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CANADIAN SPACE LAUNCH: EXPLOITING NORTHERN LATITUDES FOR EFFICIENT SPACE LAUNCH

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by

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ABSTRACT

Canada represents an advantageous location for a commercial space launch facility to launch satellites into highly inclined orbits (HIOs). Compared to launches which take place from facilities at lower latitudes, it is more efficient to launch HIOs from Canada. This is relevant because the majority of satellites currently in orbit are in this HIO category and are poised to increase in the future. While there are two Russian facilities that launch the majority of HIOs, political turmoil and potential conflict would make Canada an ideal potential location for a future space launch facility in order to mitigate these concerns. There are a number of potential launch sites available in Canada which offer a wide variety of launch azimuths, access to infrastructure and overall launch efficiency. One of the sites, located at Fort Churchill, offers the best overall potential based on all pertinent factors. Canada also offers a business-friendly environment and potential source for funding that will aid in the overall success of such an endeavor.

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Introduction

Research Question

In what aspects does Canada represent an advantageous location for the development of a commercial space launch capability?

Hypothesis

Canada represents an efficient launch location for a government sponsored commercial space launch facility capable of Highly Inclined Low Earth Orbits which would simultaneously meet the strategic national interest of the country and the needs of the commercial space industry.

Description of Research Problem

There are many considerations that make Canada an intriguing research area for commercial space development. The commercial space industry appears to be a sector of the economy that will grow in the coming years. However, while Canada is involved in certain areas of the sector, it lags behind other developed nations. In 2011 Canada's space sector posted revenues of slightly less than $3.5 billion as compared to a $290 billion global industry.[1] As one of the leading economies of the world, surely Canada should represent a larger portion of the international commercial space sector based on its political stability, access to resources and business-friendly governmental legislation. Canada also represents an excellent opportunity for space launch due to its access to three oceans which make a wide variety of launch azimuths possible. Finally, based on the theoretical advantages of launching Highly Inclined Orbits (HIOs) from Canada, the detailed analysis of Canada as a unique commercial space opportunity is an intriguing topic.

Research Argument

Canada represents an advantageous location for a commercial launch capability because its geographical location reduces the required energy to launch satellites into HIOs. Additionally, HIOs represent a large portion of total world launches, there are limitations present in current international launch facilities, and Canada's government and tax system represents an attractive atmosphere for commercial space companies. Due to the necessity to launch against the rotation of the earth, the velocity needed to launch a satellite into a retrograde orbit is lower as the launch site moves farther north from the equator. Additionally, for prograde orbits with inclinations greater than 45°, ideal launch sites are located at latitudes that correspond to the orbit inclination which takes advantage of the earth's rotation.[2] Outside of these theoretical efficiencies, there are many attractive aspects of operating in Canada due to a low corporate tax rate and possible governmental support to the space industry. The current number of launch facilities world-wide meets the demand today, but due to increased demand as well as political instability in some regions, the future demand may outpace the current launch capacity. Although it is possible to continue to launch these orbits from launch locations farther south, launches from more northern latitudes are at least as efficient and, therefore, a practical proposition.

Research Methodology

In order to examine the viability of a Canadian space launch sector, this paper will use a research methodology that logically and sequentially analyzes the issue by answering four overarching questions. *Is it more efficient to launch HIOs from higher latitudes? Do HIOs account for a significant portion of satellites? Which launch facilities conduct launches to HIOs and are they sufficient for international demand? What can the Canadian government do to*

assist in the development of a commercial space launch capability? Initially, this paper will investigate the theoretical efficiency of launches into HIOs from Canada. Once it has been established that launches from Canada are at least as efficient as other launch sites, an examination of historical HIO launches as well as a breakdown of HIO satellites will be carried out to determine if these types of launches represent a significant amount of the total market. Following this step, which proves that there is a commercial market for HIO launches, an analysis of the current major launch sites situated in latitudes similar to Canada will be conducted to determine where HIO launches are currently taking place and to determine what limitations are present in the current system. The final section will assume the previous three assumptions are valid and will investigate what activities the government of Canada can perform to develop this sector. Specifically, this paper will investigate building a launch facility as well as various aspects of taxation and legislation that make Canada an attractive destination for commercial space companies.[3]

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General Definitions

Highly Inclined Orbit. Throughout this paper the term Highly Inclined Orbit (HIO) will refer to satellites in orbits with inclination between 45° and 135° where 90° indicates an orbit directly over the North Pole.

Is it more efficient to launch HIOs from higher latitudes?

In order to proceed with an investigation into theoretical Canadian launch facilities, it is necessary to first prove that it is more efficient to launch HIOs from latitudes on Canadian soil. A simplified overview of launch characteristics and an analysis of theoretical launch efficiencies will demonstrate Canadian launch efficiency.

General Launch Characteristics

To determine the efficiency of proposed Canadian launch sites we must first examine the physics involved in launching a satellite. For a satellite to meet its mission characteristics its launch must provide a requisite amount of velocity to attain a specified orbital altitude as well as orbital velocity.[4] The $\Delta\vec{V}_{needed}$, is the "total velocity change that the launch vehicle must generate to meet the mission requirements."[5] To determine the $\Delta\vec{V}_{needed}$ we add three variables: the velocity needed to overcome gravity, the velocity of the launch pad due to the earth's rotation and the velocity needed to be in a desired orbit once the rocket burns out. The first of the three variables is called $\vec{V}_{loss\ gravity}$ and will be the same for any launch pad location. The other two vectors change depending on the launch location and as such will be pertinent to this discussion. The location of the pad changes two important factors when determining the launch velocities required, the rotational velocity of the pad due to the earth's rotation, or $\vec{V}_{launch\ site}$, and the azimuth of the launch which changes the $\vec{V}_{burnout}$ depending on the location.

The rotation of the earth is a significant factor when determining launch efficiency and is the single biggest impetus for the premise of this research paper. The variable most significant to this discussion is related to the earth's tangential velocity, that is, the speed that a point on the surface of the earth is moving based on the rotation of the earth around the axis between the north and south pole. A point on the surface of the earth at the equator is much farther away from the axis and travels much faster than a point closer to the pole because of the larger radius. As a result of this speed, which equates to approximately 1600 kilometers per hour at the equator, we can provide a launch vehicle a "head start (assist) for launches in the easterly direction" which results in the ability to "launch a larger payload."[6] As described above, the $\vec{V}_{launch\ site}$ is of a greater magnitude the closer it is to the equator. The direction of the vector is

always directly eastward, or 90°. For prograde orbits, to take full advantage of this assist the most efficient launches are those that are directly eastward. When the launch latitude is equal to the orbital inclination the launch azimuth is directly eastward and therefore the most efficient.[7] Conversely, for retrograde orbits the rotation of the earth works against the launch. As such, it should be advantageous to move farther away from the equator.

