The Small Payload ORbit Transfer (SPORT™) Vehicle and The Business Environment for the Next Generation of Piggyback Launch Options

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Abstract. AeroAstro and Astronautic Technology Sdn. Bhd. (ATSB) are developing the Small Payload ORbit Transfer (SPORT) Vehicle. Primarily designed to take advantage of the many auxiliary launch opportunities to Geosynchronous Transfer Orbit (GTO), SPORT acts as a small upper stage by moving a small payload from GTO to Low Earth Orbit (LEO), which is typically a much more desirable orbit. An innovative combination of aerobraking and chemical propulsion allows SPORT to accomplish this mission while keeping costs low. This paper provides an overview of the growing market for auxiliary launches, which also includes a discussion of launch brokering, SPORT, competing decommissioned ICBMs, as well as the needs of different user segments. The SPORT team's bilateral business arrangements with a

primary launch vehicle operator bring an additional point of view to the paper. SPORT's pioneer mission is planned for 2003, for this first mission, a Malaysian satellite mounted on top of SPORT will be launched into GTO on an Ariane 5 Structure for Auxiliary Payloads (ASAP) micro launch slot. SPORT will then place its payload, a low earth orbit satellite, into a 9° inclination, 700 km altitude orbit.

Introduction

Once a curiosity, over the past decade small spacecraft (under 500 kg) have become a key strategic element of nearly every space program, from long-time spacefaring nations to newly emerging space economies to new commercial space ventures. Obstacles that previously made it difficult to build small satellites capable enough to fulfill meaningful missions have been solved through the use of advanced technologies. Such technologies include highly efficient Lithium-Ion batteries, triple junction Gallium Arsenide solar cells, and advances in electronics such as AeroAstro's line of Bitsy™ integrated miniature satellite electronics for power, communications and computing systems. Additional benefits in miniaturization and reduced power consumption are being realized in modern sensors and actuators for attitude determination and control. For example, modern star trackers are not only smaller and less power-hungry, but also feature integrated computers and three-axis knowledge. Modern sun sensors, such as AeroAstro's MSS-1-B, as well as modern torque wheels also do away with the large auxiliary electronics boxes that older ones required. Of particular interest is the increasing viability of large inflatable space components, which allow very large deployables to be very tightly packaged.

However, despite all the technology developments on the spacecraft side, launch to orbit remains a high-cost obstacle. Launching small satellites can be difficult and expensive, especially if achieving a custom final orbit is key to the success of the mission. Often, the price advantages of building a small spacecraft for a very low cost are lost due to expensive launch systems and a lack of options for access to orbit.

There are a number of possible solutions to this problem, ranging from dedicated launch vehicles to decommissioned ICBMs (generally Russian) to auxiliary, or "piggyback", launches. However, the most cost-effective and least risky of these options, auxiliary launches on reliable larger launch vehicles, often is the least useful since large launches tend to go to orbits that are not desirable by small spacecraft.

The SPORT (Small Payload Orbit Transfer) vehicle has been developed through a global partnership between Astronautic Technology (M) Sdn. Bhd (ATSB) of Kuala Lumpur, Malaysia, and AeroAstro, Inc. of Herndon, Virginia. SPORT is coupled with small spacecraft on auxiliary or 'piggyback' launches on large launch vehicles. SPORT carries small spacecraft the "last mile" from the drop-off point on the large launch vehicle to their final custom orbits. This turns the many unused auxiliary launches into a useful and low-cost alternatives to reach orbit. In the telecommunications industry, the "last mile" refers to the high cost final link between trunk lines and people's homes- often the most expensive and most difficult part of a telecommunications infrastructure. SPORT serves a very similar purpose for auxiliary launches.

This paper presents an overview the needs of the small spacecraft market from a demand (needs of users) and a supply (available launch options) point of view. It discusses how SPORT changes that market landscape through innovative applications of small satellite technology. Besides technical aspects of the market, both business and political factors are considered. Through this discussion, the paper hopes to begin a dialogue with small spacecraft users to increase the understanding of the marketplace's emerging needs and how technologies such as SPORT can fill those needs.

Market Demand

Small Satellite Builders

The number of organizations using small spacecraft, both globally and in the United States, is continually increasing. These organizations include civil and military government bodies, commercial communications and remote sensing businesses, and even entertainment companies. These organizations all understand that modern small satellites, enabled by the latest advanced technology, are a key asset to meet their needs.

Providers of small spacecraft include ATSB, AeroAstro, Ball Aerospace, Orbital Corporation, and Surrey Satellite Technology Limited. Additionally, a number of users semi-compete with these commercial providers by building their own spacecraft, including national space agencies, NASA, military organizations, and commercial users who set up their own one-time 'in-house' satellite shops. The cost for small spacecraft can range from less than $1M to over $100M, but generally ranges from $4M to $12M for a typical small spacecraft bus of medium capability.

