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United States Senate

REPUBLICAN LEADER

COMMITTEES:
AGRICULTURE
APPROPRIATIONS
RULES AND ADMINISTRATION

July 6, 2009

Mr. Richard R. Irving
Legislative Affairs Specialist
National Aeronautics and Space Administration
Mail Suite 9042
300 E Street, SW
Washington, D.C. 20546

Dear Mr. Irving:

I write on behalf of constituents who have contacted me to share their research and suggestions for human flight and space policy with the NASA Review of U.S. Human Space Flight Plans Committee. As you will see from the enclosed correspondence, they have worked on their strategic analysis of the space program for the past fourteen years.

For your information, I have enclosed my constituents' correspondence and analysis for consideration by the Review of U.S. Human Space Flight Plans Committee. I would appreciate if you would provide their analysis to the Committee to inform its deliberations on these important topics. Please direct any correspondence and inquiries to Kelli Barbic in my Washington, D.C. office.

Thank you for your time and assistance. I will look forward to receiving your response.

Sincerely,

MITCH McCONNELL
UNITED STATES SENATOR

MM/keb

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DSER
Deep Space Emergency Response

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Bowling Green, KY 42104

Alan Thompson
208 Hickory Heights Court
Bowling Green, KY 42104

Senator Mitch McConnell
Commonwealth of Kentucky
361-A Russell Senate Office Building
Washington, DC 20510

June 24, 2009

Senator McConnell,

As Kentucky residents dedicated to nurturing high-tech endeavors within the state of Kentucky and beyond, we wish to request your help in delivering a report to proceedings currently underway to review the effectiveness of the U.S. human space flight program.

This committee has been called into existence by President Obama, with the directive to "…ensure the Nation is pursuing the best trajectory for the future of human space flight – one that is safe, innovative, affordable, and sustainable." The members of this committee are highly respected in their fields, and have been involved with the public and private space program for decades. We believe that their recommendations will be well-founded, realistic, and somewhat familiar as they will likely repeat the underlying counsel they have individually and collectively made in the past.

We have worked for the last fourteen years on a strategic analysis of the space program from a macroeconomic viewpoint. This analysis makes several probing observations regarding the underlying strategic weaknesses within the present approaches guiding the development of the U.S. space policy, weaknesses that have yet to be publicly debated.

Our work suggests that a subtle, yet critical, infrastructure element addressing situational response is required to successfully transition the space industry from a government-dependent entity to a sustainable, independent venture. This situational response element has widespread ramifications throughout the space industry. We have attached a copy of our introductory report for your consideration. Additional details may be found at our website at http://deserweb.echoechoplus.com.

As Kentucky residents living in Bowling Green, we wish to impress upon you the strengths of this proposal with respect to the nation. There has already been considerable effort expended in the U.S. space program, and despite numerous calls for independent commercial participation there has been limited response within manned orbital space flight. Without this response, it is

difficult to develop a sustainable policy for the manned orbital space flight market. The recommendations made by previous commissions have been substantially correct in their intent, and we believe that with the addition of a situational response capability the initiatives already underway can finally gain significant traction with the commercial development of manned orbital space flight. Furthermore, we believe this infrastructure element supports the goals of the 2004 Vision for Space Exploration,

We are working to contact the Committee to Review U.S. Human Space Flight, and have submitted our report through the public portal available through NASA website. However, we compete with a vocal community. Approaches that describe realistic strategies can be unwittingly placed in a large stack of submissions describing alternative technology architectures, and so be easily overlooked.

To this end, we wish to obtain your assistance in assuring our work receives careful consideration. We have already obtained the support of Congressman Guthrie's office, and have received the cooperation of George Whitesides, Senior Advisor to NASA. We believe that your voice, independently promoting our work, will go far in advancing our report. We would appreciate a letter of support directly from your office to the committee, and to its chair, Mr. Norman Augustine.

We are convinced that the subtle effects of a situation response element may result in a method by which all the effort expended from previous recommendations can finally achieve the goal of a sustainable and independent commercial market in manned orbital space flight, and have positive effects on the other space flight markets.

We look forward to any assistance you might lend to our efforts. Should you have any questions regarding our work, we may be reached at:

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Thank you again for your time.

Sincerely,

Dr. Gordon Smith, Ph.D.

Alan Thompson, BSME

Space Policy Development Via Macro-Economic Analysis

Alan D. Thompson, BSME
Gordon P. Smith, Ph.D.

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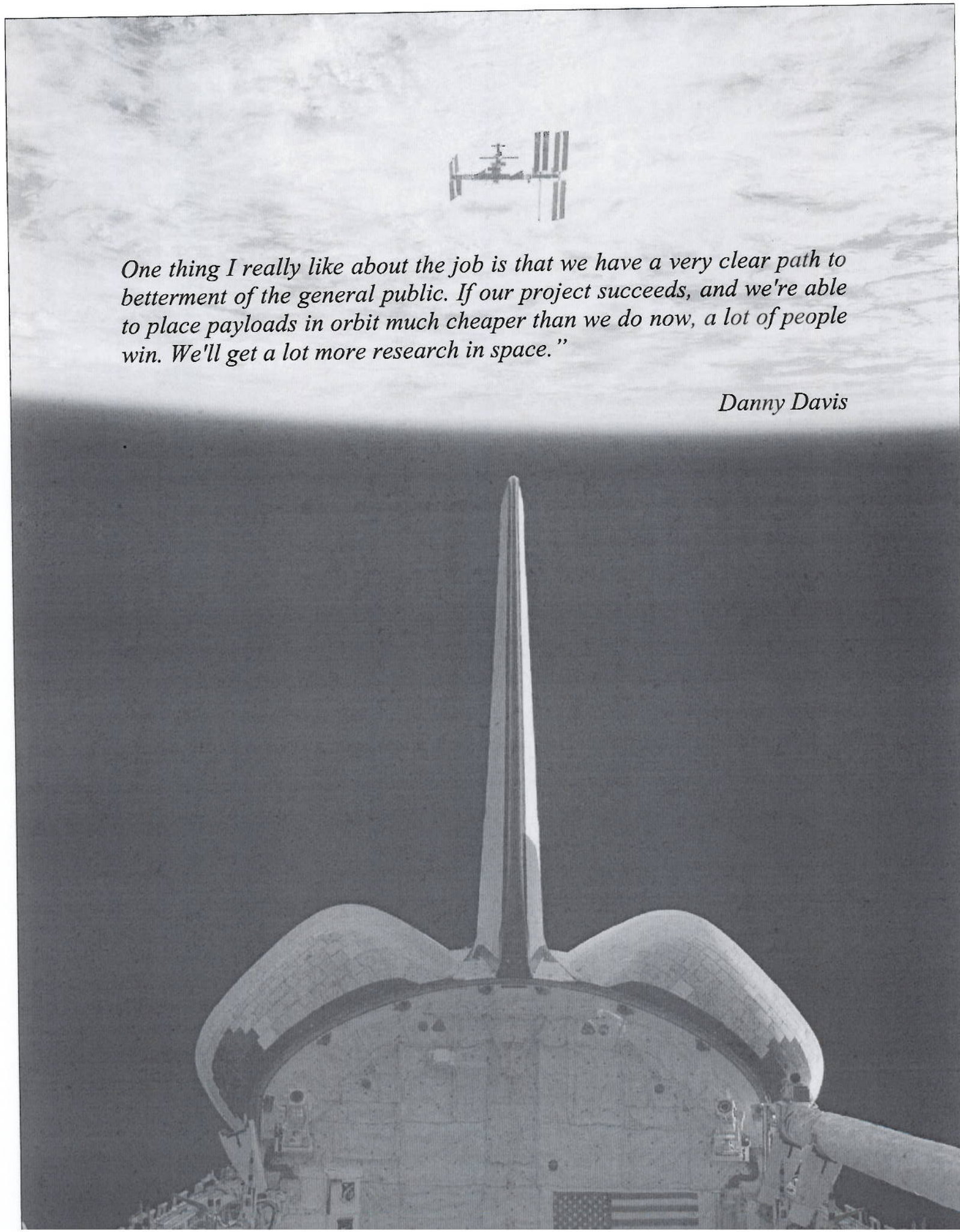

One thing I really like about the job is that we have a very clear path to betterment of the general public. If our project succeeds, and we're able to place payloads in orbit much cheaper than we do now, a lot of people win. We'll get a lot more research in space."

Danny Davis

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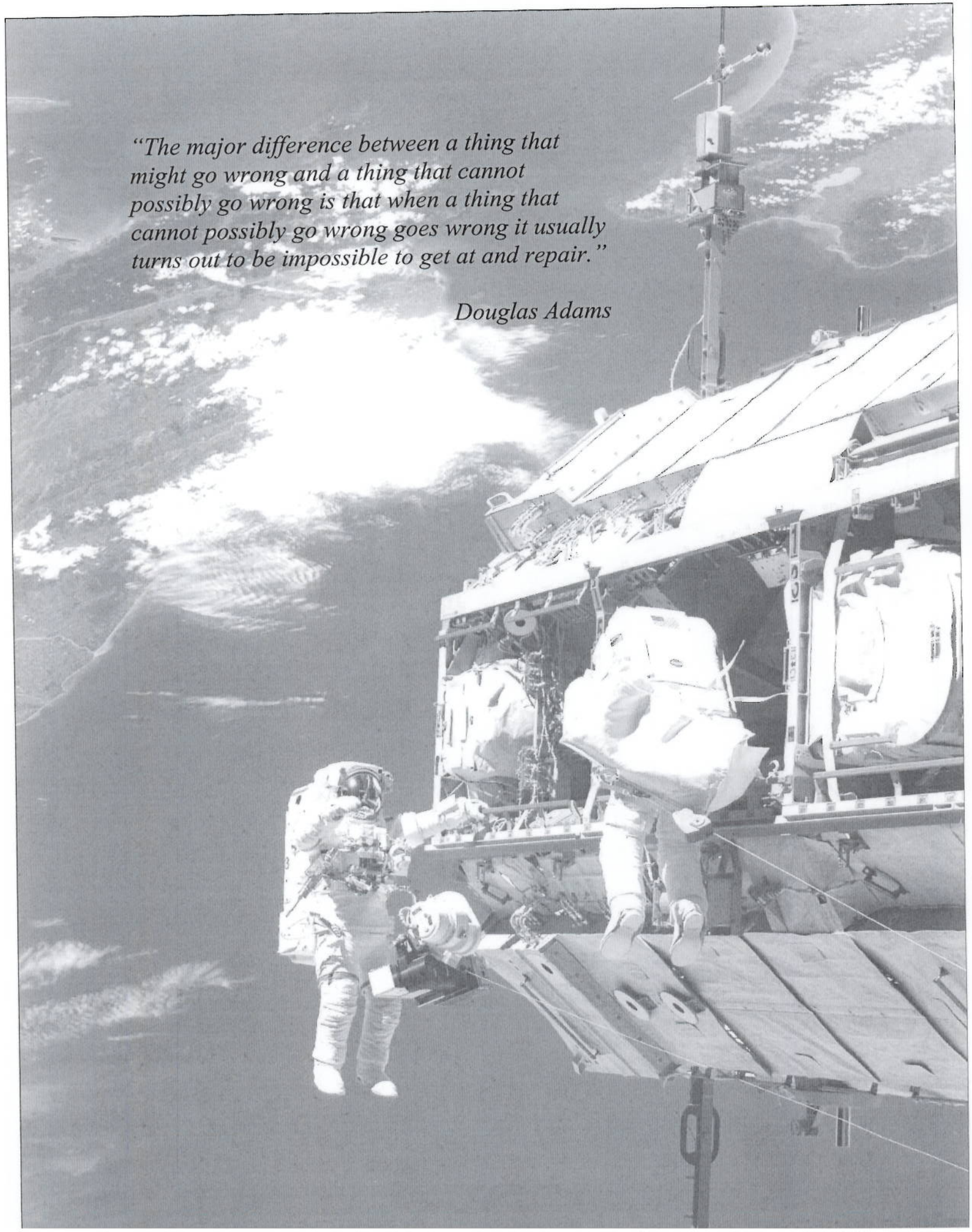
"The major difference between a thing that might go wrong and a thing that cannot possibly go wrong is that when a thing that cannot possibly go wrong goes wrong it usually turns out to be impossible to get at and repair."
Douglas Adams

