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Space Tourism – Delivering on the Dream

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Abstract

After more than half a century of spaceflight, our activities in space are still limited to a relatively small set of markets whose growth is driven mainly by government funding. Worse still, human access to space is restricted to a few people flying very infrequently to a single destination. Contrasting today's reality with the high expectations of the 1960's – as epitomised in Stanley Kubrick's film "2001: A Space Odyssey" – begs two questions: what went wrong and how can we fix it? The objective of this paper is to address these questions and, in doing so, indicate how the nascent space tourist industry may help us realise past dreams by enabling a paradigm shift in our space-based activities.

Definitions

"Conventional" space businesses: Established space companies serving existing or near-term markets (Boeing, Lockheed-Martin, EADS, etc.).

"NewSpace" businesses: Entrepreneurial space ventures intending to service new markets or existing ones in new/novel ways (Virgin Galactic, Bigelow Aerospace, SpaceX, etc.).

Space Tourism: Commercial activities offering customers a direct experience of the space environment, initially via sub-orbital flights but eventually via orbital and then deep-space flights.

Sub-orbital flights: Flights following parabolic arcs that reach above 100km and provide several minutes of zero-g.

1 Half a Century of Spaceflight – How did we get here?

We begin by identifying the key factors and trends that have driven our progress in space over the past half century. Though complex and varied, these factors can be summarised in a relatively simple manner and, in so doing, can help us identify likely future trends.

1.1 Dawn of the Golden Age (1957-1969)

The space-age began in 1957 with the launch of Sputnik, followed relatively quickly by the launch of the first human in 1961 and the first steps on another world in 1969. Such rapid progress during this first decade was essentially driven by a single dominant factor; national security – the Apollo programme was, in effect, a national security programme aimed at demonstrating to the world the superiority of capitalism over communism!

Unfortunately, the success of Apollo served only to ensure its demise because, once it had served its political purpose, its expendable architecture made it far too expensive to maintain through discretionary funding and non-government funding was essentially impossible[1]. Moreover, the political and economic environment had also changed significantly, resulting in pressures to curb spending down to more sustainable levels and activities that focused more on applications rather that exploration.

1.2 Consolidation and Commercialisation (1970-1989)

The 1970's was effectively the second decade of the space-age, which saw government economic constraints force both a slow-down and a consolidation of space programmes. The Shuttle programme aimed to make space launch more affordable but also helped conserve the US industrial base that had been established by Apollo. Meanwhile, the commercial potential of space was beginning to emerge: in the near-term via communications, earth observation and navigation satellites; and in the long-term via visions of solar power satellites and even space colonies and starships!

However, financial constraints began to lift in the 1980's as programmes like "Starwars", the National Space Plane (NASP) and Space Station Freedom (SSF) gained a real political justification, while improvements in both market and legal environments for ventures like PanAmSat enabled commercial programmes to grow, along with the emergence of quasi government/commercial entities like Arianespace and Spot Image.

1 A commercial venture, Project Harvest Moon, was mooted to pay for an Apollo mission via sales of lunar materials, TV and story rights (http://www.nss.org/settlement/L5news/1985-beginnings.htm)

1.3 Rationalisation and the Entrepreneurs (1990-2010)

The fall of communism meant that the 1990's was a time of military "rationalisation" and political change that saw major curbs in government programmes as "Starwars" became a more modest ballistic missile defence system and the SSF became the more modest International Space Station (ISS) with the help of Russia. Similarly, as NASP faded away, expendable launcher programmes became the preferred option though experimental programmes like DC-X and then X-33 did maintain the hope of an alternate path into space. Meawhile, as commercial activities grew with more advanced projects like VSATs and ventures such as SkyTV, Iridium and Teledesic, the first wave of NewSpace launch ventures emerged in the form of Kistler Aerospace, Kelly Aerospace, Pioneer Spaceplanes and the Rotary Rocket Corporation.

Unfortunately, the commercial "rationalisation" of the early 2000's (i.e. the dot-com bubble burst and the commercial failure of Iridium) led to the demise of most NewSpace ventures, while government programmes also underwent a kind of re-invention with the advent of the Vision for Space Exploration (VSE) and programmes like Galileo. However, development of these programmes was extremely slow due to their Byzantine organisational structures and wavering political support, which meant that both eventually underwent a process of severe scrutiny and fiscal "rationalisation" that resulted in either major programme changes or, in the case of the VSE's Constellation programme, outright cancellation.

1.4 Summary to Date

In summary, each of the past five decades can be characterised by specific issues such as national security and conservation of the industrial base, while much of the slow growth of commercial ventures can be attributed mainly to market and financial constraints, rather than any basic limitation of the available technology. As a consequence, the diversity and intensity of spaceflight operations have also been paced by these trends, though the manner in which they are performed on both the ground and in space has been radically improved by the phenomenal advances in computing and software over this same period.

2 Future Possibilities – What are we waiting for?

Having gained an understanding of the factors governing past space activities, we now consider future possibilities and try to identify the key factors that may either prevent or severely restrain their realisation.

