The Rise and Fall of the Capital Asset – An Investigation into the Aerospace Industry Dynamics and Emerging Small Satellite Missions

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ABSTRACT: Many studies have been conducted over the years on the relationship between spacecraft design, mission utility, cost/complexity, and the Aerospace community's ability to "commoditize" spacecraft designs and/or missions. During the Fifties and Sixties, spacecraft were limited by launch vehicle throw-weight and technical performance limitations, particularly computer processing speeds. During the Seventies and into the Eighties the personal computer revolution enabled more and more processing capability to be utilized in spacecraft bus and mission designs. This resulted in industry developed, large, "Capital" assets that took years to design, develop, integrate, test, and eventually operate. These systems, due to the very nature of their multi-mission capabilities, became critical to our nation. These systems had to function, and function reliably, therefore requiring extensive support infrastructures to assure mission success. As the Cold War ended, commercial space began to prosper. In recent years, the advanced technologies that enabled increased Capital Asset performance have also enabled small satellites to reach performance levels that could be used for operational missions. This, coupled with new mission types that are now feasible, have lead to a renewed and significant interest in small satellites. This paper investigates the changing dynamics of the market and technologies that have placed small satellites and Capital Assets at a crossroads.

INTRODUCTION

This paper reviews the progress and changes of the aerospace industry, particularly during the past twenty years that the Small Satellite Conference has been held. The paper addresses current technologies and industry dynamics that are shaping the future of aerospace acquisitions and the industry make-up. A review of previous studies and programs, what has and has not worked, what is currently working, and what is envisioned for the future are individually addressed. Changes in focus, emerging trends, new technologies and acquisition policies that are currently shaping the industry, particularly Responsive Space, Plug-and-Play avionics, standardization, and miniaturization will be evaluated to address how this is affecting the industry and how it is likely to affect the future of the industry over the next 20 years.

The original motivation for this paper was to explore the premise that "Capital Asset" spacecraft, defined for this discussion as multi-purpose, large (greater than 1000kg.), long-duration (greater than 5 years Mean-Mission Duration, or MMD), highly redundant (Class A) spacecraft, were somehow falling out of favor with government (both military and civil) and commercial customers and user sets. The premise continues that these Capital Asset spacecraft could be replaced with smaller, shorter MMD spacecraft focusing more on single mission functions with the attendant cost reductions in design and development, assembly, Integration & Test (I&T), mission operations, and launch services.

As the AIAA/Small Satellite Conference celebrates its 20th anniversary, the answer to the question "Are small satellites going to replace capital assets?" can have profound effects on the aerospace industry practices and dynamics that will help shape the next 20 years. The authors of this paper have participated in this debate over the last twenty years and have captured their insights and thoughts of potential future states herein.

BRIEF REVIEW OF SATELLITE HISTORY

Small satellites are not new, but rather the "original" satellites. The first satellite, Sputnik 1 launched 4 October 1957, was an 84 kg satellite; what we would classify today as a micro-satellite. The first US satellite, Explorer 1 launched 1 February 1958, was a 14 kg satellite. In these early days, satellites were technology development and experimental units. Launch capabilities were new, and severely limited. During the following years of the space race, technology and capabilities advanced rapidly.

The need for the unique, operational capabilities that spacecraft could provide drove two areas that fueled much of the satellite development over the next few decades. These capabilities included the ability to communicate over long distances, and the ability to view the earth from above the atmosphere. Communications satellites and remote sensing satellites played very important roles, not only for the aerospace industry development, but also in world development and world politics.

Communications Satellites

The first communications payload satellite, the 70 kg SCORE, was built in 1958. The first transatlantic satellite transmission of a television signal occurred 11 July 1962. The TELSTAR satellite that completed this milestone was a small satellite, with a mass of 77 kg. Over the following decades the use of satellites for communications increased dramatically and branched out into both commercial and military uses.

Communications satellites grew in both capacity and size until reaching the limit of existing launch capability. The DOD's Milstar satellite, for example, at approximately 4500 kg, was launched on the Titan IV, the largest US rocket available during the 1990s. Commercial satellite size growth has slowed in recent years as new technologies have allowed increased capabilities within existing mass budgets and industry focus on reliability and longevity has favored increasing the performance of existing satellite busses. Typical GEO commercial communications satellites range from 2000 to 4000 kg, with some as low as 1500 kg and some over 5000 kg. Although small satellites are still used by such organizations as AMSAT for amateur radio communications via satellite (with satellites typically around 50 kg, but some as small as a 1 kg pico-satellite), the commercial market has driven the communications satellites to these sizes based on cost and revenue margin. Larger spacecraft minimize cost for a given capability by reducing the per launch cost and efficiently using both on-orbit and ground resources.