Executive Summary

Many experts agree that the space industry will be important to the future economic growth and stability of the United States. However, maintaining its role as a global leader will require that the United States establish national space policies that can deliver measurable economic results in the near term while developing value-added capabilities to support future scientific and research objectives. The success of such policies will require industrial and national leaders to break away from paradigms that have driven our space policy development for the past 40 years. Traditionally, space policies of the past have suggested that the nation prioritize spending large amounts of money on exploration objectives, and that accomplishing these objectives will automatically allow a commercially independent sector of the space industry to develop. **While this approach in unmanned space flight has succeeded in establishing a commercially based market, we find that the manned markets have been slow to mature.**

This report analyzes the space industry from macroeconomic perspectives to assess the effectiveness of the current space policy. Further, we examine other relevant industry models to reveal insights to the developmental difficulties faced by manned space flight. We finally evaluate the role of government within successful industries to determine if any deficiencies in our current space policy can be resolved.

From our analysis we conclude that the space industry consists of commercial, scientific and military sectors that incorporate manned and unmanned operations. Though unmanned space flight has matured into a viable enterprise, manned space flight suffers an untenable weakness, due to the fact that there are no commercially based entities within this market that are independent of government-funded programs. To generate growth within the manned space flight industry, we must establish space policies that are developed through analytical methods based on realistic industrial models.

To generate growth within the manned space flight industry, we must establish space policies that are developed through analytical methods based on realistic industrial models.

The current space industry as a whole is functionally modeled after the airline industry. However, when we apply macroeconomic methodologies specifically to orbital, manned space flight market, we find that the airline industry model does not support orbital, manned spaced flight sufficiently to promote commercial growth. **Examining the automotive and cruise line industries, however, we find a closer parallel to orbital, manned space flight, as well as government agencies that have limited responsibilities for emergency response.**

From a macroeconomic analysis of orbital, manned space flight costs, we find that safety and reliability are the major driving cost factors within the entire space industry; yet again, there is no capability within our current industrial model to address these issues. Without addressing these underlying factors, the cost structure across the orbital, manned space industry cannot be optimized, preventing the growth of an independent commercial sector.

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Through this analysis we also find that the role of government within the space industry is inappropriate when compared to successful Earth-based industries. Governmental roles in Earth-based industries are limited to three major areas;

1) Support scientific research efforts,
2) Regulation and incentives
3) Protection of human and capital assets.

When comparing the manned orbital space flight market to other industries, we find that our current space policies do not address protecting assets. **If we continue to develop national space policies that ignore this oversight, we will remain without a commercially independent sector within the space industry.**

As a policy, sustained long-term manned space exploration cannot be feasible if we continue to ignore the public's perception of affordability with regard to the industry as a whole.

A commercially-independent manned orbital space flight sector is an important factor in improving the public perception that manned space flight is an affordable pursuit. Though manned suborbital ventures are gaining viability, these initial successes are not enough to support the entire manned space flight industry. As a policy, sustained long-term manned space exploration cannot be feasible if we continue to ignore the public's perception of affordability with regard to the industry as a whole. This point was made very clear in the Aldridge Commission Report[1]; though that report stopped short of suggesting any tangible strategies that would improve the current space policy.

Our analysis also indicates that strategies addressing commercialization will benefit all areas of the space industry including unmanned operations by improving serviceability issues. Manned space flight operation safety would also be improved; references to these types of recommendations were addressed in the 2003 Columbia Accident Investigation Board (CAIB) Report. In this report the authors stated:

> *"The goal of every shuttle mission is the safe return of the crew. An escape system – a means for the crew to leave a vehicle in distress during some or all of its flight phases and return safely to Earth – has historically been viewed as one "technique" to accomplish that end. Other methods include various abort modes, rescue and the creation of a safe haven (a location where crew members could remain unharmed if they are unable to return to Earth aboard a damaged Shuttle)."*[2]

It is obvious that the authors of the CAIB report recognize that rescue capabilities will be an important element in protecting human (as well as capital) assets.

When extended throughout the industry and supported by other analytical methods, we see that emergency response capabilities are paramount if we expect to sustain a commercially-based industry in orbit or beyond. **Without an independent commercial sector it will be difficult to justify to the American public that manned space travel is affordable.** A costly space program results in limited public support that will not sustain any long-term exploration vision.

These analytical studies suggest that a change in policy planning is required, and that the historical paradigms used to establish space policy in the past are inadequate. **Fortunately, the required change is subtle, and supports the initiatives already under recommendation.**

We boldly call for a new governmental emergency response support agency serving space endeavors, whose existence will finally allow past initiatives endorsed by numerous commissions to flourish and provide the means by which space flight can finally mature and become available to commercial ventures, free from government funding.

We boldly call for a new governmental emergency response support agency serving space endeavors...

The question becomes one of change: is the American industrial and political leadership willing to change, or will the development of strategic space policies, directed at commercialization, be left to the international community? Visionary space policies, built on paradigms of the past, cannot keep the United States competitive in an industry that will transition to a global, commercially independent marketplace. **Realistic space policies, guided by proven and properly applied strategic principles, are required to maintain our position as a leader in space operations.**

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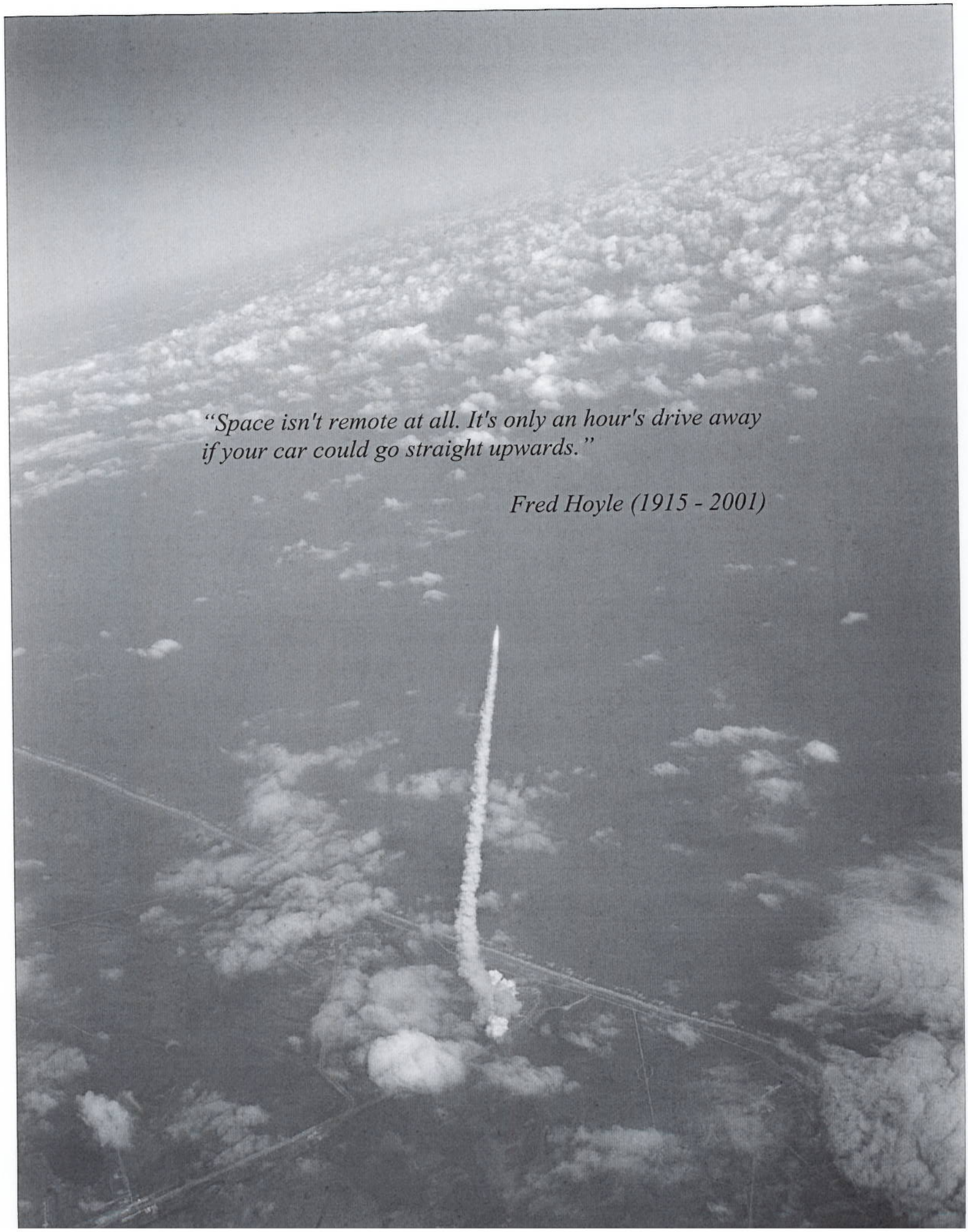
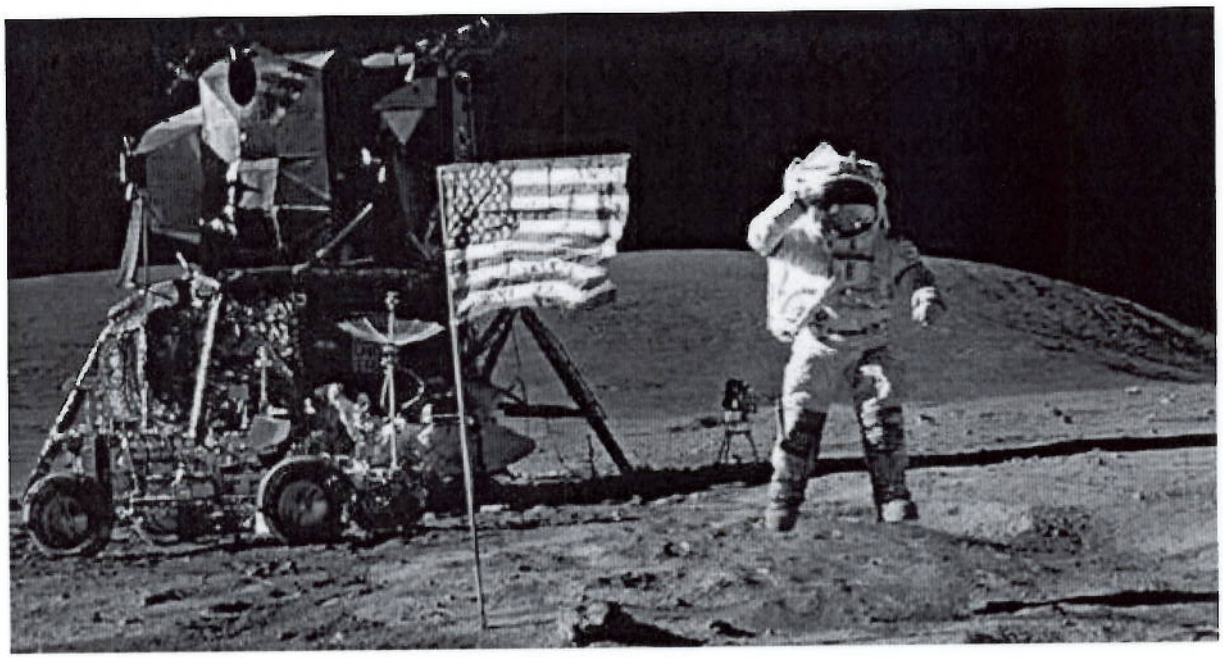

