An Examination of the Price Competitiveness of SpaceX's Falcon Rocket Family

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Introduction

SpaceX plans to launch its Falcon 9 rocket for a third tme on April 30th. If the mission is successful, this mission will prove the ability of the Falcon 9 rocket to successfully launch SpaceX's Dragon capsule into the correct orbit for an International Space Station (ISS) rendezvous and the ability of that Dragon capsule to deliver necessary cargo to the astronauts on that station. It will be the first of twelve such flights under a $1.6 billion contract between NASA and SpaceX to supply the ISS (with an option for NASA to scale up to twice that number of missions for twice the amount).

These Falcon 9 missions will also be proving the SpaceX hardware to the commercial launch market that SpaceX hopes to be able to tap by providing a reliable, adaptive, and cost-effective launch system. The commercial launch market has been a notoriously difficult one to enter, but SpaceX has come further than any other startup company. In order to gain customers, SpaceX will have to be able to provide an inexpensive enough total launch cost to compensate the company's lack of experience and precedence. One of the most important aspects in considering this launch cost for a system with unproven reliability will be the insurance expense, so a significant portion of this investigation is to determine what insurance rate the market will bear on a Falcon 9 rocket.

Historical Overview of the Commercial Launch Market

Prior to 1984, United States government policy was that all space launches would be conducted as either USAF (for defense) or NASA missions[1]. What this meant is that there was little to no incentive for private companies to develop launch systems independent of the USAF or NASA. Furthermore, both the USAF and NASA had active space launch development programs that worked closely with the major defense aerospace players: Boeing, Lockheed, Martin Marietta, and McDonnell Douglas (for the rest of the paper, I will talk about just Boeing and Lockheed Martin — Lockheed and Martin Marietta merged to form Lockheed Martin in 1994[2] and Boeing and McDonnell Douglas merged in 1997, keeping the Boeing name[3]).The prominence of these contractors, combined with their proven experience and lobbying power ensured dramatic barriers of entry to any other companies that attempted to enter the market. This didn't stop many from trying. Up until 2000, over 26 different companies tried to enter the market. Only two of them had successful rocket launches — and only one of those companies was ever profitable (Orbital Sciences — still around today). Of those, only five could be considered anything but total failures, and what success they did achieve was mostly as USAF or NASA contractors[4].

One particular commercial attempt bears repeating. In 1983, one of the major space launch contractors, Martin Marietta, developed a plan to sell launches of their Titan III system commercially and independently. The White House's Office of Management and Budget actually determined that doing so was illegal and that all US launches had to use the Space Shuttle (as a means of encouraging use of this new — and, as would become evident later, horrendously expensive launch system). It was Martin Marietta's proposal that led to the administration's policy change to deregulate the industry, however. Even in the deregulated environment, any new launch systems would have to compete with Arianespace[5], which claims to be the "world's first commercial launch company." However, Arianespace has from the beginning has been more closely integrated with European governments than the major United States defense contractors and its launches have largely been subsidized by those governments[6]. So, though the United States launch market had been deregulated so far that satellites were not required to be launched by the Space Shuttle, the existence of the subsidized Arianespace was a huge barrier to entry for any new firms.

Furthermore, though the official policy of the United States government was to encourage the development of commercial launch systems, its actions often betrayed this goal and simply further entrenched the major defense contractors. Prior to 1984, United States policy was that all space launches, including those for private companies, were to be performed by NASA spacecraft. When President Reagan signed the Commercial Space Launch Act in 1984 to deregulate the space industry, he did so with the statement that the goal of the bill was the "encouragement of the private sector in commercial space endeavors"[7,8]. In 1990, President Bush signed the Launch Services Purchase Act, which required NASA to purchase commercial launch systems whenever such were required and available[9]. This act was further enhanced by the Space Transportation Services Purchase Act of 1993[10]. And again in 1998 by the Commercial Space Act[11]. However, NASA and the USAF (United States Air Force) continued to favor launchers built by Boeing[*] and Lockheed Martin, who had produced rockets for NASA and USAF entirely under government contracts previously. In 1996, the USAF subsidized the development of two new launch families, one from Boeing and one from Lockheed Martin[12]. Although the reason behind subsidizing two of these was to establish a competitive market, the actual effect of this action was to restrict the market from new entrants.

