Small Payload ORbit Transfer (SPORT™) System: An Innovative Approach to Lowering Missions Costs Without Increased Risk

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Abstract. The past decade has seen efforts to lower costs by "doing more with less," instead of making innovative changes in the way missions are designed and implemented. Now, the industry is turning towards more intelligent approaches to mission design. AeroAstro has developed the Small Payload ORbit Transfer (SPORT™) system to provide a flexible low-cost orbit transfer capability, enabling small payloads to use low-cost secondary launch opportunities and still reach their desired final orbits. This capability allows small payloads to effectively use a wider variety of launch opportunities, including numerous under-utilized GTO slots. Its use, in conjunction with growing opportunities for secondary launches, enable "better, cheaper, faster" missions through innovative mission design and lower cost access to space, not increased risk.

SPORT uses a suite of innovative technologies that are packaged in a simple, reliable, modular system. The command, control and data handling of SPORT is provided by AeroAstro's Bitsy™ Kernel, which will be demonstrated on the Shuttle under a NASA MSFC-sponsored program in late 2001 and is available for very low cost due to its highly repeatable nature. SPORT achieves its orbit transfer capability through a combination of chemical propulsion and aerobraking technology. This paper will discuss the SPORT design and its application to overall small satellite mission development.

Introduction

There have been remarkable developments in small satellite design over the last decade, but US small satellite developers and users are hindered by space access costs. Piggyback launches on large launchers offer the cheapest and most reliable access to LEO and GTO for small satellites. By using excess capacity on large launch vehicles, small spacecraft can get into orbit extremely cost-effectively.

While the small satellite industry has found ways to use some of the excess capability of large launches to low earth orbit, especially those launches to polar orbit, a large portion of the large launches have not been used for small payloads. Launches to high earth and elliptical orbits, such as GTO, make up approximately half of all launches, and over 80% of the launches of many large vehicles such as the Ariane 4 and 5. However, only a tiny percentage of these launches carry small payloads, despite active encouragement from companies such as Arianespace. Since secondary capability exists on these launches but has not been historically used, it can be concluded that high earth orbits, such as GTO, are of limited value to small space missions. In contrast, the demand for small payload launches to low earth orbits is significant and growing.

It is evident that a low-cost means to transfer a payload from high earth orbits, such as GTO, to low earth orbits could deliver significant utility to small spacecraft users and mission planners. AeroAstro is actively developing the Small Payload ORbit Transfer (SPORT) system to meet this need. Additionally, AeroAstro and Arianespace have formed a partnership to further develop Ariane Structure for Auxiliary Payloads (ASAP) / SPORT service.

SPORT is a low-cost orbit transfer vehicle, which uses a combination of chemical propulsion and aerobraking technology to efficiently transfer a payload between orbits. The most often used configuration will be for the transfer from GTO to LEO. With aerobraking, SPORT can achieve orbit changes that are many times greater than that achievable with direct propulsion. After using the propulsion system to lower the orbit perigee, the aerobrake gradually slows SPORT via atmospheric drag. After the orbit apogee is reduced to the target level, an apogee burn raises the perigee and ends the aerobraking phase. At the conclusion of the orbit transfer maneuver, either the aerobrake or SPORT can be shed, as desired by the payload.

While SPORT is initially configured to fit within the Ariane 5 ASAP secondary payload envelope, it can be configured to fit within most other launch vehicle secondary payload slots as well, and is being designed to accommodate the NRO Universal Secondary Payload Interface (USPI). SPORT is designed with a modular architecture that allows for physical reconfiguration as well as performance optimization. A variety of low cost core electronics (Bitsy), propulsion and power options provide the mission developer with the ability to tailor SPORT to his or her individual needs.

SPORT Mission and Architecture

Mission Options

The primary mission profile of SPORT is to deliver a small payload from GTO to LEO, although other options are possible, with or without the aerobraking option. This primary mission is accomplished through a series of maneuvers, which starts with thruster firing at apogee to lower the perigee altitude to approximately 150 km. At this altitude, SPORT will experience a small amount of drag with each pass through perigee, which will gradually reduce the apogee altitude. To keep the mission duration to a manageable length, SPORT is equipped with a large deployable aerobrake (see Figure 1). This aerobrake inflates from the aft end of SPORT and consists of several inflatable booms that rigidize after inflation. These booms draw the aerobrake cloth taut and transfer the aerobraking loads to the SPORT structure.