"Space isn't remote at all. It's only an hour's drive away
if your car could go straight upwards."
Fred Hoyle (1915 - 2001)

Introduction

Section I

With the launch of the Sputnik satellite in 1957, the space age began. Since that time the human race has achieved many inspiring goals, including sending unmanned satellites to the edge of solar system and landing humans on the Moon. An unmanned commercial satellite industry and many supporting Earth-based industries have been built around the technical knowledge gained from these early efforts.



One must remember, that the space age did not begin as a grand utopian dream to better the planet. The space age began as a race to demonstrate technological superiority. At that time, the leader of the Soviet Union wished to intimidate the world by showing that he, through the use of advanced technology, could make the USSR the most powerful nation on the planet. In response to this threat, the United States of America began to develop its own space-related technologies. From the outset, the United States struggled to develop operational space technologies.

In 1961, then President John F. Kennedy outlined a visionary space policy to the members of Congress and the American public:

> *"...I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."*[3]

This space policy was clear, direct and necessary; the sole propose of which was demonstrating to the USSR and the rest of the world that the Soviet Union was

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not the only technologically capable country. Based upon this space policy, NASA and the nation began an epic journey toward the Moon. In 1969, the race was won with the success of Apollo 11. Six years later, the United States ultimately cancelled the Apollo program and discontinued manned missions to the Moon due to escalating costs and the lack of public support.

Since that time, we have developed our unmanned space flight capabilities to a level that has lead to astonishing scientific discoveries, and developed a satellite network that has changed the world in the areas of commercial telecommunications and aerial reconnaissance. Today, many countries understand the value of these satellite-based networks and are quickly developing their own systems to compete in the world marketplace.

The cost of manned space flight endeavors has led many to ask, "Is human space travel worth the investment?"

The manned space flight industry, however has struggled to find its place in this post-Cold War era. While technological achievements like the Space Shuttle and the International Space Station are operational, these technological systems are enormously expensive and the U.S. has yet to develop a manned space flight industry that is independent of government-funded programs. The cost of manned space flight endeavors has led many to ask, "Is human space travel worth the investment?"

It is common opinion that manned space travel will be an important part of the world economy in the future. **However the reality of the situation is that in the past 25 years the United States has not successfully directed its space policies toward the development of a manned commercial space flight industry that would be independent of government programs.** Instead it has chosen to develop manned space flight policies along the "grand mission" approach used during the Cold War era.

In the Commission's final report entitled; "A Journey to Inspire, Innovate and Discover", the commission stated that sustainability and affordability were the key issues in achieving this multi-decade space policy.

On January 14, 2004, President Bush announced that the United States would direct its manned space flight policies toward a goal of returning to the Moon and eventually a manned Mars mission.[4] While this type of vision is exciting and stirs the imagination, the economic realities force us to ask if this is the direction that the United States needs to travel. As part of this policy the President formed a commission, headed by the Honorable Pete Aldridge, to investigate this space policy to determine the most appropriate course of action to implement this vision. In the Commission's final report entitled; "A Journey to Inspire, Innovate and Discover"[1], the commission stated that sustainability and affordability were the key issues in achieving this multi-decade space policy. **While the commission report stated these issues, it stopped short of suggesting any tangible solutions to address either issue.** These types of space policies will not serve an industrial marketplace that is heading toward a commercially-based environment. Since the release of the Commission's report, public support for the new space exploration vision has been modest at best.

The question then becomes, along what strategic lines should the nation develop its space policy and what should be the role of government in this new policy? The Aldridge Commission report was correct in stating that sustainability and affordability are the most important aspects of this, or any, space policy.

However the very nature of these factors indicates that the affordability issue is paramount in the development of a sustainable policy. Therefore we should analyze any proposed space policy to ensure that we have addressed this affordability issue, as well as its perception. If the American public can rationalize a return on investment, the policy could be sustainable.

In the time since 1975, spin-off technologies have been a key foundation for space policy. **This differs from the 1961 vision, which was designed to answer a specific political and cultural challenge from the Communist-controlled Soviet Union.** Supporters suggest that the implementation of current space policy would produce the same reward of spin-off technologies that we received through the development of the Apollo missions. While this statement may be valid in some respect, we should consider that many of the technological breakthroughs since have occurred as a result of unmanned missions and few, if any, of these technologies can attribute their development solely to manned space flight.

Attempts to use spin-off technology arguments as justification for space flight programs today lead to policies that are expensive to implement, and are likely to face abandonment as these costs escalate. This is now happening to the various space policies that were used to justify the International Space Station and the Space Shuttle. **Now that the cost of these programs have escalated, the space policy outlined in January 2004 will require the citizens of the United States to abandon both the Shuttle and the International Space Station in order to attempt to pursue the remaining objectives of the grand vision.**

Attempts to use spin-off technology arguments as justification for space flight programs today lead to policies that are expensive to implement, and are likely to face abandonment as these costs escalate.

Other supporters of the President's space vision state that the scientific value of these missions would justify the cost; however it can be argued that science can be done more cost-effectively with unmanned robotic probes and rovers.

We understand that a manned space flight industry, though expensive, will be an important part of the future global economy. **The ability to sustain a manned space flight program will be directly related to the program's perceived affordability.** This does not mean we should attempt to sell these new space policies to the American public by initiating an advertising campaign similar to the release of a new model automobile. This will be ineffectual in the long term; the public will eventually, if not immediately, realize the cost implications of the policy and it will suffer the same fate as its predecessors. Instead, we should re-analyze the space industry in its entirety and see if the results can guide us to a space policy that is appropriate for the current industrial environment.

This is the premise for this report.

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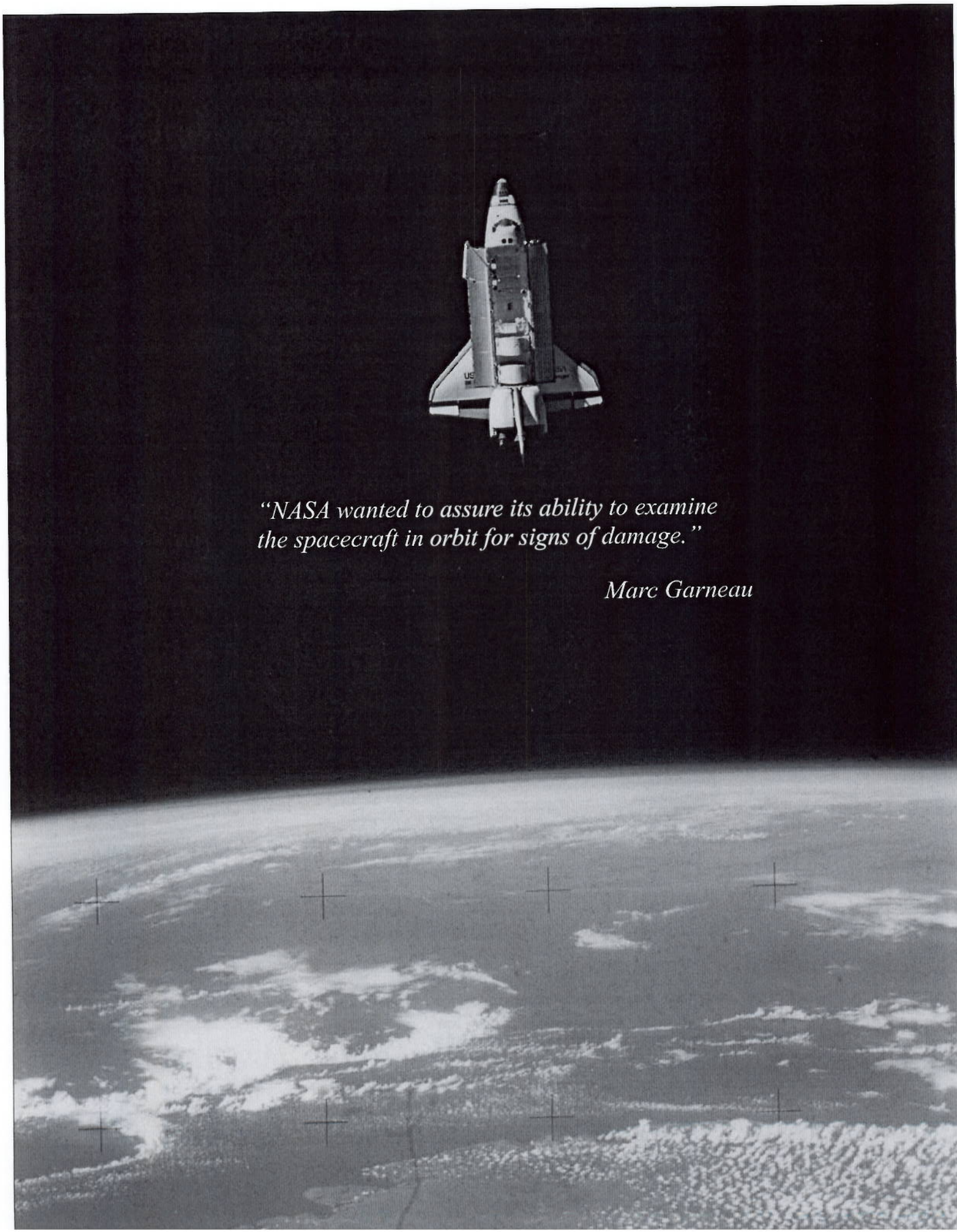

