Models were being developed by Raytheon and SAIC. SMC and AFRL began to conduct evaluation of the possibility of a GEO demonstration under an expanded RR-AIRSS program. The evaluation took place over approximately a six-month period ending in summer 2007 when SMC and AFRL decided not to solicit an RR-AIRSS GEO demonstration. One reason for the decision to forego the GEO demonstration was anticipated high cost. The Air Force estimated that a dedicated demonstration requiring completion of a flight-qualified RR-AIRSS sensor, spacecraft development, payload integration and test, and launch would cost at least $500M [Brinton].

Orbital Sciences Corporation saw an unsolicited proposal opportunity in the Air Force decision not to proceed with the GEO demonstration. Federal Acquisition Regulations (FAR) subpart 15.6 defines an unsolicited proposal. One requirement is that an unsolicited proposal not be related to a previous or current formal solicitation and the RR-AIRSS GEO demonstration had not been formally solicited. The proposal must offer something unique and not in response to a funded government requirement, and there was no requirement for a WFOV staring IR GEO demonstration. Orbital's RR-AIRSS system engineering team included commercially hosted payload business and design experience from a 2005 commercially hosted Federal Aviation Administration communications payload and from a 1996 NASA Langley Research Center/Hughes proposal to fly remote sensing payloads on a Hughes commercial HS-601 GEO spacecraft [Little] and Orbital had invented a unique and essential hosted payload interface (HPI) [Kalmanson] illustrated in Figure 3.

With a pending contract for a series of GEO satellites from Americom Government Services (AGS) (now SES World-Skies) and mindful of the rapid delivery schedule for such satellites illustrated in Figure 2, Orbital and SES prepared an unsolicited proposal for an RR-AIRSS GEO demonstration using the commercially hosted payload approach. The team included AGS as prime contractor to provide launch and on-orbit operations, Orbital as spacecraft manufacturer, payload integrator, and mission manager, and SAIC to provide sensor modifications to fit the host spacecraft and ground data processing. Raytheon's RR-AIRSS design was too large and heavy. SAIC designed a four-telescope system providing the full-earth view. One telescope provided a quarter-earth view and was small and light enough to fit the spacecraft.

The unsolicited CHIRP proposal was submitted in January 2008 and a firm-fixed price (FFP) $65M contract with SMC began in July 2008 with the intent to launch two years later on the second of three satellites Orbital was under contract to deliver for SES. Recognizing risk that the sensor might not be completed within one year to meet the second satellite launch date, Orbital made necessary modifications to both the second and third spacecraft. SES-3 was completed for delivery ahead of SES-2, and CHIRP was shifted from SES-3 to SES-2 to accommodate late sensor delivery to Orbital. Spacecraft modifications primarily included electrical harness changes to provide hosted payload power and to allow Orbital's HPI to provide an independent data-link between the sensor and the ground system. The HPI was particularly important because CHIRP data is SECRET and must be encrypted and separated from commercial spacecraft and ground systems. Especially as SES is a non-US company (based in Luxembourg), security and International Traffic in Arms Regulations (ITAR) issues had to be resolved in the six months from the Air Force decision to forego an RR-AIRSS demonstration to the unsolicited CHIRP proposal in early 2008.

