The Space Shuttle and Its Replacement

By Martin Nowicki

During its nearly one quarter century of service, the Space Shuttle has not only facilitated ground-breaking research which has given rise to countless technologies, but has also made great strides in making routine space flight, i.e. "space tourism," a likely reality within the next few decades. But the two failures in the program's history, the Challenger and Columbia tragedies, have called the career of the Shuttle into question. The Columbia Accident Investigation Board (CAIB) came to the conclusion that "because of the risks inherent in the original design of the Space Shuttle, because that design was based in many aspects on now-obsolete technologies, and because the Shuttle is now an aging system but still developmental in character, it is in the nation's interest to replace the Shuttle as soon as possible as the primary means for transporting humans to and from Earth orbit."[1]

This is not a new finding, however. Considering the astounding pace at which the US space program made developments during the 1950s and '60s for the Mercury, Gemini and Apollo projects, the developments made by the Space Shuttle program since its first flight in April of 1981[2] seem rather inadequate in comparison. The Space Shuttle "was intended to make access to space a routine and inexpensive activity. However, in the 20 years since the first flight of the Space shuttle, access-to-space remains an expensive and relatively inflexible activity."[3] For example, the price to launch a payload aboard the Space Shuttle is still $10,000/pound, a figure that has not gone down in over a decade. The goal for the replacement is to cut this cost by a factor of 10. Competing technologies, such as the European Arian 5 rocket, cost between $3500-$4500/pound.[4]

This price comparison may not be entirely fair though. First of all, the space shuttle comes with the added service of a crew that can run in-flight experiments and return them to Earth safely. But secondly, and herein lies the uniqueness of this spacecraft, the Shuttle was designed to perform multiple roles—a one-of-a-kind, "all purpose" vehicle, if you will.[5] No other spacecraft is capable of ferrying both cargo and personnel into orbit while simultaneously conducting microgravity experiments or repair and maintenance operations. Other launch vehicles are optimized to perform one task, which significantly reduces cost, but with the space shuttle, it is versatility that makes it so expensive.

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[1] Catchpole, John "Farewell to the orbital space plane" Spaceflight. Vol. 46, no. 6, pp. 248-252. June 2004

[2] http://www.thespaceplace.com/shuttle/past.html (The Ultimate Space Place, P.O. Box 541107, Merritt Island, Fl 32954)

[3] Bertin, J J; Cummings, R M "Fifty years of hypersonics: where we've been, where we're going." Progress in Aerospace Sciences. Vol. 39, no. 6-7, pp. 511-536 Aug.-Oct. 2003

[4] http://www.spaceref.com/news/viewnews.html?id=301 (SpaceRef Interactive Inc.)

[5] Spacely's rockets: Personnel launch system/family of heavy lift launch vehicles. Report Number N93-29712 11-01 In Universities Space Research Association, Houston, Proceedings of the Seventh Annual Summer Conference. NASA/USRA: University Advanced Design Program p 291-293 (SEE N93-29712 11-01)

With this in mind it is quite clear that the key to versatility lies in the Shuttle's passenger-carrying capabilities, and NASA has always regarded crew safety as its number one priority. Yet a long-standing drawback of the Space Shuttle has been the crew escape system: "NASA's requirement for the 2nd Generation RLV is 1 in 1000 Loss of Vehicle (LOV) and 1 in 10,000 Loss of Crew (LOC) over an entire flight profile. This requirement implies a 90 percent reliability of the Crew Escape system. Current crew escape system technology levels are at 75 to 80 percent reliability based on data derived from the Naval Aviation Center."[6] And this current system only operates when the shuttle is in a controlled gliding flight after reentry and is unable to reach a runway. A crew escape system that covers the "entire flight profile" needs to be planned during the design stage of a launch vehicle, because it is very difficult and expensive to add it on as an afterthought. This is arguably one of the most convincing reasons for replacing the Space Shuttle. There is little point in pursuing further advancements in an aging technology when the cost of these begins approaching the cost of developing a replacement for the whole system. This is especially true when this technology is critical to meeting the system's primary concern, as is the case in Space Shuttle's crew escape system.