"NASA wanted to assure its ability to examine the spacecraft in orbit for signs of damage."

Marc Garneau

A Review of Historical Space Policies

Section II

Before proceeding to consider new directions for the space program, it is useful to review the policies of the last 50 years to assess their strengths and weaknesses. These policies may be grouped into periods:

- Cold War Policy
- Post Cold War Policies
- Vision for Space Exploration

COLD WAR POLICY

In 1957 the Soviet Union launched Sputnik and to the dismay of the United States, the satellite functioned as expected. This event occurred in the early stages of Cold War and further amplified a very tense time in human history. The Soviet Union was attempting to demonstrate technological superiority over the rest of the world. The national leadership of America understood the militaristic danger in allowing the Soviet Union to achieve an advantage in space-based technology.

In response, the United States intensified its efforts in all areas of space travel with the goal of demonstrating that the U.S. was the dominant technological power. Since the Soviet Union had been first to launch a satellite into orbit and the first to place a man in orbit, the United States needed an ambitious vision to focus the research activities. Following much debate, President John F. Kennedy announced a space policy in 1961 that sent the United States on a manned journey to the Moon.

The goal of this space policy was not directed at developing technologies to better mankind; it was directed at demonstrating technological superiority by accomplishing a specific task. The American people understood the threat that the Soviet Union represented and were modestly supportive of the original policy. **However, once we had successfully demonstrated our technological prowess, the space policy and the Apollo program were abandoned in 1975 due to the lack of public and Congressional support.**

The goal of this space policy was not directed at developing technologies to better mankind; it was directed at demonstrating technological superiority by accomplishing a specific task.

POST-COLD WAR POLICIES

Following the close of the Apollo program, the space community was left with a sense of "what now?" After many years of examination and adjustment, President Nixon announced[5] what would eventually become the space shuttle.

As the shuttle program developed the technologies required for operation, the political administration shifted. Broad statements regarding the use of space were issued, and drew concern. In 1978, President Carter issued a memorandum calling for clarity on the issue.

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> *"I am concerned that the United States does not have a coherent national space policy guiding our civil, military and national intelligence space programs. I, therefore, direct that the Policy Review Committee thoroughly review existing policy and prior efforts, and formulate a statement of overall national goals in space, the principles which should guide U.S. government and private use of space and related activities, and a clearer definition of the roles and responsibilities of the federal government agencies involved."*[6]

Despite the call for clarity, the resulting policy[7] instead founded the broad generalities of subsequent US space policies:

- The United States would explore space in support of US policies
- That space could not be controlled by any entity
- That space could be used as an arena for self defense
- That the United States would pursue unspecified space activities to increase scientific knowledge, develop useful civil applications of space technology, and maintain United States leadership in space.

In comparison to the clarion call put forth by Kennedy, this policy had no specific goals that could be distinctly measured.

In comparison to the clarion call put forth by Kennedy, this policy had no specific goals that could be distinctly measured. It merely ascribed ideals regarding the use of space, and expressed a desire to maintain a geopolitical leadership role.

In 1982, President Reagan established a commission to review the U.S. Space policies[8], which recommended continuing the space shuttle program as a means to begin commercializing space. Later directives[9] studied the feasibility for a manned space station. **Despite these specific goals, the remaining portions of the space policy, continued to utilize political phrasing to state general ideals, but no specific commercial plans.**

Several other space policy documents have been published, but they have followed the model of earlier policy, emphasizing broad political and social ideals without proclaiming specific plans with which to enable them. Without this clarity, NASA has struggled to maintain support for the various manned space flight policies that had been proposed. **The space shuttle fleet is due to retire, the manned space station operates under international collaboration, but the commercially based space industry that was promised so many times has yet to appear.**

Not only was a specific doctrine designed to nurture a commercial market absent from space policy, NASA appeared, though its actions, to fight commercialization by discouraging independent, civilian involvement in the areas of space tourism and space launch access. **It is now generally accepted that NASA wishes to retain its monopoly on the manned space flight industry**.

VISION FOR SPACE EXPLORATION

In the aftermath of the Columbia shuttle disaster, the need for a clearer direction was again stressed. In January 2004, NASA released a report entitled; "The Vision for Space Exploration"[4]. This report outlined a proposal that would direct the national space policy toward manned Lunar and Mars missions. While the report included characteristic paradigms required for a "grand" space policy, and contained new economic approaches for operation, it too stopped short of explaining how this new vision would lead to a manned commercial space flight industry that would be independent of government programs.

While the report included characteristic paradigms required for a "grand" space policy, and contained new economic approaches for operation, it too stopped short of explaining how this new vision would lead to a manned commercial space flight industry that would be independent of government programs.

After the announcement of the new space exploration policy in January 2004, the President formed a commission headed by the Honorable Pete Aldridge, which contained members from various academic and industrial institutions. This commission reviewed the space policy and in June 2004 published a report entitled; "A Journey to Inspire, Innovate and Discovery"[1]. This report would later become known as the "Aldridge Commission Report".

In this report the Aldridge Commission recognized that sustainability and affordability would be the keys to the successful implementation of this policy. **However, the report stops short of suggesting any tangible strategies that would lead to a sustainable and affordable program.** Instead the report focuses on ways to sell the space exploration policy to the American public. **Since public support is obviously important to the sustainability of any space policy; we should embark on strategic space policies that will make logical sense to the public.**

IMPLEMENTING HISTORICAL SPACE POLICIES

With few exceptions, programs emerging from US Space Policies have revolved around grand visions and broad generalities. Policies with specific goals provide no caution for expenses, as the goal itself is so critical. These approaches indicate that, politics has influenced space programs more than commercial rationale.

Regardless of their motivation, these programs have succeeded or been replaced depending on whether or not they have been perceived as affordable and sustainable. Affordability is a very subjective area; **in the 1960's the space race was considered affordable because the American public understood the importance of demonstrating technological superiority over the Soviet Union during the Cold War.** While some of the technological improvements developed during this time would eventually become important to the economy; these technological spin-offs were secondary to the original objective of the space policy.

...these programs have succeeded or been replaced depending on whether or not they have been perceived as affordable and sustainable.

Fortunately there is no longer a Cold War that requires this aggressive type of space policy. **However, NASA has continued to use the science and spin-off technology arguments to justify the continuation of government controlled,**

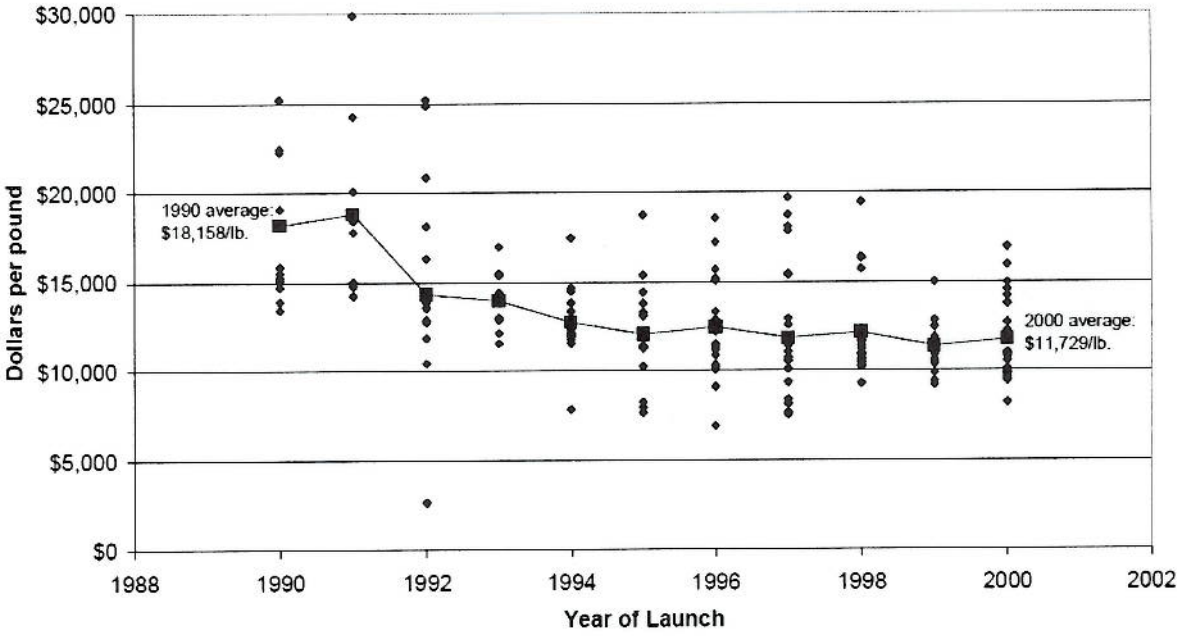
manned orbital space flight. These arguments have been less effective in sustaining space programs since the end of the Cold War. The American public understands that these same science and technological developments can be achieved with far less expense by utilizing robotic space missions to conduct science and exploration, thereby avoiding the cost associated with sending humans into space.

