2

Suborbital Market

The suborbital spaceflight market represents a fundamental shift in the nature of the manned spaceflight business. When SpaceShipTwo's and Lynx's start routine suborbital flights, it will jumpstart a new commercial space industry. But what exactly is this industry and just how viable and successful will it be?

In November 2011, Space Florida – the State of Florida's spaceport authority and aerospace economic development agency – and the Federal Aviation Administration Office of Commercial Space (FAA-AST) partnered to commission a study prepared by the Tauri Group to forecast the 10-year demand for suborbital reusable launch vehicles (sRLVs). The analysis interviewed 120 potential users and providers, polled 60 researchers, assessed budgets, and surveyed more than 200 high-net-worth individuals. The results of the study – Suborbital Reusable Vehicles: A 10-Year Forecast of Market Demand – were made available to the public via the Space Florida and FAA websites and, since it's the only study of its kind, much of what appears in this chapter is taken from the study.

At the heart of the survey – and the new spaceflight industry – are the sRLVs (Figure 2.1 and Table 2.1), commercially developed vehicles capable of carrying passengers and/or cargo. At the time of writing, 11 sRLVs are in active planning, development, or operation, by six companies. The payload capacity of these vehicles ranges from tens to hundreds of kilograms, and some vehicles such as SpaceShipTwo (SS2) can carry passengers. Others, like the Lynx, will also launch very small satellites. The companies developing these vehicles are ambitious and hope to fly regularly, and by regularly we're not talking about once a month; these vehicles may fly several times a day. Given these lofty goals, it made sense to provide information to the government and industry about the potential of this breed of space vehicle, and that's what the Tauri Group did. By analyzing dynamics, trends, and areas of uncertainty in the eight distinct markets (Table 2.2) sRLVs could support, the group came up with a projected demand.

E. Seedhouse, *Suborbital: Industry at the Edge of Space*, Springer Praxis Books,
DOI 10.1007/978-3-319-03485-0_2, © Springer International Publishing Switzerland 2014

2.1 Suborbital reusable launch vehicle. Courtesy: EADS

Table 2.1 SRLVs in Development.

Company	*SRLV*	*Seats*	*Locker equiva-lents*	*Cargo (kg)*	*Price*	*Operational date*
UP Aerospace	SpaceLoft XL		0.5	36	US$350k	2006 (actual)
Armadillo	STIG A		1	10	per launch	2012
Aerospace	STIG B		2	50	Not announced	2013
	Hyperion	2	12	200	US$102k/seat	2014
XCOR	Lynx Mark I	1	3	120	US$95k/seat	2013
Aerospace	Lynx Mark II	1	3	120	US$95k/seat	2013
	Lynx Mark III	1	28	770	US$95k/seat	2017
Virgin Galactic	SpaceShipTwo	6	36	600	US$200k/seat	2014
Masten Space	Xaero		4	25	Not announced	2013
Systems	Xogdor					
Blue Origin	New Shepard	3+	5	120	Not announced	Not announced

To generate as accurate a picture of sRLV market dynamics as possible, the Tauri Group forecast demand for each market (Table 2.3) based on three scenarios:

- *Baseline scenario*: sRLVs operate in a predictable political/economic environment. Existing trends generate demand for sRLVs.
- *Growth scenario*: New dynamics emerge from marketing, branding, and research successes. Commercial human spaceflight has a transformative effect on consumer

Table 2.2 SRLV Markets.

COMMERCIAL SPACEFLIGHT	BASIC AND APPLIED RESEARCH
Human spaceflight experiences for tourism or training	Basic and applied research in various disciplines
AEROSPACE TECHNOLOGY TEST AND DEMONSTRATION	MEDIA AND PUBLIC RELATIONS
Aerospace engineering to advance technology maturity or achieve space demonstration, qualification/certification	Using space to promote products, increase brand awareness, or film space-related content
EDUCATION	SATELLITE DEPLOYMENT
Providing opportunities to K-12 schools, colleges, and universities to increase access to and awareness of space	The use of SRLVs to launch small payloads into orbit
REMOTE SENSING	POINT-TO-POINT TRANSPORTATION
Acquisition of imagery of Earth and Earth systems for commercial, civil government, or military applications	Future transportation of cargo or humans between different locations

Table 2.3 Seat/Cargo Equivalents.

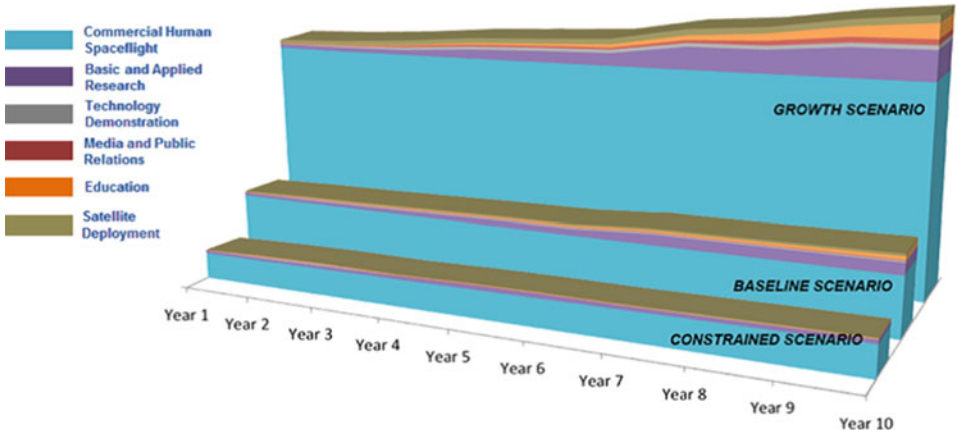
	Year										
Scenario	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*Total*
Baseline	373	390	405	421	438	451	489	501	517	533	4,518
Growth	1,096	1,127	1,169	1,223	1,260	1,299	1,394	1,445	1,529	1,592	13,134
Constrained	213	226	232	229	239	243	241	247	252	255	2,378

behavior, and more customers buy flights. Research results are productive and attract new government and commercial interest.

- *Constrained scenario*: sRLVs operate in an environment of dramatic reduction in spending, due, for example, to worsened global economy.

The Tauri Group also compared forecasts for all markets by scenario, as shown in Figure 2.2, which indicated demand for sRLVs is dominated by commercial human spaceflight, based on an analysis of 8,000 high-net-worth individuals who are sufficiently interested in buying a ticket.

As you can see in Table 2.3, the baseline forecast is 373 seats in Year #1, growing to more than 500 seats by Year #10, totaling more than 4,000 over the first decade. But, if commercial spaceflight really takes off, the growth scenario predicts 13,000 seats. If, on the other hand – and let's hope this doesn't happen – the industry stalls, the constrained scenario predicts just over 2,000. Of course, as meticulous as the Tauri Group was in generating their forecast, there is still uncertainty due to the dynamics of demand as it responds to future events. For example, demand may not always be steady because it could grow more rapidly than predicted based on social dynamics following successful launch

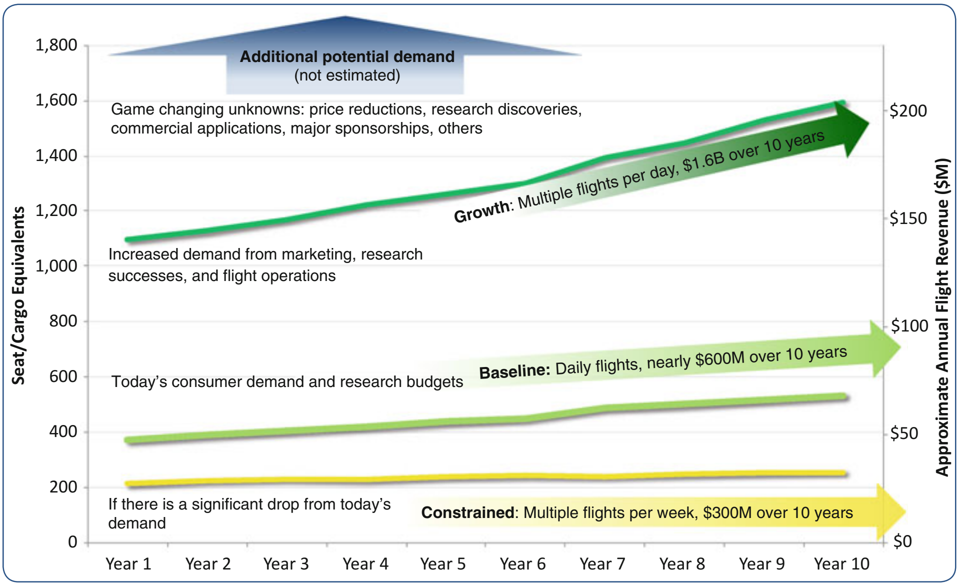


2.2 Potential growth in the suborbital markets. Courtesy: Tauri Group

experiences. Equally, if a vehicle suffers a major malfunction with loss of life, demand would decline sharply and probably come to a standstill. The bottom line is that the forecast is presented as a relatively steady state in each scenario, reflecting current levels of interest.

