Vacuum Maglev – An international endeavour for a global space program

By

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Declaration

I Tanay Sharma hereby declare that contents of this thesis have not and will not be distributed in part or in full to another University or Institution towards an award of any other degree.

Signature

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Dated: 12 April 2012

Summary

This thesis focuses on the use of magnetic levitation technology as a means to provide launch capability to future space bound vehicles. Building on past work and after an extensive literature review, we aim to show how magnetic levitation and propulsion can be an economically and socially justifiable means to launch cargo and passengers for the purpose of reconnaissance, space tourism, and deep space exploration.

Based on the validity of the technology, we look at the economic and political viability of establishing a magnetic levitation and propulsion launch system and compare it with current launch systems. With the recession caused due to the market crash in 2008-09 and the national space budget constrictions that followed, it is easy to establish that any project of this scale would not only require international collaboration and cooperation, but also an international framework developed from the ground up to engage private enterprise and promote public-private partnerships.

As the United States of America accounts for over 75% of global space spending, we focus on the impact of its internal policy and legislation such as the International Traffic in Arms Regulations and the United States munitions list that have a direct impact on collaborative and cooperative efforts made by public and private entities within the United States. The thesis goes on to describe how a new global space policy for civil and commercial projects could potentially pave the way for new avenues of collaboration and inclusion of actors who for the time being are unable to participate in the space arena either due to lack of available funds or technology inputs.

This thesis and the publications based upon it, aims to define a new era in international cooperation, with a magnetic levitation and propulsion project being a technological test -bed that would help validate the cooperation scenario.

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List of Acronyms

ABM	Anti-ballistic Treaty
AC	Alternating current
AFRL	U.S Air Force Research Laboratory
ATF	Gas Turbine Fuel
BIS	Bureau of Industry and Security
CC	Concrete Canvas
CPI	Consumer Price Index
CSIS	Center for Strategic International Studies
CSU	Central support Unit
DC	Direct current
DOC	U.S. Department of Commerce
DOS	U.S Department of State
DSB	Defence Science Board
EDS	Electrodynamic Suspension
EDT	Emergency Deceleration tracks
EMALS	Electromagnetic Aircraft Launch System
EMS	Electromagnetic Suspension
ESA	European Space Agency
ET3	Evacuated tube transport technologies
EU	European Union

FRLV	Fully Reusable Launch Vehicle
FY	Financial Year
GDP	Gross Domestic Product
GEO	Geosynchronous orbit
GSP	Global Space Project
HLV	Heavy Lift Vehicle
HNWI	High Net Worth Individuals
HSST	High Speed Surface Transport
ICE	Inter City Express
IIMS	Industrial informatics and manufacturing systems
INF	Intermediate-Range Nuclear Forces
ISS	International Space Station
ITAR	International traffic in arms regulation
LCC	Life cycle cost
LCCE	Life cycle cost estimate
LCE	life cycle extension
LEO	Low earth orbit
LIM	linear induction motors
LLNL	Lawrence Livermore National Laboratory
LSM	linear synchronous motors
LTBT	Limited Test Ban Treaty
LVB	Launch Vehicle Budget

MagLev	Magnetic levitation and propulsion
MHD	Magnetohydrodynamics
MLAS	Magnetic Launch Assist System
MOU	memorandums of understandings
MSFC	Marshall Space Flight Centre
NAFTA	North American Free Trade Association
NASA	National Aeronautics and Space Administration
NPT	Nuclear Non-Proliferation Treaty
NSII	NASA New Start Inflation Index
NSP	national space programs
NSSO	National Security Space Office
NYMEX	New York Mercantile Exchange
OMB	Office of Management and Budget
OST	Outer space treaty
PLC	Project Life Cycle
PPP	public private partnership
PRT	Personal Rapid Transit
R	Relays
R&D	research & development
SPCU	Section power control unit
SSP	Space Shuttle Program
SSTO	single stage to orbit

STS	Space Transportation System
SWF	Secure World Foundation
TAA	Technical Assistance Agreements
TCBM	Transparency and confidence building measures
TCU	Track control Unit
TPS	Thermal Protection System
TRL	technology readiness level
TSCC	Track section control centre
TSCU	Track Section Unit
TSS	Track Side Systems
UAV	Unmanned Ariel Vehicle
UNGA	United Nations General Assembly
UNHWI	Ultra-High Net Worth Individuals
UN	United Nations
UNOOSA	United Nations Office for Outer Space Affairs
US	United States of America
USML	United States Munitions List
VML	Vacuum based magnetic levitation and propulsion
VSS	Vehicle support system
WBS	Work breakdown structure
WTI	West Texas Intermediate
WTO	World Trade Organization

List of Symbols

A	Cross sectional area, area of source leak
a	Speed of sound
At	Throat area of nozzle
C	Drag coefficient, discharge coefficient
C_f	Local skin friction
C_{pw}	Specific heat of wall material
E	Youngs Modulus
F	Gas fraction remaining in source vessel, Empirical factor in transient heating equations
F_{drag}	Drag Force
g_c	Gravitational conversion factor
h	Heat transfer coefficient
H_{st}	Heat enthalpy (stagnation)
H_w	Heat enthalpy (wall)
I	Current, Inertia
k	Specific heat ratio
l	Length
L	Conductor length
$\dot{m}$	Mass flow rate
m	Mass of conductor
M	Mach number, molecular mass of gas
M_{gas}	Mass of gas
P	Power, absolute upstream stagnation pressure, absolute pressure of inlet gas
P_0	Initial gas pressure in source vessel
P_1	Gas pressure at time t1
P_2	Gas pressure at time t2
P_{aero}	Power required to overcome aerodynamic drag
P_c	Inlet chamber pressure
P_e	Absolute pressure of exhaust gas
Pt	Gas pressure at nozzle throat
q	Heat flux
Q	Mass flow rate
R	Resistance, gas constant
S	Solar or nocturnal radiation input
T	Absolute temperature, any time after initial leak

T_0	Initial gas temperature in source vessel, stagnation temperature
t_1	Any point in time after initial leak
t_2	Any point in time after t1
T_c	Inlet chamber temperature
Tt	Gas temperature at nozzle throat
T_w	Wall or skin temperature
u	Velocity component
v	Velocity, velocity component
V	Volume of source vessel
V_e	Gas exhaust velocity
V_g	Effective gas volume
V_L	Velocity (local flow conditions in the inviscid shear layer)
V_{track}	Volume of track
V_{tunnel}	Volume of tunnel
w	Load factor
z	Altitude
Z	Compressibility factor
ΔT	Change in temperature
β	Radiation factor
θ	Semivertex angle
μ_w	Dynamic viscosity
ρ	Air density
ρ_d	Material density
ρ_e	Material resistivity
ρ_L	Density of air (local flow conditions in the inviscid shear layer)
ρ_w	Density of wall material
δ_{max}	maximum deflection a centre for a beam with uniformly distributed load
σ	Real gas density
σ_o	Initial gas density in source vessel
τ	Wall or skin thickness

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1. **Tanay Sharma**, Christopher Long, Chris Chatwin, Rupert Young, Philip Birch, "Alternative Space Vehicle Launch Systems" in AIAA SPACE 2008 Conference & Exposition San Diego, California: AIAA Volume 2008 ISBN 978-1-56347-946-5
2. **Tanay Sharma**, Bhargav Mitra, Philip Birch, Chris Chatwin, Rupert Young, "Advanced MagLev Propulsion System and its Economic Impact" in 45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit Denver, Colorado: AIAA ISBN 978-1-56347-976-2
3. **Tanay Sharma**, Chris Chatwin, Rupert Young, Philip Birch, "Low Cost Propulsion Systems for the Developing World" in 4th Recent Advances in Space Technology Conference Istanbul, Turkey: IEEE ISBN 978-1-4244-3628-6
4. **Tanay Sharma**, Chris Chatwin, Rupert Young, Philip Birch, "A Global Space Policy That Would Revive Space Exploration" in 5th Recent Advances in Space Technology Conference Istanbul, Turkey: IEEE ISBN 978-1-4244-9617-4
5. **Tanay Sharma**, Chris Chatwin, Rupert Young, Philip Birch, "An international policy for sustainable space exploration" in 4th CSA-IAA Conference on Advanced Space Technology Shanghai, China
6. **Tanay Sharma**, Chris Chatwin, Rupert Young, Philip Birch, "International collaboration - a cornerstone for future space exploration" in 4th CSA-IAA Conference on Advanced Space Technology Shanghai, China
7. **Tanay Sharma**, Chris Chatwin, Rupert Young, Philip Birch, "United Space Alliance for neospace exploration" in Global Space Exploration Conference 2012, 22-24 May 2012, Washington D.C

Chapter 1: Introduction

The fantasy of travelling to space can be dated as far back as the second century, when the Greek rhetorician Lucian wrote an account of a voyage to the moon. As time passed the fascination of what lies beyond the skies intensified, and as early as 1869 author Edward Everett Hale depicted a manned satellite functioning as a navigational aide to ships in his book *The Brick Moon* [1]. Our quest for knowledge and the chance of travelling into space has compelled people to devote their lives to space science, innovation and analysis of our ever-expanding universe. In 1928, just two years after Robert Goddard launched the first rocket Herman Potocnik laid out detailed plans for a wheel-like space station in his book *The Problem of Space Travel* [2], that would later form the basis for *Wernher von Braun* proposal of how 1952 technology could be used to put a permanent space station into orbit around the Earth [3]. His article published in a ground breaking article in *Collier's* magazine by proposing a 250 foot wide inflated wheel, made from reinforced nylon that would function as a navigational aid, meteorological station, military platform and way station for space exploration [3]. Von Braun's space station was shaped like a wheel with two spokes, which would spin in order to create centrifugal force that would act as false gravity, a design similar to that depicted in Stanley Kubrick's 1968 film called *2001:A Space Odyssey.* Figure 1 illustrates the design from the film.

Figure 1: 2001:A Space Odyssey space station design (© 1968 Turner Entertainment Co.)

The film sparked the imagination of a generation and for the first time provided a realistic image of what our future in space might look like.

1.0.1 Rockets, Cold War and a blue print for National Agencies

From its humble beginnings in ancient China, rocket based propulsion has seen significant development and today can be considered as an enabler of all space technologies. It is because of this technology and that one can consider almost every nation on the planet as a space-faring nation. We all rely on space-based technology for communications, weather forecasting, satellite navigation and resource management, either through indigenous programs or through programs run by our allies. Today the most significant impact of rocketry comes in the form of manned spaceflight. Vehicles like the Space Shuttle and Soyuz began the trend of greater commercialization of manned rocketry, enabling widespread access to space.

The first liquid propellant rocket was tested in 1926, and climbed a height of forty-one feet, however it was not until the mid-1940's that the space race actually began. The German military had done extensive work on the production of chemical rockets, and had successfully tested their use. The primary aim behind the German technology though was not to access space, but to use this new power for warfare. As the Second World War came to an end, the two superpowers of the time decided to ensure that Germany would not develop into a military power again. As the country was split between east and west, the scientists and researchers who worked there found new homes. Researchers from West Germany were sent to the United States where they would conduct further experiments and help develop the base for the American space program, whilst those in East Germany were to help develop technology for the former Soviet Union. As the cold war loomed, the United States and the Soviet Union had found a new battleground, and the space race was born.

On October 4th 1957, the former Soviet Union announced the launch of a small satellite into orbit around the earth called Sputnik 1, this satellite was less than two feet long, but was still able to transmit signals back to earth [4]. Shortly after this, the United States launched their first satellite called Explorer 1 on a modified Redstone missile dubbed Juno 1 [5]. Considering Soviet technology a threat the United States replaced the National Advisory Committee for Aeronautics with National Aeronautics and Space Administration (NASA) in 1958. NASA was to be a central federal body responsible for all the space technology research in the United States, and saw its budget grow consistently over the next few decades. Over the next decade both ideological blocks launched a number of satellites and manned missions. Figure 2, 3 & 4 illustrate the number of human spaceflights conducted by the two nations, the total amount of hours spent in space and the total number of earth orbits conducted between 1961 and 1969.

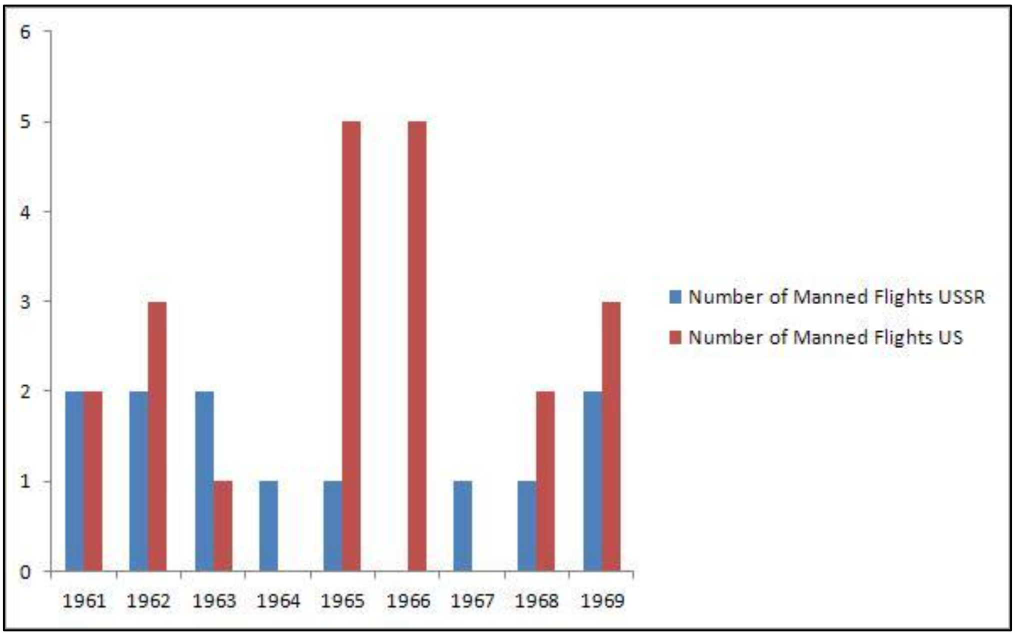

Figure 2: Number of manned spaceflights between 1961 & 1969

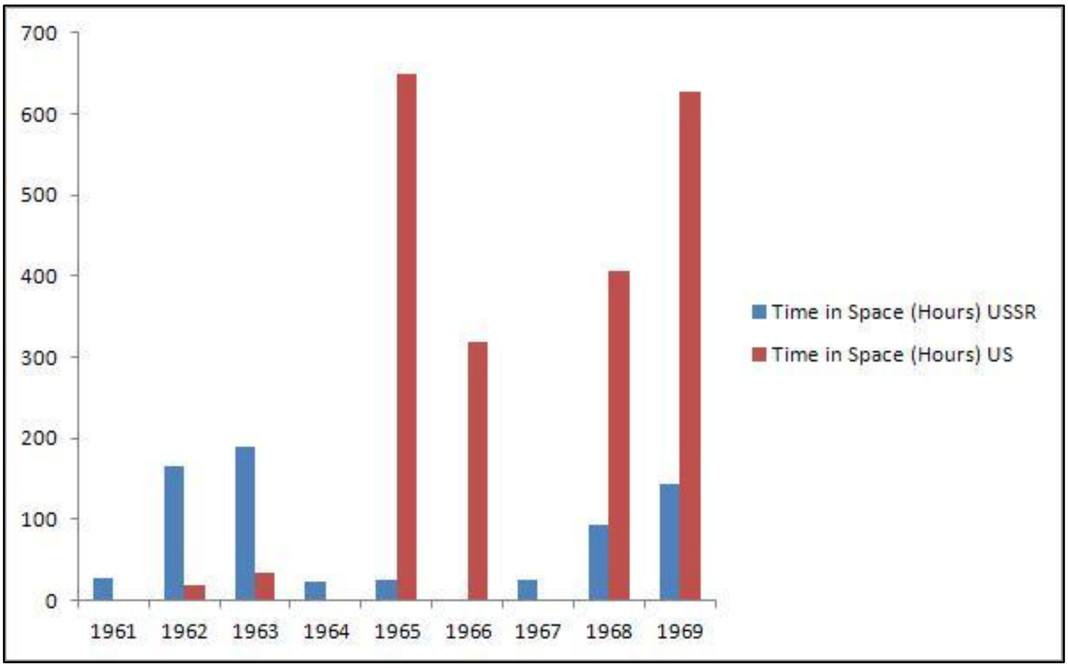

Figure 3: Total amount of time spent in space (hours)

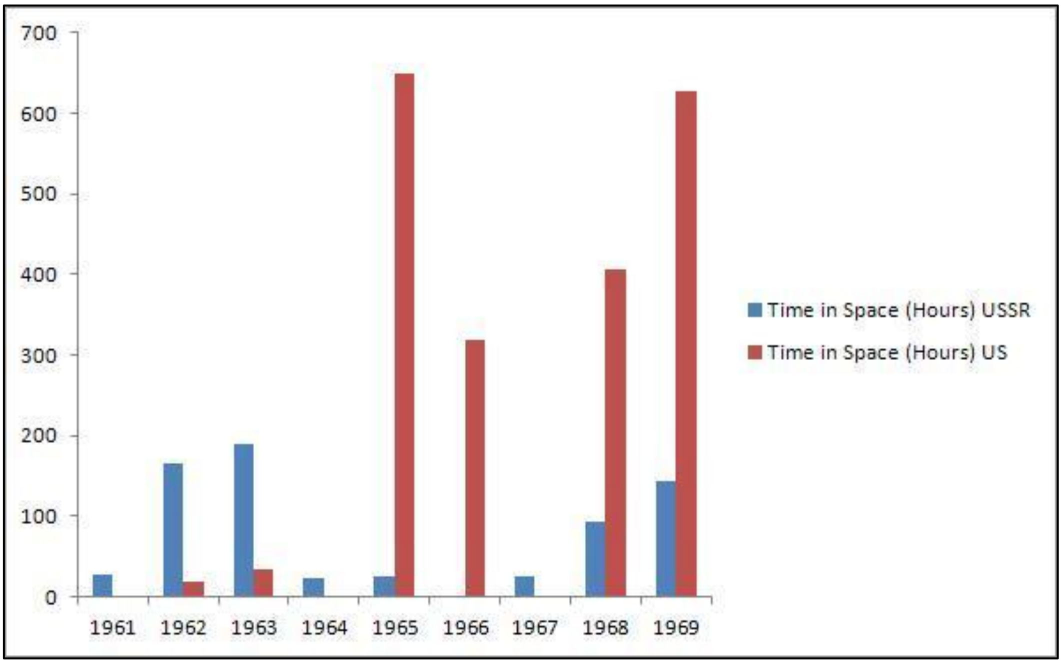

Figure 4: Number of Earth orbits conducted by year (1961-69)

In the summer of 1969, Apollo 11 became the first manned mission to land on the moon. It was the fifth human spaceflight of the Apollo program, and the third human voyage to the moon [6]. The space race finally saw an end in 1975 when Soyuz-19 craft docked with Apollo 19, allowing the previously rival nations to pass into each other's ships and conduct joint experiments [7].

1.0.2 Space Transportation System

In January 1972, then US president Richard Nixon announced to the nation that the United States would invest in the development of a new type of space transportation system, one that he considered was a step in the right direction after the success of Apollo. The announcement lead to the design and development of a program that would provide a reusable Space Transportation System (STS), more commonly known as the Space Shuttle Program. In the early 70's the main objectives behind the development of the Shuttle system were to establish a launch system that would allow low cost routine access to space, aid replacing an aging and expensive breed of launchers, have the capability to meet mission requirements for NASA and DOD, which would include both manned and unmanned missions, and provide for an option to transition to a fully reusable system [8–11]. NASA initially suggested that the Shuttle would reduce the cost per pound to orbit to roughly $100 an estimate that saw numerous revisions over the coming years. Furthermore cost estimates in 1976 represented cost per flight as roughly $18 million in constant FY75 dollars, a figure that was later revised and was closer to $60 million per flight [12], [13]. After four test flights NASA declared the Shuttle operational, and soon after the first flight in 1981 the Shuttle was to be considered as the primary launch system for civilian and government payloads [14]. Although NASA's office of manned spaceflight initially estimated that the shuttle fleet would conduct close to 75 flights per year [15] this prediction was later revised to a total of 60 flights annually [12], [16], [17], a figure that is a stark contrast to the peak flight rate achieved in 1985 of 9 launches. This significantly lower flight rate compared to NASA's initial estimates was in part due to the logistics service and repair of the shuttle fleet.

Over the years the turnaround time for the Shuttle increased in wake of the Challenger and Columbia disasters. After the loss of the second Orbiter in 2003, it was decided that NASA should consider a viable replacement for the Shuttle. National policy introduced in 2004, aimed to retire the Shuttle fleet by 2010 and directed NASA to give higher priority to space exploration. Since its first launch in 1981 the Shuttle program completed a total of 135 flights before the fleet was retired in 2011, the bulk of which have helped ensure a continued human presence at the International Space Station (ISS), whilst the rest included service missions for the Hubble telescope, deployment of satellites on behalf of the DOD and demonstrating new technologies and capabilities, be that in terms of structural systems, thermal shielding or even the use of composites. There is no doubt that the Shuttle is a magnificent technological achievement, one that has not only managed to defend its title as a symbol of human ingenuity for almost 30 years, but also it defined a new era of exploration and understanding of our universe with unwavering public support both at home and abroad until its very last flight [18–20]. However, when we consider the STS program in terms of fiscal costs, one must admit that initial predictions were rather off the mark. With a life cycle budget of over $196 billion, the cost per launch for the Shuttle comes close to the $1.5 billion mark if we include initial design and development phases. Even if initial phases are ignored the costs average closer to $800 million when adjusted to current day dollar values, which is still a long way away from the initial proposal of $18 million per flight[8][9]. Although the end of the shuttle era has left the United States with no sovereign capability for human access to space, it has allowed private enterprise to take up the challenge to develop new, innovative, safe and reliable launch systems. This has also spurred international debate on the notion of private enterprise footing the bill for a next generation launch vehicle, and models that could be put in place to provide an environment that benefits both public and private interests. Although it is yet to be seen if these new systems will provide the cost savings and the frequent launch rates that NASA hoped to achieve via STS, the opportunity to develop a new launch system has given us a window to break with the norm of conventional rocketry and design novel systems that are not only capable of providing a means for human spaceflight but can also be adapted to deliver payload to low earth orbit, carry fee paying passengers as part of a budding space tourism industry, deploy UAV's for covert reconnaissance and be used as test beds for commercial hypersonic flight.

1.0.3 Development of a new launch System

In testing times such as these, one plagued with issues such as global warming and the continuing financial crisis, space science and exploration find themselves at the bottom of a very long national priority list. The political justification of national space programs is often difficult, not only due to their budget requirements but also because spin-in's and spin-offs of the space industry are not obvious to the general public. The current economic climate has already caused a dramatic reduction in public funds for space research, with future financial uncertainty making investment even more unattractive for private enterprise. Although the vision of providing low cost space travel still exists, its application is hindered by the costs associated with current space vehicles and mission operations. If we are to better understand our universe and are keen on commercializing space, we must find a way for the commercial and civil space sectors to adopt a business model that is similar to the global aviation industry. Since current launch vehicles predominantly rely on chemical propulsion, their associated fuel costs are driven by levels of uncertainty in the market. In order to reduce the cost per flight, we must effectively increase the load factor per flight and operate multiple flights, enabling a greater number of paying passengers. To provide widespread access to space there needs to be a greater emphasis on the research and development of low cost Reusable Launch Vehicles (RLV) that rely on alternative fuel technologies and are capable of carrying a payload that is significantly larger if not comparable to the Shuttle thereby reducing the overall cost per flight. There is now, more than ever, the need for a greener technology, which is capable of providing a similar power output without compromising on safety and reliability. Similar to the aviation industry the success of future space exploration programs relies on international cooperation and alliances, however unlike the aviation industry cooperation in terms of space exploration or space missions is dominated by domestic and international politics and policies. Suggestions for reform of current arrangements will be discussed later in this thesis.

This thesis highlights the need for a new, viable, cost effective launch system and vehicle design along with a policy framework that would help us to achieve our goals. By looking at a ground-up initiative in technology, research and development and policy making, we hope to illustrate how a global space effort is not only sustainable but also more effective from a socio-economic perspective.

1.0.4 Achievements of the Research

The work done as part of this thesis and the ideas proposed for a new launch vehicle and supporting launch system has been regularly published, enabling us to ascertain industry and academic perception not only about the work being produced but also about the viability of the proposed projects and the willingness of the space community to collaborate and cooperate in developing such a system. The challenges posed by such a system are unique, and this thesis acts as a single piece to a much larger jigsaw. However the work outlined in the following chapters provides a crucial blue print for future developments.

Some of the key challenges tackled as part of this thesis were related to the system and vehicle design and more crucially our ability to highlight the cost uncertainty related to chemical based propellants. In the case of systems design, we have managed to isolate the very best in off the shelf technology that could be adapted to develop a robust system. This approach not only ensures that the overall cost associated with the system remains low but also allows system engineers to adapt components based on specific requirements and market availability. When looking at designing the launch vehicle, a number of techniques were discussed before settling on the waverider principle. The approach allows us to scale the technology and retrofit future designs based on the system and mission critical requirements.

When considering the costs associated with the system, it was vital to establish the relationship between the WTI crude oil benchmark and the cost of gas turbine fuel. This in turn allowed us to connect the cost of current day chemical propellants and the fluctuations in the trade markets. We were able to model the change in market trend and generate a high, low and average cost scenario based on crude oil trade prices between 1980 and 2008. Using this model we were able to generate graphical information that allowed us to estimate prices for the coming weeks and establish our case for moving away from chemical propellants and towards a greener fuel source.

After working through the technological and economic challenges of this project, our next key challenge was to understand how one would actually go about implementing such a system. We considered domestic and international policy, focusing primarily on US policy with regards to civil and commercial space. By understanding the intricacies of international and domestic policy and the fine line between civil and military programs we were able to develop a framework for a new policy agreement[1] that would consider involvement of vested actors both public and private. This framework and the policy architecture proposed has also allowed us to explore the possibility of a global space program, one that is dependent on cooperation and is aimed solely at civil and commercial space activities.

1.0.5 A brief chapter wise introduction

Chapter 2: This chapter introduces the concept of electromagnetic levitation, and traces the roots of ground transport ideas based on the technology. It looks at the types of levitation and propulsion systems in use today, their advantages, drawbacks and potential uses for the future. It goes on to compare the commercial operations of systems based on the technology and their development. The later part of the chapter considers NASA's interest in the technology, which is illustrated by three distinct concepts that consider the use of magnetic levitation and propulsion as a potential launch assist technology.

Chapter 3: proposes the use of a superconducting magnetic levitation and a propulsion guideway within the confines of a tunnel that is maintained in a state of vacuum. This vacuum based system works in conjunction with a purpose built launch vehicle which is designed from the ground up keeping multiple mission objectives in mind. Using this approach we are able to scale payload sizes, and work on projects ranging from sub-orbital passenger flights to satellite deployment and human exploration missions. After proposing the system and launch vehicle design, we consider the launch locations that would benefit such a system and the consequent socio-economic development. The

[1] To gain a professional objective a telephonic Q&A session was conducted with a policy advisor for the UK Space Agency (UKSA). A transcript of this interview can be found in Appendix 2.

final sections of the chapter consider how the system may be put to use in various mission categories and its potential benefits. A system would require a substantial initial investment, we discuss how an international effort related to system development would benefit all the actors involved, thereby laying the foundation for the policy framework suggested in chapter 5.

Chapter 4: This chapter considers the elements required to cost a space program. Before initiating any new program we must be able to provide a life cycle cost estimate. This estimate acts as a baseline and usually gets refined over time. The estimate is derived by focussing on projects or programs that are similar to the one being considered. Working using an analogy approach, it is usually easier to define target costs for new programs. In the chapter we consider two distinct scenarios for the development of a heavy lift vehicle and using the analogy approach illustrate which system would be more economical. The later sections of the chapter consider how the project would be financed and the cost recovery options associated with it. We focus on how commercial operation along with terrestrial supersonic/hypersonic flights on a hub-to-hub basis could help recover the bulk of the initial start-up cost.

Chapter 5: This chapter considers the role domestic and international policy plays in the space arena. By outlining the reasons nations may want a space program, we look at how one would go about developing a sustainable program and the resources required to do so. We consider the impact the United States has on the global space sector, both in terms of political impact abroad and the economic impact on local industry. Later sections discuss the proposal of a new global initiative, one based on cooperation and collaboration to ensure free and unrestricted access to space for all. By addressing current international policy issues and the restrictions of US policy, we propose a framework for this global initiative and highlight the importance of future partnerships.

Chapter 6: This is the final chapter the entire thesis is discussed. Conclusions are drawn and future work is outlined

Chapter 2: Magnetic Levitation - Past & Present

Chapter Summary

This chapter introduces the concept of electromagnetic levitation. After looking at the origins of electromagnetic levitation, we discuss the use of magnetic levitation and propulsion systems today in high speed ground transport, as well as outline the types of Maglev systems being used. The chapter then goes on to discuss proposed systems based on Maglev technology before focusing on NASA's interest in Maglev as a launch assist technology for future space vehicles. The last few sections of the chapter discuss the various Maglev based proposals that have been put forward for the development of future launch vehicles and propulsion systems.

2.0.1 Electromagnetic Levitation Introduction

The idea of using electromagnetic force to support a moving or rotating mass has been around for over a century. Robert Goddard and Emile Bachelet [21] initially proposed to magnetically levitate trains in order to provide high-speed ground transportation using alternating current loops attached to the vehicle undercarriage above conducting metal sheets on the ground. However due to limitation in technology at the time no feasible results were achieved. In 1934, Hermen Kemoer received a patent for his idea of using magnetic levitation and propulsion to run high-speed ground transport systems. His invention described a monorail vehicle with no wheels attached as a technical concept for floating a vehicle based on the principal of electromagnetic attraction [22]. Kemper's initial proposal helped fuel extensive research in the use of magnetic levitation technology. Whilst initial attempts were based on finding an arrangement of permanent magnets that would levitate or suspend an object made of ferrous material, they were stumped by a discovery made by Earnshaw in 1842, that mathematically proved that it was not possible to stably levitate an object using any static arrangement of permanent magnets or charges [23]. In 1939, Braunbeck carried out a similar analysis to Earnshow to show that suspension or levitation is possible when a material has a relative permeability or relative permittivity less than one [24].

There are a number of methods that use electromagnetic forces to support a moving or rotating mass [25]. These methods can be classed in two distinct categories – those that use electromagnetic forces of attraction are called suspension techniques, whilst those relying on electromagnetic forces of repulsion are classed as levitation techniques. Over the years there has been extensive research and development in levitation techniques that employ the use of diamagnetic materials, superconductors and induced eddy currents, to aid the design of high-speed ground transport systems, personal rapid transit systems and novel concepts such as levitation being used to support a rocket launching sledge [26–28]. Whilst work related to levitation using diamagnetic materials was purely of academic interest in the late 60's, a number of countries focussed research and development on the use of superconductors, including Japan [29], Canada [30], England [31], Germany [32], [33] and the United States [34], [35]. Systems relying on suspension or levitation techniques were envisioned as future modes of transport that could be integrated to existing infrastructure in order to provide cost and time effective transportation for the masses. Since the late 60's there has been a tremendous amount of work done in the field, which is now conveniently termed as MagLev technologies.

MagLev today is an umbrella term, that can be used to define a system where an object is either levitated or suspended, guided and propelled along a purpose built track using electromagnetic forces of attraction or repulsion. A system that employs MagLev technology allows us to move a large volume of passengers and cargo between locations at much higher speeds and lower cost, when compared to conventional systems. As systems using MagLev technology cannot be easily integrated with conventional systems and require new infrastructure development, they are classed as a new and alternative mode of transport.

2.0.2 Modern Maglev

When we consider the development and implementation of high-speed magnetically levitated systems, we primarily refer to research projects in Germany, Japan, Switzerland and the United States. Of all the projects currently being undertaken, only the German Transrapid system[36] and the Japanese MLX have reached an industry standard with active test facilities. The systems being developed in the four countries differ in terms of levitation technology, guidance systems and the types of linear motors considered as ways of transferring energy to the vehicles [37]. Current commercial and test systems rely on two distinct types of MagLev technology, Electromagnetic Suspension (EMS) and Electrodynamic Suspension (EDS).

Systems using EMS have electronically controlled electromagnets on the vehicle which are attracted by a magnetically conductive track. An EMS system is able to levitate a vehicle using on-board magnets; however it is unable to propel the system on its own. As such, EMS systems require a separate propulsion mechanism; usually this is achieved by mounting a linear motor in the track. An EMS system also relies on a complex feedback mechanism to ensure that the gap between the levitated vehicle and the track is consistently maintained [38], [39]. On the other hand systems using EDS, rely on both the vehicle and the track to exert a magnetic field. The vehicle is levitated above the track due to the repulsive force between these two fields. EDS systems allow for a larger clearance between the track and the vehicle which in turn allows for a greater speed. An EDS system is unable to levitate a vehicle from standstill, and only works after the vehicle has been propelled to an optimal speed. EDS systems primarily use superconducting magnets and are able to provide both levitation and propulsion by using on board linear motors [40].

Another method that may be used to levitate and propel a vehicle in the future is *Inductrack.* Inductrack can quite simply be defined as a permanent magnet electrodynamic suspension. Whilst like EDS this system is unable to levitate and propel a vehicle at standstill, it is capable of levitation and propulsion at a much lower transitional speed. It is a passive induced-current system that employs permanent magnets on the moving vehicle. The use of permanent magnets was not initially possible in the late 70's early 80's due to their poor weight efficiency, however further research and the development of Neodymium-Iron-Boron magnets coupled with new innovation in production methods allowed for the use of such magnets in Inductrack systems [41]. The system uses a Hallback array configuration of magnets on the vehicle that produces a magnetic field below the array and cancels the field above it. This magnetic field then interacts with the shorted electronic circuits in the track to levitate and propel the vehicle [42], [43]. There are two proposed models for the Inductrack, one designed for high-speed operation, whilst the other is designed for low-speed operation. Although no full scale model has been built for the Inductrack, the theory behind it has been tested on a small scale test track at the Lawrence Livermore National Laboratory in the United States.

2.0.3 The use of Magnetic Levitation today

Although the idea of using magnetic levitation systems for commercial transport has been around for just over a century; it was not till the late 70's that a full scale passenger system was developed and deployed. The use of Maglev today is primarily targeted at three distinct systems, an urban transport system that provides low speed city travel, a high speed intercity transport system that would effectively compete with airlines on long distance routes and commercial cargo transportation. The implementation of Maglev systems in our fast paced society appeals to researchers, developers and the masses for numerous reasons; chief amongst them being its reliability and safety factor, its ability to function in the worst of weather conditions, minimal environmental impact and a lower life-cycle-cost (LCC) when compared to conventional modes of transport.

Over the years there have been a number of prototype designs developed for Maglev transportation systems. While most Maglev systems designed are primarily focused around ground transportation systems, Maglev systems have been considered to provide a catapult launch capability to aircraft at conventional airports and those on board naval carriers. Figure 5 shows an artist's illustration of a commercial aircraft that uses an electro-magnetic aircraft launch system (EMALS) [44], [45], whilst fig 6 is a rendition of a similar system being used by a naval aircraft carrier. A description of how such a system would potentially work on a naval carrier can be seen in fig 7 [46].

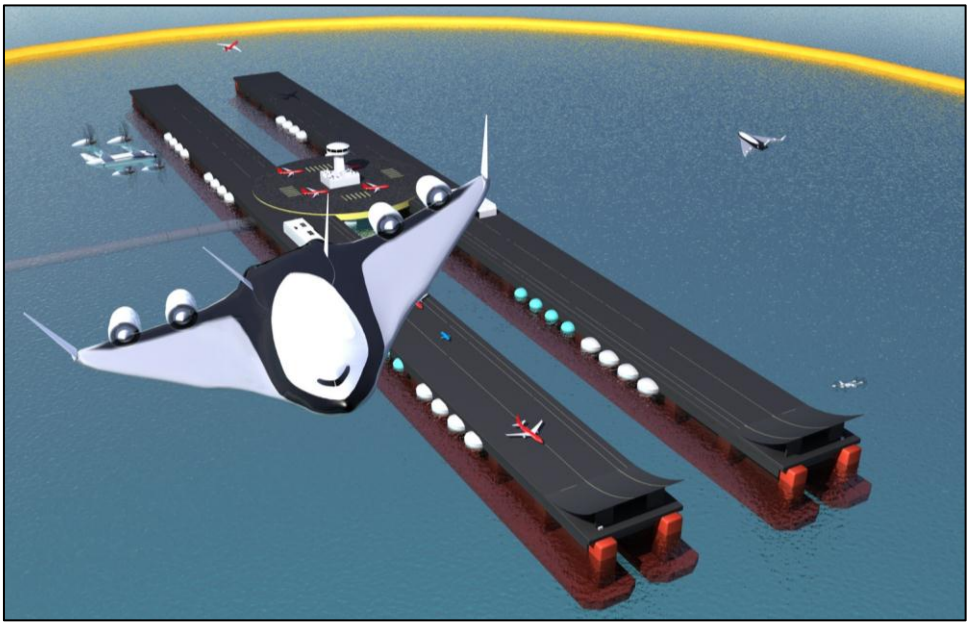

Figure 5: Artist's concept of EMALS in use for commercial aircraft

Figure 6: Artist's concept of EMALS in use on naval carriers

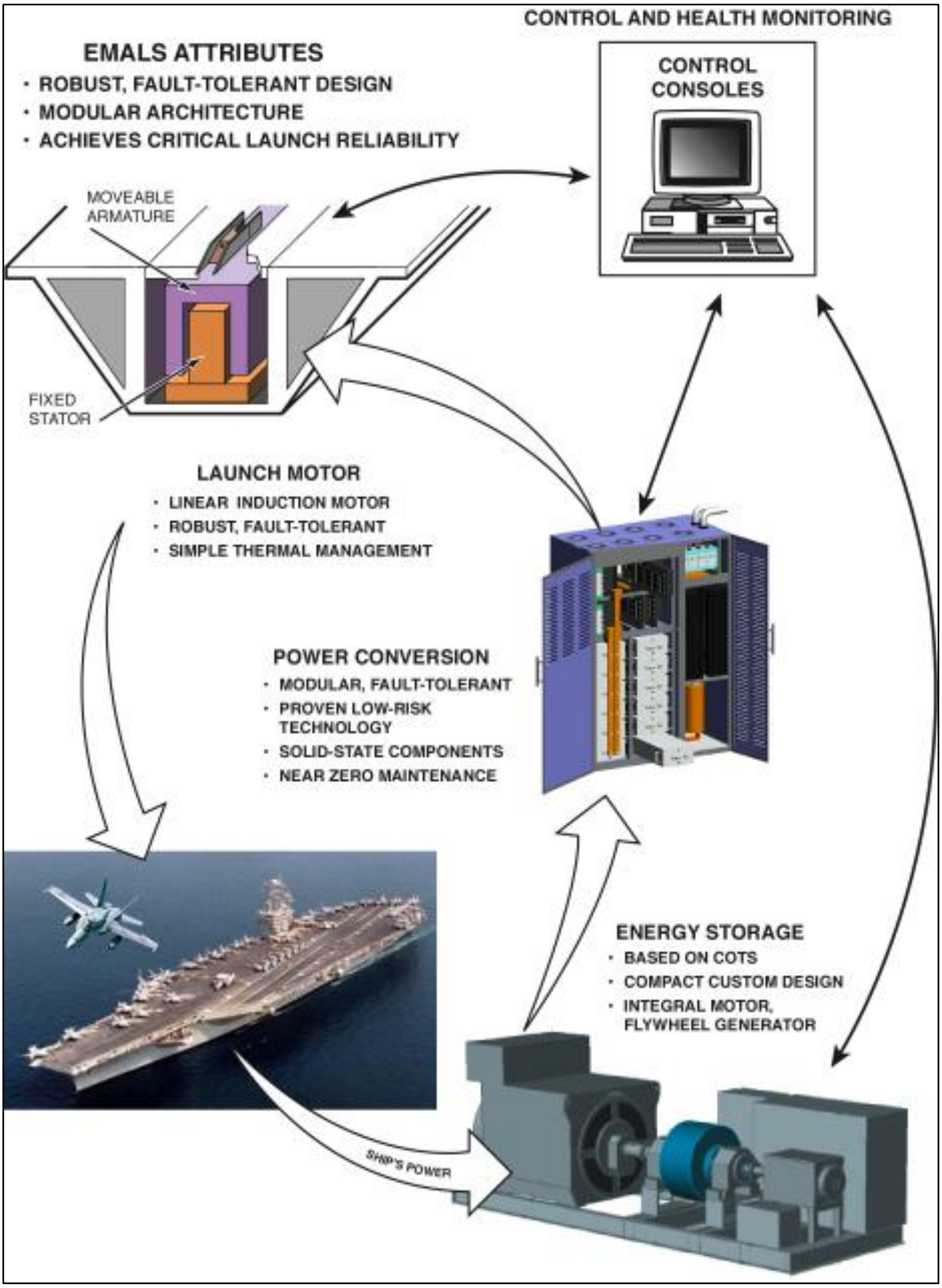

Figure 7: EMALS system design and implementation

The first commercial Maglev system developed to carry passengers at low speeds began operation in 1984 between Birmingham international airport and Birmingham international railway station. The track was roughly 600 meters and used electromagnets to levitate the carriage and linear induction motors to propel it forward, as illustrated in fig 8. Although the line was closed in 1995 it proved to be a success whilst in operation.

Figure 8: Birmingham Maglev shuttle in operation

Although the Birmingham Maglev shuttle was the first to operate commercially, Transrapid in Germany along with Japan airlines and the Japan railway group were developing and testing Maglev systems around the same time. The JR Maglev is the better known system from Japan and uses superconducting magnets that were developed by Powell and Danby [27], whilst Japan Airlines focused on high speed surface transport systems dubbed as HSST [47]. Whilst the Japanese Linimo system is currently in use it supports low speed transport, whereas the German Transrapid system has been implemented in China as a high speed commercial system that connects Shanghai financial centre to Pudong international airport. Figure 9, 10 & 11 show the Maglev systems built by Japan Airways, Japan Railway Group and Transrapid respectively.

Figure 9: HSST system developed by Japan Airlines

Figure 10: JR-Maglev train built by Japan Railway Group

Figure 11: Transrapid based Maglev system in operation in Shanghai, China

Off the three types of Maglev systems mentioned above only those run by the Japan Railway Group (designated as JR) and Transrapid are in commercial operation today. Whilst Transrapid international (a joint venture between Siemens and ThyssenKrupp) focuses on development of high speed ground transport systems JR Maglevs are used for urban transport at lower speeds. Transrapid has been developing prototypes for

Maglev vehicles for the last three decades, and its latest prototype called TR09 completed its eleven month testing phase at the Emsland test facility in June 2009. Figure 12 shows the TR09 during testing at the Emsland facility.

Figure 12: Transrapid 09 Maglev at the Emsland Test Facility

The commercial success of the Transrapid based system in Shanghai has once again made Maglev an attractive technology for a number of nations who seek to tackle the growing demand for reliable, affordable and high-speed urban transportation [48], [49]. Unlike conventional transport systems high-speed Maglev has a great energy saving potential, is capable of achieving zero discharge of polluting gases and has a rapid transit rate [50]. On average the energy consumption per seat of a high-speed Maglev vehicle is a third that of a commercial airliner, and when compared to high-speed rail systems it has been found that a Transrapid operating at 400kph consumes 33% less energy than the Inter City Express (ICE) travelling at 300kph [51]. Some of the obvious challenges faced in considering Maglev as a viable transport system are the high start-up cost, the availability of a feasible transport corridor, the integration of the system with more conventional modes of transport and the limitation imposed on the systems speed by aerodynamic drag forces. In order to overcome the limitation imposed by aerodynamic drag, Switzerland and South Korea have proposed a new high-speed train that would operate in partial vacuum that would see a dramatic decline in air resistance[52], [53]. This ultra-high-speed tube train would employ a LSM system to provide both levitation and propulsion forces and aims to reach a top speed of 700kmph [54]. The Swiss project dubbed the ‘Swissmetro’ was aimed at connecting the country by providing a transport solution that would reduce travel time between destinations to under 12 minutes. The project aimed at transporting passengers in a state of the art Maglev train that operated at a depth of about 50 meters and was capable of travelling at speeds up to 500kmph [55]. The train would operate in near vacuum conditions and would allow passengers to embark and disembark via hermetically sealed air-lock systems, as illustrated in fig 13.