Plane changes which alter the orbital inclination of a satellite after its already established into a different orbit are "*very expensive* (in terms of ΔV)," with a 60° plane change requiring "the [same] amount of velocity needed to get into the orbit in the first place."[8] Therefore, it is always more efficient to launch the satellite into a direct orbit. It is also important to note that a rocket can only launch a satellite directly into an orbital inclination greater than the launch pad latitude. For example, launching a satellite into a 28.5° orbit from Cape Canaveral is possible, but launching a satellite into a 0° orbit from the same location would require an expensive plane change. For this reason, one can assume that if we are looking for efficient launches then those that require a plane change will not be as efficient as others.

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Launches Between the Equator and 45°

Launches for orbital inclinations which are less than the latitude are inefficient as they require costly (in terms of velocity) plane changes. Therefore, this paper will not provide any further analysis for these orbit types.

Retrograde Launch Efficiency

As discussed above, retrograde orbits, which launch in a westward direction, have to work against the earth's rotation. It follows that an ideal launch location would be one where the tangential velocity was the least, that is, a latitude as close to the pole as possible. The following

graph uses an equation that calculates the total $\Delta\vec{V}_{needed}$ for launches from various latitudes and shows that as the launch site moves north for a 98° inclination orbital launch, the $\Delta\vec{V}_{needed}$ is reduced. While the difference in velocity is small, it shows that launches from a potential Canadian launch site are at least as efficient as those farther south.

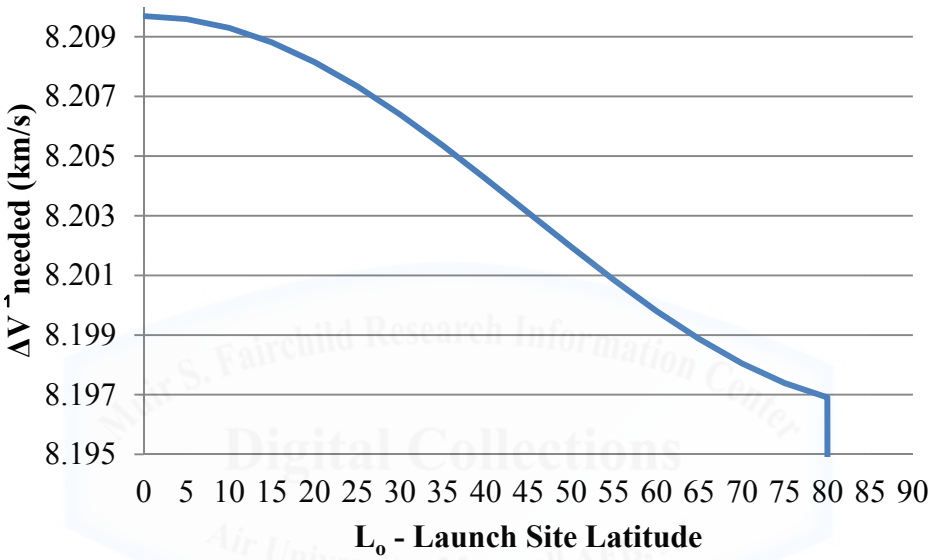

Figure 1 – Launch Site Efficiency for 98° Orbital Inclination

Greater Than 45° Prograde

The most efficient launch parameters for prograde launches are when the launch azimuth is equal to the orbital inclination. Figure 2 shows that launch efficiency increases as launch site location moves from the equator to a location equal to the intended orbital inclination and that the velocity needed is lowest when the latitude and inclination are equal.

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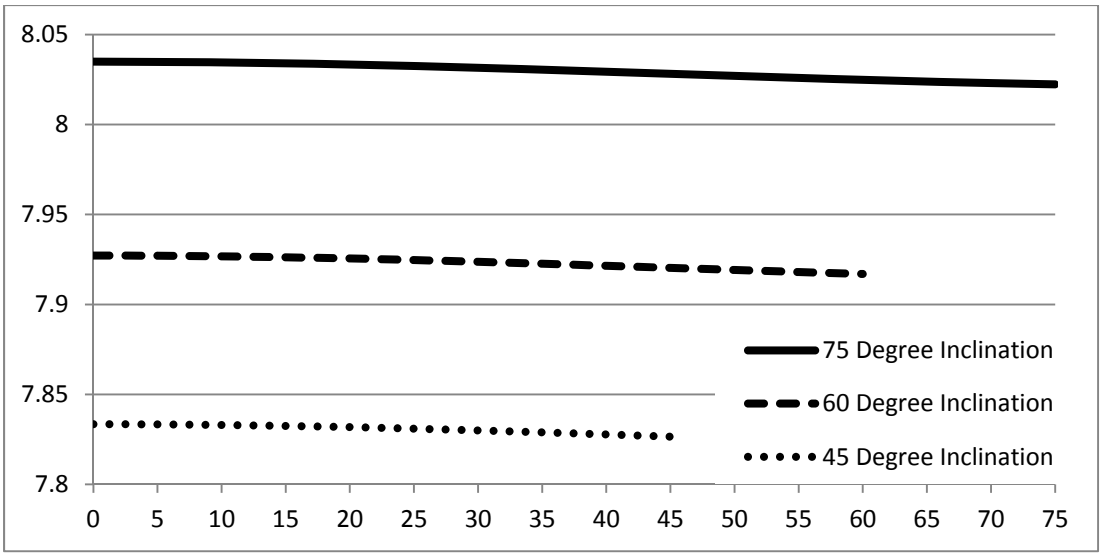

Figure 2 - Launch Site Efficiency Versus Launch Location

Initial Findings

The preceding analysis showed that there are theoretical efficiencies that can be gained by launching HIOs from a potential Canadian site. However, the differences were not as large as this author initially assumed, specifically as it pertains to retrograde launches. After some analysis it is apparent that as the launch location moved farther north the earth's rotational vector became smaller as initially hypothesized. However, the launch azimuth also changed, from 98° if launched at the equator to 53° if launched from the 80th parallel. As such, the earth's rotation caused a greater negative-assist to the launch. That being said, these calculations have proven that HIO launches are at least no less efficient than at more southerly locations.