Going back to Figure 2.2, we can see the second largest area (about 10%) of demand is basic and applied research, funded by government agencies, and research not-for-profits, universities, and commercial firms. Given all the media coverage generated by the subject of space tourists, it's easy to forget sRLVs will be used for science missions, just as they will be utilized to perform technology test and demonstration and satellite deployment. But, the majority of sRLV demand will come from individuals and, because this market is a consumer market, the capability and viability of sRLV ventures will be influenced by individual decision makers. What this means is that, unlike enterprise users (whose demand is for cargo rather than seats) who often have decision-making lead times measured in years, individuals can make purchasing decisions quickly and the behavior of consumers in the industry is unknown. It is this unknown factor that makes it difficult to estimate revenue because consumer behavior can only be based on assumptions – will passengers fly only once or will they be repeat customers? Equally, if sRLV capabilities vary from current expectations, levels of activity could be higher or lower. For example, NASA, the Canadian Space Agency (CSA), and the European Space Agency (ESA) might decide to use sRLVs for astronaut training and research integrated with International Space Station (ISS) activities. This development isn't too far-fetched given that the forecast predicts more than 50 governments will begin to fund sRLV research.

In short, the Tauri Group concluded that, at a minimum, demand for suborbital flights will be sustained, and be sufficiently robust to support multiple providers with a baseline demand over 10 years exceeding US$300 million in revenue. But, in the event of increased marketing, research successes, greater consumer uptake, *and* multiple flights per day, revenue could generate US$1.6 billion in the first decade. That's a healthy industry (Figure 2.3).

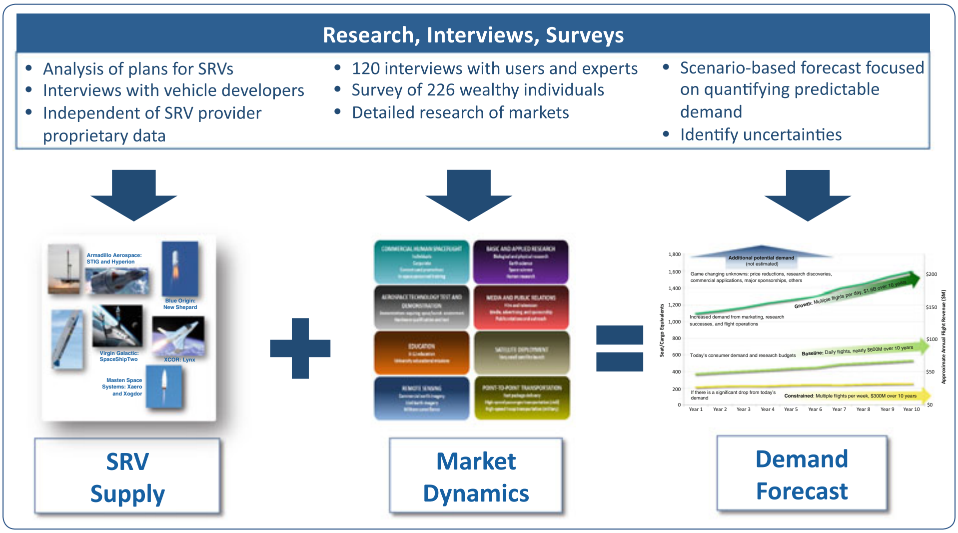


2.3 Potential flight revenue in the suborbital markets. Courtesy: Tauri Group

THE 10-YEAR FORECAST

Before going into the details of the Tauri Group's forecast, it's worth reviewing the approach they used. The group used primary research and open-source materials to assess sRLV capabilities and also reviewed government budgets to build as complete and objective a picture of sRLV market dynamics as possible. Primary research used three techniques. The group interviewed 120 potential sRLV users and experts, including scientists and researchers, filmmakers, investors, educators, astronauts, physicians, consultants, private-sector researchers and spaceflight providers. They also surveyed more than 200 individuals with at least US$5 million in investable assets, in a randomized, scientific analysis, to estimate demand for sRLV flights among customers with assets consistent with sRLV prices. Finally, 60 suborbital researchers were polled at the 2012 Next Generation Suborbital Researcher's Conference (NSRC) and a space researcher's conference in Japan. Based on these data, the group analyzed each market and submarkets in terms of current and future activity, evaluated the sRLV market position based on sRLV capabilities, and compared this to competing services and platforms. The approach they took is summarized in Figure 2.4.

Each submarket was characterized in units relevant to the market segment. For example, locker equivalents were based on the standard sizes of Shuttle middeck lockers, EXPRESS (EXpedite the PRocessing of Experiments to Space Station) lockers, and NanoRacks (Figure 2.5) and, except for the crew, passenger seats were standardized by the number of individuals and not by their mass or volume.



2.4 Tauri Group's research strategy. Courtesy: Tauri Group

Each market was then aggregated into seat/cargo equivalents which were determined using average cargo capacity compared to seats on proposed sRLVs. This aggregation resulted in the conversion of one seat/cargo equivalent equaling one seat or $3\frac{1}{3}$ lockers – a translation that allowed the group to standardize and consolidate forecasts across all markets, reflecting a mix of cargo, people, and dedicated flights. The scenarios described earlier were based on the assumption sRLV prices would remain at current levels and sRLVs would be operated safely. Based on the operators who had announced seat prices, an average ticket price was estimated at US$123,000.

REUSABLE SUBORBITAL LAUNCH VEHICLES

We'll talk more about sRLVs in Chapters 4 and 5 but, for the purposes of understanding the survey, it's useful to have a brief overview of what these vehicles are and how they are operated.

sRLVs are launched beyond the threshold of space which, according to the FAI,[1] is 100 kilometers. During their brief excursion into space, these vehicles offer up to five minutes

1 The International Aeronautical Federation (FAI) is the world governing body for aeronautics and astronautics records, which includes man-carrying spacecraft. Among the FAI's responsibilities is the verification of record-breaking flights. Some records are claimed even though the achievements fail to meet FAI standards. For example, Yuri Gagarin earned recognition for the first manned spaceflight, despite failing to meet FAI requirements because he didn't land in his spacecraft (he ejected from it).

2.5 The NanoRack is an experimental platform built by NanoRacks LLC. Two NanoRacks are installed on board the International Space Station (ISS), each of the platforms holding up to 16 NanoRack payloads in the form of a CubeSat. NanoRacks LLC call the payloads NanoLabs, others call them CubeLabs™. Each payload is a compact 10 centimeters by 10 centimeters by 10 centimeters. In addition to being compact, the platforms allow for an easy "plug and play" interface, in which every project on the platform plugs into the ISS power and communications system; a similar approach could be used on board suborbital vehicles. Another popular cargo will probably be CubeSat-sized payloads. A CubeSat is a miniaturized satellite that has a volume of one liter (10 centimeters cubed) weighing no more than 1.33 kilograms, and usually uses commercial off-the-shelf (COTS) components. Thanks to their small size, CubeSats can be manufactured and launched for about US$65,000 to US$80,000 – a price tag far lower than most satellite launches, which is why it's a favorite option for schools and universities. Courtesy: NanoRacks LLC

2.6 SpaceShipTwo glides to a landing in the Mojave. Courtesy: The SpaceShip Company/ Virgin Galactic

of microgravity before returning to Earth. Some vehicles launch and land vertically, others are slung under mother-ships and launched in mid-air, and some take off and land like regular aircraft (Figure 2.6).