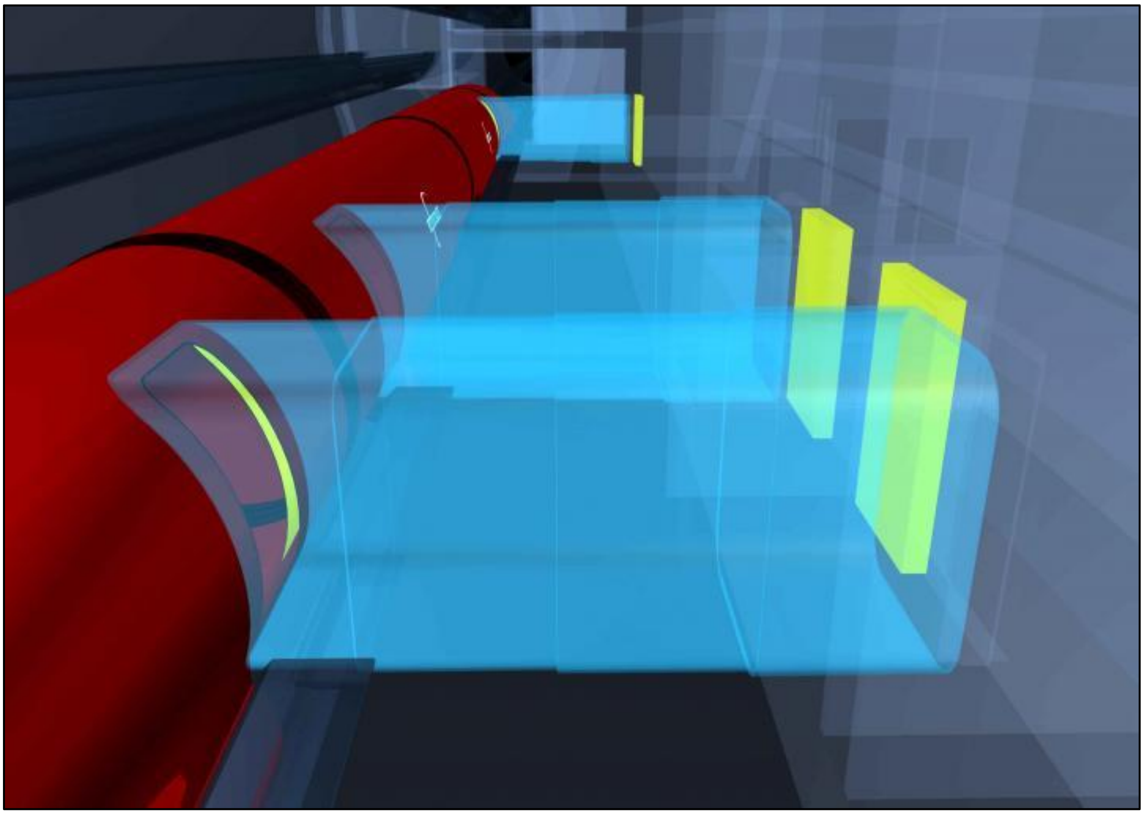

Figure 13: Proposed Air-Lock system for the Swissmetro project

Whilst the ‘Swissmetro’ concept aimed to turn Switzerland into one large metropolis and eventually provide a Europe wide transit system, a feasibility study conducted in 2006 concluded that the concept was not financially viable on Europe wide long-haul routes [56]. Although the backers of the ‘Swissmetro’ project did not agree with the findings, the financial resources to continue with the project lead to it being abandoned in 2009. Today ‘Swissmetro’ exists only as a concept of future transport capability and no funds are currently allocated to its development.

A system similar to the one proposed by Switzerland and South Korea is being considered by a Florida based company called ET3 which stands for evacuated tube transport technologies. The ET3 system transports passengers in car sized capsules within an evacuated tube with a diameter of 1.5 meters. The system would operate at a speed of 600kmph for intercity travel and aims to reach speeds of 6500kmph to transport passengers and cargo between international destinations [57]. ET3 is consortium that is owned by its licensees. Although as of March 2011 ET3 has sold 95 licences [57], they would require close to a thousand licensees before ET3 can be commercially implemented.

2.0.4 Magnetic Levitation and its application to Space Launch

There are a number of advantages in considering magnetic levitation as a potential propulsion candidate for horizontal space launch systems. In a Maglev system there is no physical contact between the vehicle and the track, as such the vehicle does not face any surface friction as it gains speed. The system is weather independent and enables high acceleration in short time frames at reduced operational cost when compared to current systems. A Maglev based system has lower maintenance costs and unlike current propulsion systems that rely on carrying on-board chemical propellant, Maglev relies entirely on external power sources. This means that the amount of power that one could supply to a Maglev system is limited only by current power generation, storage and dissipation technologies. Based on the location of a such a system, the power generation systems used could be adapted to the local environment, i.e. rather than use conventional coal fired generation units, one could consider using nuclear, solar, wind and tidal power generation units or a successful combination of selected generation models.

2.0.4.a Magnetic Levitation and NASA

The idea of using magnetic levitation as a first stage propulsion technology has been looked at before. NASA initially contracted three companies to develop a full scale technology demonstrator based on magnetic levitation [58]. Foster-Miller, Lawrence Livermore National Laboratory worked on independent projects that would try and prove the feasibility of a magnetic levitation launch assists system. A project sponsored by NASA and PRT Advanced Maglev systems looked at the development of electromagnetically levitated and propelled platforms for launching spacecraft of up to 50 tonnes in the late 90’s. An artist’s concept for a magnetic levitation system for space launch is shown in Fig 14 [59]. This initial research led to the development of a 50 foot demonstration system being built in Huntsville Alabama, which was completed in September 1999 as shown in Fig 15 [58].

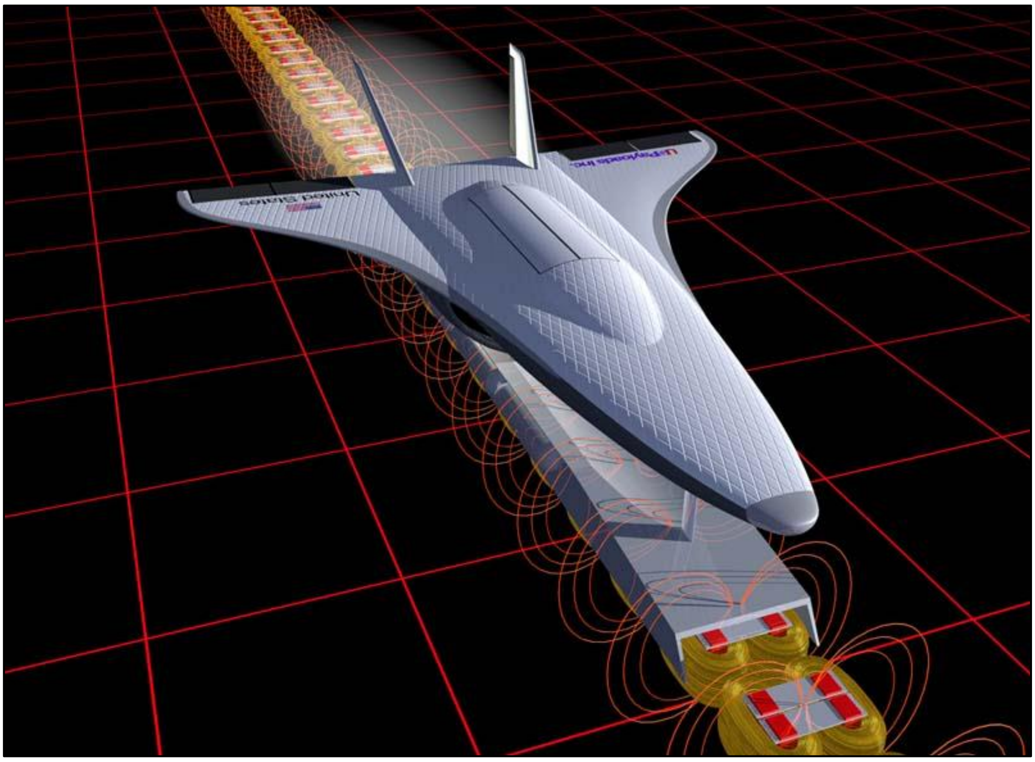

Figure 14: Artists Concept of Magnetic Levitation System for Space Launch

Figure 15: Magnetic Levitation demonstration system at Marshall Space Flight Centre

In principal, each launch carried out using a full scale Maglev track developed by PRT consume about $75 worth of electricity [58]. Marshall Space Flight Centre installed a

44 foot experimental track to test magnetic levitation and propulsion technologies on small scale models. This was led by Bill Jacobs, then lead engineer for maglev at Marshall Space Flight Centre (MSFC). Figure 16 shows Jacobs preparing a carrier and vehicle model on the Marshall track.

Figure 16: Carrier and vehicle being prepared on Marshall's experimental track

The aim of the initial research was to find a maglev technology that NASA could use as a launch assist technology on a 1.5 mile operational track capable of accelerating a vehicle at 600mph in 9.5 seconds. Figure 17 represents a 1/9 subscale model vehicle clearing the Magnetic Launch Assist System (MLAS) during a track demonstration at MSFC. The designed track uses an advanced linear induction motor that produces thrust along a straight line. The demonstration test track used is 100 feet long and 2 feet wide. Proving this technology was key to NASA's ambition of reducing the overall take-off weight of the vehicle. Due to the nature of the track and the propulsive force it is able to provide, key elements of vehicle design such as landing gear, wingspan and on-board propellant storage are affected, which in turn reduce the overall weight of the craft thereby allowing it to carry larger payloads.

Figure 17: 1/9 subscale vehicle model clearing MLAS demonstration track

A study carried out by Foster-Miller Inc. on behalf of NASA looked at two distinct designs. The first called the ‘Maglifter’ was a shuttle size replacement vehicle, whilst the second called ‘Bantam’ was a smaller 100,000 lb. vehicle. NASA’s brief for this study listed the requirement for the two systems as shown in Table 1[60].

Parameter	Maglifter (3g)	Maglifter (1g)	Bantam (3g)
M=mass(lb)	1,000,000	1,000,000	100,000
M=mass(kg)	454,000	454,000	45,400
a=acceleration(g’s)	3	1	3
v=velocity(m/sec)	270	270	270
v=velocity(mph)	600	600	600
l=length(m)=$(v^2)/2a$	1215	3645	1215
F=Ma(N)	1.36E+07	4.54E+06	1.36E+06
P=Fv(W)	3.68E+09	1.23E+09	3.68E+08
U=$1/2Mv^2$=Fl(J)	1.65E+10	1.65E+10	1.65E+09
t=sqrt(2l/a) (sec)	9	27	9

Table 1: System parameters provided to Foster-Miller, Inc

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The quantities listed in the above table allow one to calculate a number of secondary parameters such as launch motor force, power requirements for the motor and the energy that must be stored in order to achieve a launch based on primary parameters such as the total mass of the vehicle, maximum acceleration desired and the final launch velocity required. Whilst the above table provides an initial indication of the force, power and energy requirements for the system; one should note that the final requirements for either system would vary based on the total vehicle mass (dependent on the type of motor system used), the aerodynamic and levitation drag, efficiency of the motor used, transmission line loss and finally on the altitude at which the vehicle is launched[60]. For their study, Foster-Miller preferred the use of linear synchronous motors (LSM) and linear induction motors (LIM). Figure 18 shows a close up view of the drive section and the test vehicle of the track as designed by Foster-Miller Inc.[60].

Figure 18: Foster-Miller Inc. test track close up of drive section and test vehicle

The study concluded that there appeared to be no fundamental technology barriers that would need to be overcome to develop a full scale system, however the system would require significant development efforts. It also stated that both systems considered in the study could be developed using common architecture[60]. Although the above mentioned systems were developed and tested as test-beds, no full scale facility exists today. Whilst NASA still considers Maglev to be a viable launch assist technology, it is not actively investing in developing or testing the technology at this time.

2.0.4.b The Maglifter concept

The Maglifter concept was part of a NASA study that aimed to develop a catapult system based on Maglev technology to dramatically increase the amount of payload that can be carried by Earth-to-Orbit transportation systems. The study indicated that an expendable launch vehicle launched at an altitude of 3000 meters at a speed of 270 m/s would increase the payload capacity delivered to low earth orbit by 80% [61]. The full scale catapult system for the 'Maglifter' would consist of guideway that was 4 miles in length, and included a 2.5 mile accelerator system and a 1 mile decelerator. The accelerator section of the catapult would be housed within a tunnel that could be filled with a low-density gas, and ideally would be constructed on the side of a mountain at an angle of 45 degrees. The main vehicle designs considered for such a system were based on the use of rocket powered single stage to orbit (SSTO) vehicles and air-breathing SSTO vehicles. The study in 1994 concluded that whilst preliminary analysis indicates great potential in the use of Maglev for space launch there were a number of issues that needed to be resolved before 'Maglifter' could be implemented, such as the economic and cost analysis for such a system, the impact of inclination angle during launch, the latitude of launch and development of a tunnel system that would permit a successful launch[61]. Figure 19 provides an overview of the 'Maglifter' concept.

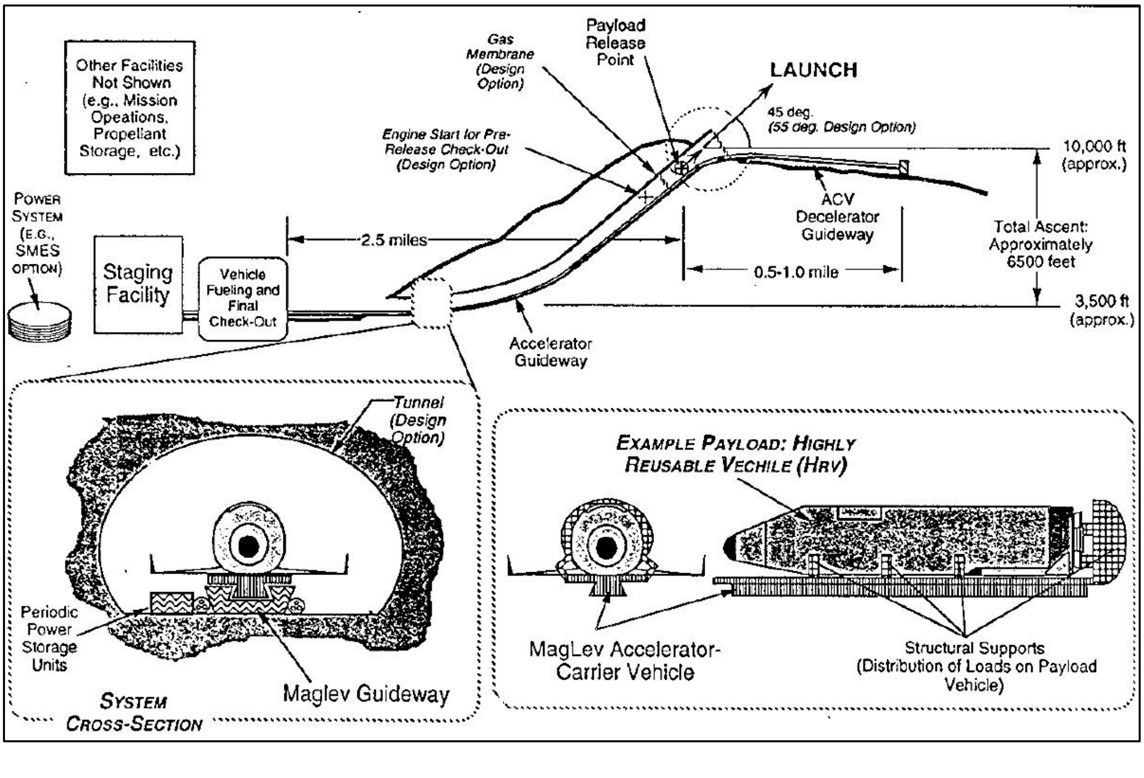

Figure 19: System overview of the Maglifter concept

2.0.4.c Startram

Startram is a concept being developed by James Powell one of the inventors of the superconducting maglev technology that is in commercial use today[27][62]. Startram is based on existing magnetic levitation technology and proposes accelerating a craft from ground level within an evacuated tube to an elevated terrain. The craft would be propelled at ground level using superconducting maglev technology and would emerge from the tube at an altitude between 26000 and 64000 feet[63]. Startram has envisioned two distinct system designs. The Gen-1 system is a high 'g' cargo launch system that aims to accelerate sealed cargo capsules at 5 miles per second at 30g, whilst Gen-2 is a passenger and cargo system that would be accelerated between 2 and 3g. Crafts using Gen1 are specifically designed to withstand aerodynamic drag and would be shot out at an altitude of roughly 26000 feet, whilst those using Gen-2 would leave the tube at roughly 64000 feet.

The developers believe that such a system would enable nations to launch hundreds of thousands of tons of cargo per year at a cost of $50 per kilogram. It is believed that the Gen1 system could be operational within 10 years and would cost approximately $20 billion, whilst the Gen-2 system would cost closer to $60 billion to develop and would take roughly 20 years to build [63]. The tube used for Startram launch would be approximately 80 miles in length and would be secured to the ground using superconducting cables as shown in fig 20.

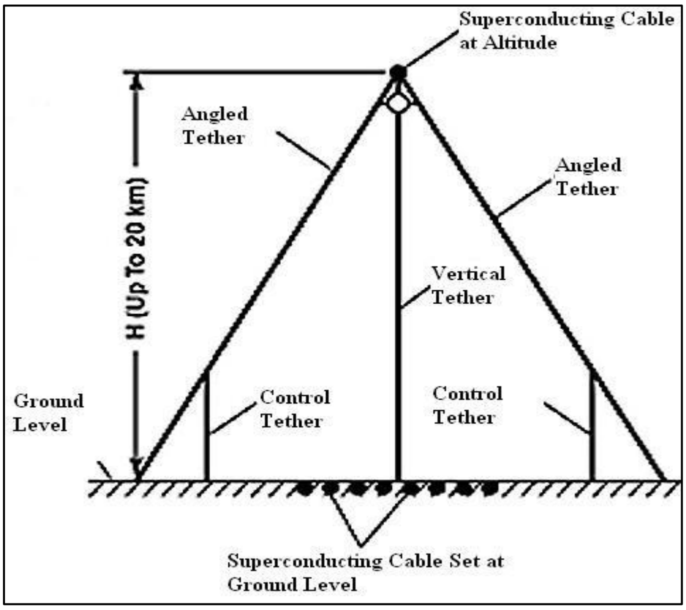

Figure 20: Startram Levitation/Tether system

There are also plans to develop a Gen-1.5 system which would be designed to ferry passengers to space and would act as an intermediate system whilst Gen-2 is being developed. The Gen-1.5 system would be based on the same principal as Gen-1 and Gen-2, however would not use a suspended evacuated tube. Instead the system would rely on an angled launch at high altitude. The launched craft would require rocket based propulsion to reach orbit, however the amount of on-board fuel required would be minimal when compared to current launch systems[63]. The Gen-2 system uses an MHD window which allows one end of the tube to remain open thereby permitting vehicle launch. An applied DC current flows through the ionized air within the pump section of the MHD window, pushing the air outward and helping maintain near vacuum conditions within the acceleration tube[63]. Figure 21 shows an artist's rendition of a launch vehicle exiting the Startram system.

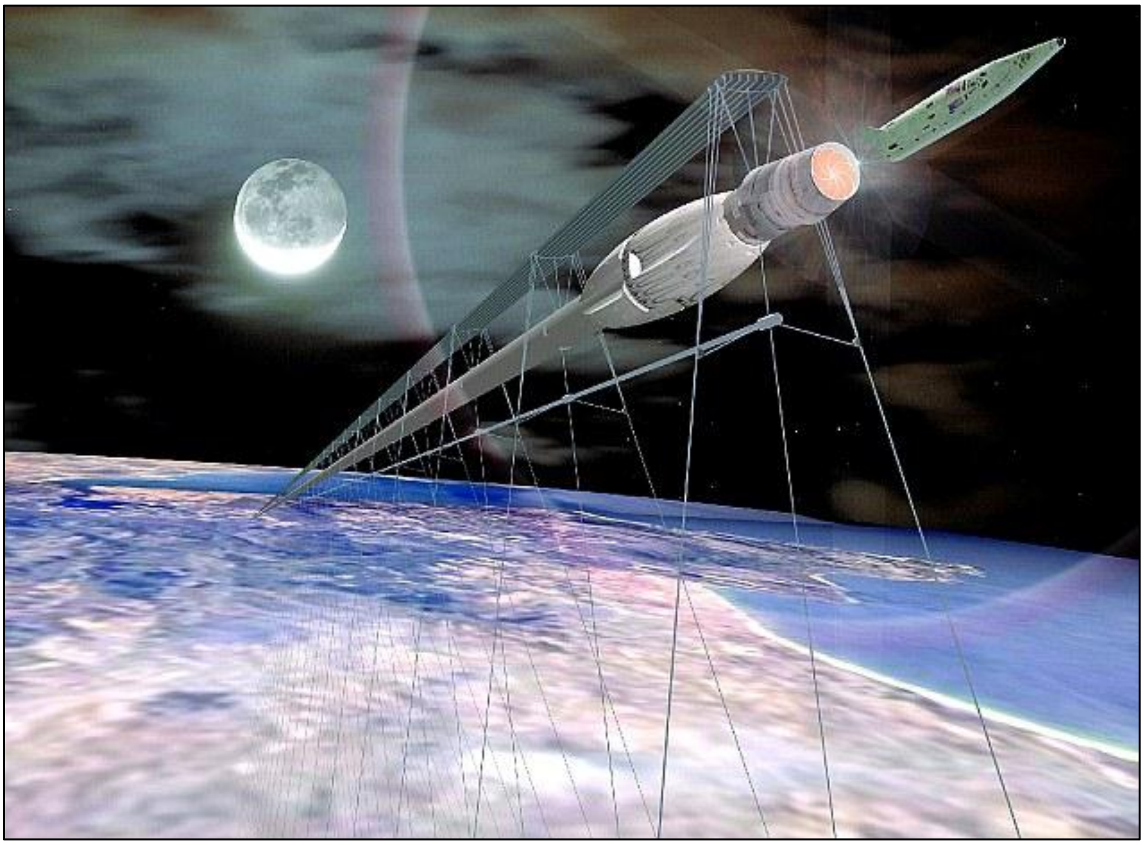

Figure 21: Artist's rendition of a vehicle exiting a Gen-2 Startram system

Although Startram systems are still conceptual, NASA scientists have declared the project and its technology as feasible. The creators believe that Startram would be the 'next great step' for the human civilization, however stress that such a project would not be possible without international cooperation[63].

2.0.4.d Launch Loop

The ‘Launch loop’ concept was proposed by Keith Lofstrom in 1983 as a way of launching objects in to space. The concept proposes a cable-like system attached at two ends to the Earth’s surface with a section maintained at an altitude of 80km, to provide electromagnetic acceleration to payload on a 2000km launch track [64]. In his paper Lofstrom describes how the launch loop relies on an EMS system where the payload applies a magnetic field on the rotors that form part of the launch loop. Using the EMS system, the payload accelerates along the track until it reaches orbital velocity. Figure 22 shows a schematic of the ‘Launch loop’ system.

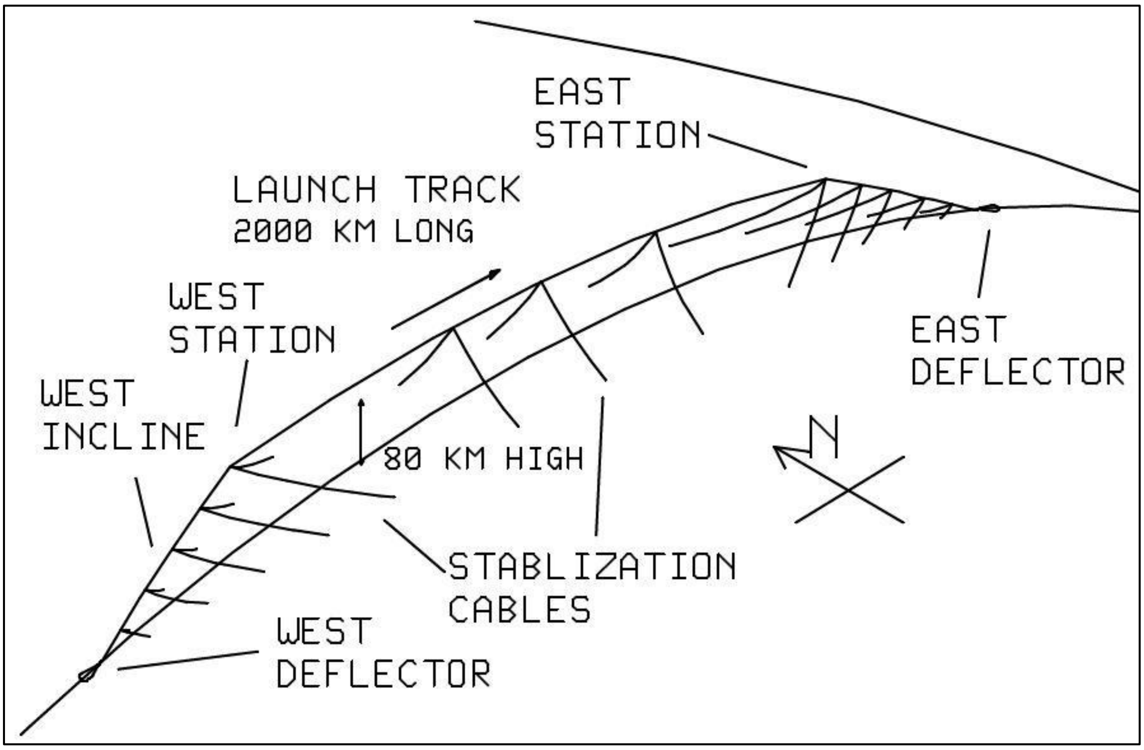

Figure 22: Schematic of the Launch Loop system

The development of such a system also relies on the ballistics of high-speed continuous flow. The structure would contain an iron core rotor that travels along the entire length of the loop. Initially when the rotor is not operational the entire loop will be at ground level, however as the rotor accelerates to a required speed it would cause the loop to arc which in turn exerts a reactive centrifugal force on the sheath that houses the rotor [64]. It is worth noting that once the rotor is activated it will require a continuous power supply for the loop to function properly. A similar but smaller concept called the ‘Space Cable’ has been proposed by John Knapman that uses an EDS system to provide launch assist capability to conventional rockets[65]. Although Lofstrom’s provides an interesting concept to ferry passengers and cargo to space as shown in fig 23, the 'Launch loop' requires new innovations and research in multiple fields simultaneously[64]. The non-availability of off the shelf technologies for this system along with its proposed location in the middle of the ocean means that it is not a practical project in the near future.

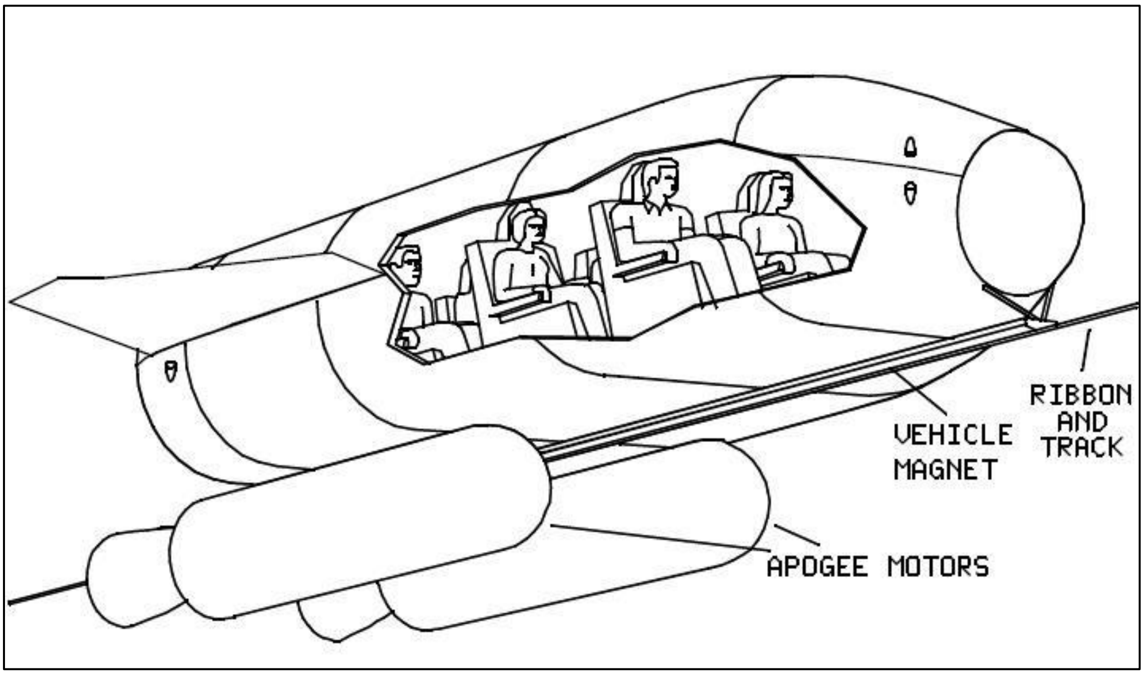

Figure 23: A Launch Loop passenger vehicle with apogee motors for orbital insertion

2.0.5 Chapter Conclusion

This chapter has introduced the concept of electromagnetic levitation and propulsion techniques by discussing the origins of the technology and its primary use today. By outlining NASA's involvement in the technology and their research on its use as a launch assist we have established that a Maglev system could be used to propel future vehicles. The next chapter will introduce our proposal for a vacuum based Maglev system that would be capable of providing both launch assist and direct launch capabilities based on the design chosen.

Chapter 3: Vacuum Maglev for Launch

Chapter Summary

This chapter proposes a propulsion system that combines the use of magnetic levitation and propulsion technology with that of vacuum tubes. It discusses the development of the system and why such a system along with a custom designed launch vehicle would be better than current propulsion mechanisms. We define the objectives that such a system would need to meet and discuss the design criteria for the launch system and the launch vehicle. The later part of the chapter discusses the potential future uses for such a system.

3.0.1 Vacuum Maglev Proposal

All open air transportation systems that rely on the use of magnetic levitation and suspension are subject to both aerodynamic and electrodynamic drag forces. Although the electrodynamic drag faced by the system is negligible at high speeds, the aerodynamic drag forces quadruple as the systems velocity doubles. As such, the power required to overcome the aerodynamic drag is eight times the original value for effective increase in velocity, as described in appendix 1. The frictional drag faced by the vehicle during a horizontal launch would also lead to a large increase in the surface temperature at the vehicles extremities, which may damage various internal components. As a result the maximum speed of current day ground transport systems operating on MagLev principle is capped at 350mph. As the aerodynamic drag faced by such a system is proportional to the air density, if we were to reduce the air density coming into contact with the launch vehicle, we would effectively lower the amount of power required to overcome the drag force.

To consider the development of a launch system design based on magnetic levitation and propulsion, we must ensure that the launch vehicle faces minimal aerodynamic drag, which in turn would affect the power systems required to maintain the system and the overall economic viability of the system. To achieve this we propose the development of a magnetic levitation and propulsion system inside a purpose built tunnel that is maintained in a state of vacuum, enabling us to provide initial launch velocity to a fully reusable launch vehicle (FRLV). The tunnel would be designed with an inbuilt air handling and control system that would not only monitor the temperature and pressure conditions within the tunnel at the time of launch, but would also be responsible for gradually equalizing the pressure within the tunnel to the ambient pressure outside just before the vehicle leaves the tunnel. This horizontal launch approach within the confines of a tunnel, allows the vehicle to attain much higher speeds by minimizing the negative impact of aerodynamic drag. The electrodynamic drag the vehicle would face at low speeds can be controlled using a null flux suspension mechanism. The null flux system results in a high field gradient and an overall reduction in drag, whilst providing a high lift to drag ratio and strong restoring forces [66]. Such a system can be designed in two distinctive ways:

A vehicle based design – by using such a method the vehicle is levitated directly over the guideway, and is propelled magnetically using a series of linear synchronous motors (LSM). Within the LSM, small alternating current magnets push on superconducting magnets to provide a net propulsive force. Whereas the magnets in the LSM are AC magnets those on the vehicle are DC, allowing the magnetic polarity to alternate along the vehicle.

Mass driver design – by using such a method the vehicle is placed on a purpose built magnetisable stage, which is then levitated and accelerated by the sequential firing of a row of electromagnets. Once the vehicle is accelerated to optimum speed the two separate and the stage is slowed down and recycled for another launch. After leaving the guideway the vehicle continues to move due to inertia. The key issue with the mass driver design is that it is only practical for accelerating small objects [67–69]. The limitations on the design are imposed primarily by the cost of the silicon to switch current and the cost of the power supply and temporary storage.

3.0.2 System objectives for a Vacuum Maglev system (VML)

Whilst there is continued development in the area of magnetic levitation and propulsion, future development is critically dependent on our ability to justify the need and benefits that a vacuum Maglev system can provide. The construction of a vacuum Maglev should be considered as a long-term project and development of such a system should not seek immediate or short term results, but instead focus on long term goals and returns. We should ensure that as the technology and instrumentation evolve, they could be incorporated in to the existing framework at low cost.

In terms of aerospace, the attraction to traditional implementation of Maglev is based on its ability to achieve relatively high speeds in a short time frame, an overall reduction in the amount of chemical propellant required at the time of launch, low wear and tear, its safety features and most importantly the ability to provide crew with a reliable launch-abort mechanism. Bearing this in mind, the following design and development objectives have been identified for the vacuum Maglev system:

a) The system should be capable of competing with current launch vehicles and facilities in terms of payload deployment, cost structure and quality of service.

b) The system should be flexible, capable of growth and one that can easily adapt to industry changes and needs.
c) The system should have a lower carbon footprint compared to current technologies, not be weather dependent for launch and capable of providing a multitude of launches.
d) Finally the system must ensure safe, efficient and reliable transportation for crew and cargo.

3.0.3 Launch System Design

One of the most challenging aspects of designing a VML system is the construction of the actual launch system. Since the proposed system requires a number of technologies to work in harmony to enable a successful launch, each component must be designed to meet specific requirements. To develop the launch system, we shall split the design process to three distinct areas that focus on the launch system tunnel, the construction of the guideway that would support and accelerate the launch vehicle and the pressure and control networks that maintain the system in a state of vacuum.

3.0.3.a The launch system tunnel

The launch system tunnel is the most crucial part of the design process, as it not only houses the guideway for the launch vehicle but also has control systems that monitor the pressure and temperature conditions within to allow for perfect launch conditions. The overall length of the tunnel is determined by the net weight of the launch vehicle and the speed we want it to achieve. By considering a launch vehicle initially at rest if we wished to achieve a velocity between 100mps and 250mps at accelerations ranging between 1g and 3g, the distance required to achieve these figures would fluctuate between 170m and 3.2km as illustrated by the figure 24 below. However as we increase the required velocity there is a dramatic increase in the minimum track length required as shown in figure 25. Before designing the actual tunnel it is vital to establish the final velocity we wish to achieve and the net acceleration we wish to operate at. When considering launch vehicle acceleration, we should bear in mind the maximum acceleration threshold that we can use for human rated missions. It is also possible to design a tunnel system for non-human missions where higher acceleration values would be acceptable. Figure 26 shows the minimum length requirement for a non-human rated mission where the payload can withstand an acceleration of up to 20g.

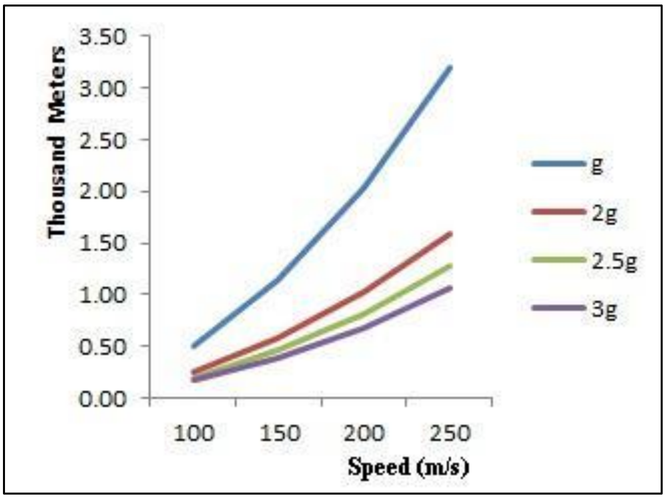

Figure 24: Minimum track length based on velocity and acceleration requirements

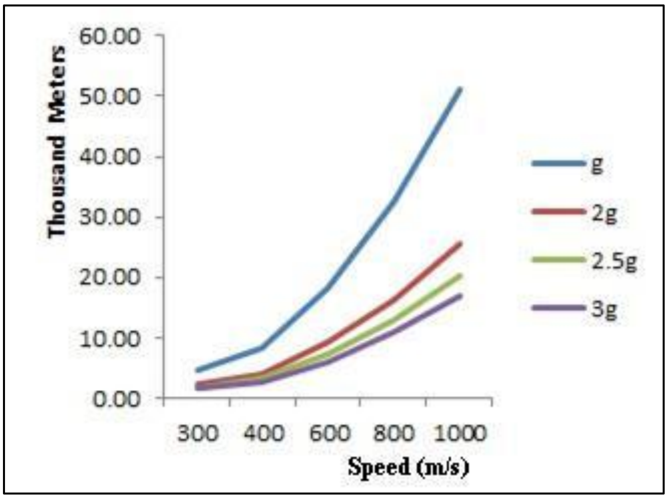

Figure 25: Change in minimum length based on change in required velocity

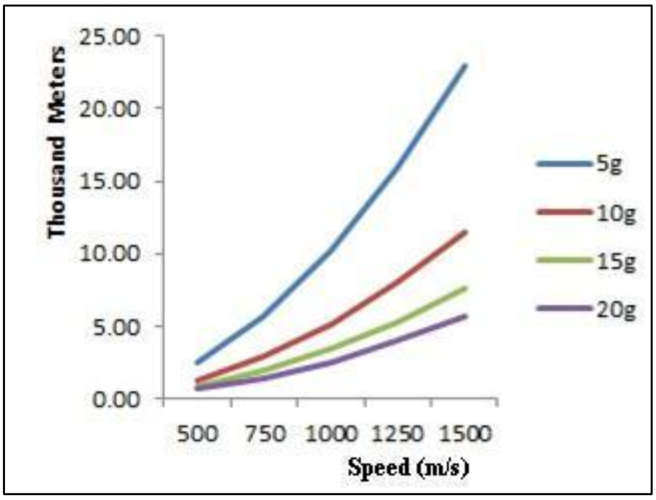

Figure 26: Minimum length requirements for acceleration between 5g and 20g

Once the length requirements for the tunnel have been established, we must consider the structural design and the vibrational stability of the tunnel structure. Since the launch vehicle would initially accelerate whilst the tunnel is in a state of vacuum, and emerge as the tunnel pressure is stabilized to ambient external pressure; the tunnel would need to withstand and dissipate the shockwaves generated by the vehicle whilst ensuring that they do not interact with or damage the integrity of the structure.

3.0.3.b The launch vehicle guideway

The guideway is housed within the main tunnel structure and is used to propel the launch vehicle to a desired velocity using Maglev technology. The desired velocity is determined by the type of vehicle, its mission classification and the net payload weight. It may be used to assist with orbital launches or as a single stage to orbit system. For the VML structure we propose the use of superconducting magnets with a null flux method to control the initial electrodynamic drag as mentioned before [66]. The length of the guideway is determined based on the net weight it is required to support which in turn determines the net power requirements. In a standard guideway with a single power source we would expect a transmission line loss across the length of the guideway as the transmission line must supply maximum power and the full energy requirements for launch. In order to minimize transmission line loss we recommend splitting the guideway into multiple sections whereby each section has a dedicated sub-power station capable of meeting the design requirements. Each section of the guideway would be powered by an external source, and activation of the various sections controlled by a central system. Only single sections of guideway would be active at any given time, as illustrated in fig 27. Once the launch vehicle clears a section of guideway, power to that section is automatically cut. By doing this we are also able to transfer power from sections of the track that are not in use to parts that may require additional resources. If we assume the transmission line is copper based, we can use the equations in appendix 1 to calculate the resistance, mass and the cross sectional area of the segments.

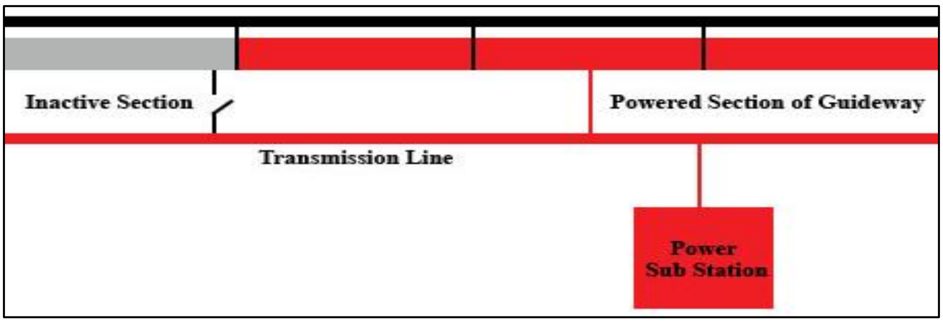

Figure 27: Section of guideway with a dedicated power source

Each element of the guideway, from power distribution to vehicle support and track side adjustments is controlled by the track control and central support unit. Figure 28 illustrates the hierarchy of the control unit and a description of the various units involved can be found below.

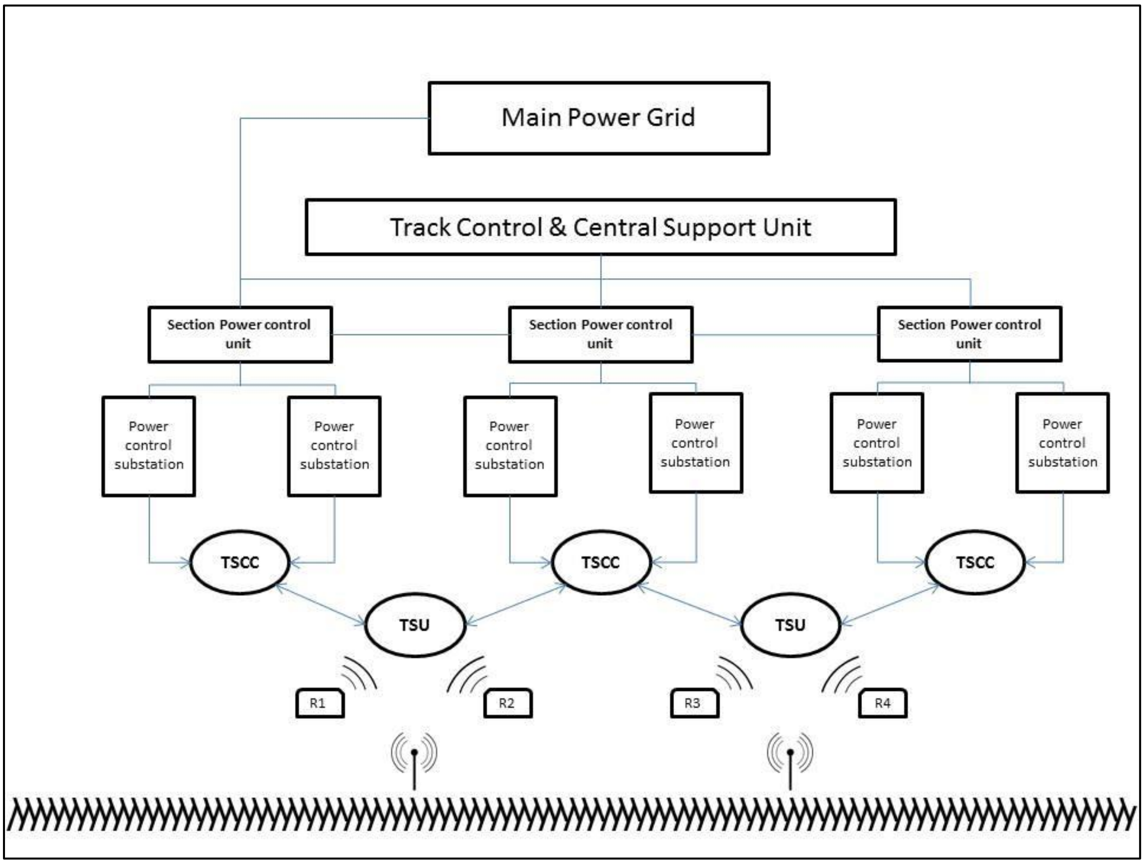

Figure 28: Hierarchy of Track Control and the Central Support Unit

Central support Unit (CSU): assists crew or UAV controller in terms of system guidance, launch/abort sequences and maintains real time control over the track guidance systems (which includes levitation, propulsion and air gap distances).