Any affordable commercial venture must have a demonstrable cost model that predicts a reasonable (or substantial) return on the original investment.

From a commercial standpoint, however, affordability becomes much more objective. Any affordable commercial venture must have a demonstrable cost model that predicts a reasonable (or substantial) return on the original investment. **The goal-oriented nature of past programs do not emphasize such cost models.** In fact, costs vary wildly within historical programs.

Comparing market and industry projections show this problem clearly. A representative example can be drawn from the US Department of Commerce Industrial Outlook, company annual reports, NASA Reports and various compilation reports from technology consulting firms (Teal, Futron, etc.). **Depending upon which firms or organizations data was used, the data varies as much as 50% from one source to another.** Further difficulties arise in distinguishing between commercial, military and governmental scientific payloads. If a military satellite was sent into orbit with a commercial launch vehicle, one source might classify it as military, another would classify it as a commercial, and yet another source would actually place the same money under both classifications (in effect counting the same occurrence twice).

Shown below is a representative example of data Futron collected showing the wide variance in data.



Estimated Launch Price per Pound for Commercial GSO Payloads (constant 2000$)[10]

This same problem can be found in the Space Shuttle "cost per pound" (CPP) measurement. In a report titled "The Near-Term Roadmap" published in December 2002 by DFI International[11], the authors quote the Space Shuttle (CPP) at $16,000 per pound. Other sources such as NASA, quote the price at $10,000 per pound. In December 2002 a report entitled "Space Economic Data" prepared by Henry R Herztfeld, confirmed there did indeed exist reporting inconsistencies in the way industrial data was reported.

As an attempt to attract commercial ventures, the current space industry model attempts to mitigate economic risk by relying solely upon Damage Tolerant Design (DTD) methodologies to build satellites and spacecraft that can withstand any possible problem the equipment may encounter during the life of the mission. Once in orbit, little room for error is acceptable; otherwise the satellite or spacecraft will be lost.

DTD methodologies require that multiply-redundant systems be included in the design of equipment that will allow the equipment to withstand a high level of damage and still perform the intended task. Total reliance on these types of design methodologies causes a significant increase in the cost of space assets, further increased by the pressures of a political schedule that relentlessly strive for positive headlines.

RATIONALE FOR A NEW DIRECTION

The last fifty years of broad, politically-motivated space policies have produced an industry that accepts uncertain operational costs; and focuses solely on expensive DTD methodologies to reduce risk. It is no surprise, then, to find that the programs emerging from historical space policies have limited acceptance in the commercial world.

At this moment, we are again in a position to redirect space policy, and have begun to recognize key elements that are required for its success. The Aldridge Commission Report identified affordability and sustainability as key success drivers that will be of paramount importance in implementing this new space policy.

How do you convince the public that space flight is affordable? Quite simply; show the public a direct, positive economic impact, which is independent of the government funding programs. Despite the limitations under which the space program operates, this justification has worked well for certain portions of the industry

How do you convince the public that manned space flight is affordable? Quite simply; show the public a direct, positive economic impact, which is independent of the government funding programs.

The unmanned orbital telecommunications industry is a fine example of how independent commercial industries improve the "perceived" affordability of an industry. **No one in the general public can legitimately argue that the investments made in unmanned space science is an unaffordable pursuit, since the bulk of the science and technology developments generated in this area are utilized by an independent commercial sector to produce improved communications and imaging satellites.**

Manned, suborbital flights are also beginning to experiment with commercial ventures, such as Virgin Galactic. At this time, however, it is difficult to truly assess the long-term sustainability of these ventures.

...manned, orbital space flight market has yet to see any commercially independent companies

On the other hand, the manned, orbital space flight market has yet to see any commercially independent companies. NASA justified the space shuttle program by telling the American public that this spacecraft would open the door to a manned commercial industry. The same promise was used to justify the International Space Station, yet no commercially independent companies exist in the manned, orbital space flight market. All of the companies in the manned, orbital space flight market remain reliant on government programs for their survival in this marketplace. **Until such issues are addressed within the national space policy, the manned space flight industry will continue to struggle with justifications for manned, orbital space flight policies.**

A Macroeconomic Analysis of the Space Industry

Section III

Historical approaches to implementing space policy have been selectively successful. However, the details of the space industry provide little guidance as to the underlying reasons, as there are few unifying patterns in the available economic data.

In such situations, it is useful to change the perspective from the specifics of a microeconomic analysis to the broader view of a macroeconomic analysis in search of more fundamental insight. Macroeconomics studies the economic behavior of systems as a whole, as opposed the considering the details of specific aspects of those systems.

In broad terms, the space industry contains three main sectors: scientific, military, and commercial. **Each sector of the industry plays an important role in the success of the others**. The scientific sector provides knowledge and advanced technologies that are used by the military and commercial sectors. The military sector protects the assets of both the scientific and commercial sectors, while the commercial sector provides positive economic benefit to the national economy and supports the scientific and military sectors. **Note that the military and scientific sectors are not designed to be profitable entities.** Producing profit, a positive economic impact that is independent of government-funded programs, is the function of the commercial sector only.

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Commercial ventures develop within sustainable or soon-to-be-sustainable industries seeking to generate profit. A commercial venture must understand the nature of the costs, and how they influence the industry. The classification details of these costs are not important in a macroeconomic analysis. **The important question is, "Why is the money being spent"?** What factors, inherent to this industry, force us to spend this money? Why is it so expensive to build equipment for the space industry?

Within a commercial industry, the key goals are sustainability and affordability. A successful industry creates enough revenue that it may continue operating, if not expand its markets; otherwise its existence must depend upon outside resources, such as government subsidy. This identifies our focus; we must look for cost factors that contribute to sustainability and affordability.

A successful industry creates enough revenue that it may continue operating, if not expand its markets; otherwise its existence must depend upon outside resources, such as government subsidy.

Industry Cost Factors

With this focus, we can divide the space industry into sub-industries depending on their success at achieving a sustainable, affordable operation.

As noted earlier, the unmanned space industry is successful; having created an independent commercial sector that maintains vibrant growth. Success within the manned space flight industry cannot be clearly described until the industry is further separated into suborbital and orbital ventures. The manned, suborbital space flight industry is beginning to see commercial development, though it is

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too early to determine its sustainability. The manned orbital space flight industry, however, is clearly not sustainable as it is solely dependent upon government funding.

Examining the cost structure of the unmanned space industry, one can see that much of the expense comes from the reliability that is required. Multiply-redundant systems are integrated into the designs to ensure that the unit will be able to operate despite inevitable mishaps that cannot be addressed in orbit.

While safety and reliability are important in the unmanned space market, these issues become paramount in the manned space flight market.

This same cost structure appears in the manned space industry, magnified by safety requirements that are in place to protect the crew piloting the craft. While safety and reliability are important in the unmanned space market, these issues become paramount in the manned space flight market. **Safety and reliability have to be built into every component of a spacecraft to extreme levels, increasing the cost of manned orbital space flight beyond which commercial ventures are readily prepared to explore.**

Any new approach to space policy must include realistic and specific plans to address the cost factors of safety and reliability. Further, these plans should be designed to nurture a commercial sector, rather than simply calling for its participation.

INDUSTRIAL BASIS OF THE U.S. SPACE PROGRAM

To date, programs emerging from space policy have primarily modeled themselves after the airline industry. This approach is natural, given that NASA was formed to "provide for research into problems of flight within and outside the earth's atmosphere, and for other purposes"[12], and in its first days it absorbed the National Advisory Committee for Aeronautics (NACA) in its entirety.

It can readily be shown[13] that the airline industry has a significant and direct economic impact that is commercially-based and independent of government programs, having many private sector aircraft manufactures and industrial components that do not receive government funding. It also conducts scientific research that is funded by both the government and private sectors. This research has allowed the aircraft industry to achieve astonishing revolutionary and evolutionary breakthroughs in past 100 years. **From this analysis we can conclude that the global airline industry is successful.**

Applying this model to the unmanned space flight industry has yielded commercially-based telecommunications and global positioning businesses that have a significant, direct, positive economic impact independent of government programs. It also conducts many scientific research programs that have completely changed our understanding of the universe. **From these successes it would appear the airline model successfully supports the unmanned space flight industry.**

Though also modeled after the airline industry, the manned sub-orbital space flight area conducts less scientific research; however it is beginning a

commercial transition with companies like Virgin Galactic and Scaled Composite's SpaceShipOne. In October 2004 this team successfully completed the requirements to win the Ansari X-Prize competition, and a number of sub-orbital adventure companies are beginning to show interest in developing a commercially-based market. **While the prospects of commercially-based, manned sub-orbital space travel remain untested, it would tentatively appear that the airline model supports the manned sub-orbital space flight market.**

Operating under the same airline model as the unmanned space flight industry and manned sub-orbital space flight industry, the manned, orbital space flight area contains no commercially-based companies that are independent of government-funded programs. While there has been scientific research conducted on the space shuttle and International Space Station, these efforts have been very limited and are extremely expensive.

It has been argued that the manned, orbital space flight industry produces spin-off technologies that indirectly impact the economy; however, it is difficult to identify any technologies developed in the past 25 years that can attribute their development solely to manned, orbital space flight programs. The bulk of technological breakthroughs can be attributed more to the unmanned space flight programs (for example, improved CCD and telecommunications systems). **Hence we conclude that the airline industry model does not adequately support the manned, orbital space flight industry, as a successful, independent commercial sector has yet to manifest.**

The question now becomes, why has the commercial sector of the manned orbital space flight area not matured over the past two decades when many reports published by NASA and others during that time, each promised that commercialization was just around the corner?

The question now becomes, why has the commercial sector of the manned orbital space flight area not matured over the past two decades when many reports published by NASA and others during that time, each promised that commercialization was just around the corner? We must look deeper into the infrastructure systems of these industries to find the answer.

MODELING INDUSTRY INFRASTRUCTURES

From a macroeconomic perspective, there are several fundamental operations that make up the infrastructure of the space and airline industries. From an oversight perspective, these operations are managed either by government agencies, commercial entities, or shared by both. For the airline/space industry, this breakdown is shown below.

