

ENTREPRENEURIAL NICHE MARKETS

FOUR CASE STUDIES ON THE DEVELOPMENT OF SPACE COMMERCE

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Introduction

Throughout history, trade routes have emerged to serve those pursuing commerce in all its many forms, from the recovery of value from natural resources, to tourism, to manufacturing and agriculture, to migration and exploration. Specialized markets, or niche markets, inevitably develop along trade routes to take advantage of specific conditions and to meet the specific needs that exist there.

During the last thirty years, space commerce has emerged as a commercial reality at various orbital altitudes around Earth, and it too, is conducted along the trade routes that lead to various Earth orbits, along the

highway between Earth and the surface of the moon. Space commerce to date has certainly occurred within niche markets, and capturing such a niche market in today's very limited commercial space business usually requires very specialized innovative hardware, as well as an innovative business concept.

This chapter discusses four startup ventures that address 'niche' markets and products in space. We discuss how each started with a business model concept, raised risk capital in various stages (which is sometimes referred to as 'smoke and mirrors'), used its core innovation effectively to produce a profit, protected it with patents and other means, and eventually how a small team of varying talents survived the startup venture environment and absorbed some lessons learned.

1. Since its founding in 1983 by Bob Citron, and with early funding by Walter Kistler, SPACEHAB,^{2,3} has created and operated a commercial microgravity module in the space shuttle. The company has progressed through the entire cycle of development, from an entrepreneurial commercial space company to a viable commercial space company that changed its name to Astrotech in 2009, stock symbol ASTC.
2. SPACEHAB raised more than \$105M in capital, built two modules in Italy, has flown its module and other company hardware on 24 Space Shuttle missions, and has earned more than a billion in revenues from NASA and commercial customers.
3. GLOBAL OUTPOST was founded in 1988,⁴ and proposed to NASA that the external fuel tank of the Space Shuttle could be salvaged and reused. After winning a NASA External Tank Solicitation in the 1980s, (1988) the company confirmed the technical feasibility of its concept by hiring the fuel tank manufacturer Martin Marietta Aerospace, (Michoud Advanced Programs group) in 1988 to conduct the necessary Salvage study. The company received a letter from NASA on February 19, 1993 confirming technical feasibility. The salvage concept used the space shuttle to attach a propulsion control package to the ET in orbit and the reboost of the salvaged ET 5 times for an orbital life of ~55 years at a cost of ~\$200M.
4. The Kistler Aerospace Corporation was started in 1993 by Walter Kistler and Bob Citron and almost created an innovative, fully reusable launch vehicle (RLV) with traditional aerospace equity partners and \$860M in private capital and \$40M of NASA funding. Originally designed to offer affordable launch for replacement satellites for Teledesic and other emerging space

based cell phone networks, which were to dominate the emerging cell phone market. One other mission for the fully reusable launch vehicle, called the K-1, was to reduce the salvage cost of the ET to ~ \$40M. The company raised over \$900M in mostly private Equity Risk Money and built launch hardware in partnership with traditional aerospace organizations.^{5,6}

5. Lunar Transportation Systems, Inc. was started in 2004, and intends to support lunar resource recovery operations to permit NASA to move on to Mars and beyond without being slowed down with the necessity of continuing support for lunar exploration operations.^{7,8}

Each of these companies addressed a niche market, had a strong technical and managerial startup team, raised money, partnered with traditional aerospace companies to achieve its own operational and business goals, and pursued cooperation with NASA. In this chapter we will describe them in detail, and explore what happened and what can be learned by other would-be entrepreneurs.

Terminology Used in this Chapter

ET - External tank in a variety of upgrades to 138 ETs over a 40 year history, not reusable
SPAB - SPACEHAB, INC. stock symbol (SPAB), recently changed name to Astrotech (ASTC)
GOI - GLOBAL OUTPOST, Inc
KAC - Kistler Aerospace Corporation
LTS - Lunar Transportation Systems, Inc.
NSTS - National Space Transportation System, including SRBs, ET, Orbiter and launch facilities
SRB - Solid Rocket Booster
Shuttle - The reusable fly back orbiter vehicle of NSTS
BTF - Basic transportation frame, used in four versions of the LTS vehicles

Niche Markets in Space

This is a special time in our species' history, an era in which we begin to move off the home planet and seek opportunities and livelihoods elsewhere in space. With the potential for economic value to be derived from available resources, private investors can and will support high-risk, niche-market ventures that have the potential for appropriate return on investment.

These niche markets¹ in space will likely develop in ways that are similar to how they have developed on Earth, along early commercial trade routes that emerge in the course of exploration beyond Earth. These niche markets will be the foundations upon which entrepreneurs will build businesses capable of raising the risk capital needed to build aerospace hardware, or provide services that in the end will earn profits and generate a return for investors.

This is a very different business scenario than the one that has predominated in the space industry for the last half century, the one in which aerospace companies supplied hardware to NASA for its science and exploration activities on behalf of the taxpayer-customer. As NASA refocuses on a new space mission, development of space commerce is properly falling to private sector.

In the current environment, new startup ventures for space commerce are likely to require specialized and often very innovative hardware to function in the very demanding rigors of space. The entrepreneurs themselves may sometimes create this hardware, or it may be designed and fabricated by traditional aerospace companies, or by new, emerging ones that are formed to exploit this new niche.

To launch such a business successfully, a good entrepreneurial startup team is essential. Unless one of the founders is already wealthy (as is the case with a number of today's emerging commercial ventures, such as SpaceX) the entrepreneurs will have to raise capital.

From the perspective of venture investor, the quality and experience of the management of the team will be more important than the actual concept or business model itself, as most venture capitalists would prefer to back a 'second rate idea developed by a first rate startup team' than the reverse. The reasoning is that a first rate team can always improve its ideas, but a second rate team may not be able to do so.

SPACEHAB, Inc.

The SPACEHAB Module is carried in the Space Shuttle payload bay, and provides a microgravity experiment capability for \$2M in Mid-Deck Lockers within a pressurized volume.^{9,10}

A mid-deck locker is a storage module, originally designed to contain an astronaut's toothpaste, accessories and clothing on the Space Shuttle. Some early, battery powered research experiments were also stored in these lockers, operated by the astronauts in the mid-deck volume below the pilot's flight deck.