Do HIOs account for a significant portion of satellites?

Now that the theoretical efficiency of a potential Canadian launch site has been proven, the next step is to determine if HIOs account for a large enough portion of overall launches to justify the construction of a Canadian facility. Following an analysis of the Union of Concerned

Scientists' Satellite Database, of the 1235 listed satellites orbiting the earth 58% are located in HIOs. Figures 3 and 4 below are a graphical representation of the database and show that a significant portion of orbits do occupy HIOs. In addition, the data shows that of the HIOs, 64% are in polar orbits. These findings continue to point towards the potential of a northern Canadian launch facility which would take full advantage of the efficiency gained from a high latitude launch site catering to polar launches.

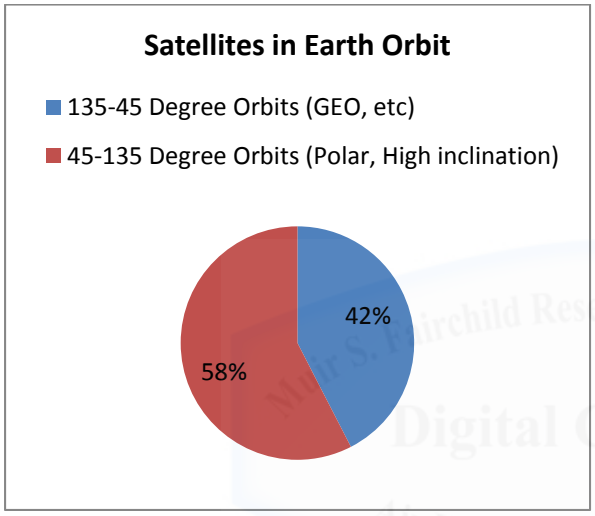

Figure 3

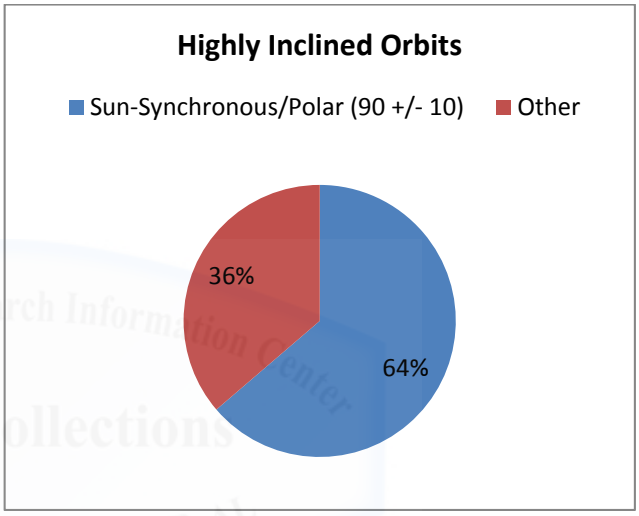

Figure 4

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Which launch facilities conduct launches to HIOs and are they sufficient for international demand?

The following nine launch facilities were chosen for further examination for a number of factors. They are all located at a latitude of 35° or higher and, therefore, represent a similar efficiency as compared with Canada. They also account for 77% of all satellites in HIOs and 73% of all of the associated launches.[9] As such, focusing the analysis of current launch facilities to these nine facilities should represent a comprehensive view of this segment of the international launch sector. The intent of this section is to investigate where the launches to HIOs are taking

place and to determine if the addition of a Canadian site would be worthwhile given the capabilities and characteristics of these facilities.

Russia

Russian facilities represent a good comparison to Canada because they represent similar latitudes, climates, and geography. As such, they will be examined in greater detail than many of the other launch sites.

Baikonur Cosmodrome. Baikonur is located roughly 2,100 km southeast of Moscow in the Republic of Kazakhstan. The world's first artificial satellite, Sputnik, was launched from Baikonur on 4 October 1957 making the site the oldest and longest continually running site in the world.[10] Baikonur is not only the busiest Russian launch facility, but it is also the busiest facility in the world. It accounts for nearly 30% of all launches for the last ten years and 28% of all satellites currently in HIOs were launched from the site. [11] Despite its latitude of approximately 46^{o} N, Baikonur is used to launch satellites in a variety of orbits ranging from geostationary to sun-synchronous. The Russian government currently has a long-term lease with the Kazakhstan government for the land that the site inhabits that is valid until 2050.[12] The Baikonur Cosmodrome has an annual temperature average of 13^{o} Celsius, but can experience a large range in temperature between -40^{o} and 45^{o} Celsius.[13] A number of geographical aspects make launches from Baikonur less than ideal. Launch azimuths are limited for Baikonur in order to avoid rocket stages impacting populated areas or other countries and spent boosters, rife with residual toxic substances, land in the Russian countryside and now pose numerous health hazards.[14] Due to range safety restrictions at other launch sites, Baikonur is the onlyRussian site that can launch satellites directly into retrograde orbits.[15]

Plesetsk Cosmodrome. The Plesetsk Cosmodrome is located at approximately 63 ^{o} N, about 600 kilometers northeast of St. Petersburg. Between 1969 and 1993 it was the busiest launch facility in the world having hosted over a third of all orbital or planetary missions worldwide.[16] Plesetsk is Russia's most northern launch facility which makes it useful for reaching polar orbits not accessible from Baikonur.[17] It is now the second busiest Russian launch facility accounting for over 8% of all worldwide launches in the last 10 years and 20% of all launches for payloads put into HIOs.[18] Due to its northern latitude, the types of orbits suitable to be launched from the facility are limited to higher inclinations. However, unique orbits such as the highly elliptical Molniya orbit can be achieved by a natural eastward launch azimuth.[19] This site has provided Russia "with valuable experience in the conduct of extreme cold weather launch operations."[20]

Dombarovsky Launch Facility. The Dombarovsky launch facility is located in Southern Russia north of the Kazakhstan border. Originally built as a Soviet ICBM base, the facility's purpose has been expanded to include commercial space operations using the Dneper booster.[21] The site is located at approximately 50.7° N, and is a potential Russian-based alternative for Baikonur. Launches from the site could provide southerly launches of Dnepr booster into highly inclined sun-synchronous orbits with stages landing in Turkmenistan and the Indian Ocean as well as 65° inclination orbits launched in an eastern direction with stages dropping in the Tyumen regions and the Pacific Ocean.[22] While the site may eventually become more active, only 3% of the launches associated with all current HIOs and only eleven total launches in the past ten years have taken place at Dombarovsky.[23]