After 20 to 90 days, depending upon atmospheric conditions and target altitude, the aerobraking phase is concluded by a thruster firing at apogee to raise perigee above aerobraking altitude. Additional thruster firings are made to trim the orbit to the desired parameters. Upon completion of the orbit maneuver, SPORT can separate from the payload and use residual propellant to lower the perigee so that additional atmospheric drag will ultimately de-orbit the spent stage.

Since at its heart, SPORT is an orbital maneuvering vehicle, it can perform a variety of orbital transfer missions without using the aerobrake. SPORT can be employed to perform Hohmann and other transfers to raise or lower the orbit. This capability can be used by SPORT to expand the orbit possibilities that can be achieved from a secondary launch. SPORT ultimately can be used from the Space Shuttle to raise shuttle-launched payloads to stable long-life orbits.

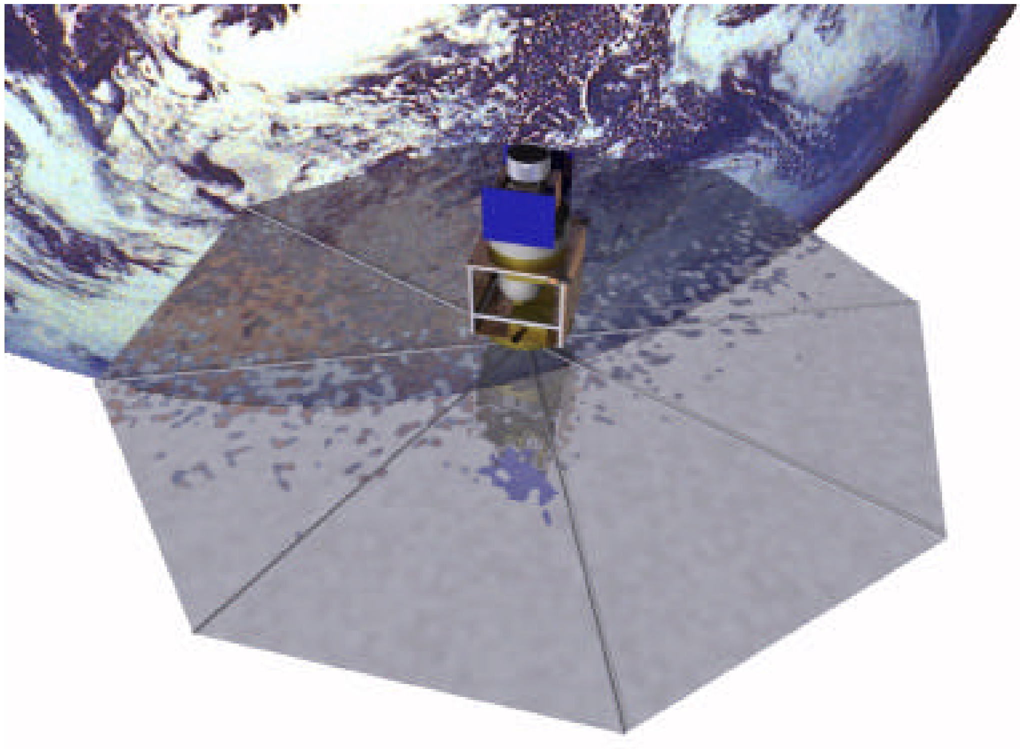

Figure 1. SPORT Configuration with Deployed Aerobrake

The highest performance versions of SPORT also offer the possibility of interplanetary capability to small payloads, which start from GTO. By expending most of its propellant load at perigee in one or more burns, SPORT can impart sufficient ΔV to a small payload to achieve Earth escape velocity.

In addition to these orbit transfer missions, SPORT can also provide long duration station keeping with part, or all, of its propellant load. For the station-keeping mission, SPORT may be hard mounted to the payload to become an integral part of the small spacecraft mission. In this use, payload components, such as solar panels, can be integrated with SPORT to meet the mission needs.

SPORT is designed with a modular architecture built around AeroAstro's Bitsy kernel, which is available for very low cost due to its repeatability and modularity. With this modularity, a SPORT version can be configured to meet the specialized needs of the small mission developer without custom development.