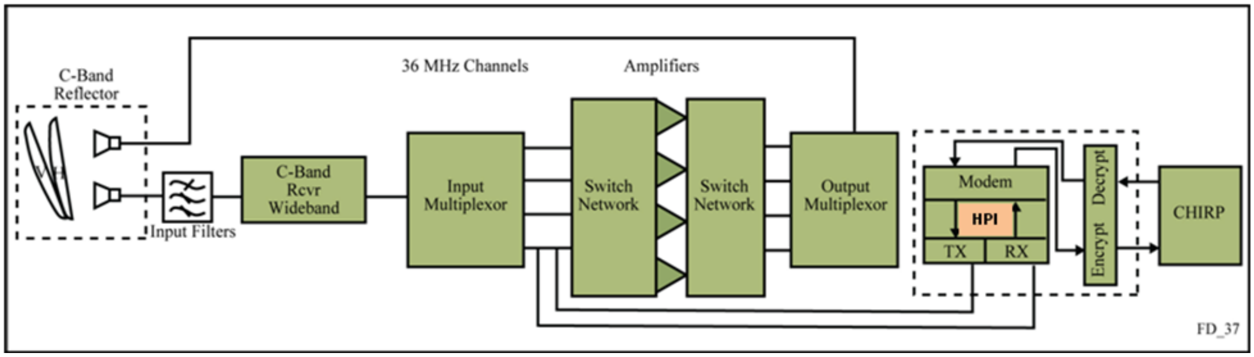

Figure 3. Host spacecraft communications with Orbital's patented HPI.

Commercial Hosting Imperatives

Specific Air Force CHIRP objectives specific to missile warning (MW) and CHIRP sensor performance can be found elsewhere [Levi, Newberry, Simonds]. Imperatives of commercially-hosted payloads include:

- **"Do no harm" to the primary commercial mission.** To successfully operate a hosted payload on a commercial telecommunications spacecraft, the hosted payload provider must recognize that the host spacecraft is operated as a service to customers of a 15 year commercial mission. Interference with that mission would rob the host operator's customers of satisfactory service and make it difficult to sell future hosted payload opportunities. Therefore, the fundamental system engineering challenge before the CHIRP team at the outset was to ensure that the sensor would not in any way interfere with the primary commercial satellite mission. This mandate trumped all other CHIRP objectives, including sensor performance. Compromises ensured the "do no harm" mandate, and examples are provided in the next section.

- **Hosted payload to spacecraft interface.** One of the unique challenges of a commercially hosted mission is that the hosted payload must be ready for integration to the spacecraft more than a year before integrated spacecraft completion for launch. This means the payload must have been designed years in advance of the identification of which spacecraft will serve as host or what launch vehicle will be employed. Moreover, the host spacecraft is typically a "standard bus" with little or no design consideration related to the hosted payload it will carry. As each hosted payload is likely unique, the challenge is designing and implementing interfaces after both the hosted payload and spacecraft have been fully and independently designed!
- **Optimize hosted mission cost and performance.** The commercially hosted mission must make business sense for the satellite operator, provide a cost-effective ride for the hosted payload provider, and of course offer adequate technical performance. Trades to optimize these parameters cannot be reduced to a "cook-book" formulation, as each mission is unique. Some basics are common to all, though, and are described with CHIRP providing a case-in-point.
- **Mature ground system.** CHIRP commands the sensor and receives and processes data, providing Air Force access to raw data from the CMOC in near real-time and to processed data and reports from the CMAC. CHIRP first light was achieved within about a month following spacecraft checkout, and the performance of the sensor and spacecraft were assessed over the next several months.

"Do No Harm" to Primary Mission

"Do No Harm" drives system engineering from contract inception to launch and operations. Indeed, even efforts to accommodate launch shock and vibration impacts on the sensor through the spacecraft must focus more on ensuring that hosted payload damage will not negatively impact the spacecraft than on ensuring payload operation. Noninterference with the host primary mission is not solely a commercial operator or spacecraft manufacturer concern. The hosted payload customer and the hosted payload provider must be "on board" with this philosophy.

Fortunately, GEO spacecraft normally accommodate various communications and electronics assemblies with different designs for each mission. For example, Orbital incorporates custom subsystems on each new spacecraft. Three documents define requirements on subsystems to be carried by an Orbital StarBus: the General Environmental Requirements & Test Document (GERT), General Interface Specification (GIS), and the electromagnetic compatibility (EMC) & electrostatic discharge (ESD) Plan.