As you can see in Table 2.1, there are six companies in the business of planning, developing, and operating sRLVs, which have capacities ranging from tens to hundreds of kilograms. The vehicles, some of which can carry up to six passengers, have been in development for years and, as with so many aerospace ventures, development timelines have slipped and flight dates have been delayed. As this book is being written, George Whitesides predicted Virgin Galactic revenue flights would start in 2014. Many in the industry hope he's right. With so much uncertainty surrounding revenue flights, it isn't surprising operators have been reluctant to provide details on how rapidly they will increase flight rates, although most vehicle operators have targeted operational rates between once per week to multiple flights per day.

MARKET ANALYSIS

Before looking at each of the markets identified by the Tauri Group, it's useful to understand how each was defined. We'll start with the Commercial Human Spaceflight market, the expected market driver, which is divided into the following submarkets:

Individuals: space tourism and science/research flights
Corporate: flights as promotions for corporate customers
Contests and promotions: providing seats as a prize
Personnel training: training for orbital flights

Next is the Basic and Applied Research market, which is focused mainly on activities that expand the pool of knowledge (this is different from the Education market, which focuses on activities that use flights as a learning tool). This market is also divided into four submarkets:

Biological and physical research: payloads to investigate biological/physical responses
Earth science: observations and measurements of Earth
Space science: observations and measurements of the space environment
Human research: investigating human psycho-physiological responses

The Aerospace Technology Test and Demonstration market will advance technology maturity or achieve space demonstration, qualification, or certification. This market has two submarkets:

Demonstrations requiring space/launch environment
Hardware qualification and test

It is inevitable companies will use sRLVs to promote products and increase brand awareness. For example, the first job Astronauts for Hire (A4H) was hired for was to fly beer during a parabolic flight to promote an Australian beer company. The flight gained A4H a lot of media attention and no doubt the Media and Public Relations market will bring in a significant amount of revenue via the following four submarkets:

Film and television: filming for space-themed entertainment
Media advertising and sponsorship: logos/advertisements placed on space hardware
Public relations and outreach: awareness/recognition through association with SRLVs
Space novelties and memorabilia: objects that have flown in space

The fifth market is the Education market which – hopefully – will increase access to and awareness of space to schools, colleges, and universities. This will be achieved via the following two submarkets:

Education: payloads and activities for schools or students
University education missions: payloads developed by university students

Thanks to its payload adaptor, sRLVs such as the Lynx will be able to deploy satellites and launch small payloads into orbit. Depending on the success of XCOR, other operators may follow their lead and this (sixth) market – Satellite Deployment – could increase significantly.

The seventh market – Remote Sensing – includes the imaging of Earth and Earth's systems for commercial, civil government, or military applications. Finally, the eighth market – the Point-to-Point Transportation market (Figure 2.7) – will transport cargo and/or humans between distant locations, with three potential submarkets:

Fast package delivery (e.g. FedEx)
High-speed passenger transportation
High-speed troop transportation[2]

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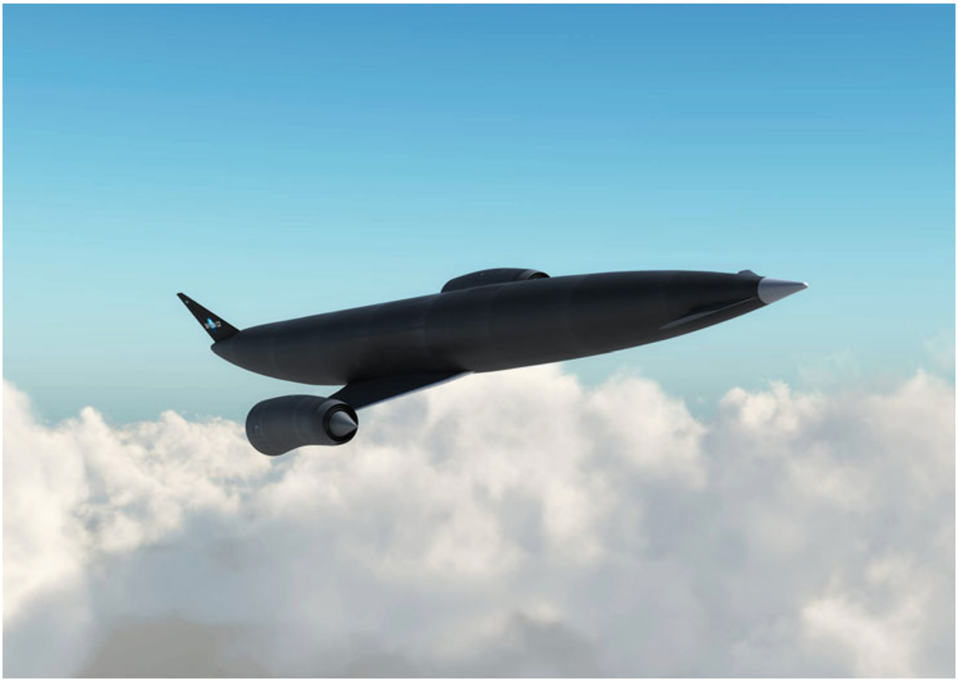
[2] Small Unit Space Transport and Insertion (SUSTAIN) is a concept first proposed in 2002 by the US Marine Corps to deploy Marines via suborbital flight to any location on Earth.



2.7 Reaction Rocket Engines' revolutionary transportation system. Courtesy: Reaction Engines

THE MARKETS

In their report, the Tauri Group analyzed each market in terms of market dynamics, how sRLVs fit into the market, current sRLV activity, sRLV demand forecast methodology, estimate of 10-year demand, uncertainty, and lack of awareness. What follows is a synop-sized version of that report.

Commercial Human Spaceflight

This is the market that gets the lion's share of media attention and is divided into four submarkets:

- individuals;
- firms using seats as incentives or rewards;
- organizations offering seats in contests and promotions; and
- space agencies using SRLVs for training.

To date, just over 500 people have flown in space and only a handful of these flew commercial. In fact, since 2001, just seven leisure travelers (Figure 2.8) have purchased eight orbital flights (one passenger flew twice) for up to US$35 million per flight.

2.8 Richard Garriott. Courtesy: Richard Garriott

For those who don't have deep pockets, there is a whole industry offering space-related experiences that deliver key elements of the space experience, such as a view of the curvature of Earth, zero-G flights, and MiG fighter jet flights. Then there is the experience of training for spaceflight offered by the National Aerospace Training and Research (NASTAR) Center which has trained over 100 future tourists.

To wealthy individuals or to those willing to remortgage their house, suborbital flights are attractive because they offer a combination of space experiences combined with the bragging rights opportunity to say they're an astronaut, all at a price significantly lower than orbital flights. An added bonus is the training (three days in most cases) is much less than the six months required to train for an orbital flight. Plus, you don't have to learn Russian!

Thanks to its cachet of offering a trip into space, it won't be surprising that corporations may be one of the suborbital industry's best customers. After all, executives of large companies often receive incentives comparably priced to a suborbital seat, including items such as zero-G flights (the cost to charter a zero-G flight – for up to 36 participants – is US$165,000 or about US$4,600 per employee). Then again, while offering suborbital flights may be attractive as a bonus, those executives may be prohibited from flying under corporate insurance coverage for senior executives. Too bad.

Another source of income from flying passengers will come from contests. When I attended the NSRC conference in San Francisco in February 2012, XCOR offered the prize of a free flight on board their Lynx via a draw. Unfortunately I didn't win, but Jennifer Brisco did – she was presented with the award in May 2012 after the main winner couldn't accept the prize:

> "It's been my lifetime goal to take a suborbital flight. This is an absolute dream … I am in shock right now, I am speechless."
>
> Jennifer Brisco after being presented with the award at the Expo

A year later, XCOR hit the news again when UK-based Unilever bought 22 flights on board the company's Lynx as part of Unilever's space-themed AXE (brand of men's cologne) Apollo™ Campaign. The campaign included Apollo astronaut Buzz Aldrin and a 30-second Super Bowl ad.