Although the industry had been deregulated in 1984 and had active stated government support in 1990, it wasn't until the first decade of the 21st century that new firms successfully started to develop their own launch systems. One of the large factors behind the lack of launcher development was uncertainty over the insurance market[13]. When the market was first deregulated, the rockt families that had been used for years by the USAF and NASA at least had a track record on which insurance policies could be based. Even with this background, the insurance market for space launches has been incredibly volatile, with premium rates, market capacity and plan availability. Startup launch providers faced the additional hurdle of their customers having to acquire insurance to cover the launch risk when the risks are largely unknown.

The last decade has seen a resurgence of commercial space launch efforts, largely funded

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[*] including McDonnell-Douglas, which was purchased by Boeing in 1997[3]

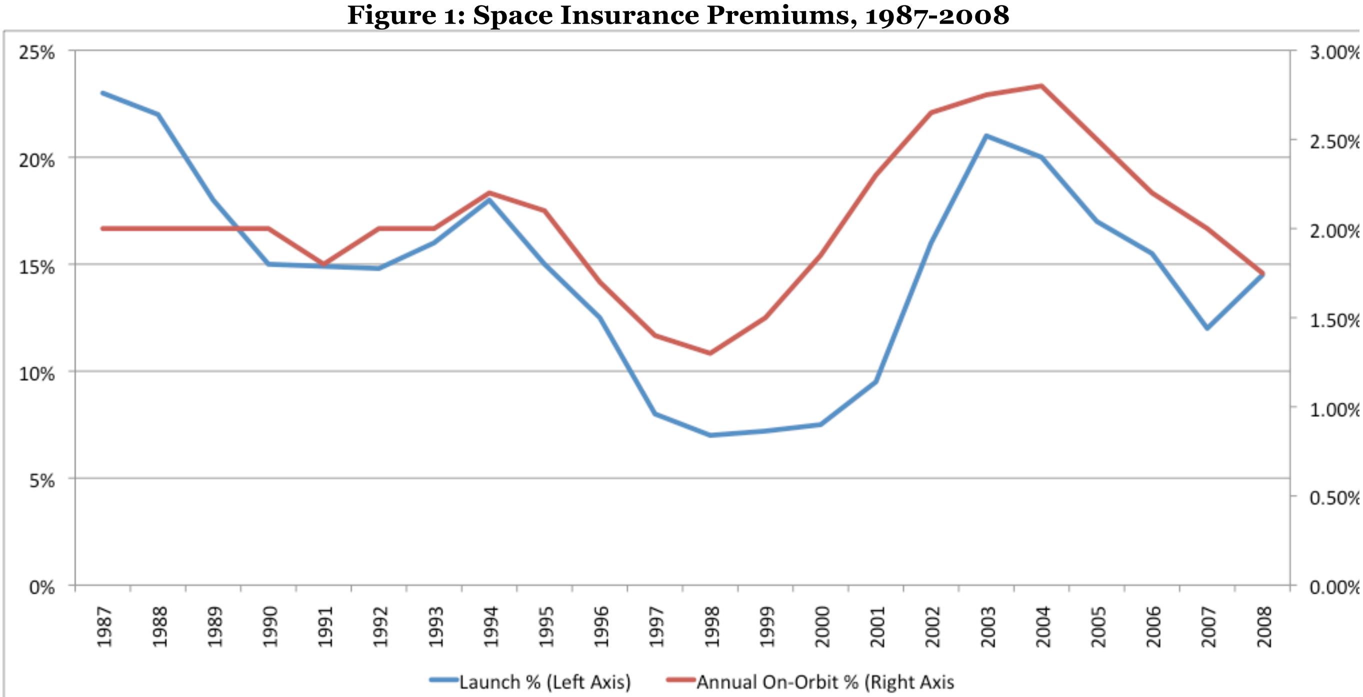
by individuals (and mostly by their wealth earned during the 1990s tech boom). In particular, Space Exploration Technologies (SpaceX) of Hawthorne, California — funded by Elon Musk from funds generated by his sale of PayPal — and Virgin Galactic of Mojave, California — funded by Richard Branson's Virgin Group have both successfully launched privately funded space missions[14].