Therefore, SES and Orbital required that the CHIRP hosted payload equipment either meet all the requirements in those documents or that Orbital and SES approved a waiver for any requirement that could not be met. A straightforward, albeit tedious, interface requirements evaluation and approval process ensued after contract inception extending through spacecraft integration. An excel workbook was created with comprehensive tabulation of analyses regarding each of some 250 GERT, GIS, and EMC/ESD plan requirements for each of twenty CHIRP sub-assemblies. Monthly meetings were coordinated by the program chief scientist with the SAIC Sensor program manager and chief engineer and spacecraft chief engineer to push the process along and identify issues requiring analysis and resolution.

An example of a minor issue resolution was requiring SAIC to adjust the sensor filter wheel design after a vibration-test induced crack in the filter holder. Two more substantial issues required resolution in favor of avoiding primary mission impact with resulting reduced sensor radiometric sensitivity and MW performance:

1. The solar shield in front of the telescope aperture (the cone at the top of the sensor in Figure 1) was found to interfere with one of the omni-directional antennas (visible next to the CHIRP sensor on the spacecraft at far right in Figure 1) because of electromagnetic interaction between the solar shield material and the antenna field pattern. To ensure no interference affecting primary mission communications, the shield was cut shorter than desired by the CHIRP sensor team per SES and Orbital specification. The predicted performance of the sensor was compromised by increased solar radiance into the telescope aperture, increasing stray light and decreasing sensitivity. This was not negotiable as it was understood that primary mission compromise was not allowed.
2. The original spacecraft integration plan included a set of radiator panels on the north or south face of the spacecraft connected to the cryo-coolers via heat-pipes. This plan, however, was soon found to interfere with the primary mission's electronics cooling subsystem performance. Therefore, the CHIRP team was forced to accept the alternative of placing the radiator panel on the nadir deck facing the earth and also for part of the orbit facing the sun. This created a predicted diurnal cycle of varying optics temperature over a substantial

temperature range from near the desired operating temperature at noon (sun behind spacecraft) to warmer than desired around 0900 and 1800 local time when the sun shines on the nadir deck.

Hosted Payload to Spacecraft Interfaces

Structural mounting and launch load survival. Figure 1 shows the CHIRP sensor observed by a technician. Looking closely, one can see that the sensor is mounted on the Hosted Payload Support Deck (HPSD) – a “table” designed to provide structural support for the sensor and to raise it above a spacecraft nadir deck crowded with waveguides, cables and the like. In addition to providing the sensor with a flat surface upon which to rest, the HPSD is designed to soften launch vehicle shock and vibration loads. The CHIRP sensor was designed with no specified launch environment or spacecraft. Therefore, after the CHIRP contract was initiated in July 2008, a year after the RR-AIRSS sensor critical design review (CDR), the CHIRP team considered the spacecraft interfaces for an as-yet unspecified launch vehicle! Months of coupled loads analyses combining sensor and spacecraft structural dynamics models determined that shock and vibration load reduction was necessary.

Thermal. A close examination of the CHIRP sensor mounted to the nadir deck of the spacecraft at the right of Figure 1 reveals a nadir-mounted radiator. While not an optimal location because the surface is sun-exposed for a significant portion of the day in GEO (around 0900 and 1800), it was impractical to place radiators on the preferred north or south facing sides of the spacecraft because the north and south facing panels are used by primary mission radiators. As the CHIRP hosted payload mission was not allowed to interfere with the primary mission, but radiator surface was essential to reject heat generated by the cryogenic coolers connected to the optics and the focal plane array (FPA), there was no alternative but to place the radiator on the nadir-deck. For much of the orbit, with sun behind the spacecraft, this works well. During a few hours in morning and evening, the sun shines on the radiator and the sensor operates warmer than desired.