Another popular use of sRLVs will be in-space personnel training for orbital activities because sRLVs offer long-duration microgravity, frequent launches, and opportunities to train for challenging physical or medical situations. For example, in June 2012, Excalibur Almaz, a company developing an orbital commercial human spaceflight vehicle, announced it will train its crews on XCOR's Lynx as a requirement for pre-mission training.

So where does the suborbital passenger-capable launch industry stand as we begin 2014? Well, there are a number of manned sRLVs in development, operated by companies that have booked 925 reservations, with ticket prices ranging from US$95,000 to US$250,000. The majority of reservations are for individuals, but a number of research flights have also been bought. Confirmed ticket holders include celebrities such as Ashton Kutcher, Tom Hanks, Brad Pitt (scheduled for the second flight), X-men director Bryan Singer, Formula 1 racing legend Michael Schumacher, Paris Hilton, and, of course, Sir Richard Branson himself. According to recent announcements by Virgin Galactic, 35–40% of deposits originate from the US, 15% from the UK, and 15% from the Asia-Pacific region. Incidentally, if you're a frequent flyer and would like to use those miles for a suborbital flight, it will cost you two million miles to redeem via Virgin!

Profiles of Select Suborbital Celebrities

> *Bryan Singer, 41, film and television director/producer*
> You know him from such movies as *The Usual Suspects* and *X-Men*. Singer, a science-fiction fan, who says *From the Earth to the Moon* is his favorite miniseries, met Sir Richard Branson at a hotel in Australia, where Branson described his plans to offer commercial spaceflights. Singer signed up.

Edward Roski Jr, 68, real estate developer, sports team co-owner
Roski has trekked to Mount Everest base camp, biked across Mongolia, and gone scuba-diving in New Guinea. In 2000, he chartered a submersible to tour the *Titanic*. Roski, who is co-owner of the Los Angeles Kings and the Los Angeles Lakers, figured if he had gone down that far, it would be nice to go up on the other side to see what Earth looked like from up there. He snagged ticket #128.

Victoria Principal, 57, actress
Best known for her role as Pamela Ewing on the 1980s television show *Dallas*, Principal signed on within the first 24 hours of Virgin's announcement. Another thrill-seeker who enjoys paragliding, bobsledding, and car racing, the Dallas star is so enthusiastic about the prospect of visiting space that she offered to join a test flight.

James Lovelock, 87, atmospheric scientist
More than 40 years ago, Lovelock worked at the Jet Propulsion Laboratory (JPL) where he marveled at images of Earth and Mars transmitted by satellites. The British scientist is best known for proposing Gaia theory, which suggests Earth is a living, self-regulating organism whose parts work together to sustain life. When he received a letter from Branson inviting him to go on a suborbital flight, he didn't hesitate.

Since there isn't an inexhaustible supply of celebrities, the Tauri Group was interested in forecasting demand among other groups with the financial wherewithal to afford a suborbital jaunt. Their assessment of demand for individuals included estimates among high-net-worth individuals (worth over US$5 million) and (poorer) space enthusiasts. To estimate demand for suborbital flights among high-net-worth individuals, the group conducted *The Tauri Group 2012 Survey of High Net Worth Individuals*, which revealed a relatively robust market of those willing to purchase suborbital flights. Analysis suggests there are enough – about 8,000 high-net-worth individuals across the planet – customers willing to pay current prices to constitute a sustained demand for suborbital flight. But it won't just be rich people flying. Although there are few reliable data available to predict the purchasing behavior of space enthusiasts, there will be some individuals with lower net worth who will spend a large proportion of their assets to purchase an sRLV flight. How many, we don't know, but several sRLV providers feel that more individuals outside the US$5 million population than predicted by the Tauri Group will seek to fly at current prices. Take Lina Borozdina-Birch for example:

Lina Borozdina-Birch, 38, chemist
Lina Borozdina-Birch says she has had two dreams since she was a girl in the former Soviet Union; one was to visit Disneyland and the other to visit space. In 1991, Borozdina-Birch came to the US and sought asylum. It wasn't long before she visited Disneyland and then, in 2004, the opportunity to realize her second dream came about following the launch of SpaceShipOne. Her husband, Jo, contacted Virgin and, after some deliberation, the couple took out a second mortgage on their home so that Borozdina-Birch could buy her ticket to space.

How many space enthusiasts like Borozdina-Birch and how many affluent individuals will fly will depend largely on the myriad factors that influence the market? In the best case growth scenario, potential customers' interest in suborbital flight will grow thanks to

Table 2.4 Forecasts for the Commercial Human Spaceflight Market.

	Year									
Scenario	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Baseline	340	344	353	359	366	372	379	385	392	399
Growth	1,046	1,060	1,079	1,099	1,118	1,138	1,159	1,179	1,200	1,222
Constrained	187	188	191	195	198	202	205	209	213	216

increased marketing, publicity surrounding the start of human flights, and positive flight experiences. But, if the economy tanks, demand will fail. In short, if everything goes really, *really* well, the total number of seats purchased across all human spaceflight submarkets over the 10-year forecast period will be around 11,300, whereas if everything goes bad, the number of seats purchased across all submarkets totals just over 2,000 (Table 2.4).

The numbers in Table 2.4 look healthy, but you have to bear in mind there are many uncertainties and those numbers are based on assumptions. For one thing, it is impossible to predict the dynamics of demand as it responds to future events; demand may – and probably will – evolve in unpredictable ways. For example, demand may grow more rapidly than predicted based on "me too" effects, following exciting launch experiences. Equally, demand could decline if a large proportion of individuals report unpleasant flight experiences such as space motion sickness. Also, the forecast assumes individual passengers fly once only, that only 40% of interested passengers will fly within the next 10 years, and that most passengers have net assets exceeding US$5 million; relaxing any of these assumptions will increase demand significantly. For example, if 80% of interested passengers fly in the next 10 years, the forecast doubles!

Basic and Applied Research

There are some who argue the main source of revenue for the commercial suborbital industry will come not from rich tourists, but from research institutions and universities paying for science flights. In fact, the premise upon which A4H was created was in anticipation of such science flights and the expectation that organizations will hire a cadre of highly trained astronauts to conduct science experiments. It wasn't long before operators also realized a sizeable slice of their revenue will likely come from science flights and set about reconfiguring their cabins.

With the Lynx and SpaceShipTwo flying, sRLVs will support many types of space-related research, which are generally grouped into four disciplines: space science, biological and physical research, Earth science, and human research. The sRLV capabilities most useful for research are access to the space environment, access to microgravity (for biological and physical research), transit through the upper atmosphere (Earth science), and access to passengers being subjected to acceleration and deceleration.

There may be some wondering just how popular this market will be. After all, isn't most space research being conducted on board the ISS? Well, yes it is, and that is precisely why suborbital research flights will most likely be *the* revenue driver of the industry, the reason being the protracted and costly process of having an experiment accepted on board the ISS – a process that can take years and years. Science on board sRLV flights on the other hand will be a much more stream-lined process (see Chapter 8).

There are four research applications – *microgravity research*, *atmospheric science*, *suborbital astronomy*, and *human longitudinal research* – particularly suited to sRLV capabilities and these support a wide range of experiments. Let's take the first of these – microgravity research.

There are a number of niche applications for microgravity research including experiments that can use the five-minute sRLV microgravity window – experiments such as the crystallization of particles in a charged plasma that can't be modeled by computer simulation, experiments that don't have adequate terrestrial research alternatives, and those requiring human tending. A bonus for scientists flying these experiments is that sRLVs provide frequent research opportunities at a lower cost and these vehicles are more accessible than orbital systems, albeit for a shorter microgravity duration.