Section power control unit (SPCU): The Sectional power control unit administrates both power substations in its designated zone.

Track section control centre (TSCC): The TSCC relays information received via the Track Section Unit (TSU) and regulates the power supplied by each substation. If a single substation is able to provide adequate power, the TSCC would either assign the other substation as an auxiliary station or divert its power to a storage utility. The TSCC manages the vehicle schedule and propulsion power directly. The vehicle schedule includes designated launch time, route control and the vehicle speed profiles. Propulsion power control means speed control and electric power distribution between neighbouring TSCC's.

Track Section Unit (TSU): The TSU ensures that the section of track in its zone is active at the time of launch. The TSU activates or deactivates the section of track, based on information provided by relays (R1, R2, R3 & R4). Whilst the launch vehicle is between two consecutive relay points (e.g. R1 & R2), both the corresponding tracks are live.

Relays (R): The relays collect real-time information about the speed of the launch vehicle, available track length, vehicle pressurization, chamber pressure and vehicle/system alerts via track side systems (TSS).

Vehicle support system (VSS): not only allows the crew to communicate with the CSU, but monitors all system activity on-board the vehicle and feeds the information to the TSS.

Track Side Systems (TSS): The TSS gathers information from the VSS and feeds the information to the relays and the CSU. Consecutive TSS's communicate with each other and feedback power and air-gap adjust alteration requests to the Track control Unit (TCU).

During normal operation the launch of the vehicle is controlled by the Central Support Unit and would require no input from crew. In case of launch aborts or system emergencies the CSU would automatically reduce power to the track and allow the crew to manually control the vehicle's deceleration until it comes to rest. If however, there is a vehicle based alert the CSU will reduce power to the active section of the track and apply emergency braking procedures, ensuring that the vehicle is brought to a standstill as quickly as possible. In cases, where the vehicle has crossed 50% of the total track length, the CSU would also have the option to divert the vehicle onto emergency deceleration tracks or EDT's.

3.0.3.c Pressure and control networks

The overall tunnel design includes the construction of a high pressure pipe network that runs along the length of the entire tunnel. This network connects valves placed on the side and top of the tunnel system to extraction pumps that enable us to extract air within the tunnel thereby lowering overall internal pressure. Each valve segment consists of a number of converging nozzles that are manufactured to operate at optimal design conditions[2] ensuring there is no shock wave generated as gas exits the nozzle. The extracted air is then pressurized and gradually returned to the tunnel via the same converging-diverging nozzles as the launch vehicle begins to accelerate.

Once the length of the tunnel and guideway is determined, we can calculate the net volume of air that needs to be extracted. The mass of the gas that needs to be extracted is established as a product of the gas volume and its density. After establishing the overall mass of the gas that needs to be evacuated from the tunnel we can evaluate the number of nozzles required to refill the tunnel before the vehicle exits. By calculating the mass flow rate for a single nozzle, it is possible to estimate the total number of nozzles required to refill the tunnel in a specified timeframe. Whilst doing this calculation, we must account for choked flow conditions and the consequences of accidental release flow rates from the pressurised gas systems[3]. Equations for the above can be found in appendix 1. A gas control system ensures that the nozzles remain in a choked condition permitting a maximum flow rate. The calculation for maximum flow rate when the Mach number is 1, and the gas exhaust velocity are given in appendix 1. When initiated, the gas control system regulates the pressure such that all the convergent nozzles operate simultaneously, allowing sonic gas flow into the tunnel. The designed system should incorporate switchable extra inactive nozzles, which could be used in a contingency situation.

3.0.4 Launch Vehicle Design and vehicle launch phases

To achieve an effective design for the VML launch system we needed to ensure that the proposed vehicle would have a payload capacity compared to current systems, would be a fully reusable launch vehicle and that alternative configurations of the proposed vehicle could be constructed to serve the hypersonic transport and space tourism markets. The only fully functional system that can be used as a template for the proposed vehicle is the Shuttle Orbiter, and as such it was determined that it would be best to keep the proposed vehicles dimensions and payload capacity similar to that of

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[2] When operating at design conditions the back pressure is equal to the pressure at the nozzle exit, resulting in supersonic flow without producing shockwaves.
[3] Accidental release flow rates can be calculated using the ‘Rasouli and Williams source model’ or the ‘Bird, Stewart and Lightfoot source model’[122], [123]. Equations for both can be found in appendix 1.

the Orbiter. Table 2 below shows the dimensions of the proposed launch vehicle, whilst fig 29 shows a wire-frame rendering of the vehicle.

Total Length	37.24 meters	122.17 feet
Height	17.25 meters	56.58 feet
Vertical Stabilizer	8.01 meters (each)	26.31 feet (each)
Wingspan	23.79 meters	78.06 feet
Wing Thickness	1.5 meters (max)	5 foot (max)

Table 2: Proposed Vehicle dimensions

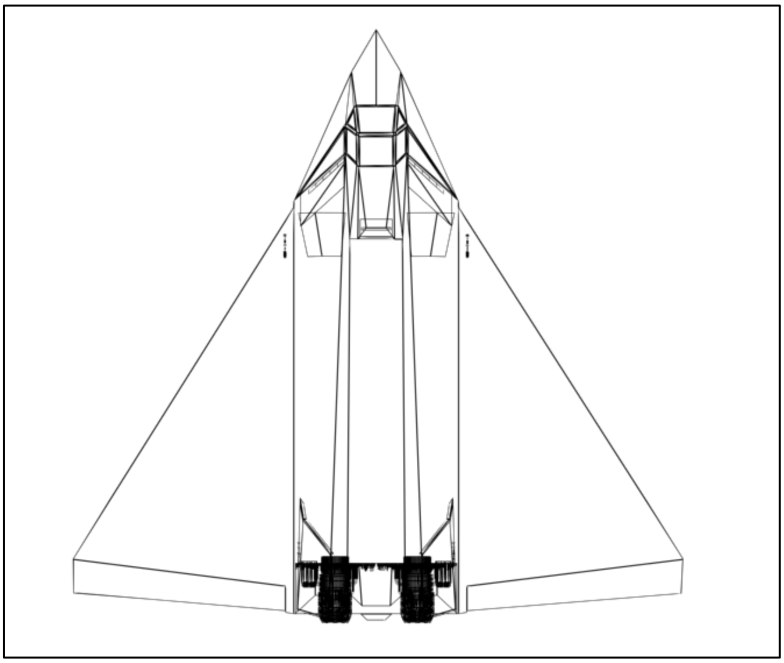

Figure 29: Wireframe rendering of proposed launch system

Once we had chosen the overall dimensions of the major segments that would make up the proposed vehicle, we needed to consider the main wing design and construction mechanism for the vehicle. The most suitable design found for developing a launch vehicle that is capable of hypersonic flight and has a high lift to drag ratio was based on the waverider principal [70]. The principal has been studied in the past to design systems capable of cruising at hypersonic speeds [71–73] and examine the aerodynamics of a waverider system for its application in a two-stage-to-orbit mission [74], [75]. As our launch vehicle would initially accelerate inside the VML tunnel, it would require a secondary propulsion system to sustain hypersonic flight. This can be achieved by integrating scramjet engines into the initial airframe design. Since waveriders have a wedge like configuration, they typically have a high-pressure lower surface which acts as a compression surface. By using an inverse design method, one where the supersonic or hypersonic flow past the body is predefined, we can ensure that the compressed air is funnelled towards the scramjet engines as shown in fig 30. Due to the initial compression achieved by the body itself, one only requires the secondary stages of the scramjet thereby reducing the engine weight.

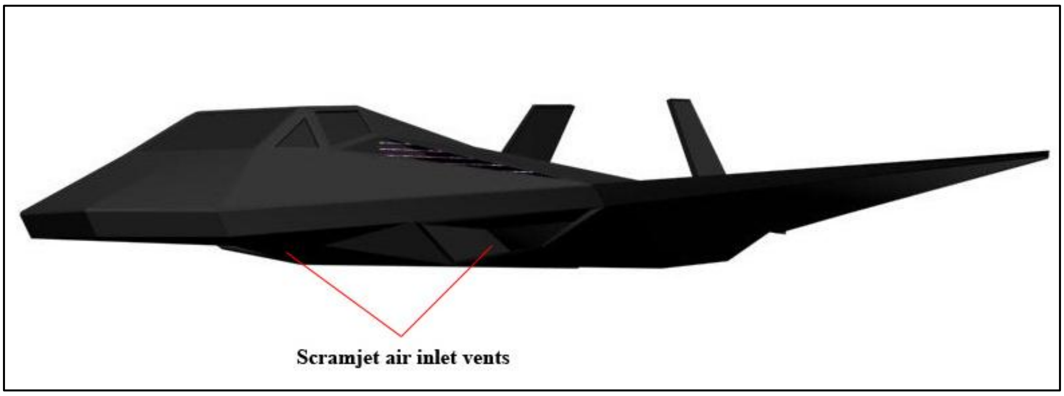

Figure 30: Scramjet air intake vents on proposed launch vehicle

To design the waverider we use a cone flowfield, as the derived system has a larger usable volume and a better lift to drag ratio when compared to systems based on a wedge flowfield. By using the Taylor-Maccoll equation below we can express the flowfield generated by a cone in supersonic or hypersonic flow in terms of spherical coordinates [76].

$$\left(1-\frac{v^2}{a^2}\right)\frac{d^2u}{d\theta^2}+\cot\theta\frac{du}{d\theta}+\left(2-\frac{v^2}{a^2}\right)u=0 \quad \textbf{Equation 1}$$

Where θ is the semivertex angle, ‘a’ is the speed of sound and ‘u’ and ‘v’ are the velocities components in $\widehat{e_r}$ and $\hat{e}_\theta$ respectively, as shown in fig 31.

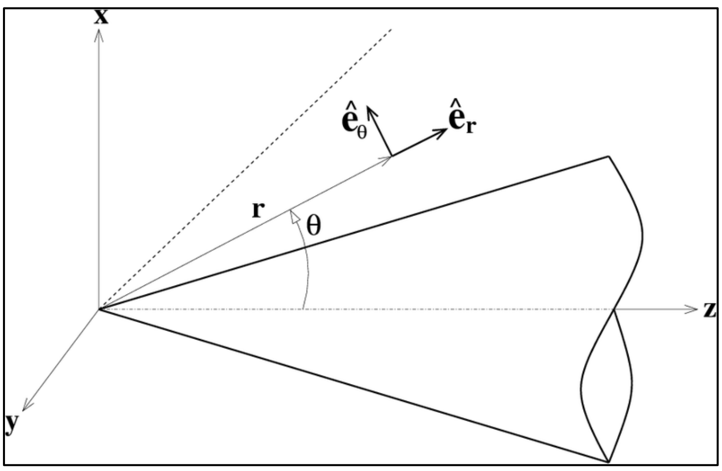

Figure 31: Conical shock represented as dotted line

Despite its size, in order to land safely the vehicle is designed to be as agile as possible, in order to control excess speed at re-entry. The preferred mode of vehicle recovery would be a horizontal landing on a conventional designated runway. The proposed launch vehicle would employ thermal heat-insulation tiles along the body and extra active cooling systems along the base to regulate sudden temperature increase at the point of re-entry. Whilst figure 32 represents the basic structural design chosen for the VML launch vehicle, it is important to remember that only two waverider based designs have been tested with scramjet engines, and the longest flight duration recorded was 140 seconds by the X-51A. Although the full system design of the launch vehicle is beyond the scope of this thesis, this preliminary design enables us to lay the framework for future development.

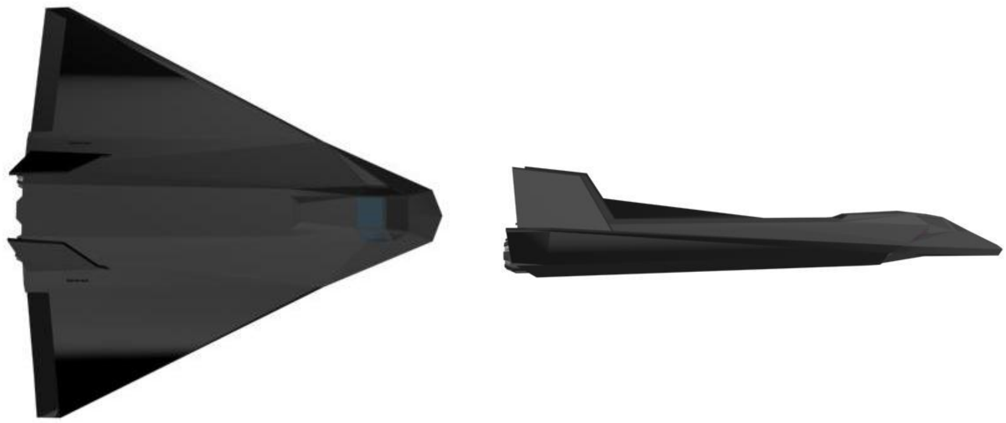

Figure 32: Top & side render of the proposed VML launch vehicle

3.0.4.a Vehicle launch phases

After integration of the launch vehicle and its payload, the following three stages are observed for successful orbital launch:

Depressurization: Once the launch vehicle is in place over the guideway, multiple extractor jets are activated to reduce the density of air within the tunnel. These jets deliver the expelled air into large high pressure storage tanks placed throughout the system. Once the pressure within the tunnel is reduced to nominally zero, the first section of the guideway is activated. This process also automatically activates the magnets on the undercarriage of the launch vehicle. After initial checks are completed, the landing gear of the launch vehicle is retracted. At this point the vehicle is automatically controlled and levelled using on board computers. The control systems for the guideway ensures that it is capable of supporting the weight of the launch vehicle, and automatically determines the power required throughout the guideway for a successful launch. They also set activation times for the remaining sections of the track. Once this information is relayed to the control centre and the vehicles on board computers the craft begins acceleration.

Acceleration: as the launch vehicle begins to accelerate, guideway control systems use data acquired from the vehicles on board computers to increase the overall speed of the craft, ensuring that it is capable of reaching orbital velocity before reaching the end of the guideway. During acceleration, communication loss between the vehicles computers and the guideway control systems leads to an automatic abort. In such a scenario, the power output to the active section of guideway is reduced and the vehicles landing gear is engaged.

Pressurization: even before the launch vehicle begins to accelerate, the storage tanks placed throughout the system deliver pressurized air to over two hundred thousand converging choked nozzles. The gas pressure is maintained by an automated system which ensures that the nozzles remain choked until the ambient atmospheric pressure is reached. As the launch vehicle approaches the last section of the guideway, the tunnel pressure has increased from zero to ambient atmospheric pressure. This ensures that a standardized pressure exists both inside and outside the launch tunnel. It is important to remember that since the proposed launch vehicle is entirely reusable, the same vehicle is capable of providing multiple launches each month. If a fleet of launch vehicles was to be designed, we could theoretically launch multiple times each day.

3.0.5 Launch System location

There is an ever increasing need to guarantee the security and sustainability of space activities by all actors to ensure safe and unrestricted access to space. Investment in the space domain today is largely a governmental activity, due to the scale of the investment required. Actors choose to invest in space capabilities as it directly impacts the technological and scientific development of the nation providing an improved framework for managing natural resources, furthermore it helps advance industrial capacity and the local economy. However, the future success of space activities depends on having a clear focus on national and international goals along with long term funding options provided via a successful PPP. To achieve a sustainable and viable space domain, we must engage universities, research institutions, private sector entities and actors who currently are unable to contribute to the domain due to barriers faced in terms of technology, economies or local politics. A global space program, one aimed at conducting civil and commercial space activity that benefits all participating actors would help bring together the best creative and analytical minds irrespective of their national background to solve truly global problems.

The VML system as described would be an ideal starting point for a global space program. By bringing industry and nation states together, the program would help set up specialized research and development facilities across the globe providing state of the art facilities. These R&D centres would focus on core areas of the system and launch vehicle design and would work in sync to provide an optimal timeline for project completion. It would also allow interested parties to invest a smaller percentage than their current national programs whilst gaining access to a global platform. Countries unable to invest large sums of capital, could contribute in terms of skilled and unskilled labour force or by providing launch sites and test-beds. This program would most certainly have an impact on local economies across the globe, and has the potential to become the largest non-profit organization developing technologies and capabilities whose impact affects all of humankind.

The beauty of a Maglev system is that whilst it may initially be designed for space vehicle launches, it can also be used commercially. By placing such a system closer to the equator the thrust and fuel requirements for sending a vehicle into orbit are lower due to the earth's rotational speed. Also, being closer to the equator the earth's rotational speed provides an added boost to the vehicle's velocity (usually around 6%). As such, current day systems launched from Cape Canaveral in Florida gain an approximate boost of 911mph whereas those launched from the French Guinea (5 degrees from the equator) gain roughly a 1000mph boost. The active magnetic guidance and flexibility in design of the propulsion system allow the guideway to be adapted to various landscape conditions. Current Maglev systems have been tested to withstand sudden gradients up to 10 degrees at an estimated speed of 280mph. However, as the proposed system is enclosed and has operational speeds much greater than 280mph, a sudden gradient of 10 degrees would cause massive g-forces to accumulate. As a result, ideally the system should be built on the side of a mountain, as that would provide the launch system with gradual inclination. Figure 33 illustrates a ± 5-degree section close to equator, which may support the viable launch of a space vehicle using a VML system, whilst fig 34 shows that most countries in that band have either signed (in yellow) or signed and ratified (in green) the international space treaty. This means that these countries have committed to exploring and using space for peaceful purposes. By doing so, they have also insured that each country has equal rights to space exploration and habitation. By implementing such a system in any of these developing nations we would not only ensure the economic prosperity of the nation but also a change in the socio-economic background of its people.

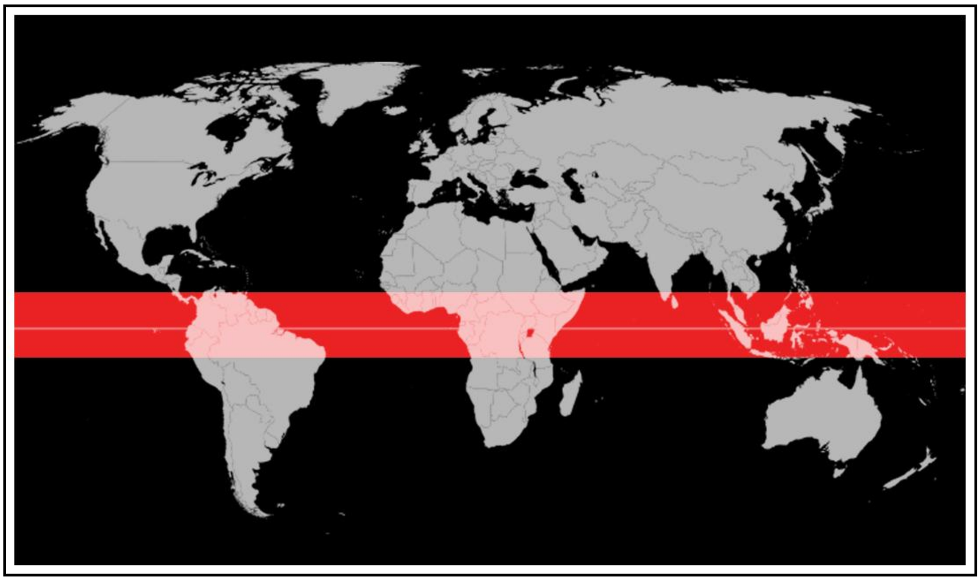

Figure 33: Potential Launch locations for the VML system

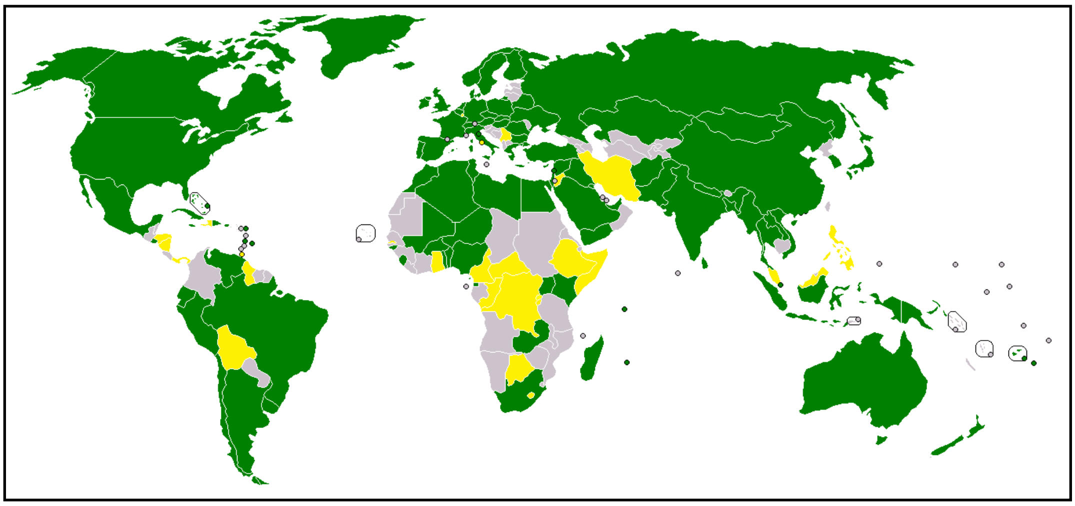

Figure 34: Countries that have either signed or signed and ratified the OST

As we consider the theoretical, it is our suggestion that such a system be developed on the side of a mountain which would provide a gradual incline for the guideway. If we were to consider Africa as a possible launch location, the ideal place would be Tanzania; more specifically mount Kilimanjaro in Tanzania. Tanzania is an ideal country for investment due to its relatively stable political situation and an economy that has progressed steadily since the implementation of the structural reform program in the mid 1990's. Figure 35 shows the possible configuration of the tunnel within the Kibo peak of Mt. Kilimanjaro, where '*a*' represents the tunnel and guideway and '*b*' shows the natural formation at the top of the Kibo peak that can be used as the tunnel exit.

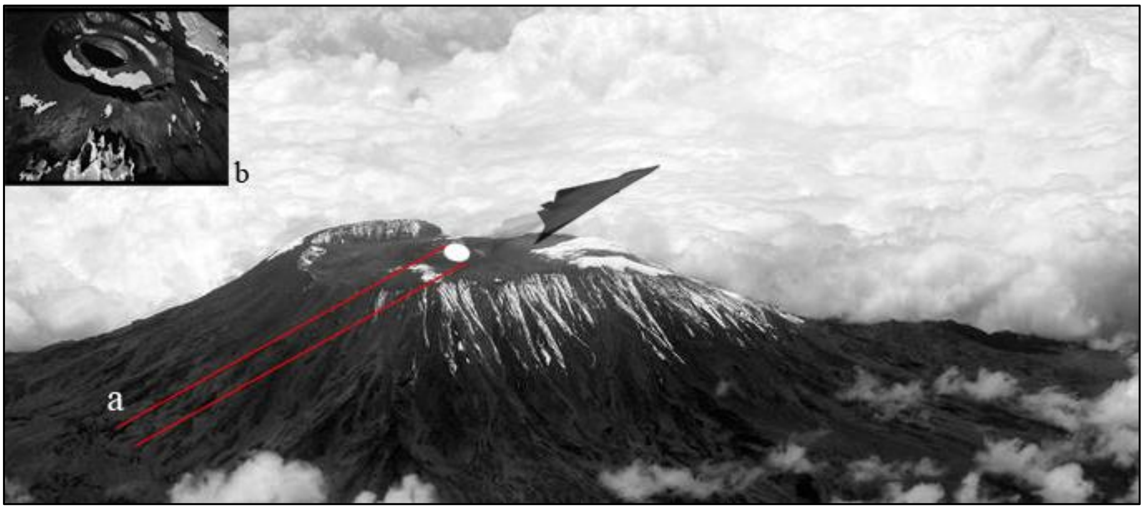

Figure 35: Mt. Kilamanjaro as a possible launch location for VML

In considering a launch from the Kibo peak, we must take in to account that we would need to drill through the mountain range in order to access the void present at the top of the peak. As we know the vertical height of the peak to be 5895 meters, we need to deduce the bore length required to construct the tunnel for the given system. To find the associated values we use trigonometric functions to calculate the base length for the tunnel at varied angles (15^o, 20^o, 30^o, 45^o, 70^o). Once we have the base length we are able to calculate the required tunnel length in meters as shown in table 3 for the same bore angles.

	15^o	**20^o**	**30^o**	**45^o**	**70^o**
Base distance (m)	1580	2100	3400	5900	16000
Tunnel length (m)	6100	6200	6800	8300	17000

Table 3: Base Length and Tunnel Length calculation

Once we have the required tunnel lengths we can calculate a number of variables such as exit velocity, time taken to exit the tunnel and the Mach speed associated with the vehicle as it exits the tunnel. For the given tunnel lengths, table 4 and figure 37 shows the speed achieved by the vehicle at varied accelerations (g, 2g, 2.5g, 3g), table 5 and figure 37 represent the Mach number achieved at exit whilst table 6 and figure 38 show the time taken by the craft to exit the tunnel at the given accelerations.

	Acceleration (m/s^2)					
		g	2g	2.5g	3g	
Tunnel Length (m)	6102.948	345.85804	489.11712	546.84957	599.04369	Speed achieved (m/s)
	6273.319	350.65232	495.89727	554.43001	607.34764	
	6806.96	365.26212	516.55864	577.53012	632.65255	
	8335.53	404.19845	571.62293	639.09387	700.09225	
	17234.57	581.20355	821.94595	918.96351	1006.6741	

Table 4: Final exit speed achieved at given acceleration with specific tunnel lengths

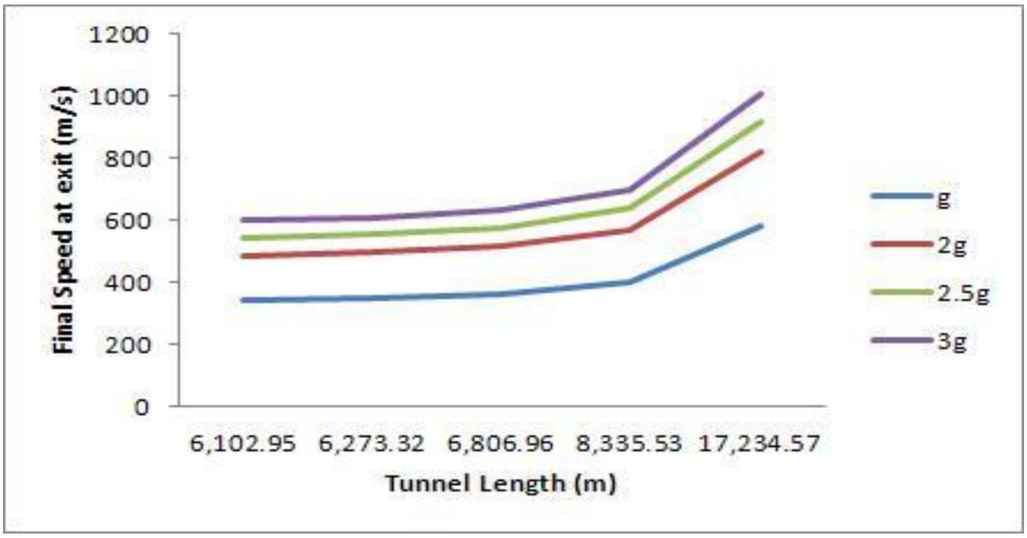

Figure 36: Graphical representation of the speeds achieved at varied acceleration via desired tunnel lengths

	Acceleration (m/s^2)					
		g	2g	2.5g	3g	
Tunnel Length (m)	6102	1.0163626	1.4373538	1.6070104	1.7603917	Mach Number (M)
	6273	1.0304515	1.4572784	1.6292868	1.7847943	
	6806	1.0733848	1.5179954	1.6971704	1.859157	
	8335	1.1878058	1.6798111	1.8780859	2.0573401	
	17234	1.7079654	2.4154279	2.7005305	2.9582829	

Table 5: Mach number achieved at vehicle exit

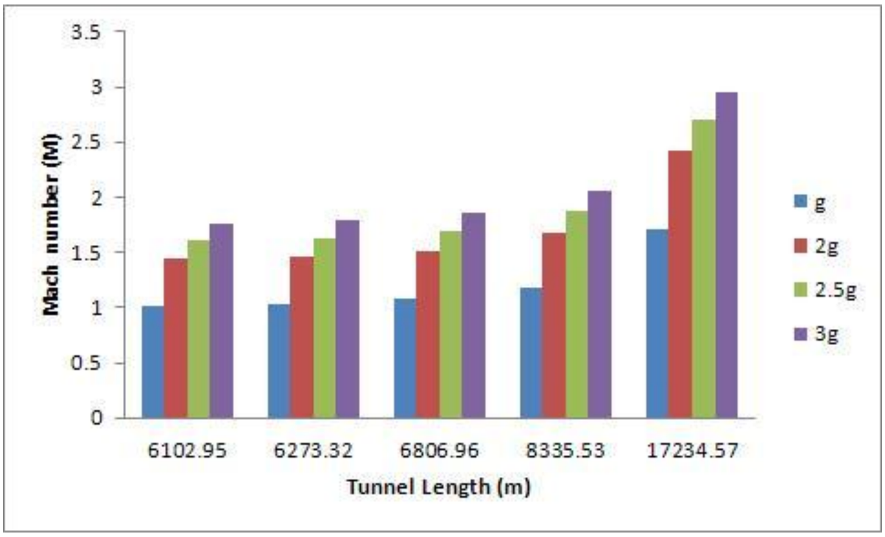

Figure 37: Variance achieved in Mach number based on acceleration and tunnel length

		Acceleration (m/s^2)				
		g	**2g**	**2.5g**	**3g**	
Tunnel Angle (Tl)	Tl @ 15	17.645818	12.477478	11.160195	10.187818	**Time taken (s)**
	Tl @ 20	17.890425	12.650441	11.314898	10.329042	
	Tl @ 30	18.635822	13.177516	11.786329	10.759397	
	Tl @ 45	20.62237	14.582218	13.042732	11.906331	
	Tl @ 70	29.653243	20.968009	18.754357	17.120308	

Table 6: Time taken by the craft to exit the tunnel at given acceleration

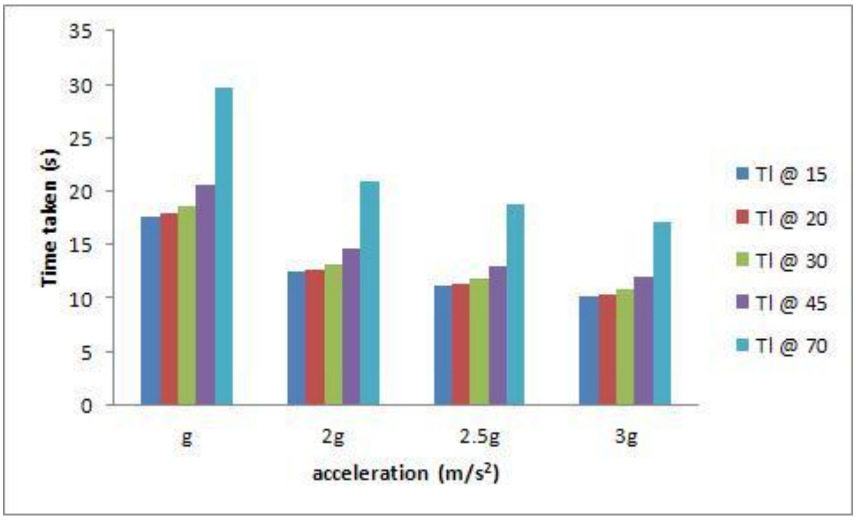

Figure 38: Time taken by the craft to exit the calculated tunnel lengths at given accelerations

The overall tunnel length and speed achieved by the launch vehicle are also crucial in determining the time available to equalize pressure within the tube to ambient pressure outside. As mentioned earlier in the chapter, this would be done using a set of converging nozzles that would initially operate at choked flow. The mass flow rate for the nozzles can be calculated as a product of the gas density, its velocity and the throat area of the nozzle. Calculations for all three are shown in appendix 1. Keeping with the system design and seeking off-the-shelf technology, we shall consider commercially available industrial vacuum systems to extract air from the tunnel. In order to do so, we have considered a guideway length similar to the tunnel lengths shown in table 3. The guideway height is taken as 5 meter, the width is taken as 6 meters across whilst the inner radius for the tunnel is 15m. Based on these figures we are able to calculate the effective gas volume within the tunnel that needs to be extracted as shown in table 7 below.

Tunnel L (m)	Tunnel R (m)	Tunnel Vol (m^3)	Guideway Vol (m^3)	Effective Gas Volume (m^3)
6103	15	4311733	183088	4128644
6273	15	4432100	188200	4243900
6807	15	4809117	204209	4604908
8336	15	5889052	250066	5638986
17235	15	12176224	517037	11659187

Table 7: Effective Gas Volume to be extracted based on tunnel length

Based on the above we can calculate the number of pumps that would be required to extract the gas volume in a given timeframe. We considered 3 reference case scenarios to determine the total evacuation time taken by a single pump based on industrial systems with a flow rate between 2 and $10m^3/s$. Based on initial calculations we concluded that a single commercially available pump would take anywhere between 42 and 602 days to evacuate the tunnel based on the tunnel length selected and the volume flow rate used. By fixing the required evacuation time as 120 minutes we were able to calculate the volumetric flow rate and the total number of nozzles required, which based on calculation comes to a total of 440 thousand nozzles. As the aim is to fill the tunnel as rapidly as possible, it would be best to distribute the required number of nozzles across the entire length of the track. It is important to note that the total number of nozzles is directly dependent on the volumetric flow rate produced, by adapting the throat size we can adjust the flow rate, thereby either reducing the number of nozzles required or reducing the time taken to evacuate the tunnel Figure 39 illustrates how the proposed launch tunnel would look with the nozzle lattice in place, whilst figure 40 shows a close up of the launch vehicle with a wireframe render of the tunnel and nozzle lattice structure..

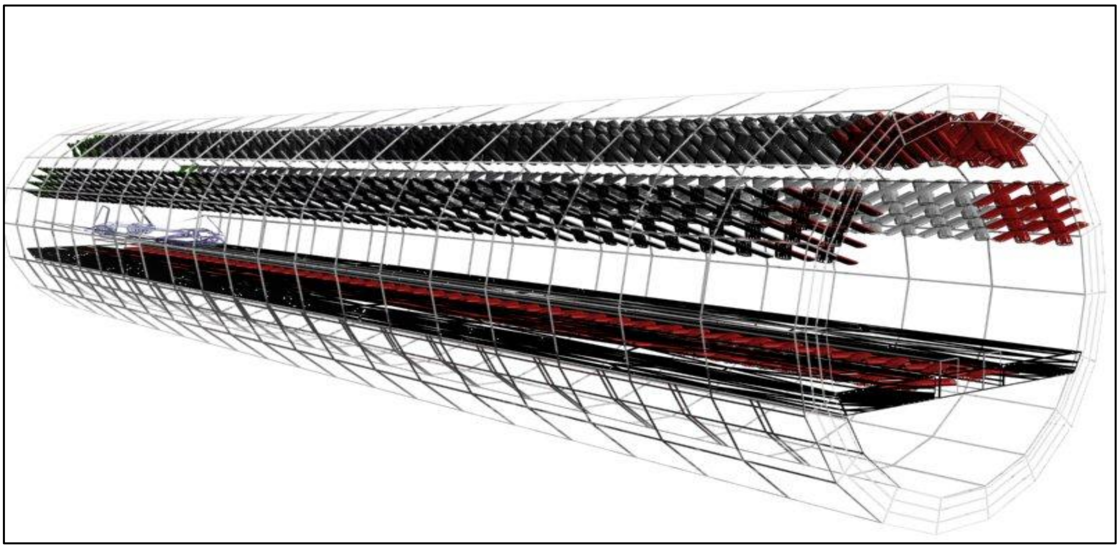

Figure 39: Side rendering of launch tunnel with nozzles and vehicle in place

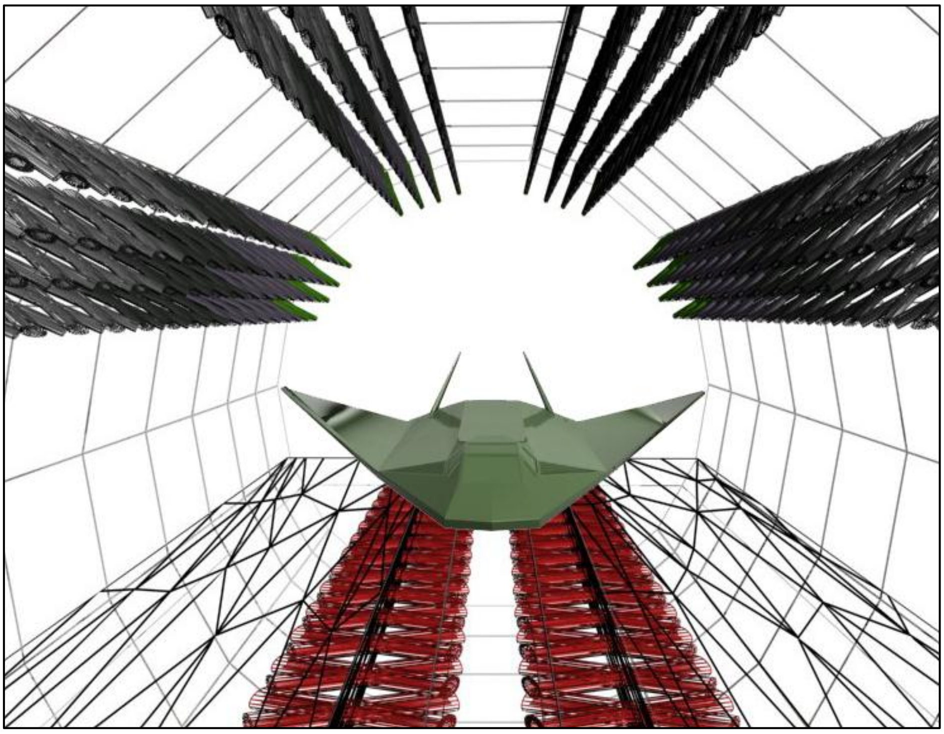

Figure 40: Close up view of the launch vehicle

By working out the Mach number attained within the tunnel we can work out the shockwave interaction as gas is released into the tunnel to equalize ambient and internal pressure. Figure 41 represents a shockwave generated when at Mach 4 when the attack angle is chosen as 10^{o}. Figure 42 shows the interaction between the shock wave and a side structural wall at the same conditions.

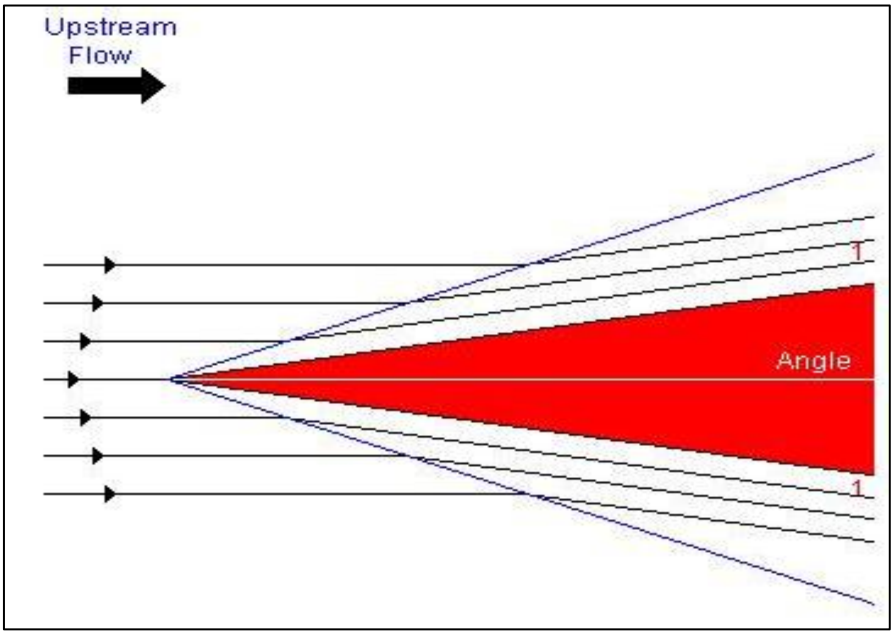

Figure 41: Shockwave generation at Mach 4

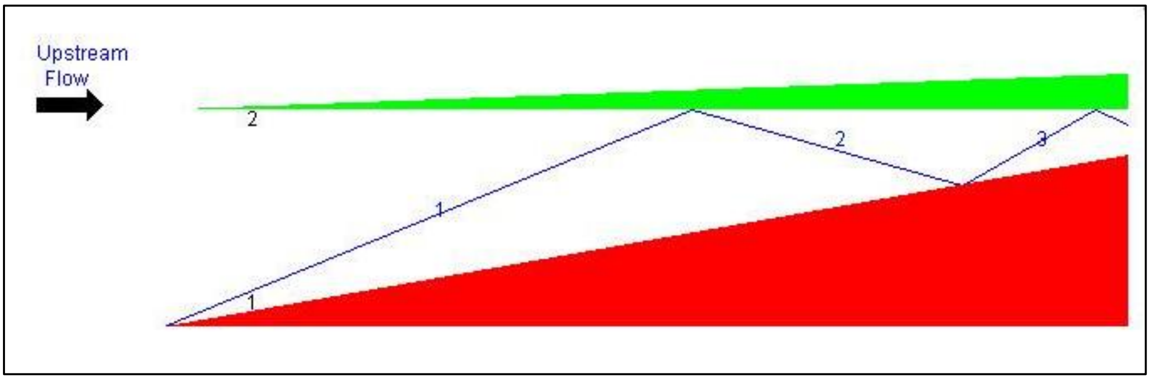

Figure 42: Shockwave interaction with secondary surface

Figure 42 shows the generation of three distinct waves. In the first instance shockwave 1 is caused by the interaction of upstream flow with the body with an attach angle of 10^o. As the initial wave interacts with the secondary body (shown in green), it generates a secondary wave that affects the Mach conditions in the region and upstream of the shockwave. This pattern repeats until the flow becomes subsonic. When designing the vehicle we consider the angle of attack for the craft such that the initial shockwaves generated diverge from the body of the craft and so that reflected waves only interact with each other once the craft has passed the shock zone. Another important aspect to consider at the system design stage is the aerodynamic heating of the vehicle would face at the time of launch and at re-entry. As we have assumed the dimensions of the proposed craft to be similar to the Space Shuttle Orbiter, we shall also consider using a thermal protection system (TPS) similar to the Shuttle. The TPS is used to protect the

Orbiter during aerodynamic heating during atmospheric re-entry and the extreme cold whilst in space [77]. Whilst the best method for predicting aerodynamic heating is via viscous computational fluid dynamics [78], the process is time consuming and rather expensive since each variable change (e.g. Mach number, speed, altitude) requires new computational results. A vehicle such as the one proposed in this thesis will have stagnation points as it flies through the atmosphere. At these points the local fluid (air) velocity is zero as it is brought to rest by its interaction with the vehicles surface. Figure 43 shows the difference between the boundary layer flow around the body of the craft and the generated shock wave at a given angle of attack.