Refueling	Provide fuel for the vehicle's single or multiple trip legs at dedicated facilities.
Resupply	Refresh food and other supplies required for the crew and passengers during flight
Flight Control	Oversee relevant information critical to the in-flight operation of the vehicle
Vehicle Design	Develop designs addressing mechanical requirements and FAA safety regulations.
Facility	Day-to-day operations overseeing the support functions for the industry
Security	Control access to dedicated facilities and the aircraft stationed therein

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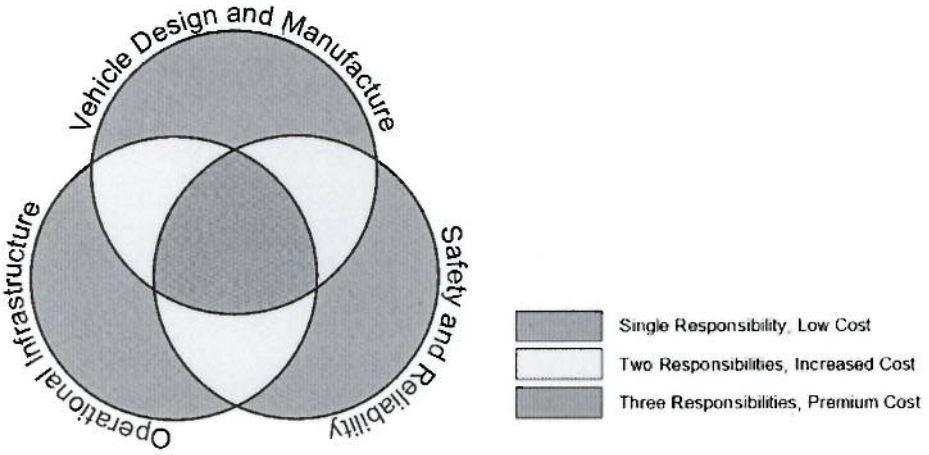
Note that all of these infrastructure areas are required and must remain in relative balance for the industry to function efficiently.

Note that all of these infrastructure areas are required and must remain in relative balance for the industry to function efficiently. It should also be noted that some of the infrastructure elements described are themselves industries independent of the airline industry. For example, the petroleum industry controls the refueling infrastructure element utilized by the airline industry while servicing other industrial markets as well. However, if the petroleum industry experiences operational or economic challenges, these challenges will affect the airline industry.

It is also useful to consider the responsibilities of each of these operations with regard to the overall industry, and compare them to their relative costs. These responsibilities lie within three primary categories for transportation.

Operational Infrastructure	Systems ensuring the regular operation of vehicles throughout the industry
Safety and Reliability	Systems ensuring the safety of the operators and passengers within industry vehicles
Vehicle Design and Manufacture	Systems relating to the design of new vehicles for the industry, as well as mass production of proven vehicles.

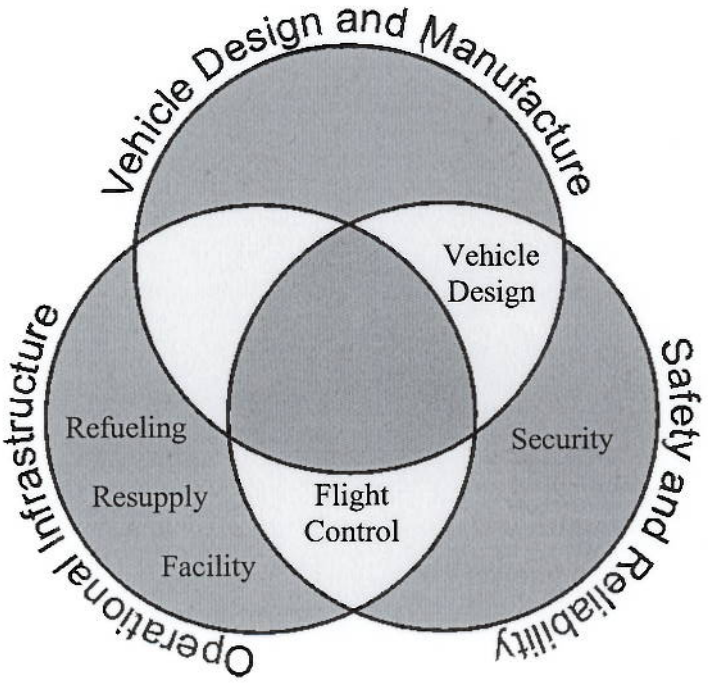
We represent these responsibilities within a Venn diagram to display their cost relationships. This approach is most useful since specific operational components can share responsibilities. **Where infrastructure components must support multiple responsibilities, their cost naturally rises.**



Airline Industry

Using these tools, we can describe the airline industry in the following manner

	Oversight		
	C	C/G	G
Refueling	X		
Resupply	X		
Flight Control			X
Vehicle Design	X		
Facility		x	
Security			X



As can be seen from the representation, many of the infrastructure elements are in the lower cost range. **In particular, refueling and resupply are relatively inexpensive due to the mature nature of the commercial market, the large number of available locations to perform the operation, and the competitive nature of supplier contracts.**

Flight control is considered an increased cost element due to its dual responsibilities of operations and safety. Furthermore a significant amount of dedicated technology is required for operation. **Vehicle design also deserves an increased cost rating; the vehicle must meet federal regulations from a structural standpoint, and operate without incident between airports (thus meeting both design/manufacture elements as well as safety/reliability).** Though isolated in flight, aircraft enjoy a significant number of established public and private airports should they need to land quickly.

From a market sector standpoint, there is a healthy division of responsibilities between the commercial and government sectors. Note that the facility infrastructure is a unique element in that airports are built with federal, state and local government funding along with other financing options that include municipal bond sales. **Once constructed, these types of infrastructure elements are then turned over to government and commercial enterprises that are responsible for the day-to-day operations of the element, thereby reducing the overall cost to government agencies.**

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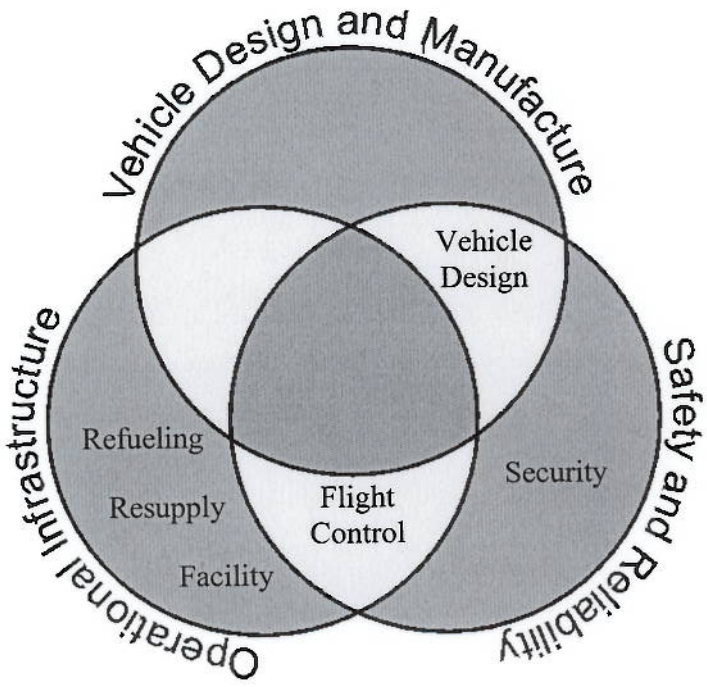
Suborbital Manned Space Flight Industry

We can also apply these tools to describe the Suborbital Manned Space flight industry.

	Oversight		
	C	C/G	G
Refueling		X	
Resupply		X	
Flight Control		X	
Vehicle Design	X		
Facility		X	
Security	X		



The manned suborbital space flight market follows the airline model quite well; it consists of a spacecraft that leaves the Earth's surface, flies to a specific altitude for a relatively short period of time and returns to the surface of the Earth.

The manned suborbital space flight market follows the airline model quite well; it consists of a spacecraft that leaves the Earth's surface, flies to a specific altitude for a relatively short period of time and returns to the surface of the Earth. **The only significant difference between airlines and sub-orbital flight is that sub-orbital flight achieves impressively higher altitudes.** Both sub-orbital and conventional airline flights last from less than an hour to several hours depending on the destination, and return to the Earth's surface where the spacecraft or aircraft is inspected and maintained before the next flight.

The Operational Infrastructure consists of relatively low-cost entities, as Refueling and Resupply occur at a dedicated Facility, all of which can be supported by government or commercial interests. As occurs in the airline market, Flight Control merits increased costs to meet the multiple responsibilities required.

The emphasis on Safety and Reliability also drives the cost of Vehicle Design to increased cost levels. In addition to the increased safety requirements that occur during the design phase, inspection and maintenance procedures are executed while the craft is in service, similar to airline industry approaches.

In the case of airlines, these inspection and maintenance procedures are regulated by federal government agencies such as the Federal Aviation Administration

(FAA) and the Department of Transportation (DOT). **These regular inspections allow for damaged parts to be replaced before their failure is imminent.** Similar operations are likely to occur for suborbital craft.

Given the success of the mature airline market with this model, it is not surprising to see the recent emergence of an independent commercial sector within manned, suborbital space flight. The reward of the Ansari X-prize competition may have been a contributing factor to this growing sector, but the $10M purse was not sufficient to recover the estimated $25M in development costs of the winning SpaceShipOne, much less the investments of the 25 other teams. In the time since SpaceShipOne successfully won the Ansari X-prize, there has been more than $1.5B[14] in public and private expenditure in support of the private spaceflight industry.

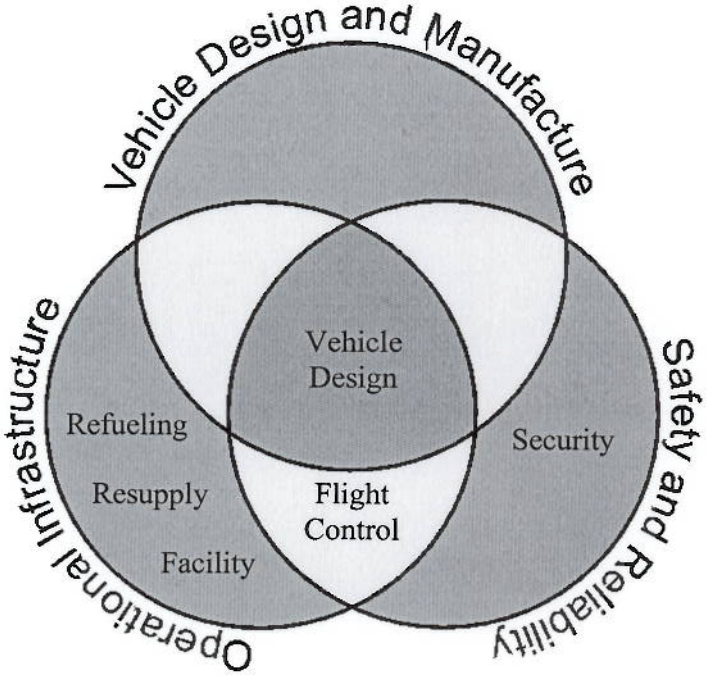
Given the success of the mature airline market with this model, it is not surprising to see the recent emergence of an independent commercial sector within manned, suborbital space flight.