The second research application – Atmospheric Science – is particularly suited to suborbital flight profiles because they offer scientists the opportunity to study the upper atmosphere (sounding rockets can also be used but at a high cost). And, given the flexibility of suborbital flight profiles and the diverse launch locations, trajectories can be tailored to visit all sorts of regions of interest.

Suborbital Astronomy – until the advent of sRLVs, the opportunity for high-quality astronomical observations could only be conducted using orbital telescopes, which always have very (very!) long waiting lists. But sRLVs reach altitudes that provide access to ultraviolet (UV) and infrared (IR) spectra, which contain useful astronomical information. And, budget sRLV flights will provide an opportunity for launching low-cost telescope payloads that may observe phenomena deemed too risky for billion-dollar orbital telescopes.

The fourth of these applications – Human Longitudinal Research – will provide a mother-lode of physiological data for space life scientists because the data sets of humans flying suborbital flights can be counted on the fingers of one hand. Researchers will want to study the physiological responses to microgravity and especially the acceleration transitions that occur during ascent and descent. They will also want to understand the mechanical responses in the vascular system, cell structure, and chemical changes in immune pathways, because these responses are poorly understood in suborbital flight. Then there is the issue of pharmaceuticals that minimize the discomforts (space motion sickness) some passengers may experience. While conducting human research on scientist astronauts won't be a problem, the extent to which suborbital passengers will wish to participate has yet to be determined, although the indications are that some are willing to be guinea-pigs.

Given human spaceflight will represent the biggest slice of the market, it's likely the best-funded research will be in the field of human research. Funded by such entities as the National Space Biomedical Research Institute (NSBRI), a non-profit science institute established by NASA in 1997 to research safe human spaceflight, this research will start as soon as revenue flights start, and will likely grow to a large clinical research trial by the end of the forecast.

As far as non-commercial microgravity research is concerned, the Tauri Group estimate this will be driven by internal research funding from universities, and augmented by non-profit organizations. In its forecast, university spending on sRLV microgravity experiments starts at about US$200,000 and grows to over US$500,000 in the last year of the forecast. It doesn't sound like a lot of money, but the problem with microgravity research is there is no well-understood commercial application for this type of research on sRLVs – at least not among the biotech, pharmaceutical companies, and technology-focused venture capital firms analyzed as part of the study. However, some venture-focused companies predicted there would be some level of exploratory commercial research, to enable firms to gain insight into sRLV capabilities and assess how those capabilities might benefit their research portfolios. Investing in research projects without connection to clear commercial outcomes sounds like a non-starter, but there is always the *what if* factor that may drive exploratory research, and it is this the Tauri Group think will start slowly and increase to a total of about US$5 million annually.

In terms of *where* this money will be spent, it is anticipated that, in the early days, the US government will be the primary user of sRLVs for basic and applied research, funding astronomy, atmospheric research, and longitudinal human research. But, after five or six years of revenue operations, other nations' governments will begin to implement larger standing sRLV programs; the Tauri Group suggest as many as 50 nations may be potential sRLV users for government-funded research, based on current research activities and budgets.

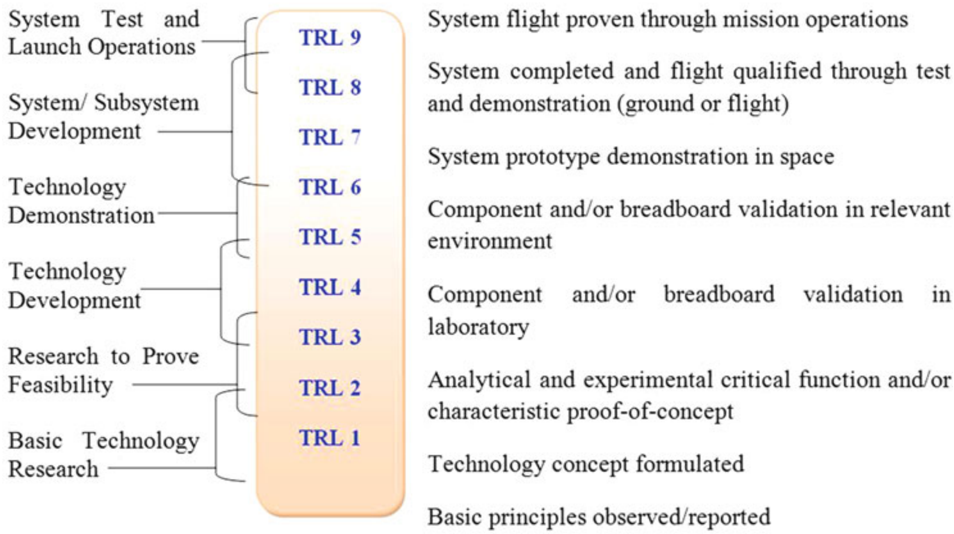
Aerospace Technology Test and Demonstration

Another use of sRLVs will be to advance technology maturity or achieve space demonstration, qualification, and/or certification. In the Aerospace Technology Test and Demonstration market, payloads will be tested and/or demonstrated on sRLVs to qualify and/or obtain data on flight systems in development. These payloads may be at any level of maturity, but will most likely be at the higher technology readiness levels (TRLs) that require test or demonstration in relevant environments (Table 2.5).

Today, space agencies and companies conduct test and demonstration activities in terrestrial facilities and during spaceflight. Terrestrial facilities include rocket test stands, thermal chambers, vacuum chambers, drop towers, and wind tunnels. In addition to using these facilities, computer modeling is being used more and more, thereby reducing requirements for high-fidelity tests. Spaceflight test and demonstration activities use sounding rockets such as the Black Brant (Figure 2.9), the ISS, and other platforms such as evolved expendable launch vehicles (EELVs), although this latter category is predominantly associated with missile defense.

Given that a typical sounding rocket test can cost anywhere between US$2 and US$5 million or more, sRLVs are likely to be very popular supporting test and demonstration activities, especially since sRLVs have the potential for human interaction. Like sounding rockets, sRLVs provide access to high altitudes, upper atmosphere aerodynamics, and can provide access to similar thermal, radiation, and vacuum environments as orbital space systems, although sRLV performance in these environments is mitigated by just five minutes of exposure. How much business sRLVs will take away from traditional platforms is