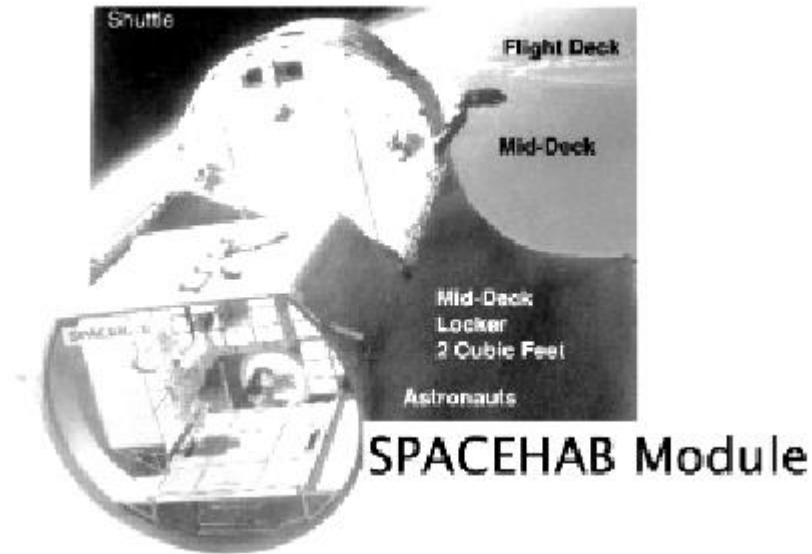


Figure 1

The Mid-Deck Pressurized Module in the Space Shuttle offering Microgravity Research Capability in space at 1/10th the previous Customer Cost.

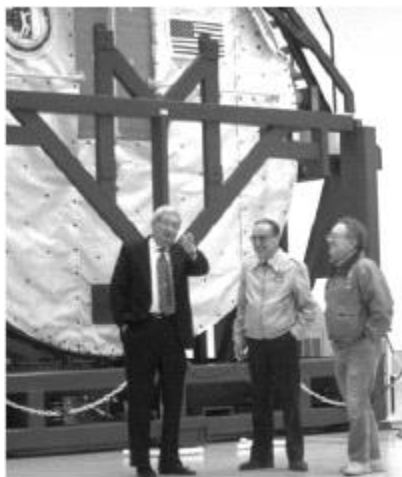


Figure 2

The SPACEHAB Module in late 1980s with Chet Lee, former President, left, Walter Kistler, early investor, and Tom Taylor, co-inventor, at the SPACEHAB Florida Facility. Photo by Bob Citron.

The SPACEHAB innovation was to expand the capability to more than 60 additional mid-deck experiments in a small, pressurized module located in the Space Shuttle payload bay. SPACEHAB provided additional electrical power, a container for the researcher's experiment and communications plus additional support supplied by the company in cooperation with NASA. An initial \$400M NASA Contract for 200 Mid-Deck lockers with a lease arrangement for shuttle transportation allowed low cost access to microgravity for commercial and government researchers around the world. Not only was the cooperation between NASA and the private SPACEHAB company innovative, but the resulting cost was also an order of magnitude less for commercial customers and NASA researchers.

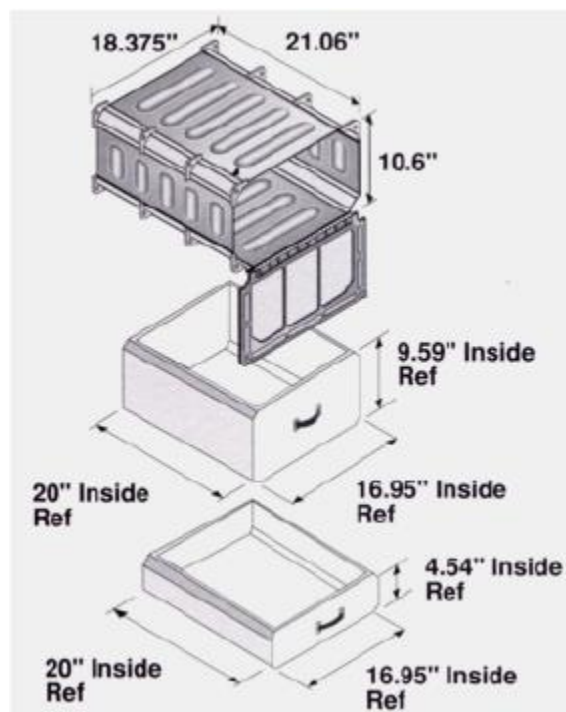


Figure 3
The mid-deck locker.

The Business Concept

The Business Concept was to provide a commercial service module in low earth orbit consisting of plug-in Mid-Deck volumes of 2 cubic feet. It was manned and supplied with power, communications, and microgravity.

The SPACEHAB module enabled ~2,000 early microgravity researchers to get a head start on their access to space in the shuttle payload bay and to quickly repeat and refine experiments using the same hardware on future shuttle launches leading to the Space Station.

The unique features included an order of magnitude reduction in cost compared with a similar Spacelab Module in the shuttle offering the same access to microgravity. The SPACEHAB Module was built for one-ninth the cost of traditional aerospace hardware, as documented by Price Waterhouse.¹¹

Figure 1 depicts a SPACEHAB Module in orbit with astronauts working with experiments in microgravity in orbit.

Figure 2 shows Chet Lee, former President of SPACEHAB, Walter Kistler, and Tom Taylor. Early investor Bob Citron and Tom Taylor were co-inventors of the module in U.S. Patent.

The Lessons Learned

1. The early SPACEHAB Module concept was exhibited at 12 International Aerospace Conferences and became known within the global aerospace industry, but global recognition of the concept was less important than its innovative design, unique approach to cost reduction and fabrication progress in Torino, Italy.
2. Offers to buy the company were received from major aerospace companies, but an assessment of the value of the future market was difficult for both sides. Meanwhile, a larger firm wanted to buy the startup company at a low price, while the entrepreneurs wanted a fair price based on the future value they expected.
 - a. The discussions broke down after 8 months.
 - b. At the time, the entrepreneurial team was operating in a plant owned by the larger firm, so the firm simply kicked the entrepreneurs out.
 - c. The larger firm also put a team of about 30 engineers on a project to replicate the SPACEHAB concept, but later stopped when they apparently realized that SPACEHAB had filed for a U.S. Patent.
 - d. The larger firm also faced a bad public relations scenario.
3. SPACEHAB then requested other American aerospace companies to build the two 10' long modules, but were rejected because it was believed that a big ISS Module Contract was about to be released by NASA, and none of the major firms wanted to risk losing an opportunity to bid on a huge NASA contract if that had already accepted the smaller contract from SPACEHAB. American designers and major aerospace fabricators probably still fear that working for or with entrepreneurs may reduce their opportunities to win large government contracts.