Without a suitable infrastructure, we would not be seeing the emergence of the manned, suborbital space flight commercial sector as the venture would be unsustainable in a profit-driven market.

Orbital Manned Space Flight Industry

The Orbital Manned Space Flight Industry can be represented as well.

	Oversight		
	C	C/G	G
Refueling			X
Resupply			X
Flight Control			X
Vehicle Design		X	
Facility			X
Security			X



Though similar to the airline and suborbital manned space flight representations, there is a subtle yet critical difference.

Though similar to the airline and suborbital manned space flight representations, there is a subtle yet critical difference. The manned orbital space flight market requires that a spacecraft leave the surface of the Earth and fly to specific orbital location and remain in this orbit for time periods ranging from several days to several weeks before returning to Earth. In the case of the International Space Station and satellite systems, the duration of the mission is considered permanent.

This difference between the orbital manned space flight market and the airline and suborbital manned space flight markets drives the degree to which Damage Tolerant Design (DTD) methodologies must be applied. **Systems that allow an orbital vehicle safe reentry to an earth-based facility can become damaged upon launch**. While there is an opportunity to inspect these systems on orbit, options to fix the situation are limited.

Hence, DTD methodologies push Vehicle Design into the extreme cost region, as they must be sufficient for every conceivable incident, and any repair options must be completed in orbit, utilizing replacement parts on board the vehicle.

This indicates that the airline style infrastructure may be insufficient to support the orbital manned space flight market.

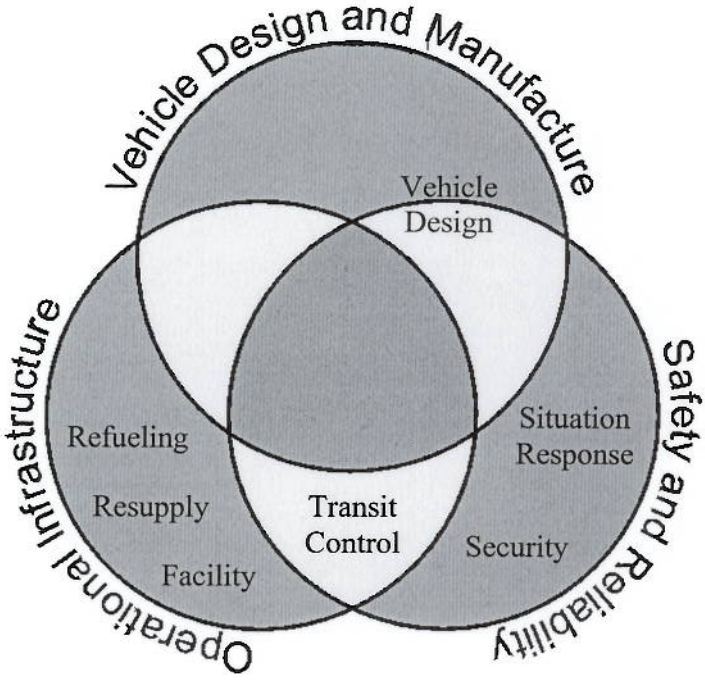
If the airline infrastructure model were sufficient to support the orbital, manned space flight industry, we would expect to see a similar development in the independent commercial sector of this market as well. **However, there are currently no indications that an independent commercial sector is beginning to develop or will develop in the foreseeable future.** This indicates that the airline industry infrastructure may be insufficient to support the orbital, manned space flight market.

Fortunately, there are other similarly functioning industrial models to the airline market that merit examination to see if other operational infrastructures may be successfully applied.

Cruise Line Industry

Functionally, the Cruise Line industry is very similar to the airline industry in that cargo and crew are transported from one place to another. **In addition to the entities contained within the airline industry, there is an additional entity not inherent in the airline industry, an entity to handle emergency situations (i.e., the U.S. Coast Guard)**

	Oversight		
	C	C/G	G
Refueling	X		
Resupply	X		
Transit Control		X	
Vehicle Design	X		
Facility		X	
Security	X		
Situation Response			X



Functionally there are few differences between the cruise line industry and the manned orbital space flight industry. Cruise ships and spacecraft depart from a particular location and operate for an extended period of time before reaching another port or space station. **However, cruise ships have a strategic plan in place by which emergency conditions may be successfully addressed by the U.S. Coast Guard fleet, sent out on demand to meet the cruise ship while away from port.**

Adding this situation response entity to the infrastructure reduces the vehicle design costs, as now it is not of paramount importance to cover every contingency; one has only to ensure that should an emergency occur, the crew is safe until help can be dispatched.

Adding this situation response entity to the infrastructure reduces the vehicle design costs, as now it is not of paramount importance to cover every contingency; one has only to ensure that should an emergency occur, the crew is safe until help can be dispatched.

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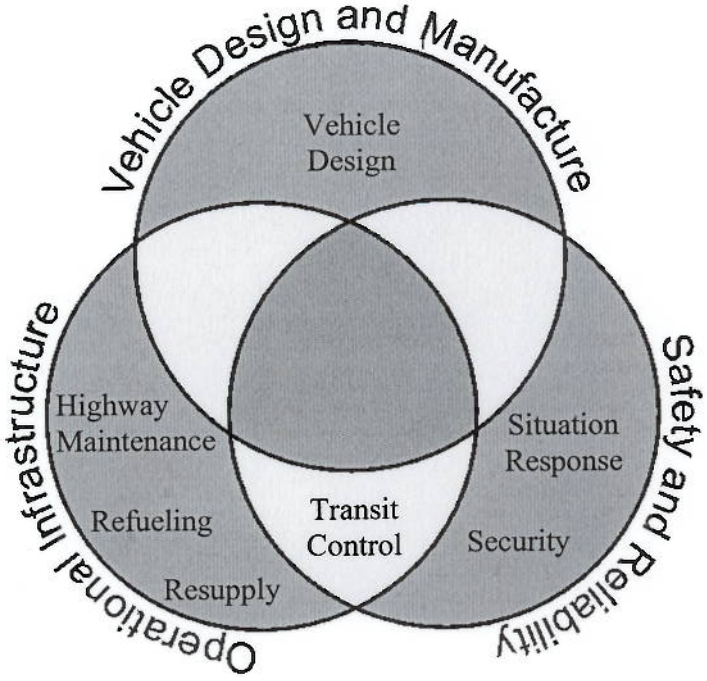
Automotive Industry

Functionally, the automotive industry is also very similar to the airline industry in that cargo and crew are transported from one place to another. **As with the cruise line industry, there is an entity to handle emergency situations (i.e., tow trucks and ambulances).** Additionally, there is a minor adjustment in that the facility entity is replaced with a Highway Maintenance entity.

	Oversight		
	C	C/G	G
Refueling	X		
Resupply	X		
Transit Control			X
Vehicle Design	X		
Highway Maintenance			X
Security			X
Situation Response		X	



Functionally there are few differences between the automotive industry and the manned orbital space flight industry, and in fact, more than a few close similarities. Automobiles and spacecraft depart from a particular location and operate fairly indefinitely without necessarily needing to return to that particular location. **However, the automotive industry has a strategic plan in place by which emergency conditions may be successfully addressed through a variety of government and commercial entities that can be sent out on demand to meet the automobile while out on the road.**

If the automotive industry relied solely on manned, orbital space flight levels of DTD to maintain safety and reliability, it is safe to say that automobiles would be so expensive that few individuals could afford to buy one.

This capability is very important for the automotive industry. If the automotive industry relied solely on manned, orbital space flight levels of DTD to maintain safety and reliability, it is safe to say that automobiles would be so expensive that few individuals could afford to buy one. **So we must conclude that the automotive industry, as we know it today, would not exist without the emergency response infrastructure elements.**

INSIGHTS OF A MACROECONOMIC PERSPECTIVE

Applying a macroeconomic analysis to the manned space flight industry reveals that the model of the airline industry cannot be universally applied throughout the manned space flight industry. The unmanned space flight industry and the manned suborbital space flight industry are sufficiently similar to the airline industry that the underlying strategies successfully generate an independent commercial sector. **However, when a macroeconomic analysis is applied to manned orbital space flight, we find that the airline model, while close, is not the best match from an operational vantage; and those subtle differences account for why a commercial sector have been slow to develop.**

Applying a macroeconomic analysis to the manned space flight industry reveals that the model of the airline industry cannot be universally applied throughout the manned space flight industry.