The core of this capability is the Bitsy kernel, which is designed to include all of the core electronics components common across spacecraft of a similar class and to provide them for a significantly reduced cost. This includes data processing, communications, and power regulation components, but does not include ACDS, power supply, or energy storage components which often vary from mission to mission. Several versions of Bitsy will ultimately be available. The first version, Bitsy-SX, is currently under development and will be flown as a technology experiment on the Shuttle in 2001. Bitsy-SX provides sufficient capabilities to control SPORT through its basic mission profile. More advanced versions, such as the Bitsy-DX and the Bitsy-LX, can be used to support more elaborate mission profiles, such as orbital rendezvous or autonomous missions.

The nominal SPORT configuration is designed to use a primary battery for its 90-day mission. For longer durations or missions with higher power requirements, SPORT can be equipped with body mounted solar arrays and secondary batteries. In any configuration, the power is routed through the Bitsy power regulation system, which can handle up to 50-100 W of power.

SPORT uses a single propellant in its propulsion system, so the propulsive capability can be adjusted by stretching the single tank. While this stretching is relatively simple with composite pressure vessels, only a limited number of tank sizes are projected due to the high cost of tank qualification. Further flexibility can be achieved by only partially filling the tank, and using the associated mass savings for the payload or other systems.

While the nominal propellant used on SPORT is nitrous oxide, an option to use a hydrazine-based propulsion system is available for those users who require the strong heritage and capabilities of hydrazine. SPORT also supports options in the number and size of thrusters used. In the nominal spin-stabilized configuration, SPORT is equipped with one transfer thruster and four ACS thrusters. Additional transfer thrusters, up to four total, and ACS thrusters, up to sixteen total, can be used on SPORT for missions requiring additional maneuvering and control.

At the conclusion of the orbital transfer maneuver, the customer can choose to keep or shed SPORT from the payload, through a standard payload interface. For missions which intend to keep SPORT with the payload for a long duration, SPORT can be equipped with the means to shed only the aerobraking hardware after the completion of that mission phase. Ideally, this shedding would occur before the perigee raising maneuver to allow the residual aerobraking hardware to quickly deorbit from atmospheric interaction.

SPORT Components and Technologies

Low-Cost Bitsy Core Electronics

The Bitsy kernel approach is to offer a very low-cost set of spacecraft electronics not by attempting to draw the line between bus and payload, but rather between mission-specific and cross-mission or "core kernel" functions. Instead of trying to design a generic bus that meets the needs of a wide variety of mission types, Bitsy selects the functions that are in common across a variety of mission types and provides them in a single, reliable, repeatable, standard unit.

The Bitsy model being developed for the SPASE mission, funded by NASA Marshall Space Flight Center, is the most basic version: the Bitsy-SX. It communicates at an average of 9600 baud from LEO to a very moderate-gain ground antenna, supports power loads up to 50-100 Watts and power supplies from solar panels and/or Lithium-Ion rechargeable batteries and/or Lithium-Thionyl-Chloride one-time batteries. It uses RS-232 in addition to analog and digital discretes to communicate with the payload, and supports simple timed commanding (turn this device on at time T1, send these bytes at time T2, and so forth). It monitors telemetry and performs a specified action when an input value crosses a threshold – the most basic type of housekeeping, but still sufficient to perform thermal control and simple ACS as needed for SPORT and similar missions.

Ultimately, a more advanced version of Bitsy will be made available. It will have a low-power commercial microprocessor on-board, with 16 Megabytes of memory, 32 independent RS-422 channels for communication with mission-specific subsystems and devices, a 300 Watt-capable power system, up to 20 Watts EIRP out of the radio, and commensurately greater numbers of discrete inputs and outputs.

Aerobraking Technology

The use of aerodynamic forces to assist in orbit transfer maneuvers has been used since the earliest space missions. In addition to the use of aerobraking to return space vehicles to Earth, multi-pass aerobraking has been used in several major space missions, including Magellan and Mars Global Surveyor. These missions have demonstrated and matured aerobraking technology to the point that commercial missions can now take advantage of its capability.