4. SPACEHAB then looked internationally for help, and settled on Aeritalia, a Torino, Italy based contractor (to avoid confusion with the airline Alitalia, Aeritalia was later renamed Alenia Spazio). One member of the SPACEHAB team had previously worked with Aeritalia. Earlier, Aeritalia produced the ESA Spacelab Module pressure shell, and subsequently produced two SPACEHAB modules (with some technical help from McDonnell Douglas) at a cost to SPACEHAB of \$105M.
5. During the course of about 200 marketing meetings and events, SPACEHAB was offered as a less expensive alternative, but this could not be proven until SPACEHAB was actually in operation.
 - a. This market-based business model is very different from how NASA operates. In NASA's model, aerospace firms are paid to do Phase A through Phase D design and engineering contracts to define the hardware that they will later bid on to manufacture.
 - b. Through this process innovation (including cost reduction) is a negative inducement, and hence a cause of high hardware and operations costs.
6. The commercial SPACEHAB Module was required to be a truncated circular shell design to permit astronauts the capability of latching the payload bay doors in orbit should the automatic door latches failed to work. The full circular ESA-supplied Spacelab Modules had a NASA safety waiver unable to be obtained by an American entrepreneurial company. The European Space Agency financed and fabricated the Spacelab Module and the related equipment was given to NASA free in exchange for access to the Space Shuttle services. The truncated SPACEHAB module was more expensive, but stimulated other innovations including experiment windows that looked into space from the flat top and allowed Mid-Deck lockers to be prepared, attached, and integrated cost effectively on the ground.
7. SPACEHAB pioneered many enhancements to NASA's two-cubic-foot mid-deck locker volume to draw researchers in with a 10-fold decrease in cost for a 'microgravity research' volume in the shuttle. SPACEHAB provided electrical and other services, while NASA provided some astronaut assistance on orbit.
8. Mid-deck lockers in the shuttle were priced at \$2M each. Transferring them to ISS raised the price to approximately \$5M, and required changing the mid-deck volume to fit into a Space Station rack, which in most cases excluded relaunching the ~2,000 previous fabricated research hardware inserts that were

fitted to the mid-deck units. This unfortunately meant that customer-fabricated research hardware was less able to fit in the new volumes.

9. SPACEHAB's stock price rose from 5 cents per share to nearly \$15 per share over a decade. (This 300 times increase in the stockholders' original investment is the reason that venture capitalists invest in startups.) Private investors were able to recover their investment plus a significant gain. In an understated way, this suggests that opportunities for wealth enhancement for private investors are available in the commercial space industry.
10. This shows that a relatively non-technical entrepreneurial startup team can enter the technical aerospace industry, use private funds, hire others to design and fabricate the hardware, and create a successful commercial business at a significantly lower cost (an order of magnitude) than NASA.
11. A significant portion of the cost reduction resulted from the ability of SPACEHAB to hire about 150 of the NASA staff and subcontractors who were needed to perform the work.
 - a. By comparison, NASA required a staff of about 1350 to manage Spacelab Module flights, although it should be noted that Spacelab was three times larger, 30' long, and filled the payload bay completely, while SPACEHAB was 10' long.
 - b. The 10' long SPACEHAB Module allowed NASA to cost effectively use the remaining shuttle payload bay for other payloads.
 - c. With the order-of-magnitude cost reduction available in a previously non-commercial environment, other things also occurred. This new, lower cost level allowed NASA to spend the money saved (90% of the previous cost) to use the commercial SPACEHAB Module service on other NASA project, which increased the overall level of activity in microgravity research funded by NASA.
 - d. On the commercial side, the cost reduction of a mid-deck locker space from \$20M per locker to \$2M per locker stimulated the rental of about 2,000 mid-deck lockers, with many flown multiple times because of the additional benefit of more frequent repeat flights. This stimulated researchers to explore what might happen in a new environment like microgravity, which tends to be a 'research the unknown, fly a little, learn from it' environment.

The early SPACEHAB experiments focused on pioneering research to explore a different gravity and its effects on all basic science laws and on basic industrial processes. Purely commercial researchers explored proprietary innovation, mostly without peer review, and were able to uncover a variety of new phenomena in every field, from combustion science to protein crystal growth. Some researchers explored new solar cells capable of being produced from lunar materials to how best communicate between the researchers on the ground to the astronauts in space helping the experiment. A Google search for the term 'spacehab experiments' provided 65,500 results.

STS-77 in March 1996 included a Crystal Growth by Liquid-Liquid Diffusion investigation that was intended to grow protein crystals by diffusing one liquid into another; and a National Institutes of Health-C7 (NIH-C7) experiment to evaluate the effects of space flight on muscle and bone cells from chicken embryos. Kyser Thebe, an Austrian startup firm and later a successful customer of SPACEHAB, indicated that the reduced cost to the customer was a major economic driver in the growth of their space business and the success of their company.

The transfer of the mid-deck locker research projects to ISS raised the price to the customer because the dimensions of the container changed, which forced additional cost onto customers. While cost to the research customer is a huge issue for small and medium sized research organizations, it is sometimes ignored in government facilities where cost growth is treated differently, but it is the small and medium organizations that are usually the most innovative.

(Editor's note: Please see Chapter 8, An Open Source, Standardized Research Platform for the International Space Station for additional discussion of the mid-deck locker.)

Global Outpost, Inc.

The External Tank (ET) of the Space Shuttle achieves about 99% of full orbital velocity, before being jettisoned and forced back into the atmosphere where most of it burns up upon re-entry. The ET is about 20% by weight and some of its thicker aluminum alloy components fall into an ocean disposal area north west of Hawaii.

The Business Concept

The proposed GLOBAL OUTPOST, Inc. (GOI) Business Concept calls for preserving the External Tank after launch, taking the ET into orbit, and salvaging it for other uses in space.

To get the shuttle near to orbital altitude, each ET (weighing 58,000 lbs empty) has invested transportation energy in it, and this investment can have value if a productive use for the ET can be found in orbit.

How much value does the salvaged ET in space have, and what is the cost to salvage it? GLOBAL OUTPOST submitted a proposal, and was one of three winners in a Reagan Administration 1988 NASA Solicitation focused on the ET in space.^{12,13,14,15}

One winner dropped out almost immediately, while the other two placed cash deposits for five ETs transported free to orbit by the space shuttle.

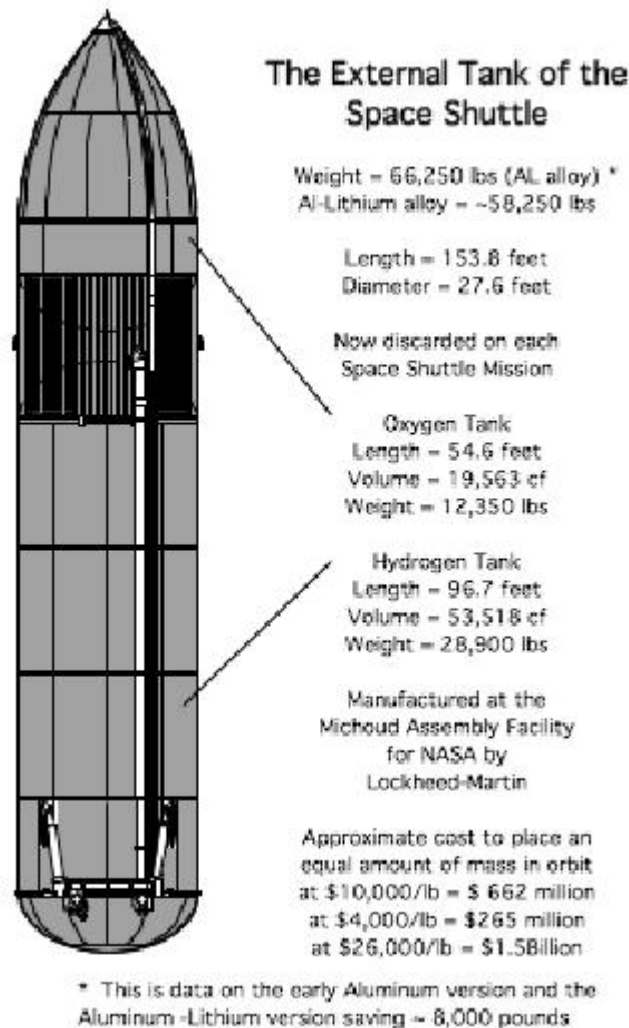


Figure 4

The External Tank technical information is the latest of a series of upgrades and design changes over the series of ~130 each External Tanks fabricated at the NASA Michoud Assembly Facility near New Orleans.