2.1 Current Constraints

Current space activities range from pure science missions through to civil and military applications like communication, navigation and observation systems. Nevertheless, growth and evolution in all these areas is limited by a few key factors:

- government priorities and constraints;
- competition from terrestrial alternatives;
- low market elasticity (i.e. lower prices stimulate little market growth);
- launcher cost/availability/reliability.

The first factor is important because the growth of space activities is still dominated by government programmes, both civil and military. Communication satellites represent the nearest thing to a truly commercial market sector, but government funding still underpins much of their basic R&D while the second and third factors have placed significant restraints on their growth and evolution, as witnessed by the problems of commercial ventures like Iridium, Globalstar, ICO, SkyBridge and Teledesic.

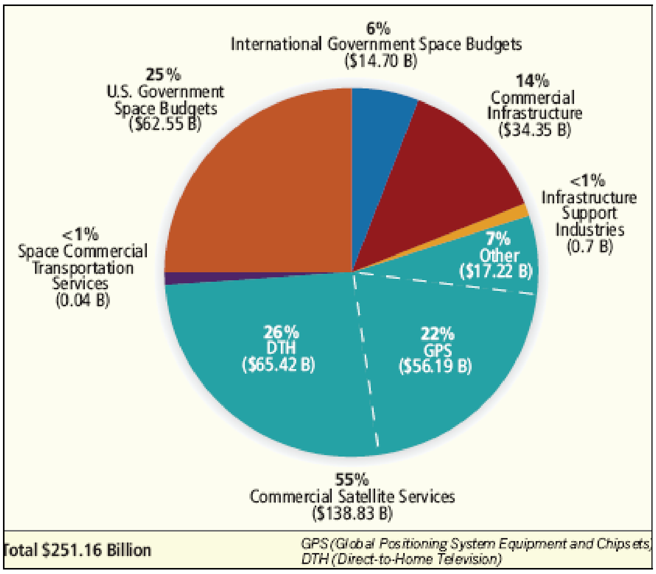

Figure 1. Global Space Activities, 2007 [RD.1]

To put the situation into perspective, Figure 1 shows a breakdown of the global space industry's annual revenue, which was $251 billion in 2007. However, this was still less than the annual turn-over of a single successful commercial company like Wal-Mart [RD.2], which was founded in 1962 but has managed to outgrow the entire world space industry by servicing vastly bigger and established markets.

2.2 Future Potentials

A wide range of future space-based activities and associated business opportunities[2] have been discussed for many decades (e.g. space manufacturing facilities, solar power satellites) but their realisation has also been limited by a few key factors:

- large investment requirements;
- operation and utilization cost uncertainty;
- market demand and elasticity uncertainty/variability;
- launcher cost, availability and reliability.

Given these circumstances – and in the absence of a major government imperative, equivalent to that which justified Apollo (i.e. the Cold War) – it has become clear to many that the current paradigm will not lead to any significant growth of space activities in the foreseeable future. As a consequence, a second wave of NewSpace ventures has now begun to emerge[3] (see Table 1) that represent an attempt to change the paradigm by placing greater emphasis on entrepreneurial rather than government activities. They believe that the best way to do this is to stimulate existing and/or new markets in order to drive and sustain their growth, primarily through the power of commercial enterprise. Moreover, as launch issues are seen as the common factor that limits both current and future growth, most have chosen to address this issue first; their ultimate aim being to reduce specific launch costs by an order of magnitude to below about

2 For example, the Commercial Space Transportation Study (CSTS) performed a comprehensive review in 1994 of all current and foreseeable markets [RD.3]

3 Summaries and links for all current ventures are at (http://www.space-frontier.org/commercialspace)

$1000/kg to LEO, the point where significant growth in all market sectors is expected to be triggered.

Company	Initial Market	Initial Funding
SpaceX	Commercial orbital launch	Founder (~$100m)
Masten Space	Sub-orbital research	Founder (>$1m)
XCOR	Sub-orbital research/tourism	Angel investors (>$10)
Armadillo Aerospace	Sub-orbital research/tourism	Founder (>$5m)
Blue Origin	Sub-orbital tourism	Founder ($?)
Virgin Galactic	Sub-orbital tourism	Corporate (~$20m)
Bigelow Aerospace	Commercial space stations	Founder (~$80m)

Table 1. Leading NewSpace Ventures, Markets and Funding

Nevertheless, it is important to realize that this NewSpace paradigm is not solely restricted to entrepreneurial start-up companies. A more thoughtful definition would also include groups working within established companies, such as Boeing, Lockheed-Martin and Orbital Sciences, who are also seeking to stimulate existing and new markets by applying novel technologies and commercial practices such as fixed-price, rather than cost-plus, contracts.

3 The Launcher Challenge – Is it just a technology problem?

It has long been recognised that the only way of achieving significant improvements in space access is via the use of reusable launch vehicles (RLVs), rather than expendable launch vehicles (ELVs), because they offer:

- major reductions in marginal costs, as expensive components tend not to be discarded after use;
- better amortisation of investments, as costs can be spread across more users;
- higher reliability and safety, due to the intrinsic value of the vehicle.