Historical Overview of Space Insurance

For much of the history of space launch, the insurance market was insubstantial. This was due primarily to the fact that all or nearly all launches were government sponsored and neither the USAF or NASA insure their launches or satellites[15]. Since before 1990 all commercial satellites launches happened on government sponsored launchers, there was no market for launch insurance to cover the cost of the launch system[9]. Companies would still often insure their satellites against launch failure and failures once on-orbit, when sure insurance was available. However, the availability of on-orbit insurance has been extremely variable. Between 1995 and 2002, this on-orbit insurance period that was available for purchase varied from half a year to five years. Although it looked at the turn of the millennium like it was on a general upward trend, by 2004 it had reduced to back to half a year[14,16]. So, the majority of past launches and satellites have not been insured, keeping the market quite small.

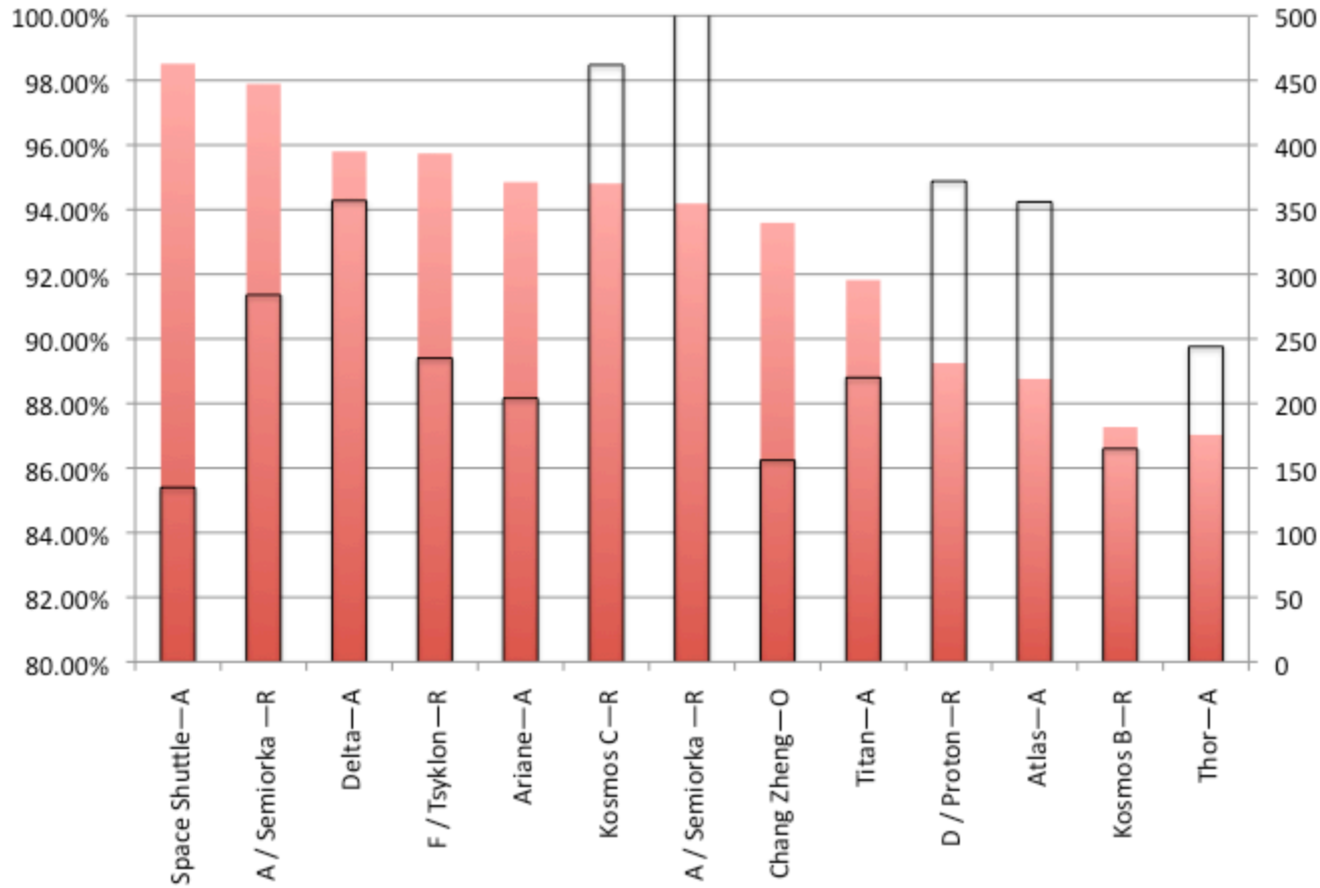
The insurance rates offered have also been extremely variable. Between 1986 and 2009, the insurance premium on launches varied between 7%-24%. And the annual insurance premium against on-orbit failure has varied between 1.8%-4.0%[17,18] (15, 17).