Historical Demand for Small Satellite Launches

A good method of gauging demand is to analyze historical trends, which are often considered more reliable than predictions based on press announcements in the market place. In a study for the United States Department of Defense, AeroAstro researched the history of small satellite launches, some results of which are presented below. Data was culled from sources including the TRW Space Log and Teal Group reports, as well as from AeroAstro internal databases.

As shown in Figure 1, there is robust demand historically for small spacecraft. A plurality of these are in the 0-60 kg range, with over 350 launched. Russian spacecraft were removed since their overwhelmingly large numbers of military microsatellites tend to skew the results, and since they are virtually guaranteed to launch on decommissioned Russian ICBMs they are not active players in the marketplace. Even discounting Russian launches, nearly 200 spacecraft have launched in the 61-150 kg range, and nearly 300 have launched with masses ranging from 151-600 kg.

Although there is strong demand for small satellite launches, they have historically accounted for less than 10% of the overall launch marketplace, and therefore the overall launch market is strongly dominated by the needs of much larger satellites and payloads with masses usually well over 1000 kg. The demands of large satellites are often much different from the demands of small ones, and that leads to the GTO paradox- a high global supply, with accompanying low-cost auxiliary capacity, for launches to orbits not desirable for small spacecraft. Furthermore, as shown in Figure 2, the trends in this sector are all upwards, with significant growth trends in the 0-60 kg mass class just as an example.

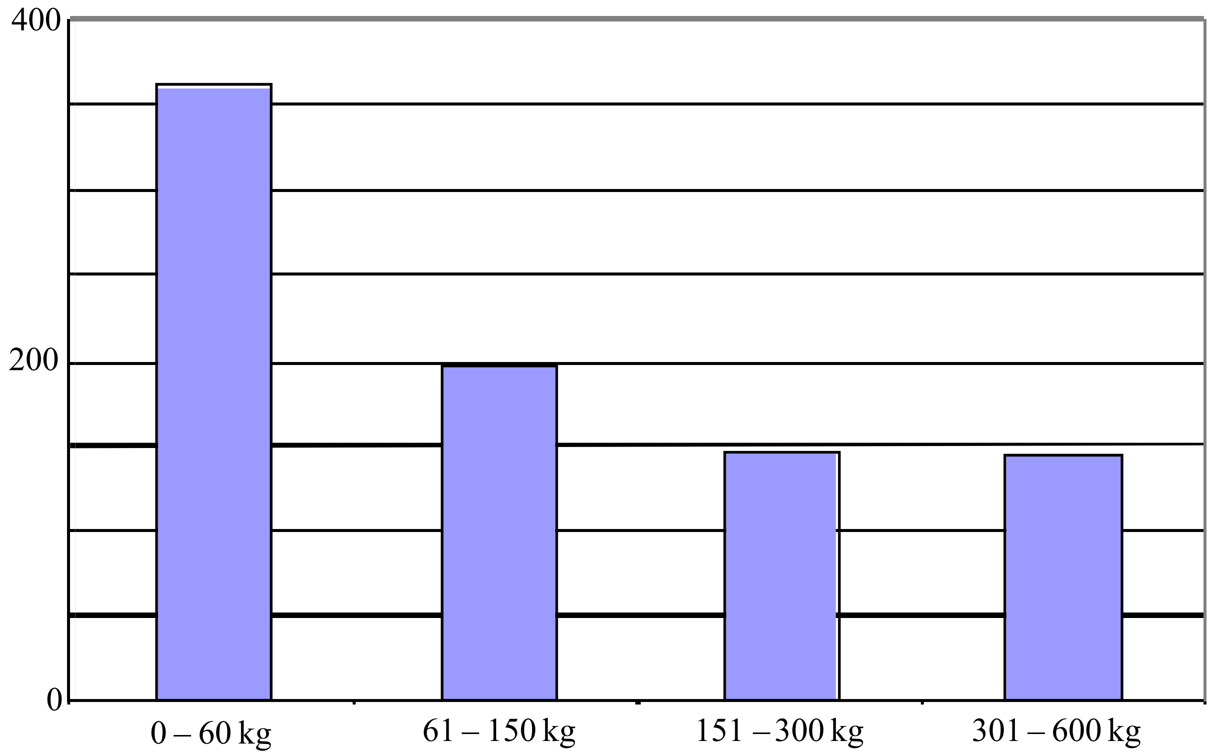

Figure 1: Small Satellites Launched Worldwide (Not Including Russian) Through 1998.