Unfortunately government efforts to field such systems have, to date, either missed many of their original goals (i.e. Shuttle) or been outright failures (X-33/VentureStar, X-34, etc.). Moreover, commercial efforts to develop such systems have been hampered because their development costs are difficult to justify against potential markets, for example:

- many studies estimate it will cost $10-20 billion to field an operational system;
- the existing markets that would justify their development have limited growth and elasticity[4] (i.e. lower prices stimulate only limited market growth, as illustrated in Figure 2);
- the new markets that could justify their development are far too uncertain and speculative.

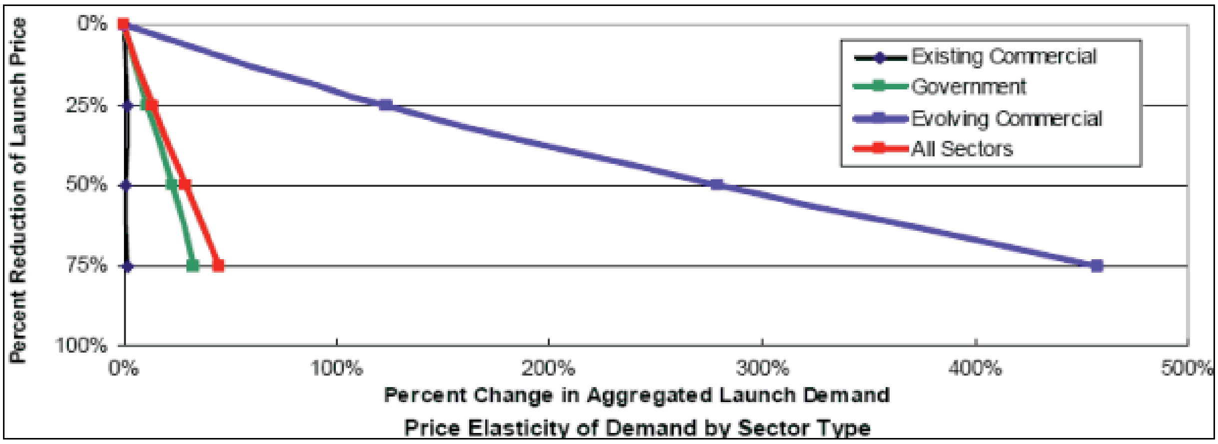

Figure 2. Space Launch Market Elasticity by Sector [RD.4]

Such factors show that both market and financial issues play just as important a role as the obvious technical ones. They also explain why NewSpace ventures have chosen to begin by developing RLVs to service sub-orbital markets, which demand significantly less of an initial investment, with many estimating that only $100m-$200 million will be required. However, the limit performance of sub-orbital RLVs clearly prevents them from servicing the majority of existing and future markets, which are based in LEO, GEO and beyond, thereby raising the question: how could they evolve in order to overcome this major limitation?

4 Space market elasticity is difficult to estimate due to the relatively small size and low diversity of current markets, though studies such as the NASA ASCENT Study [RD.4] and the CSTS [RD.3] have derived tentative estimates.

3.1 Technical Challenges – Suborbital to Orbital Evolution

When addressing the question of how a sub-orbital vehicle could evolve into orbital vehicle, it is worth noting that the energy difference between a sub-orbital (~4Mn) mission and an orbital (~25Mn) mission is a factor of ~40. For a rocket powered vehicle, this not only means using more propellant but also requires better/lighter engines (T/W), structures, thermal protection, control systems, power systems, life support systems, etc. However, it is very important to recognise that, given the right concept, such capabilities could be added, incrementally, to enable flight envelope expansion and so deliver an evolutionary growth of system performance.

In fact, a relatively simple first step in this evolutionary process is to use a suborbital RLV, or clusters of the basic units[5], as a launch platform for an expendable upper stage and a number of the current NewSpace ventures are actively pursuing this approach, while Figure 3 and Figure 4 illustrate two conceptual examples.

It should be stressed that the orbital performance of such a launch system will be fundamentally limited by the size of suborbital RLV and so the expected payload performance of these systems is likely be less than 1000kg into low Earth orbit (LEO). Nevertheless, most of these suborbital RLVs are being designed to fly at least once per day – typically, three sorties per day are envisaged – and are expected to require a ground crew on the order of a dozen people to prepare and maintain them at costs on the order of $10k per flight, which means that the orbital system's cost should be more than competitive with current equivalents (e.g. Pegasus). Moreover, because they will launch their upper stage much higher (~30km), faster (~4Mn) and at a steeper

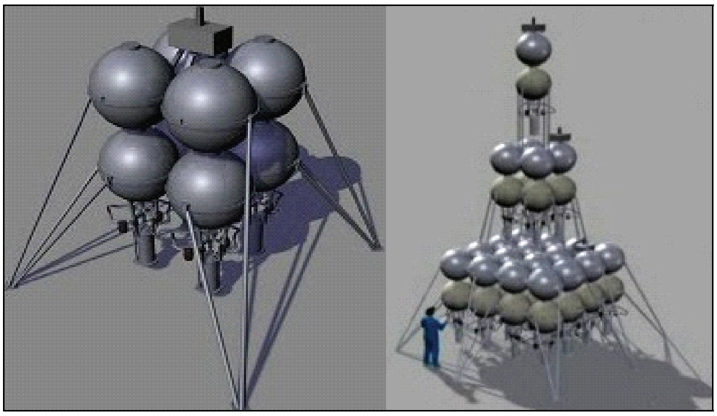

Figure 3. Armadillo Sub-Orbital & Orbital Concepts

5 This concept was first pioneered by OTRAG, a West German company founded in 1975

flight path angle than would be possible from a conventional aircraft, the performance and cost of the upper stage should be reduced commensurately.