Technically, all low earth orbit spacecraft experience multi-pass aerobraking orbit profiles as they gradually decelerate from atmospheric drag. However, in general, these spacecraft take years for substantial orbit changes to occur. To be useful in an orbit transfer vehicle, this deceleration must be enhanced so that substantial orbit changes occur within time scales on the order of weeks to months, at most. This enhancement can be achieved by increasing the spacecraft profile area by at least one to two orders of magnitude. When deployed, the SPORT aerobrake increases the SPORT profile area by a factor of fifty.

For nearly circular low orbits, the nearly constant atmospheric drag causes the spacecraft to slowly spiral to Earth. However, for highly eccentric orbits such as GTO, only the perigee portion of the orbit experiences significant atmospheric drag. This asymmetrical drag reduces the orbit apogee, while leaving the perigee altitude relatively unchanged. Over time, the cumulative energy loss at perigee produces large altitude changes in the orbit apogee.

Below 150 km altitude, small changes in perigee altitude produce large changes in aerobraking force due to the high rate of change in atmospheric density, as shown in Figure 2. In an effort to maximize the aerobraking capability while avoiding this region of sensitivity, SPORT is designed to

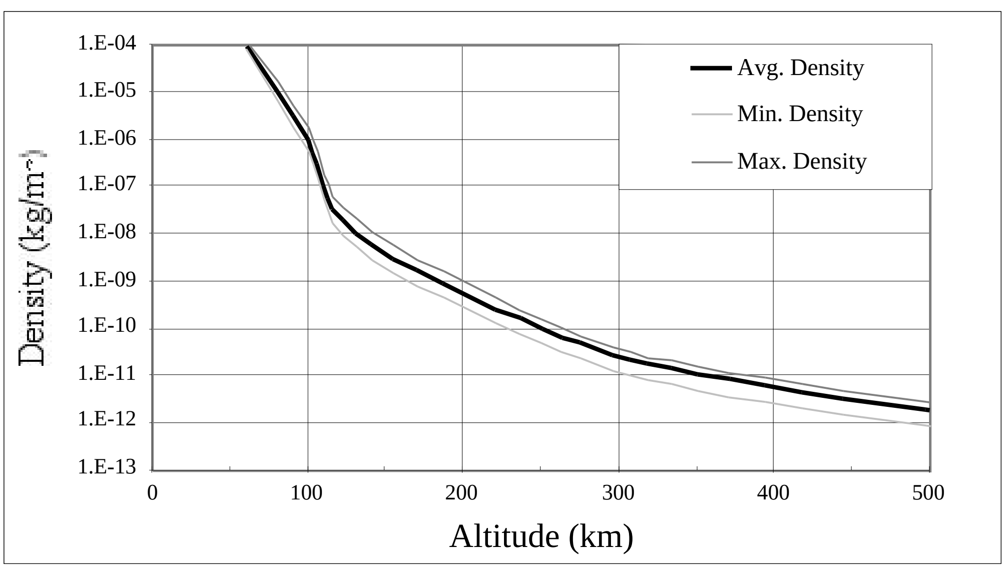

Figure 2. Earth Atmospheric Density at High Altitude

operate with a perigee altitude in the 150 to 200 km range.

To achieve an aerobrake with maximum area and low mass, SPORT uses inflatable structure technology. SPORT uses several radially oriented tubular spars, which rigidize after deployment, to stretch the aerobrake cloth. Since it is unnecessary to minimize the aerobrake mass to the extent needed for other inflatable missions, SPORT uses a conventional fabric that is held under tension by the booms.

SPORT Performance

The following describes the projected performance for the various versions of SPORT in baseline missions.

Aerobraking from GTO to LEO

The use of aerobraking technology allows SPORT to deliver an effective propulsive capability that is many times that achievable with direct propulsion. In the nominal mission profile, only a small amount of the ΔV budget (~50m/s) is used to reduce the orbit perigee to allow aerobraking. During the aerobraking phase, the orbit change is essentially free and requires no propellant expenditure, though some propellant may be used to trim the perigee altitude to increase or decrease the time needed to complete the aerobraking maneuver safely.

Upon reaching the target apogee altitude, SPORT will expend most of its ΔV budget to raise the perigee. Since the ΔV requirement to raise the perigee is proportional to the perigee altitude change, the propellant requirement increases for high altitude circular orbits, resulting in smaller payload capability for those orbits. Since the aerobraking mission starts from GTO, a substantial plane change can be achieved by expending additional propellant during the perigee-lowering maneuver. However, this expenditure does reduce the propellant available for final perigee-raising.