Figure 1: Space Insurance Premiums, 1987-2008



Insurance rates have varied significantly for several reasons. The primary reason is a sheer lack of data about the success and failure rates of rocket launchers and satellites. Most rockets are launched relatively infrequently, so it is difficult to determine what their true failure rates are. There are only thirteen launch systems that have been launched more than 100 times, with an overall success rate of 93.15%, only slightly better than the 91.79% historical success rate for all attempted space launches[19]. However, this 93% success rate does indicate that an insurance premium floor of 7% is understandable — and is what was observed as a rate floor.

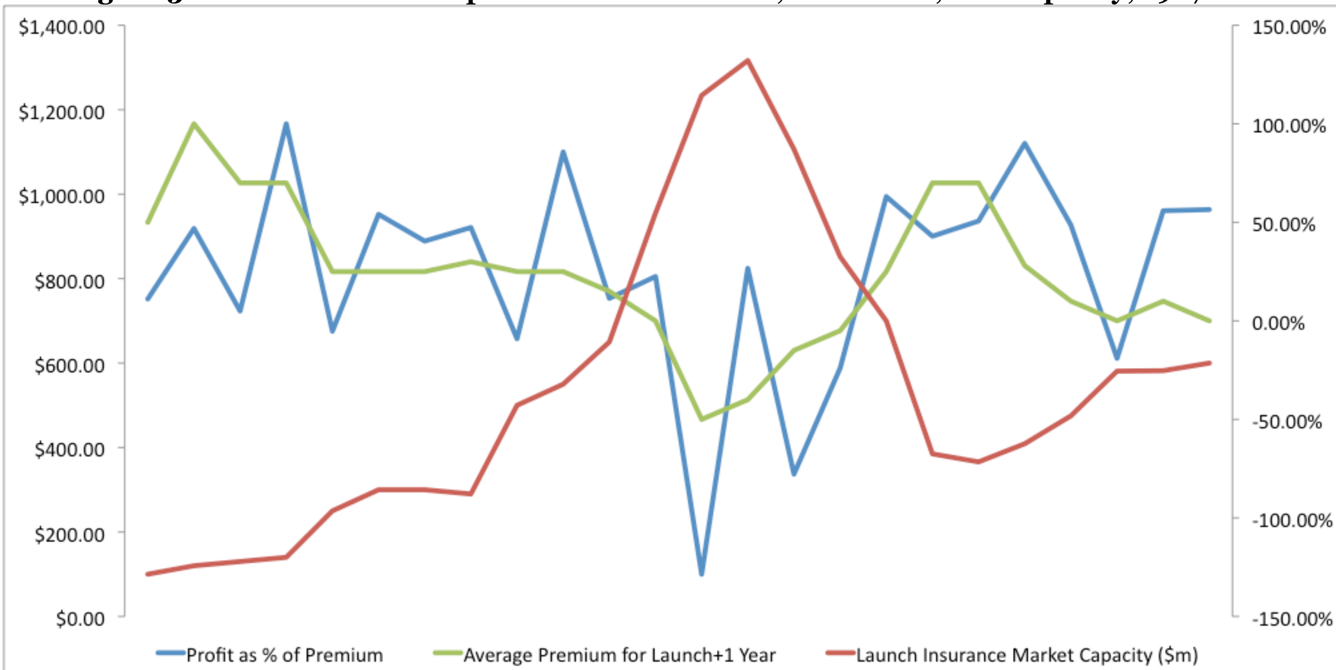
Figure 2: Reliability Rates for All Rocket Families with Over 100 Attempted Launches