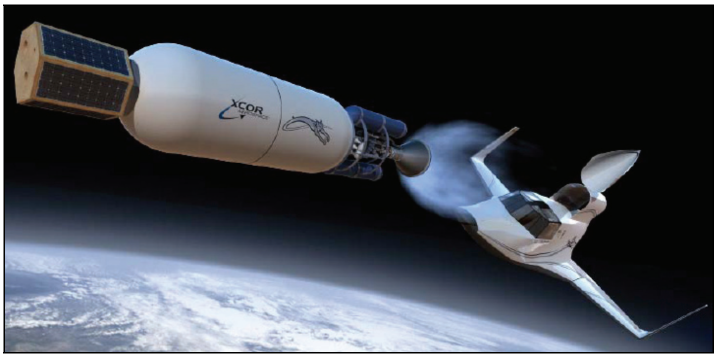

Figure 4. XCOR Orbital Launch Concept

Beyond this relatively simple first step, the path to realizing launch systems with larger LEO performance and fully reusable upper stages will be significantly more challenging, requiring larger first stages and upper stages capable of withstanding the rigors of high speed re-entry. Nevertheless, past studies have shown how such fully reusable systems can be developed from smaller units and Figure 5 illustrates an example called MUSTARD, which was developed by the British Aircraft Corporation (BAC) in the mid-1960's and was capable of placing medium sided payloads of around 4t into LEO.

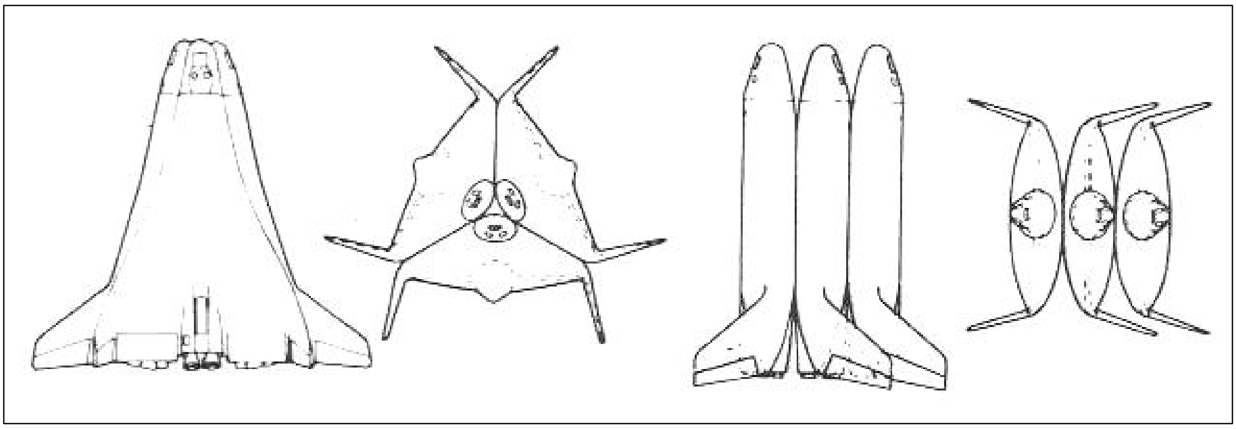

Figure 5. The MUSTARD concept (BAC, 1964-65)

Though MUSTARD was a trimese concept, others have proposed using only two vehicles (i.e. a bimese concept) and Figure 6 illustrates one such example[6], which also shows the proposed evolutionary development path from much smaller but conceptually very similar vehicles (N.B. the F-15 is shown only as a scale reference).

[6] Taken from the paper "A Rocket-Powered Technology Demonstrator for Responsive Access to Space" (AIAA-RS3 2005-6006)