Figure 3 shows the projected performance for the various SPORT configurations. The

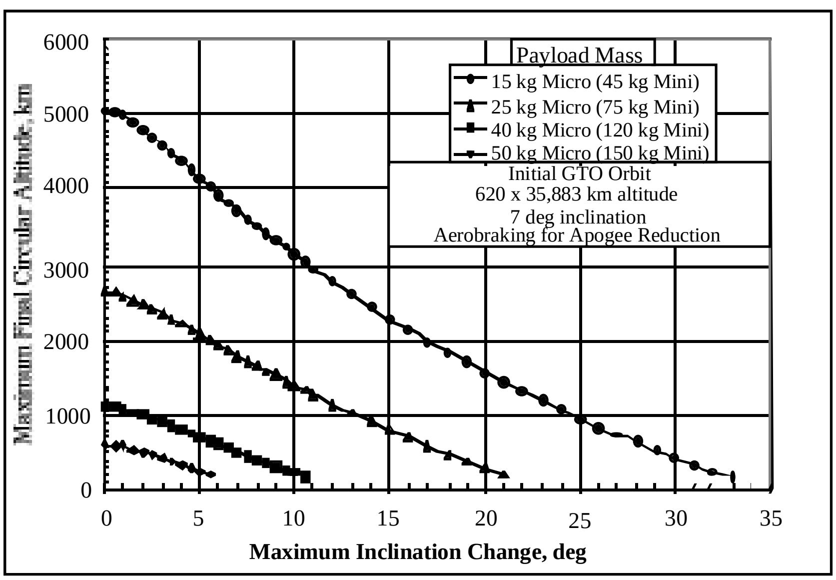

Figure 3. SPORT Aerobraking Performance

"Micro" payload masses are based upon the Ariane ASAP 5 microsatellite slot, which is limited to 100 kg total mass. The capability achievable from the 300 kg Ariane ASAP 5 minisatellite slot is designated as "Mini" in Figure 3.

LEO Orbit Transfer

For non-aerobraking missions, SPORT operates as a traditional orbit transfer vehicle. Figure 4 shows the projected performance for several SPORT configurations. The "Micro" versions assume a total launch mass of 100 kg, while the "Mini" versions assume 300 kg. Since additional propellant mass is required to achieve large altitude or inclinations changes, missions with higher energy requirements are limited in payload capability.

Payload Accommodations

Since the overall size of the baseline Ariane 5 ASAP payload envelope is fixed, changes in the size of the SPORT propellant tank directly affect the volume available for the SPORT-carried payload. AeroAstro offers several standard propellant tank sizes for SPORT, which provide a range of performance capabilities.

However, since larger tanks require additional volume, the higher performance versions of SPORT have correspondingly smaller payload volumes available. Figure 5 shows the variation in payload envelope height as itrelates to ΔV. Note that the 170 and 300 m/s ΔV versions of SPORT use the same size propellant tank and hence support the same size payloads. The performance of these various SPORT versions can be seen in the figures on the following page.