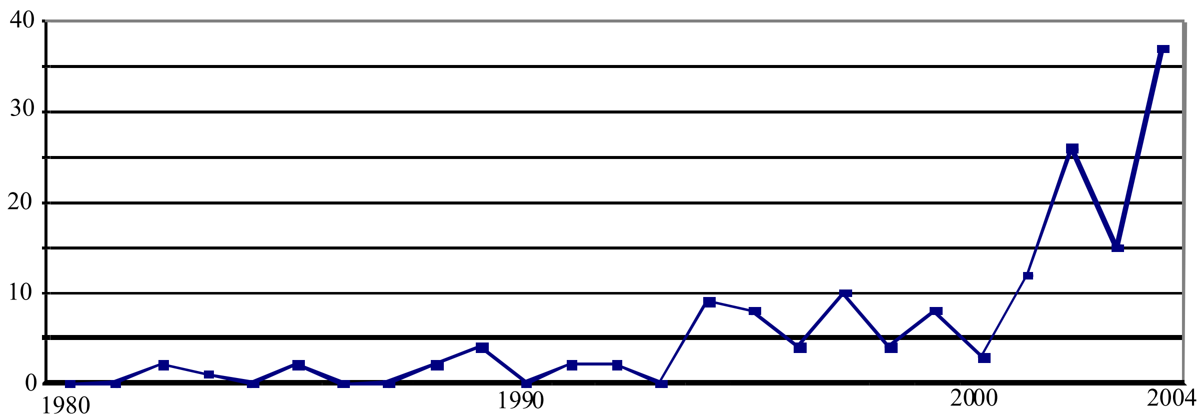

Figure 2: Teal Group Projections Show Growth in the 0-60 kg Mass Class.

Large spacecraft tend to exhibit a strong demand for Geosynchronous Transfer Orbit (GTO), since many large remote sensing and communications satellites are destined for Geostationary Earth Orbit (GEO). As shown in Figure 3 in the left-hand graph, when large launches are considered along with small ones, there is strong historical demand for launches to GTO being fulfilled by large launch vehicles such as the Ariane 4 and 5 and the Atlas and Delta II. Satellites bound for GEO tend to be very large due to large and complex payloads requiring large and complex support buses. Furthermore, the cost to launch to distant GEO, including the satellite's own propulsion system, is so high that it makes sense to design with significant redundancy and margin, to reduce mission risk

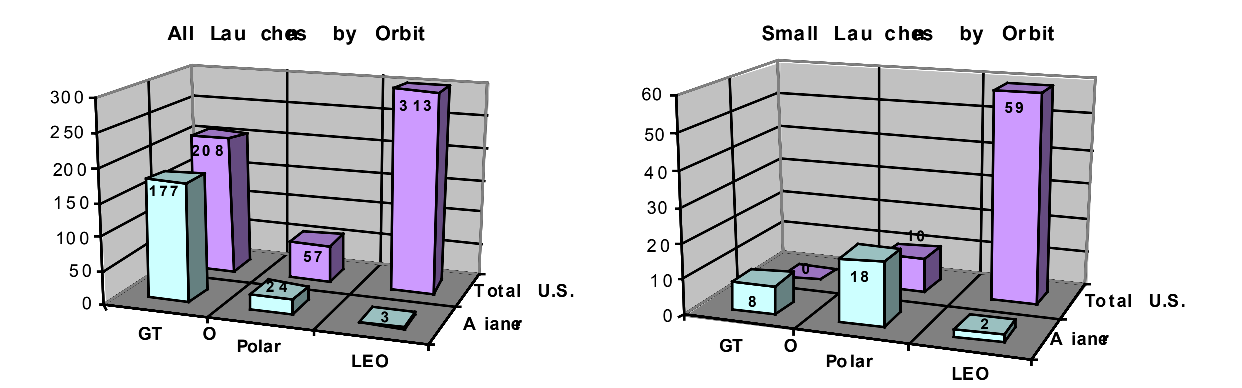

Figure 3: Large vs. Small Satellite Launch Destinations Through 1999 Show GTO Paradox.

to an absolute minimum. These large spacecraft require large launch vehicles, which in turn tend to have significant mass margin remaining on each launch.

However, as seen in the right-hand graph in Figure 3, most small satellites are not destined for GTO or GEO. They are mostly used for remote sensing, space and atmospheric science, technology demonstration, and low data rate communications. The aperture-limited nature of small spacecraft limits the emitted RF power for communications links, limiting the distance from which meaningful data can be transmitted to the Earth. Small optics apertures drives small spacecraft towards LEO orbits where they can be closer to the ground targets they are imaging. The inherent advantage of small spacecraft is the ability to build a large number of them for low cost, and this drives communications architectures towards constellations of LEO satellites. For all these reasons and more, small spacecraft almost universally prefer LEO orbits to higher MEO or GEO orbits. GTO orbits tend to be the worst of all possible worlds- their orbit parameters are not constant and present a significant operations and communications challenge. Due to their high orbital velocities at perigee, GTO spacecraft are nearly useless for remote sensing missions.