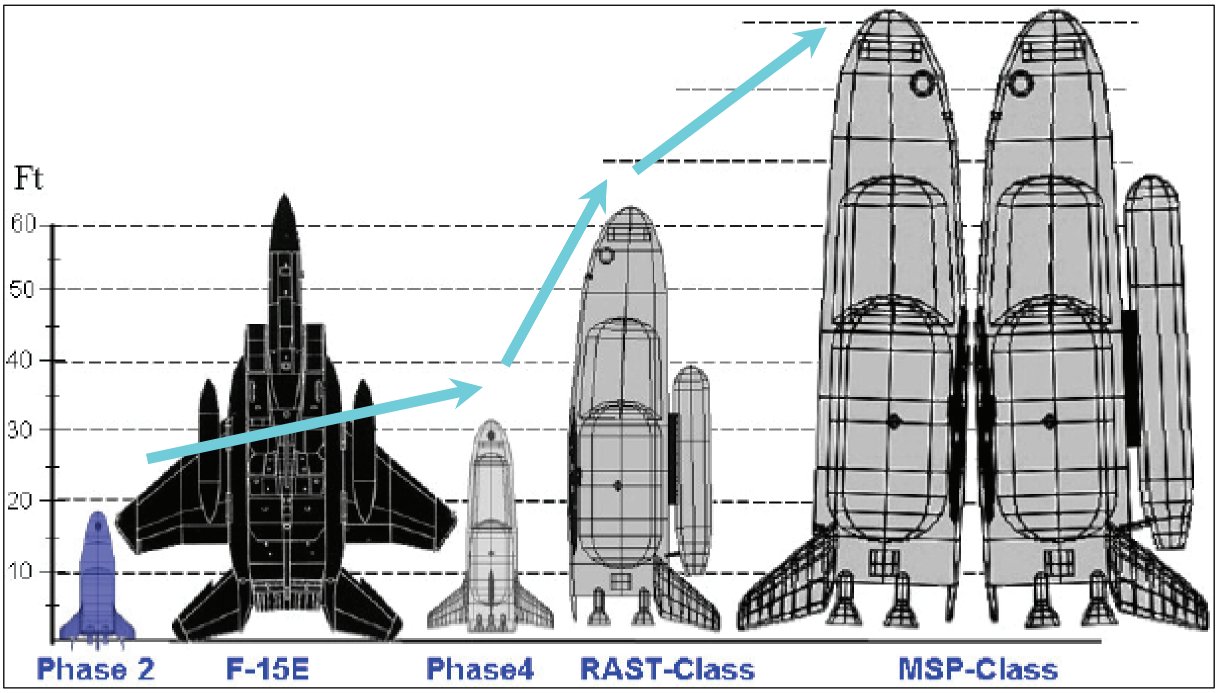

Figure 6. Evolutionary Steps for a Bimese Launcher

In addition to these potential evolutionary paths for vehicle design, there is an interesting operational concept that may enable relatively small or medium sized RLVs to service the largest and, currently, the most lucrative commercial launch market sector; communications satellites (comsats). Past analyses by VEGA indicates that a vehicle capable of delivering a 4t payload into LEO could service all currently planned commercial payloads, including comsats bound for geosynchronous orbit (GEO), because all have a beginning of life (BoL) mass ~35% below their initial launch mass. This is because a significant fraction of their launch mass is propellant that they must burn in order to transfer themselves from GTO to GEO. The key to servicing these markets is, therefore, the on-orbit assembly of a kick-stage capable of delivering the comsat directly into GEO, as illustrated in Figure 7.

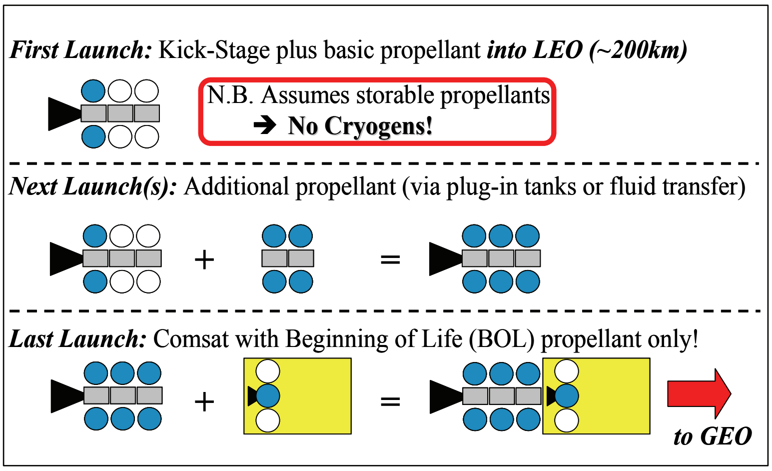

Figure 7. Orbital Assembly Scenario (Standard Comsat)

Clearly, this operational approach would be an evolution of the basic orbital vehicle's capabilities but the upgrades to enable rendezvous and docking are not considered to be a major technological challenge, since they have already been demonstrated successfully by Japanese and US projects (i.e. ETS VII and Orbital Express).

3.2 Business Challenges – Developing the Markets

As the rationale for NewSpace depends upon the commercial viability of these ventures, a brief discussion of the challenges related to their business case is considered worthwhile. The current crop of NewSpace companies, such as those listed in Table 1, is actually the second wave of such ventures. The first wave began in the mid-1990's and was aimed at servicing the expected launch demands[7] of systems like Teledesic, which initially envisage a constellation of more than a thousand satellites in LEO providing direct global internet services. Sadly, Teledesic was never built and similar though less ambitious ventures like Iridium, which did launch, were such commercial failures that they effectively killed all prospects for similar ventures in the foreseeable future.

Nevertheless, as Table 1 shows, the nascent concept of sub-orbital space tourism is now fostering development of a number of reusable launch systems that appear to have a potential to evolve into a disruptive technology[8]. This has been driven by the combined effect and interplay of a number of factors, namely:

- the significant "challenges" faced by government space programmes, in particular human spaceflight initiatives that have had encountered severe cost and schedule overruns (i.e. Constellation);
- improved development and production methods, which enables small groups to perform advanced design and manufacturing activities;

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[7] ESA study "Assessment of Small Reusable Launcher Developments" (ESA HQ Contract No. 970801)

[8] The term 'disruptive technology' was first coined by Professor Clayton M. Christensen in his 1997 book "The Innovator's Dilemma – When New Technologies Cause Great Firms to Fail"

- increased wealth of the individual, which increases the potential market's size.