Data. CHIRP commands and telemetry are extracted from a C-band transponder as illustrated in Figure 3 between the Input Multiplexer and the Switch Network and routed through the hosted payload interface (HPI) to CHIRP on the far right. The HPI is physically located below the nadir mounted radiator next to the CHIRP sensor on the far right of Figure 2. Orbital’s patented HPI ensures SES that CHIRP is isolated from the primary communications mission, and it ensures the Air Force that data collected from CHIRP are invisible to SES and their customers. 2 to 2.5 MHz bandwidth is used to uplink commands to CHIRP, and because the channel is passively coupled, uplinked commands are amplified and sent to the CMOC as a command verification echo. 2 to 2.5 MHz allows command rates up to 1.0 Mbps.

The remaining portion of the 36 MHz transponder bandwidth is used to transmit sensor data at 70 Mbps.
The HPI allows the CHIRP C-band transponder to be returned to commercial service after the CHIRP mission is completed, so that the Air Force needn’t pay for data (or power) after the CHIRP mission is terminated. The HPI receives minimal spacecraft services including power ON/OFF, basic discrete Telemetry reporting through the spacecraft, and thermal rejection. It is fused so that no HPI fault can damage the spacecraft or communications. CHIRP on-board command and data encryption and decryption shown between the HPI and CHIRP in Figure 3 are provided by the National Security Agency (NSA)-certified Type 1 Miniature Encryption Unit-121 (MEU-121) and Miniature Communication-Security (COMSEC) Unit-110 (MCU-110) as Government Furnished Equipment (GFE).

Mission Optimization

Not only must the hosted payload fit on the host spacecraft, it is also beneficial to minimize hosted mass because the spacecraft commercial operator’s hosting cost rises with increased hosted mass. This is not due to increased launch cost of adding hosted mass to the spacecraft, but is due to reduced spacecraft on-orbit “maneuverable life” caused by removing fuel to compensate for hosted payload mass. Fuel tanks are filled to take the spacecraft to maximum launch mass. A hosted payload requires cutting a kg of fuel for every kg of hosted mass to stay within maximum satellite launch mass, which cuts end of fuel life (EOFL) revenue as illustrated in Figure 4.

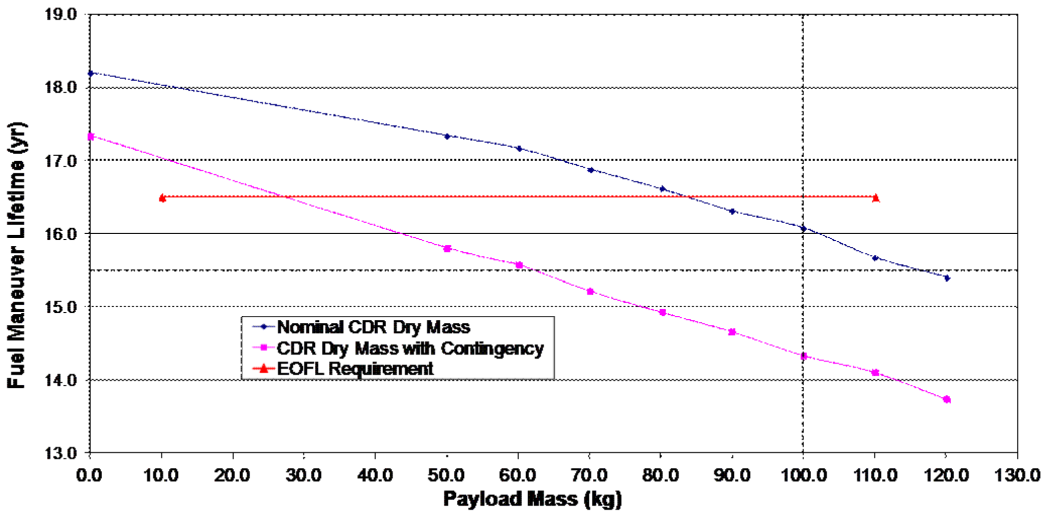

Figure 4. GEO spacecraft maneuverable life vs. hosted payload mass.