Only half of the launchers that have been used over 100 times have been used as commercial launchers, so there are very few systems that have a significant amount of historical data with which to determine insurance rates. Furthermore, nearly every satellite is custom built for its specific purpose, so even when there are components that are re-used between satellites, the total composition of the satellite is a complex mixture of these and unique components[20].

In addition to the sher unpredictability of individual launcher and satellite reliability rates is the fact that insurance markets have been observed to be cyclical. This is a cycle where premiums vary from high to low and insurance industry profits vary similarly. High premiums lead to high profits, which give the industry higher capacity, leading to lower premium rates and therefore lower profits, lower capacity, and the need to once again increase premiums[21]. This effect can be observed quite clearly in the satellite insurance market.

Figure 3: Relation Between Space Insurance Profits, Premiums, and Capacity, 1987-2008



*Note: "average premium for launch + 1 year" (green line) has been scaled to fit on graph. These values vary between 10%—25%

Beyond unpreditable reliability of individual launchers and satellites, there are also global insurance market issues. When an event like the Katrina hurricane happens, it causes the insurance capacity to be cut across the board. And such cuts hurt high-risk insurance such as space insurance even more heavily (when insurance companies have had to provide massive payouts, they are generally in a more conservative mindset going forward — and as we are seeing, the space insurance market is *not* a conservative one).

When it comes to on-orbit insurance rates, one significant problem with the market as a whole is that satellites are all subject to higher failure rates due to higher levels of sunspot activity. There is therefore the possibility for systematic failure of all satellites in orbit. Indeed, higher sunspot activity in 1998 meant that insurance payouts in that year were 228% of premiums gathered, for a total loss of nearly $1 billion. There has been a strong negative correlation found between on-orbit satellite insurance profits and the solar cycle. And a one to two year lagging correlation between satellite insurance rates and the solar cycle[22].

To combine these two market-wide problems is the fact that a massive solar storm could potentially have a substantial impact on property on Earth's surface as well (the massive electromagnetic discharges caused would wipe out huge portions of Earth surface based elecronics). A big enough solar storm could cause upwards of $2 trillion in damage[23]. One of the most important facts about this situation for the insurance industry is that space-based assets (and insurance based on them) are not simply uncorrelated with typical Earth-based assets. The space insurance market is therefore not a perfect method of insurance portfolio diversification. So, insurance companies probably provide less capacity to space insurance than they otherwise would if it were a non-correlating market that would provide true diversification.

Many of the difficulties with insuring space missions are shared with insuring other megaprojects, however, such as major tunnels, bridges, buildings, and power plants (especially nuclear). Many of these, like a large portion of the space market, are government-sponsored and so have the practically unlimited insurance ability of the government (or the lack of a legal need to provide for liability coverage)[24]. In cases where the projects are not government sponsored, owned, or operated, governments often provide indemnity caps. For nuclear power plants, the indemnity cap is often at $0, meaning that the entire risk is born by the government (assuming that at the time of the problem there is the political and economic ability to deal with the problem — a situation we've seen played out in the last year due to the failure of the Fukushima nuclear power plant during the Japanese Tsunami)[25]. In the United States, the Price-Anderson Act sets up an industry-funded fund that can pay up to$12.6 billion towards liability in the case of a massive nuclear power plant catastrophe[26]. This $12.6 billion is the effective indemnity cap.