The uses of radiofrequency transmissions expanded over time, broadening the market. Navigation, and GPS in particular, has been an ever-growing portion of the market.

Remote Sensing

The ability to view the Earth from above enabled a number of science, weather, and reconnaissance missions. Tiros I, launched in 1960 was the first weather satellite, sending cloud cover imagery to Earth. With the continuation of the Cold War, and the downing of the U2 reconnaissance plane piloted by Gary Powers, increased emphasis was placed on using the "high ground" of space for reconnaissance. NASA, formed early in the space race, increased the use of space for science; e.g., visiting the Moon and other bodies in the solar system, viewing the sun and stars, investigating Earth and it's atmosphere, and learning more about space itself.

As was the case for communications satellites, remote sensing system wet masses tended to match launch vehicle performance in order to maximize spacecraft performance versus total system costs. Larger, heavier payloads allowed increasingly more capable Earth monitoring (both civil and military). Higher resolution, wider coverage and faster downlink rates have lead to near real-time Intelligence, Surveillance, Reconnaissance (ISR), and Earth weather monitoring for forecasting and disaster monitoring all contributing to the emergence of the Capital Asset. Simple physics and the desire for larger apertures also drove the growth to larger spacecraft. The Hubble Space Telescope is probably the ultimate example of a NASA capital asset.

Advent of the Capital Asset

With more capable launch vehicles, the high cost of spacecraft, and an increasing reliance on space, the aerospace industry developed every more capable, reliable, and massive satellites. The high performance and reliability required of these satellites gave birth to the Capital Asset. Customers continued to request better on-orbit capabilities (higher resolution, more bandwidth, etc.) that drove the launch vehicle designs to provide more throw-weight which in turn allowed bigger and more capable spacecraft designs, either through redundancy or increased mission performance. Table 1 shows examples of how several spacecraft lines went from a relatively small demonstration wet mass (bus and propellant Mass) to the larger "Capital Asset" across a number of mission areas.

Table 1: Capital Asset Wet Mass Trend[4,5]

Mission Area	Launch Dates	Wet Mass (kg)
Wide-Band Comm.		
DSCS I (IDSCS)	1966-1968	45
DSCS II	1971-1989	520-611
DSCS III	1982-2003	2615
Wideband Gapfiller	~2006-	~4500
Protected Comm.		
Milstar, Block I	1994-1995	est. ~4500
Milstar, Block II	1999-2003	~4500
Advanced EHF	~2006-	~4100
Navigation		
GPS Block 1	1978-1985	770
GPS Block 2	1989-1990	1665
GPS Block 2A	1990-1997	1816
GPS Block 2R	1997-2004	2032
GPS Block 2RM	2005-2007	2032
Weather		
DMSP1	1962	91
DMSP2	1964	130
DMSP3	1965-1966	150
DMSP4	1966-1969	125
DMSP5A	1970-1971	195
DMSP5B/C	1971-1976	195
DMSP5D	1976-	450-830
NPP	est. 2008	2000
NPOESS	est. 2010	est. >2000

In conjunction with the increase in wet mass the systems grew more capable. For example, after the initial demonstration constellation, GPS Block 2 satellites incorporated improved design life, power, and stabilization. Block 2A purportedly provided a slightly improved version of the Block 2, Block 2R greatly enhanced navigation accuracy, survivability, autonomy, upgradability, affordability, and self-location, and Block 2RM further added M-code signal to reduce jamming while providing more navigation signals. It is interesting to note that the Block 2F (Not shown on the Table) has a wet mass of 1545 Kg but does not include the 1147 Kg Kick Motor required in previous configuration since it will utilize the EELV insertion capabilities. The same advancements in technology that enabled ever higher performance Capital Assets also enabled smaller spacecraft to execute missions within current mass allocation.

During the Eighties and Nineties U.S. launch vehicle inventories consisted primarily of the Delta, Atlas, and Titan families. These systems had evolved from Intercontinental Ballistic Missiles (ICBMs) developed with Fifties, Sixties, and Seventies technologies and were expensive to maintain, utilized exotic materials and propellants, and required significant infrastructure and personnel to maintain launch readiness. Failures in the mid-Eighties of a number of these systems drove the need to develop new launchers for future space missions. The Evolved Expendable Launch Vehicle or EELV program was initiated to replace, or upgrade, Deltas and the combined Atlas and Titan families. At the same time, a number of smaller launch vehicles focusing on smaller spacecraft were in design. Orbital Sciences Pegasus Air-Launch vehicle, Taurus, and Minotaur and the Lockheed Martin Athena launch vehicle enabled smaller spacecraft in the US the opportunity for rides to orbit.