One example of ET use is shown in Fig.4. In this scenario, the ET jettisons the Aft Cargo Compartment (ACC) Shroud at an appropriate time on ascent, and the ET is salvaged in orbit.

The 100' long Liquid Hydrogen tanks are joined with a 25' diameter connector ACC module to form a 300' diameter ring, and provide a partial gravity 25' diameter torus volume for living on long trips in space.

This is one of the few modifications to the ET design that would be required.

The Liquid Oxygen tanks are used for utility purposes at each node, but are not shown.

The 10 (each) Liquid Hydrogen tanks near the center of the Torus provide 100' long 'flying Volumes' 25' in diameter with trampolines at each end.

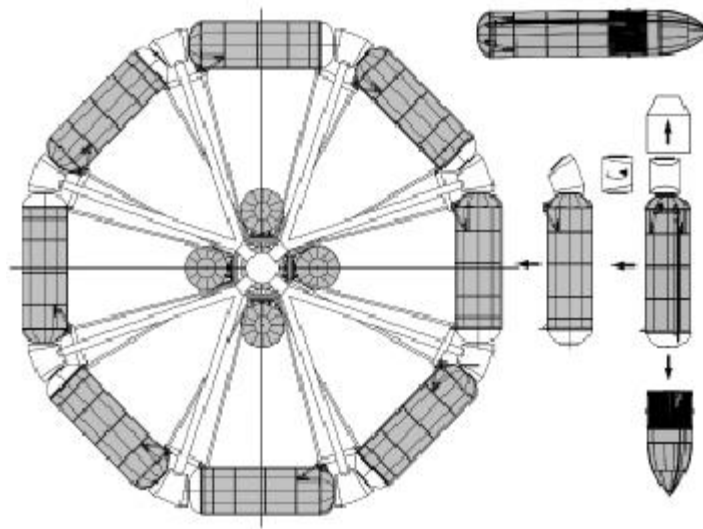


Figure 5

The eighteen ET Torus is capable of rotating at 2-3 RPM to provide $\sim 1/5^{\text{th}}$ Earth Gravity and 10 each center 100' long free flying volumes with Trampolines at each end.

GLOBAL OUTPOST hired the ET fabricator, Martin Marietta Aerospace (MMA), Advanced Programs Group at the Michoud Assembly Facility to assist in the technical confirmation of proposed ET salvage concept. The design called for a change in the operational software sequence that controlled the separation of the ET from the orbiter, delaying separation until the orbiter was in orbit. A simulation run at NASA-JSC run by astronauts was successful and confirmed the salvage and separation software delay could be accomplished.

The salvage mission required using a portion of the orbiter payload bay to transport a reboost package and place it on the ET before separation to ensure that the ET did not re-enter the Earth's atmosphere in an uncontrolled manner. The NASA ET reboost package solution cost \$200M and used the shuttle robot arm to place a propulsion device on the ET for reboosting the ET orbit.

The reboost package supported a 55-year life for the ET in orbit, reboosting it periodically to raise the ET orbit at intervals to provide orbital make-up.

A 1988 Global Outpost NASA Enabling Agreement, now in Revision 3 was signed; GOI placed a cash deposit with NASA for five ETs in orbit, and MMA assisted GOI in extensive technical discussions with NASA HQ and NASA-JSC. GOI paid MMA and NASA-JSC to review the technical procedures and salvage mission, and received a letter dated 19 Feb 1993 which stated the NASA-JSC “*appears technically feasible*” and “*the ET salvage mission was technically acceptable.*”¹⁶

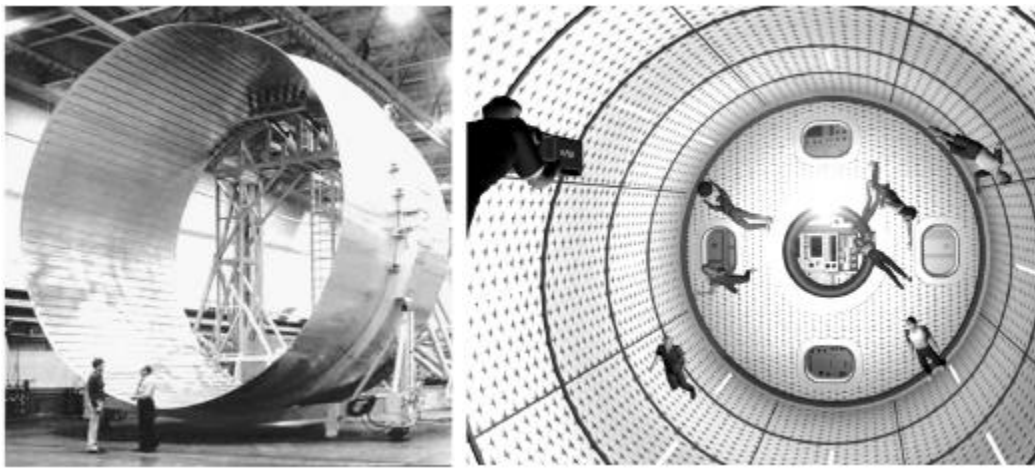


Figure 6

The interior of the ET is 27.6'. The interior padding is shown on the right is by Space Island Group.

The Startup Phase

The startup phase for GLOBAL OUTPOST, Inc. (GOI) involved raising capital from 32 private investors, placing a cash deposit with NASA, and discussions and marketing studies with potential customers and support organizations including SDIO, DOE, the Russian TOPAZ II reactor organization, (The Kurchatoff Institute of Atomic Energy), University of Maryland (MIPS) research grant program, as well as commercial customers including Space Island Group, Japanese organizations and others.

Many customers were interested, but few could afford the \$200M salvage operations cost.¹⁷ The opportunity for salvage may still exist, and the GOI President became the first employee in an entrepreneurial startup team called the Kistler Aerospace Corporation creating a reusable launch vehicle that could potentially reduce the cost of ET salvage to ~\$40M.

The Lessons Learned

The process revealed that customers who liked the ET concept, and had uses in orbit for the ET, did not have the money to pay for salvaging it.

Other solutions could get the cost down to \$40M with a Kistler Aerospace K-1 Reusable Launch Vehicle or other rockets. Figure 4 depicts one innovation possible with ET salvage by taking the 100' long LOH tank and combining it with an Aft Cargo Carrier (ACC) launched connector module to create a partial gravity torus, ~ 300' spun at 2-3 RPMs could produce ~20% of Earth's gravity and become a standard transport volume for humans to explore the universe and use as nodes around a variety of planets and moons.