The space industry also has an indemnity cap, of $2.5 billion in 2012[27]. This indemnity cap is renewed by congress only several years in the future and each time it is up for review, there is doubt as to whether or not congress will renew it, or what it's amount will be in the future. It is also possible that Congress will consider and possibly pass an indemnity-cap system like those for nuclear power plants, where the insurance is funded by the industry as a whole. This would have two primary effects:

- Cost of risk would be shifted away from startup firms (with more uncertain risk)
- Cost of risk would be born by defense industry mainstays that receive massive amounts of government funding

Given the lobbying and political power of these industry mainstays, such a measure seems unlikely in the near future[28].

Unfortunately, predicting the space insurance market seems to be near impossible. The market is relatively small and rates are largely determined by the availability by a small number of vehicles. Any one major launch failure can have a significant effect on that market capacity and on the premium rate charged. Furthermore, there is little correlation between market factors that determine future rates (see sidebar for factors considered) — no correlation greater than .5 was observed.

<u>Factors Considered</u>

Launch Premium %

On-Orbit Premium %

Space Insurance Profit/Loss & Various Moving Averages

% of Year's Premiums Paid Out in Claims

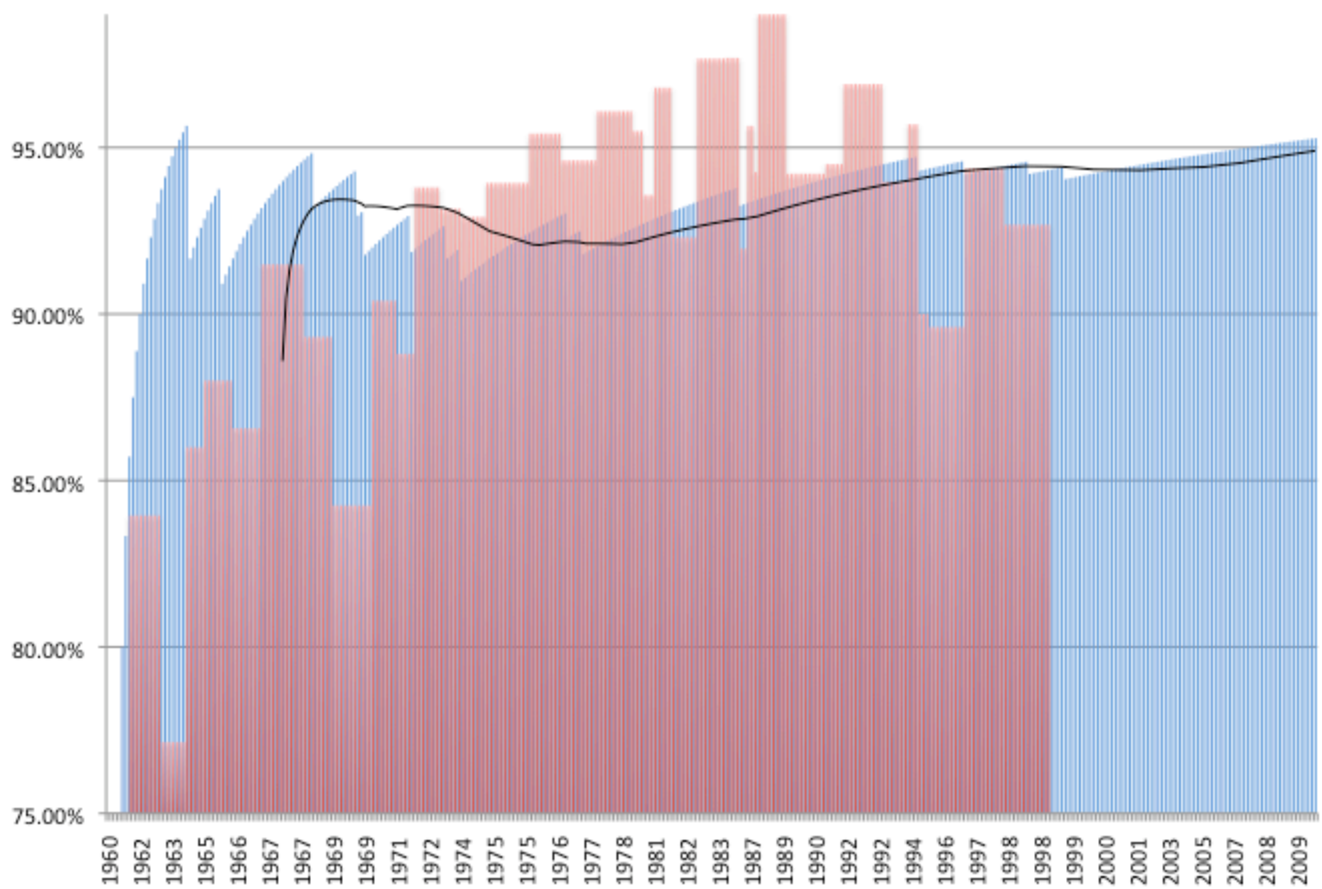
Launch Insurance Market Capacity

On-Orbit Insurance Market Capacity

Launcher Reliability: A Case Study — The Delta Family

When it comes to an individual rocket launcher, or base satellite system, the reliability is almost impossible to predict before many launches have occured. Rockets are notorious examples of extreme variability for early reliability rates. One way that we can look at reliability rates beyond individual rocket launchers is by looking at rocket families. As an example of this, let us examine the Delta Rocket Family (which has been manufactured by: the Douglas Aircraft Company, McDonnell Douglas, Boeing and the United Launch Alliance — all due to mergers or friendly spinoffs)[29]. This rocket family is one of the most widely used and has been around for the longest period of any American launch system and has the longest history of commercial use. It has been launched 356 times and has an overall launch success rate over 95%.

Figure 4: Reliability of Delta Rocket Family Over Time



Blue indicates overall family success rate over time. Black line is a 50-launch moving average.
Red is the reliability rate of all rockets launched in that year
Delta launches have been roughly consistent at about 7 per year
The peak reliability rate in 1962 was at the 23rd launch.

From the example of the Delta family, we see that:

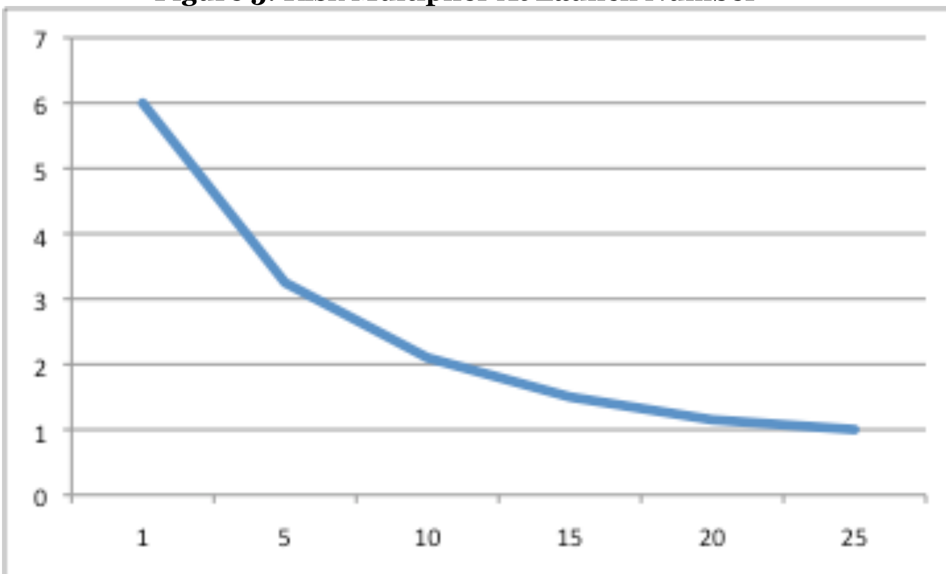
1 — Reliability is poor at the beginning of use