A noticeable recent decline in the number of small satellite launches has been caused by the constraint low-cost access to space has placed upon the market. Secondary launch payload adapters are near-term solutions that could provide small satellites with quick launch opportunities. The University of Surrey has achieved much of its success by taking advantage of secondary launch opportunities. A similar capability in the United States could have a similar effect for the small satellite industry. The EELV Secondary Payload Adaptor (ESPA) with its first launch later this year offers this opportunity if the process can be improved and if it becomes utilized on many of the potential EELV missions with excess mass margin. This could create significant future flight opportunities for small satellites. A dedicated launch vehicle would be the optimum solution, but there is not an affordable, reliable small satellite launch vehicle yet available. As in the start of the space age, the symbiotic relationship between the availability of access to space in a given mission class and the role that small versus large satellites play in the market is extremely coupled.

A qualitative graph of the development of mission areas and the transition of missions from technology development to small satellite dominated missions to Capital Assets is shown in Figure 1. It is interesting to note the relative transition point for those mission areas that have developed into Capital Assets relative to known development timelines for US launch vehicles. The reconnaissance mission area is only shown for time periods for which data is publicly available.

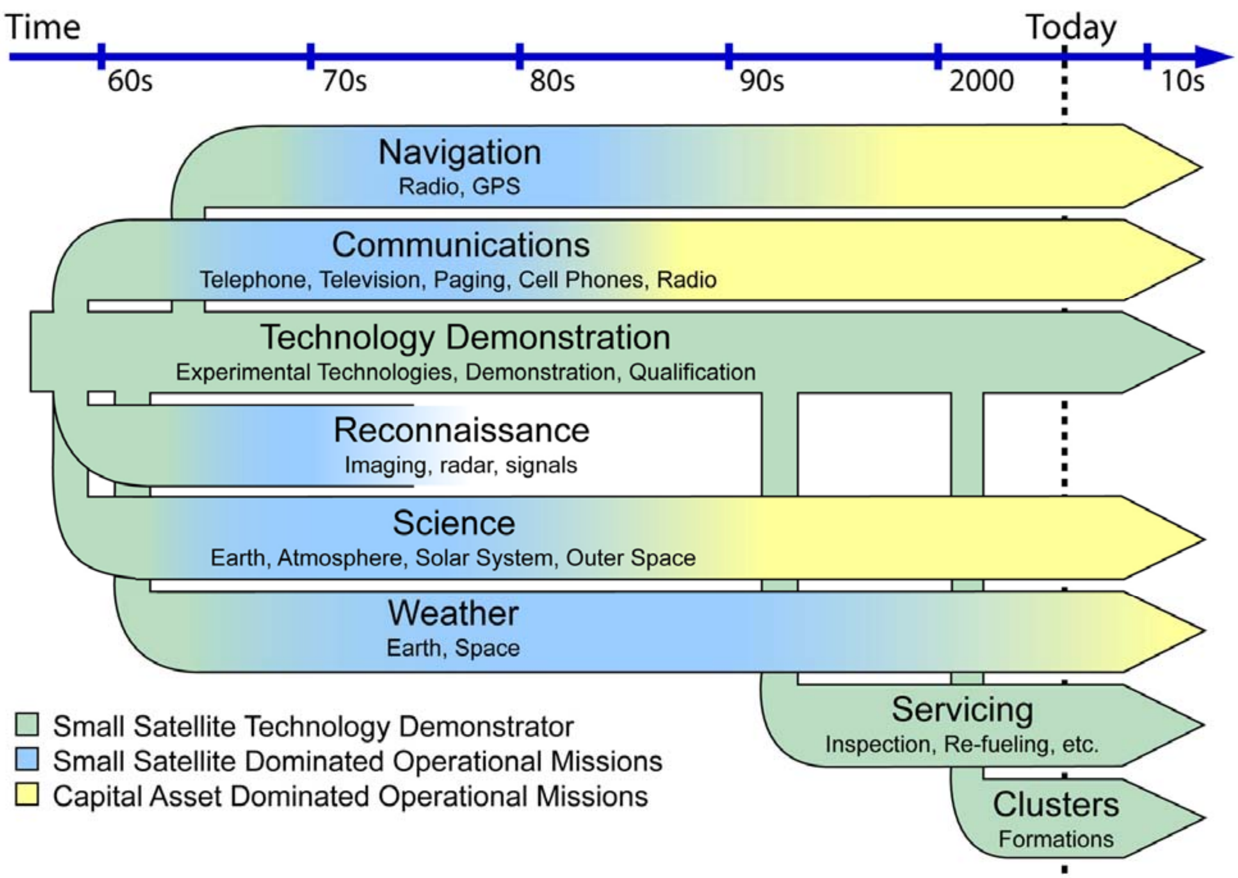

Figure 1: Qualitative timeline for development of mission areas and Capital Assets