Svobodni Cosmodrome. Svobodni Cosmodrome was established in 1996 as a possible alternative to both Baikonur because of its "unclear political and economic status" and Plesetsk

because of its limitations for launching lower orbital inclinations.[24] The latitude of the site is similar to that of Baikonur, but much farther east into Russia. The site was mothballed in 2007 due to funding issues but later that year it was decided that the site would be upgraded and was renamed "Vostochny Launch Site." [25] If the site is developed as detailed then it will take over the responsibility for the manned space program from Baikonur in 2020 following the conclusion of Russian participation in the International Space Station project and most likely also equatorial and other low-inclination orbits.[26] The Russian space agency has committed to staying in Baikonur until the expiration of the current lease, but hopes to shift 45% of all launches to the site by 2020; however, the first operational launch has yet to take place.[27]

Peoples' Republic of China

There are two Chinese launch facilities located north of the 35th parallel that launch satellites into HIOs. Together they account for approximately 22% of all launches of satellites into HIOs.[28] While the PRC accounts for a sizeable portion of HIO launches, they are not a major factor in the commercial space sector at the present time. All launches have been for either the Chinese government or Chinese companies with the only exceptions being the launching of nine Iridium satellites for Motorola in the late 1990s as well as single satellites for Luxembourg, Turkey and Argentina. [29]

Jiuquan Satellite Launch Center (JSLC). Sometimes referred to as the East Wind launch facility, JSLC is located on the southern edge of the Gobi Desert at a latitude of approximately 41° N. In 1970 China became the fifth nation to deploy a satellite in space when a DFH-1 satellite was successfully launched from JSLC. The launch site is used mainly for low altitude orbits with inclinations of 40° or more.[30] The JSLC accounts for 9% of all HIO launches from sites north of the 35th parallel.[31]

Taiyuan Launch Center. Located at 37° North, Taiyuan is primarily used for sun-synchronous mission of meteorological and earth resource satellites.[32] Taiyuan accounts for 13% of all HIO launches from sites north of the 35th parallel.[33]

USA Launch Facilities

There are 3 US based launch facilities that conduct launch operations north of the 35th parallel that launch satellites into HIO. In terms of overall launch output in this category, the US is second only to Russia, representing 35% of all launches in the category for comparison.[34] Vandenberg AFB accounts for the vast majority of these launches with Mid-Atlantic Regional Spaceport and the Kodiak Launch Complex also active. Regardless of the large difference in the current capacity, the other two sites are worth discussing as they both have aspects in common with a potential Canadian site.

Vandenberg AFB. The Vandenberg Launch Complex is capable of launching sun-synchronous orbits over water and therefore launched the majority of all US HIO missions with 21% of all launches for satellites still orbiting in HIOs having occurred there.[35] Its location of 35° N does not equate to a velocity savings to the extent that a more northern latitude facility would.

Mid-Atlantic Regional Spaceport (MARS). The MARS is located at the NASA Wallops Island Flight Facility at approximately 38° N. The Virginia Commercial Space Flight Authority (VCSFA) was established by both the Virginian and Maryland Governors in 1995 and leases land from NASA for their site which consists of two launch pads licensed by the FAA for launching up to 11,000 pounds into low earth orbit.[36] MARS is capable of launching between 38° and 60° inclinations or outside of these parameters with costly in-flight maneuvers.[37] MARS may represent a possible advantage over government run sites because it exists within the private

sector and strives for cost effectiveness. The details of this site are pertinent when comparing it to a theoretical Canadian site because it represents many ideal theoretical similarities such as public-private partnership, relatively small size and overall cost. Due to these similarities, the MARS site will be used to determine requirements of the proposed Canadian site in later sections of this paper. MARS does not currently represent a large portion of HIO launches having only 5 launches, or less than 2% of all HIO launches for satellites still in orbit.[38]

Kodiak Launch Complex (KLC). The owner and operator of the KLC is the Alaska Aerospace Corporation, a public corporation that was established by the State of Alaska. KLC is located at 57° N and is a commercial spaceport which is not collocated on a federal range. Unlike MARS which leases its land from the government, KLC is situated wholly on state owned land. As the only high latitude spaceport on US soil, KLC's facilities are designed to support launches to polar HIOs and KLC is the only US site capable of economically launching to the highly elliptical Molniya and Tundra orbital inclination of 63.4°.[39]

As with the MARS site, KLC has many similar aspects to any future Canadian launch facility. Based strictly on its launch history, KLC is mostly a non-player in the commercial space sector as it has only hosted 3 launches to HIO in its history.[40] However, in addition to many similarities also shared with MARS such as small size and public-private cooperation, the northern latitude of the site makes it a good comparison tool for any future Canadian facility. Due to these considerations, details of KLC's infrastructure and design will factor into the later discussion about a Canadian site.

Future Launch Demand

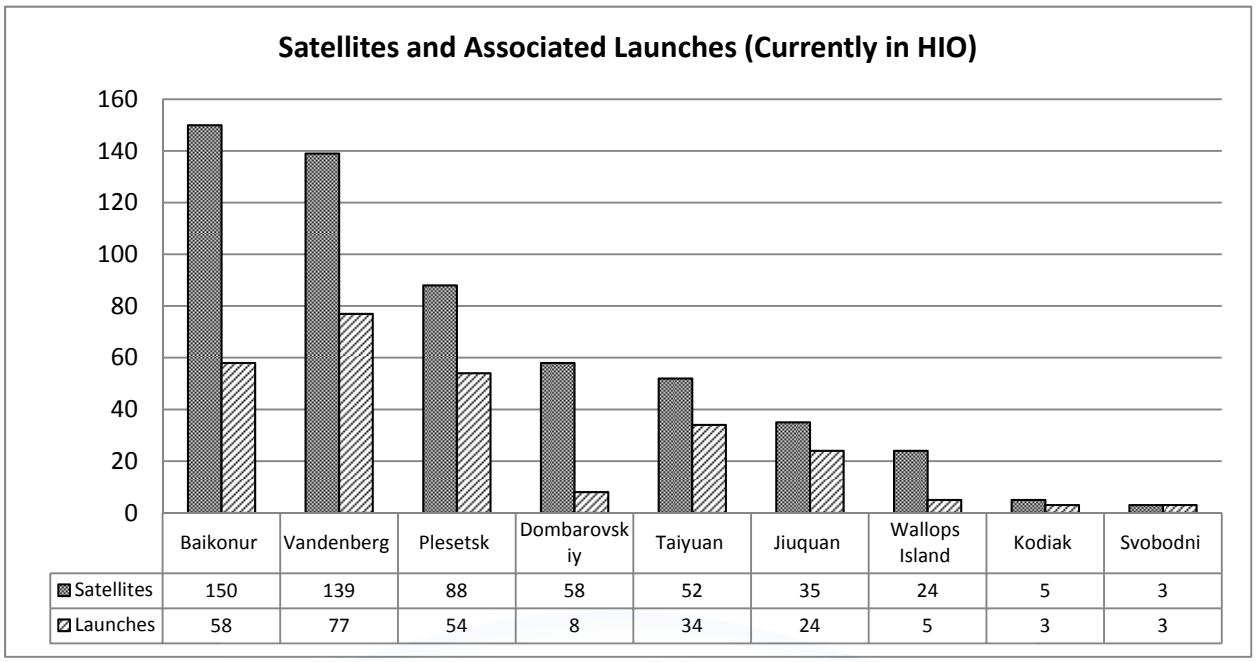
The current forecast for space launch rates do not indicate large overall increases, but HIO launch rates may increase. In its *Commercial Space Transportation Forecast*, the FAA