Table 2.5 Technology Readiness Levels

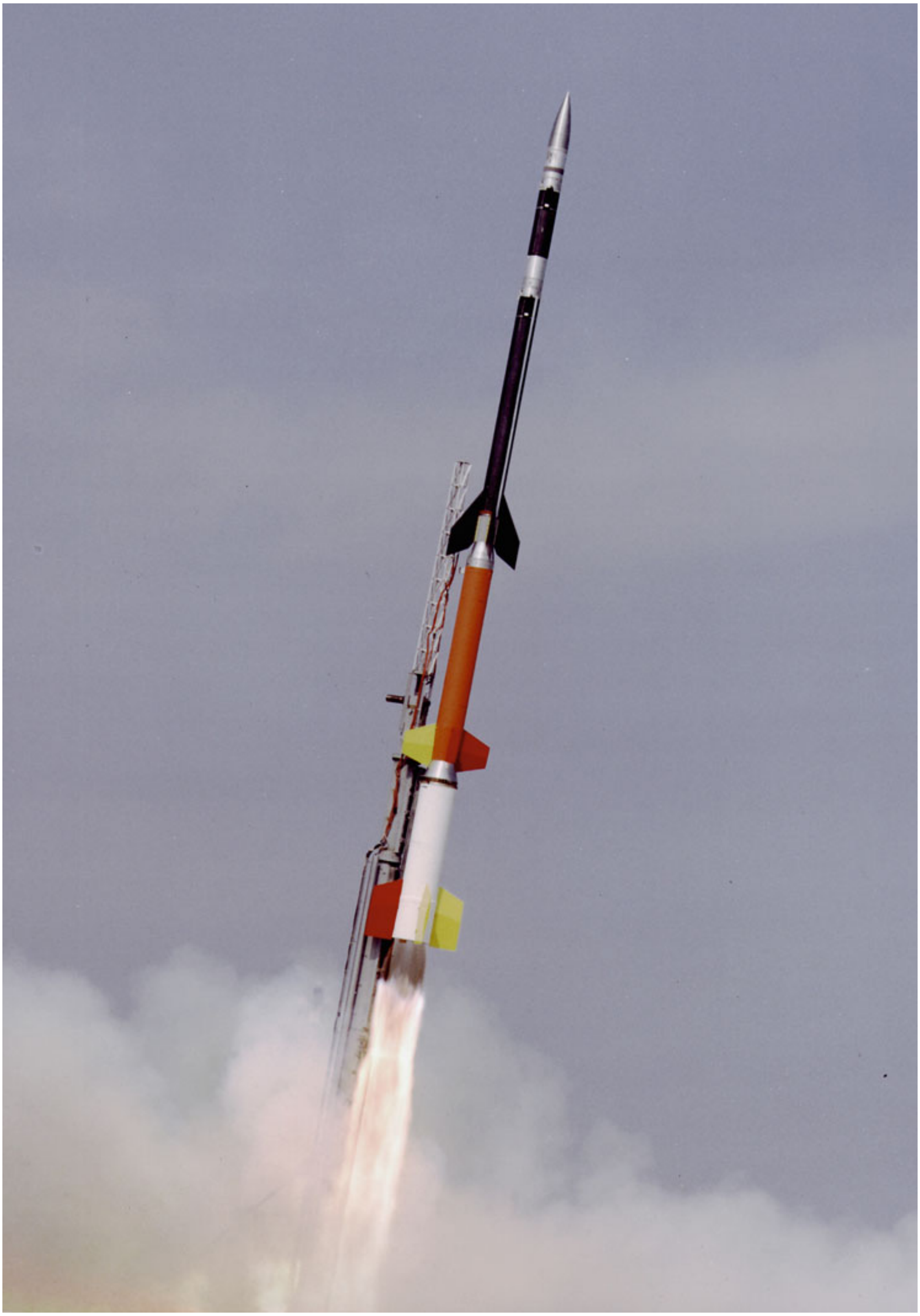


hard to say, but the Tauri Group estimate up to 25% of orbital test and demonstration missions require capabilities that could be provided by sRLVs. If you're interested in testing a payload on board an sRLV, you can apply through NASA's Flight Opportunities Program, which supports technology payloads on sRLV precursors and alternatives, like parabolic platforms; through this program, NASA has already procured payload capacity from Virgin Galactic. In fact, NASA and other space agencies will likely be the major users of sRLVs for test and demonstration in the near future, with half of the sRLV-suitable payloads previously launched on the Shuttle estimated to transition to sRLVs (the other half are better matched to the capabilities provided by the ISS).

Media and Public Relations

On April 18th, 2013, XCOR Aerospace General Sales Agent (GSA) Space Expedition Corporation (SXC) CEO Michiel Mol announced the latest Lynx Mark I flight participant would be Japanese film actor Koichi Iwaki. Mr Iwaki, who also happens to be a spokesman for the US watch company Luminox, an SXC affiliated partner, has starred in over 50 films and TV series since 1975. Andrew Nelson, XCOR's Chief Operating Officer, noted:

> "We are thrilled to announce that SXC has welcomed an exceptional artist – both on the screen and the road – to the growing list of Lynx flight clients. Iwaki-san is known as a groundbreaking artist in Japan and around the globe, and will be the first Japanese citizen to fly on board a Lynx and I suspect he'll be wearing his Luminox space watch."



2.9 Black Brant sounding rocket. A sounding rocket basically comprises solid-fueled rocket motor(s) and a payload. The Black Brant has a two-stage solid-fueled rocket; the first stage is a Terrier booster and the second stage is a Black Brant motor. Courtesy: NASA

Just one example of how sRLVs may shape the Media and Public Relations market! Incidentally, if you would like to follow in Mr. Iwaki's rocket plume, you can buy a flight on the Lynx by going to spacexc.com or xcor.com.

This market includes activities that use spaceflight to promote products, increase brand awareness, and film what happens during a flight. Of these submarkets, perhaps the potentially most lucrative is film and television for the simple reason people love space-themed movies, as evidenced by the fact that about 5% of all major feature films have been space-related and, of the top 50 domestic grossing movies of all time, eight are space-related. Films and television programs actually filmed in space are less common, although *Apollo 13* director, Ron Howard, filmed 3 hours and 54 minutes of raw footage over 612 parabolas to simulate the in-space scenes.

The *Apollo 13* Space Scenes

When it comes to making believable space movies, the special effects gurus can only take you so far. Sure, they have ways of moving the camera, they can suspend astronauts in harnesses and even "float" objects on invisible threads, but when it comes to replicating weightlessness, these tricks don't cut it. In fact, even the most famed directors get it wrong. Take the iconic *2001: A Space Odyssey*, which features the most famous piece of weightless fakery in film history. In the early part of the film, a space traveler sucks food up a straw, only to have the food slide back down the straw when he takes it from his lips; in real zero-G, that wouldn't happen.

So, when Tom Hanks, Bill Paxton, and Kevin Bacon signed on to make *Apollo 13*, which tells the story of how NASA rescued astronauts Jim Lovell, Fred Haise, and Jack Swigert on the ill-fated third Moon-landing mission, director Ron Howard and his cast paid a visit to Bob Williams, NASA's test director for the Zero-G Aircraft Program. Howard was so impressed with the experience that he began thinking about how to shoot the weightless sequences inside the aircraft by building a mock-up of the interior of the Apollo capsule inside the Vomit Comet – which is exactly what Howard did. He and his crew broke down each weightless scene into segments shorter than 25 seconds, and had the actors act while being bounced around inside the plane.

It made for a tough shooting schedule that included nearly four hours of weightlessness, which is more than most astronauts get before their first flight. To begin with, efforts were frustrating, with actors drifting in and out of shots, crewmembers landing on hard edges, and generally a mad scramble. Then there was the sound of the KC-135 engines, which screamed so loudly that none of the dialogue was usable. But, with practice, the cast and crew adapted, making two flights a day with 30–40 parabolas on each flight. The end result was convincing – even to real astronauts. In fact, when some of the Apollo astronauts were invited to a sneak preview, the theater exploded with applause when the movie ended.

The use of suborbital flights to film scenes for a movie could prove appealing if the scenes are of relatively short duration, because it would be expensive, not to say logistically challenging (at least one provider has received a proposal to produce adult films during flight, which was declined), to have to do what Ron Howard did when making *Apollo 13*. Commercials on the other hand are more suitable, and could prove popular with companies looking for an edge to promote their product. Flight rates could also be boosted by the placement of logos and advertisements on the vehicle (echoing the placing of the Kodak logo on the outside of the ISS in 2001) and its occupants. Some companies will also pay money to have their product flown in space. Take A4H, for example. Shortly after I joined A4H, the organization received its first job offer to fly an Australian beer in space. In case you're wondering what NASA's position is on this, the agency forbids the consumption of alcohol. But, with space tourism just around the corner, the idea of testing beer in space seemed well timed to take advantage of the impending market. And, since research would be performed on the effects of alcohol on astronauts in a microgravity environment, the "beer in space" flight would have scientific value! The deal was signed between A4H, the 4-Pines Brewing Company, and Saber Astronautics Australia. Rather than studying the physics and chemistry of carbonation or fermentation, the research focused on the human experience of consuming the beverage in microgravity. The A4H flight researcher – Todd Romberger (who happened to be a home brewer) – sampled the beer during weightless parabolas on a series of Zero-G Corporation flights and recorded body temperature, heart rate, blood alcohol content, as well as reporting on the beverage's taste and drinkability.

For those who are interested in space beer, the box for the terrestrial six-pack version of the Vostok Space Beer read:

> "From the dawn of civilization, people have brewed beer and wherever people went, beer followed. In the Middle Ages, beer helped monks survive long periods of fasting. Sailors drank beer (with a splash of lime) to stave off scurvy. During the age of exploration, distances traveled necessitated brewers to get creative, making beer recipes to last the voyages that would bring this great beverage to the world!
>
> To continue this great tradition we have created a beer for another momentous voyage. A beer specifically designed for the next frontier of space exploration. Space engineers from Saber Astronautics Australia have teamed with 4 Pines in our own space race; to take this 4 Pines stout which tastes fantastic on Earth and adapt it for space to produce the world's first space beer.
>
> Enjoy! (no matter where on Earth or in space you are)"

As for Todd, this is what he had to say:

> "It was exciting to participate in this ground breaking research. I'm happy to say the flight was a success. We provided the customer with the data they needed, and made a little history along the way. Not to mention, the beer was delicious!"