Invigoration of Small Satellite Market

As Capital Assets continued to garner the lions share of the satellite development market a small segment of the aerospace industry began to focus on smaller, cost constrained proof-of-concept, advanced technology demonstrations. Increasing capability of electronics, miniaturization, and other advances in technology enabled similar performance in smaller designs. Over time experimental small satellites became capable enough that interest increased in potentially using small satellites for operational missions.

Capital Assets were not always desired or affordable due to prohibitive cost restrictions to execute quick, technology demonstrations and/or new mission Concepts of Operations (CONOPS). These limitations, coupled with the customer community's desire for a more "commodities-based" approach to acquisition lead to new designs that could address these niche markets. Also driving these new smaller spacecraft designs were the Capital Assets themselves. With increasing reliance and importance of the Capital Assets there arose the need to protect those assets or quickly replace those assets if the need presented itself. No longer could customers accept ten to fifteen year development cycles to field new or next generation mission systems. This change in focus to balance Capital Asset production with smaller, shorter time-to-market assets gave way to Responsive Space initiatives, technology demonstration programs (TACSAT and XSS-series spacecraft) and a new push for modular, commodities-based mission designs (STP/SIV and JWS programs). These new areas of development were slow to gain traction and remain largely the purview of University research, small businesses (via Small Business Innovative Research or SBIR funding) and limited technology demonstration missions specifically addressing current or emerging operational needs (STEX program as an example).

CAPITAL ASSETS & SMALL SATELLITES AT A CROSSROADS

Many studies over the last several years have discussed the design strategy known as "small sat" design. In 1997 Cyrus Jilla and Dr. David W. Miller postulated that the "most important driving force behind the design of NASA and commercial communications satellites is not the desired science or most advanced technology, but simply the budget with which the sponsoring organization has to work with"[1]. This 1997 paper further postulates that "based on this conclusion, government funded scientific spacecraft should continue to decrease in size and embrace the “small sat” revolution, while commercial communications satellites will remain relatively larger as long as the markets they serve continue to grow.”

Almost ten years after these statements, the industry shows no sign of abandoning the Capital Asset in favor of smaller satellites. There are strong indications that Capital Assets will continue to capture the majority of program dollars available; however, the small satellite market is expected to see significant increases in funding relative to current spend profiles, but will lag the major programs in total funding allocations. Major areas for advancement for small satellite development include: supporting adjunct missions in cooperation with Capital Assets; developing new mission areas that require smaller satellites (Tactical Support, Inspection/Servicing missions, High maneuverability missions); and, reconstitution missions.

Spacecraft that can interface to existing Capital Asset infrastructure while providing adjunct capabilities (i.e., shorter gaps in coverage) or through new technologies or mission enabler capabilities (i.e., new sources and methods) will be in high demand. It is expected that this will help further fuel small satellite development.

Recent interest in Space Situational Awareness (SSA) and Space Control mission areas tend to favor small, maneuverable spacecraft. Due to Keplerian motion, inclination and/or altitude changes are most efficiently executed with smaller, high delta-velocity capable spacecraft designs. The highly successful XSS series of spacecraft have demonstrated these emerging capabilities.

Finally, the introduction of gapfillers and reconstitution capabilities can be addressed via small satellites. With more and more entities gaining access to space the ability to move through and operate in space becomes a challenge. This results in a need for fast replenishment of assets to resume certain missions in a reduced performance mode until Capital Asset replenishment can be completed.

In summary, there will always be need for both Capital Asset and small satellite capabilities. Although it is anticipated that small satellite missions will continue to garner ever increasing portions of the market, the mix will ultimately be determined by mission needs, cost, and political necessities.

IS THE CAPITAL ASSET LOOSING FAVOR?

Our research indicated that Capital Assets are not declining in wet mass but rather increasing in wet mass to maximize the utilization of existing launch vehicle capacity as a function of per launch, launch costs. Until launch vehicles dramatically reduce their cost per kilogram to orbit ratio this trend will likely continue.