The GTO paradox is that a relatively (in the context of small spacecraft) large amount of mass margin is usually left over on large launch vehicles headed to GTO. This mass margin could be used at a very low cost by much smaller auxiliary payloads, but there is no need for launches, no matter how affordable, for small satellites to GTO. It offers a plentiful supply of launch capacity to a useless orbit for small spacecraft.

Market Supply

Small Launch Vehicles

There are numerous small launch vehicles that may be used to launch small payloads, including Athena, Pegasus, and Minotaur in the United States, J-1 in Japan, Shavit and LK1 in Israel, Shtil, Dnepr, and Start in Russia, as well as the VLS and VLM in Brazil. However, demand tends to be low for such small vehicles compared to larger ones. Due to inefficiencies in small launch vehicles, where costs for items such as range safety and avionics must be recouped over a smaller number of launched kilograms, the cost per kilogram for small vehicles tends to be higher than for large ones. Figure 4 illustrates this fact.

Adding to the small launch vehicle challenge, in the cases of larger vehicles such as the Athena and the Minotaur, a single small

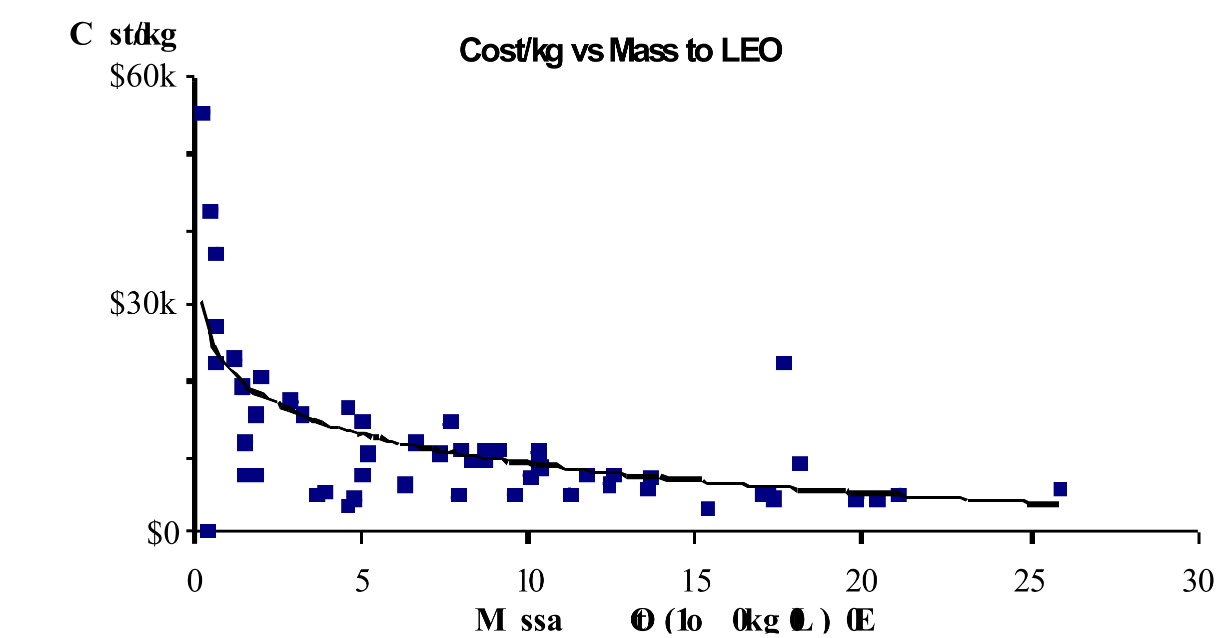

Figure 4: Cost Per Kilogram as a Function of Total Vehicle Mass.

payload is many times not enough to fully pay for the vehicle's capacity. The perceived solution to this problem is usually to co-manifest two to four small satellites on the same launch vehicle. While this may seem like a convenient solution, it actually greatly complicates the situation. Multiple small satellites must be found that all want to go to the same approximate orbit at the same time. Moreover, they must all be politically and contractually agreeable to using a particular launch vehicle.

Many of these dedicated vehicles are not available for the general marketplace. The Brazilian and Japanese vehicles are not seen as available for use, while the Israeli and Indian have not yet made a significant impact in the marketplace. The Minotaur is only available for U.S. Government payloads and has only been used for small spacecraft once.

Finally, the Russian vehicles tend to be highly risky from a business perspective. Notwithstanding the nature of the Russian market, costs can increase after the initial contract has been signed and it is difficult to be sure of the terms of any deal for a Russian launch. While the Shitl claims to be able to launch outside the Barents Sea, it launches from a Russian strategic national asset that is unlikely to leave polar waters for any lower inclination launch.

Overall, small launch vehicles, while dedicated to orbits desirable by small satellites, have their share of disadvantages. They tend to be expensive, unavailable, high risk, or require significant sharing of launch capacity- none of which makes them highly accessible from both a cost and a risk perspective to the small satellite user.