With passenger transport, an ¹⁸ ET Torus Facility in orbit could be profitable, given the possible extension of the shuttle and the ability to salvage future ETs. The long-term artificial gravity might be helpful to NASA in creating larger crewed vehicles with a reusable design for exploring and homesteading our solar system.

The real commercial market pull is the commercial tourist transportation for passengers to and from the Torus location and could evolve into a huge Earth to Orbit commercial transportation industry within the next decade.

The saving of money on space projects was ahead of its time in the 1980s and 1990s. Few in the traditional aerospace environment were concerned about cost to the customer. Space commerce, even with cost reduction innovation, was still too expensive for those interested in mankind's movement off planet in numbers beyond a few NASA astronauts. Given the potential extension of the shuttle use beyond 2010, the ET innovation may still be possible.

The ET inside volume is difficult to imagine, but Figure 5 depicts a 20' section of the 27.6' diameter ET interior.

Kistler Aerospace Corporation

Walter Kistler and Bob Citron founded Kistler Aerospace Corporation in 1993. Tom Taylor was hired as the first employee, so Tom and his family moved to Las Cruces, NM to prepare to use the White Sands Missile Range for launching a fully reusable launch vehicle (RLV) and in the process became the first customer to express interest in the commercial spaceport later called Spaceport America.

KAC participated in the Environment Impact Studies for the spaceport, and attended to answer some early town meeting questions from ranchers concerned about potential damage to their cattle.

The Business Concept

The Business Concept, invented by Walter Kistler, is a fully reusable launch vehicle that consumes propellant, but does not destroy the rocket in the launch process. The first stage rocket called the Launch Assist Platform (LAP) boosts the orbiter stage to 138k feet and separates to propel the first stage return back toward the original launch site. The first stage lands 5-10 minutes later at the original launch site, using large parachutes that deploy at about 70,000 feet to reduce the re-entry velocity, and air bags to reduce ground impact.

Burt Rutan of Scaled Composites (now famous as the designer and builder of the Virgin Galactic spacecraft system) was an early subcontractor on the KAC Project, and built several early innovative hardware items.

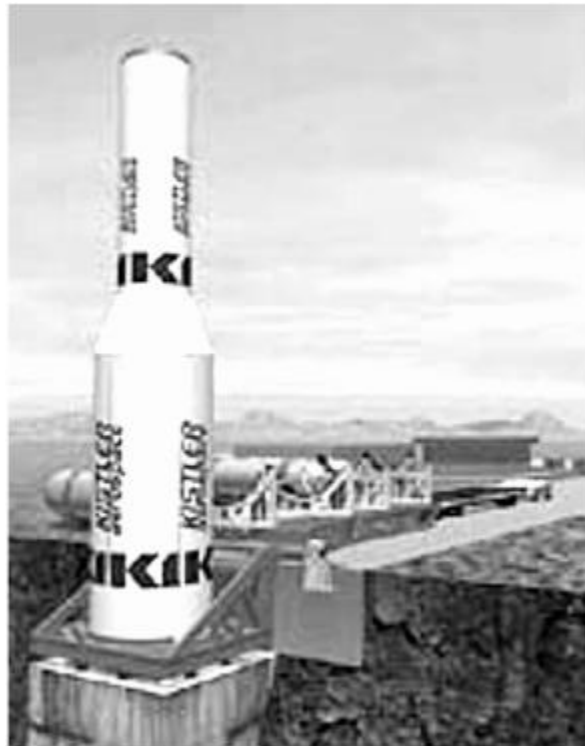


Figure 7

The 150' long K-1 RLV rolls out from a horizontal processing building on right on rails to be tilted upright and loaded with propellants.

After the first stage lands it is transported in the horizontal position into a preparation building to prepare for the next launch.

The orbiter stage continues to orbit and delivers its payload, and then goes to 'sleep' until the Earth turns a full 24 hour rotation to permit landing at the same launch site on the same orbital inclination trajectory. The orbiter stage also lands with parachutes and airbags at the original launch site.

New payloads are then fastened to the orbiter with eight bolts, and the 150' long mated K-1 RLV rolls out to the launch pad on rails to be tilted up for fueling and launch.

Fig. 6 shows the resulting design.

The Startup Phase

The startup phase continued from 1993 to 2005 with the firm raising money, and hiring design and fabrication work from traditional aerospace contractors, including Northrop Grumman, Aerojet, Lockheed Martin, Draper Labs, Irvin Aerospace and others.

Reduction of cost and reusability were key production goals. Over time the design evolved to use Russian NK-33 and Nk-43 rocket engines, composite structures, aluminum cryogenic tanks, and innovative software development. The large cargo parachutes were the only major hardware component that required a new technology development and testing program, as the other major RLV components were pre-existing aerospace hardware applied in a reusable way.

The company raised a total of \$860M in private equity financing without government help or customer commitment.

Figure 6 depicts the K-1 vehicle vertical at the launch site. KAC won one of the NASA's Commercial Orbital Transportation Services (COTS) demonstration program, but was unable to raise an additional \$500M to complete the fabrication and the program of five test launches.

The Lessons Learned

1. We learned that a fully reusable launch vehicle could be built with private funds. 2 vehicles were about 75% assembled for approximately \$900M.

With an anticipated K-1 launch cost of \$17M to \$20M per launch carrying 12,500 lbs to low Earth orbit (LEO), success of the project would have started the space transportation industry down a path toward other launch innovations that would have

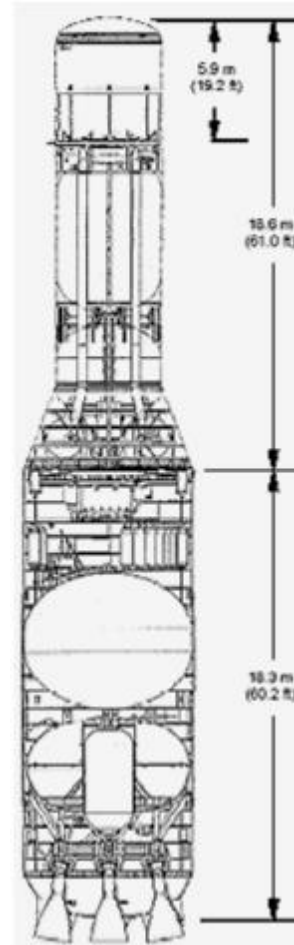


Figure 8

The RLV Costs more to build, but costs less refurbish and operate.

significantly reduced the cost of commercial space transportation.

Assuming that the unmanned K-1 vehicle was capable of launching every two weeks after refining the turn around operations, then a fleet of five K-1s would have been capable of launching more tonnage per year than the entire rest of the market. Admittedly, the K-1 was a small-payload vehicle in the Delta II Class of expendable launchers, but reusable launch vehicles can bring cost reduction to a government supported launch industry that has steadily increased in cost over time. While the K-1 never proved the \$17M launch price was achievable, such a cost was 39% of the existing the Delta II Class of expendable launcher at \$70M, when compared side by side with the \$17M K-1 over a 12 launch sequence as shown in Figure 5. The Delta II recently was quoted at \$100M per launch.