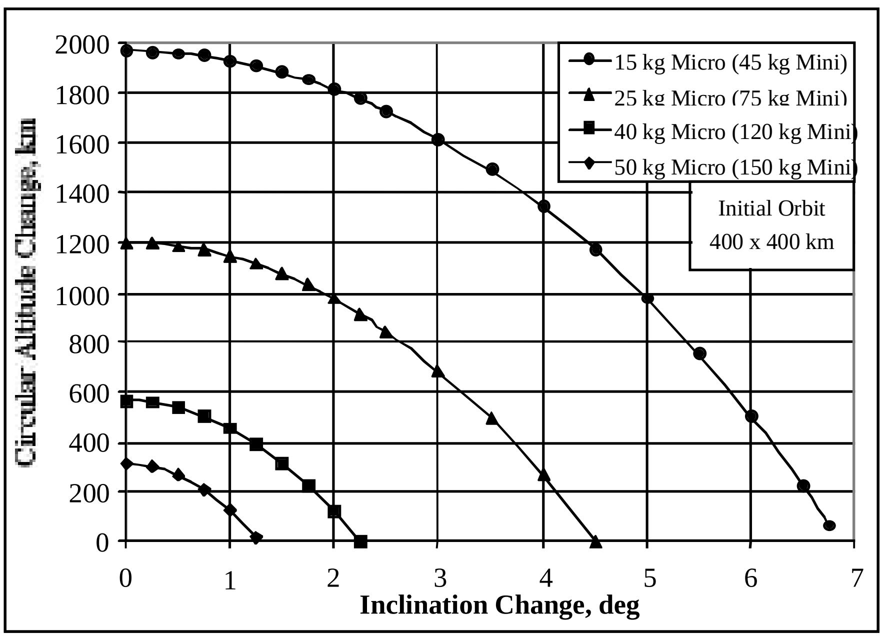

Figure 4. SPORT Direct Propulsion Performance

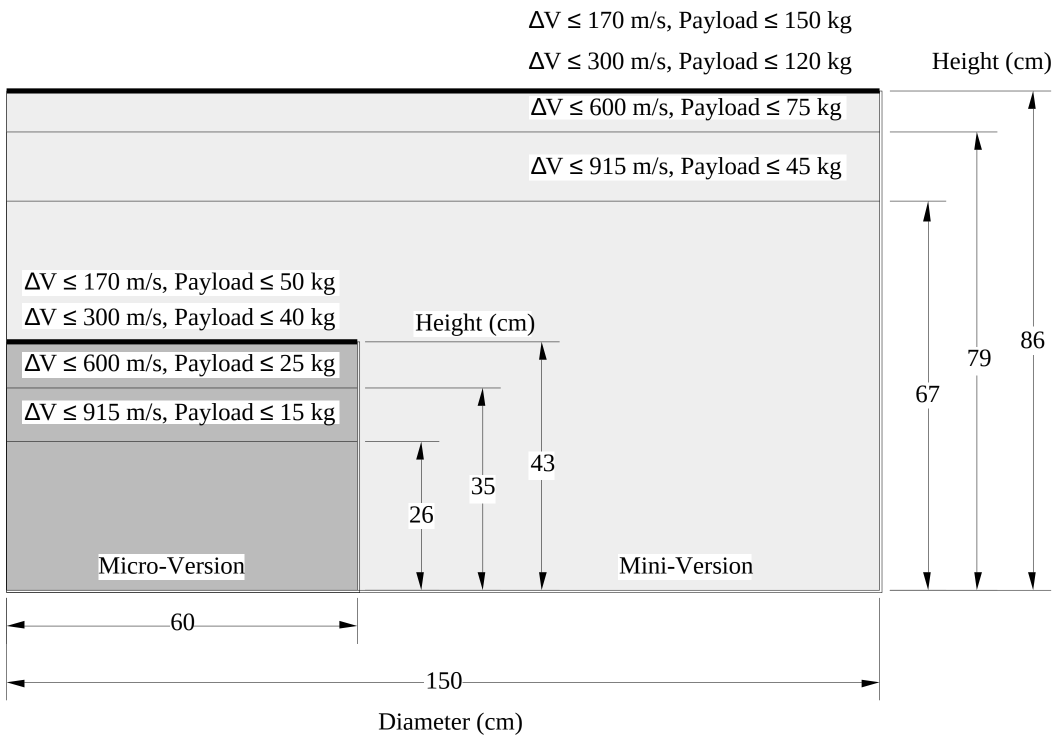

Figure 5. SPORT Payload Envelope Capability for Ariane ASAP Micro and Mini Slots

Benefits

Solving the challenge of low-cost access to space is a key to the success of small spacecraft. SPORT provides a revolutionary capability to the small spacecraft community and promises to greatly enhance the ability of small mission developers to deploy their systems.

There are a significant number of low-cost secondary payload opportunities which go untapped by small spacecraft users. This is mainly due to the lack of good orbits available on a secondary launch.

The SPORT orbit transfer system will move spacecraft from their initial piggyback orbit to a more desirable final orbit. This capability, at very low cost, enables a much lower launch cost for small spacecraft missions.

This total launch cost, including delivery to final orbit, ranges from $3-9MM depending on the mission specifications. With the modularity of SPORT, the mission developer can select the SPORT configuration that best meets their need.

SPORT uses existing capabilities to solve one of the most pressing problems with small spacecraft right now—exorbitant launch costs compared to the cost of small spacecraft missions. SPORT delivers low-cost launch today.