projected launch rates to remain relatively stable over the next ten years.[41] However, satellites that are smaller than traditional payloads are forecast to increase by roughly 40%.[42] Additionally, over half of these types of satellites will be conducting earth observation, a task that lends itself to polar orbits.[43] Taken together, these facts point to the likelihood that the demand for HIOs will most likely increase in the future and validate an increase in the number of launch sites capable of HIO launches.

Identified Issues

Russia is the most interesting case to study based on both its volume of launches as well as its comparable latitudes to Canada. Figure 5 shows the significant portion of HIO launches that take place from Russian facilities. Numerous western companies either have operations dependent upon the facility or rely on the facilities to launch payloads. Although the lease between the governments of Russia and Kazakhstan has been uninterrupted since its establishment in 1994, the possibility remains that internal or external conflict in the region could interrupt space operations in the future. Internal unrest and rioting in the towns of Baikonur and Leninsk that took place from 1992 until 1993.[44] In addition, recent Russian involvement in the annexation of Crimea and the civil conflict in Eastern Ukraine highlight the possibility of future Russian aggression that could result in issues for Western countries to continue space launch from Russian launch facilities. This volatility and political turmoil could induce risk into an already extremely expensive endeavor. Multi- billion dollar space projects carried out by publicly traded companies might see space operations in a stable country as ideal. For these reasons it is likely that an increase in North American launch capacity with similar

latitudes to Russian facilities would be a welcomed alternative for commercial space companies.



	Baikonur	Vandenberg	Plesetsk	Dombarovskiy	Taiyuan	Jiuquan	Wallops Island	Kodiak	Svobodni
Satellites	150	139	88	58	52	35	24	5	3
Launches	58	77	54	8	34	24	5	3	3

Figure 5

What can Government do to assist in development of this sector?

To summarize up to this point, we have now established that HIO launches are more efficient as the latitude of the launch site increases, there are currently a large number of launches taking place from higher latitude launch sites with Russian facilities representing the bulk of the launches, and that polar orbits represent a large portion of all satellite orbits. Logically, these facts point to the likelihood that a Canadian facility would be appropriate to pursue. The final section will assume that this is the case and focus on what the Canadian government can do to assist in the development of the Canadian commercial space sector. The following will provide an in depth analysis of the various governmental activities such as building a commercial launch facility, tax incentives and other legislation that can contribute to a successful space launch initiative.

Build Launch Facilities

To spur growth in a Canadian space sector, the government of Canada should build a spaceport similar to what state governments did in Virginia and Alaska. As with the Virginia and Alaska examples, the size of the initial investment in a launch facility is quite high, potentially higher than a commercial entity is willing to undertake. The reported cost of MARS was $145 million.[45] This excessive cost has halted prior attempts by commercial companies to develop a launch facility and demonstrates that governmental funding and initiative is a logical conclusion. In addition, it is in the interest of the Canadian government to develop a space launch facility, however small, if only to increase its self-reliance and stature within the international community. To determine the scope of what is required, first we need to look at these types of facilities and determine the composition of a launch facility. With this information we can then compare three potential sites across Canada and come up with advantages and disadvantages for each in order to make a final recommendation.

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Description of Launch Facility

While a similar sized launch facility as those found at Kodiak or MARS should be the goal for Canada, the best example to illustrate the general characteristics of a launch facility is Kodiak. The rationale is that Kodiak, unlike MARS, is a standalone facility whereas MARS relies on NASA for a portion of its infrastructure. A second important factor is that Kodiak is located in a similar climate to Canada and must deal with much more inclement weather than sites located in the continental US. In either case, the majority of the factors to discuss are similar in all facilities.

A potential launch site must have the appropriate size to accommodate the required physical infrastructure of a launch site. Situated on over 3,200 acres, KLC has five primary

facilities as well as a number of smaller support facilities.[46] The primary facilities, which include the launch pads, operations center and payload processing, are tailored towards the northern climate as they feature all weather capabilities. The supporting infrastructure provides the necessary communications, administration, utilities and other services.

Another critical aspect of any potential launch site is access to transportation links necessary to move people, equipment, rockets, fuels and other supplies from major centers to the general vicinity of the launch complex. Obviously some sites are located in relatively populated areas such as is the case with Vandenberg and MARS. However, if the potential launch site is located at more northern latitudes to take advantage of reduced tangential velocity, then a site must be located near an ample blend of air, sea, road and rail transportation links. For larger rockets, access to a sea port may be required such as is the case with rockets manufactured in Huntsville that are too large to be moved by road or rail. Kodiak is serviced by either air or sea with final transport to the facility by highway.[47]

Weather is another factor when analyzing launch sites. It is important to note that cold weather operations exist and therefore Canada is viable even at higher latitudes. The presence of various cold weather sites in Alaska and Russia prove that temperature alone does not impede space launch operations. However, infrastructure at the potential site must be designed to allow all weather preparations as illustrated by the KLC indoor launch pad building that is designed to swing away from the rocket once assembled and ready for launch.

Available launch azimuths must also factor in to launch site selection. While it is possible to launch to any orbital inclination that is less than the latitude of the launch site, due to safety and other restrictions, the launch azimuth is limited to flight over water and other sparsely populated areas.