Large Launch Vehicles (GTO)

A number of large launch vehicles offer auxiliary launch capacity for small spacecraft, sharing lift capacity with larger payloads, but almost always to GTO. These can be divided into two categories: those with established, clear guidelines for launching auxiliary payloads, and those who only do so on a custom basis. Auxiliary launches tend to be very low cost, since they are using extra capacity that has already been paid for by primary payloads bound for GEO.

Most large launch vehicles launch secondary payloads on a custom basis. The process for manifesting auxiliary payloads on Delta and Atlas is opaque and there are no User's Guides for their auxiliary slots. Frequently, these American launch vehicles give their primary payload providers the right to accept or reject any small spacecraft interested in a possible launch as an auxiliary payload. In approximately three to four years a facility for future Delta IV and Atlas V launch vehicles (Evolved Expendable Launch Vehicles – EELV) called the EELV Secondary Payload Adapter (ESPA) will become available. While this facility will allow EELVs to accommodate auxiliary payloads in a simple and well-defined fashion, it is highly possible that ESPA will be used only sparingly and not on a commercial basis.

A number of large Russian launchers also offer auxiliary launch capacity, but also on a custom basis. They do tend to be more willing to launch secondary payloads, however.

Currently, the only large launch vehicles with a clear facility for launching auxiliary payloads is Arianespace with the Ariane Structure for Auxiliary Payloads (ASAP) on the Ariane 4 and now the Ariane 5. Arianespace has a long tradition of launching auxiliary payloads on the ASAP 4 with a total capacity of 60 kg and up. It is now launching auxiliary payloads on the ASAP 5 of a variety of mass classes, from 120 kg to 300 kg and up to 1000 kg or more. Launches are open to all customers and user's guides are available for them, as well as cooperative points of contact.

Large launch vehicles tend to be lower risk, since they are launched more often and have been studied in more depth than newer, smaller launch vehicles. Many accept small satellites as auxiliary payloads, with the Ariane 5 being the most auxiliary payload-friendly option. They are highly reliable and also tend to be very low cost, since the capacity has already been paid for by the primary payload.

The only drawback to large launch vehicles is the destination orbit. With no control over the launch vehicle and the dependence on large primary customers, these auxiliary opportunities tend to be exclusively for GTO, a largely unusable orbit for small spacecraft. For this reason, auxiliary launch opportunities many times got untapped and unused.

The SPORT Vehicle

SPORT Design

The SPORT vehicle was designed to solve this problem in the small satellite launch marketplace. Small dedicated launch vehicles, while useful for specific missions, tend to be very expensive per launch or very risky from a business perspective. Auxiliary payloads on large launch vehicles are low-risk and low cost, but almost always go to the wrong final orbit. SPORT was designed to fix this problem with large launch vehicles and to deliver an affordable, low-risk launch solution- auxiliary launches with a tailored, custom final orbit for the user.

SPORT transforms a low-cost auxiliary launch to GTO to a usable launch to LEO by transferring the small spacecraft payload to its final destination using a combination of chemical propulsion and aerobraking in the Earth's atmosphere. The technical innovations inherent in the SPORT system are described in detail in other technical papers, this paper will focus on the capabilities of the SPORT system as it relates to the user.

SPORT is a fully functional spacecraft bus, with power, command and data handling, communications, attitude control, and propulsive capabilities. Just like any other spacecraft, SPORT has the ability to orient itself in space, create, store, and distribute power using solar arrays and rechargeable batteries, plan and execute commands, and communicate with the ground. Furthermore, it has the capability to perform propulsive transfers with a hydrazine propulsion system.

The SPORT vehicle is a carrier vehicle, so the most integral portion of the SPORT vehicle is the payload being transported. A top-level illustration of the SPORT vehicle is shown in Figure 5 below. This is the smallest of the SPORT configurations (Micro and Mini).

In order to perform the GTO to LEO maneuver, SPORT requires over 1.5 km/s of delta-v (change in orbital velocity). To perform this maneuver with a chemical propulsion system is impossible due to the volume and mass constraints of auxiliary launch slots. A system with enough propellant would have no capacity left for the payload. This being the case, SPORT is designed to use aerobraking in the Earth's atmosphere for most of its propulsive transfer. SPORT carries a deployable aerobrake, which deploys upon reaching GTO and helps it execute the orbit-lowering maneuver. This large deployable aerobrake enables SPORT to pass through the atmosphere at an orbit high enough to avoid risk of overheating in the Earth's atmosphere.