Entrepreneurs can never entirely predict that they are going to reduce the cost of a project by an order of magnitude in a highly technical industry such as aerospace, but previous ventures, like the SPACEHAB described above, have indeed produced that kind of order of magnitude cost reduction.

Comparing Reusable Launch Vehicle & Expendable Launch Vehicle Costs												
Launch	1	2	3	4	5	6	7	8	9	10	11	12
K-1 RLV						Replace parachutes		Refurb high speed parts-engines				
Vehicle Cost	250	0	0	0	0	0	4	0	0	10	0	0
Relaunch	5	5	5	5	5	5	5	5	5	5	5	5
Cumulative	255	260	265	270	275	280	289	294	299	314	319	324
Expendables			Breakeven				K-1 ahead over \$500m					516
Vehicle Cost	65	65	65	65	65	65	65	65	65	65	65	65
Launch	5	5	5	5	5	5	5	5	5	5	5	5
Cumulative	70	140	210	280	350	420	490	560	630	700	770	840

Figure 9

Comparison of the costs of an RLV and a Delta II rocket in similar payload class, launching 12 each in Earth-to-orbit missions

2. It may be unfair to compare a vehicle that has not launched with one that has, but Figure 9 shows a reusable launch vehicle compared with an expendable rocket of the K-1 and Delta II Expendable Launch Vehicle class, with the following assumptions:
 - a. 12 launches each
 - b. K-1 frame designed for 50-100 launches
 - c. Engines refurbished after 10 launches and replaced after 20

- d. Parachutes last 7 cycles, and are then replaced at a cost of \$4M.
- e. The RLV saves \$516M over the 12 launches.

Figure 7 depicts a vertical launch, but because the K-1 is processed in the horizontal position, this significantly reduces preparation time. The RLV may launch twice a month while an expendable may take 2-3 months to erect vertically on the launch pad, so the time to perform the launches is different and the time value of money is not well depicted in the above cost comparison.

3. The RLV costs about 4-5 times more to produce than an expendable and carries components designed to be reused, which weigh more than expendable parts, but the RLV uses components that are mostly pre-tested after the first launch.
4. It takes four launches for the cost breakeven to occur between using an RLV and an ELV in this case.
5. The launch sites are also different, and probably cost different amounts. The simple comparison shows ~ 40% reduction in launch costs.

Lunar Transportation Systems, Inc.

Commercial lunar transportation architecture can start small and grow as the market emerges, which is the way most breakthrough businesses develop in the private sector. Expendable transportation architecture can be the early solution for a new commercial lunar transportation system, and then evolve toward a reusable, more affordable system that will be required to support and sustain an emerging lunar commerce that will then permit NASA to move on toward exploration of Mars and beyond.

Lunar Transportation Systems, Inc. (LTS) proposes a transportation architecture that uses 4 variations of a Basic Transportation Frame (BTF). Each frame is fitted with components that permit each version to perform specific tasks.^{18,19}

This architecture is characterized by modularity and extreme flexibility, leading to

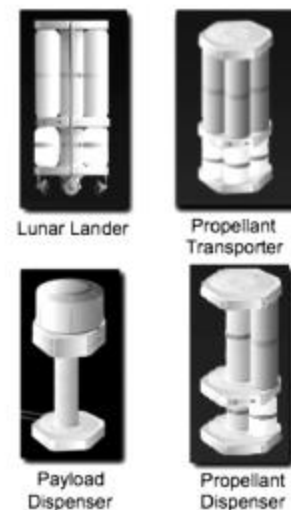


Figure 10

The Four LTS versions of the Basic Transportation Frame (BTF) hardware provide opportunities for reuse in space.

reduced development costs and enabling a system more capable of evolution as the market changes and grows.

The new architecture can be seen on YouTube at <http://www.youtube.com/watch?v=26Y5w0vqtIU>.^{20,21}

A hard look at this concept will show that it enables NASA to meet its strategic objectives, including sending small payloads to the lunar surface in a few short years, sending larger payloads to the lunar surface in succeeding years, and sending crews to the Moon and back to the Earth by the middle of the next decade.

The architecture is based on the concept of refueling a fleet of fully reusable spacecraft at several locations in cislunar space, which create the equivalent of a two-way highway between the Earth and the Moon.

In the startup phase the LTS hardware is abandoned on the moon to deliver early payloads and later grows with propellant depots. The use of the hardware for a different purpose at the destination can also contribute to cost reduction.

Figure 10 depicts lunar surface logistics. The moon is 20 times further than any logistics support of a remote base on Earth, so lunar logistics is not just about transportation to the moon, as there will also be a need for use of the LTS hardware in surface operations. Lunar logistics involves managing the movement, planning and control of the flow of goods and materials to, from, and on the moon, and deals with the procurement, distribution, maintenance, and replacement of materiel and personnel.

An affordable transportation system is the first objective of a sustainable commercial trade route supporting mankind's first off-planet base. An equal requirement is a market or commercial reason for being there. The initial markets will be on the moon's surface and later in space.

The Business Concept

The business approach calls for the use of existing ELVs, which are already commercially available. As 70% of the energy required for a lunar trip is used in getting out of the gravity well surrounding Earth, the first 200 miles, this new lunar architecture utilizes ELVs to bring a new fleet of reusable spacecraft, lunar payloads, propellants, and eventually crews from the Earth to Low Earth Orbit. The LTS reusable spacecraft could do the rest of the job, taking payloads from LEO to the lunar surface and back.

This commercial strategic roadmap permits a 'pay as you go' and a 'technology development pathway' that allows NASA to achieve a series of its strategic objectives as funding and technology developments permit. This approach reduces recurring mission costs by advancing in-space transportation technology, and later, resource utilization, because this is less costly than investing in new Earth to orbit transportation.