Potential Canadian Launch Locations

Various Canadian launch sites have been proposed over the years for a variety of factors. The Canadian Space Agency (CSA) has been investigating two possible locations while the director of Space Launch Canada has proposed a third. Each potential site will be described in greater detail in the following paragraphs.

Situated on the eastern Canadian coast, Cape Breton Island has been investigated as a potential launch site by the CSA and at least one private consortium in the past. The likely site would be located at Sydney Mines at a latitude of approximately 45°. The findings for a CSA pre-feasibility study undertaken in 2008 indicated, "it would be possible for Canada to launch its own rockets [from the potential site]."[48] While the potential site would benefit from easy access to transportation and labor, its physical location limits launch azimuths because of the presence of Newfoundland to the northeast. Sun-synchronous and other near polar inclination launches could most likely take place as the flight of a potential launch vehicle would be over water and extremely sparsely populated areas of the Arctic. However, launch azimuths required for many other orbits, such as Molniya, would not be possible.

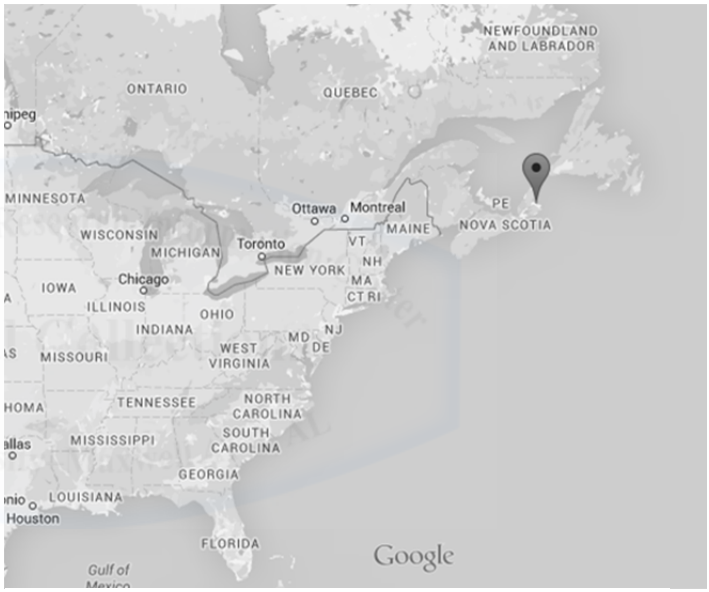

Figure 6

The second potential launch site that was investigated by CSA is the Fort Churchill site in northern Manitoba. The high latitude of this site of approximately 59° and remote location

would allow for efficient polar launches as well as a full range of HIO options. Another distinct advantage of this potential site is that it was used until 1981 as a sub-orbital rocket facility and therefore has some basic infrastructure in place. It housed 4,500 personnel and launched over 3,500 sub-orbital flights.[49] While the site is mostly in disrepair, it still has an airport, rail line and road access to the port of Churchill. In the late 1990's a company called Akjuit Aerospace developed a business plan to develop the site into a commercial polar spaceport.

Figure 7

Akjuit Aerospace refurbished the existing facilities and planned to expand the facility with the construction of two additional pads "ideally located for Polar and High Inclination orbital launches" capable of launching payloads up to 4000 pounds into low earth orbit.[50] The company ultimately failed to raise the funds necessary to complete the project which was estimated to cost between $100-$300 million.[51] While the company was unsuccessful, they employed a technical team which included Raytheon Engineers and Constructors as well as ACTA which gives credence to their claims of the technical feasibility of the site.

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The third potential launch site is located on Canada's west coast and offers similar launch characteristics as both Vandenberg and Kodiak. This site has been proposed by Space Launch Canada, an organization headed by Astrophysicist Redouane Fakir. Located on a remote peninsula, Estevan Point is optimal for polar launches from both an efficiency as well as a safety standpoint.[52] This site is not served by road or rail and would therefore require the building of a currently non-existent sea port. Another potential issue with this site is the political sensitivity inherent in the region as a large proportion of Vancouver Island's inhabitants are more sensitive to environmental issues. As the potential site is currently a large provincial wildlife park, the environmental impact posed by any development would be certain to draw extensive criticism. This site is also limited to launching polar orbits and holds less flexibility in launch operations as compared to the other two sites.

Figure 8

Governmental Aspects

Canada is an attractive location for business due to its lower corporate tax rates as compared to other countries, and continued governmental support to business through low corporate taxes is ideal for commercial space development. A report published by KPMG that assessed the tax competitiveness of Australia, Canada, France, Germany, Italy, Japan, Mexico,

the Netherlands, the United Kingdom, and the United States found that the relative tax burden in Canada was the lowest, specifically "46.4 percent lower than in the United States."[53] Due to this much lower tax burden, many established commercial space companies would likely find Canada an ideal location for business. The recent trend of corporations moving their headquarters to Canada for tax purposes demonstrates the logic of this assertion. As long as the government's tax policies favor low corporate taxes, Canada will represent a tempting option for relocation.

The Canadian Government can provide tax breaks directed at the space industry and spend money on enabling infrastructure. Canada could offer tax breaks such as Virginia's "income tax incentives to locate and headquarter space flight launch and training business operations."[54] In addition to tax breaks the government can continue to provide funding for infrastructure to enable development of sites such as Fort Churchill. Projects such as the $17 million federal government plan to improve the Port of Churchill and rail line leading to it provide key enabling functions to a future space industry in the area.[55]

Another distinct advantage that Canada can manifest for commercial space launch is that it offers an alternative to US launches that have to contend with excessive regulations. Much of the satellites and launch components are placed on the US Munitions List (USML) which results in the State Department controlling what technologies can and cannot be sold to international customers due to the International Traffic in Arms Regulation (ITAR).[56] It would benefit a company a great deal to have the ability to develop technology and launch it for an international consumer base without unnecessary governmental intervention. The Canadian government can offer an alternative to these issues.