For the primary telecommunication mission operator's business case to close, the hosted payload pays a base hosting fee, data communication services fee, a charge for power, and a charge for estimated net present value (NPV) of end-of-life (EOL) revenue lost from hosted payload mass-induced fuel displacement. As long as the spacecraft manufacturer can mount the hosted payload within the launch vehicle fairing, hosting cost is primarily affected by hosted payload mass.

Power consumption and data rate also affect cost. While beginning of life (BOL) power has significant margin on most commercial GEO spacecraft, EOL power margin is slim. Therefore, the commercial operator may decide to shut down commercial transponders to compensate for hosted payload power draw. Each commercial transponder that is shut down while the hosted payload mission is in operation costs the operator lost revenue.

Data rate is perhaps the least cost sensitive parameter up to the data rate of a single transponder. As a single C-band transponder can provide up to 100Mbps, it is the rare hosted payload that would require more than one transponder for data transmission. The actual costs associated with transponder shut-down (for power) or dedication for hosted payload data depend on the satellite and operator cost profiles which vary by operator and mission.

Ground System

The CHIRP ground system is highlighted in the lower half and left side of Figure 5. Less than a rack of CHIRP Command & Telemetry (C&T) equipment is located at the SES Teleport. A key feature of the CHIRP mission architecture is segregation of CHIRP command uplink and data downlink from commercial SES operations. The only connection between SES's SOC and the CHIRP mission is SES SOC "CHIRP power ON/OFF" authority in case of emergency should SES require CHIRP to be powered down due to primary mission interference. The SOC also supplies spacecraft telemetry to the CMOC, but no CHIRP information is provided by the CMOC to the SOC. Most of the CHIRP ground system is in the CMOC and CMAC, both designed and developed within the $82.9M CHIRP contract. The CMOC and CMAC perform all CHIRP commanding and data reception, archiving, and processing. As CHIRP operations (commands and data) are SECRET, it is impractical to divulge the rate of command changes and amount or type of data collected.