The aerobraking concept has been patented by AeroAstro, and is key to the GTO to LEO orbit transfer. The aerobrake operates like a badminton shuttlecock, self-orienting as it passes through the Earth's atmosphere. The maneuver itself is designed to take 30-90 days

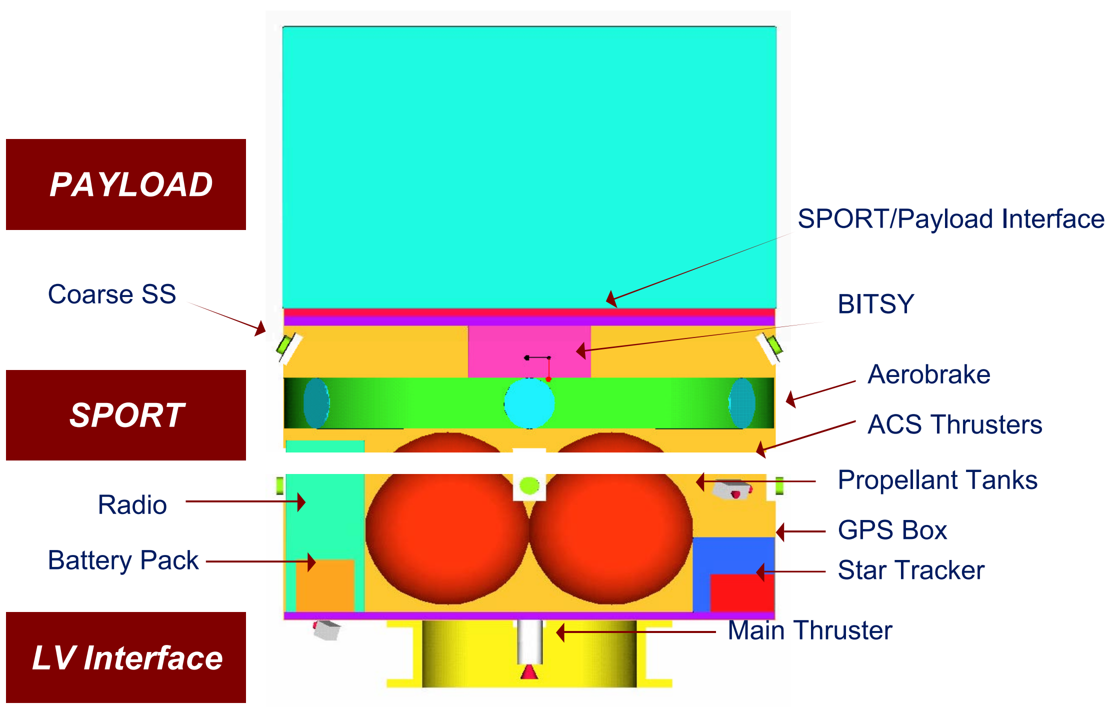

Figure 5: The Smallest MicroSPORT vehicle Showing Customer Payload.

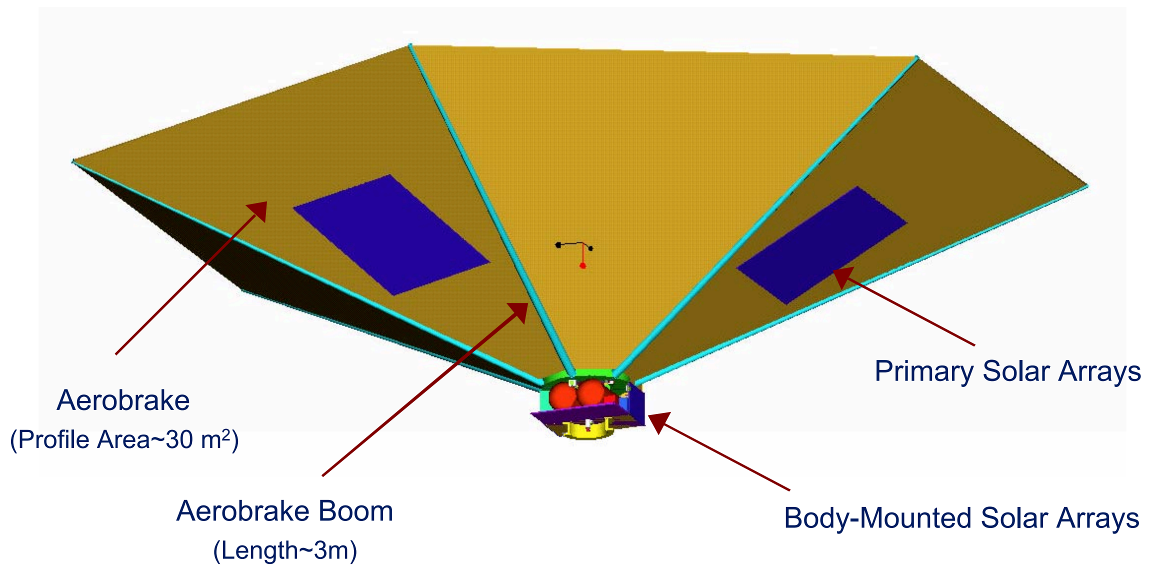

Figure 6: SPORT With Deployed Aerobrake (Customer Payload Shielded Behind Brake).