Conclusion

Recommendations

The Canadian government should build a launch facility as it is in its strategic national interest to do so and because government assistance will be required to develop a site. Having no indigenous launch capability, Canada must rely on a foreign country to launch satellites into orbit. The Radarsat-2 program which launched in 2007 illustrates an example of when this lack of capability has had strategic impacts. Because of a disagreement between the company that built the satellite and the US government, the satellite was launched six years behind schedule aboard a Russian launcher.[57] The strategic impacts inherent in such a delay and in launching a possibly classified payload through a foreign entity should be readily apparent. Governmental assistance to develop a site is required because the large financial investment involved compared to the possible profits exceeds the risk level of private industry. Past attempts by private consortiums have failed such as was the case with the Akjuit Aerospace Fort Churchill plan. While they were able to raise close to $30 million privately, they fell short by hundreds of millions of dollars. The KLC and MARS examples point to what is potentially the best model for governmental involvement in such an endeavor and should be followed by Canada. Establishing an arm's length agency to build and operate the site using federal and provincial funding offset by competitive launch fees would make the facility a relatively small and acceptable risk. In addition to funding the development of the launch facility itself, the Canadian government should continue its corporate tax policies and also extend tax breaks specifically to the space sector.

While each of the three potential Canadian sites have their merits, the one that should be developed is Fort Churchill. The most important factor that makes this the best alternative is the range of potential launch azimuths. With over 25% of all satellites in polar orbits it follows that

a site that takes full advantage of launch efficiencies is ideal. Fort Churchill also has some basic infrastructure in place from its history as a sub-orbital launch site as well as multi-million dollar refurbishments undertaken by Akjuit Aerospace. Compared to the other sites, Fort Churchill has better access to transportation links as it possesses a major rail line, a large sea port, and an airport already in place.

Conclusions

Canada does represent an advantageous location for the development of a commercial space launch facility for launches to HIOs. These launches are more efficient than those which occur at lower latitudes and, therefore, represent an economical alternative to many of the existing launch facilities. In addition to this efficiency, the data shows that the majority of orbits are in the HIO category which demonstrates the potential usefulness of a Canadian launch site. The existence of two high latitude launch facilities and the fact that 20% of all HIO launches have occurred at Plesetsk prove that a high latitude Canadian site would be both feasible and useful. Due to factors such as available launch azimuths, existing infrastructure and efficient location, the Canadian government should fund a commercially operated spaceport located at Fort Churchill. While the current demand does not exceed the international capacity, the fact that Russia makes up such a high percentage of HIO launches coupled with the possibility of future political conflict between Russia and the West once again illustrates why a Canadian launch facility makes sense. In addition, growth in the HIO segment of the space sector seems poised to grow in the near future. Finally, the business-friendly nature of the Canadian tax system and governmental support would be very conducive to an increased commercial space sector. All of these factors highlight the advantageous nature of a potential Canadian launch site.

Notes

All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. Canadian Space Agency, *State of the Canadian Space Sector 2011*; Space Foundation, "Space Foundation's 2012 Report."
2. Sellers, *Understanding Space*, 311.
3. Brownell, "Canada ranked world's most tax-friendly country for business."
4. Sellers, *Understanding Space*, 311.
5. Ibid., 312.
6. Ibid., 311.
7. Ibid., 302.
8. Ibid., 204.
9. This number was derived by the author using data found in the UCS Satellite Database.
10. International Launch Services, "Baikonur Cosmodrome."
11. This number was derived by the author using data found in the UCS Satellite Database.
12. International Launch Services, "Baikonur Cosmodrome."
13. NASA, "Baikonur Cosmodrome."
14. Federation of American Scientists, "Plesetsk Cosmodrome Launch Facilities."
15. Federation of American Scientists, "Baikonur Cosmodrome Launch Facilities."
16. Federation of American Scientists, "Plesetsk Cosmodrome Launch Facilities."
17. European Space Agency, "Plesetsk / ESA Permanent Mission in Russia."
18. This number was derived by the author using data found in the UCS Satellite Database.
19. Federation of American Scientists, "Plesetsk Cosmodrome Launch Facilities."
20. Ibid.
21. Russian Space Web, "Dombarovsky (Yasny) ICBM Site."
22. Ibid.
23. This number was derived by the author using data found in the UCS Satellite Database.
24. Russian Space Web, "Vostochny (formerly Svobodny) Cosmodrome."
25. Ibid.

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Notes

26. Ibid.

27. Ibid.

28. This number was derived by the author using data found in the UCS Satellite Database.

29. Ibid.

30. GlobalSecurity.org, "Jiuquan – Chinese Space Facilities."

31. This number was derived by the author using data found in the UCS Satellite Database.

32. GlobalSecurity.org, "Taiyuan – Chinese Space Facilities."

33. This number was derived by the author using data found in the UCS Satellite Database.

34. Ibid.

35. Ibid.

36. Virginia Commercial Space Flight Authority and Mid-Atlantic Regional Spaceport, "Mid-Atlantic Regional Spaceport."

37. Virginia Commercial Space Flight Authority and Mid-Atlantic Regional Spaceport, "History of MARS."

38. This number was derived by the author using data found in the UCS Satellite Database.

39. Alaska Aerospace Corporation, "Kodiak Launch Complex Overview."

40. This number was derived by the author using data found in the UCS Satellite Database.

41. Federal Aviation Administration, *Commercial Space Transportation Forecast,* 66.

42. Spaceworks, "2014 Nano/Microsatellite Market Assessment," 7.

43. Ibid., 10.

44. Federation of American Scientists, "Baikonur Cosmodrome Launch Facilities."

45. Dietrich, "Virginia wants Orbital, NASA to help fund $20M repairs to launch pad."

46. Waite and DeLuna, "Kodiak Launch Complex (KLC)," 5.

47. Ibid.

48. Canadian Press, "Space agency eyes Cape Breton for satellite launch."

49. Canadian Space Agency, "Fort Churchill – a landmark in Canadian space research."

50. Akjuit Aerospace. *Canada's International Spaceport.*

51. Braga, "The Failed Plan to Build a Commercial Spaceport in the Subarctic."

52. Canadian Press, "Should Canada have its own space-launch facility?"

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Notes

53. Kpmg, *Competitive Alternatives 2014,* 1-2.

54. Virginia Commercial Space Flight Authority and Mid-Atlantic Regional Spaceport, "History of MARS."

55. Canadian Press, "Space agency eyes Cape Breton for satellite launch."

56. Winters. "Enabling the Commercial Space Transportation Industry at the Mid-Atlantic Regional Spaceport."

57. Boucher. "Is Canadian Sovereignty at Risk by a Lack of an Indigenous Satellite Launch Capability?"

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Digital Collections
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BIBLIOGRAPHY

Alaska Aerospace Corporation. "Kodiak Launch Complex Overview." http://www.akaerospace.com/klc_overview.html (accessed 12 Mar 2015).