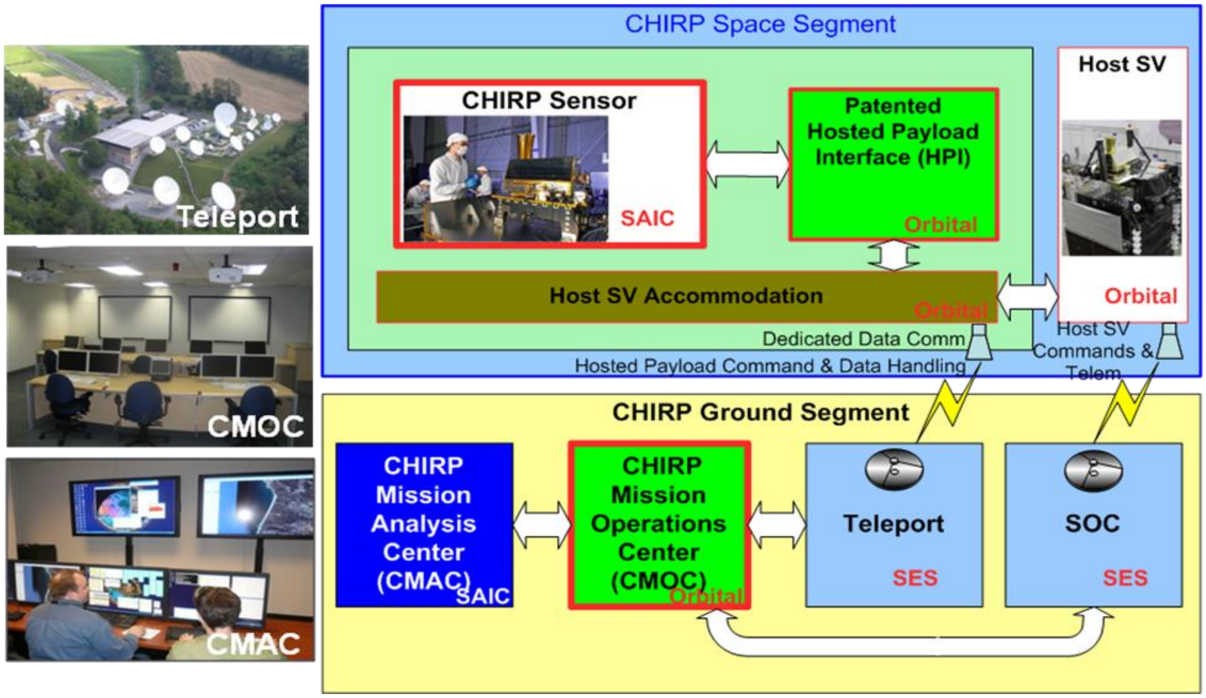

Figure 5. CHIRP Space and Ground architecture with key ground mission operations elements at left.

Future Commercially Hosted Payload Opportunities

A number of commercially hosted GEO missions are planned. Among these is the USAF CHIRP+ mission [Ledbetter], NASA's GEO Coastal Air Pollution Events (CAPE) mission [Al-Saadi], and GEOMetWatch, a privately funded venture [Crain].

Additionally, a 2011 National Research Council (NRC) study [National Research Council, Schueler 2012a] on the future of Ocean Color research noted the benefits of ocean color remote sensing demonstrated by the polar-orbiting Sea-viewing Wide Field-of-view Sensor (SeaWiFS) launched in 1997, and the MODerate-resolution Imaging Spectroradiometers (MODIS) on the 1999 and 2002 NASA Terra and Aqua polar-orbiting remote sensing satellites. Figure 6 illustrates SeaWiFS (and MODIS) ocean color remote sensing.

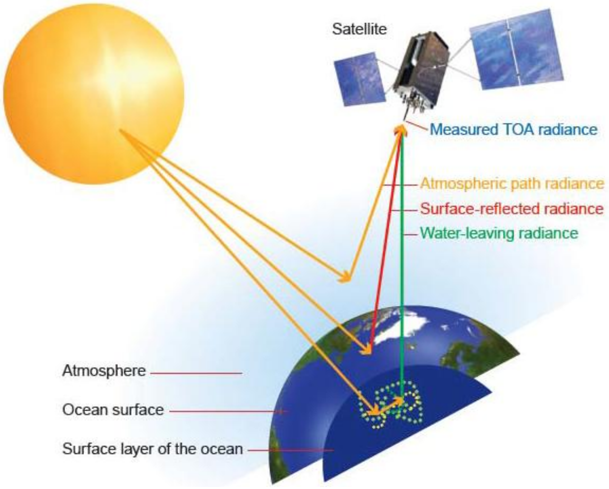

Figure 6. Ocean color remote sensing concept.

The NRC report notes that while SeaWiFS, MODIS, and other polar-orbiting ocean color systems developed since have demonstrated the value of ocean color data, they don't provide sufficiently frequent repeat temporal coverage of rapidly varying ocean color features such as those in coastal areas. Key operational applications requiring more frequent repeat coverage include:

- *Fishery management*
- *Coastal zone management*
- *Harmful algal bloom monitoring*
- *Naval support (e.g., bathymetry, coastal conditions)*
- *Oil spill monitoring*

The NRC report also notes the South Korean Communications and Ocean Monitoring Satellite (COMS) launched in June 2010 and illustrated in Figure 7. COMS carries a GEO Ocean Color Imager (GOCI) which provides ocean color data similar to MODIS and SeaWiFS [Amin], but from GEO offers nearly continuous data over the area delimited in the map shown in Figure 7. While COMS GOCI is not a commercially hosted payload because the system was funded and designed from the outset to carry GOCI, the GOCI payload is mounted on the nadir deck of an Astrium GEO communications spacecraft. Therefore, COMS demonstrates the technical practicality of a commercially hosted GEO ocean color instrument. Consequently, the NRC report recommends that NASA and NOAA consider funding a commercially hosted GEO ocean color capability similar to COMS GOCI but stationed over CONUS to provide the required temporal coverage of US coastlines.