(nominally 60), with any variation due to fluctuations in the Earth's atmosphere.

The customer payload is shielded behind the aerobrake from interaction with the Earth's atmosphere. Its ephemeris is constantly monitored during operations and its altitude adjusted as necessary using the on-board propulsion system to keep it at a safe altitude. Figure 6 shows the aerobrake fully deployed. The aerobrake will carry flexible solar arrays for power during the orbit transfer maneuver.

Mass and Accommodation Classes

SPORT is a highly flexible launch system that offers several size classes that can be modified as needed for each mission. It is designed to be modular, and the propellant tanks specifically are designed to be switched out for larger or smaller tanks as the mission demands. The aerobrake can be made larger or smaller or removed altogether for orbit transfers that do not require GTO to LEO capabilities.

Despite its highly flexible nature, it makes sense to design several classes of the SPORT vehicle based on existing auxiliary payload supply. Based on existing marketing and technical agreements with Arianespace, two main versions of SPORT have been developed: Micro and Mini.

MicroSPORT

The MicroSPORT class is designed to fit inside the Microsat slot on the Ariane 5 ASAP launch accommodation. The Micro ASAP slot has the capability to lift 120 kg to orbit according to the ASAP 5 User's Guide. In order to perform the GTO to LEO maneuver, the SPORT vehicle takes up approximately half of that mass capacity. The exact amount of mass available is shown in the left-hand graph in Figure 7 and is based on the final altitude desired by the payload.

MiniSPORT

The MiniSPORT class is designed to fit on either the Minisat slot on the Ariane 5 ASAP launch accomodation or on a larger custom slot on the Ariane 5. The Minisat ASAP slot can carry 300 kg total, with an approximate ratio of 2:3 of SPORT mass to payload mass.

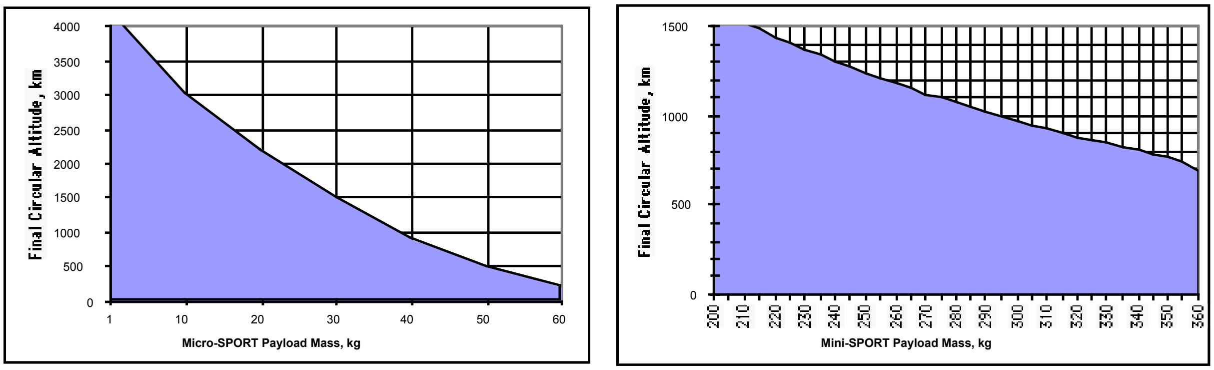

Figure 7: MicroSPORT (L) and MiniSPORT (R) Mass Capabilities Based on Altitude.

However, the Ariane 5 also has custom sized launch slots which can take large payloads, up to 1000 kg and more depending on the primary payload. The mass capacity of the MiniSPORT is shown on the right in Figure 7.

A set of examples of MiniSPORT configurations are shown in Figure 8. There are a variety of configurations for customer payloads, depending on the mission and the launch vehicle.

Other Orbit Transfers

AeroAstro and ATSB are developing SPORT for a GTO to Near Equatorial Orbit (NEqO) transfer in late 2002 or early 2003 using the patented aerobraking maneuver. However, other orbit transfers are possible using the SPORT vehicle. SPORT is specifically designed to be modular. The aerobrake can be enhanced or removed, and the supporting electronics can be used as a full spacecraft bus for payloads and experiments who do not have their own supporting bus.

One key set of orbit transfers are low altitude to high altitude Hohmann transfers. SPORT is designed to execute this transfer maneuver by removing the aerobrake. It contains the propulsive and the guidance systems to execute this maneuver to raise parking orbits to longer-lasting orbits. SPORT can also perform other orbital maneuvers, such as Molniya to sun synchronous orbit, transferring polar to sun synchronous and back, and Molniya to LEO. The modular nature of SPORT, designed around the Bitsy core electronics module, is key to this capability.