These factors mean that the NewSpace approach to system development is more akin to a 'Skunk Works' approach, which gives it the potential to service rapidly evolving markets by:

- limiting its investment requirement to between \$10m to \$200m;
- making use of existing systems and technologies, whenever possible;
- employing small teams that can evolve designs in small but rapid steps (build, test, correct …).

Obviously, none of these factors guarantees the success of any NewSpace venture. However, they show that the lessons of past commercial failures have been learned and that strategies to minimize the inherent risk of such ventures have been adopted. However, one of the most significant business challenges relates to market elasticity and the way that it has effectively stifled incentives to reduce current commercial ELV launch prices.

Figure 8 illustrates this problem, which relates to the fact that most commercial businesses would expect that any price reduction of their product or service would, to some degree, encourage new customers and thereby increase their revenue. However, the very low elasticity of current space markets (see Figure 2) combined with the price structures of commercial launch operators means that lower prices will actually result in a significant decrease in total yearly revenue!

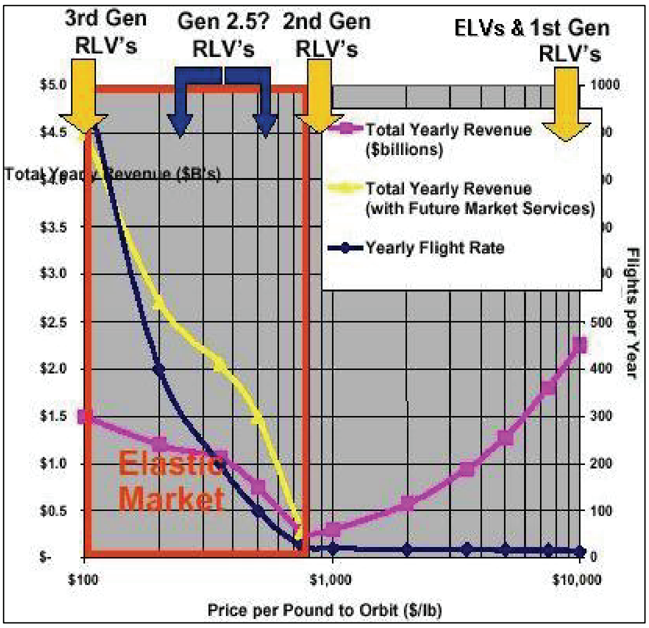

Figure 8. Market Elasticity Issues [RD.5]

The only way to overcome this situation is via a radical drop in launch price to around $1000/kg or less, which can only be achieved via a mature RLV. Obviously, this assumes that RLVs can be flown at a sufficiently low cost so that their operators could charge such a low price and still make a profit (N.B. Price - Cost = Profit). However, given that all other mature transportation systems (i.e. road, rail ship and aircraft) have operations costs between 3 and 8 times their fuel cost, simple calculations would suggest that a mature RLV with a conservative payload fraction (payload/gross launch mass) of 0.01 and a propellant cost of about $1/kg (e.g. for liquid hydrogen/oxygen propellants) should be capable of making a profit charging a specific launch price well below the $1000/kg target.

Nevertheless, it should be appreciated that cost isn't everything and that frequent flight availability and a timely and efficient integration process are just as important. A good example of this is NASA's Get Away Special (GAS) canisters [RD.6] that were priced on the order of $100/kg to LEO but, because of the long and complex Shuttle integration process, were undersubscribed so that many GAS canisters were filled with ballast and were eventually discontinued after the Columbia accident.

4 Prospects for the Future – Routine Suborbital Flights

Most mainstream news media coverage of NewSpace ventures has tended to focused upon space tourism and, more especially, the publicity surrounding Virgin Galactic. However, as has already been mentioned, there are quite a number of other markets that will likely be stimulated by vehicles capable of routine daily flights above 100km into the near-space environment and their accompanying short periods of weightlessness. Indeed, there is now a small but very active initiative to stimulate the interest of researchers and other groups to exploit these nascent services, which is led from NASA Ames and is called the Commercial Reusable Suborbital CRuSR Research Program.

Currently, the only way to access these environments is via sounding rockets or parabolic flights but, as Figure 9 shows, services based upon reusable systems will bring significant benefits. Moreover, as a good many of these services do not necessarily require people flying aboard the vehicle, they will not demand the high levels of reliability that would be expected from a passenger carrying system. This is extremely important because it means that such systems can begin revenue earning flights far sooner than would otherwise be possible, which will not only improve their cash flow but will also help demonstrate the viability of their business case by providing real evidence of market demand. Similarly, systems that are not built primarily to fly passengers can be much smaller and so become more affordable to both build and test, particularly if they can later be clustered together to increase their payload performance. For these reasons, many believe that the suborbital science and research services will play a vital role in both establishing and a providing proof-of-principal for the NewSpace paradigm. Nevertheless, it is clear that once vehicle become available with the necessary levels of safety and reliability to enable revenue earning passenger services, space tourism will likely become the most profitable market sector for suborbital flights.