Also included in this market are novelties and memorabilia. Take Celestis Memorial Spaceflights. Celestis is a service that will fly cremated remains into suborbital space, Earth orbit, onto the lunar surface, or even into deep space. To date, the company has flown its canisters on 11 launches, carrying the remains of over 800 individuals. Other memorabilia companies include Space Wed, a wedding ring company, which flew 50 sets of wedding rings into space in May 2011, and To Space, which has brokered sending custom payloads into space, such as business cards and personal items. Even commercial spaceflight juggernaut, Bigelow Aerospace, got in on the action by flying small personal items for US$300 while testing the Genesis II module (the items were visible via a webcam on the company's website).

Tauri's forecasting for this market was based on costs, historical data, and interviews, which indicated interest in producing films and TV programming on sRLVs will be related to the novelty of the experience and the association with suborbital spaceflight. It's a difficult market to forecast because some suborbital companies will allow sponsorships, advertisements, and commercials on their vehicles, while others will probably limit third-party sponsorship due to brand maintenance. Then there is the difficulty predicting the public response to sRLV marketing, flight activity, and the reports of flight experience; if several passengers return complaining about motion sickness, then this market will suffer. What will likely happen is there will be a near-term surge in interest that fades as suborbital flights become more common. Let's hope not, but with attention spans reducing by the week, it's possible.

Education

This should prove to be a dynamic market because sRLVs provide opportunities for schools, colleges, and universities to increase access to and awareness of space, especially through the flight of student-built payloads. Then there is the potential of teacher-in-space and student-in-space programs, so it's difficult to see how this market won't drive up the flight rate. In 2013, students who want to fly their experiments in space could take advantage of the CubeSat program, which can cost in the tens of thousands of dollars, although universities can sometimes use government-sponsored complimentary rides to orbit as secondary payloads. With more affordable suborbital flights on the horizon, there are several projects already scheduled to be flown on the new fleet of sRLVs as part of the research and education mission (REM) program. And the REM market isn't limited to the US; at a price of US$250,000 per seat, virtually every one of the 190-plus nations on Earth can afford an education mission. Think of the returns – motivating students into science careers by seeing physics and chemistry classes, and doctoral theses streamed from space on a daily basis. No doubt about it, education missions will be a game-changer for the simple reason that sRLVs can potentially enable novel and unprecedented levels of participation by students in space. And, with such frequent launches, schools won't have a problem aligning projects with academic calendars. The only hurdle operators will have is developing awareness of the possibilities of sRLV programs among science teachers because this will be a marketing effort that may come with a high marketing cost.

Already, there are several ongoing efforts to develop this market. In Florida, an effort is underway to develop integrated curriculum modules that use sRLV services and link those activities to state curriculum requirements. The Space Frontier Foundation, a space industry advocacy organization, is sponsoring a non-profit project called "Teachers in Space" that will sponsor teachers to fly on sRLVs. In fact, XCOR has donated three seats to this program. Then there is UP Aerospace, which has launched educational payloads (funded by NASA or New Mexico state funds) through the New Mexico Space Grant Consortium that includes 29 public high schools and 17 universities. The Tauri Group expects this market to be dynamic, forecasting three teacher seats in the baseline forecast, growing to 60 total seats over the 10-year forecast period, which is similar in expenditures to a previous program that flew 1,300 educators on Zero-G.

Table 2.6 Satellite Categories.

FAA categories	*Mass and non-standard classifications (kg)*
Heavy	>9,072
Large	4,537–9,072
Intermediate	2,269–4,536
Medium	908–2,268
Small	92–907
Micro[1]	up to 91

[1]Includes "very small satellites" (<15kg), Nanosats (1–10kg), CubeSats (1–2kg), Picosats (0.1–0.9kg), and Femtosats (<0.1kg).

Satellite Deployment

sRLV satellite deployment is the launch of satellites weighing under 15 kilograms. These micro-satellites, which can include single application satellites or large constellations of redundant satellites working together, are mated to a propulsion stage and launched into low Earth orbit (LEO). The very small satellite (Table 2.6) market gained traction with the introduction of the CubeSat (a 1-kilogram, 10-centimeter cube) and the Poly-Picosatellite Orbital Deployer (P-POD) deployment system, which allows for rapid payload development and standard launch interfaces. Between 2002 and 2011, 105 satellites under 15 kilograms were launched, primarily for universities in the US. It's a market that is continuing to grow, especially among civil and defense agencies, which are using more and more very small satellites and developing new capabilities and supporting infrastructure. For example, the US Army is developing the Kestrel Eye imaging satellites and SNAP communication satellites (weighing under 25 kilograms) and the National Reconnaissance Office (NRO) has a CubeSat program and has already purchased 10–20 CubeSats, with an option to purchase up to 50.

Most very small satellites have been deployed as piggyback payloads on low-cost, commercial launch vehicles, primarily Dnepr, while larger payloads launch from a custom EELV using adapters that allow for several satellites to be launched together. There are more than a dozen EELVs sized and designed specifically to deploy very small satellites such as the US Army's Soldier Warfighter Operationally Responsive Deployer for Space (SWORDS), a nanosatellite launch vehicle, and the Defense Advanced Research Agency (DARPA)'s Airborne Launch Assist Space Access (ALASA) program. As commercial suborbital spaceflight moved closer to reality, it wasn't surprising to see awards to Virgin Galactic, which leverages the WhiteKnight2 carrier aircraft for an orbital launch system. Then there is XCOR, which has announced plans to serve the very small satellite deployment market, using its Lynx Mark III that will carry very small satellites (12 kilograms) to LEO from a dorsal pod on flights beginning in 2017.

The Tauri Group forecasts the demand for very small satellites will continue to increase through the end of the forecast with about 100 satellites of 15 kilograms and under being launched worldwide in Year 10 and 760 satellites – split evenly between civil, military, and university – launched over the 10-year forecast. As ever, the forecast assumes various factors, such as continued support for the NASA CubeSat Launch Initiative, which should energize the suborbital community, resulting in more payloads and providing more launches. The forecast also assumes the US defense community will be a potential customer for sRLV satellite deployments in the near term.

Remote Sensing

This market is the use of sRLVs for the acquisition of imagery of Earth for commercial, civil government, or military applications. As you can see from Table 2.7, this is already a robust market served by aerial and satellite platforms, which are well established. In fact, due to customer requirements such as timeliness, accuracy, resolution, quality, and other parameters, sRLVs might find it difficult to break into this market due to over-flight restrictions, high launch and re-entry velocities, and fixed runways.

Given the large increase in the use of UAVs for intelligence, surveillance, and reconnaissance in the past decade, it's difficult to see how sRLVs fit into this market, but they could create a niche between aerial and satellite remote sensing in terms of swath width, resolution, and revisit time. sRLVs also have potential applications in civil, commercial, and military remote sensing in the areas of disaster management, border security, policy enforcement, pipeline surveillance, and agriculture. Also, for military applications, sRLVs could ascend in friendly airspace and achieve views of hostile territory without violating airspace restrictions or exposing the vehicle to the threat of engagement. That said, this is a marginal market, and it is unlikely to drive flight rates appreciably.