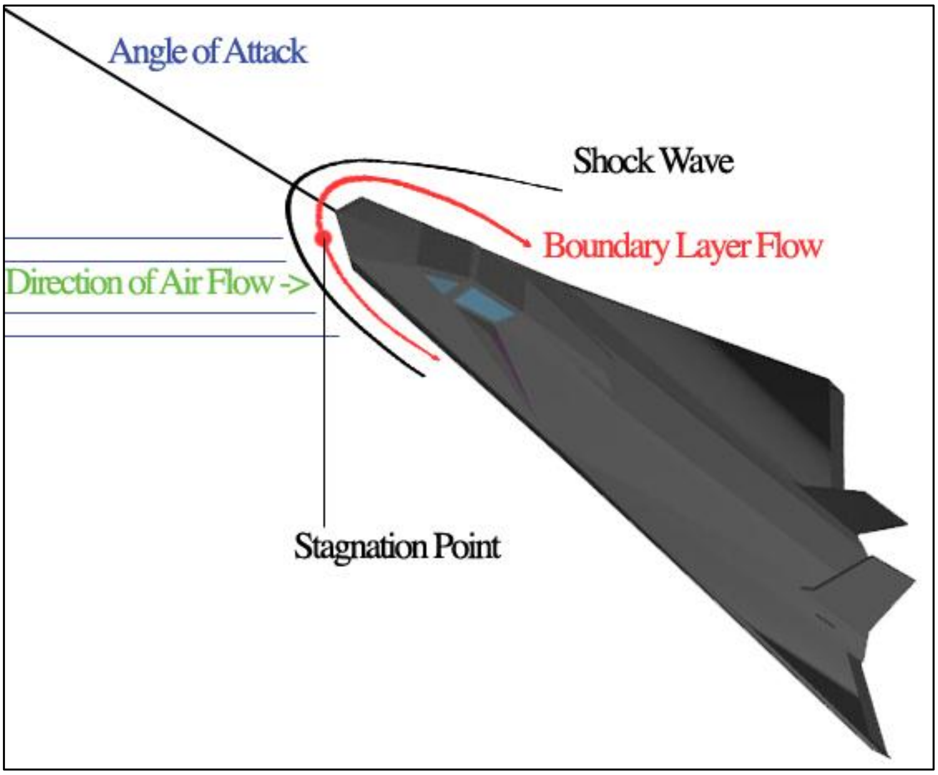

Figure 43: Boundary layer flow and stagnation point

Equations used to calculate surface temperature, heat transfer coefficient, skin friction and the relationship between pressure, temperature and altitude can be found in appendix 1.Figure 44 shows the plot for the variance in pressure with increase in altitude.

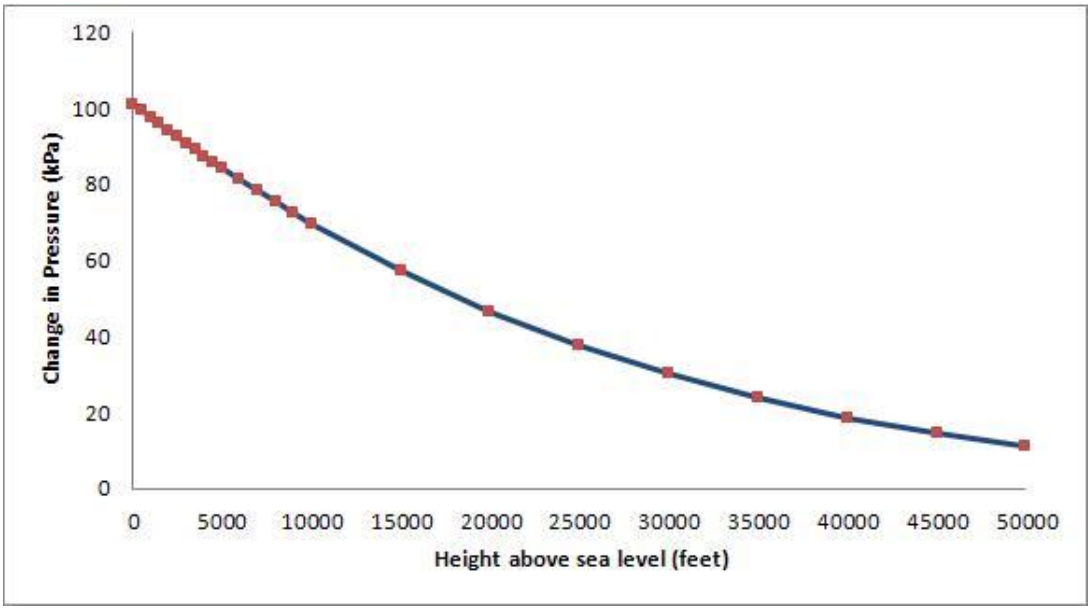

Figure 44: Change in Pressure with rinse in altitude

We have also calculated the stagnation temperature which is denoted as T_o.

$$\boldsymbol{T_0 = T\left(1 + \frac{\gamma - 1}{2} M^2\right)} \qquad \mathbf{2}$$

As the craft can be designed to exit the tunnel at varying Mach, we shall consider a case where the value for M ranges between 1 and 12 to show the gradual increase in temperature as the vehicle climbs and by considering values of M between 1 and 30 we shall plot the reduction in temperature decelerates to land.

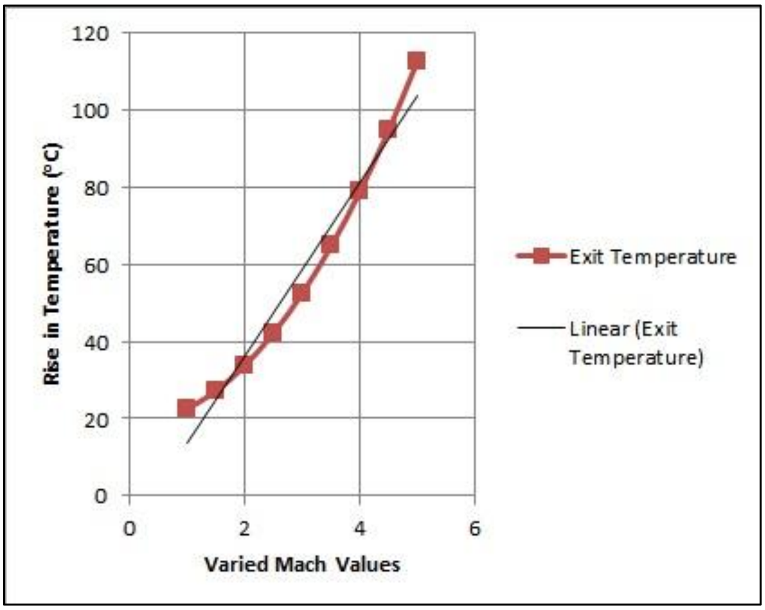

Figure 45: Temperature increase with rise in M value

Figure 45 represents the rise in temperature with rise in Mach number at the tunnel exit, whilst figure 46 shows the decline in stagnation temperature as the launch vehicle decelerates to land.

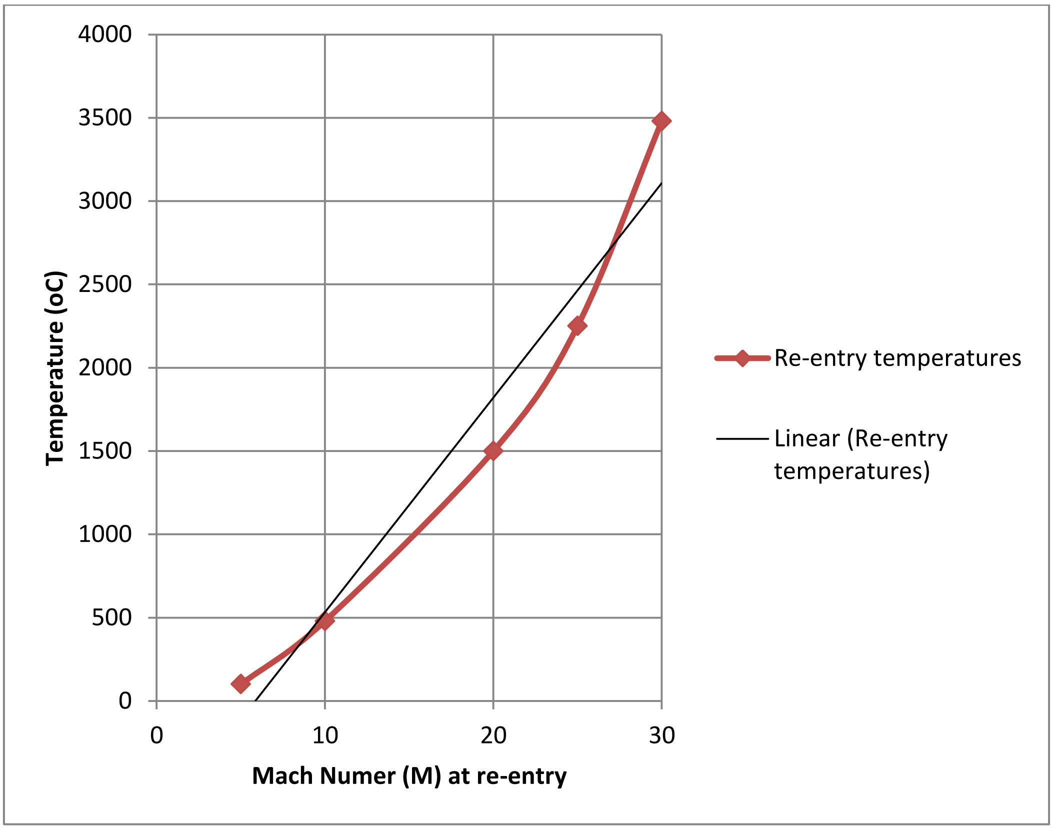

Figure 46: Temperature decrease as the M value drops after re-entry

The plots in the figure above correspond to the temperature values that are consistent with the Space Shuttle and the Orbiter during ascent and re-entry. It should be noted that these are base calculations and further plots can be derived based on CFD analysis.

One of the key things to address as the launch vehicle leaves the craft is how the tunnel exit would open once pressure within the tunnel is equalized to the ambient pressure outside. To achieve this, we propose two joining doors, each with a width equivalent to the tunnel radius. As the tunnel exit is at the top of the mountain peak we plan to raise the upper sliding door mechanically and expect acting gravitational forces to retract the bottom door. Due to the tunnel diameter, it is worth considering the deflection that such a structure would face. We estimate that a system such as ours would require a sealed doorway roughly 2m thick to avoid deflection based on Youngs Modulous for steel and stainless steel. As composite technology is developed, we could potentially consider using a carbon fibre based structure faced with an aluminium alloy for vacuum sealing purposes, this would allow the thickness and weight of the exit mechanism to decrease. Designing the door assembly along with calculations for the rollers required to move a structure that size are beyond the scope of this thesis and would need to be considered at a later design stage. The equation for maximum deflection at the centre of a uniformly distributed load can be found in appendix 1.

By cooperating and collaborating as part of an international effort, participating actors and private enterprises would not only encourage others to join but would be able to define an appropriate code of conduct that is recognized and legally enforced by the UN and participating national governments.

3.0.6 Potential uses for the VML system

Whilst there is continued development in the area of magnetic levitation and propulsion, future development is critically dependent on our ability to justify the need and benefits that a VML system can provide. The construction of a VML should be considered as a long-term project and development of such a system should not seek immediate or short term results, but instead focus on a long term goals and returns. We should ensure that as the technology and instrumentation evolve, they could be incorporated in to the existing framework at low cost.

Bearing this in mind, it should be noted that the proposed VML system has multiple possibilities in the future. Not only can the system and launch vehicle be designed to cope with future demands of ferrying crew and cargo to the ISS and beyond, but they can also be adapted to operate as launch mechanisms for commercial satellites, hypersonic travel, sub-orbital flights for the space tourism industry and UAV’s. The system’s ability to have a quick turn-around rate means that it could cope with multiple launches in different categories each day. The ability to diversify would help the system generate extra revenue, which can then be used to sustain the system. Also, with regards to space tourism, such a system would actually help make affordable space travel a reality for many rather than the privileged few.

3.0.6.a Development of the Ithaca Space Station

The Ithaca space station is intended to be the first commercial space station, which would act as a permanent metrological station, navigational aid and a hub for deep space exploration [79]. It is designed to accommodate the needs of both researchers and space tourists, and would have a capacity of a thousand inhabitants. Ithaca was primarily proposed to test the cost effectiveness of the alternative launch system and launch vehicle described earlier. The station is based on a standard torus design, and is projected to have a rate of rotation of 1.4rpm, which would be enough to generate artificial gravity.

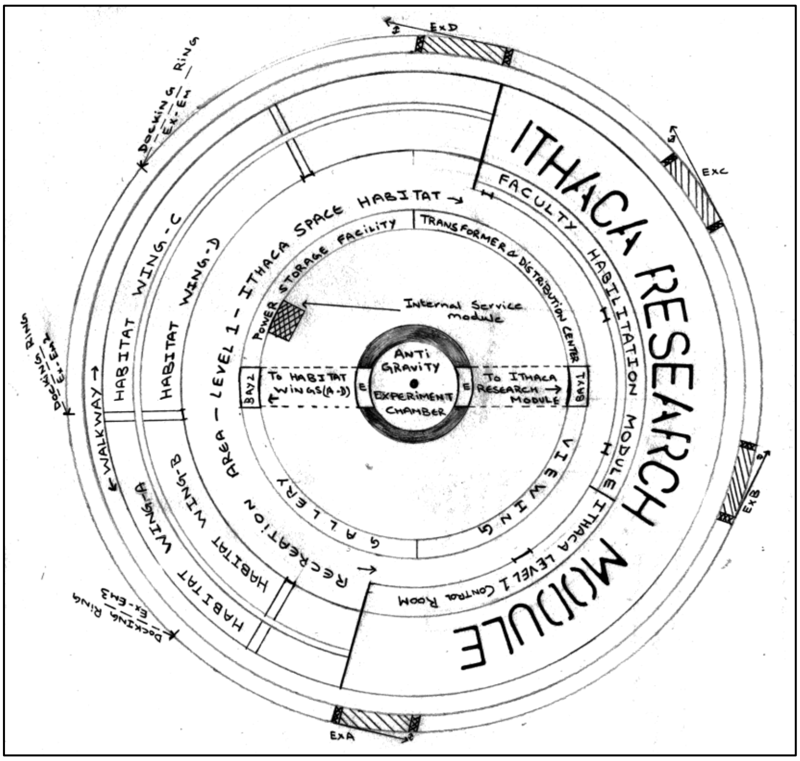

Figure 47: Ithaca space station proposal

At its core, the structure would house an anti-gravity experiment facility, which would be designed to conduct experiments taken over from the current ISS. A basic overview of the station is presented in fig 47. The various specifications for the Ithaca space station are detailed in Table 8. Although various materials were investigated for the construction of the space station, keeping the overall mass of the station as low as possible was essential; since structural weight reduction is vital for maintaining low flight costs.

Ithaca Station Station		
Station Requirements		
Population		1000
Major Radius	(m)	450
Minor Radius	(m)	65
Gravity	(g)	1
Air Pressure	(atm)	1
Calculated Values		
Area/Person	(m2)	246.0956
Surface Area	(m2)	7469048.8
Volume	(m3)	2.50E+07
Shielding	(Mt)	3.537
Oxygen Mass	(kt)	9.185
Nitrogen Mass	(kt)	36.741
Structural Mass	(kt)	163.807
Rate of rotation	(rpm)	1.4088

Table 8: Ithaca Station Properties

As a result materials with low density are most appealing. Hence Al-Li alloys were considered, as they have lower density than similar alloys, have excellent fatigue and cryogenic toughness properties and superior fatigue crack growth resistance. The physical properties of Al-Li alloy 8090 chosen for construction are detailed in Table 9.

Property	8090
Density, g/cm^3	2.55
Melting range, ^0C	600-655
Elastic modulus, GPa	77
Thermal conductivity at 25 ^0C, W/m-k	93.5
Specific heat at 100 ^0C, J/kg-k	930

Table 9: Al-Li Alloy Properties

The Space Station would be manufactured in sections, and be transferred to via separate missions due to payload specifications. It would be assembled and placed in a sun-synchronous orbit 700km from the earth's surface and would have a 45^o inclination so that it has continual exposure to the sun. For the assembly and transportation of the Ithaca space station, the proposed launch system and vehicle would be used. It is estimated that a total of 25 missions would be required to deploy the main structure of the space station and another 20 missions required to complete construction. By using a reusable launch vehicle, we ensure that despite economical fluctuations the financial impact to the launch system is minimal. Since Ithaca is designed to act as a destination for space tourists, substantial operational costs for the station can be recovered by operating chartered flights, and providing docking privileges. Most importantly, Ithaca would act as an ideal platform to conduct deep space human exploration and achieve a better understanding of the known universe.

3.0.6b Application towards Space Tourism

With space tourism soon to become a reality with the impending retirement of the space shuttle in 2010; ambitious plans for commercial spaceports are beginning to take shape in the United States and around the world. While industry optimists insist that despite the current economic situation, growth in the commercial space sector is inevitable, there is concern that the market for space travel may not be large enough to sustain multiple spaceports. Furthermore, based on the current economic climate and the ever-increasing price of crude oil, future systems must prove their cost effectiveness before obtaining government or private funding. In order to be viable, they must be able to provide a high payload capacity at reduced costs, which under the current climate can only be achieved by developing new launch technologies that rely predominantly on alternative fuel sources.

The Futron/zogby survey conducted in 2002 provides an insight to what would be a viable consumer base for the space tourism industry [80]. Although the survey needs to be updated, it asked a number of key questions that identified a potential market and defined consumer expectations with regards to sub-orbital and orbital space travel. The survey polled 498 respondents who belonged to a group that either earned a minimum of $250K per year or had a minimum net worth of $1 million. The survey indicates that 52% of those polled would not only choose to travel to space knowing full-well the post-flight discomfort they might face, but that they were also indifferent when it came to choosing between a privately developed vehicle with limited flight experience or a government based vehicle with a proven track record. The idea of viewing the earth from space was ‘very important’ with the majority (62%). The initial conclusions of the survey were updated in 2006 with regards to sub-orbital flights. A follow up to the Futron/zogby survey was conducted in 2006 by spaceport associates and Incredible Adventures, with the idea of picking up on potential market changes due to the passage in time between the two surveys. Although the survey results cannot be scaled, they provide a useful insight in relation to the perception of space travel. 29% of the 998 respondents preferred the concept of horizontal take-off and 53% preferred a horizontal landing.

The VML system and the launch vehicle proposed earlier in this chapter are capable of achieving the markers identified in the surveys. If one was to conduct a similar survey today, the potential target audience would consist of high net worth individuals (HNWI) with a net worth of $1M (10 million globally), and roughly 93 thousand ultra-high net worth individuals (net worth of $30M) who account for 0.9% of all HNWI's. Based on the Futron/Zogby survey and the current estimate of HNWI's, one's target audience for those potentially interested in space-travel would be in the region of 5.2 million globally. This figure would grow as the industry matures, with privately developed launch systems being established as primary service providers and a reduction in flight costs either due to demand or cheaper access to established and tested technology. By adapting the system and the launch vehicle for commercial use, we could generate added revenue by offering hypersonic travel and the experience of weightlessness to paying customers. Based on the overall flight time and launch rates a fee of $10000 per flight per passenger could be justified. It should be noted that the fee would offer a 95% reduction, when compared to the charges imposed by Virgin Galatic. The number of passengers per flight could range from 8 to 16 based on the launch vehicle configuration. If 3 such launch vehicles were designed for commercial use with a 10-seat configuration, the overall cost would amount to $1.11 billion. By operating 20 flights a week, the net revenue would amount to $2 million (considering 100% capacity). This would mean that at full capacity, the system would generate $104 million in a single financial year. In order to break even on the cost of the 3 launch vehicles it would take just over 10 years. Furthermore, while initial flights will originate and terminate at a single port, the development of another system would open the possibilities of exploring hypersonic travel to cut long-haul flight times by half. Current airlines charge up to $4500 for a first class seat on a twelve-hour flight. By offering a similar seat configuration to commercial airlines and halving the overall flight time, it would be possible to compete with the aviation industry and lure premium customers.

3.0.6.c Ferrying an inflatable modular structure to the lunar surface

NASA has toyed with the idea of inflatable lunar structures for the past few decades, primarily due to the convenience offered in transporting such a habitat, the volume to weight ratio and the flexibility available to developers in designing a modular structure. Moreover as the cost per pound to the lunar surface is around $50 thousand, the overall structural cost for an inflatable habitat is significantly less than a rigid structure. By looking at a modular design similar in comparison to other inflatable structures, we would like to investigate the use of the VML system to transport inflatable modular structures to the lunar surface based on a technology developed by ‘Concrete Canvas ™’. ‘Concrete Canvas’ is a company based out of the United Kingdom that has developed a cement impregnated fabric that hardens when hydrated [81]. They have two distinct structures ‘CCS25’ and ‘CCS4’ with different design specifications that can be unpacked, inflated and hydrated in a couple of hours and would form a rigid shell in approximately 12 hours. The structures can be joined to form a modular environment, and based on current design specifications allow for earth berming[4]. This would be especially useful on the lunar surface as one could use lunar regolith to cover the structure to provide added shielding against thermal and radiation mechanisms.

The current deployment of concrete canvas structures requires one to hydrate the exterior surface, however our proposed application we intend to reverse the concrete cloth so that we can saturate the concrete surface during the inflation process. This could be achieved by either transporting a premixed aerosol mixture or if possible by mining water on the lunar surface itself.

Concrete Canvas Specifications			
	CCS25	**CCS54**	
Water Requirements	850L	1500L	
Length	2.55m	2.55m	
Width	2.30m	2.30m	
Height	1.05m	1.05m	
Net weight	1800	3100	**Kg**
	3967.2	6832.4	**lbs**
Length (m)	5	10	
Width (m)	5.6	5.6	
Height (m)	2.6	2.8	
Floor Space (sqm)	26	54	
ISS weight in pounds	885652		
CCS requirement for ISS by volume	223	130	
Weight for required CC structures	401,838.48	401,838.48	**KG Apx.**
	885,652.00	885,652.00	**lbs**

Table 10: Concrete Canvas Structural requirements

[4] Earth Berming can be defined as a process whereby external walls including the roof are packed with soil to provide greater protection against the elements. When this process is used, the resulting site ends up looking like a mound with a door, one where the whole structure is encased by the terrain.

In order to gauge the costs for such an endeavour, we looked at developing an ISS size structure on the lunar surface and calculated the net material that would need to be transported. Table 10 shows the dimensions and water requirements for the two modular structure variants, and also the total number of structures required to build the lunar settlement. Based on the above requirements and the average cost per pound LEO/GEO and the lunar surface as shown in table 11, we were able to calculate the transportation cost per unit of CCS25 and CCS54 and the overall transportation cost for the lunar settlement, this is shown in table 12.

Cost per pound to Orbit	High	Low	Avg
Low Earth Orbit (LEO)	$4,587	$3,632	$4,110
Geosynchronous Transfer Orbit (GTO)	$9,243	$11,243	$10,243
Avg cost to lunar surface	$50,000	$30,000	$40,000

Table 11: Cost per pound to orbit

Transportation Costing	High	Low	Avg
CCS25 Transport cost per unit	$198,360,000	$119,016,000	$158,688,000
Total CCS25 transport cost	$44,282,600,000	$26,569,560,000	$35,426,080,000
CCS54 Transport cost per unit	$341,620,000	$204,972,000	$273,296,000
Total CCS54 transport cost	$44,282,600,000	$26,569,560,000	$35,426,080,000

Table 12: Net Transportation cost and cost per unit

By accounting for the net water requirements for this project, and assuming that initially all supplies would need to be transported from earth we were able to define high, low and average costs for water transportation as shown in figure 48 and 49.

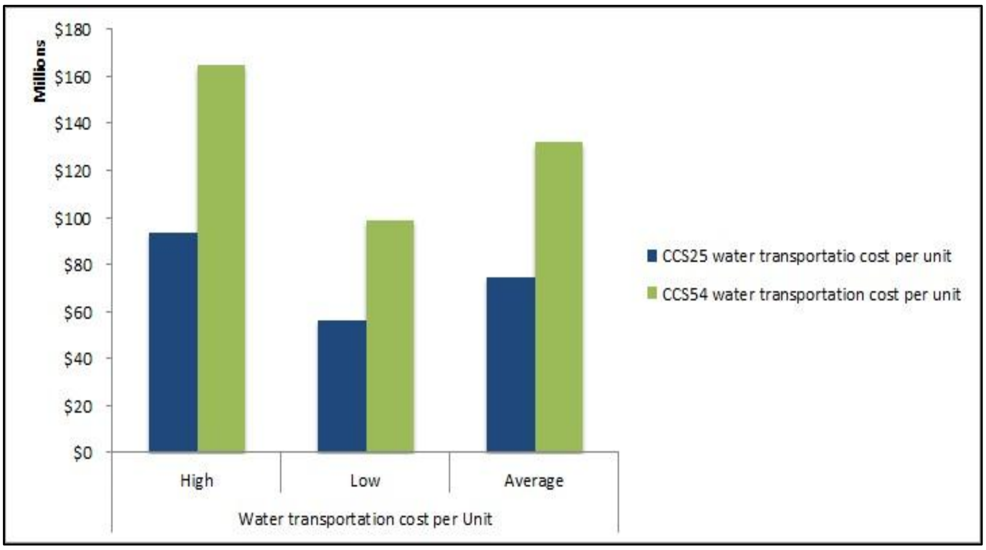

Figure 48: Water transportation cost per unit

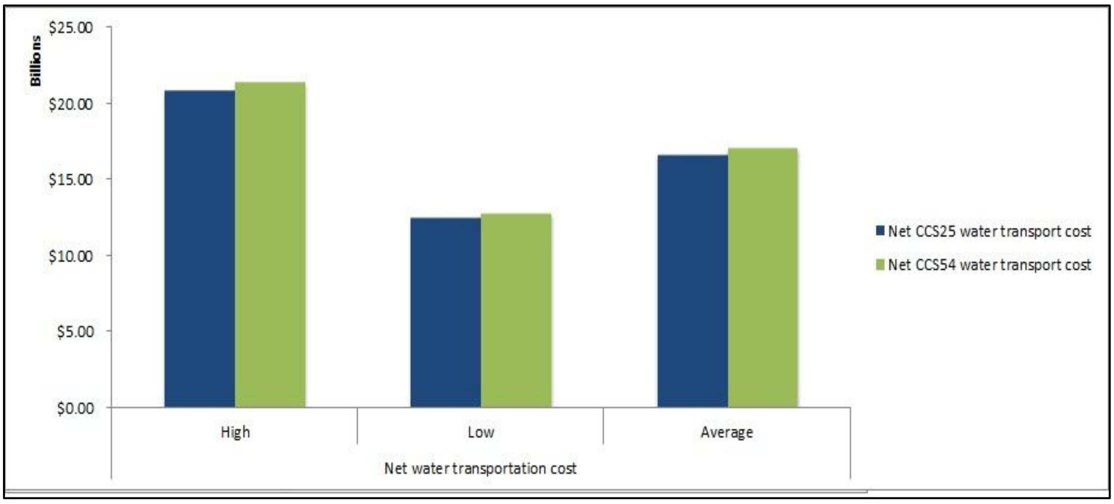

Figure 49: Net costs associated with water transportation to the lunar surface

Net transportation costs for the entire modular structure and associated water transportation costs are shown in figure 50, whilst fig 51 illustrates the average cost in transporting structures with comparable floor size to current ISS modules.

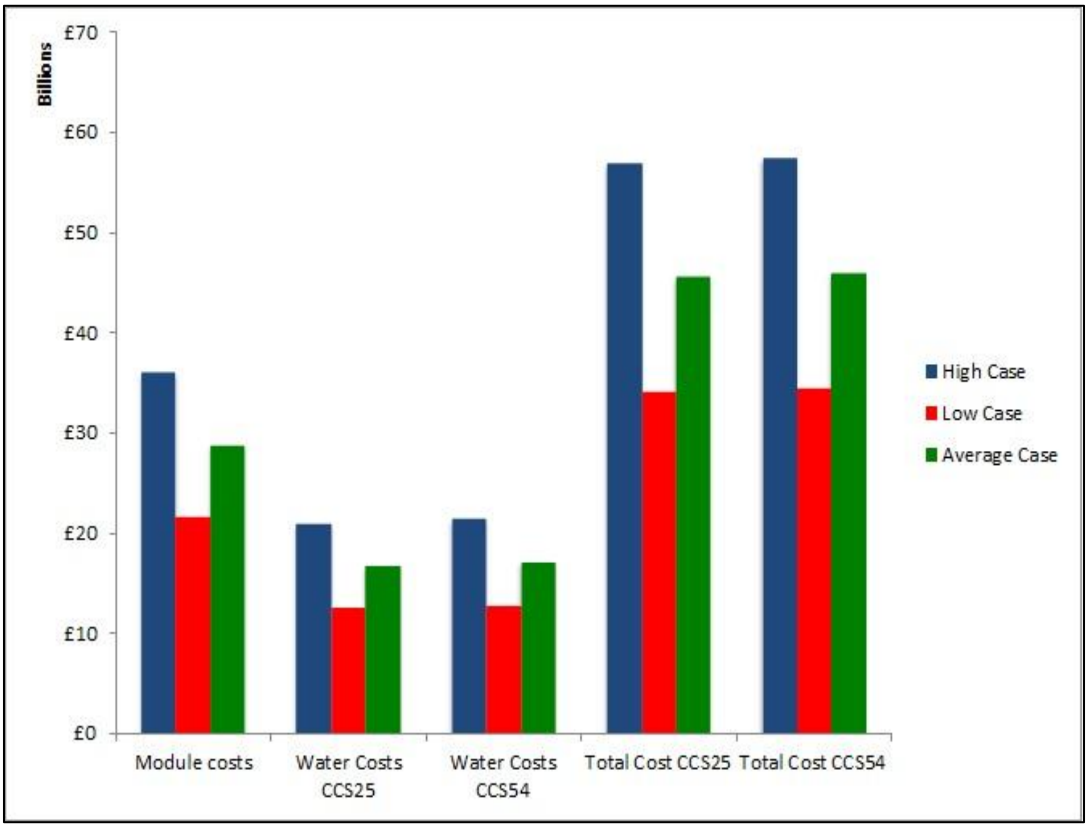

Figure 50: Net costs associated with modular lunar settlement transportation

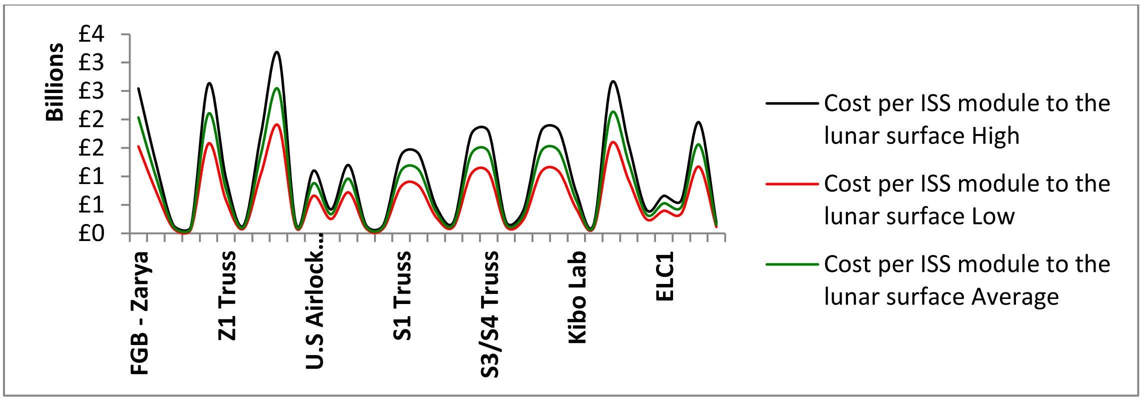

Figure 51: Cost per ISS module to Lunar Surface

Costs associated with CCS24 and CCS54 assume that the structure has not been modified. Using the basic inflatable design the costs to land either structure on the lunar surface range between $158-$341 million per unit. Total transport costs range between $1.47-$3.1 billion. The cost estimations shown above do not include costs for crew transportation, a crew habitat module, transfer vehicle or a lunar lander. They have been derived to illustrate how off-the-shelf technologies could be adapted to work on the lunar surface at a fraction of current development costs. Furthermore as the technologies associated with the VML system mature and our ability to tap in to alternative fuel sources increases the overall cost associated with constructing a lunar settlement would reduce. Given the proposal for the VML system and the adaptability of concrete based cloth, one could even construct a VML system on the lunar surface which could potentially look similar to lunar mass driver concept as illustrated by an artist's rendition in figure 52.

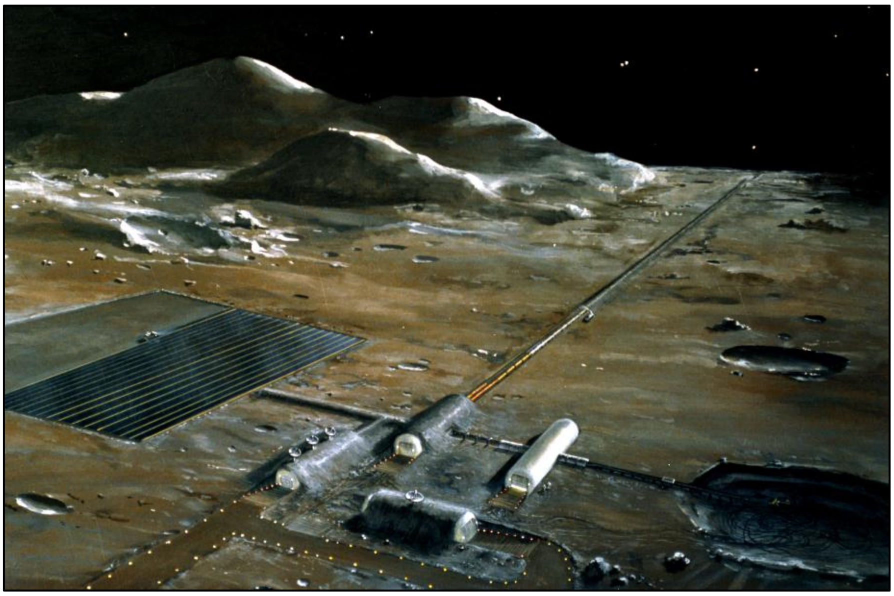

Figure 52: A painting of a lunar Supply base (NASA-S78-23252)

3.0.7 Chapter conclusion

This chapter has proposed the use of Maglev technology within the confines of a purpose built tunnel kept in a state of vacuum, to provide initial acceleration to a horizontal launch vehicle. It highlights the importance of this technique, the viability of the technology and the potential for this system to be developed in the near future. By proposing an international development effort we have considered setting up such a system in Tanzania and have discussed the socio-economic merits of the system and its launch location. The final section of the chapter provides a few scenarios that could justify the development of the proposed system.

Chapter 4: Cost Estimation – process and requirements

Chapter Summary

This chapter discusses the challenges faced in considering the overall cost associated with a space program, and the complexities around costing a human rated mission. We consider the role of the cost estimation process and the intricacies involved in deriving an accurate work breakdown structure, one that would for the backbone for all future costs. After looking at mission risk methodologies we consider two distinct cost scenarios and discuss the merits of each. Later sections of this chapter provide a bare bone cost estimate of the VML system based on an analogy costing method and describe how one could finance such a project and recover associated costs by entering niche markets.

4.0.1 Costing a human spaceflight program

In 2004, the then president of the United States George Bush Jr. announced a bold new vision for NASA. He proposed that NASA focus its energies and workforce on developing technologies that would allow humans to return to the moon and venture to Mars. When announced, the new human spaceflight program was received with mixed reviews. Whilst a large part of the scientific community was pleased with the mission directives and the chance of being able to send humans back to develop a lunar base, there were those who argued that the new directives of the human spaceflight program were an attempt to rekindle the magic of the Apollo era.

With NASA budgeted to devote over $99 billion in the U.S human spaceflight program over the next 10 years, the magnitude of planned expenditures and the status of the current human spaceflight program were called into question. The White House Office of Science and Technology Policy called for an independent review of NASA's present and planned efforts. The committee established to conduct the review comprised of ten members with diverse professional backgrounds, including scientists, engineers, astronauts, educators, and executives of established aerospace firms, former presidential appointees and a retired Air Force general. The committee was charged with conducting an independent review of the current program and suggest alternatives to the program, rather than making specific recommendations [82].

In September 2009, the independent review committee presented its findings to the current U.S administration. It noted that NASA's budget should match its mission and goals[5]. NASA's current human spaceflight activities are on a tipping point, primarily due to a mismatch of goals and resources. Either additional funding needs to be made available or a far more modest program involving little or no exploration needs to be adopted. Furthermore, NASA should be given the ability to shape its organization and infrastructure accordingly, while maintaining facilities deemed to be of national importance [82].

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[5] GAO report noted that efforts to establish a sound business case for Constellation's Ares I and Orion projects are complicated by (i) aggressive schedule (ii) significant technical and design challenges, (iii) funding issues & cost increases, and (iv) an evolving acquisition strategy that continues to change Orion project requirements. It also mentioned that NASA's previous attempts to build new transportation systems had failed in part because they were focused on advancing technologies and designs without resources to adequately support those efforts [129].

As part of the fiscal budget for 2011 the U.S administration proposed the cancellation of the Constellation program. The administration agreed with the observations of the human spaceflight review and noted that the Constellation program was already behind schedule and could not achieve its goals without multi-billion dollar budget increases, furthermore, it was not clearly aimed at meeting the nation's priorities. In April 2009, the congressional budget office estimated that NASA would require an added $2.5 billion per year to maintain the current schedule, and even then the International Space Station that is scheduled for completion in 2010, would need to be abandoned in 2016 to free up funding for the Constellation Program [83]. The U.S administration also agreed with the review committee's suggestion that commercial services to launch astronauts into space could potentially arrive much before the projected Constellation deadline and could prove to be less expensive than government owned rockets.

The President's budget proposal suggested that NASA initiate several new programs to transform the state of the art in space technologies, including flagship exploration technology development and demonstration programs, invest in early-stage advanced concepts, and new propulsion technologies – all intended to increase the reach and reduce the costs of future human exploration as well as other NASA, government and commercial space activities. It further suggests that NASA must forge partnerships with the aerospace industry in a fundamentally new way, making commercially provided services the primary mode of astronaut transportation to the International Space Station.

For NASA, in terms of financial impact this means that after spending over $9 billion on the Constellation program since 2005, it would have to spend an extra $2.5 billion in contract termination liability and closedown costs over the next two years. It also means that after the space shuttle's retirement at the end of 2010, the U.S would no longer have human spaceflight capability until a commercial option becomes available. Whilst numerous government officials have asked for the life of the Space Shuttle to be extended, NASA has been quick to point out that extending the life would require an extra $2.5 billion per year and would only be feasible if contractors were able to jumpstart production for its external tanks. As such, up till 2014 NASA will rely on Russian Soyuz rockets to transport its astronauts to the International Space Station and has signed an agreement worth $335 million with the Russian Federal Space Agency to that effect [84].

4.0.2 Challenges associated with costing a new human exploration mission

With the cancellation of the Constellation program and NASA's new directive of looking at the commercial market for a launch system the only way to cost a future human exploration mission is by looking at the past. However, whilst the Apollo program can be used as a benchmark, it should be noted that its inception was more of a political decision than a technological one. As such, at the height of the program it constituted 70% of NASA's budget allocation.

Theoretically it should be easy to conduct a costing exercise for a new launch vehicle that would be used as a workhorse for future exploration missions, however in reality it is a rather complex and daunting task. This is primarily because the market for elements associated with such missions is not the same as the commercial market for most goods. It does not respond predictably to price changes since resources are not allocated to supply and demand conditions.

Before conducting a cost estimation exercise it is important to remember the following key principles with regards to launch vehicle development:

- There are a limited number of companies capable of designing and developing launch vehicles. These companies rely heavily on government backed funding to conduct initial research and development.
- The end users for launch vehicles are mainly national governments, who usually subsidise the development of such vehicles
- The price tag of the launch vehicle does not always represent the true cost to the government (i.e. infrastructure costs, internal R&D and support function costs are not usually included in the price tag)
- Launch cost is not the final cost. Other associated costs include reliability assurance, risk assurance, on-time guarantees, insurance etc.
- Launch vehicle development is specific to mission requirements. One size fits all policy does not apply to launch vehicle development.
- The structure of the industry allows many companies to bundle products and services, which make it harder to separate launch costs from overall costs.

In order to create our own cost estimate for future lunar exploration, we shall base our preliminary estimate on data obtained from the Apollo Program. Calculations based on this data enable us to determine if future missions are financially feasible and also help to identify areas that require further attention.

To understand the costs associated with the Apollo program, we must first start by converting those costs with respect to the relative value of the US dollar. For the purpose of our calculation, we shall convert all costs associated with the program between 1962 and 1973 into relative US dollar values for 2009. Cost conversion will was achieved using the following three methods:

a) Consumer Price Index (CPI) – CPI is a measure of the average change over time in the prices paid by urban consumers for a market basket of consumer goods and services.
b) GDP Deflator – measures the changes in the overall level of prices for goods and services that make up GDP. It is simply the ratio of nominal to real GDP times 100.
c) NASA New Start Inflation Index (NSII) – NSII represents an index maintained by NASA cost analysis division, which is derived using a weighted average of commercially available inflation indices that represent the market basket of goods and services that NASA purchases. It is meant to reflect price changes for the composite group of contractors, vendors and suppliers with whom NASA deals[6].

Figure 53 shows the original overall budget request and budget appropriations for NASA and the Apollo program between 1962 and 1973. During the Apollo years NASA's overall budget request was $41.2 billion, whilst funding request for the Apollo program was $19.7 billion. To obtain costs in FY09 relative dollar values, we must first calculate the cost of $1 for each year of the Apollo program using the above methods; these values are denoted in fig 54.

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[6] The NASA NSII can be obtained from NASA Cost Analysis Division (CAD), which falls under the Office of Program Analysis & Evaluation (PA&E). The CAD is also referred to as Code BC.

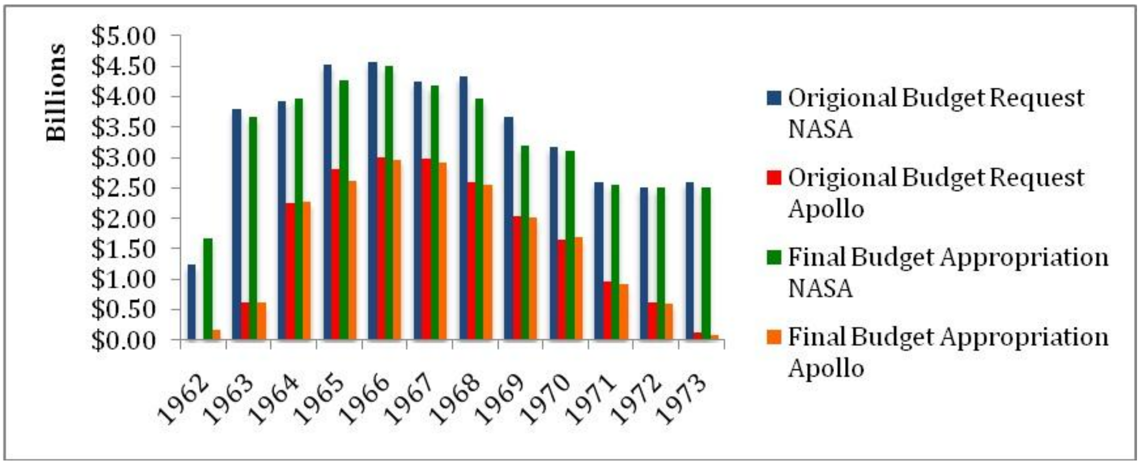

Figure 53: NASA and Apollo Program Budget requests and final appropriations

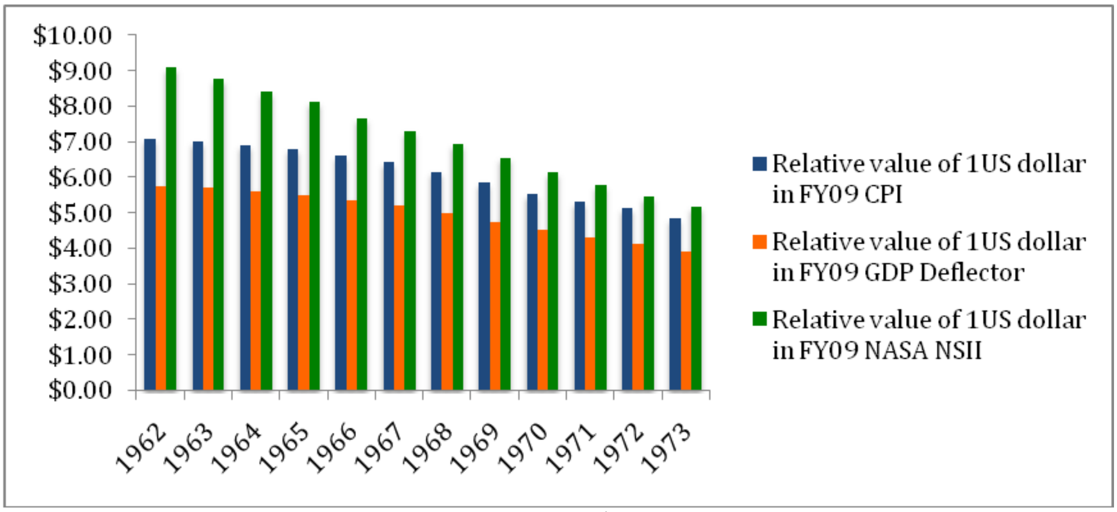

Figure 54: Corrected value of $1 to relative FY09 value

By adjusting NASA and Apollo budget appropriations to FY09 values, we notice that NASA's budget in FY09 dollar terms would range from $202-$289 billion, whilst budget allocated to the Apollo program would range from $99-$141 billion as shown in table 13. As illustrated by fig 55, at the height of the Apollo program 70% of NASA's overall budget was allocated to space exploration, whilst during its life span the Apollo program received an average of 49% of NASA's overall budget.