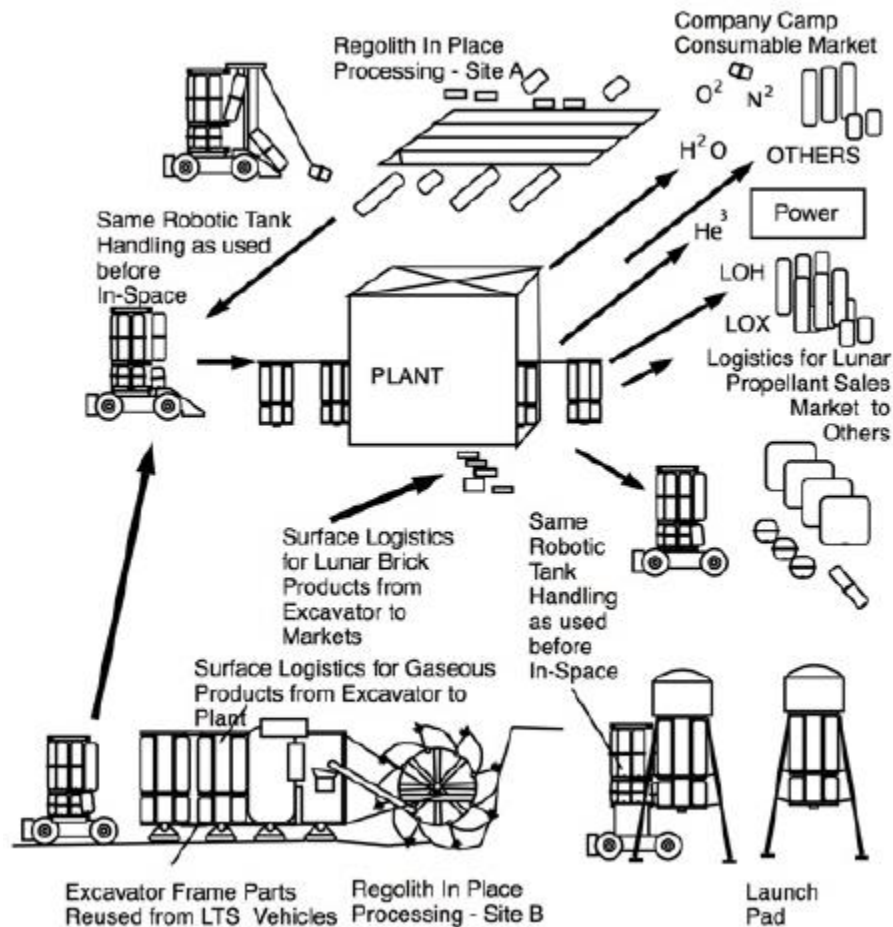


Figure 11

The Surface Logistics can profit from the reuse of LTS hardware components.

The initial design of reusable spacecraft was based on the K-1 RLV or the payload capabilities of Delta II Heavy class launch vehicles or other vehicles with an 11' diameter payload shroud. In fact, the diameter of the Earth to orbit vehicle payload bay defines the diameter and size of the LTS vehicle system. The larger the diameter of the initial payload, the more capable and efficient the LTS highway scale-up becomes.

Lunar Lander spacecraft can deliver payloads of up to 8 metric tons from LEO to the lunar surface, depending on where and how frequently they are refueled on their way to the Moon. This architecture is capable of delivering 800kg to the lunar surface directly from LEO without the need to refuel in space, or delivering payloads of 3.2 metric tons to the lunar surface with refueling at L1 only. Comparable payloads can be returned from the lunar surface to the Earth with refueling at one or more of those locations.

This initial system is not meant to transport crews to and from the Moon, but as a technology development testbed to prove the reliability

through repeated non-critical cargo missions, leading a crewed Earth-Moon transportation system.

If a 33' payload diameter could be derived from the existing NSTS or current space shuttle program vehicles and was available to commercial ventures, then the entire process of the trade route development and LTS vehicle deployment would be significantly accelerated.

Key Features

Scalability

This new Lunar Transportation System vehicle is scalable, which means it can be used in Earth to orbit stages with payload diameters from 11' to 33'. A follow-on fleet of larger spacecraft, designed to fit the payload capabilities of Delta IV Heavy class launch vehicles, can transport payloads of up to 30 metric tons from LEO to the lunar surface, depending on where and how frequently they are refueled on their way to the Moon.⁵ These larger spacecraft are capable of transporting crews to the lunar surface and returning them to the Earth, and also have the capability to provide heavy cargo transportation to support a permanent lunar base.

Cost Reduction

The non-recurring costs to develop this Earth-Moon transportation system are much lower than the cost of developing systems that use more traditional architectures because there are fewer unique pieces of technology to develop, and in addition LTS relies on existing launch systems, and a significant reduction in lunar mission costs comes from the reusability of the major elements of this system.²¹

The largest cost in operating this system, 70%, or more, is the delivery of the original LTS spacecraft to LEO. The next large cost is the delivery of propellants to the reusable LTS vehicles, and the lunar payloads from the Earth to LEO, so if propellants can be manufactured on the Moon, then Earth-Moon mission costs may be reduced by 60% or more, and allow affordable round trip operations of reusable vehicles.

These payloads could be other commercial vehicles, while commercial launch vehicles in a variety of sizes could transport individual cryogenic propellant fuel tanks to a propellant depot. The different propellants required for various spacecraft systems use tanks that could service several classes of emerging commercial vehicles.

While existing NASA vehicles are expensive to operate, the development cost of a significant new launch capability represents at least 100 launches of existing EELVs and many years of lunar transportation operations.

If and when reusable Earth to LEO launch vehicles become available, lunar mission costs may be reduced further by 60% or more.

Schedule

Because this LTS concept relies on existing technologies and existing ELVs and only requires the maturation of several enabling technologies, LTS could deliver payloads to the lunar surface relatively quickly and well within NASA's schedule for robotic and human lunar exploration.

The Bottom Line

This lunar architecture is based on concepts that reduce lunar mission life cycle costs and technical risks, improve reliability and eventually crew safety by demonstrating reliability through cargo-only transport until the vehicles are proven by many years of operations.

Figure 10 shows lunar logistics hardware made from discarded fuel tanks and BTFs, to become part of the lunar surface commercial logistics systems that can potentially reduce costs, accelerate early lunar mission schedules, and allow for routine, frequent delivery of lunar payloads on a two-way highway between the Earth and the Moon. Cost reduction is part of the ultimate goal, using the most affordable and efficient transportation hardware on each leg of the trade route in both directions.²²⁻²³

The Startup Phase

The 2004 startup of Lunar Transportation Systems, Inc. began with multiple conceptual innovations by Walter Kistler, followed by the formation of the LTS Corporation and the continued exploration of the potential market opportunity. The company participated in Roadmap Conferences and presented proposals to NASA Centers, but with mixed reception.

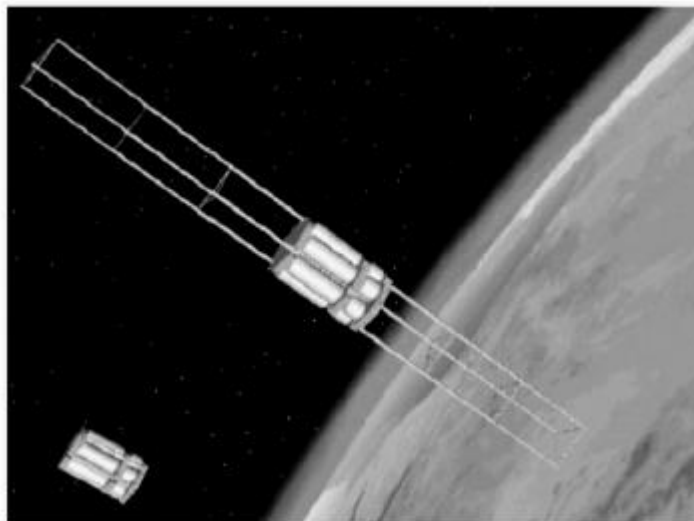


Figure 12

The LTS Basic Transportation Frame (BTF) provides for the reuse of hardware for Truss Units and future propellant depots.