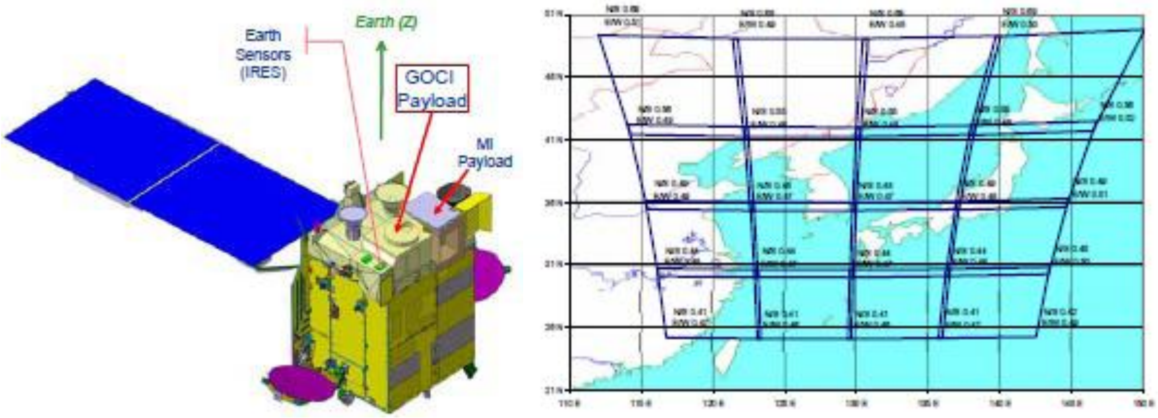

Figure 7. COMS and GOCI spatial coverage

SUMMARY

Significant differences between a "hosted payload" and a "commercially hosted payload" are explained pointing to dramatically lower cost compared to a dedicated remotes sensing mission. CHIRP demonstrated that a host spacecraft or launch system can be modified in a short time to survive launch and operate in GEO. The CHIRP sensor was a year beyond CDR before the spacecraft host and launch system were identified. Once those systems were identified, mechanical and thermal analyses were initiated leading to surprisingly minor modifications to the sensor and spacecraft to guarantee sensor survival and to ensure that the sensor would not interfere with the primary commercial telecommunications mission. The requirement not to interfere with the primary commercial mission came to be known as the "Do No Harm" requirement.

Beyond "Do No Harm," CHIRP demonstrated three other objectives reported in this paper. CHIRP met a tight cost and schedule envelope: $82.9M (plus a $28M sensor upgrade) and launch 39 months after contract inception. The spacecraft demonstrated attitude stability within a few microradians allowing a remote sensing mission to be successfully conducted with a telecommunications satellite not designed for remote sensing. The program demonstrated correlation between modeled and predicted thermal performance. CHIRP demonstrated a space and ground architecture with mature C&T via a CMOC and a CMAC separated by 2500 miles and linked via secure ground communications to share encrypted data in real time.

Finally, CHIRP spawned several follow-on commercially hosted GEO missions including CHIRP+ and Research to Operations science missions to take advantage of the dramatically lower cost of commercial hosting compared to a dedicated GEO remote sensing mission.

REFERENCES

AFRL Space Vehicles Directorate (VS) Broad Agency Announcement (BAA) VS-06-04 Pre-Solicitation Notice: Risk Reduction for Alternative Infrared Satellite System (RR-AIRSS) April 2006

Al-Saadi, Jassim A.; P. Bontempi, L. Iraci, A. Mannino, D. J. Jacob, J. Salisbury, D. Edwards, P. DiGiacomo, S. Kondragunta, B. Schaeffer, R. Scheffe, J. Szykman, and T. Watkins, "The NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) Mission," *AMS Proceedings*, 2013

Amin, Ruhul; R. Gould, S. Ladner, I. Shulman, J. Jolliff, P. Sakalaukus, A. Lawson, P. Martinolich, and R. Arnone, "Inter-Sensor Comparison of Satellite Ocean Color Products from GOCI and MODIS" AMS Proceedings, 2013