	Expendable Near-Space	Reusable Near-Space	Parabolic Aircraft Flights
Cost/Person	N/A	$200K	Included in payload cost
Cost/Payload	~$0.5M - $1.2M	~$2.5K/kg	~$8K
Time in Microgravity (Continuous)	20 minutes	4+ minutes	23 seconds
Quality of Microgravity	High	High	Comparatively Low
Launch Frequency	Once / month	Multiple flights per day possible	Multiple flights per day possible
Maximum g-Loading	20 g	2 – 4 g	2 – 4 g
Human Tended Science	No	Yes	Yes
Reliability	≥ 99%	TBD	≥ 99%
Late Payload Load / Early Payload Recovery	Special Arrangement	Yes	Yes

Figure 9. Comparison of Suborbital Options [RD.7]

In terms of operations, routine suborbital flights will involve activities more akin to those of an airline than those of a satellite. With an expected minimum fleet size of three vehicles and flight times measured in tens of minutes, rather than hours, reusable sub-orbital vehicles will still spend the majority of their time on-ground rather than in-flight, even if their operational tempo rises to three flights per day. This implies that most of the operational demands will relate to ground-based activities and, in particular, the maintenance and turn-around cycles. These will have to be both thorough and timely in order to meet the conflicting demands of high reliability and availability. As these vehicles will be expected support a profitable commercial business, such demands will be compounded by the need for an absolute minimum of ground crew in order to minimize overhead costs and so this will naturally drive the ground segment's technical requirements towards highly automated operations for vehicle maintenance and turn-around.

From the customer side, a variety of sub-orbital services and a desire for short booking and integration times, along with a minimum of paper work and other administrative overheads is likely to stimulate the creation of service agents. These will act as the interface to the service provider with the aim of both simplifying and streamline the integration operations. Moreover, as many potential customers are likely to see a sub-orbital flight as a precursor to orbital flights (e.g. as a way of checking out equipment intended for use aboard the ISS), these agents would eventually be expected to act as a one-stop-shop for LEO based services too. In this way, such agent would eventually be expected to make bulk purchase of both sub-orbital and orbital launch services and so offer users a tailored package to enable whole test campaigns to be preformed in an efficient, timely and cost-effective manner.

5 Prospects for the Future – Commercial Orbital Transport Services

In January 2006, NASA assigned the sum of $500million for a series of contracts entitled Commercial Orbital Transportation Services (COTS) that will culminate in flight demonstrations of commercial ISS cargo re-supply and, if Option-D is exercised, crew launch services. NASA had studied alternate ways to ensure ISS logistics re-supply and crew access for more than a decade and the last major initiative prior to COTS, the Alternate Access Study [RD.8], was begun one year prior to the Columbia accident in 2003 that resulted in the Presidential directive to retire the Shuttle fleet by 2010. Recent presidential policy changes have strengthened the commitment to COTS and, more importantly, have proposed a further $300million increase in COTS funding to help ensure that NASA can purchase such services, worth up to $3.5billion, once they have demonstrated the required levels of safety and performance.

SpaceX and Orbital Sciences Corporation (OSC) are the only companies currently funded by COTS and both are developing new ELVs to service this market, though SpaceX were already developing their Falcon 9 to service the GEO comsat market before proposing it for COTS. However, there is no guaranteed that they will be awarded follow-on service contracts because it is very likely that Boeing and Lockheed-Martin, who each build and operate ELVs with suitable performance capabilities (i.e. Delta 4 and Atlas 5), will also compete for them. This is because, in addition to the launch vehicle, the key component to enabling these services is a service module and payload carrier or, in the case of crew launch, a capsule that must be able to perform both orbit maneuvering and rendezvous operations, with the final attachment to ISS being performed via berthing, rather than docking, operations under control of the ISS crew. Moreover, in order to ensure robustness against launcher unavailability (e.g. after a failure), such systems will very likely be compatible with several launchers and so could be built by a completely different contractor.

While the ISS and COTS may provide a stable market for LEO cargo and crew delivery, COTS contractors like SpaceX are also attempting to stimulate associated markets by offering a version of their pressurized cargo carrier called DragonLab (Figure 10) for dedicated free-flying microgravity missions. Even more speculative ventures are being considered by both Boeing [RD.9] and Lockheed-Martin [RD.10] that would use crew capsules developed for COTS to service the Sundancer commercial space station being

Figure 10. The 'DragonLab' Free-Flying Capsule

developed by Bigelow Aerospace (Table 1 & Figure 11), which could be launched as early as 2014 and thereby enable a large number of new market opportunities for commercial manned operations in LEO. One of the most interesting business aspects of the Bigelow concept is the idea that whole or parts of the space station modules could be leased to commercial companies or even sovereign states that currently do not have their own space transportation or in-orbit infrastructure. In addition, such facilities are also expected to encourage the concept of commercial astronauts providing on-orbit support to these users, who would hire their services in a similar manner to commercial deep sea divers.