The White Knight turbojet with SpaceShip One attached http://www.scaled.com /projects/tierone/photos.htm

Many lessons have been learned from the world's first Reusable Launch Vehicle (RLV) and that knowledge will prove invaluable for subsequent generations of Space Launch Vehicles, but with progress comes change, and change in this case means the end of the Space Shuttle. Unfortunately this change may be slower then initially anticipated. The CAIB report also found that "none of the competing long-term visions for space have found support from the nation's leadership, or indeed among the general public."[7] Because of developmental shortsightedness, which undoubtedly stemmed from a lack of sufficient funding, not only did the developments in the Space Shuttle Program reach a point of stagnation several years ago, but it also seems that there was "little or no attempt to develop parallel 'access to space' technologies."[8] In other words, there is currently no substantial backup plan.

In the public sector however, things have gone slightly different. In 1995, Peter H. Diamandis, Byron K. Lichtenberg, Colette M. Bevis and Gregg E. Maryniak founded the Ansari X-Prize Foundation. Inspired by the competitions from the early days of aviation

[6] Reaves, W; Seavey, R; Sharp, S "Crew escape: Past, present and future - A historical survey of all crewed U.S. launch vehicles" HSTE 2000 - Human Space Transportation and Exploration Workshop, Galveston, TX, Proceedings; Feb. 28-Mar. 1 2000
[7] Catchpole, John "Farewell to the orbital space plane"
[8] Catchpole, John "Farewell to the orbital space plane"

that helped that fledgling industry move forward, the X-prize foundation set out to start a similar push within the commercial space industry by offering a $10 million prize to the first team that: Launches a piloted, privately-funded spaceship, able to carry 3 people to 100 kilometers (62.5 miles); returns safely to Earth; and repeats the launch with the same ship within two weeks.[9] To date, the leader in this competition is the Scaled Composites team. Funded by Paul Allen and designed by Burt Rutan, Scaled Composites has developed SpaceShipOne, which on June 21st, 2004 became the first spacecraft in this competition to reach outer space.[10] Though this was a tremendous milestone in opening space travel to the public, the flight was not flawless. The pilot, Michael Melvill, "had to battle to stabilize the craft, and the vehicle barely made it to 62 miles in altitude … Rutan said he would not try for the X-prize until the problems had been found and fixed."[11]

The X-Prize is a key factor in opening the door to a whole new marketplace, space tourism. "The Federal Aviation Administration, the body which regulates commercial space flights in the USA, has considering drawing up formal guidelines for private passenger space travel, causing speculation that space tourism could soon become a realistic proposition. Recent market research, based on a survey of 450 millionaires, indicates that there is a considerable demand for space tourism, despite the NASA space shuttle problems."[12] With 20 teams entered in the competition, many of which are almost as far along as the Scaled Composites team, the X-prize is succeeding in its mission of bringing space flight to the masses.

As exciting as these recent developments have been, the fact remains that the government sector is a half-century ahead of the commercial sector and any progress we can hope to see in the immediate future will be coming from government-funded programs. But without proper motivation the wheels of government move rather slowly when dealing with scientific needs. In matters of political pride however, these wheels have been known to speed up significantly. Such was the case during the Cold War era-inspired Space Race. But while the Russians are still pursuing some developments in the aerospace field, they lack the resources to pose any significant threat to the US's title as the reigning champion of space exploration. This year however, the Chinese became the third nation to put a man into orbit. With the resources they possess, the Chinese could be seen as a significant threat by those in Washington who are concerned with matters of national pride.

One of the catalysts for recent and upcoming changes in the US Space Program came from George W. Bush's Exploration Initiative. In a manner similar to President John F. Kennedy's 1961 challenge to land a man on the moon before that decade's end, Bush delivered a speech from NASA HQ on January 14, 2003 that challenged this generation to return to the moon and send a manned mission to Mars within the next thirty years. Some might speculate that this was motivated by the recent developments in China, though oth-

[9] http://www.xprize.org/ (The X PRIZE Foundation, 722-A Spirit of St. Louis Blvd., St. Louis, Mo. 63005)
[10] Mullins, J. "Who needs NASA?" New Scientist. Vol. 178, no. 2394, pp. 12-13. 10 May 2003
[11] USA Today, Tuesday, June 22, 2004 pg. 3A
[12] Klerkx, Greg "The High Life" New Scientist; 179 (2410) 30 Aug 2003, pp.24-28

ers have written it off as a reelection tactic. Regardless of the reasons, the fact remains that the a time of change is upon us, and the world finds itself poised once again at the forefront of a technological boom—a boom that will most likely be kicked off by the unveiling of the Space Shuttle's replacement.