The reasons that Capital Assets came to be are still valid. The high cost of launch, the high reliability of the asset, and the savings in mass, cost, and schedule of grouping resources together are all still important factors. Increased reliance on space assets as well as the desire for tremendous increases in data generation and data transfer that has resulted in this Information Age are resulting in increased interest in very capable, cost effective spacecraft. The Capital Asset is still the best fit for this need. As the need for performance escalates, spacecraft size is, if anything, continuing to increase.

Increased interest in small satellite missions may be more an indication of a new maturity of space exploitation than a declining interest in capital assets. The same technologies that are improving the capabilities of Capital Assets are enabling small satellites to be more capable. This increasing capability allows previously unfeasible missions to now be considered. Small satellites are, therefore, a complimentary rather than a supplanting technology.

COMPLEMENTARY MISSIONS

While small satellites do not appear to be replacing their larger siblings, they are providing complementary mission utility in a number of ways. Two categories are readily apparent: service missions and complementary data collection missions. Even the traditional roles of small satellites as experiments or technology demonstrators are complementary, as they aid the implementation of new technologies into Capital Asset programs.

Service Missions

Small satellites can provide significant services that aid Capital Assets. The Orbital Express program will investigate the possibility of two satellites docking and transferring fuel. XSS-11 is demonstrating the ability to inspect other objects in space. As technology matures, it is possible for a disabled satellite to be inspected, and perhaps repaired, by a small, inexpensive, easily launched micro-satellite. Servicing missions could also enable spacecraft to be updated with new electronics, solar panels, or batteries. The Hubble Servicing Mission studies investigated doing this type of mission.

Complementary Data Collection Missions

Another complementary role for small satellites receiving a lot of attention in recent years falls within the Responsive Space mission area. This is the ability to quickly launch a satellite to either replace a disabled capital asset with some limited capability as a gap filler, or to cover a temporary remote sensing need.

A second complementary role in this regard is one of aiding a Capital Asset, either as a Capital Asset servicing unit as mentioned previously, or as some form of protection for the asset. The ability for local space awareness could be a valuable protection of the nation's assets. These types of missions, in addition to the traditional role applied to small satellites can provide a valuable extension to our space capabilities.

Risk Created by Small Satellites in the Wrong Hands

For a number of years there has been the worry of the effects a "space Pearl Harbor"[2] could cause to a nation so dependant on space. With the proliferation of less expensive small satellite launchers across the globe, the "cost of entry" for rogue nations to access space is decreasing. The threat rogue states could pose due to their use of small satellites for malicious intent has been discussed in a number of studies, including the "Report of the Commission to Assess United States National Security Space Management and Organization"[2] published in 2001. Recently Lt. General Frank Klotz, vice commander of Air Force Space Command, addressed this issue, stating that he believes in future conflicts it is "absolutely certain that an adversary would attempt to somehow negate the advantage which the use of space systems provides to our military forces."[3]

In addition to the threat small satellites could be in the wrong hands, in the right hands they could provide an element of protection against this threat. Just recently General Robert Kehler, the deputy commander of US Strategic Command told a congressional panel that "Space capabilities have revolutionized the way we fight today by providing our forces with battlefield situational awareness, environmental understanding, precise weapons effects, and the ability to control and synchronize military operations on a global scale."[6] Kehler also said, "Our enemies clearly understand the reliance we place in our space capabilities. We cannot assume that space will be a sanctuary for US national security assets and must take prudent steps to ensure that we have the capability to protect our space assets." These are important statements for the aerospace industry and for emerging missions. The ability to directly aid the battlefield is a developing area where small satellites can play very effective roles. In addition, small satellites are currently positioned to be the most effective tools available for the role of protecting the larger Capital Assets.

Emerging Technology Demonstration

Small satellites are likely to play their traditional complementary role as technology demonstrators for a number of new technologies. Among these are efforts to standardize satellite buses, particularly payload and launch interfaces (e.g. STP/SIV program), and to create plug-and-play capabilities and modular satellites (e.g. JWS program). These technologies have the potential to further change the landscape of the aerospace industry.

CONCLUSIONS

The fall of the Capital Asset has not occurred, and does not appear to be on the near horizon. As small satellite capabilities grow, and as technologies are miniaturized, the current state may change. Current indications are that small satellites will play an important role, but in missions that complement rather than supplant the Capital Asset. Since the beginning of the space age and in a trend that continues today, the use of small versus large satellites continue to be highly coupled to the capability and affordability of launch vehicles. New mission frontiers have opened up as technology has improved, while existing Capital Asset missions still remain critical to our nation. Indeed, the importance of the small satellite may be greatest as a protection of critical national assets. The authors await the future of small satellites with anticipation.

ACKNOWLEDGEMENTS

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