Budget Analysis	**Total**
NASA budget request FY62-73	$ 41,188,576,000
NASA Budget Appropriation FY62-FY73	$ 40,128,207,000
NASA Budget FY62-73 corrected to FY09 (CPI)	$ 249,596,514,330
NASA Budget FY62-73 corrected to FY09 (GDP Defactor)	$ 202,425,448,380
NASA Budget FY62-73 corrected to FY09 (NASA NSII)	$ 289,579,112,082
Apollo Budget Request FY62-73	$ 19,674,449,000
Apollo Budget Appropriation FY62-FY73	$ 19,406,784,000
Apollo Budget FY62-73 corrected to FY09 (CPI)	$ 122,476,701,110
Apollo Budget FY62-73 corrected to FY09 (GDP Deflator)	$ 99,347,816,960
Apollo Budget FY62-73 corrected to FY09 (NASA NSII)	$ 141,556,209,542

Table 13: NASA and Apollo program budgets corrected to FY09 dollar values

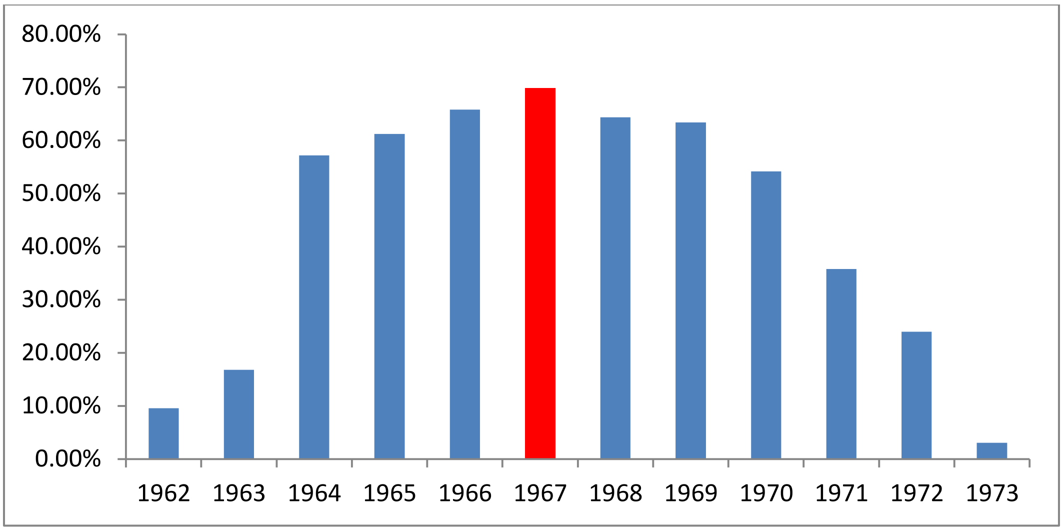

Figure 55: Apollo Program as a percentage of overall NASA appropriations

By using the dollar adjustments from fig 54 we can derive the costs for NASA appropriations between 1962 and 1973 when adjusted to 2009 relative dollar values. It also allows us to look at the cost of the Apollo program if it were to be initiated today. Figure 56 shows NASA's budget appropriations during the Apollo era, whilst fig 57 shows the NASA's total appropriation towards the Apollo program

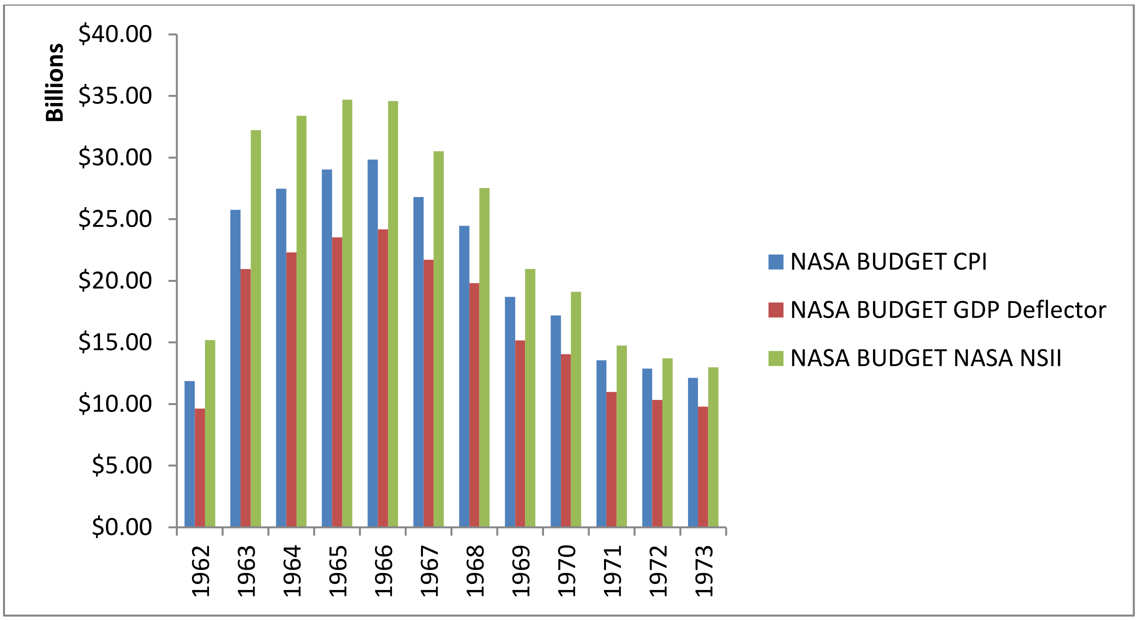

Figure 56: NASA budget adjusted to relative FY09 dollar values

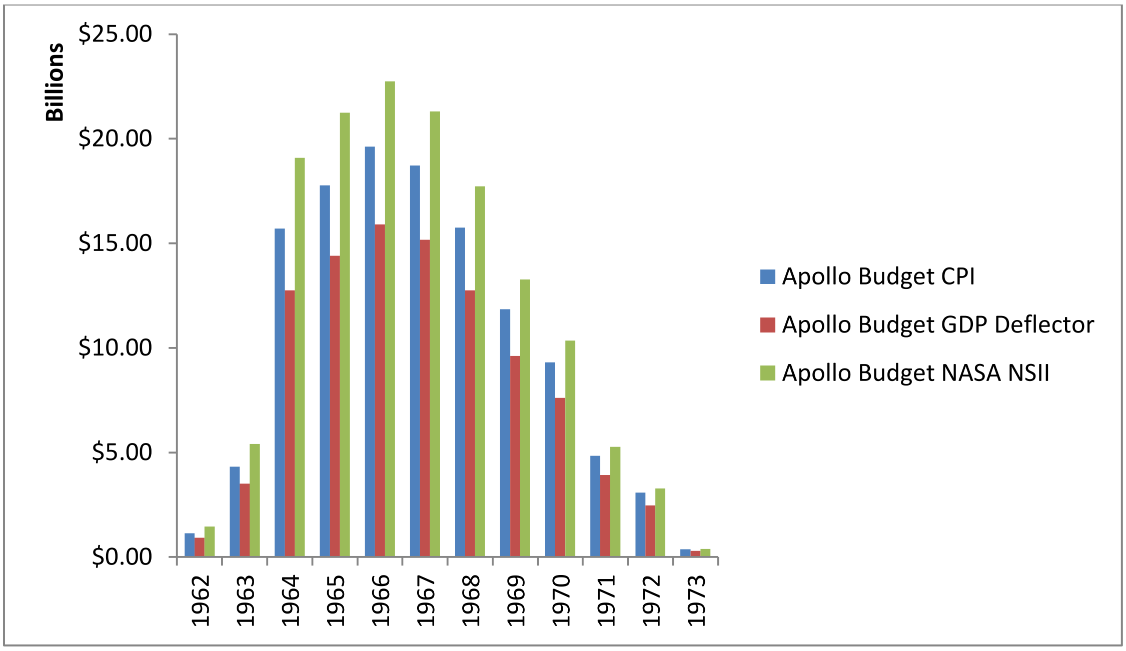

Figure 57: Apollo program budget adjusted to FY09 dollar values

The primary issue with initiating a human spaceflight program is always affordability. Figure 58 and 59 put into perspective NASA's budget trend over time in absolute terms and in relationship to the GDP and federal budget respectively. Going by the numbers obtained from the Apollo program, NASA would have to spend a minimum of 53% of its overall budget on space exploration if it seriously wants to consider going back to the lunar surface.

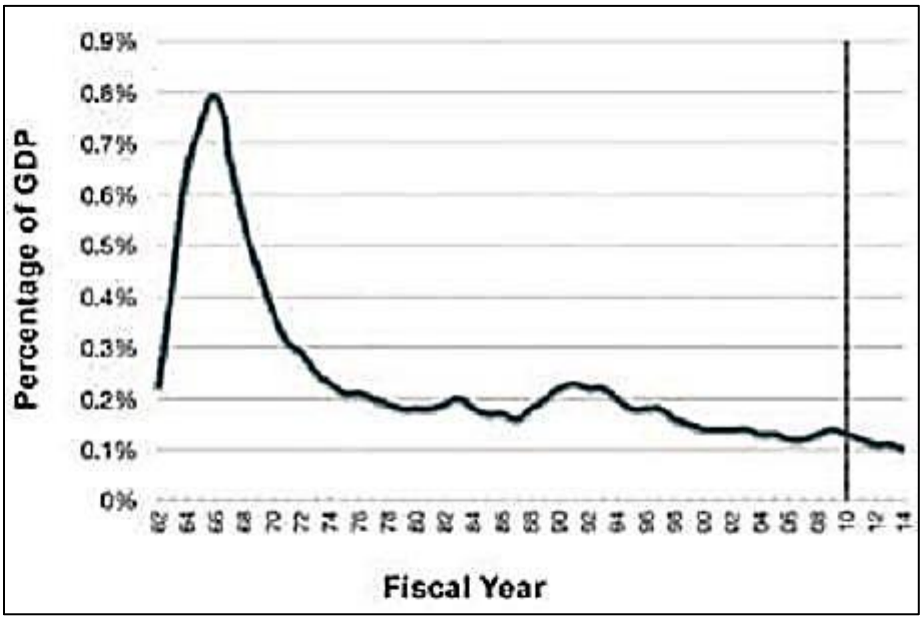

Figure 58: NASA budget drops consistently when compared to US GDP

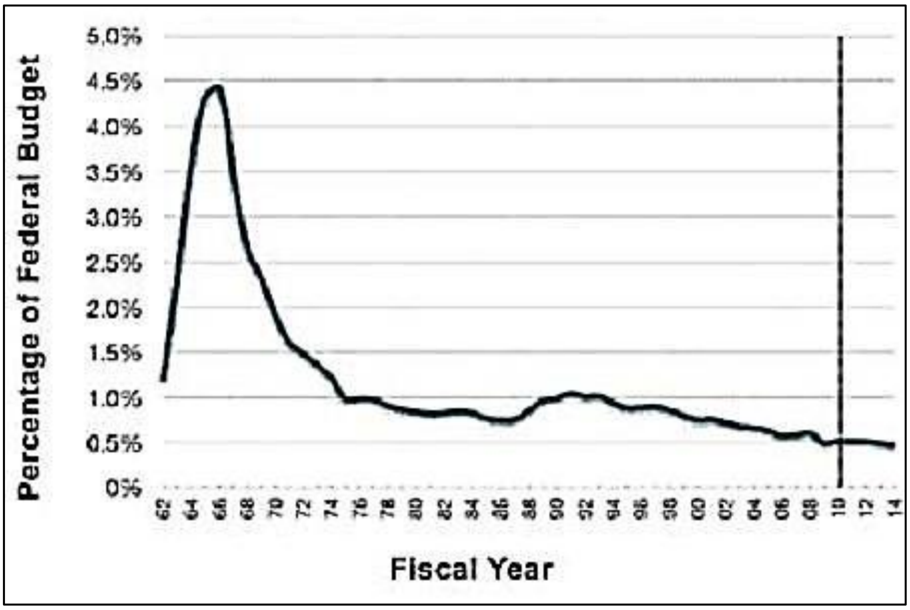

Figure 59: NASA budget as a fraction of the US Federal Budget

Before the Constellation program was cancelled, NASA projected a steady rise in its annual budgets up to FY2013 in terms of real year dollars as shown in fig 60 and fig 61. This was primarily because it was assumed that once the shuttle retired, the STS programs annual budget which averages $3 billion per year would transition to the constellation program allowing NASA to devote up to 56% of its annual budget to the Constellation programs final stages. NASA estimated that the cost of developing and deploying the Constellation program by 2020, including a 15% reserve would amount to just under $97 billion. If the program was to be extended to 2030 however, its LCC was estimated at $220 billion.

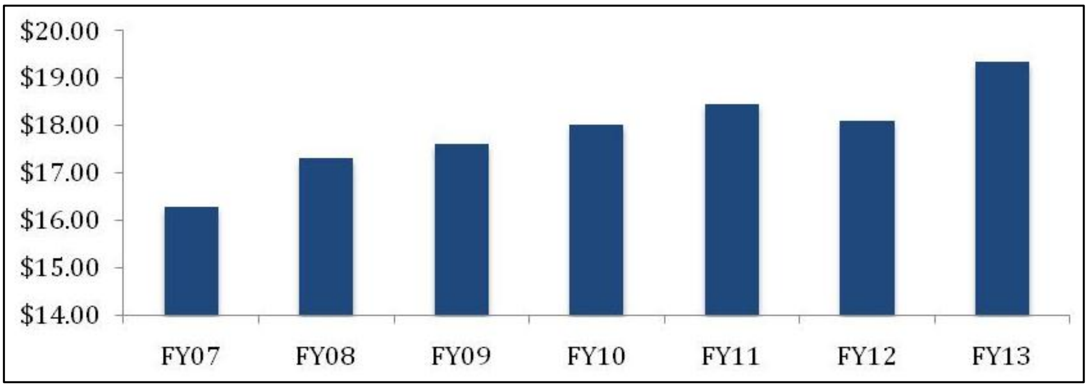

Figure 60: NASA budget authority FY07-FY13 ($ Billions)

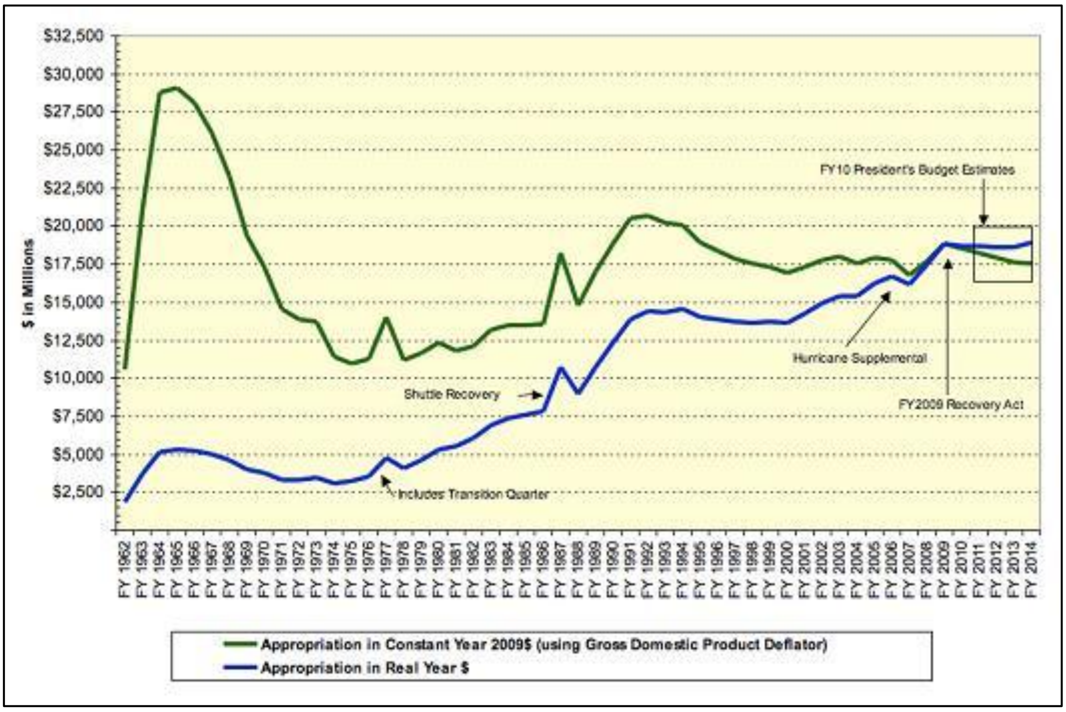

Figure 61: NASA appropriation history in real year and constant year 2009 dollars

Although this estimate is relatively close to that of the Apollo program in FY09 dollar values, it should be noted that NASA has already fallen behind schedule and its decision to redesign components for a HLV rather than adapt current methods has pushed this schedule even further. Whilst many argue that NASA's budget requests for the coming years would be enough to sustain Constellation, the human spaceflight review committee noted that NASA would not only be focussing on developing an out-dated technology but would also require a large capital injection if it aimed to finish the project in time.

Based on the committees review, it was proposed in January 2010 that the constellation program is cancelled, and that NASA find a new direction by investing in the commercial space sector. This decision also gave NASA a $500 million stimulus package that it could use to invest in technology being developed by commercial space companies like Orbital and SpaceX, and a further $6 billion that would be invested over the next five years to update and renovate NASA centres across the U.S with the hope that NASA would soon be able to compete with other space ports for commercial vehicle launches to generate an extra revenue stream.

With the cancellation of the Constellation program, NASA would effectively have no human space flight program after the space shuttle's retirement at the end of 2010. Even if congress agreed to allocate funds to extend the life of the STS program, NASA's plan for a manned lunar mission would still be grounded until a commercial HLV capable of transporting humans was developed and tested. From a costing perspective, as NASA begins to rely heavily on commercially available transport systems, it would act as an end user. As such costs associated with commercial HLV's sold to NASA would not reflect the true cost to the agency, as many research projects would have received financial aid through NASA's stimulus package. Furthermore, stringent ITAR regulations would restrict the agency's trade to companies and research organizations based within the US, for which NASA would be forced to pay a premium. With the current funding crisis and NASA's human spaceflight programs future in question, there exists a real possibility that three out of the four BRIC nations may land a man on the moon before the United States. As such from a costing point of view, it becomes even harder to generate financial models, as there is no associated data available. Whilst we can make assumptions and estimate based on data available from the Apollo program, it should be noted that when the Apollo program was initiated NASA had only 14 minutes of spaceflight experience. As such, it spent as much on developing ground facilities, training staff, flight tests and instrumentation as it did on developing spacecraft, rockets and boosters. A lot of the costs associated with Apollo would not form part of current financial models, as ground support infrastructure and real estate already exist and would not need to be developed. Furthermore, as various costs within the system are interlinked or clubbed together, it is extremely difficult to obtain precise data.

4.0.3 The Role of Cost Estimation

Cost estimation is based on both engineering and economics. The cost analyst must be familiar with the physical and operational characteristics of the proposed program at an engineering level of detail so that the likely costs can be estimated using standard techniques such as analogy or parametric estimation. The analyst needs to work intensively with the most knowledgeable people that will be directly involved in the project, that understand the various concepts, the physical nature and the operational properties that enable the analysis of the program's likely costs and risks; and then synthesize an accurate cost estimate from all the diverse data. Cost estimation is concerned with deriving the likely costs of a specific future activity. The intent is to derive a realistic cost estimate so that the relative merits of the proposal may be judged against its cost. In the early development phase of a project there are various unknowns.

In order to cost a program we must ask insightful questions which help make decisions regarding key aspects not normally considered in the early stage, addressing issues such as manpower, schedule, technologies and cost drivers that have major impact on the project. Gathering relevant data is more important in the later stages of the project, when more is known. The most difficult issue is uncertainty. Since new investments are unique and have no exact historical antecedents, there can be substantial uncertainty associated with predicting the actual likely costs. In order to reach a realistic projection, we need to understand and apply these uncertainties and risks to derive probabilistic measures of cost outcomes. Furthermore, a project can have numerous goals and objectives, depending on its size, structure and complexity, but they all intersect when making decisions. This intersection often requires trade-offs between competing objectives and goals. As shown by figure 62, the specific trade-offs may vary from project to project, but they always return to the concept of the triple constraint – technical requirements, schedule and cost. By following an integrated, process-centred and disciplined approach to life-cycle management we ensure that we are able to improve cost and risk performance.

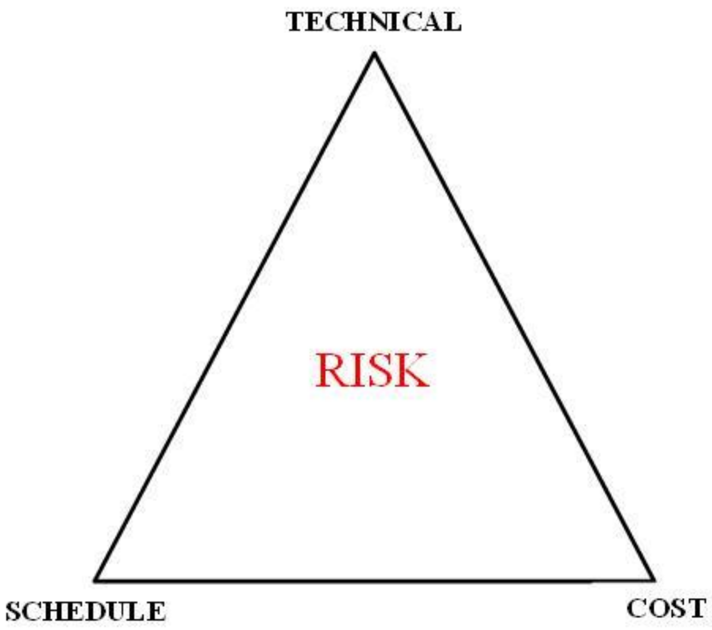

Figure 62: Triple constraint principal

4.0.3.a Project Definition

The first part of cost estimation is the project definition. At this stage, as an estimator, we clarify the reason behind the estimate, define expectations and begin to understand the project that needs to be estimated. As we begin to understand the project and start gathering data we establish a work breakdown structure (WBS). The objective of defining a WBS is to provide a consistent structure that includes all elements of the project that the cost estimate will cover. We must determine the initial need and the desired outcome of the estimation process, as they are essential to starting the estimate on a solid foundation. There are three tasks associated with the cost estimation process that help establish the project definition.

- ***Receive and understand the project*** – the goal of this task is to interface sufficiently with the customer to gather enough project information to generate an accurate estimate. In order to understand the project we must review all relevant project data and discuss the schedule, expectations and resource requirements. It is also important to evaluate the project's mission needs, objectives and goals and assess the operating environment.

- ***Build/Obtain WBS*** – the objective of this task is to provide a consistent structure that includes all the elements of the project that the estimate will cover. In order to obtaining a WBS we must consider the following:

  i. Determine if a WBS exists or work towards creating one

  ii. Create a WBS dictionary that defines all WBS elements

  iii. Ensure that the WBS is consistent throughout

  A detailed WBS ensures that all work performed on the project is organized and aligned in accordance with the scope of the program using a hierarchical structure. This structure acts as our framework for ensuring full coverage of the project objectives including:

  i. Project technical planning & scheduling

  ii. Cost estimation and budget formulation

  A project WBS must be comprehensive and include all life cycle phases, recurring and non-recurring costs and items including the hardware for the project and other items such as training, systems engineering, integration, systems test and project management.

- ***Develop Project Description*** – the objective of this task is to establish a common baseline that describes the project, which can be used by both internal and external teams to develop an estimate.

4.0.3.b Cost Methodology

The second stage of cost estimation is the costing methodology. This stage includes developing ground rules and assumptions for the project life cycle, which may change during the course of the estimation procedure. As we select an estimation methodology and gather data, the ground rules and assumptions, methodologies and even the cost model may be refined. There are four tasks that create the approach and framework for the cost estimate.

- ***Develop Ground Rules & Assumptions*** – the objective of developing ground rules and assumptions is to communicate the scope, context and environment within which the estimate is being developed. In order to establish ground rules and assumptions we must establish a set of technical and schedule ground rules that define the scope of the estimate. Each project has two distinct sets of ground rules, the global set affects the entire estimate whilst the local ground rules are usually element specific.

- ***Select a cost estimation methodology*** – the aim of this task is to select the best, cost estimating methodology for the data readily available in order to develop an accurate cost estimate.

- ***Select a cost model***

- ***Gather data*** – the objective of this task is to gather as much information as possible, so that we can develop an accurate and justifiable cost estimate.

- **Estimate** - The third stage of the cost estimation process is the estimate itself. This stage has five tasks that include the conduct, presentation and maintenance of the cost model. These tasks are critical for a defendable and complete cost estimate.

4.0.3.c Cost Risk and Risk Assessment

Cost risk can be defined as risk due to economic factors such as currency value fluctuations, estimating errors and statistical uncertainty inherent in a cost estimate. A cost risk assessment is the process of identifying critical risk within a defined set of costs, schedule and technical capabilities. It is used to balance the probability of failing to achieve a particular outcome against the consequences of failing to achieve that outcome. Conducting a cost risk analysis allows us to capture uncertainty in cost methodologies, technical parameters and program factors, enabling us to develop a probabilistic cost estimate.

Historically, for most large-scale projects NASA has addressed the possible impacts of risks by adjusting the base line cost for a given project. As a rule of thumb, 10% is added to the base line cost as a risk allowance.

A cost risk analysis fundamentally consists of answering the following questions [85]:

i. What can happen?

ii. How likely is it to happen?

iii. If it does happen, what are the consequences?

Risk analysis utilizes various methods of modelling, analysis and evaluation and thus contains various types of uncertainty. In general these uncertainties may be attributable to a number of factors such as [86]:

i. Statistical nature of the data

ii. Insufficient understanding of physical and biological phenomenon

iii. Unpredictable events

For a project's cost estimate the uncertainty is based on risks encountered through the projects life cycle (i.e. from the planning phase through to development and production). When carrying out risk assessment on a project it is important to define risk drivers such as engineering & design, technology, complexity, interaction/dependencies, integration, schedule, manufacturing, etc. These risk drivers help determine the risk associated with each WBS element by assigning a level of uncertainty based on technical risk. Deriving weights for the risk driver categories and the corresponding rating scale intensity develops the risk score for a given WBS element risk scenario. By applying the Analytic Hierarchy Process [87–89] we can apply weights for both categories based on the technology readiness level (TRL), a sliding scale from 1 to 8 that defines the current state of the technology being implemented in the project we are able to associate development with a defined risk category. Table 14 provides a brief description of the various TRL's.

TRL	Definition	Risk	Std Dev (%)
8	Full functional capability	Low	<10
7	Engineering model tested in space	Low	<10
6	Prototype tested in relevant environment	Low	<10
5	Component tested in relevant environment	Moderate	10-15
4	Critical characteristic demonstrated	Moderate	15-20
3	Conceptual design tested analytically or experimentally	Moderate	20-25
2	Conceptual design formulated	High	>25
1	Basic Principles observed	High	>25

Table 14: Description of various Technology Readiness Levels

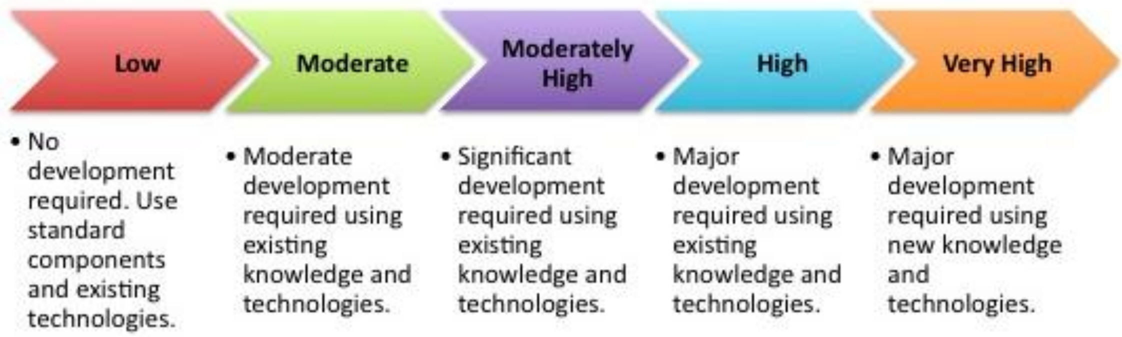

Figure 63: Basic risk assessment categories

Figure 63 explains the basic risk assessment categories that are associated with the TRL's. In order to assign a risk class we to the system as a whole and the various sub-systems we would use a 5X5 matrix like the one shown in table 15 below.

The matrix below the risk category for a particular system is classed based on multiplying the likelihood of an occurrence with the severity of the consequence the particular occurrence would cause. Table 16 explains the impact on cost caused by the severity of the consequence, whilst table 17 illustrates what is meant by the likelihood of a given occurrence.

Likely hood of occurrence						
	5 Maximum	5	10	15	20	25
	4 High	4	8	12	16	20
	3 Medium	3	6	9	12	15
	2 Low	2	4	6	8	10
	1 Minimum	1	2	3	4	5
		1 Negligible	2 Significant	3 Major	4 Critical	5 Catastrophic
	Severity of Consequence					

Table 15: 5X5 Risk Matrix

Negligible	Up to 3% utility loss	Minor impact of cost and project timeline
Significant	Up to 10% utility loss	Significant impact to cost and project timeline
Major	30% utility loss	Severe impact to cost and project timeline
Critical	60% utility loss	Critical impact on overall cost and project timeline
Catastrophic	100% utility loss	Leads to termination of project/system development

Table 16: Severity of Consequence explained

Minimum	Event will occur once in every 1000 missions
Low	Event will occur once every 100 missions
Medium	Event will occur once every 10 missions
High	Event will occur once every 3 missions
Maximum	Event will occur one or more times during the mission

Table 17: Event occurrence likelihood explained

In order to establish the life cycle cost for a new mission, we must first identify the launch vehicle and associated technologies that would enable us to achieve such an endeavour. By doing so, we establish the risk class for each mission and are able to derive an accurate WBS that would help define a project timeline.

Let us consider costing a new lunar mission, and in order to do so let us assume that since there is no current system capable of achieving lunar orbit, or delivering cargo to establish a lunar outpost, we must calculate costs based on data from previous lunar missions, and guidelines with regards to research and development of new technologies. We shall now define two distinct scenarios and select the best scenario as a cost exercise.

Scenario 1: Development of HLV based on proven Saturn V design

This case considers how we could develop on lessons learnt during the Apollo program and build on existing technology and infrastructure to establish a framework for a new lunar mission, one that either plans to land a probe on the moon or help establish a permanent lunar outpost.

To do so we initially consider a HLV that is the same as the Saturn V, with little or no modifications made to the propulsion system. By doing so, we establish the system as an existing technology with a low-moderate risk category. This means than in terms of operation and technical capability the system requires minimal reconfiguration and that system processes are based on existing technologies. By considering a system like the Saturn V, we have the added advantage of knowing that such a system could be launched using existing ground facilities and would not require added infrastructure cost. As such we can assume that ground costs for the system would be similar to the Apollo era missions. To aid in our estimation process we could also presume, that like the Apollo program the reserve level would be kept at 15% of the overall project cost.

Key issues with Scenario 1

Whilst the initial assumptions made above are valid and predictions based on such assumptions could be backed up with historical data, there are a few issues with building a HLV similar to Saturn V for any new lunar venture. Although, some may argue that such a project is based on time tested technologies and would be cheaper based on our current capabilities, let us consider the following:

a) Developing a HLV similar to Saturn V means we assume that the technical knowledge base that was present during the Apollo era still exists, and that their expertise in the field has not faded

b) Any new developments would be subject to current day safety laws, international agreements with regards to liability and recovery. Since new developments are not intended to prove superiority in the space domain unlike the Apollo program, there is an extremely high likelihood that a system design based on the Saturn V would fail today's stringent verification requirements.

c) A Saturn V based design would require new procurement routes, which would be dependent on the overall length of the lunar project. Whilst procurement issues can be resolved they would have an impact on the overall cost of the project. Since the entire system would be expendable and only capable of delivering a limited amount of cargo, it would not prove to be a viable delivery system for future projects unless we could increase the payload carrying capacity.

d) For the system to have a minimal cost increase based on initial development costs, it would need to be classed as a low or moderate risk system. The Constellation program looked at developing a similar system, however as they investigated the technologies and capabilities of the old design and made changes, the system soon jumped from a moderate risk to a very high risk system. This meant that in order for such a system to be developed it would require a major technological overhaul that relied on completely new technologies.

Scenario 1 Verdict

If we consider the costs adjustments shown in figure 57 and 58, we see three distinct costs adjusted values of which we are primarily interested in the value shown by the NASA New Start Inflation Index. NSII represents an index maintained by NASA cost analysis division, which is derived using a weighted average of commercially available inflation indices that represent the market basket of goods and services that NASA purchases. It is meant to reflect price changes for the composite group of contractors, vendors and suppliers with whom NASA deals. NASA uses future inflation projections provided by the Office of Management and Budget (OMB), rather than relying on a commercially available projection, as recent OMB projections have been relatively close to actual market values.

Looking at the cost adjustments shown, we notice that at the height of the Apollo program NASA’s annual budget was close to $35 billion, which is almost double NASA’s current annual budget. Furthermore, if we compare it to NASA’s annual appropriation in the last decade, its average budget during the Apollo era is consistently higher. Similarly, when we look at the appropriations associated with the Apollo program we notice that at its peak the program have cost just above $20 billion when adjusted to FY09 relative dollar values. Again this amount, which would have mainly used for research and development, is significantly higher than NASA’s current annual appropriation of $17.17 billion.

If we were to breakdown the Apollo program budgets to individual component costs, we notice that the largest costs associated with the project relate to the ‘command and service module’ and the development of the ‘Saturn V’ rocket. The actual costs associated with the two between 1962 and 1973 are $3.73 billion and $6.42 billion respectively. Figure 54 illustrates the breakdown of costs associated with the Apollo program between 1962 and 1973.

Considering the above, if we were to look at the development of a HLV based on the proven Saturn V design we would expect to bare a percentage of the initial development cost to set up production for the various components required, assembly lines and a procurement cycle to ensure a consistent and timely supply of future vehicles. To emphasize the cost associated with this, let us once again look at the breakdown of costs associated with the Apollo program; however this time adjusted to FY09 relative dollar values, as shown in figure 64.

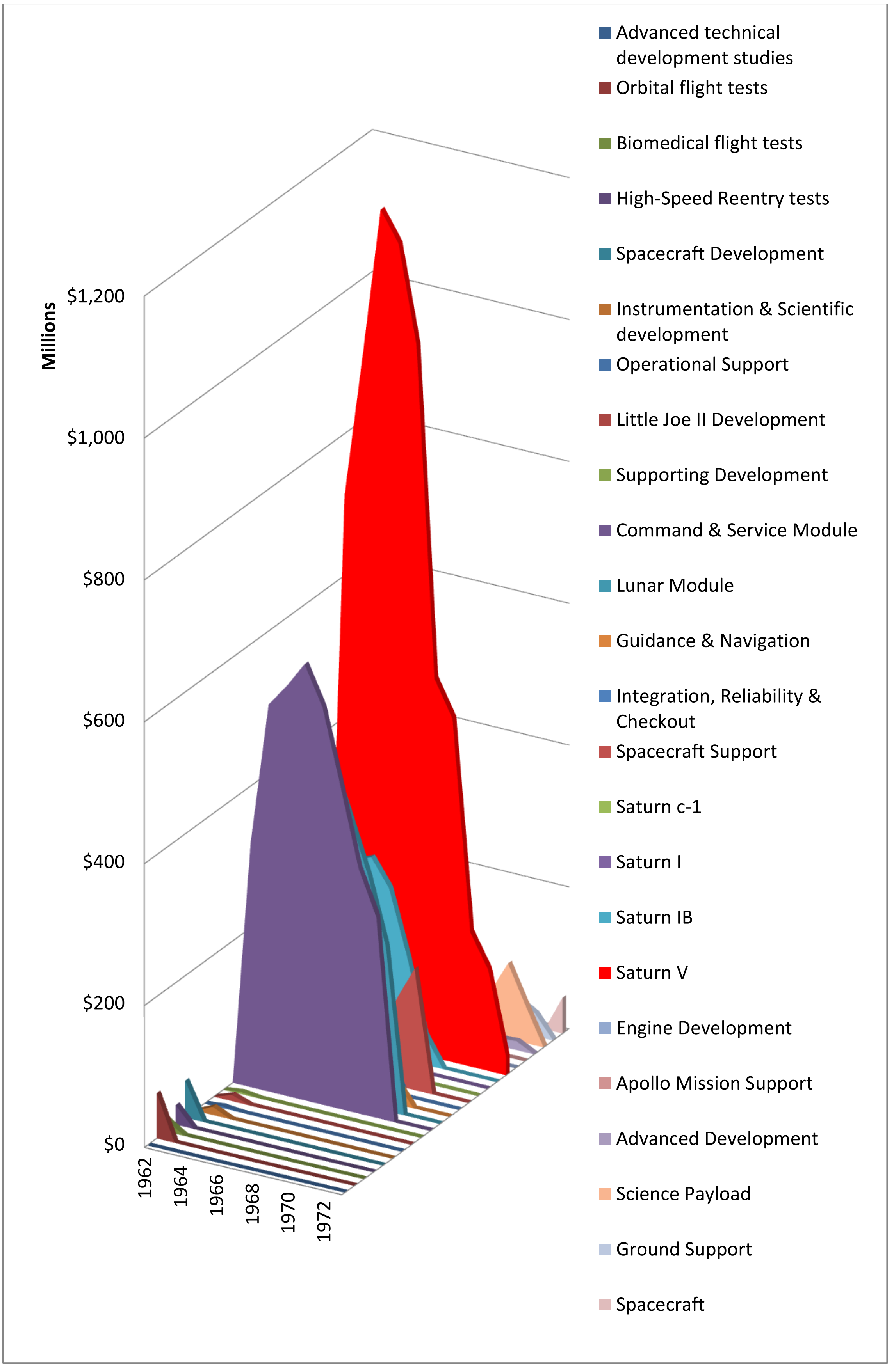

Figure 64: Apollo program cost breakdown

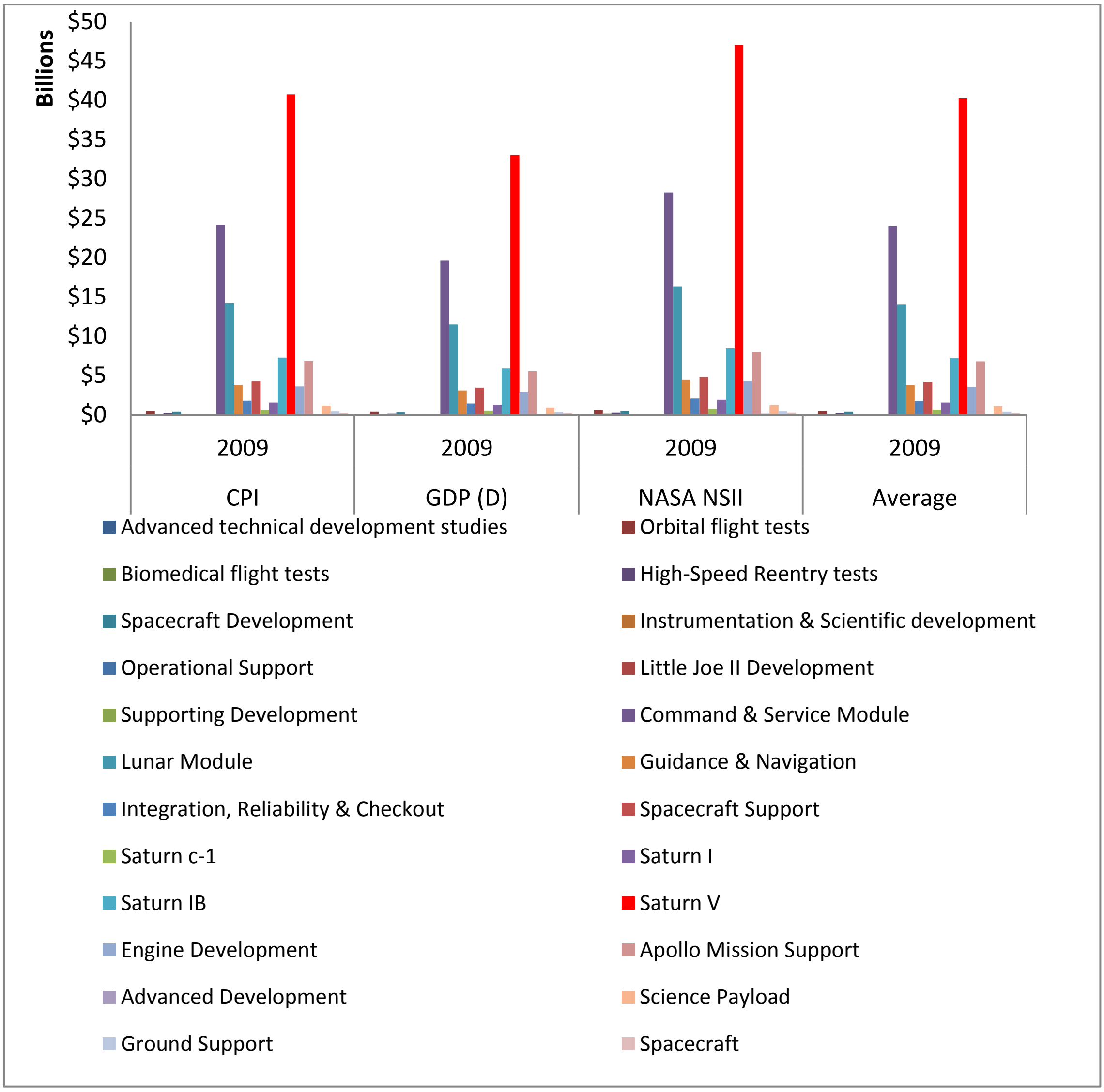

Figure 65: Apollo program individual systems cost breakdown adjusted to FY09 dollar values

As illustrated above, if we consider the NASA NSII index development of a Saturn V equivalent from scratch would cost approximately $45 billion in constant FY09 dollars, a cost that is 2.5 times NASA's current annual budget. Even if we were to consider a 10 year development and test cycle as with the original program, in constant FY09 dollar terms the average cost would amount to $4.7 billion. This average cost would account for 26% of NASA's annual appropriations without considering factors such as inflation and a decline in future appropriations made by the agency. Whilst one might argue that a funding approach based on public-private partnership could help in acquiring relevant funding, it is important to remember that since the technology and the knowledge base associated with the program is based out of the United States any future developments would be governed by ITAR and USML which would make external (international) funding virtually impossible.

Even if one was to assume that using the current ground facilities and command centres we could develop a Saturn V equivalent for $22.5 billion which is half the projected cost, we would still be looking at raising capital that dwarfs NASA's current budget authority and its projected appropriations going up to 2013 as shown in fig 66.