As we currently stand, the first step towards accomplishing these visionary goals is to complete the International Space Station (ISS). Although its primary role is for research, the ISS can also function as intermediary between here and the moon. Bush wants the ISS to be completed by 2010 so that "we will meet our obligations to our 15 international partners on this project… The shuttle's chief purpose over the next several years will be to help finish assembly of the international Space Station. In 2010, the Space Shuttle, after nearly 30 years of duty, will be retired from service."[13] To fill the void left behind by the Shuttle's retirement a new spacecraft will be developed that will not only be capable of ferrying passengers and cargo to the ISS, but also "beyond our orbit to other worlds." This spacecraft has tentatively been dubbed the Crew Exploration Vehicle and the project has been dubbed Project Constellation.[14]

The recent developments in air breathing propulsion systems have drawn a clearer picture of what the Crew Exploration Vehicle may look like. To date, every vehicle placed into orbit has been propelled solely by rocket engines. Both rocket and air breathing propulsion systems produce thrust by combusting various fuels with an oxidizer, the difference being that the first carries its oxidizer with it, while the latter extracts oxygen from the atmosphere within which it is flying. Clearly an air-breathing engine will not function out in space, but it can get a vehicle into space while realizing significant reductions in take-off weight. Therefore, the current vision for the next SLV is to have multiple stages, one of which would incorporate an air breathing propulsion system that would operate before the vehicle leaves the Earth's atmosphere. After all, the solid rocket boosters of the Space Shuttle separate while still in the atmosphere (29 miles, or 47 kilometers)[15], which shows that the whole first stage of the Shuttle could be replaced by an air-breathing engine.

This is precisely how SpaceShipOne operates. It rides piggyback on The White Knight, a turbojet (two J85GE-5's) powered aircraft, until it reaches an altitude of 50,000 feet. At this point the spacecraft separates from its carrier and the rocket-powered stage of the ascent begins. SpaceShipOne is propelled by a hybrid rocket engine that burns a synthetic rubber solid fuel with liquid nitrous oxide (N_2O), and brings the craft to an altitude of 328,000 feet (100 km), the threshold of outer space.[16]

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[13] Catchpole, John "Farewell to the orbital space plane"

[14] Morrissey, Susan R. "Vision Targets Heavenly Bodies" Chemical & Engineering News, 82(9), pp.22-24. March 1, 2004

[15] http://www.aerospaceweb.org/question/spacecraft/q0183.shtml (Aerospaceweb)

[16] Sweetman, Bill "SpaceShipOne: Riding a White Knight to space" Aerospace America. Vol. 42, no. 1, pp. 45-48. Jan. 2004

The limitations to this configuration are the turbojet engines: "At a flight Mach number of 3.5-4, thermodynamic analysis indicates that the compressor is no longer needed; the most efficient engine is the ramjet. The ramjet has the virtue of maximum simplicity, with no need for turbo-machinery, and maximum tolerance to high-temperature operations and minimum mass-per-unit thrust at suitable flight Mach numbers."[17]

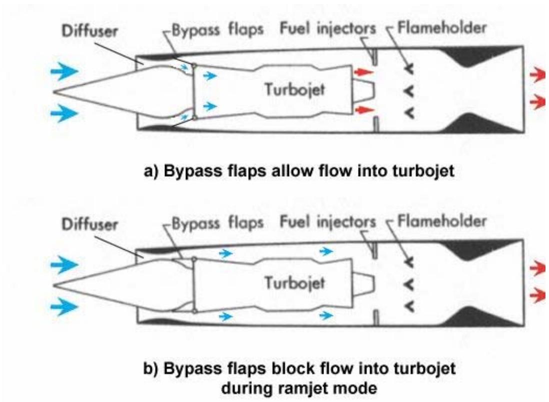

Diagram of a turboramjet engine http://www.aerospaceweb.org/question/propulsion/q0175.shtml