Point-to-Point Transportation

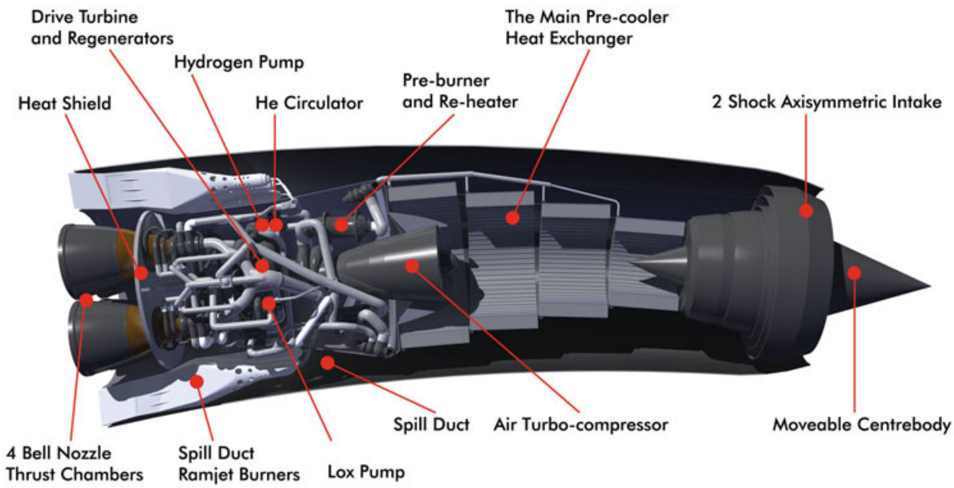
Imagine a flight from London to Los Angeles and you'd probably think of being stuck in an airplane seat for the best part of a day. But, if XCOR has its way, the endurance test that is a transcontinental flight may have an expiry date because the company believes future commercial flights may take passengers to the edge of space to dramatically reduce travel time. So, instead of spending 13 hours flying from, say, New York to Tokyo, your edge-of-spaceflight time would be reduced to just 90 minutes. All thanks to the Lynx, a two-seat rocket plane which can utilize conventional airport runways for horizontal take-off and landing.

This future accelerated point-to-point (P2P) service between distant hubs is thanks to the fact that the Lynx can take advantage of many more take-off and landing options than spacecraft that require dedicated facilities. Not surprisingly, there is significant interest in P2P services, but it is unlikely to be realized before the turn of the decade because there are still several technologies that need to be matured – aerodynamics, hypersonic, guidance, navigation, and control, propulsion, high-temperature materials and thermal protection systems, and fuel/propellant storage, to name but a few. But, while we may have to wait a few years before taking that hypersonic trip across the pond, sRLVs will play a key role in setting the stage.

The promise of hypersonic flight sending us halfway around the world in a matter of hours may also be realized thanks to Reaction Rocket Engines, a British company that reckons its hypersonic engine will send us streaking across the sky at speeds well over Mach 5. The hypersonic engine design (Figure 2.10) includes a novel way of cooling the

Table 2.7 Remote Sensing Market.

Platform	*Resolution*	*Swath width*	*Revisit time*	*Spectrum*	*Remarks*
Aerial imagery (piloted)	Very high resolution (cm)	Tens of km^2	On demand	Any	Established market Flights regulated Over-flight permission required Moderate investment High cost per image
Aerial imagery (UAVs)	Very high resolution (cm)	Tens of km^2	On demand	Any	Emerging market Flights not formally regulated Over-flight permission required Low investment Moderate cost per image
SRLVs	High resolution (m)	Hundreds of km^2	On demand	Any (due to short loiter time, may not be ideal for radar)	Emerging market Launch/re-entry regulated (US) Over-flight permission required Moderate investment High cost per image Currently limited viewing area
Satellites	Low to high resolution (km to m)	Thousands of km^2	Days	Any	Established market Some regulation No over-flight permission required Shutter control High investment Low cost per image Revisit time can be enhanced by increasing number of satellites in one orbit

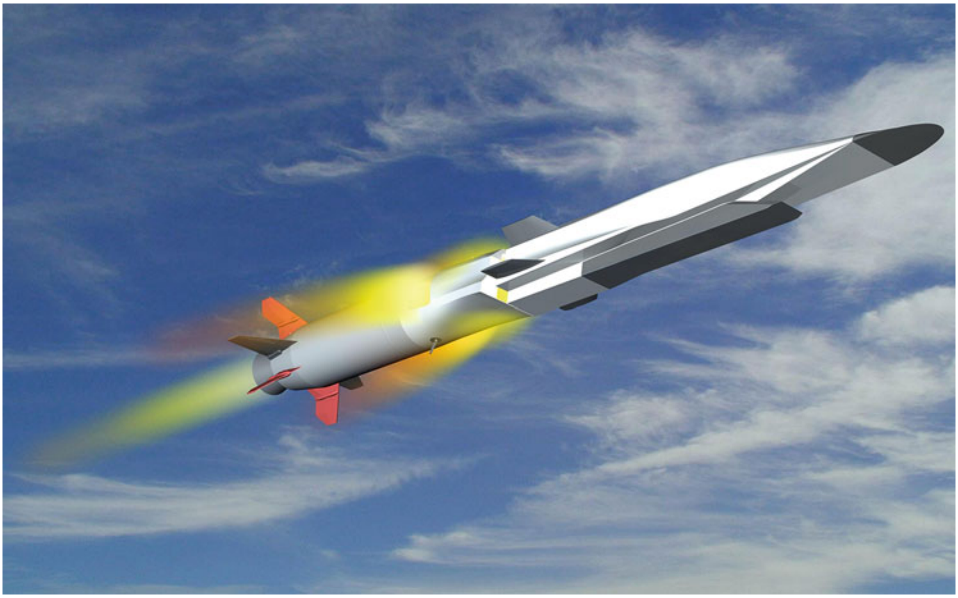


2.10 Reaction Rocket Engines' SABRE engine. Courtesy: Reaction Engines

air for an engine that will use oxygen in the atmosphere up to Mach 5.5 before switching to rocket power for the ride in space.

Until Reaction Rocket Engines came along, the big problem had been propulsion, because at speeds beyond Mach 2 or so, a jet engine has trouble getting the oxygen needed for combustion, although Kelly Johnson's SR-71 Blackbird design used creative ways to deal with the incoming air needed to achieve record-setting Mach 3+ speeds. But, beyond Mach 3, it gets really tough, mainly due to heat issues. Of course, rocket engines can achieve hypersonic flight, but the vehicles use multiple stages. To avoid carrying a supply of oxygen, as rockets do, some engineers figured they could develop an air-breathing design that could operate in the hypersonic speed range as a first stage. And now Reaction Engines reckons its cracked the problem – their secret is cooling the air as it enters their hypersonic SABRE engine, which uses pre-cooler technology to cool the incoming air-stream from over 1,000°C to −150°C in less than 1/100th of a second. If all goes well over the next several years, the air-breathing engine will accelerate a vehicle to about Mach 5.5, after which a liquid oxygen tank will supply a rocket engine for part of the flight in space. But unlike today's SS2, there will only be one stage involved for the entire flight thanks to the SABRE design. To date, Reaction Engines has completed more than 100 test runs of the cooling system and it hopes to have a subscale ground engine running by 2015. Sounds promising but, as the X-51 Waverider (Figure 2.11) team discovered, hypersonic flight is a difficult nut to crack.

But, if the hypersonic nut *is* cracked, there are still some technical, logistical, legal/regulatory, and economic barriers that have to be addressed. First of all, a P2P infrastructure needs spaceports at each destination, and these spaceports have to be integrated with other modes of transportation and local air traffic control systems. Then there are the issues of international air systems, over-flight restrictions, environmental regulations, insurance.



2.11 Waverider. Courtesy: NASA

Several years ago, there weren't many people in the industry sold on the idea of using sRLVs for anything but tourist flights. But, with NASA stating the agency is now open to flying people on suborbital vehicles, the thinking on the subject of suborbital research and other markets is much more of a reality:

> "We absolutely do not want to rule out paying for research that could be done by an individual spaceflight participant – a researcher or payload specialist – on these vehicles in the future."
>
> Lori Garver, NSRC, June 3rd, 2013

Thanks to this policy change, operators now have a backlog of flights that serve the markets discussed in this chapter. In fact, at NSRC 2013, NASA representatives of the agency's Flight Opportunities program appealed for more applications, saying there weren't enough being submitted. And, while many bemoan the delays in getting the vehicles flying, once routine flights begin, the potential identified by the Tauri Group may finally be realized.

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