The company engaged some former Lockheed Martin employees to assist in the proposal and design process.

The Kistler Aerospace K-1 Vehicle was used as a prototype for early LTS designs with an 11' diameter by 17' long payload bay. However, design work showed that the LTS Payload needed to be a vehicle in LEO, which is actually very scalable, and can fit into any payload bay diameter from 11' to 33'. 18,22,23

Figure 11 shows the LTS Basic Transportation Frame (BTF) as a system of rotating concentric tubes, expanded longitudinally to become a truss. The finished truss uses the structural strength within the BTF for the second reuse of the same BTF mass or discarded hardware.

The Lessons Learned

1. A key lesson learned from previous entrepreneurial ventures is the importance of protecting the firm's intellectual property. The aerospace industry is a sophisticated marketing environment, with traditional companies working to retain dominance and not wanting to decrease the cost of entry for competing commercial companies. Rockwell, for example, tried to overrun the startup SPACEHAB by quickly designing a competing module with similar characteristics, but abandoned the effort, when they heard the small company had applied for and later was awarded U.S. Patent 4,867,395 (a copy of which is available free from www.pat2pdf.org).

The cycle of interest by Venture Capitalists is normally five years, including the time frame in which they receive their return on investment. But in five years the lunar market has yet to define any commercial opportunities capable of utilizing an affordable transportation system, or even defining a market for commercial participation.

2. Entrepreneurship has become more expensive and more difficult over the 32 years of activity by the authors. The reasons are many, including International Traffic in Arms Regulations (ITAR), which keeps American aerospace products expensive compared to readily available aerospace products from other nations.

There is a cyclic back-and-forth swing of support and encouragement from NASA to commercial efforts. NASA's inability to mesh existing innovations, private financing, and entrepreneurial development methods that have flourished in the commercial world puts extra pressure on start-ups. Entrepreneurs are rarely acknowledged in NASA procurement documents, and NASA doesn't pass on to entrepreneurs all the

Bid/Proposal, IRAD and other cost advantages given to traditional aerospace companies.

3. The degree to which NASA and government recognize and help entrepreneurs and commercial space ventures has varied over the years. At one time there was an Associate Administrator with 'Commercial' in the job title printed on the door, and there are other periods, when 'commercial' has seldom been mentioned, although we note a significant upsurge in interest in space commerce since 2009.
4. Without NASA or a major lunar effort by other governments or companies, it is very difficult to finance the entrepreneurial ventures described here. Private investors always ask, 'What does NASA think of your venture?' It took us 3 years to find, understand and solve that problem at SPACEHAB.

Conclusion

The entrepreneurial startup process for space ventures has changed significantly over the last 30 years. SPACEHAB was a small company start-up that slipped through the cracks to become successful by applying start-up techniques to commercial aerospace. In recent years, however, it has become much more difficult for a startup company to slip through today's narrower procurement cracks, all of which is complicated by bigger NASA budgets that include fewer dollars focused on actually saving money, or targeted to entrepreneurs that advocate saving money.

Today, the high cost of getting to orbit is the significant barrier to the development of space, and has driven even American companies to try and launch systems developed by other nations. Our hope is for a transportation system to rise from the ashes of the current confused situation, and to stimulate cooperation between commercial aerospace entrepreneurs and NASA. The next vehicle may be a Shuttle Derived Vehicle (SDV), and by using the existing Shuttle hardware and applying innovation to all aspects of its operations, operating costs can be significantly reduced, which will stimulate the development of many major space commerce markets that are now emerging, including these nine:

- ☐ Lunar trade route logistics & surface development
- ☐ Assemble affordable orbital solar collectors:
materials & depot logistics
- ☐ NASA-JSC bigger Solar System exploration assembly in orbit
- ☐ NASA-MSFC exploration engine development and test to orbit
- ☐ Second generation depots on lunar trade route
- ☐ More robust Orion life boat transported unmanned
- ☐ Space tourist support and facilities in orbit, ET profit center

- VASIMR engine testing for Mars logistics missions
- Asteroid missions and homesteader support - two way support logistics.

The four entrepreneurial examples discussed in this chapter all applied innovation to reduce operations costs for space ventures. In fact, the innovations came from very small businesses started by serial entrepreneurs, whose only chance of success was by lowering costs. The four companies raised \$1.2B in private equity, and most of the money was paid to major American aerospace companies for hardware design and fabrication, although when American companies wouldn't take our money, we turned to companies in other nations.

Now the leaders of many nations recognize the importance of the emerging space commerce markets, and they are very aware that the nations that capture those markets will build national wealth and consolidate their central positions in important global markets.

Entrepreneurs are forming teams of innovative small companies, and joining together to accelerate the use of private financing to forge the trade routes beyond humankind's first planet. Our hope is that the four stories presented in this chapter will help these entrepreneurs to succeed.

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Acknowledgments

Thank you to Walter Kistler and Bob Citron for being the huge risk takers you are, and for enabling three of the four companies discussed above to come into being. The early money is always the most difficult to obtain for entrepreneurs, and without money entrepreneurs don't move off the starting line into the ever-changing world of commercial space.

Thomas C. Taylor



Thomas C. Taylor is an entrepreneur, inventor and a Professional Civil Engineer in the commercial aerospace industry. His goal is building commercial space projects including an unmanned transportation cargo service to and from the moon's surface with Lunar Transportation Systems, Inc.

Since 1979, Tom has helped to form 22 entrepreneurial aerospace startup companies with four successful commercial space startup companies raising a total of \$1.2B in private equity financing. These four actually completed the commercial space startup process and evolved into meaningful private commercial space companies, but each took almost a decade to unfold.

Tom enjoyed working in the trenches for 4 to 12 years on each of these commercial space successes with Walter Kistler and Bob Citron, the founders of most of the successful startups, as described in this chapter, including SPACEHAB, Inc., Kistler Aerospace Corporation, and Lunar Transportation Systems, Inc., an unmanned logistics service anticipating commercial cargo to the moon's surface at commercial rates with scalable hardware. Started in 2005, LTS proposes a privately financed logistics service for commercial lunar development. The goal is a sustainable commercial transportation system for the moon to support government and commercial efforts.

Walter P. Kistler



Walter Kistler holds about 50 patents worldwide and has invested time, innovative energy and early money for emerging entrepreneurial ventures in America and abroad.

Trained in physics, Walter was instrumental in starting and financing Spacehab, Inc., the Kistler Aerospace Corporation, and Lunar Transportation Systems, Inc. among other startup ventures.

Robert A. Citron



Bob Citron was the spark behind and founder of many aerospace and space ventures including Spacehab, Inc., the Kistler Aerospace Corporation, and Lunar Transportation Systems, Inc. Bob is a graduate aerospace engineer from UCLA, a serial entrepreneur, and early pioneer in space businesses.

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