One of the most well recognized aircraft to incorporate a ramjet is the SR-71 Blackbird. In order to sustain a supersonic cruise of more then Mach 3.0 at an altitude of 15miles (24 km.) the SR-71 depended on a turbo-ramjet power plant.[18] This propulsion system functions as a typical afterburning turbojet engine, but at the higher speeds of the flight regime a set of bypass flaps blocks the airflow to the turbo-machinery and redirects it to the afterburner, which essentially acts as the combustion chamber of a typical ramjet.[19] NASA has already started looking into this exact propulsion systems as a booster stage for a two-stage-to-orbit replacement for the Space Shuttle.[20]

Ramjets were also used on the D-21 drone aircraft. First launched in 1966, the drone was intended to be an unmanned reconnaissance plane, but none have flown since 1971. NASA however is now thinking about reviving the aircraft "for reusable launch vehicle (RLV) propulsion tests… If the project is approved by NASA, a D-21 would be re-engined for flight tests in 2005 with a revolutionary air-breathing propulsion system, the rocket-based combined cycle (RBCC) engine. If successful, the tests could open the prospect of replacing the space shuttle with a 2-stage-to-orbit design using partial air-breathing propulsion."[21]

But the ramjet also has its limitations. First, it is incapable of steady operation at subsonic speeds because it relies on ram compression. It therefore can at best act as a second stage in a launch system. Secondly, there is an upper end limit of around Mach 6 above which the entering air, which needs to be slowed down to subsonic speeds before entering the

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[17] Mechanics and Thermodynamics of Propulsion

[18] "Lockheed's Lone Ranger - Reconnoitering at Mach 3 (SR-71/YF-12 production)" Air International. Vol. 7, pp. 159-166, 203. Oct. 1974

[19] http://www.aerospaceweb.org/question/propulsion/q0175.shtml (Aerospaceweb)

[20] Snyder, Christophera; Maldonado, Jaime J "The design and performance estimates for the propulsion module for the booster of a TSTO vehicle" AIAA, AHS, and ASEE, Aircraft Design Systems and Operations Meeting, Baltimore, MD, Sept. 23-25, 1991. 13 p.

[21] Covault, C. "NASA eyes secret D-21 for RLV engine tests" Aviation Week & Space Technology. Vol. 151, no. 23, pp. 28-30. 6 Dec. 1999

combustion chamber, is so hot that combustion cannot occur.[22] The solution to this problem is the scramjet, or supersonic combustion ramjet. As the name implies, a scramjet is simply a ramjet that facilitates combustion in a supersonic air stream. Though simple in premise, scramjets are extremely complicated, and have over 40 years of research associated with them.

The X-43 research vehicle http://www.dfrc.nasa.gov/Gallery/Photo/X-43A/HTML/ED99-45243-01.html

The culmination of this research was undoubtedly the March 30, 2004 successful flight of NASA's experimental X-43 hypersonic research vehicle. Part of the space agency's Hyper-X program, which seeks alternate propulsion technologies for access to space and high-speed flight within the atmosphere, the X-43 not only marked the first successful flight testing of a scramjet, but also managed to set the speed record for air breathing flight by accelerating past Mach 7.[23] The X-43 was attached to a Pegasus booster rocket in order to reach the supersonic velocity needed to start the scramjet engine. Once started, the X-43 separated from the booster and achieved positive acceleration while climbing. Although the powered portion of the flight lasted only 10 seconds, it marked a tremendous leap for air-breathing technology.

In the last decade NASA has cut funding to several promising programs, including the X-30 National Aerospace Plane which was "designed to take off and land on standard runways and cruise between any two points on the Earth in 2 hr, at cruise speeds of up to Mach 12, using a scramjet."[24] Another victim of budgetary setbacks was the X-33, the most promising Space Shuttle replacement program to date. Perhaps the success of the X-43 will spark a resurgence of funding for similar programs, which would undoubtedly benefit the next generation of Space Launch Vehicles. The Space Shuttle has served us well and will always be remembered as a brilliant technological achievement, but the tremendous advances in recent years have warranted taking the next step forward in space flight. It is time for the design of a new RLV that will make space flight cheaper, safer and more flexible so that as a society we can continue to satisfy the age-old desire to explore the cosmos and advance science.

[22] Mechanics and Thermodynamics of Propulsion
[23] Catchpole, John "Farewell to the orbital space plane"
[24] Croft, John "Weapons delivery goes hypersonic" Aerospace America. Vol. 42, no. 5, pp. 38-40. May 2004