Andraschko, Mark; Jeffrey Antol, Rosemary Baize, Stephen Horan, Doreen Neil, Pamela Rinsland, and Rita Zaiceva, 2012: "The Potential for Hosted Payloads at NASA," *Proceedings 2012 IEEE Aerospace Conference*, pp. 1-12

Baddeley, Adam, "High Promise for Hosted Payloads," *Military Information Technology*, Vol. 14, Issue 2, March 2010

Baker, Charles, "Hosted Payloads," *Satcon 2010*, 13 October 2010

Brinton, Turner, "Industry Banking on Market for Hosted Payloads," *Space News*, 6 October 2008

Buxbaum, Peter, "Saving on SatCom," *Military Information Technology*, Vol. 16, Issue 2, March 2012

Crain, David J., "GeoMetWatch: A global, commercial Hyperspectral Imaging/Sounding System," *AMS Proceedings*, 2013

Foust, Jeff, "Emerging Opportunities for Low-Cost Small Satellites in Civil and Commercial Space," *24th Annual AIAA/USU Conference on Small Satellites*, August 2010

Kalmanson Phillip C.; Carl Schueler, Michael Do, and Quang Lam, "A Standardized Interface and Accommodation Methodology for Commercially Hosted Payloads on the StarBus," *Proceedings SPIE*, Vol. 7087 (2008)

Ledbetter, Titus III, "After Hosted Payload Success, U.S. Air Force Plans Follow-on," *Space News*, 13 April 2012

Levi, Alejandro; LtCol Lawrence Halbech, Maj Craig Phillips, Maj Randy Flores, Capt Dennis Murphy, Joe Simonds, and 1Lt Jason Belvill, "CHIRP Technology Demonstration Project," *AIAA Space 2010 Proceedings*, AIAA 2010-8724

Levi, Alejandro and Arian Agheli, "CHIRP Technology Demonstration Project," AIAA Space 2011 Conference and Exposition, 27-29 September 2011

Little, Alan; Doreen Neil, Glen Sachse, Jack Fishman, and Arlin Krueger, "Remote Sensing from Geostationary Orbit: GEO TROPSAT, A New Concept for Atmospheric Remote Sensing," *Proceedings SPIE,* Vol. 3221, 480-488 (1997)

Morring, Frank and Michael Taverna, "Time is Ripe: Stars align for hosted payloads as budget crunch drives market," *Aviation Week & Space Technology*, 14 March 2011

National Research Council, *Assessing Requirements for Sustained Ocean Color Research & Operations*, National Academies Press, Dec 2011

Neil, Doreen, "Catching the Bus: NASA payloads & commercial GEOs," *NASA Common Interface Workshop*, June 2011

Newberry, Colonel Bob, "System Engineering Challenges for Satellite Hosted Payloads: Commercially Hosted Infrared Payload (CHIRP)," *NDIA 14th Annual Systems Engineering Conference*, October 2011

Schueler, Carl 2012a; J. Yoder, D. Antoine, C. Del Castillo, R.Evans, C. Mengelt, C. Mobley, J.Sarmiento, S. Sathyendranath, D.Siegel, C. Wilson, "Assessing Requirements for Sustained Ocean Color Research and Operations," *AMS Proceedings*, January

Schueler, Carl 2012b: "FD-CHIRP: Hosted Payload System Engineering Lessons," *Proceedings SPIE*, 8516, August

Schueler, Carl 2012c: "FD-CHIRP: First Commercially-Hosted OPIR Sensor," *Proceedings AIAA*, 5267, Sept.

Simonds, Joseph; Jie Zhu Jacquot, Charles Kersten, Patricia Lew, and George Sullivan, "Lessons Learned from Hosting an Infrared Payload on a Communications Satellite," *Proceedings 2010 IEEE Aerospace Conference*