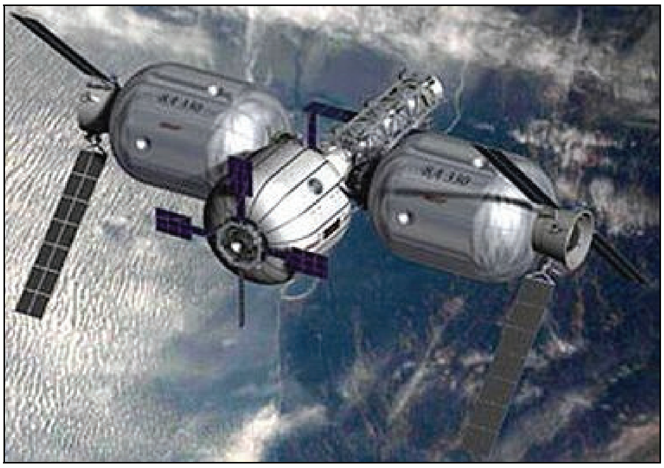

Figure 11. The 'Sundancer' Commercial Station

Nevertheless, it must be stressed that the initial cost of these services will still be very high because of their reliance on ELVs to get them into LEO. However, they will demonstrate the potential demand for these new markets and, if this proves sufficient, will boost the business case for commercial RLVs and thereby foster the means to achieve a radical reduction in launch costs by the end of the decade. This, in turn, is expected to substantially alter the cost-benefit trade-off between human and robotic operations in LEO, shift the emphasis away from remote operations executed by teams of ground-based engineers to in-situ operations performed by cadres of professional commercial astronauts.

Considering all of these potential future developments, it is obvious that COTS could be a huge stimulus for new commercial markets and, therefore, have significant impacts on future space operations, especially as these commercial LEO markets will have a strong synergy with many of the suborbital markets, such as microgravity. It should also be noted that the recent presidential policy changes have proposed an additional $650million in 2011 for technology demonstration efforts, largely focused on so-called flagship-class projects costing between $500million and $1billion apiece to demonstrate breakthrough capabilities such as in-orbit refueling and propellant storage and autonomous rendezvous and docking. These capabilities are seen as key to deploying in-space infrastructure that will enable far more ambitious missions and operations in higher Earth orbits (e.g. polar orbits and GEO) and deep-space destination such as the Earth-Moon Lagrange points, the Moon itself, near-Earth asteroids and beyond to destinations such the moons and surface of Mars.

Unfortunately, as such radical changes will require a significant redirection of limited NASA funds, their progress is very likely to be hampered by both political debate and a general reluctance to either modify or terminate the existing programs. Nevertheless, the long-term benefits of these concepts make it inevitable that they will have to be adopted in some form or another if humans are ever to going to make substantial advances beyond low Earth orbit.

6 Steps towards the NewSpace Paradigm Shift

This paper has identified the key reasons why space activities have so far failed to achieve the great expectations set out at the dawn of the space age, over half a century ago. It has also describe the ways in which small groups of people are attempting to change the current paradigm but has also indicated the enormity of the challenges they must overcome in order to realize their ultimate goal. Finally, it has shown how recent initiatives are providing the necessary technical and business environments in which to nurture and grow the capabilities that may ultimately deliver this paradigm shift.

Based upon all of the information presented in the previous sections, Table 2 attempts to consolidate these ideas by briefly sketching out the most likely steps to achieving the NewSpace paradigm shift, their associated timeframe and their most significant impacts on future space activities.

Clearly, many of these steps will slip, change or may never be realized. In fact, the NewSpace paradigm shift may prove to be unachievable because of fundamental constraints that have yet to be discovered. So, although there is good reason for cautious optimism, it would be better to regard these activities as experiments within a process of Darwinian evolution rather than the milestones of some overarching space program.

Timeframe	NewSpace Steps	Impacts
Proof of Concept (2010-2015)	Frequent reusable suborbital flights for small science/research experiments (~2011)	SIGNIFICANT: Rapid flight vehicle turn-around and payload processing
	COTS payload services to ISS (~2011)	MODEST: Increased microgravity experimentation
	COTS crew rotation to ISS (~2015)	MODEST: Improved human in-situ servicing and support
Concept Maturation (2015-2020)	Commercial space station & ELV support (~2015)	SIGNIFICANT: Increased human in-situ servicing and support
	Frequent reusable suborbital services for tourist passengers (~2015)	SIGNIFICANT: Rapid flight vehicle turn-around and passenger training
	2nd generation RLVs for ISS cargo and GEO satellite launch (~2017)	VERY SIGNIFICANT: Increased satellite missions and space infrastructure development
	2nd generation RLVs for passenger services to ISS and commercial stations (~2017)	VERY SIGNIFICANT: Increased human in-situ activities supporting complex space developments
	In-orbit propellant depots for crewed exploration missions (~2020)	VERY SIGNIFICANT: Enables deep space exploration missions and exploitation of space resources

Table 2. Steps towards the NewSpace Paradigm Shift

Nevertheless, given the current number of NewSpace ventures and their success to date, it seems reasonable to believe that some will manage to “boot-strap” themselves into orbit within the next decade and so begin to deliver on the dream of opening the space frontier and thereby harness the infinite resources of outer-space for the benefit of all mankind.

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