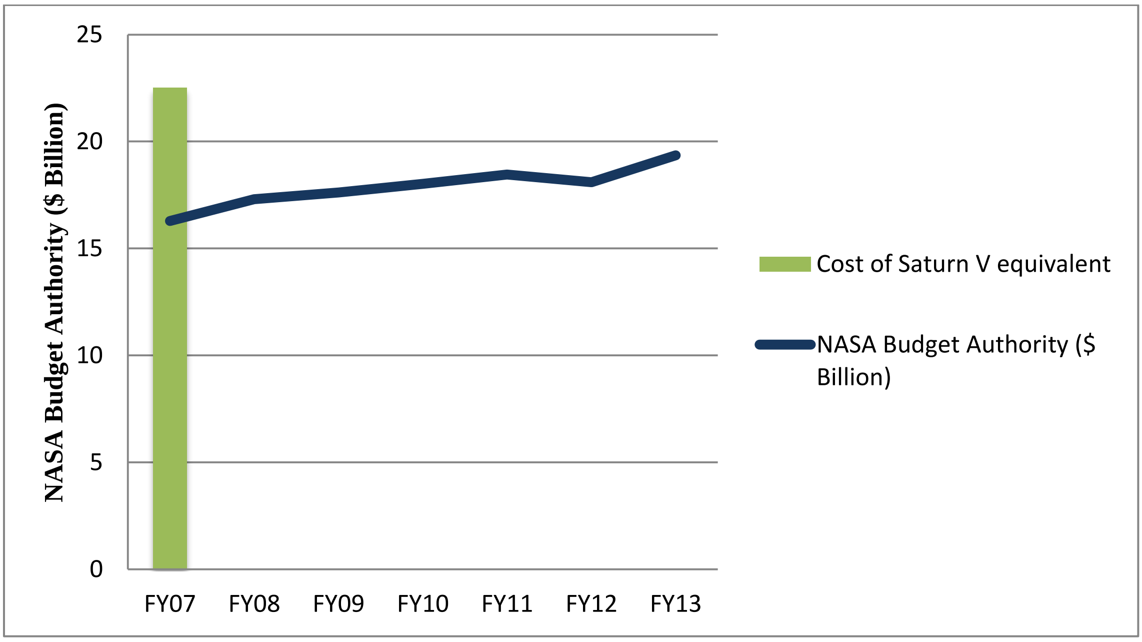

Figure 66: Cost comparison breakdown of Saturn V equivalent and NASA annual appropriation

Although our projection of $4.7 billion per year as an average development cost for a Saturn V equivalent is lower than NASA's projected costs for the 'Constellation' program, it is worth noting that our costs reflect only the base costs associated with developing a HLV capability and does not include estimates for operational support, spacecraft systems, engine development, instrumentation etc. Furthermore, when initiated the 'Constellation' program did look at building a HLV based on some of the technologies developed for the Saturn V. However, as the project progressed changes made to the initial design not only changed the overall cost risk category for the project but also rendered the project economically unviable. A presidential review carried out in 2010 suggested that the program be scrapped in part due to economic uncertainties associated with the project and the risk of it going over its projected $200 billion price tag by 2030[82].

Based on the above data and the recent cancellation of the 'Constellation' program that aimed to build on the HLV success of the Saturn V, it is safe to say that developing a launch vehicle based on dated technologies and limited support infrastructure is neither economically viable nor sustainable.

Scenario 2: Develop HLV system based on Vacuum MagLev (VML)

In this case we consider developing a HLV system based on new unproven and untested technology that is based on a vacuum magnetic levitation or VML system. By doing so we identify the technology to be in the very high risk category, thereby assuming that all components and systems required by such a design would require major development based on existing and new technologies.

By considering this as our primary option to service missions to lunar orbit and play a vital role in developing a lunar outpost, we are faced with the issue that not only does such a system not exist, but also that as it would be the first of its kind, there is no background data that could aid us in our analysis efforts. Since this system has limited similarities to the current fleet of launch vehicles, there exists no framework for comparative costing. To establish costs for such a scenario we must assume the following points:

- Technology: The system relies on new untested concepts, and would require a major development based on new and existing technologies.
- Base Costs: There are no existing base costs for a VML based system. Base costs for the system would depend on the following factors:
  1. Cost of land procurement for a VML system. This cost would vary based on region and level of government or private funding available.
  2. Cost of establishing a ground support network if current sites cannot be utilized
  3. Operational costs, including maintenance of systems and services integral to a VML system
  4. Cost associated with linear motors and power supply stations associated with the system
  5. Cost related to research, development and testing of a VML based launch vehicle and its flight certification for carrying cargo and/or a human payload.
- Project funding: A constant level of funding is maintained for a VML system. This funding could be obtained through a single source (government or private), or via multiple sources (coalition of trusted nations or a private-public partnership).

- Reserve: As most of the technologies associated with this system would be classed as new, the project reserve is set as 25% of the estimated LCC.

- Project Life Cycle: For research and development to deployment the overall project life cycle is set as 15 years.

- Life Cycle extension: Since an operational VML system would be able to provide sub-orbital and hypersonic flight capabilities apart from servicing lunar missions, it's life cycle extension (LCE) for aviation and space tourism purposes would depend on the following criteria being met. Furthermore we define the criteria for LCE Aviation and LCE Space tourism as follows:

LCE Aviation:

- VML system has proven track record for deployment and has been successfully operational for a minimum of 2 years
- Hypersonic travel must cater for a hub-to-hub market design, where flight time using conventional aircraft exceeds 8 hours.
- The system allows for a minimum of 6 hypersonic flights per vehicle per day.
- A minimum of 2 vehicles are maintained at any given time for this purpose.

LCE Space Tourism:

- VML system has proven track record for deployment and has been successfully operational for a minimum of 2 years.
- Turnaround time for each vehicle can be maintained at 24 man-hours.
- Sub-orbital flights lasting 45 minutes are priced at roughly $25000.
- A minimum of 2 vehicles are maintained at any given time for this purpose.
- Overall system costs are driven down by using the same vehicles in different configurations to deliver commercial payload to orbit.

Cost estimates for the development and testing of the launch vehicle, along with the construction of the VML chamber are based on current technologies and construction methods. Estimates for the power requirement for the VML system are based on current electricity generation methods that include, but are not limited to solar, wind and nuclear power.

Scenario 2 Verdict

As mentioned in the case definition above the scenario requires us to assume the practical background data or WBS structure that could be used as a test bed to establish costs. However, by developing an entirely new system although we assume the initial costs to be high, we are able to control costs by defining a staggered financing approach that takes into account current markets and future investment strategies. In developing a new system, we are also able to define the system from the ground up i.e. we are not limited by the payload size, turnaround time, on board fuel capacity or existing launch facilities. This essentially means we can design a system capable of delivering the maximum payload required by a single operation.

Another way of reducing overall cost is by ensuring that the system has a fully reusable launch vehicle, which can be adapted for a multitude of payloads. By doing so we embrace the opportunity of using the system as an earth based hypersonic vehicle as well as a cargo delivery system initially for low earth orbit. Its ability to adapt to a number of roles would allow the system to generate revenue that can then be used to maintain and develop future capabilities.

4.0.4 Cost Summary for HLV system based on VML

Whilst it is possible to design an ideal propulsion system and space launch vehicle, capable of carrying a multitude of payload weights and has an extended life cycle; all designs are limited by the quality of resources available, overall construction time frames and the system's climatic and economic impact. In order to lower the overall cost of a system, we must be able to reduce the cost per launch. In order to better understand the cost performance of current launches, it is vital to evaluate the current launch systems. The key comparison factor for current and future systems is the cost associated with launching 1Kg of payload into orbit. This concept is extremely fragile, since launch systems often do not have similar capabilities, characteristics or dimensions. Since this project is a new investment proposition, it is quite unique as there are no exact historical antecedents, as such there is a substantial uncertainty associated with predicting the actual LCC's. In order to provide a realistic cost analysis of the project, we have looked into various government-funding models for current space operations, costs associated with large-scale construction projects, and financial stability and future economic projections for current systems like Transrapid. This review has enabled us to draw a model timeline for the successful completion of the project. In order to obtain costs associated with the launch vehicle, the research and development costs have been mirrored to that of the space shuttle, costs associated with the guideway-housing, reflect costs of large scale tunneling projects, whilst the overall cost of the guideway is estimated based on the Transrapid Maglev design. In order to obtain costs related to the launch vehicle, all costs have been modeled based on NASA budget reports from 2003 to 2009. By doing so, we are able to ensure that we can compare costs derived for the proposed system with existing systems. Furthermore, the system fabrication is directed towards developing nations, where labor and real estate costs are comparatively cheaper than in the west, for this reason we believe that western capital can be stretched much further. In most developing nations, the average cost of labor is estimated at just over $1.5 per day[79], [90]. By providing a higher wage, and implementing incentives for staff such as health care, education and employment opportunities upon the completion of the project, it is believed that the project would attract a more determined and likeminded work force, ensuring that minimal delays are incurred. Before the proposed launch system is employed we must be able to illustrate the various infrastructure components. Within this infrastructure is the construction of a dedicated power plant, the construction of support facilities, guideway housing and guideway. The labour dynamics for the power plant is estimated within the budget request for the station included in the materials and equipment forecast. The budget for facilities is also estimated with the launch system development. For the construction of the chamber and guideway, the personnel needed are calculated as a separate factor in the chamber budget request. From investigation of other large scale construction projects, we can estimate over a 1000 people would be employed and would be deployed in project specific groups. By doing so, the project not only injects foreign currency and revenue into the local economy but it also tackles issues such as local unemployment rates, housing, education and skills specific training, thereby leading to the overall development of the community. As the cost of living and average wages in most developing nations are much lower than the west, we can afford to offer a higher than average wage without compromising the financial stability of the project. To highlight the economic impact of such a project, we can use data collected as part of the Space Shuttle Program (SSP) as a benchmark. In FY 2006, the SSP put nearly $74.3 million (including civil service and prime contractor salaries and non-payroll procurements) into the regional economy. Those expenditures translated into additional economic output, jobs, and income in supporting industries [91].

Our initial budget request is estimated at $20 billion spread over a 3 year period, which is just over NASA's current annual budget request of $17.71 billion [92]. This amount includes the total cost of manufacturing the launch vehicle, development costs associated with each mission, and costs associated with payload launch for a total of 25 missions. The initial budget request can be broken down into five primary areas:

a) *Launch Vehicle Budget* (LVB) – the initial LVB request is for $994 million and includes the design, development and manufacturing of the launch vehicle, launch control and monitoring systems and the flight management systems. The initial cost for development of the vehicle is estimated at $500 million, a figure close to the development cost of the Shuttle. Each subsequent vehicle's development cost is estimated at $370 million. The costs associated with test flights and airworthiness are estimated at $30 million per test, with each vehicle going through a cycle of four qualifying tests thereby making the total cost $120 million. Our initial request allocates a total of $480 million, as we envisage a fleet of four launch vehicles by the end of year 3. In order to ensure the overall success of each mission, simulator training and emergency procedure rehearsals are performed prior to each mission, along with test flights to ensure the functionality of the various control systems. This procedure with the necessary upgrades that may be needed for controlling and monitoring of a mission is defined as the Checkout and Launch Control System. This is estimated to be around $2 million for each mission. In every mission a performance monitoring system is employed, ensuring the best possible performance of the launch vehicle and external control mechanisms. The monitoring system relies on a real time communication between the launch vehicle and the control center, and would be employed to automatically address system anomalies. Whilst the cost of the monitoring system would be mission and flight specific, we estimate the cost at $855 thousand per mission. The final procedure of development is the flight management control system, which constantly monitors and adjusts the trajectory and flight dynamics of the launch system. The budget request for this system is estimated at $12 million.

b) *Guideway Budget Request*: The total guideway budget request is estimated at $315 million. This can be split in to $15 million for the magnetic levitation guideway which is based on TR06 design [93] and the remaining $300 million would be utilized for constructing the tunnel that would house the guideway along with the apparatus and components required to ensure that we can maintain vacuum conditions during the launch phase. This would also include the cost of sensors that would monitor temperature and pressure conditions along the entire length of the tunnel.

c) *Ground Facility Budget*: Our estimate for the ground facility budget includes the cost of labor and the training they would require, cost of land development, a dedicated runway, control tower and auxiliary buildings and hangar facilities for the launch vehicles. The overall estimate for ground facilities is $336 million, which includes $150 million for labor and training, $100 million for the control tower and auxiliary buildings and an estimated $86 million for the runway and hangar facilities.

d) *Program Integration Budget*: The Program Integration procedures assure the successful technical integration of all the craft's elements and payload into each mission to efficiently and effectively meet the customer requirements. The Program Integration budget includes funds for the analysis, management, safety, reliability, maintainability and quality assurance functions that are performed in each mission. The overall budget request is $45 million [79]. The final Procedure estimated is the flight hardware that ensures the vehicle hardware and software are designed, developed, manufactured, and tested sufficiently to enable the safe and reliable operation of the launch vehicle. Flight Hardware and software assures the success of each mission by producing space components to support each mission requirement. The software activities included in this budget include development, formulation and verification of the guidance, targeting and navigation systems software of the craft. The budget requested for this is $200 million [79]. In order to maintain a low cost system, most aspects discussed above would be pre-programmed and would be part of the launch vehicle development.

e) *Operational Surplus*: This budget request is estimated at $109 million, which includes a surplus request of $59 million and a $50 million request for overhead costs related to unforeseen delays.

It should be noted that a number of elements that form part of the budget request only apply as a one-time investment. The ground infrastructure, along with the guideway and program integration budgets are all based on elements that would require minimal capital injection once they are conceived. As such the main costs associated with the system once initial development takes place would be related to launch vehicle development, flight tests and maintenance of the tunnel and guideway systems. The balance available from the operational surplus would be reinvested as fresh capital after initial development. Figure 67 shows a breakdown of the overall budget requested.

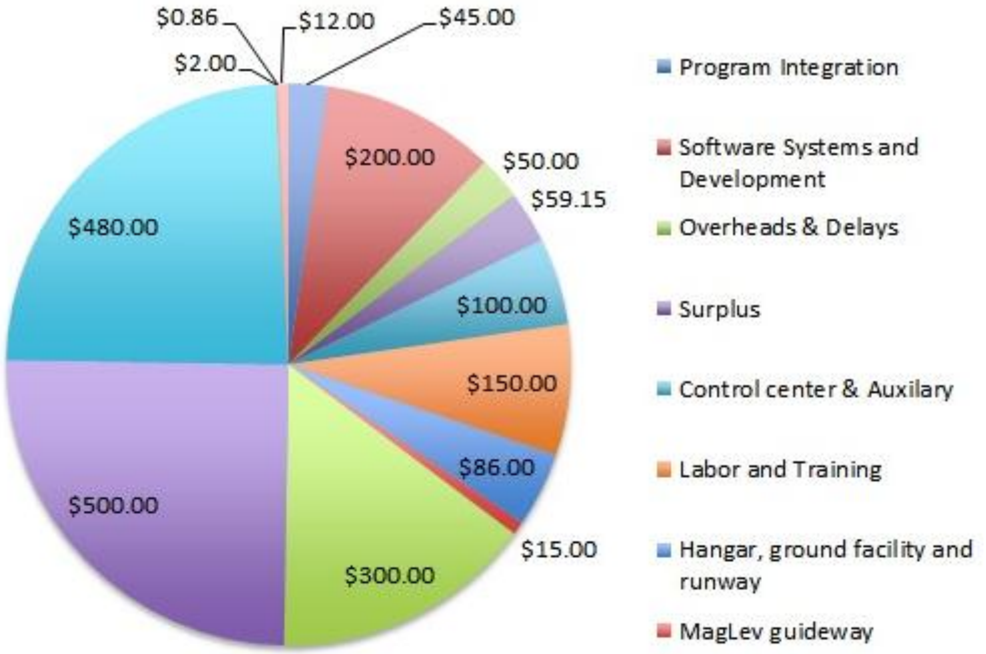

Figure 67: Breakdown of Budget Request ($ millions)

As with all initial cost estimates, the figures provided are subject to change as the system is developed. To highlight the scope of such change, let us consider the costs associated with the Space Shuttle program. When the program was in its infancy NASA projected that the cost per launch would be roughly $7 million, however based on NASA's current LCCE of $115.5 billion for the Shuttle program the cost per flight is closer to $860 million and that's without adjusting costs for inflation over the years. Another example would be NASA's Aries 1, which was being developed as part of the now cancelled constellation program. Aries 1 had an initial projected budget of $18.10 billion which would account for development between 2008 and 2020, however this figure was revised to $28 billion in 2006. This did not account for the projected flight cost of $1 billion if the Aries 1 was used only once a year [82].

Since the estimates provided are based on the research and development cycles of technologies and capabilities that exist today, we should start by assuming that the overall cost for the system would be close to or lower than current projections. This is because as new technology is developed and it enters the mass market, production costs will gradually reduce. Another important factor to consider is the investment model this system will use, which relies on both public and private investment over a period of three years, rather than banking on a single governmental source.

4.0.5 Financing & Cost Recovery

In the current economic scenario, we are witness to the largest ever-global crisis. Nations, that one seemed economically stable and immune to the growing pandemic are now trying to do everything possible to prevent a massive recession. The unemployment rates in these nations have skyrocketed and their local economies are crumbling. Countries that have already spent billions on saving banks and industries are now looking to bolster their position. Their downturn on spending will also affect the scientific community, especially space science. Going into space is not cheap, but it will take only a small proportion of world resources. Even if we were to increase the international budget 20 times to make a serious effort to go into space, it would only be a small fraction of global GDP. We exhibit a tendency to overestimate the amount of money spent on space exploration and research and underestimate amounts spent on defence and social programs. NASA has an annual budget of $16 billion (as of FY08). To put this into perspective: the United States spends just over $1.14 trillion on social programmes each year, which amounts to $3807 per person per fiscal year. In comparison the US space program costs an average of $53 per person per fiscal year [91]. One of the key issues that plagues investment in the space science sector is the high level of risk involved. Also, in order to invest in such a system, governments would have to justify the costs to congress and other ruling bodies. Private investors on the other hand would stay away from such developments, because of the wait period associated with returns, and a high probability of unseen risks. In order to gain investment and attract both governments and private bodies as prospective investors we propose a mixed-financial model known as private-public partnership (PPP) which would allow both governments and private investors to share costs and risks associated with the project. The backing governments for this project could contribute by providing low-interest loans that would be repaid over a fixed timeframe, prioritized by the level of investment. Participating government agencies could finance their investment by diverting funds earmarked for the research and development of low cost systems that would be rendered superfluous by the realization of this project. Essentially, in order to develop a low cost model for the space industry, one that may be cost neutral in the long-term, we must begin by aligning it with the civil aviation sector. This can only be achieved if we ensure that the cost of power per launch for the VML system is lower than current gas turbine fuel (ATF) prices. Figure 68 shows a representation of ATF prices over the last three years. As shown the cost of ATF or jet fuel dropped below $40 per barrel towards the end of 2008.

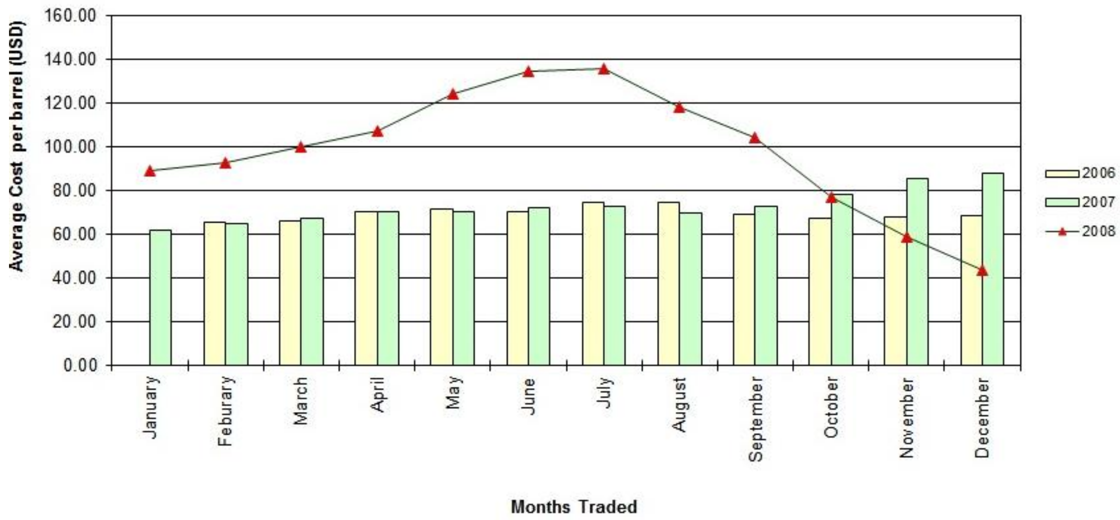

Figure 68: Crude Oil Trade Averages

Figure 69 is a graphical representation of actual world oil prices from 1980 to 2008 and speculative prices from 2008 until 2030. It represents a high/low and reference case for each year, which clearly indicates the instability in the market over the last 12 months.

It also puts into perspective the uncertainty in the years to come. Bearing that in mind, in order to make new oil exploration economically viable the average cost per barrel needs to be in the range of $70-$80 per barrel. The fourth quarter results for 2008 show average cost per barrel rapidly declining below $80 and stabilizing at an average of $43.75 in the beginning of the first quarter of 2009. This rapid decline in crude oil averages has already led to new exploration projects being shelved in Canada, USA, Mexico and Dammam. In order for us to succeed in developing a low cost propulsion system, we must not only ensure that our cost per pound to orbit is lower than current space vehicles but also that our cost per seat undercuts the aviation industry, enabling us to dominate the commercial market as well.

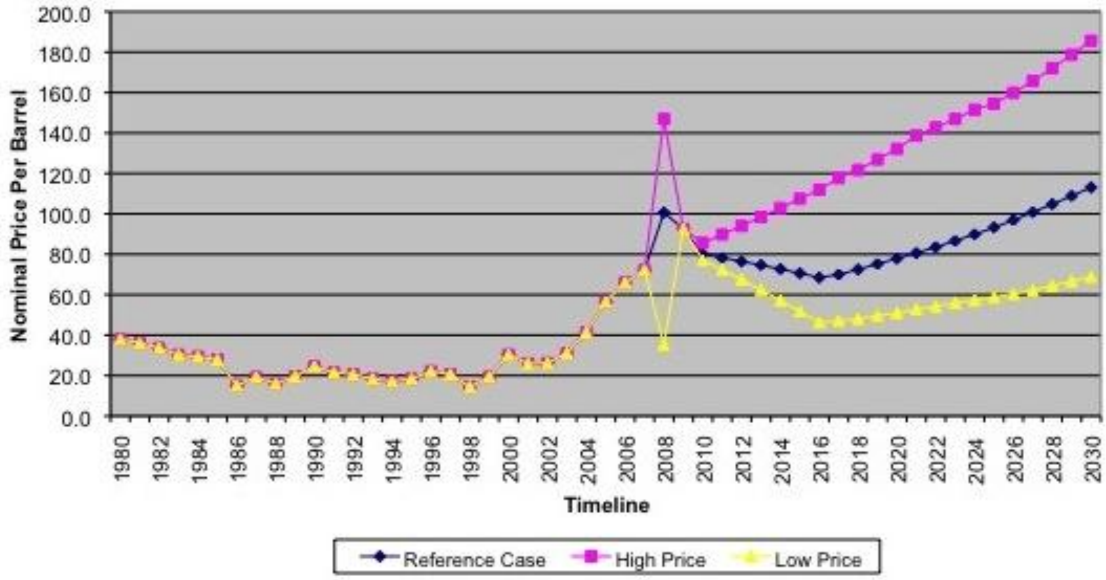

Figure 69: World Crude Oil trade actuals and predictions

In order to derive a robust cost model for the VML system based on predictions of crude oil trade we need to be able to predict the cost per barrel of crude oil for the coming months. To do so, working with Bhargav Mitra at the IIMS research lab at the University of Sussex, we have developed a statistical model using Matlab[7] that considers crude oil data from February 2006 to December 2008, based on the NYMEX[8] WTI index. This model takes into consideration regular market fluctuations and excludes data that corresponds to extremely turbulent periods. The model employs a robust outlier detection strategy that picks up data values that do not follow the pattern shown by the bulk of the data [94–96]. Such detection processes, in many cases, depend on the determination of a nominal reference value of the dataset, and a scatter estimate of the dataset[94–96]. The strategy based on Hampel Identifier advocates the use of median as the nominal reference value of the dataset, and the median absolute deviations from the median (MAD) as the scatter estimate. According to this rule, a data value ϕ in the dataset Φ would be considered as an outlier if:

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[7] Data and code for the given calculations available in appendix 2

[8] NYMEX light sweet crude oil futures contract is the world's most liquid forum for crude oil trading, as well as the world's largest-volume futures contract trading on a physical commodity, and is used as a principal international pricing benchmark.

$$|\phi - \phi_r| > \varpi \phi_{se} \qquad (2)$$

where, $\phi_r = median(\Phi)$, ϖ is some specified threshold, and ϕ_{se} the scatter estimate. Note ϕ_{se} is scaled by a multiplying factor of 1.4826; this makes the scatter estimate equal to the standard deviation of a normally distributed data[97]. Also, note that we are not using the '3σ- edit rule' since both the mean and the standard deviation is heavily influenced by outliers present in the dataset[97]. The threshold value was taken as 3, this would help in future to compare our predictions with those based on the '3σ- edit rule'. In the model, all the available NYMEX WTI index data for the period are considered. The discussed outlier detection strategy was deployed to exclude the data points that do not follow the trends shown by the majority of the data. Two separate cases are drawn; in the first the outliers are not replaced by any value (the corresponding data points excluded), and in the second the outliers are replaced by the nominal reference value of the data set as shown in fig 70 and fig 71 respectively. A linear least square fit based on the included data is then used to predict prices/barrel of crude oil for the next three years.

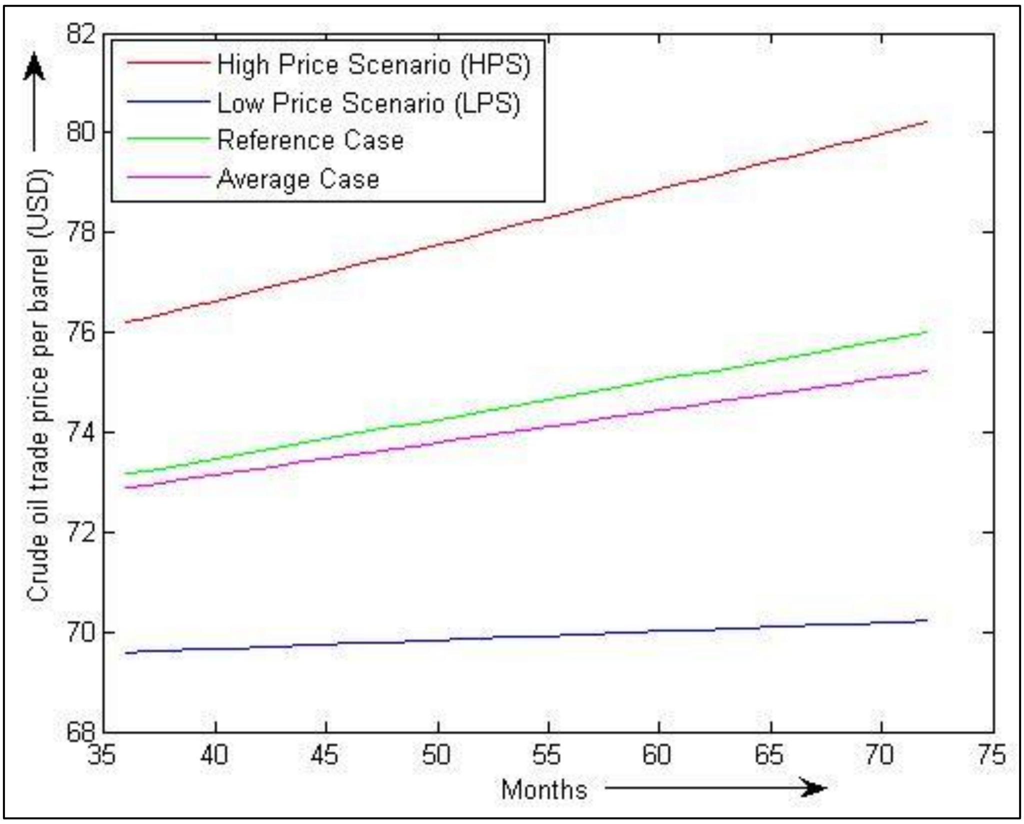

Figure 70: Crude predictions with outliers excluded

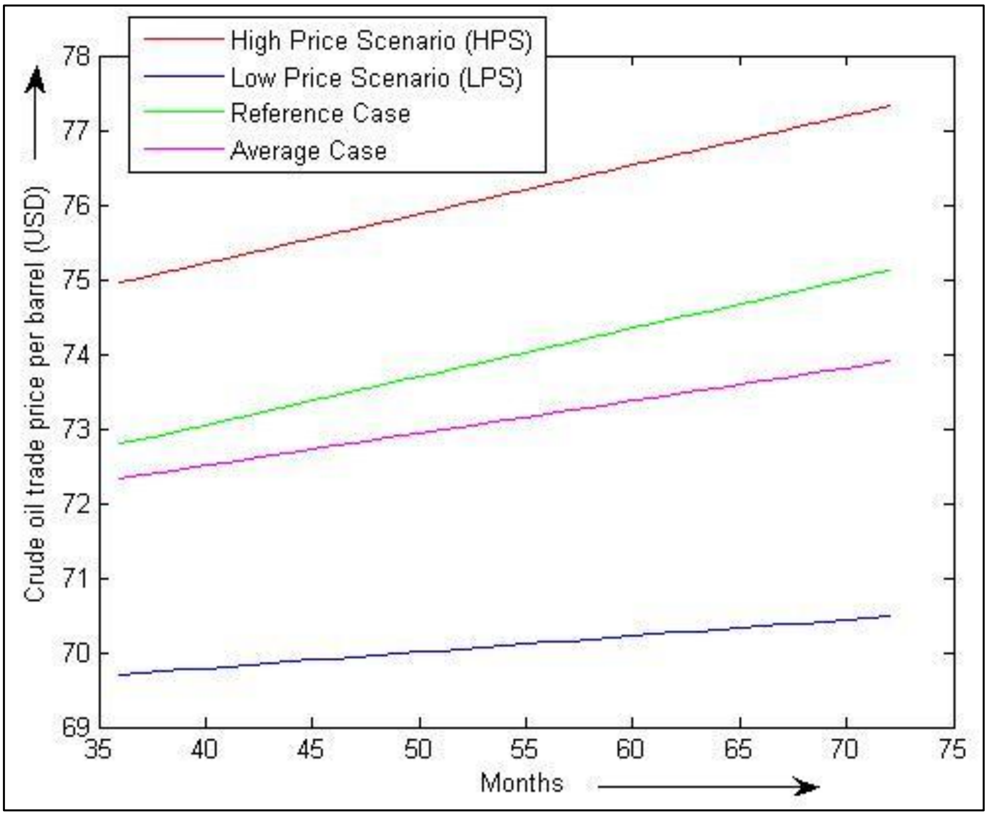

Figure 71: Crude oil prediction with outliers replaced

Note that the predictions are made based on the maximum, minimum, and average figures available on a monthly basis. Also, dividing the corresponding maximum and minimum values by two generates the lines for the average cases shown in the two figures. By applying a similar methodology to the entire work base strand, we hope to create a robust prediction mechanism that would allow us to better understand the long-term fiscal implications for the VML system. It would also enable us to develop a cost analysis mechanism that would take into account the various fluctuations in the market and predict the worst, best and reference case scenarios for the system. By doing so, we hope to achieve results close to the estimates mentioned earlier in the paper and prove theoretically that a VML system would provide a cost-effective launch solution in the future.

4.0.6 Chapter Conclusion

This chapter focuses on the complexity of cost estimation and the various elements involved in arriving at final estimates for any given program. By considering the various risk categories and the structures associated with a human rated mission we have used an analogy method to derive costs for the overall structure and associated structures. By doing so we are able to assign a fiscal value in current dollars to the project, one that acts as a base line cost for the overall project. Like with any large scale project, it is important to remember that delays in schedule, servicing, acquisition of resources and project development would cause a change in base estimates. The estimates provided in this chapter consider the project development to take place in Tanzania, however if we change the project location we must factor in the strength of the local economy, the currency value and the costs of shipping and procurement of raw materials. Based on the estimates provided in this chapter we have also considered how we could finance the project with a robust PPP model and ways of generating revenue from the project in order to provide a sustainable future revenue stream.

Chapter 5: Policy: Past, Present & Future

Chapter Summary

Space is an integral part of our daily lives, and certainly in the advanced nation's one tends to rely on space more and more to make our daily tasks more efficient. Be it using global positioning systems to find our way, hi-speed fibre optic networks to connect to resources, or using a microwave to prepare a meal, the technology behind the products and services we most depend on can be traced back to space. Whilst independent access to space may only be the purview of a handful of nations, all nations today depend on information gathering systems, be it military, meteorological or earth observation to fulfil their social, economic and military obligations.

This chapter considers why nations choose to initiate a space program, along with the drivers and barriers they face in sustaining national programs. It then discusses the importance of the United States in a time where emerging actors have a keen interest in space. The export control regime within the United States and the impact it has on local and global industry is described briefly. To conclude, this chapter proposes a global space program which would rely on a truly global policy, allowing both advanced and emerging nations to cooperate and collaborate in areas that benefit all of humankind.

5.0.1 Introduction

Almost every nation today relies on space-based technology for communications, weather forecasting, satellite navigation and resource management, either through indigenous programs or through programs run by its allies. As such, it is safe to say that every country has a vested interest in space. However, when one considers the major developments made in the space domain and advancement of technology and research in the field, one primarily focuses attention on a select group of nations that not only have successful national space programs, but also possess the ability to launch payloads.

Although there is extensive activity in the space domain across the globe, Russia, Japan, China, ESA[9], India, Israel, Iran and the United States form an exclusive club of nations that dominate research and development in space sciences, and act as drivers for the global space domain. The success of their programs comes in part due to their national space policy which sets out a framework for their goals and national vision. With the exception of the ESA, whose space policy is dictated by its member states and primarily serves the EU, all other countries have national space programs governed by a dedicated national space policy. It is interesting to note that whilst national policies are designed to serve nations strategic and socio-economic interests, all actors including the EU have the following objectives in common:

1. Development and exploitation of space applications to serve the state's public policy objectives,
2. Ensuring that the state's national security and defence needs are met with regards to space,
3. Securing unrestricted access to critical technologies allowing states to pursue independent applications, and
4. Further international collaboration between like-minded nations through improved coordination of international activities and by setting in place a better mechanism for sharing of resources.

[9] The European Space Agency (ESA) is a multi-national agency that currently has 18 members.

Whilst the above nations agree in principal to the UN Outer Space Treaty, they all consider space to be a vital resource for ensuring national security. As such, any application or development of critical technologies is used primarily to bolster a state's national defence capability. Current national space programs run by these countries cover various commercial, civilian and military aspects. This cross disciplinary research and development has led to an extremely integrated industrial base, where drawing a line between civilian and military programs is often impossible. This hazy line has often hindered technology transfer even in commercial applications as companies grapple with stringent export control regulations. With respect to the United States, whilst ITAR has ensured that critical technology is not transferred without the states consent, many in Washington agree that the regulation fails to meet its objectives and must be overhauled. It has also hindered US companies wanting to sell their products outside the United States, prompting other nations to develop indigenous technologies and market them as ITAR free. Although it is safe to assume that research and development with regards to space will be dominated by the United States and its partners in Europe for the foreseeable future, the recent recession has caused financial strains on both sides of the Atlantic causing drastic changes with regards to space budgets and the future outlook for both NASA and ESA.

Why do nations choose to initiate a space program? What are the drivers and barriers they may face in successfully sustaining a national program? What impact does it have on national development?

5.0.2 Why do nations choose to initiate a space program?

"Space systems allow people and governments around the world to see with clarity, communicate with certainty, navigate with accuracy and operate with assurance [98]"

Space is no longer the final frontier but a key strategic asset. Unlike the earlier days of the space age, space is steadily becoming a congested, contested and competitive domain. There are currently close to 60 nations and government consortia that own and operate satellites, in addition to numerous commercial and academic satellite operators, as shown in figure 72[98]. Whilst there has been a steady rise in the number of launches, it is worth noting that in 2010 there were a total of 74 orbital launches conducted by eight countries, as shown in figure 73 and 74 [99].

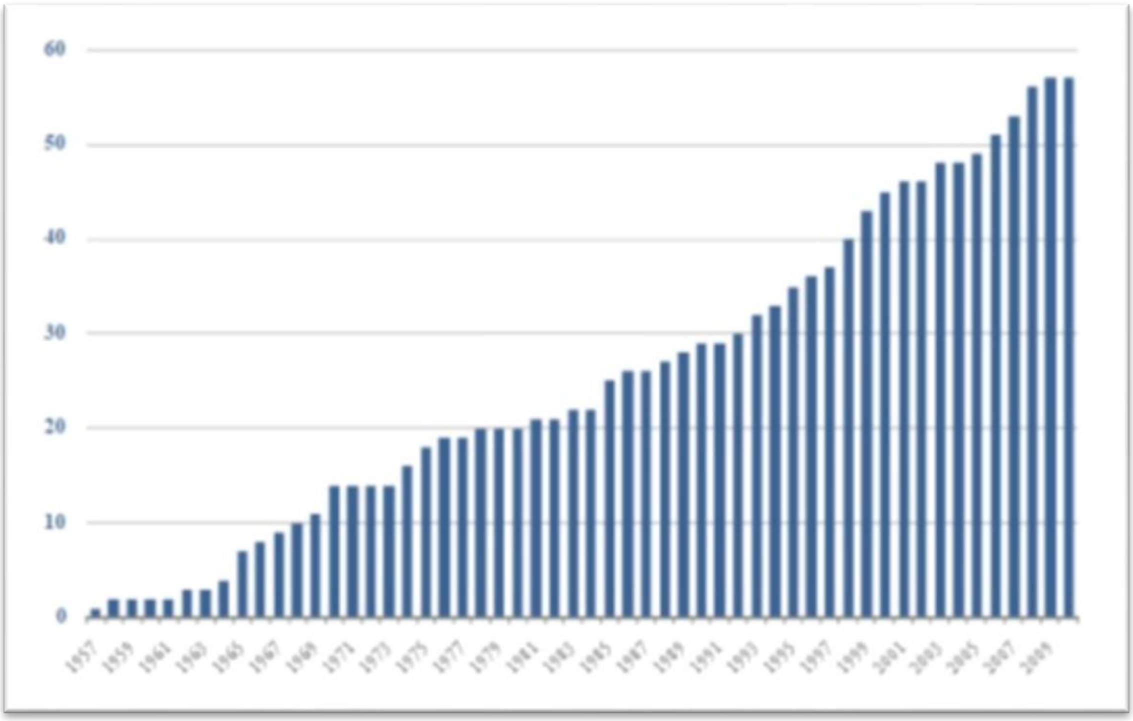

Figure 72: Number of Nations and Government consortia operating in space

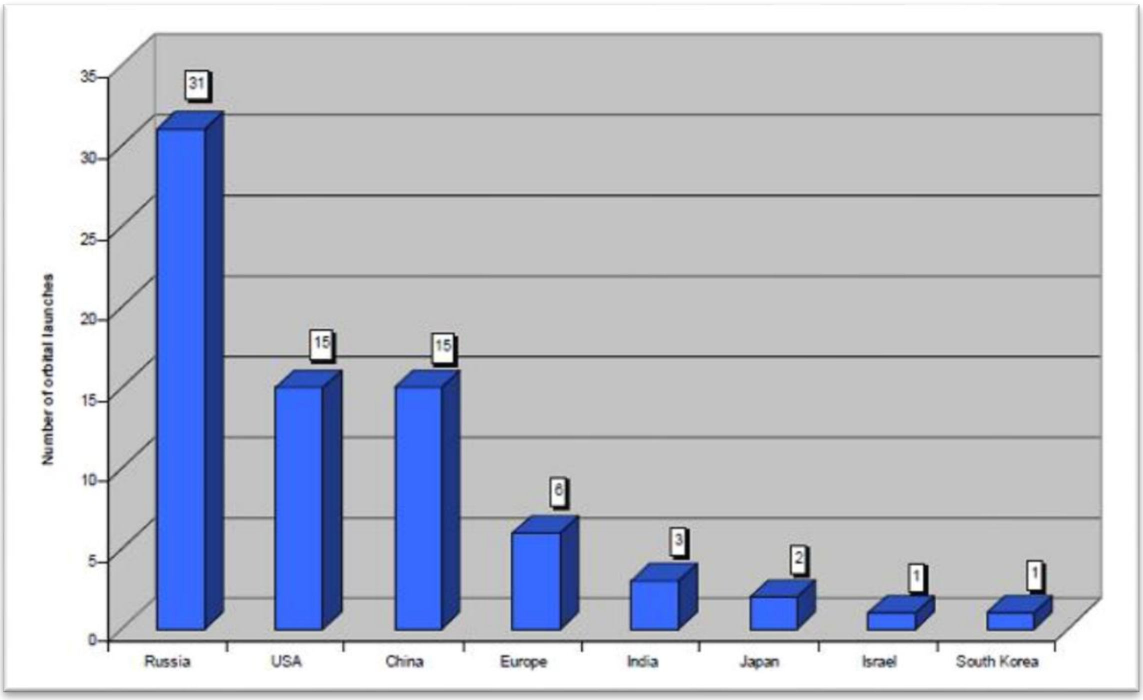

Figure 73: Orbital launches per country in 2010 (Source: FAA)

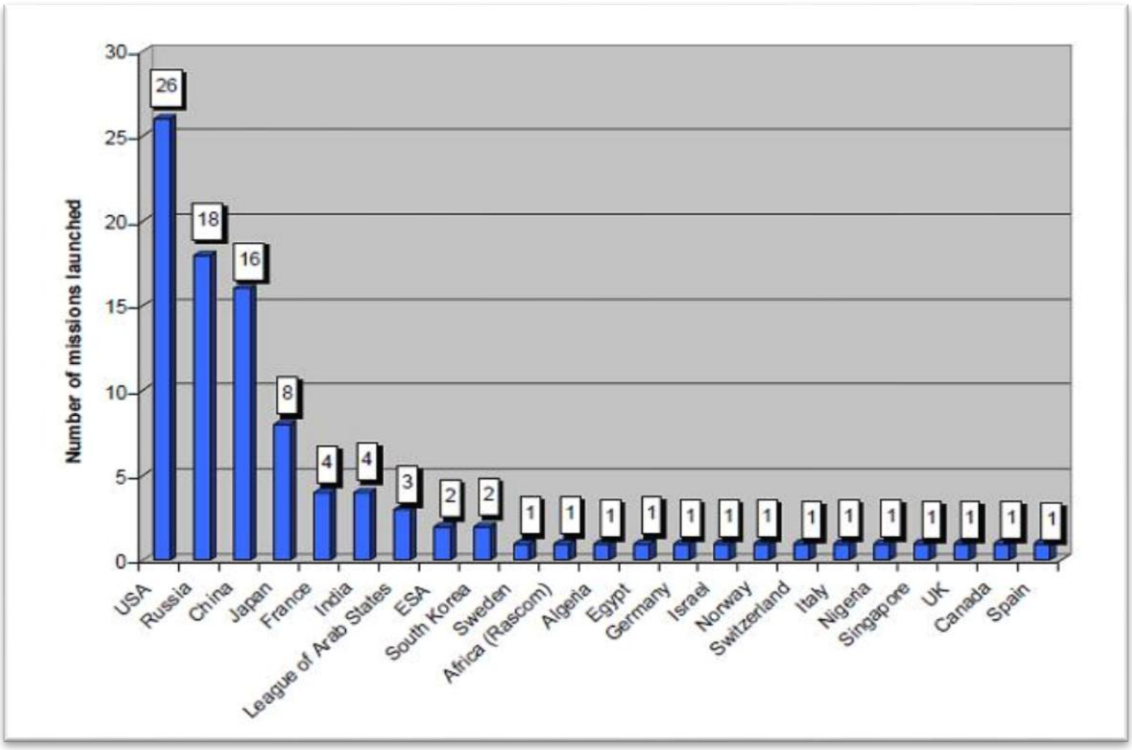

Figure 74: Number of missions launched per country/organization in 2010 (Source: FAA)

Whilst one can consider most countries as space faring nations, only nine possess the technological capability for launching payload. If one traces the origins of national space programs (NSP) in these nine nations one finds that they were all initiated due to a successful combination of the following five factors:

i) ***Power**:* or the perception of power is vital for all nations. By developing a NSP, the nation becomes a member of an exclusive club. This membership often comes with fringe benefits like technology transfer, training and development of inter-agency cooperation.

ii) ***Pride**:* NSP's are often used by nations to demonstrate their technological might to the rest of the world. In effect they often become a symbol of national pride.

iii) ***Politics**:* Both local and national politics play a crucial role in the development of any space program. Let us consider the United States as an example: The US space program, initiated at the height of the Cold war was more of a political decision than anything else. It was a political stand-off that prompted the US to enter the space race, it was a political decision to put a man on the moon and it is both local and national politics that ensures that

NASA still exists.

iv) ***Technology:*** A NSP ensures that there is R&D of the highest standards within the nation. This cutting edge R&D is not only applied to bolster a nations national defence systems but often finds use in various civilian applications. Almost all of the technology developed as part of a space program finds primary use in national defence and military applications. This R&D and the industrial base supporting it are essential tools for a nation to fulfil its commercial, social and defence obligations.

v) ***Economics:*** NSP's and R&D related to space science & technology is definitely not cheap. Its cost can most definitely put a strain on national finances, especially when pursued by developing nations. Current funding for NSP's runs into billions of dollars; however nations determined to initiate a NSP have to overcome the economic hurdle. One should also remember that nations wishing to assert themselves as space faring, often do so because of nationalistic pride and as such are ready to bear the costs involved despite the financial burden. E.g. In 2003 Nigeria funded its first satellite NigeriaSat-1. Whilst this was a great feat for Nigeria, it was extremely expensive as the micro-satellite cost approximately $13 million. A significant sum for a country whose annual budget was just over $3 billion and with $30 billion in foreign debt.