Conclusion

Most small spacecraft users prefer LEO or equatorial orbit for their missions. However, the options to reach those orbits are limited:

- Dedicated launch vehicles: Good orbital delivery parameters but expensive;
- Decommissioned ICBMs: Good price but entail risk from a business perspective;
- Auxiliary payloads on large launch vehicles: Good price but delivery to the wrong orbit.

The third of these options, using excess capacity on large launch vehicles, is available at a low price and with minimal risk. However, auxiliary launches almost always go to undesirable orbits.

In order to take advantage of this resource which currently goes to waste, a global partnership between AeroAstro, Inc. of Herndon, Virginia and Astronautic Technology (M) Sdn. Bhd of Kuala Lumpur, Malaysia has been established to develop the

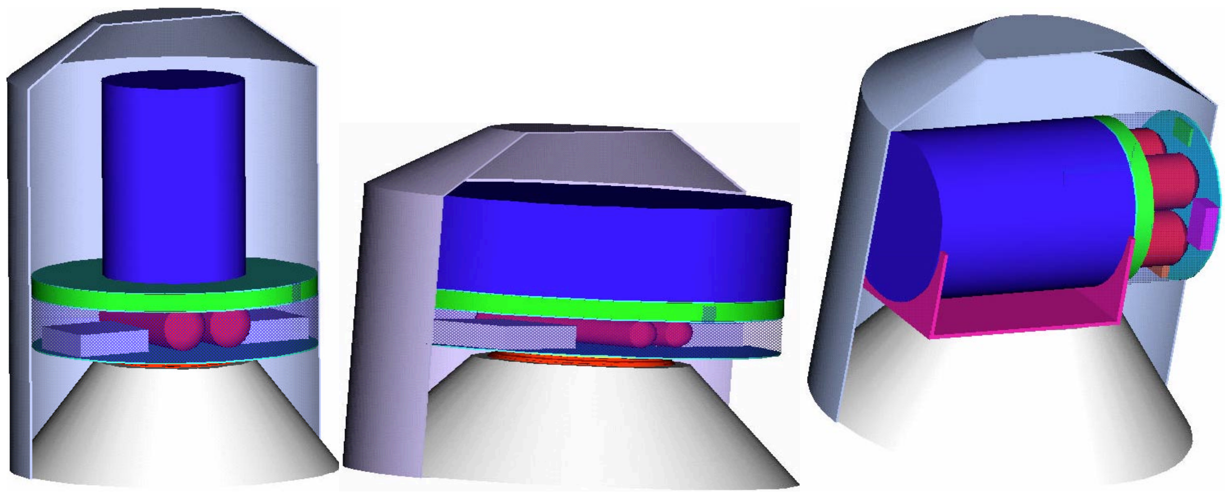

Figure 8: Three Configurations of MiniSPORT, Showing the Customer Payload in Blue.

Small Payload Orbit Transfer (SPORT) vehicle. SPORT has the capability to transfer small payloads from less desirable orbits such as GTO to their final destinations in LEO.

SPORT can execute this and other orbit transfer missions for payloads ranging from 60 to 600 kg. It is currently baselined on the Ariane 5 vehicle but has the capability to use other vehicles as well, including the Shuttle.

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Biographies

Ahmad Sabirin Arshad, or Sabirin, is presently the Managing Director and CEO of Astronautic Technology (M) S/B (ATSB). The company is located in Kuala Lumpur, Malaysia and its main activities are development and operations of small satellites. He was the project manager for ATSB's first microsatellite project, TiungSAT-1, which was launched on September 26th, 2000. He was also a project engineer during the manufacturing of MEASAT-1, Malaysia's first geostationary satellite. Prior to joining ATSB, he served as an academic in one the universities in Malaysia. He obtained his PhD from University of Wales College of Cardiff in 1993 and now lives with his wife and two children in Shah Alam, Selangor.

Aaron Jacobovits works on project development at AeroAstro. He has an MS in Aeronautics and Astronautics from Stanford University and a BSE in Aerospace Engineering from the University of Michigan. During school he held internships at NASA-Dryden and GE Aircraft Engines. His technical specialties are propulsion systems as well as control systems.

Yasser Ahmad works for ATSB as an Electrical Engineer, he is currently working at AeroAstro's facilities in Herndon, Virginia on the cooperative SPORT project. As a Project

Engineer for SPORT, he is designing SPORT power and TT&C systems. He has a BE in Electrical Engineering with a minor in Mathematics from Vanderbilt University

David Goldstein is AeroAstro's Vice President for Business Development, he manages a full-time staff of four. He has been closely involved with customer and partner relations for all of AeroAstro's current projects including the SPASE, SPORT and Team Encounter satellites. He holds a BS in Mechanical Engineering from Brown University.