Akjuit Aerospace. *Canada's International Spaceport.* http://commons.erau.edu/cgi/viewcontent.cgi?article=1625&context=space-congress-proceedings (accessed 31 Mar 2015)

Boucher, Marc. "Is Canadian Sovereignty at Risk by a Lack of an Indigenous Satellite Launch Capability?" SpaceRef.ca, 4 Jan 2015. http://spaceref.ca/national-security/is-canadian-sovereignty-at-risk-by-a-lack-of-satellite-launching-capability.html (accessed 19 Mar 2015).

Braga, Matthew. "The Failed Plan to Build a Commercial Spaceport in the Subarctic." Motherboard.com, 25 Sept 2015. http://motherboard.vice.com/read/the-failed-plan-to-build-a-commercial-spaceport-in-the-subarctic (accessed 27 Mar 2015)

Brownell, Claire. "Canada ranked world's most tax-friendly country for business." Financial Post, 17 June 2017.

Canadian Press. "Should Canada have its own space-launch facility?" CTV News, 30 July 2011. http://www.ctvnews.ca/should-canada-have-its-own-space-launch-facility-1.677533 (accessed 19 Mar 2015).

Canadian Press. "Space agency eyes Cape Breton for satellite launch." CTV News, 28 Mar 2010. http://www.ctvnews.ca/space-agency-eyes-cape-breton-for-satellite-launch-1.496622 (accessed 27 Mar 2015).

Canadian Space Agency. "Fort Churchill – a landmark in Canadian space research." https://web.archive.org/web/20140313085522/http://www.asc-csa.gc.ca/eng/sciences/fort_churchill.asp (accessed 17 Mar 2015).

Competitive Alternatives 2014 – Focus on tax, KPMG LLP, 2014. http://www.kpmg.com/Ca/en/services/Tax/Focus-on-Tax/Documents/kpmg-focus-on-tax-2014-en.pdf, (accessed 4 November 2014).

Dietrich, Tamara. "Virginia wants Orbital, NASA to help fund $20M repairs to launch pad." Daily Press, 18 Nov 2014. http://www.dailypress.com/news/science/dp-nws-spaceport-cost-to-fix-20141118-story.html (accessed 17 Mar 2015).

European Space Agency. "Plesetsk / ESA Permanent Mission in Russia." http://www.esa.int/About_Us/ESA_Permanent_Mission_in_Russia/Plesetsk (accessed 10 Mar 2015).

Federation of American Scientists. "Baikonur Cosmodrome Launch Facilities." http://fas.org/spp/guide/russia/facility/baikonur.htm (accessed 10 Mar 2015).

Federation of American Scientists. "Plesetsk Cosmodrome Launch Facilities." http://fas.org/spp/guide/russia/facility/plesetsk.htm (accessed 10 Mar 2015).

Federal Aviation Administration. *Commercial Space Transportation Forecast.* https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2012_Forecasts.pdf (accessed 3 Mar 2015)

GlobalSecurity.org. "Jiuquan – Chinese Space Facilities." http://www.globalsecurity.org/space/world/china/jiuquan.htm (accessed on 13 Mar 2015).

GlobalSecurity.org, "Taiyuan – Chinese Space Facilities." http://www.globalsecurity.org/space/world/china/taiyuan.htm (accessed on 13 Mar 2015).

International Launch Services. "Baikonur Cosmodrome." http://www.ilslaunch.com/node/8 (accessed on 13 Mar 2015).

NASA. "Baikonur Cosmodrome." http://www.nasa.gov/mission_pages/station/structure/elements/baikonur.html (accessed 10 Mar 2015).

Russian Space Web. "Dombarovsky (Yasny) ICBM Site." http://www.russianspaceweb.com/dombarovskiy.html (accessed 12 Mar 2015).

Russian Space Web. "Vostochny (formerly Svobodny) Cosmodrome." http://www.russianspaceweb.com/svobodny.html (accessed 12 Mar 2015).

Sellers, Jerry Jon., Astore William J., Giffen Robert B., Larson Wiley J., Kirkpatrick Douglas H., Gay Dale, and Shute Anita. *Understanding Space: An Introduction to Astronautics*. Boston: McGraw-Hill Custom Pub., 2004.

State of the Canadian Space Sector 2011. Canadian Space Agency. 2011. http://www.asc-csa.gc.ca/pdf/eng/industry/state-2011.pdf (accessed 4 Nov 2014).

Space Foundation. "Space Foundation's 2012 Report Reveals 12.2 Percent Global Space Industry Growth in 2011," 5 Apr 2012. http://www.spacefoundation.org/media/ press-releases/space-foundations-2012-report-reveals-122-percent-global-space-industry-growth (accessed 4 Nov 2014).

Spaceworks Enterprises Inc. "2014 Nano/Microsatellite Market Assessment," Atlanta, GA, 2014. http://www.sei.aero/eng/papers/uploads/archive/SpaceWorks_Nano_Microsatellite_Market_Assessment_January_2014.pdf (accessed 25 Mar 2015).

The Economic Impact of Commercial Space Transportation on the U.S. Economy, Federal Aviation Administration, April 2008.

The State of the Canadian Aerospace Industry. Industry Canada, 2014. https://www.ic.gc.ca/eic/site/ad-ad.nsf/vwapj/ The_State_of_the_Canadian_Aerospace_ Industry2014.pdf/$file/The_State_of_the_Canadian_Aerospace_Industry2014.pdf, (accessed 4 November 2014).

Union of Concerned Scientists. "UCS Satellite Database," Aug 2014. http://www.ucsusa.org/nuclear_weapons_and _global_security/solutions/space-weapons/ucs-satellite-database.html (accessed 3 November 2014).

Virginia Commercial Space Flight Authority and Mid-Atlantic Regional Spaceport. "Mid-Atlantic Regional Spaceport." http://www.marsspaceport.com (accessed 16 Mar 2015).

Virginia Commercial Space Flight Authority and Mid-Atlantic Regional Spaceport, "History of MARS." http://www.marsspaceport.com/mid-atlantic-spaceport-history(accessed 16 Mar 2015).

Waite, Arthur C. and Alan T. DeLuna. "Kodiak Launch Complex (KLC)." BRPH Architects. Melbourne, FL. http://www.spaceops2012.org/ proceedings/documents/id1295313-Paper-002.pdf (accessed 10 Mar 2015).

Winters, Nathan J. "Enabling the Commercial Space Transportation Industry at the Mid-Atlantic Regional Spaceport." Naval Postgraduate School, Monterey, CA, September 2011.

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