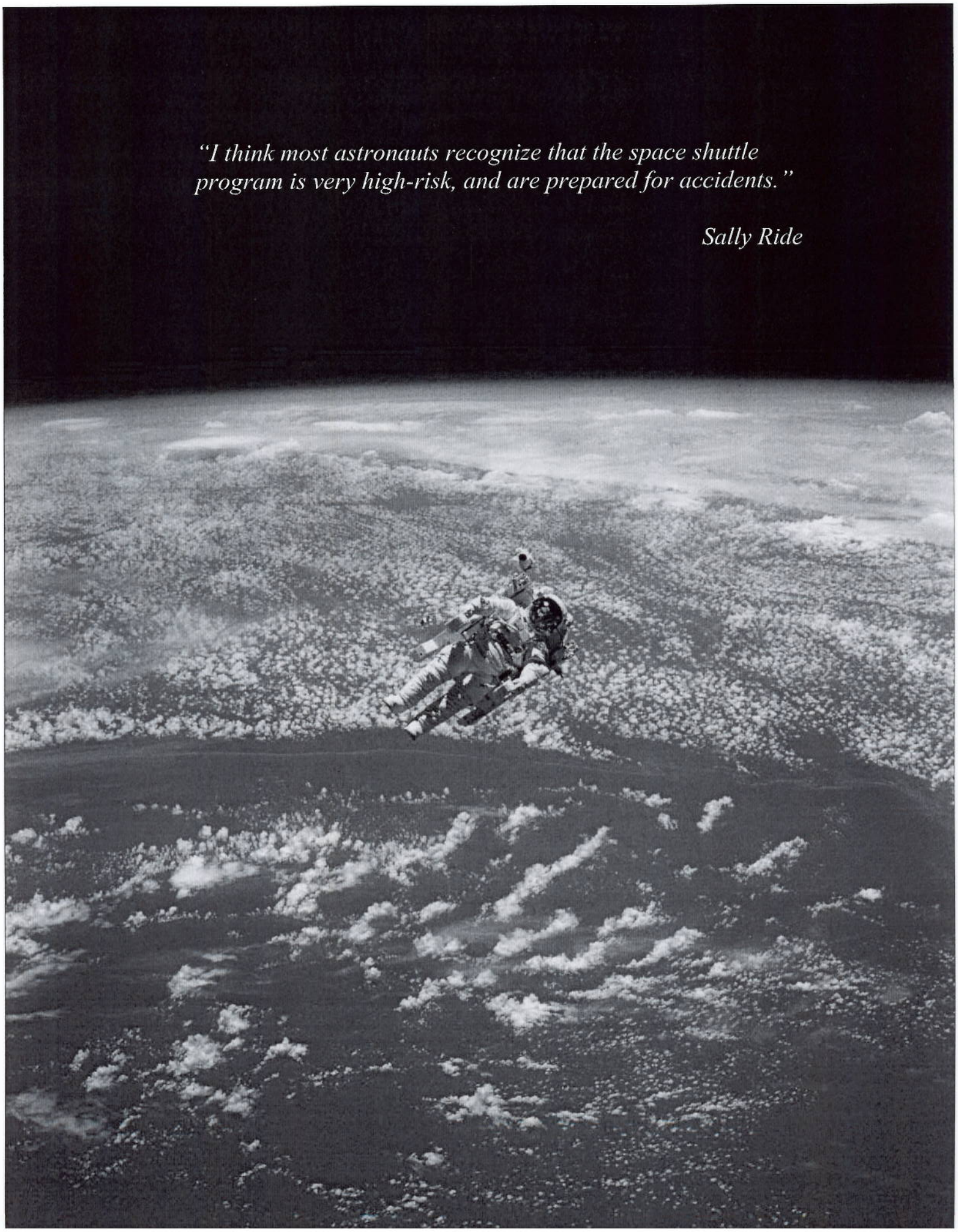
Looking at other similar industries, we find that the cruise line and automotive industries provide fundamentally equivalent services from a macroeconomic perspective; and they both utilize an additional infrastructure element addressing emergency situations. **This emergency response element contributes to the low costs of the automotive and cruise line industries, specifically addressing the cost drivers of safety and reliability that inflate the orbital manned space flight industry costs to commercially unaffordable levels.**

We propose that the lack of an independent Situation Response capability is fundamentally responsible for the manned orbital space flight industry's consistently excessive costs as it requires a zero-tolerance engineering approach in Vehicle and Equipment Manufacture. **These high costs have deterred commercial businesses from naturally pursuing the opportunities of manned, orbital space flight, as has been promised throughout the last forty years.**

We propose that the lack of an independent Situation Response capability is fundamentally responsible for the manned orbital space flight industry's consistently excessive costs as it requires a zero-tolerance engineering approach in Vehicle and Equipment Manufacture.

Without an emergency response capability, enabling the means to correct problems that might occur in a hazardous orbital environment, the manned space flight industry will be unable to attract the vital commercial sector needed to mature into a sustainable and affordable industry.

This emergency response capability, then, should be made a priority in forthcoming policy so that the long-promised commercial sector may finally develop.



"I think most astronauts recognize that the space shuttle program is very high-risk, and are prepared for accidents."

Sally Ride

Emergency Response and The Role of Government

Section V

Having identified that an emergency response capability is missing from the US space policy that addresses the cost drivers of safety and reliability, we now turn to the role of government in fulfilling such capabilities.

The Role of Government

Government has three major roles in industry; 1) support of scientific research, 2) industry regulation and incentives and 3) protection of human and capital assets.

Government has three major roles in industry; 1) support of scientific research, 2) industry regulation and incentives and 3) protection of human and capital assets.

Within the context of emergency response, government establishes and funds emergency response capabilities in industries that have operational systems where these capabilities can improve public safety. Where appropriate, government also establishes regulations for commercial industries.

The orbital manned space flight market operates under hazardous conditions, but the government has not sponsored policies to address emergency response within this market outside of DTD methodologies. Until this issue is corrected, the industrial infrastructure is incomplete, and the development of a commercially based sector will be delayed.

With a mature government-supported emergency response capability in place, the commercial sector can develop orbital assets with confidence, either attached to the existing ISS or operating as an independent structure, secure in the knowledge that assistance is available for mechanical or medical emergencies. As the commercial sector begins to develop its own assets, it will naturally begin developing additional infrastructure elements, i.e. refueling and re-supply elements.

Emergency Response Benefits

Implementing an emergency response system within the orbital, manned space flight industry will provide numerous benefits across all space flight sub-industries.

Implementing an emergency response system within the orbital, manned space flight industry will provide numerous benefits across all space flight sub-industries.

From a government standpoint, an emergency response capability will add to national prestige by allowing the U.S., in times of emergency, to support any nation that is conducting space operations. It will also establish a resource for defining standards and recommendations for future commercial spacecraft & space habitats.

The rapid response nature of an emergency will require technologies that will lead to lower industry costs and timely space access. These technologies will also be able to be support in-orbit assembly services for both manned and unmanned satellites and spacecraft.

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An emergency response capability will create several other incidental benefits by creating a consumer confidence in the industry. **Knowing that help is only a few hours away will encourage private investment for orbital assets.** The commercial ventures entering this industry will then naturally establish other related infrastructure elements for re-supply and refueling, among others.

One commercial opportunity is satellite maintenance. **With an effective and efficient way to repair satellites in-orbit, the manufacturing cost of satellites can be reduced by removing many of the redundant systems.** There would also be an associated reduction in insurance costs.

A successful commercial industry would help reinvigorate interest in science and engineering fields. **A stable and sustainable industry would inspire younger generations, ultimately strengthening the technical aspects of the U.S. workforce.**

Of all these benefits, the strongest is that an emergency response capability will establish an industry that is commercially-based, fulfilling the promises of earlier space policies.

Of all these benefits, the strongest is that an emergency response capability will establish an industry that is commercially-based, fulfilling the promises of earlier space policies. **This industry will generate tax revenue back into the economy through industrial growth.** As the commercial industry develops, the American public will finally view manned, orbital space flight as an affordable, sustainable venture.

Space Policy – Planning For The Future

Section VI

We are again at a point where space policy is under scrutiny. On May 7, President Obama formed a commission to review human space flight plans, chaired by Norman Augustine. **The members of this commission are very well qualified, and have a genuine interest in seeing the space industry develop into a sustainable venture.** Despite their qualifications, it is commonly believed that this commission will only once again cite safety and reliability as critical within the space industry, and suggest that commercialization is imminent. Specific plans how to achieve this commercialization are not expected, and we believe that without the subtle insight our analysis provides, such plans will be difficult for any commission to create.

Our analysis of the current space industry infrastructure shows that the current manned, orbital space flight market lacks infrastructure elements that can address safety and reliability problems should they occur during a mission. An emergency response infrastructure element specifically developed to support the manned orbital space flight market would have additional benefits that would extend to all other sectors of the industry.

An emergency response infrastructure element specifically developed to support the manned orbital space flight market would have additional benefits that would extend to all other sectors of the industry.

In similar industries where such a need exists, the government already provides emergency response capabilities. We believe a call to create such an emergency response system within the manned, orbital space industry would be readily accepted by the general public; especially if accompanied by clear objectives to develop an independent commercial sector instead of sweeping ideals.

The federal government exclusively funds the current manned, orbital space flight industry. As this funding is somewhat dependent upon public perception, the progress of the manned, orbital space flight industry has varied year to year. **If all government funding for manned, orbital space flight activities were discontinued, the manned, orbital space flight market would collapse.** Furthermore, there would be a large backlash of negative opinion in that the monies spent on previous programs would now be perceived as wasted.

In the past NASA has attempted to convince the public that spin-off technologies from the manned space flight market are reason enough to continue the manned space flight programs. We are now seeing indications that the general public is no longing willing to accept this argument. Given this ever-reducing public enthusiasm, any space policy that needs to last decades will require a strategic plan specifically addressing how to develop a manned commercial sector that can have a direct, positive economic impact that is independent of government programs.

Given this ever-reducing public enthusiasm, any space policy that needs to last decades will require a strategic plan specifically addressing how to develop a manned commercial sector that can have a direct, positive economic impact that is independent of government programs.

The manned, orbital space flight market has yet to see any commercially independent companies promised in policies past. NASA justified the space shuttle program by telling the American public that this spacecraft would open the door to a manned

commercial industry. The same promise was used to justify the International Space Station. All of the companies in the orbital manned space flight market remain completely reliant on government programs for their survival in this market place and the space policies presented by NASA have been unable to remedy this problem. **Until such issues are addressed within the national space policy, the manned, orbital space flight industry will continue to struggle for justification.**

By adding a single additional infrastructure element, we believe the work accomplished to date will at last be well-placed to usher in a new commercial era of orbital manned space flight.

Future space policies should address issues that affect the entire space industry and not be based solely on the prestige associated with arriving at some destination. This report offers an insight to what has prevented all the previous approaches from succeeding. By adding a single additional infrastructure element, we believe the work accomplished to date will at last be well-placed to usher in a new commercial era of orbital manned space flight. **NASA has already demonstrated the technological prowess to achieve this; we simply need to apply the appropriate strategy to realize it.**

Appendix A - Biographies

Alan D. Thompson. Mr. Thompson received a Bachelor of Science Degree in Mechanical Engineering from the University of Missouri – Rolla and has 23 years experience in new product development and launch. In this capacity, Mr. Thompson conducted market research that was used to guide the development strategies within these companies. He was also involved in the design, design analysis and manufacturing launch phases of various product lines within the automotive industry.

Currently Mr. Thompson working in the advanced composites industry and is pursuing a Bachelor of Science Degree in Physics from Western Kentucky University in Bowling Green, Kentucky, while advising individuals within the international community in the development of commercially based space policies and strategic implementation methodologies[15].

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Gordon P. Smith, Ph.D. Dr. Smith received a Doctorate in Physics from the University of Mississippi. An experimental physicist by training, he possesses a wide range of interdisciplinary experience within the fields of mechanical and electrical engineering, manufacturing advances, and systems integration. Dr. Smith spent 6 years in academic positions, leaving that world for an additional 5 years manufacturing experience within various advanced composites companies, authoring 2 patent applications for novel structures. He has extensive skills in modeling kinematic systems, data acquisition techniques, experimental design, and other detail-oriented tasks requiring the rapid assessment of large amounts of information.

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