The world government expenditure in the space domain totals $71.5 Billion, while commercial revenues in 2010 add up to $189.39 Billion [100]. Space expenditure is comprised of $37 billion in the civil domain, whilst the defence expenditure totals $34 billion. Out of the overall $34 billion in defence expenditure, the United States accounts for almost 82% share at $28 billion. It is worth noting that not all funding is made public, resulting in a degree of uncertainty with regards to the exact figures.

Looking at the global spending in the space domain and budgets of the major space actors, it is interesting to note the rise of China and India as major space powers with a funding of $2.4 billion and $1.25 billion respectively. This puts these emerging actors in the top 10 major space powers as shown in figure 75 [101].

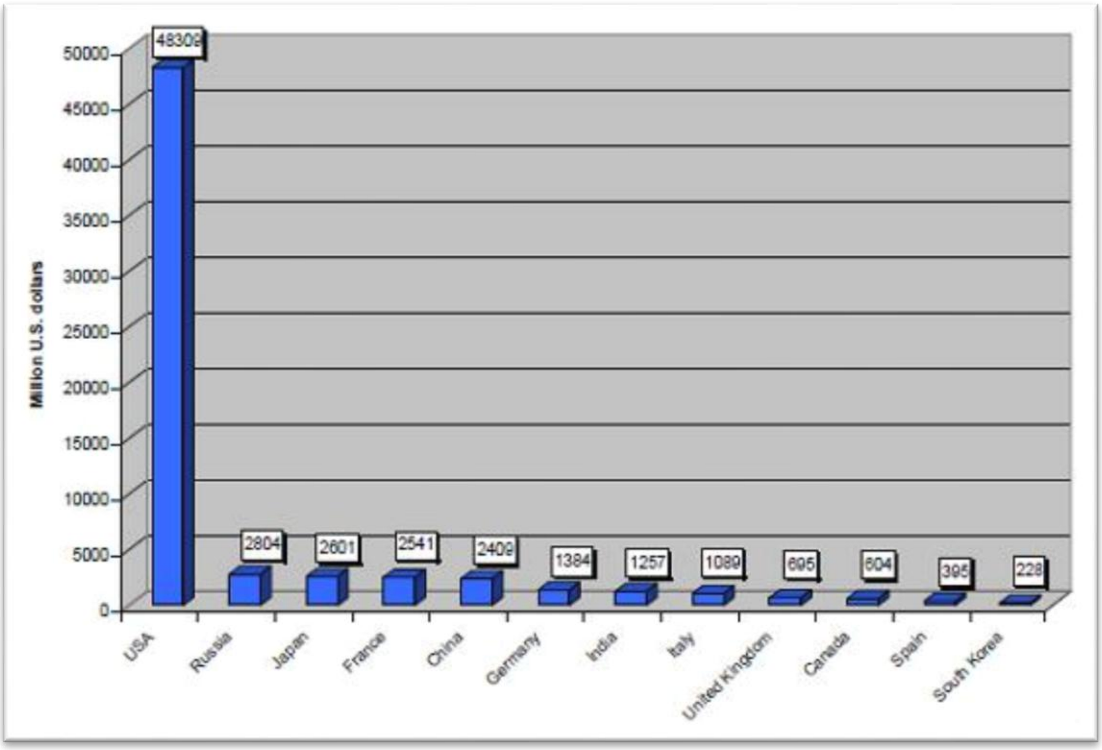

Figure 75: Public space budgets for major space powers in 2010

To better understand the efforts made by countries in the space domain, it is essential to compare their space funding as a fraction of their GDP, as represented in figure 76. It is unwise to draw direct comparisons between two or more space actors that have different economic conditions, like prices, wage levels can often be misleading. If one were to consider the difference between established and emerging actors when we look at space budgets per capita, one would notice that countries like India and China are under-represented due to their socio-economic conditions and their large populations; although they spend a larger percentage of their GDP on space activity compared to some of their counterparts in the west. Figure 77 represents national space budgets as a direct cost to each individual. Based on current trends, it is our opinion that costs associated with programs in the west will reach a point of saturation and then begin to decline, whilst budgets associated with emerging actors shall steadily increase until the point that spin-in and spin-off's from their projects provide the socio-economic benefits that advanced nations enjoy today.

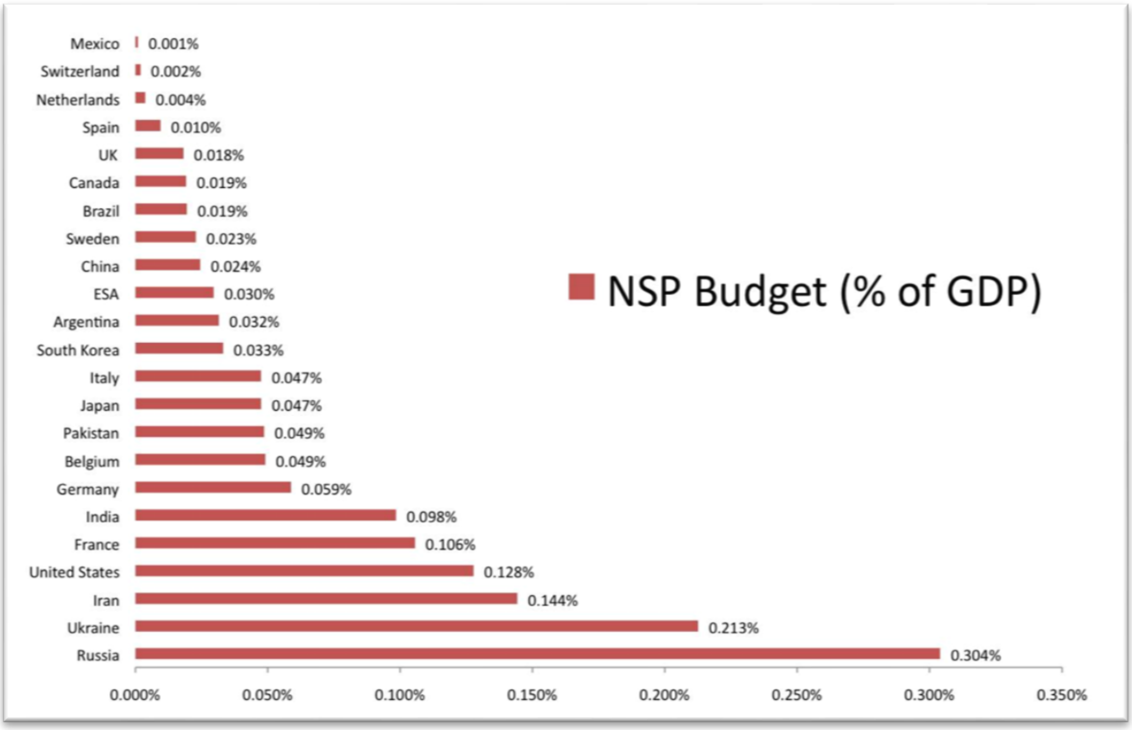

Figure 76: National space program budgets as percentage of GDP

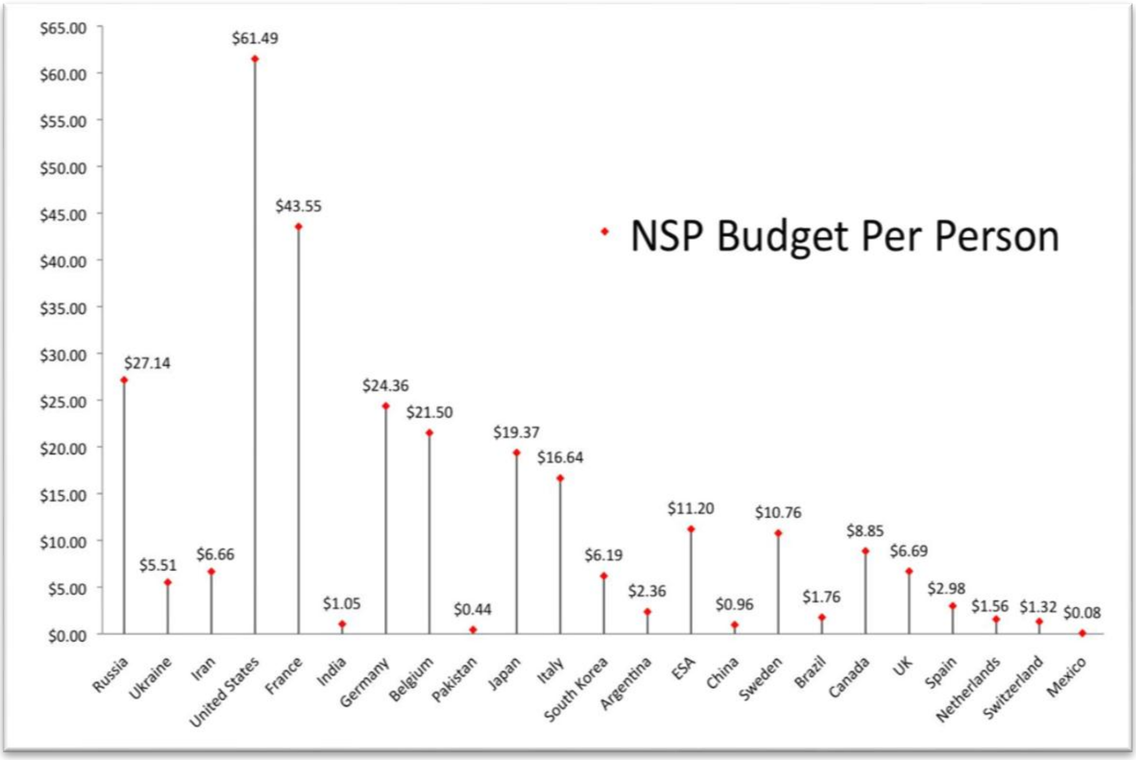

Figure 77: National space program budgets represented as cost per person

5.0.3 The Equation to Space

Now that one has identified five principal factors that play a vital role when nations consider initiating a national space program, one must find a way to link their relationship. In order to do so, let us represent the five factors in the form of equation 2.

$$\Sigma(P)\times T\times E = NSP \qquad 3$$

In the above equation $\sum P$ represents a combination of power, pride and politics with politics being a deciding factor; T is technology and E is economics. It should be noted that whilst these factors act as drivers for the majority of national programs, they can also be potentially significant barriers for a minority of nations. Once initiated, all NSP's require the following drivers to be met consistently in order to ensure the sustainability and further development of the NSP.

1. ***Politics*** *(P):* Both advanced and emerging nations must justify the capital they spend on space activity to the public. This is often a difficult task, especially if public perception is that space has little to no impact on their lives. Hence, politicians often sell space to the public as a matter of national pride, and establishing a relationship between space and national defence to garner public support. Furthermore, for any program to have a chance of success there needs to be majority support at local, state and national levels. There also exists a need for legislation to be in place that protects the interests of all parties involved with the NSP whilst ensuring that the program yields national benefits, and ensures that the nation's defence and national security needs are met

2. ***Technology*** *(T):* Nations keen on initiating and developing a NSP must ensure that they possess a strong research base, and have links to relevant industry. Nations should be able to develop indigenous technologies whilst ensuring an ample supply of locally sourced skilled labour. Whilst technical collaboration between nations & research groups is essential, there must be checks in place that ensure critical technologies are not transferred or sold without a MOU with other like-minded nations. As such, nations should also make certain that embargo's on technology transfer imposed by others do not limit national capability with regards to space.

3. ***Economics*** *(E):* Nations not only require ready capital for the initiation of the NSP, but must also ensure that there is a budget allocation associated with the NSP. The objectives of the NSP must be clearly defined and sources of revenue and income generation should be identified prior to its establishment. The action-plan generated for a NSP must have provisions that ensure that there exists a viable economic return.

If any of the above requirements are not satisfied sustaining the development of a NSP becomes increasingly difficult. It should be noted that currently all NSP's are funded by a national budget and serve the commercial and strategic interests of their respective nations as laid down by their Governing space policy. The only exception to this is the ESA, which is governed by a space policy laid out by the EU and its member nations. The ESA budget is controlled by the EU, which is in turn allocated funds from the national budgets of member states. The member state contributions to the ESA budget for 2010 are represented by figure 78 [101].

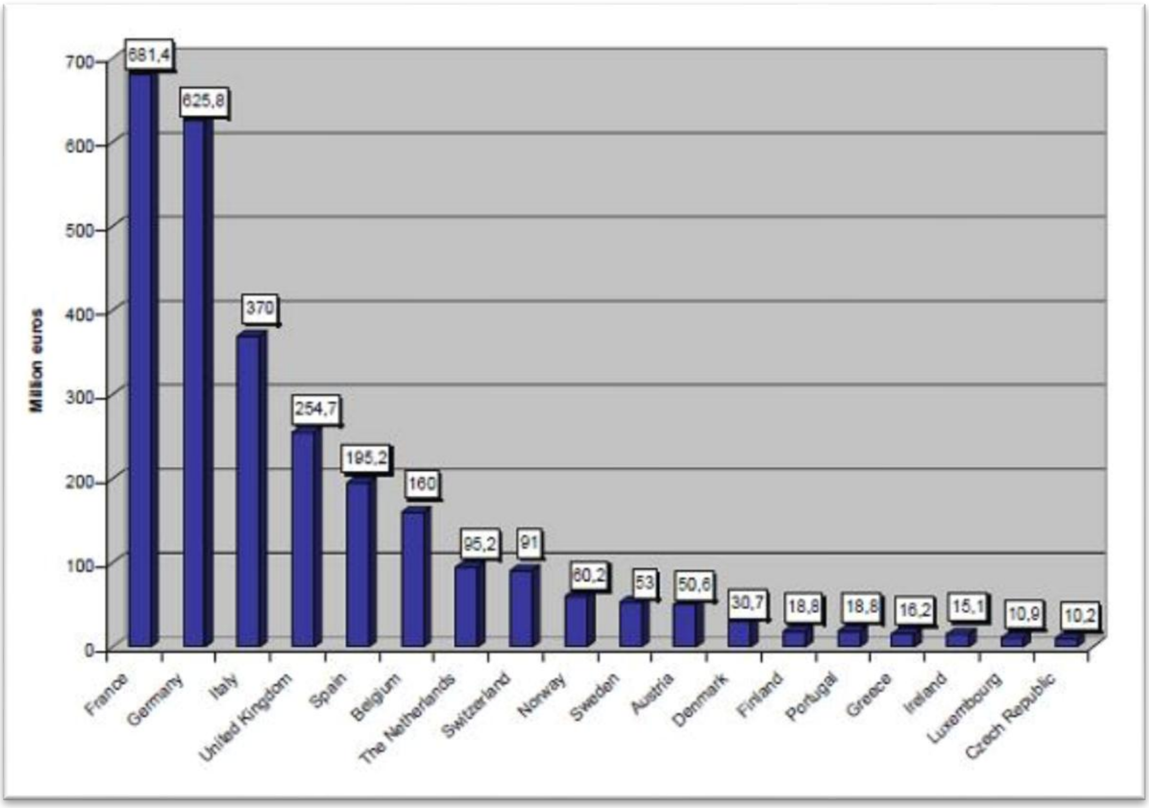

Figure 78: Member state contributions to ESA budget in 2010 (Source: ESA)

5.0.4 The Role of the United States vis-à-vis the World

There have been dramatic changes in the space environment since the launch of Sputnik in 1957 that have enhanced our knowledge and ability to use space. Whilst most of these changes have been beneficial to the growth of the industry and the space sector as a whole, there are a few ominous trends with regards to the outer space environment that threaten the basic foundations of the governing international principles of space activity. One could argue that the United States has not effectively exercised leadership in support of the basic principle of using space for peaceful purposes. Although the efforts of the United States with regards to space continue to grow and it stands at the forefront, its share of economic and military power has decreased. This phenomenon should be viewed as an inevitable and on-going evolution of a world where economic growth has spread too many nations and wealth has been accumulated by many nations [102]. This trend only goes to show that the US share of the world economy has decreased. Whilst the US economy is still relatively strong, and will predictably grow in the future; US policy often seems to treat this trend as a situation that needs to be controlled and stymied through actions that close borders to trade and that attempt to keep technology and power centred within the US.

Policies of pre-emption combined with a policy of not engaging other nations in multilateral negotiations, coupled with a policy of strict export controls has already lead to the US being isolated in many important areas. From an unbiased perspective, it would seem that the US policies formulated in the last decade with regards to space, have a rather aggressive tone, and are most likely counterproductive to US commercial and military interests [103]. It should be noted, that whilst the new US space policy [104] hopes to rejuvenate the sector and create an effective working partnership between private and public enterprises; many within the American establishment have not welcomed its implications and it will be some time before we can assess the impact it has made.

Policy directives with regards to space, especially when considering the US often tend to fall at the bottom of the policy food chain, trumped by defence and overall monetary and fiscal policy. This emphasizes that space is a relative newcomer, a fact that is bolstered by the small fraction of the budget devoted to its development. Policy directives with regards to space often tend to overlook the fact that space capabilities and applications have gone from being an alternative way of conducting business, to being an integral part of our daily lives. Most of the growth can be attributed to the last two decades, and as this growth continues to accelerate in the near future so will our dependence on technologies and products obtained from this vital sector.

As nations are predominantly built on the concept of sovereignty and territorial rights, which are paramount to maintaining their existence; it should come as no surprise that it is a rare exception rather than a rule that nations cede such powers. Space policy presents a very interesting set of contradictions. Space and the use of space, by international agreement have no sovereignty [105]. Whilst it is free for any nation to use, the ability to use space came during the cold war and was initially developed by the two superpowers to show-off their technological powers. The by-product of this development was the advancement of dual-use technology in space. Over time, as the use of space and related technology has matured, it has allowed many nations and private enterprises who have the required capital to purchase services. There are many reasons that explain why commercial space activities need to be global in nature to survive in a competitive world. To make a profit on an investment that has high technological risk and an extremely high up-front demand, having a large market is vital. Since most space-based applications have a global coverage, having a global market offers an attractive profit potential.

It can be argued that a single, large provider can have the ability to serve multiple customers more inexpensively than multiple providers. However, this in no way guarantees that prices charged to end users will be lower than if the industry was competitive. The monopoly of a single provider, would most certainly lead to higher prices and fewer quantities on the market. Using economic theory, it is possible to derive a working model for the space industry; one that would ensure that expensive technologies and assets are not duplicated and provide for a steady growth. Whilst arguments for a competitive space industry are persuasive, it is often overlooked that space economic activity is at best the province of a handful of companies who rely critically on large government orders, two factors that prevent space from fitting any textbook definition of a price-competitive sector. As such, competition within the space sector is more of a goal than reality.

Globalization is not a new phenomenon nor is it inevitable. Decreases in barriers of trade through North American Free Trade Association (NAFTA), World Trade Organization (WTO) and various bilateral agreements in the past through coordinated efforts among nations, opened new markets and opportunities during the 1990s and led to rapid expansion and globalization. However, the last decade has been marked by wars, economic depression and terror strikes that have made nations more cautious, slowing down the booming trend toward globalization. History shows that there is no way to accurately predict that the trend of globalization will stay on a stress free path in the coming future. Economic globalization in the future will be dependent on nations actively seeking a free-market economy regulated via a uniform system that is predictable, fair and enforceable.

5.0.4.a The U.S. space industrial base

Taken as a whole, the aerospace industry in the U.S. Goes rather well with a constant augmentation of its sales between 2008 and 2009, however progression related to space activity alone is limited to $50 million over the same two year period [106]. Making an overall assessment of the U.S space industrial base is often difficult to do, as figures are only available for the entire aerospace sector as a whole. However, it is possible to note a steady decline in sales between 2008 and 2010, in both commercial and military sectors. Manufacturers within the United Sates rely heavily on the domestic market, and this is confirmed through industry figures [106]. In the last two years the domestic market sales through orders placed by NASA or the Department of Defence accounted for 70.6% and 72% respectively. This indicates that public expenditures must increase at a steady rate to cover market weaknesses.

The current economic situation has put U.S. suppliers, especially those in the second and third tier at risk due to inconsistent acquisition and production rates, coupled with long development cycles, consolidation of suppliers and a competitive foreign market. The current procurement philosophy within the United States seem to be to place an order for launchers today and then place secondary orders after a decade. Whilst such a model may be okay for tier 1 companies, whose main source of income is not confined to the space domain, it is reckless and perilous for other tiers.

This worrying situation has resulted in a number of consultations within the U.S. Government and related agencies, who seem to agree that in order for the U.S. industrial base to survive there should be a review of export control regulations and in particular ITAR, to encourage export of high technology material.

5.0.4.b The Impact of Export Control

Space is now truly a global industry. Companies and enterprises, within established political limits, compete to provide launch and industry services internationally. Satellite development, which was once primarily dominated by US companies, is now conducted internationally by companies located around the world [102]. However, the US space industry is currently concerned that its competitiveness is being undermined by the export control regime that regulates trade between the US and the rest of the World [107]. The U.S. export control regime was built during the cold war, on the ideology of peer-to-peer competition and the need to secure critical technologies. However current export control regulations seem to run counter to the national space policy.

A survey conducted by the Space Foundation in 2007, shows that while US companies are aware of the need for protecting certain critical technologies, they do not believe that regulations like International Traffic in Arms Regulation (ITAR) are working the way they should. The survey also indicates that smaller companies are most likely to feel adverse effects from ITAR than their larger counterparts. This is alarming as low-tier contractors are a significant source of new technology and innovation within the US.

There is no doubt that ITAR is an essential tool to help protect critical technology, however there needs to be a radical change in both the regulations and processes of implementation. The focal point for change should be the modernization of ITAR to reflect the current global nature of the industry, promoting competition and innovation. It should be noted that the US space industrial base is largely dependent on the U.S. defence/national security budget. The implication is that the national security community "owns" the U.S. space industry, and must either provide for the health of the industry or encourage and enable it to participate more in the global market to broaden its economic base [108].

One of the goals of the current U.S. National Space Policy is to "encourage international cooperation with foreign nations on space activities that are of mutual benefit"; it also states "space-related exports that are currently available or are planned to be available in the global marketplace shall be considered favourably". However, in certain instances it is evident that elements of the U.S. export control laws are in conflict with U.S. National Space Policy. The U.S. space export control regime does not seem to match its goals of both enabling cooperation with allies and denial of capabilities to opponents. The current regime does not provide policy makers the refinement or flexibility needed to serve the National Space Policy. Congressional action helped place satellites and their components back on the US munitions list in 1999, with the intent of limiting the spread of space technology. However, this has had the unintended consequence of encouraging the proliferation of space capabilities and has not prevented the rise of other space powers. In turn, export control policies have constricted US engagement and partnership, whilst encouraging foreign space capabilities. To put this in perspective, since 1999 when the US was part of a very exclusive club, the number of nations active in space has continued to grow, so that today:

I. There is triple the number of countries with their own positioning/navigation systems.
II. There is double the number of countries with their own reconnaissance/earth observation satellites.
III. There are now a dozen countries capable of launching their own satellites, and
IV. There are 38 countries with operational control over their own communication satellites.

Furthermore, this rapid growth has meant that the sophistication of overseas and commercial capabilities has steadily increased. ITAR implementation and its adverse industrial and technological impact means that US companies trying to compete in the global market lose as much as $600 million a year, which in turn feeds space development that the US is not involved in [108]. It should be noted that at present the US has treaties with the United Kingdom and Australia that enable technology transfer of certain items without being constrained by export control regulations. However, although the treaties have been signed they are yet to be ratified by the US Senate, with various members of the administration arguing that critical US technology must remain in-house. All of this clearly indicates that the strategic intent of the space export controls is not being achieved. In order to suggest recommendations that may help improve the export control system and bring their goals in line with the US National Space Policy, it is essential to define the issues that organizations face.

5.0.4.c Issues related to Export Control

Exports of space products and services in the US fall under the jurisdiction of the Department of State (DOS), regardless of their purpose, whether it is military, civilian, commercial or academic. These transactions are covered by ITAR and are considered by many members of the space industry as a government-imposed hindrance that prevents the US from reaching its full potential as a leader in global space activity. A joint survey conducted by the U.S. Department of Commerce (DOC), Bureau of Industry and Security (BIS), Defence Science Board (DSB), National Security Space Office (NSSO), AFRL and NASA [107] in 2007 showed that 58% of the companies questioned, listed export controls as the main barrier to gaining entry when attempting to market products in foreign countries, as shown in figure 79.

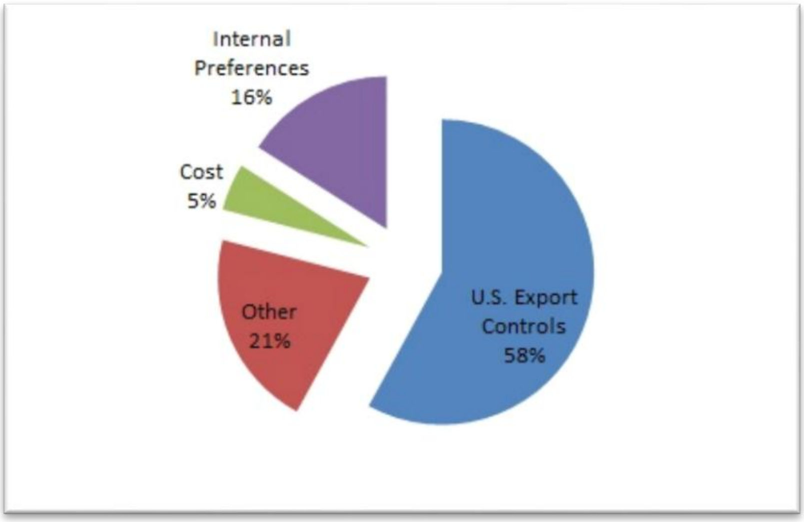

Figure 79: Barriers to foreign markets (Source: Doc Survey, Q18)

It is now a common feeling within the industry that export of technical data, defence services, technology and commodities is overly restricted under the current export control regime, in which individual licences are required for each transaction and minimal exceptions are made. The issue with ITAR for the space industry is not an insurmountable one, but it may be difficult to address unless parties with a stake in the matter have a common understanding of the issues. Without a shared perspective, efforts to modernize the export control process are likely to add to the complexity of an issue that is already complicated. There have been numerous studies conducted in the last few years that look at the impact of the US export control policy on national security and US competitiveness in the space industry. CSIS, AFRL, DOC and the Space foundation conducted independent surveys on the health of the U.S. space industry, taking into account concerns of all three tiers of the space industry

Whilst each study has its own viewpoint and recommendations, they all find common ground on the following points.

I. The export licensing process is lengthy, unpredictable and inefficient. The expertise required to understand the technical details often lies outside the State Department and consultation is time consuming.

II. ITAR restricts the ability of US firms to compete because foreign companies do not operate under equal restrictions. Technology remains on the USML, even when it is commercially available in other countries, because lists of critical US military technologies are seldom updated. Up to 40% of the surveyed companies agree that the export control lists must be updated to keep in line with services and technologies available in the global market, as shown in figure 80 below.

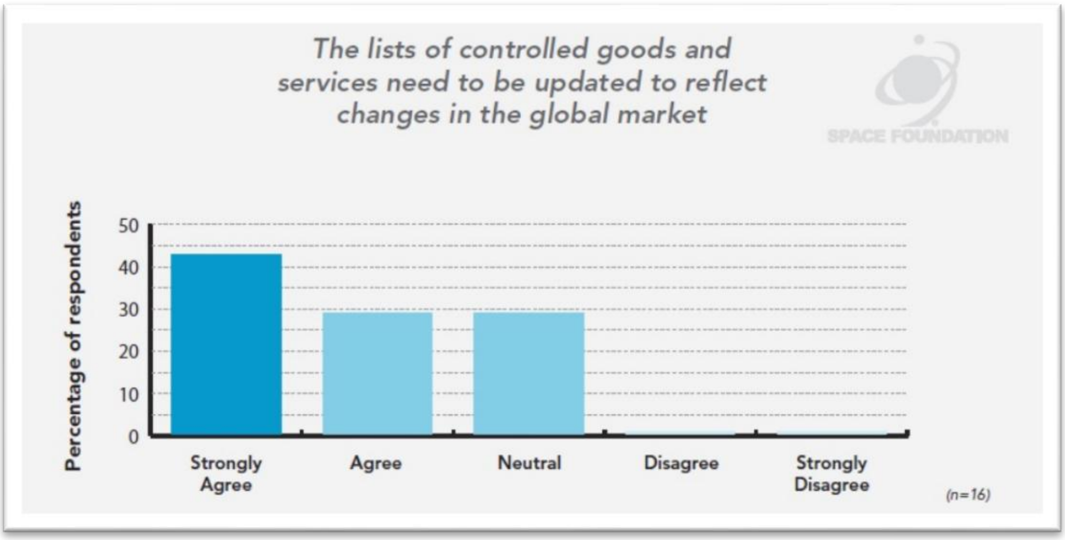

Figure 80: Controlled goods in foreign markets (Source: Space Foundation Survey)

III. Small firms do not have sufficient resources to comply with ITAR so the cost of compliance is a barrier to entry; this is a concern since low-tier companies are a major source of innovation. Regulations also deter or delay collaboration with foreign partners, increasing the financial burden on a sole firm. This has forced a number of companies to change their business strategy as a result of export control policy, as represented by figure 81.

Figure 81: Business strategies as a result of ITAR (Source: Space Foundation Survey)

IV. There is growing concern that export control policies have constrained US engagement related to Technical Assistance Agreements (TAA). TAA's, which are critical for partnerships and marketing, are taking longer to approve, as shown in table 18 below.

	TAA Submitted	TAA Approved	% Approved	TAA avg. time (days)
2003	508	439	86%	52
2004	610	565	93%	59
2005	829	722	87%	85
2006	698	627	90%	106

Table 18: Technical Assistance Agreements time-frame (Source: AFRL analysis 2007)

V. US international engagement and partnership is hindered by its ability to conduct anomaly resolution.

Over the last decade the US congress has discussed extensively a broad range of issues affecting the competitiveness of the US aerospace manufacturing industry. In FY2000 the 'Presidential Commission on the Future of the US Aerospace Industry' released its recommendations on how to maintain the competitiveness of the aerospace sector [109]. The commission called for a national policy along with a government wide framework and the removal of prohibitive legal and regulatory barriers that impede the ability of the industry to grow [110], a point echoed by the Space Foundation survey in 2008 as represented in figure 82.

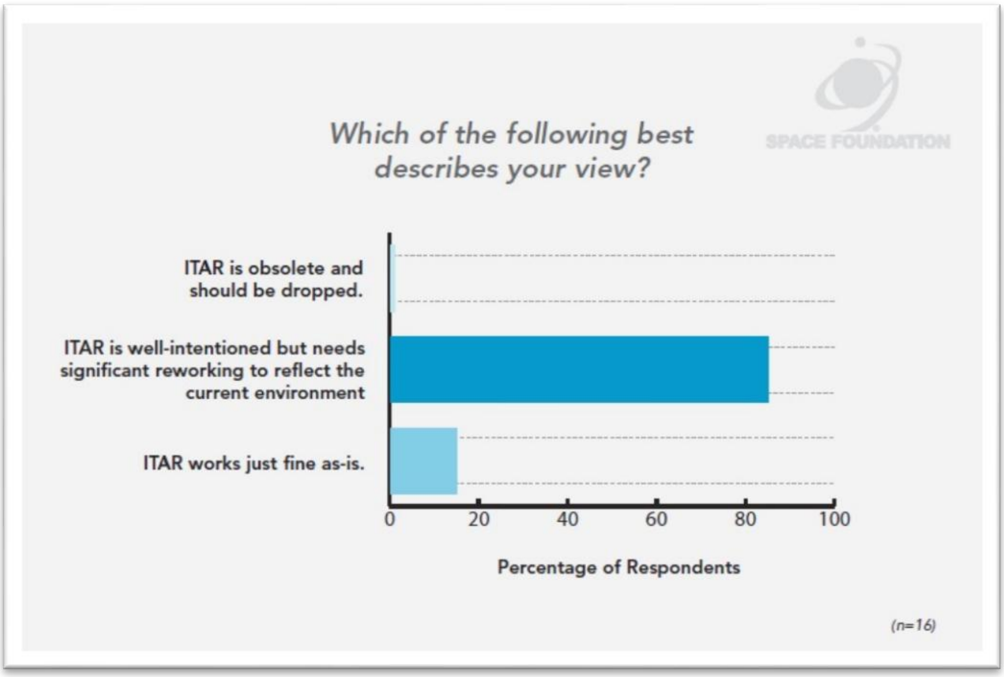

Figure 82: Industry views on ITAR (Source: Space Foundation Survey)

Industry analysts have long argued that globalization is the key to achieve business objectives, enhance competitiveness and vitality of exports for the United States, however export licensing laws and their wording hinders progress a statistic that is clearly demonstrated by figure 83.

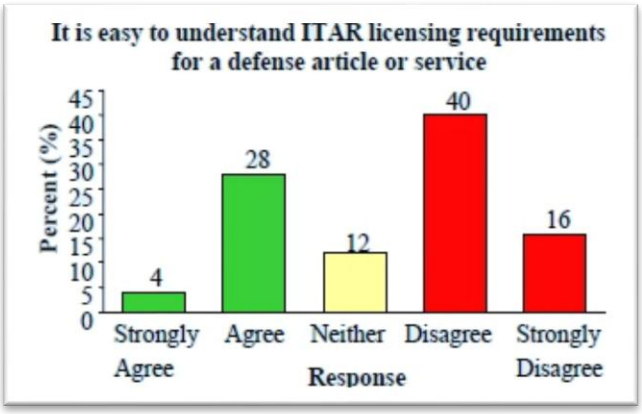

Figure 83: Is ITAR easy to Understand (Source: Booz Allen survey of industry execs, May 2006)

While Tier1 firms have learned to manage export control requirements, they remain a burden for Tier2 and Tier3 companies [108]. The extra cost associated with export control compliance, not only discourages the low tiers but forces them to rely on the U.S. domestic market.

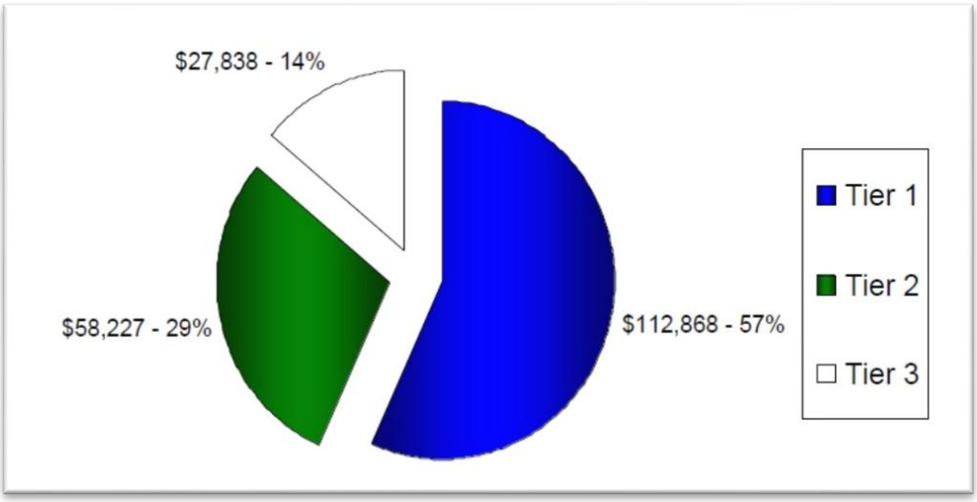

Figure 84: Financial cost of export control across all tiers in $K (Source: DOC survey, Q17)

Figure 84 shows the financial costs (2003-06) related to export control compliance for all tiers. Whilst Tier1 accounts for over half the costs, Tier2 and Tier3 combined report significant costs of over $85M for a four-year period. If it were easier to compete globally, smaller companies would have a better chance of survival during lean times. The loss of lower tier companies would eventually lead to a decline in development of new technology within the US [109]. An indicator of this decline is the rise of companies overseas developing indigenous technologies and marketing them as ITAR-free [108].

India, China and South Korea are the most recent examples of countries that have in some way benefited due to ITAR. The technology base within these countries has grown significantly, allowing them to collaborate with other space agencies on various projects. This sudden growth in local space industry has also prompted India and China to announce their intentions with regards to human space-flight programs; with both countries determined to carry out a manned mission within the next decade. If this were to happen, India and China would join the elite group of nations capable of conducting and operating human space-flight programs. The steady rise in number of space actors brings with it a variety of positions regarding the future of space activity. These positions emerge from the capabilities and experience of new actors on varied national projects and underline their future space investments. These varied positions and trends emerging due to them, often create a tense atmosphere when it comes to the space debate. The rise in the number of actors, be it public or private sector entities, demands a collective reflection on new rules, guidelines and policy implementation strategy that guarantees development of space activities with the consistent notion of common good in order to gain widespread adherence [111].

Although it is beyond the scope of this thesis to discuss all the recommendations made by numerous studies in the past few years, it is suffice to say that there is intense debate at Capitol Hill and within the US administration of the future of export control policy and the role it shall play in shaping the new era of US presence in space. Some of the main recommendations made as part of the review process are listed below[10]:

I. The US administration and congress should review and reconcile the strategic intent of space export control.

II. Remove from Munitions List commercial communication satellite systems, dedicated subsystems, and components specifically designed for commercial use. Provide safeguards by identifying critical space components and technologies that should always require licensing.

III. Set time-lines on transfers, technology thresholds and adopt special licensing vehicles.

IV. Create a special program authority to permit timely engagement of US participants in mutual space projects.

V. Conduct an annual assessment of the industrial base, addressing concerns raised by all tiers.

VI. Shift the focus of ITAR from a system that regulates individual transactions to a system that reviews the scope of an entire project.

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[10] These recommendations represent a fraction of suggestions made by independent reviews conducted by CSIS, AFRL, DOC and the Space Foundation; and have been selected for their relevance to this thesis. Full studies can be found by consulting ref [108],[109] and [110].

VII. When reviewing USML and ITAR, DOS should take into account the availability of space technology in the global market. U.S. companies should be allowed to compete freely to sell goods and services that are not materially different from those offered by international competitors.

VIII. Exports should only be governed by ITAR if they represent a technological advantage that is militarily significant.

IX. Develop a validated end-user program for ITAR controlled exporters, enabling transactions that require notifying DOS rather than applying for licences.

X. The validated end-user database should be made available to exporters, enabling them to see which customers have been granted access to certain categories of ITAR-controlled exports and which customers require greater scrutiny. This database would also provide incentives for foreign entities to maintain ITAR compliance, as a negative listing would hinder trade and commerce with the US.

XI. The overall licensing process should be as transparent as possible without harming the competitiveness of the companies involved.

Whilst the above recommendations were made keeping the ITAR and US export control policies in mind, they can be also be applied to export control systems outside the US. These recommendations, if adopted in a broader sense, would enable the growth of a streamlined industry with healthy competition, and would help eliminate the issue regarding the duplication of technology.

We should remember that with a surge in the number of participants, be it public or private, there needs to be a collective reflection on new rules, guidelines and policy implementation strategy that guarantees development of the industrial base with a consistent notion of common good. A resilient, flexible and healthy industrial base must underpin all space activity.

5.0.5 Could a Global Civil Space Program be the future?

With any kind of space technology, its application for national defence and security will always be a priority. Whilst the appropriate role of the government in facilitating commercial space businesses is an on-going debate, international cooperation and competition in space is fundamentally based on the world economic situation and the post-Cold-War political climate. The current space industry comprises of 3 tiers of capabilities and products. The first tier includes principal companies with integrated design and production capabilities for fully integrated stand-alone systems. The second tier companies manufacture systems and major substructures like engines, fuel control systems and communication systems for the principal companies; whilst the third tier comprises of suppliers of components and parts and other specialized services. In order for the global space industry to grow, there needs to be opportunity for healthy competition [112]. This however can only be achieved if all companies involved in the space sector are allowed to compete for the same projects. However, due to the very nature of the industry there lies interdependence between the various sectors, as illustrated in fig 85 [113].

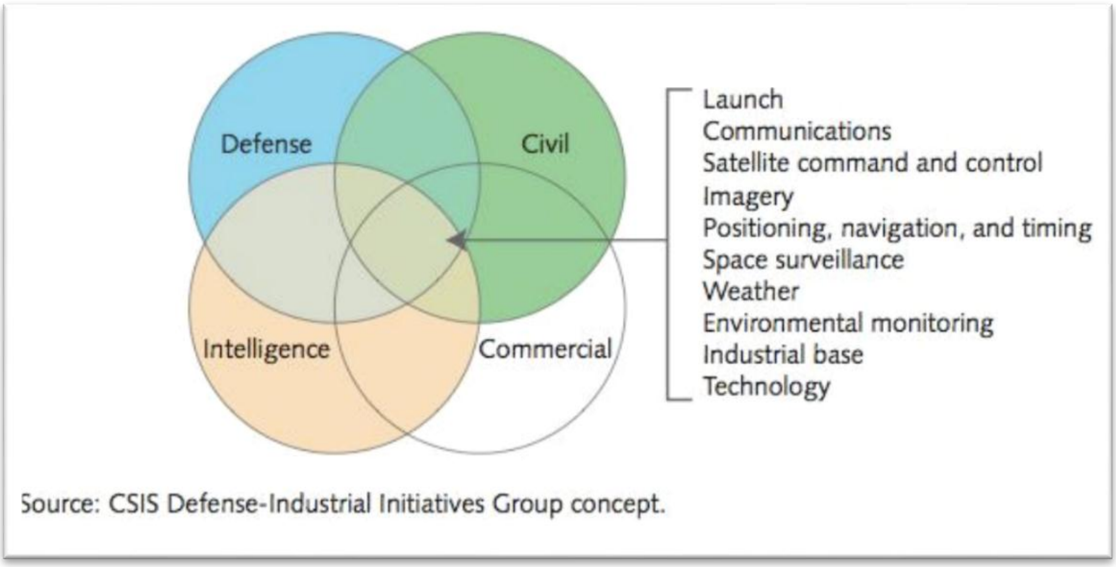

Figure 85: Space Sector interdependence

Since it is not always possible to clearly distinguish between the civilian and military applications of space-based technology, it might be worth considering a global space program (GSP). In order to implement a GSP one would establish a consortium of like-minded nations, with verified end users who broadly agree to the following guidelines:

i. To cooperate in full with regards to a global space program: Similar to the collaboration required for the International Space Station, this point suggests bringing together like-minded nations, who intend to use space as a resource to benefit all humankind. By doing so, member states encourage technology and skills transfer that helps build a competitive environment for industry, leading to accelerated R&D. This proposal also makes it possible to develop and define a verified end user list for each participating nation, the controlling body for the end user, and the type of research or development it specializes in.

ii. To set up a global charter that outlines the civil space milestones to be achieved by the consortium: By outlining key milestones and pooling together resources, member nations encourage growth of the civil space sector, ensuring that both consortium and national benchmarks are met. It also ensures that member nations agree to a stringent set of policies that will govern such a program. As it stands today, most space faring nations govern their activities through a central space policy. Almost all national space policies discuss the importance of a collaborative effort, however they do not clearly define the approach nations should take or consider existing legislation that hinders progress.

iii. To comply in full with policies and directives laid out by the consortium, and in turn inform governments of member states of progress made on projects and milestones in a timely manner: This is primarily to ensure that there exists a system of checks and balances. As member nations are effectively stakeholders in the consortium, and are liable under current international law for activities conducted on their behalf or by companies associated by origin; it is vital to ensure that there is a periodic review of activities conducted by the consortium and that all regulations are met by each member state. This process would also enable member nations to debate and discuss various aspects of the consortium, allowing them to fine tune policy, law and directives to better suit the global need.

iv. Enable local industry and talent to compete on a global scale, by providing financial and technical support as and when required: Currently, private firms find it extremely hard to go it alone when it comes to space. Even if firms had the necessary capital and manpower, the risk involved with space programs is high. Firms that are currently involved with space programs are contracted by national agencies, and as such their research focus is directed by the governing agency. Consortium members could provide financial incentives to the private sector to rejuvenate the industry and in turn the consortium could become the primary customer for all the technologies developed. By doing so the consortium not only reduces the risk factor for private firms, but also ensures healthy competition.

v. To ensure that the civil space sector focuses research and development of technology and services that benefits all humankind: With a global mandate all member nations would work together in ensuring that R&D conducted on behalf of the consortium is for civilian purposes only and there is no transfer of critical technology, or of items that may be on the export control lists of member nations. The consortium must also have a defined list of all end users and verification and vetting processes that establish the intent and credentials of the end user.

vi. To share real time information with consortium members and their relevant agencies with regards to potential threats: Given that any serious space-faring country would be willing to recognize the existence of present and short-term security threats in space, a gradual approach could be envisioned, this would address the immediate and short-term concerns, then creating a spill-over effect leading to a better mutual political understanding and trust [11] [111].

Such a program would take into account various actors, their values and views with regards to space, and would promote global science by identifying future trends and encouraging regional co-operation. The purpose of a global space program is not to overshadow international engagement taking place through the UN or bodies like SWF, but to streamline the process by implementing a global umbrella policy that would focus all actor investments to ensure the sustainable development of space based research. By adopting a global space program, we could ensure that there is targeted R&D, hence, a better return on investments made by the public/private sector, greater potential for expanding capability beyond that of a single nation program and reduce the risk associated with 'rouge actor' activities, as each member party (private or public) would have a vested interest.

Although a simple enough idea, its implementation would be rather complex. In order to start such a program, we would not only require nations to streamline their export

[11] For further information please read "A European approach to Space Security" by Xavier Pasco. The paper was prepared as part of the Advanced Methods of Cooperative Security Program at the Centre for International and Security Studies at the University of Maryland.

control policies, but would also require them to define export control based on an international standard whilst finding the right balance between national interests and global prosperity. The verified end user database, as discussed earlier, could be implemented on a global scale allowing nations to exchange technology, resources and offer services whilst complying with national and agreed international export control policies. Even though the wording of a governing policy for such an endeavour would be subject to intense international debate, it is possible to find a middle ground without compromising the industrial base. Furthermore, a GSP can be utilized to develop the vacuum maglev (VML) propulsion mechanism, enabling us to guarantee cheap, reliable and safe access to space and an alternative to conventional rockets. Whilst defining such a policy is beyond the scope of this thesis, it is possible to suggest a framework for a global space program.

5.0.6 The role of government and private enterprise

As a general argument most would agree that we as a society have not paid as much attention to space and space based research as other fields. This argument is based on the success of the Apollo era and the steady decline in technology development over the decades that followed.

Whilst there may be some truth to this, we should not be comparing development in the space arena to any other field; primarily because there are no parallels. When we look at the advances in technology in computer sciences and the circuitry behind them, we are reminded of Maxwell's theorem and this theory has held up for the last 40 years. However, when we consider space it is important to remember that no similar theorem or equation exists. It is all well and good to dream of future space travel being as cheap as modern day airline tickets, but it is just that, a dream with no basis in reality and no evidence to support its eventuality.

In terms of current day launch systems and vehicles, we in the space arena already operate at the boundary of what is theoretically possible. Over the past few decades there have been countless interviews and papers that propose low cost space travel for all, and most of them falsely believe that this can and will only be achieved by an active and healthy private sector. One disagrees with this notion. The private sector has taken a few steps towards commercialising space and providing cheaper access, but overall costs are still roughly the same. Private sector enterprises working in the space arena are often able to do so due to government grants, national procurement of products and heavily subsidised loans. Their 'technological leap' is based on infrastructure that was developed for national programs at a time where going to space was a strategic/political priority for their national government.

To say that the private sector can do better that the government in the space arena is a false belief in the same way as assuming government sponsored projects are the way forward is wrong. What is required is a new approach to public-private partnership that would allow both government and private enterprise to work towards a common goal. National programs today are driven by need and necessity that is often short-lived. A project life-cycle is primarily dependent on what the government wants to achieve and how soon it can achieve it. On the other hand, private enterprise sees space and space based assets as a business opportunity where the idea is to make money over a standard five year projection. As governments and private enterprise often take a different approach in the space arena it is important to find common ground to build upon. Private enterprise must prove that there is demand for a service and then lobby for government support, who in turn could help provide infrastructure and support for private investment. We can only achieve advancement in the space arena if there is a mutually beneficial partnership between private enterprise and government.

To that affect we agree with *Gangle's* viewpoint in his book '**THE DEVELOPMENT OF OUTER SPACE**'.

"Today, private companies build and operate trucks, ships, aircraft, launch vehicles, and satellites, but governments that maintain the highways, seaports, airports, and space-ports – the infrastructure that is the foundation of all these commercial activity".

This sums up the key message to the critics of government involvement in the space arena. It is unlikely that we would ever reach a stage where private enterprise could independently develop and sustain the space arena. One believes the notion that future space policy is better left in the hands of government is false. Whilst one agrees that politicians endure to promote national and strategic interests often represented in terms of policy, one could argue that development of future space policy should be based on the expertise and knowledge of those practicing in the space domain. International policy must reflect not only the current state of the domain but also make provisions for new advancements, a notion that can only be achieved if experts in the domain are given unprecedented access to policy frameworks both nationally and internationally, and are not bound by bureaucratic red-tape. A government perspective on policy is limited to its shelf-life. Whilst future candidates may agree with the outlook presented, they do so based on a political viewpoint rather than a scientific one.

Nations possessing space capabilities must pursue policy from a scientific yet realistic perspective, rather than speculative political will. Nations like the US, Russia, China, India and members of the EU must collectively help usher in a new era of collaboration, one that is represented as a collective front despite political issues and challenges faced in other arenas.

5.0.6.a TCBM as a tool of diplomacy

Transparency and confidence building measures (TCBM) have been employed by governments for decades, with a number of measures being put in place during the Cold War era. The Cold war defined an era where adversaries and threats could be clearly identified and diplomacy acted as an essential preventive measure. The initial focus of TCBMs was to help manage the nuclear and missile proliferation issue. Although initial transparency measures were a by-product of US-Soviet competition, the accords and treaties signed between 1963 and 1987[a] still exist today and form the backbone of nuclear arms control programs.

Today as risks associated with operations increase, governments and local groups are looking at TCBMs as a way to define guidelines allowing nations free, secure and unrestricted access to space. However, transparency is often trumped by secrecy for a host of reasons, including the deterrent value of withholding certain information [114]. Previous TCBMs have also turned some nations into sceptics, who would argue that such agreements demand significant concessions to be made with very little return. Nation states today believe that bi-lateral agreements tend to easier to achieve and offer mutually rewarding benefits to member states. We could take this a step further and look at multi-lateral agreements, that would allow nation states to participate and cooperate collectively based on common goals and principals. However, multi-lateral agreements are often difficult to achieve as participating nations must not only be on

[a] Limited Test Ban Treaty (LTBT), Nuclear Non-Proliferation Treaty (NPT), Anti-ballistic Treaty (ABM), Intermediate-Range Nuclear Forces (INF)

equal footing, but should also view the 'issue' as a collective defining of a common strategic approach. Such agreements can often be viewed as means of stifling national interests, making nation states reluctant to agree to policy or sign binding agreements that have different priorities compared to national interest. Multi-lateral agreements however, do possess the benefit of imbibius partner states with a greater sense of responsibility and accountability with key actions monitored and regulated by peers.

For the purpose of this work let us consider the definition of Transparency as “the degree of openness in conveying information and a device of strategic negotiations signalling the trustworthiness of the actor in negotiations”[115]. TCBMs can thus be considered as an essential tool for diplomacy and international relations. Such measures have been introduced and exist in current legally binding space agreements and related UN resolutions. There currently exist two approaches for initiating TCBMs. They can be classified as the 'top-down' approach that is primarily initiated and led by government effort or the 'bottom-up' approach that could be initiated by independent think-tanks, research institutions or the wider scientific community. In both cases however, the final negotiation, adoption and implementation of policy requires government involvement. A good example of the 'top-down' approach is 1967 Outer Space Treaty (OST). TCBM for space was initially accepted by the UN via resolution 60/66 entitled “transparency and confidence-building measures in outer space activities” [116]. When one considers the 'bottom-up' approach, the argument presented is that an informal structure over time positively influence the overall security matrix and lead to a broader formal agreement.

The UNGA resolution 1721 (XVI) of 1961 coupled with resolution 1962 (XVIII) lays down the framework for the main principals governing outer space activity as described in the UN OST [117]. The OST marked the first effort to establishing an institutionalised, multilateral for space security and as of January 2010, 100 countries have ratified the treaty [118][119]. Today there is a budding argument that the OST should be brought in to the 21st century by implementing new rules that would address future and current challenges associated with space security [120], however with little to no consensus amongst nations on renegotiating the OST we are left with the alternative of considering a 'bottom-up' TCBM similar in principal to the 'Code of Conduct' proposed by Europe in 2008; that could eventually feed in to a global space policy initiative as discussed in this chapter. One agrees with the argument put forth for the

'EU code of conduct' and its draft preamble that states “a comprehensive code, including TCBMs could contribute to promoting common and precise understandings [121]”. TCBM with regards to space are born out of necessity, in the current scenario that would be to ensure sustainable and secure access to a rather congested, contested and competitive domain. As such, whilst one considers the recommendations made in this chapter with regards to a global space policy, one must not neglect the role carefully constructed TCBMs can play. By utilizing a 'bottom-up' approach one must market TCBMs as a tool that could not only help balance national and international interests but also help advance cooperation in space by facilitating the establishment of predictable processes and helping generate greater political will and understanding.

5.0.7 Global Space Program Framework

GSP Agreement Objective: The objective of the agreement is to establish a long-term international cooperation framework among partner nations, on the basis of genuine partnership for the detailed design, development, operation and utilization of a VML system, for peaceful purposes in accordance with national and international law. The ideology behind this agreement is to enhance the scientific, technological and commercial use of outer space. The VML system and its various elements shall be developed, operated and utilized in accordance with international law, including but not limited to the Outer Space Treaty, the Rescue Agreement, the Liability Convention and the Registration Convention.

GSP Management: The system should be established on a multilateral basis and the participating nations, acting through their cooperating agencies and private stakeholders will participate and discharge responsibilities in management bodies in accordance with any memorandums of understandings (MOU) and implementing agreements. The management body shall plan and coordinate activities affecting the design and development of the VML system and its safe, efficient and effective operation and utilization. Decision-making by general consensus will be a key goal for the management body.

GSP Funding: Each partner nation, acting through their cooperating agencies and private stakeholders, shall bear the costs of fulfilling its respective responsibilities as part of this agreement, including sharing on an equitable basis the agreed common system operations costs or activities attributed to the operation of the VML system as a whole. Financial obligations of each partner nation pursuant to this agreement will be subject to its funding procedures and the availability of appropriated funds. Each partner nation shall make its best effort to obtain approval for funds to meet its obligations. All partner nations shall seek to minimize costs associated with the VML system. Partner nations, shall develop where possible procedures intended to contain the common system operation costs and activities within approved estimated levels.

GSP Liability: Except where individual partners have come to an agreement, all partner nations shall remain liable in accordance with the Liability Convention. In the event of a claim arising, partners must consult promptly any liability or appointment of such liability. With regards to the provision of launch and return services provided by the VML system, the partner nations may conclude separate MOU's regarding the appointment of any potential joint liabilities.

GSP Data Exchange: The agreement shall not require a partner nation to transfer any technical data and goods in contravention of its national laws or regulations. National laws and regulations will apply to all transfers made. All transfers will be limited to cooperating agencies of partner nations. If a private stakeholder has developed the data or goods being transferred, the transfer must be approved by the partner state, which shall in turn act as the contracting agent for any such services. Where national law or regulation protects goods, their transfer shall be clearly marked under the following categories:

i. Data or goods protected by export control regulations – In such a case the partner nation, through their cooperating agency shall mark and identify any specific conditions regarding how such technical data or goods may be used by the receiving cooperating agency, its contractors and subcontractors.
ii. Data or goods protected for propriety rights – In such a case the partner nation, through their cooperating agency shall mark and identify any specific conditions regarding how such technical data or goods may be used by the receiving cooperating agency, its contractors and subcontractors.
iii. That such technical data shall be used duplicated or disclosed only for the purposes of fulfilling the receiving cooperating agency's responsibilities.

iv. That such technical data shall not be used by persons or entities other than the receiving cooperating agency, its contractors or subcontractors, or for any other purpose without prior permission of the furnishing partner nation.

v. Data or goods deemed classified – In such a case the partner nation acting through its cooperating agency shall clearly mark and identify any items deemed classified. Any such transfer would be pursuant to a security of information agreement or arrangement that sets forth conditions for transferring and protecting such technical data and goods. If the receiving partner nation does not provide for the protection of the secrecy of patent applications containing information that is deemed classified or otherwise held in secrecy for national security reasons, the transfer cannot and should not be completed. No classified technical data or goods shall be transferred with regards to this agreement unless both nations agree to transfer.

Each partner nation and their cooperating agency, shall take all reasonably necessary steps, including ensuring appropriate contractual conditions in their respective contracts and subcontracts, to prevent unauthorized use, disclosure or retransfer of any technical data or goods that meets one of the criteria's above.

5.0.8 Chapter Conclusion

Over the last decade we have witnessed a steady rise in the number of nations interested in accessing space, or space based technology and industry. At the moment there are 28 states with sub-orbital launch capability, 9 with orbital launch capability and 47 states that have accessed space either through indigenous programs or via the commercial sector. As the number of nations accessing space increases, the space environment will become more crowded and complex. Since most technology developed with space programs in mind is dual use in nature, the steady rise in the number of space actors raises security concerns as space systems would become highly exposed to attack. Whilst there are four main treaties that provide the basis for the sustainable, equitable and secure access to space for current and future users of space, there are a number of nations who have still not acceded to these treaties [105][119].

The new US national space policy [104], echo's some of the points discussed in this thesis. Whilst the US remains committed to many long-standing tenets in space activities, it emphasizes the need for expanded international cooperation and the commitment of nations to act responsibly in space in order to prevent mishaps, misperceptions and mistrust. The new commercial and civil space guidelines seem to be designed to expand private sector involvement in space activities, encourage and actively promote the export of U.S commercially developed and available space goods and services. After considering the amendments made to the U.S space policy, the suggested ideology behind setting up a global space program (GSP) is to have an independent body working in conjunction with the current UN structure. The GSP would bring together nations and private investors who are keen to develop technology and conduct space based research, whilst ensuring mandatory compliance of all UN treaties with regards to space. The ethos of such a body would be to ensure sustainable and secure access to space whilst promoting technology transfer and collaboration amongst member groups. It would act as a global platform to discuss issues of collective interest, develop agreements that oversee operations and promote transparency. Most importantly, it would distinguish clearly between the 4 space sectors (civil, commercial, military & intelligence) and define a global munitions list to ensure non-proliferation of technology that is vital to a nation's national defence. This clear distinction would open up avenues for trusted nations and private companies to trade and transfer technology related to the civil and commercial space sectors more openly, leading to greater competition within the industry. As the GSP would draw funds from member nations and private firms associated with the body, each investor/actor would have a vested interest in ensuring the security and safe passage of technology and products developed by the GSP. This vital interest by all parties would help promote a peaceful yet competitive environment for future space actors. It would also make it possible for emerging space faring nations to participate on a global scale and reap the benefits of space without having to initiate the costly process of setting up an indigenous program, but most importantly a GSP would provide a more sustainable development path for human exploration of space.

Chapter 6: Conclusion & Future Work

6.0.1 Conclusions

It was only after the cancellation of the Constellation program and the retirement of the Space Shuttle fleet in 2011 that the United States agreed it was time to let the private sector develop new and innovative technology that could potentially pave the way for the launch vehicles of the future. As part of NASA's $820 million funding initiative for the private sector, four companies were shortlisted that would receive seed funding to design new launch systems to guarantee US pre-eminence in space and ensure a rapid return to indigenous human-spaceflight capabilities. The companies themselves project NASA as a small part of their future market, and are relying on the growth of the space sector, in particular space tourism to better their odds of survival.

While current development is focused on new crew capsules, they rely on integration with independent launch vehicles for successful launch. The fundamental flaw here seems to be the idea of developing capabilities that would predominantly act as potential space taxi's ferrying crew and cargo to the ISS, and would therefore have a limited life-span and would be most likely out-dated half way through their predicted shelf life.

If we truly wish to explore space and achieve our goals of sending humans to Mars and beyond, we must start designing launch systems and vehicles from the ground up. The rational should be to develop a multi-role system, one that can be adapted based on mission specifics, be capable of transporting crew and/or cargo, offer additional safety and reliability, provide a cost-benefit ratio that ensures system sustainability and an opportunity to use alternative energy sources to provide a green launch.

We currently look at space individually; we talk about human exploration, deep-space probes, and planetary science and so on. It is vital to stop this individual approach, and develop a more comprehensive strategy to deal with space on a more rational basis. The current economic climate has already caused a dramatic reduction in public funds for space research, with future financial uncertainty making investment even more unattractive for private enterprise. The development of a multi-role system would require greater levels of international collaboration with assurances that multinational research is not stifled by national bureaucracy. Furthermore, initiating a ground up development would require large start up investment, a commitment that no single nation can achieve in the current economic climate. However this can be achieved by persuading governments and private industry to collectively pool financial and technical resources and consider the bigger picture, one that is based on common good and the betterment of society through development.

There is a public consensus that space activities are essentially a waste of money, money that could be used to alleviate some of society's problems. From a public perspective we need to change this attitude across the board, to help people understand that space is actually part of a solution – a better understanding of space, allows us to better serve the wider community; whilst from a political perspective our message should emphasize that globalization is an advantage rather than a threat, and that in the next few decades no single country will possess the economic might or the political will to 'go it alone' in space. It is essential to develop a combined space doctrine with principals, goals and objectives that in particular endorse and enable the collaborative sharing of space capabilities. We must expand on mutually beneficial agreements with likeminded nations to utilize existing and planned capabilities, and ensure that space-derived information is shared as a 'global utility'. Diplomatic engagement is essential in enhancing our ability to cooperate and collaborate with likeminded nations and partners and seek common ground.

This research introduces the VML system and assesses its advantages over conventional propulsion systems, whilst keeping in mind its financial impact. The chapters explain the reasons for the development of a VML system, and how such a system could be implemented in the current financial climate, where governments and private investors have considerably reduced the amount of capital available to new projects. In order to have a sustainable, low-cost launch system, the VML system uses the aviation industry as a reference model. To achieve a robust costing mechanism that would allow us to compete with current launch vehicles and the long-haul aviation market as it is only by expanding horizons that we can assure lower costs for future missions. We have also proposed a funding and cost recovery strategy that if implanted correctly, would allow the VML system to be cost neutral in a few years, whereby the operational costs for the system can be covered by revenue generated from hypersonic and sub-orbital flight.

When compared to other sectors the space sector is still in its infancy. The development of the VML system would help spearhead innovations of new technologies and materials that would not only allow us to realize our goals of low-cost space systems, but by enhancing cooperative and collaborative efforts we could ensure that the financial burden on member nations is reduced and there is a knowledge and skills base that all member nations could use. Most importantly the VML system would provide a more sustainable development path for human exploration of space.

The first part of this thesis provides an introduction to the space arena, discusses the public's fascination with space or the lack thereof and gives an overview of our past and present launch capabilities. It then goes on to discuss the development of the Space Transportation System (STS) which is often referred to as the Space Shuttle program. Considering the STS from its conception to the end we emphasize how development, costs and projected outlooks associated with a program of this nature change over time, and how factors beyond our control can alter the very nature of a given program. It goes on to discuss why we would consider the development of a new launch and propulsion system, one that breaks away from conventional design and fuel requirements.

Chapter 2 of the thesis provides a background on magnetic levitation technology, from the first patents received for the use of the technology for ground transportation to the current advances being made in the field. We discuss the existing Maglev technologies such as EDS, EMS and the potential for Inductrack. The chapter then discusses the use of Maglev technology in ground transport systems by considering the development of HSST systems and commercial urban systems developed by companies like Transrapid, highlighting some of its key advantages such as low LCC, weather independence and the ability to transport passengers and cargo at nominal costs. It also shows how Maglev technology is being considered for military applications such as EMALS a system specifically designed to allow military aircraft to launch from small operational runways like those on aircraft carriers. After looking at how a conceptual Maglev system in Switzerland aimed to revolutionize cross country travel, we go on to discuss the role of Maglev in the space sector. By considering programs initiated in the early 90's and the various developments since, we focus on why NASA considers Maglev to be a viable technology that could act as a launch-assist system for future orbital vehicles. We look at programs initiated and developed by NASA as well as concepts such as Startram, Maglifter and the Launch loop.

Chapter 3 of the thesis proposes the development of the VML system. After outlining the difficulties associated with considering current day Maglev systems to provide launch assist capability we outline the requirements of the overall VML system. The chapter then looks at the design and development phases of the launch system and the proposed launch vehicle. With respect to the launch system we consider three distinct elements, namely the launch tunnel, the guideway and the high-pressure network that would allow us to maintain pressures within the tunnel as close to absolute vacuum as possible. The launch vehicle design is based on the waverider principal, one where we can identify shockwave interaction with the craft body before the design process begins. By using the Taylor-Maccoll equation, we can define a conical flow field for supersonic and hypersonic flow. This in turn enables us to design a vehicle that allows for secondary propulsion system integration such as a scramjet to maintain velocity, whilst ensuring maximum payload capacity. We then go on to discuss the various phases that would be associated with vehicle launch and the advantages of choosing a launch location closer to the equator. After outlining a suitable band for launch sites that lays ±5 degrees of the equator, we discuss why choosing Tanzania for the development of the system seems like an ideal choice. The final section of the chapter looks at the potential uses of the VML system; be it for the development of a new civilian space station called Ithaca, the application of the system with regards to space tourism and hypersonic terrestrial flight or even its potential role in transporting inflatable modular structures to the lunar surface that would help in the construction of a permanent lunar outpost.

Chapter 4 of the thesis starts by looking at costs associated to human spaceflight programs. By considering the retirement of the Shuttle and initial US appropriation of $99 billion over a 10 year period we look at the validity of the proposed Constellation program, the reasons behind the presidential review of the programs and its eventual cancellation. After identifying the key principals associated with launch vehicle development, we consider the various challenges associated with costing a human spaceflight program. Looking at the role of cost estimation, we are able to consider the importance of project definition and the need for a comprehensive WBS that would identify the life cycle phases of all recurring and non-recurring costs associated with the program. After introducing risk assessment, we look at the use of TRL's and the importance of assigning an associated risk-class to each structural element of the project. We then consider two specific cost scenarios, the first looks at costs associated with the construction of a HLV based on the proven Saturn V design whilst the second looks at costing associated with the development of a HLV based on the VML system. Using the NASA NSII index we are able to illustrate the various component costs associated with the development of a HLV similar to Saturn V and how the HLV development itself would cost twice NASA's annual budget. In order to define costs associated with a VML based system, we identify five primary areas for budget consideration. By applying an analogy costing approach, we consider cost data from past programs and projects which are technically representative of the project at hand allowing us to define base line costs that would help initiate the project.

Chapter 5 of the thesis focuses on the policy aspects associated with the international space arena. We start by considering the key common objectives nations choose to address in their respective national policies before discussing why nations choose to start a space program. We define how factors such as power, politics, pride, technology and economics play an integral role in a nations decision on initiating a space program and how budgets associated with existing programs in emerging nations would continue to rise steadily until their capability creates spin-offs that better their socio-economic position. By establishing what have termed 'The equation to space' we look at how the five factors mentioned above act as potential drivers or barriers to space programs, and how a change in relationship between them can make a national program unsustainable.

Since the United States has the largest civil and commercial space budget, we consider the impact of US policy on a global stage, as well as how national policy within the United States is hampering the growth of local tier 2&3 industries. By assessing the impact of ITAR and USML, we conclude that engagement of US industry outside the country is untenable and that it has a growing risk of losing its skills base to emerging actors who can market technology and components as ITAR free. The chapter then discusses why a global space program might provide a solution. By developing a program that focuses purely on civil and commercial space development, we consider the role of governments and private enterprise can play in enhancing cooperation and collaboration across international borders. After discussing the role governments and private enterprise currently play in the domain, we focus on how the gap between could be bridged allowing us to set up new PPP initiatives. It then outlines the framework that would be required for such an initiative and how the VML system as proposed earlier in the thesis could act as a test bed for new collaborative efforts. The chapter concludes by describing why a global space program would be in the best interests of developed, developing and emerging space actors, and how this collective interest promotes a sustainable, competitive and robust space domain.

6.0.2 Future Work

The design of the VML system and its associated costing has enabled us to consider the various challenges associated with initiating a new and unique space based project. There are not only technological limitations to consider, but also those associated with costs, political will and international policy. Although the system proposed in this thesis relies on the design and development phases of the project to be based on off the shelf systems, we have been able to identify a number of areas which we think are crucial for the implementation of such a system.

Tunnel Vibration Study – As discussed in Chapter 3 the length of the tunnel required for the project would vary based on the final payload category chosen for the launch vehicle and its proposed speed requirements. The structural integrity of this structure is of vital importance to the overall system; hence one would need, once the speed requirements for the proposed launch vehicle are established, to conduct a technical study that looks at the interaction of shockwaves generated by the craft and the tunnel structure as it accelerates along the guideway.

Guideway design and Implementation – The current guideway system is based on superconducting Maglev, a technology that has only been tested for HSST. Final designs should include a practical technology demonstration and address the vibration, stability and guidance issues. They should also consider new developments made in the field and how they could be incorporated in to the VML architecture.

Vehicle Engine Development – If the project is to be implemented it would be worth investigating how new engine developments could be integrated to the launch vehicle body. Also in the case of terrestrial applications such as supersonic or hypersonic flight, it may prove more practical to use a dual-mode ramjet engine as it would be capable of operating in both flight modes.

System Location – Whilst we consider Tanzania as an option for system development in this thesis, the final location of the system should be dependent on factors like regional stability, level of national involvement in the project, availability of resources be it in terms of labour, infrastructure or power resources. Being an international effort, one should consider a viability study that looks at all of the above factors and calculates the probability of success based on standard defined variables.

Overall system cost – Since designing each component and accounting for all system variables that could be associated with the project over its effective life cycle is beyond the scope of this thesis; one should consider expanding on the WBS structure before initiating the project and developing a more comprehensive cost strategy that defines a funding and procurement cycle which is based on actuals. This can then be applied to the analogy costs derived to update the market model and the LCC for the project.

Policy Initiatives – we consider current international policy to have a limited scope for the future. Whilst we believe that the framework proposed for the GSP will enable actors to develop the VML system, current national and international policy will act as the biggest barriers towards its creation. Current steps such as the EU proposed voluntary ‘Code of Conduct’ are worth monitoring over the next few years, as they would highlight the will of the international community in coming together to develop and design future missions.

Appendix 1

Drag and Power relationship
The basic equation to calculate drag forces on a body is given below:

$$f_{drag} = -\frac{1}{2}C\rho A v^2 \qquad 4$$

The total power required to overcome the aerodynamic drag force can be represented as:

$$P_{aero} = -\frac{1}{2}C\rho A v^3 \qquad 5$$

Transmission line loss
An optimal transmission line should ideally taper from thin too thick as it runs along the track, since electrical heating along each segment would cause a net temperature increase. If we assume the voltage in the line to be constant and the capacity of current carried by the line to be limited based on the temperature rise then:

$$\int P\,dt = m\,c\,\Delta T \qquad 6$$

This can be rewritten as

$$\int I^2 R = m\,c\,\Delta T \qquad 7$$

Where ‘R’ and ‘m’ represent the resistance and the mass of a conductor segment of length L, whilst ‘c’ represents the specific heat of copper. The following equations allow us to calculate the respective values for ‘R’, ‘m’ and the cross-sectional area of the segment given as ‘A’.

$$R = \frac{\rho_e L}{A} \qquad 8$$

$$m = A\,L\,\rho_d \qquad 9$$

$$A = \sqrt{\frac{\rho_e \int I^2 dt}{\rho_d\, c\, \Delta T}} \qquad 10$$

Where ρ_e represents resistivity and ρ_d represents the density of the material.

Gas system equations
After establishing the length of the tunnel and the guideway, we can calculate the effective gas volume (V_g) with the tunnel as follows:

$$V_g = V_{tunnel} - V_{track} \qquad 11$$

Mass of gas is calculated as:

$$M_{gas} = V_g \times \rho \qquad 12$$

Where $'\rho'$ represents gas density. Now we can calculate the mass flow rate for a converging-diverging nozzle with a throat cross-sectional area ‘A’ and velocity of gas ‘V’.

$$\dot{m} = \rho A V \qquad 13$$

By applying newton’s second law along a streamlined body we can derive the following:

$$\frac{dv}{v} = -\frac{dA}{A}\left(\frac{1}{1-M_a^2}\right) \qquad 14$$

This implies that for a diverging or converging duct the relationship between subsonic and supersonic flow is as follows:

	Subsonic Flow (M<1)	**Supersonic Flow (M>1)**
Converging Duct	dA < 0 ; dv > 0	dA < 0 ; dv < 0
Diverging Duct	dA > 0 ; dv < 0	dA > 0 ; dv > 0

Table 19: Flow relation to nozzle duct

Choked Flow

Since gas flows from a higher stagnation pressure to lower pressure, if we were to assume ideal gas behaviour, then steady state choked flow occurs when the ratio of the absolute upstream pressure to the absolute downstream pressure is equal to or greater than:

$$\left[\frac{k+1}{2}\right]^{\left(\frac{k}{k-1}\right)} \qquad 15$$

Where ‘k’ is the specific heat ratio of the gas. Since the value for ‘k’ ranges between 1.09 and 1.41 for most gases, the value for Eq 15 ranges between 1.7 and 1.9. This means that choked flow usually occurs when the absolute source vessel pressure is at least 1.7 to 1.9 times as high as the absolute downstream pressure. When the gas velocity is choked, we can calculate the mass flow rate by using the following equation.

$$Q = CA\sqrt{k\sigma P\left(\frac{2}{k+1}\right)^{\left(\frac{k+1}{k-1}\right)}} \qquad 16$$

In equation 15, if the density of the gas ‘σ’ is not directly known, we can eliminate it using the ideal gas law corrected for real gas compressibility as shown in equation 16.

$$Q = CAP\sqrt{\left(\frac{kM}{ZRT}\right)\left(\frac{2}{k+1}\right)^{\left(\frac{k+1}{k-1}\right)}} \quad 17$$

The above equations calculate the steady state mass flow rate for the stagnation pressure and temperature that exists in the upstream pressure source. If the gas is released from a closed high pressure vessel the steady state equation only approximates the initial mass flow rate.

Accidental Release flow rates

In order to determine the consequence of accidental release flow rates from a pressurised gas system, it is necessary to choose the right dispersion model [122], [123]. For gases that are lighter than or equal to the ambient air density we use a Gaussian model, whilst for those heavier than ambient air density we use a dense gas model. The two models shown below only apply to gases that are at high pressure and are released under choked flow conditions.

Rasouli and Williams's source model:

$$P_2^{\left(\frac{1-k}{2k}\right)} = P_1^{\left(\frac{1-k}{2k}\right)} + (t_2 - t_1)\cdot\frac{CA}{v}\cdot\frac{(k-1)}{2k}\sqrt{\frac{g_c R k^3}{M}\cdot\frac{T_0}{P_0^{\left(\frac{k-1}{k}\right)}}\cdot\left[\left[\frac{2}{k+1}\right]^{\left(\frac{k+1}{k-1}\right)}\right]} \quad 18$$

Bird, Stewart and Lightfoot source model:

$$t = \left[F^{\left(\frac{1-k}{2}\right)} - 1\right]\left(\frac{2}{k-1}\right)\left(\frac{V}{CA}\right)\sqrt{\left[\frac{g_c k P_0}{\sigma_0}\right]\left[\frac{2}{k+1}\right]^{\left(\frac{k+1}{k-1}\right)}} \quad 19$$

Exhaust gas velocity for a converging diverging nozzle

$$V_e = \sqrt{\left(\frac{TR}{M}\right)\cdot\left(\frac{2k}{k-1}\right)\cdot\left[1 - \left(\frac{P_e}{P}\right)^{\left(\frac{k-1}{k}\right)}\right]} \quad 20$$

$$A_t = \frac{\dot{m}}{P_t}\sqrt{\frac{RT_t}{Mk}} \quad 21$$

When the nozzle is operating at design conditions, the equation for the velocity of exhaust gases is modified as below

$$V_e = \sqrt{\left(\frac{2k}{k-1}\right)\cdot\left(\frac{RT_c}{M}\right)\cdot\left[1 - \left(\frac{P_e}{P_c}\right)^{\left(\frac{k-1}{k}\right)}\right]} \quad 22$$

Where 'T_c' is the inlet chamber temperature, 'P_c' is the inlet chamber pressure and for a given Mach number '*M*' can be calculated as below:

$$\boldsymbol{P_c = P_e\left(1 + \frac{(k-1)M^2}{2}\right)^{\left(\frac{k}{k-1}\right)}} \qquad \mathbf{23}$$

$$\boldsymbol{T_c = T_t\left(1 + \frac{k-1}{2}\right)} \qquad \mathbf{24}$$

Surface temperature and Heat Flux

We can use the following equation to calculate the surface temperature and heat flux for three dimensional stagnation points [124].

$$\boldsymbol{q = (\rho_w C p_w \tau)\dot{T}_w = F(h)(H_{st} - H_w) - \beta T_w^4 + S} \quad \mathbf{25}$$

Where '*S*' is the solar and nocturnal radiation input which is negligible except at low speeds. Since specific heat and density relate to thermal values for the given material, we are only able to alter the heat capacity associated with the material by altering its thickness. In order to solve the above equation, we must resolve the heat transfer coefficient denoted as '*h*'. This can be done using the Fay and Riddell method if we consider three-dimensional stagnation points [125]. If we were to consider a constant entropy flow we could rewrite the above equation as the following.

$$\boldsymbol{q = (\rho_w C p_w \tau)\dot{T}_w = (h)(H_R - H_W) - \beta T_w^4 + S} \quad \mathbf{26}$$

This can be reduced to the following equation based on the '*Blasius*' incompressible skin friction formula [126].

$$\boldsymbol{h = (F)0.332\sqrt{\frac{\rho^* \mu^* V_L}{x}}\left(P_{r_w}\right)^{-0.6}} \qquad \mathbf{27}$$

Where $\left(P_{r_w}\right)^{-0.6}$, is the modified Reynolds analogy factor. When considering compressibility effects we can obtain the values associated with wall enthalpy, temperature and dynamic viscosity at reference enthalpy via real gas tables [127]. In order to calculate the turbulent heat transfer coefficient, we must resolve the skin friction coefficient and then relate the skin friction to the heat transfer coefficient. By using the '*van Driest*' method [128] we are able to calculate the heat transfer coefficient as:

$$\boldsymbol{h = F\frac{C_f \rho_L V_L}{2\left(P_{r_w}\right)^{0.4}}} \qquad \mathbf{28}$$

To simplify the equations above if we were to consider the proposed launch vehicle in hypersonic flight, with respect to gas flow we would notice a boundary layer flow and a hypersonic shockwave generated in front of the vehicle. The area between the shockwave and the boundary layer is known as the shock layer and this is where density and pressure changes lead to a dramatic rise in temperature. If we consider points 'a' and 'b' as shown in fig 86, where point 'a' represents any point just after the shock wave whilst point 'b' represents a point that is downstream of the generated shockwave, we can state that since the gas is presumed to be thermally perfect it would obey thermodynamic laws such that:

$$\frac{P_a}{(\rho_a R T_a)} = \frac{P_b}{(\rho_b R T_b)} \quad \mathbf{29}$$

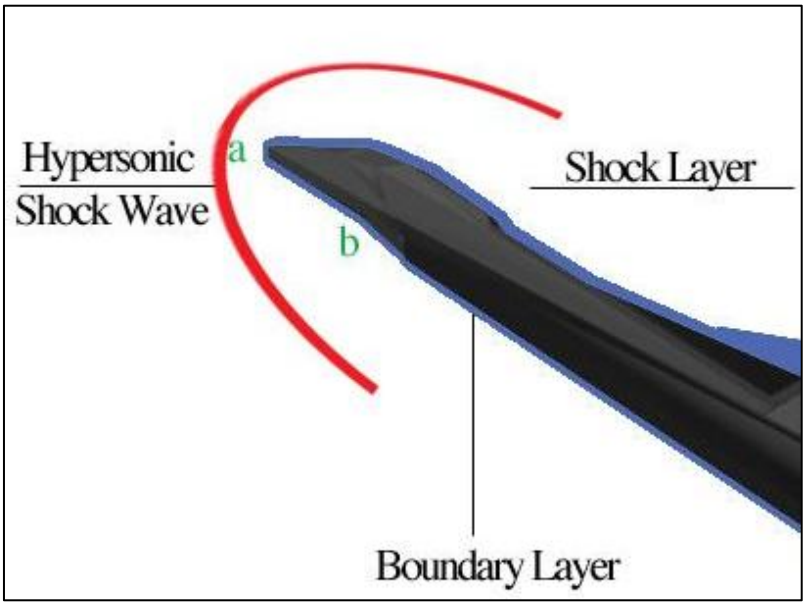

Figure 86: Representation of Shock layer

Since specific heat exchange is related to entropy, we can calculate the adiabatic lapse rate (change in temperature with variance in altitude) for dry air as:

$$\frac{dt}{dz} = -\frac{mg}{R} \cdot \frac{\gamma - 1}{\gamma} = -9.8\,°\mathrm{C}/km \qquad \mathbf{30}$$

For the purpose of the proposed launch vehicle we make the assumption that heating effects caused during take-off and re-entry would be comparable to that of the shuttle, and with the given TPS the craft would be able to withstand a nose temperature up to 3000^{o} F at a 40^{o} re-entry angle [77].

Maximum Deflection

$$\boldsymbol{\delta_{max}} = \frac{5wl^4}{384EI} \qquad \textbf{31}$$

By considering the Youngs modulus for Stainless steel we can work out the varied thickness of the beam.

We can now rewrite the equation as:

$$\boldsymbol{\delta_{max}} = \frac{5(10^5)(30)^4}{384(180*10^9)\frac{b}{12}} \qquad \textbf{32}$$

Resolving this equation we get:

$$\boldsymbol{\delta_{max}} = \frac{0.281}{h^3} \qquad \textbf{33}$$

Appendix 2

Disclaimer

The following questionnaire contains views that were received as part of a telephone conversation conducted on 20th January 2011. The questionnaire is designed to provide the undersigned a basic understanding of certain issues as part his DPhil research being conducted at the University of Sussex.

The undersigned agrees that all views expressed in the following questionnaire are strictly personal and should not in any way be interpreted as those of the UK Space Agency or affiliated bodies. The undersigned also agrees to seek the interviewee's permission before publishing any part of this interview alongside his thesis.

Interview/Discussion held with: ***Mr. Andrew Payne (UK SA)***

Interview Conducted by: Tanay Sharma

Interview conducted on: 20/01/2011

Mode of interview/discussion: Telephone Conversation

Tanay Sharma

UK Space Agency Questionnaire

1) **Do colleagues feel that the future of space lies as a contested domain, or would it still be possible to maintain space as a cooperative domain?**
   Yes and No.

   There are two ways to look at space activity, institutional development and commercial activity. There exists a fair amount of cooperation in the institutional arena with a possibility of further cooperative ventures. ESA is a prime example in terms of cooperation between various likeminded states and there are also a number of bilateral space agreements. NASA would also acknowledge that international cooperation is essential.

   In terms of commercial activity, there is already a strong competitive market and there may well even stronger competition as nations like India and China develop. Due to the rapid growth of China and India there may eventually be competition in largely non-commercial areas such as manned space, space stations and lunar exploration mainly for reasons of national prestige. However it is probably too early to predict, how this will develop. It should be noted that due to the current economic climate and the financial constraints of large scale missions, cooperation would be necessary even in the foreseeable future.

2) **Is the United Kingdom's commercial and economic interest hindered by current export control regulations?**
   Mr. Payne suggests the above question should be referred to the Export Control Office.

3) **Would colleagues agree with the statement that "current international governance of the space environment is effective and adequate"?**
Due to the shape of the global space sector there are a few difficulties this question is not straightforward. NASA and DoD have a large space operations budget, with the NASA budget accounting being by far the largest worldwide. Whilst the ESA is relatively strong, countries like Russia, India, China, Japan and Brazil also have a growing space budgets. Emerging countries also have the advantage of being able to employ a large, well-educated workforce at relatively low costs, the cost of components and the ready availability of labour.

ESA is essentially a European institution, although a number of MOU's exist with NASA and others.. The European Union has recently taken a keen interest in space, based on a competency specifically stated in the Lisbon treaty. However, the EU and ESA currently have very different industrial and procurement policies. There is a general European concern with the ITAR regime, as many electronic components in satellites can now only be sourced from the US. For the EU and ESA it would also prove very expensive to catch up in terms of technology if they pursued internal development of ITAR-free products and services.

4) **Would it be beneficial for the United Kingdom to consider the development of commercial space ports in conjunction with international partners, providing a dedicated launch facility and launch vehicles?**
There are potential problems:

i) Like the US, where commercial operations within the atmosphere require a licence from the FAA, atmospheric flight of any vehicle taking off from UK soil would need to be licensed by the Civil Aviation Authority and in future by the European Aviation Safety Agency.
ii) Furthermore where that vehicle leaves the atmosphere and enters space, it would have to meet regulations such as the Outer Space Act.
iii) Insurance of such vehicles is extremely expensive and could prove to be a potential problem.

Whilst the UKSA would be supportive of such developments in policy terms, these are essentially privately funded ventures.

5) **Is there scope for a broad global space policy to engage emerging nations, and develop a centralized multilateral response to space research?**
There are a number of localized groupings that are currently emerging. Whilst India and China have independent programs, there have been talks of an African Space Agency that would serve the interests of partner nations. Similarly Indonesia, Singapore and others I the Far East may find they have common interests.

Countries like India and China are driven by three elements:

i) National prestige that comes with a successful program
ii) Addressing national security concerns
iii) Commercial aspects and the need for them to develop technologies that would help with remote sensing, medicine, military aspects and satellite development.

There currently exists a small degree of cooperation between India, China and Europe.

Whilst there are advantages to a unified policy of multilateral groupings, it is difficult to see how that could be implemented or work in a context very different from the establishment of the European Space Agency in the 1970s.

6) **What role do colleagues see for a public-private partnership in the development of civil and commercial space sectors in the future?**
There has been enthusiasm with regards to the concept of PPPs in the UK. Skynet is a good example; one that has proved extremely successful in terms of both services provided and returns. In other areas, such as the recently launched Hylas satellite, UK has provided development funding, through ESA, to enable its owners, Avanti, to leverage that support to raise considerable PV funding on the market.

There would appear to be little chance that the UK would ever consider getting back in to development of traditional launchers. However, the UKSA has provided funds through ESA for the Skylon project that hopes to develop a ground to space to ground vehicle based on new technology through the company, Reaction Engines. There is a growing demand for delivering bigger payloads, and a current debate in Europe, on how to fund what launcher comes after Ariane 5.

7) **Would colleagues consider the notion that future growth of space activities will be driven by emerging markets like India and China as international economic activity shifts to the east?**
Space activity for the foreseeable future would still be driven by the US, not just in terms of technology but also in terms of research due to the amount of capital available. However, there are a number of nations that could play a significant role in the future, such as Japan, India, China, Brazil and with certain Middle Eastern and African countries still some way behind.

Building relations and industrial links with these nations would be essential. In order for these countries to play a significant role in the future growth of space activity, they will need to move from using space to predominantly service their internal programs to competing in the international market. Such a move would provide risks for European industry through competition. But may also have benefits in providing alternative sources of components that are currently only now available from the US.

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