2 — Reliability is extremely variable due to the low number of launches

3 — Reliability levels off after 20-25 launches

4 — Reliability rate significantly improves when first failures are dropped

Figure 5: Risk Multiplier At Launch Number



So, a rocket launch is six times riskier at its first launch than its 25th
(by which time it has hit its true reliability)

This pattern is indicative of rocket launchers as a whole[30], though there are launchers with significantly worse records. In general, these significantly less reliable rocket families were abandoned after a number of unsuccessful launches, so it is impossible to say for certain what their reliability ratings would have ended up being after dozens or hundreds of launches[31]. Looking across the spectrum of launch families, we find that nearly all have higher realized success rates than predicted ones — so, reliability improves the more times a rocket from that family have been launched. On average, launch vehicles are 5.5% more reliable than predicted, a number that is almost certainly more substantial for modern launch systems[32].

Estimating Rocket Success Rate With Little Data

The Problem

One of the biggest challenges a startup space launch system firm such as SpaceX faces is the fact that its system has no track record. This is a serious problem for acquiring customers, as these customers are investing huge sums of money and time into the satellites they launch. Although the cost of using a startup firm's rocket may be significantly less than one of the industry mainstays, the lack of a track record will make them often still go with the industry mainstay.

The reason these reliability numbers are so difficult to deal with is how heavily each launch is weighted when the numbers are low. For instance, in the Delta example, the first launch was a failure, then there were 23 successful launches before another failure. Since the first launch was a failure, it wasn't until the rocket had been launched five times that it passed a 80% success rate. And it looks fairly evident from the data that the rocket does in fact have a reliability rate well over 90%, even from its beginning. If the rocket had not failed on its first launch, then it would have had a 100% success rate up until its 24th launch.

Past insurance rates for rocket launchers indicate that they do take into account the fact that reliability rates increase over time[33]. Using available data on insurance premiums in 1998, we see that there was a high negative correlation between the insurance rate and the success rate of the rocket family that year of -.77[*]. This is to be contrasted with the relatively insignificant correlation between the insurance premium and the rocket family's historical success rate.

From this data we also observe a high negative correlation between the relative cost of a launcher and the insurance premium of -.75[*]. This is unsurprising, as we would expect more expensive launchers to be more reliable and therefore for the market to demand a lower insurance premium rate.

	Nation/ Private Corp	Metric Tons to LEO[†]	Million $ / Metric Ton[‡]	*Launcher % of Total Cost*	Success Rate, Family	*1998 Family SR*[§]	1998 SR[‡]	1998 Insurance Rate
Long March 2C	China	3.2	$7.03	*6.95%*	90.36%	*90.70%*	90.70%	25.00%
Ariane 5	Europe	17.25	$12.75	*12.61%*	94.85%	*95.18%*	50.00%	16.00%
Atlas 2AS	USA	8.618	$11.31	*11.19%*	88.76%	*95.90%*	95.90%	16.00%
Proton M	Russia	19.76	$5.06	*5.00%*	89.25%	*97.23%*	97.23%	20.00%
Delta II	USA	6.1	$15.57	*15.40%*	95.80%	*98.60%*	98.60%	16.00%
Falcon 1	SpaceX	1.01	$10.79	*10.67%*	40.00%	n/a	n/a	n/a
Falcon 9	SpaceX	10	$5.60	*5.54%*	100.00%	n/a	n/a	n/a
Space Shuttle High[**34]	USA	28.8	$60.76	*60.08%*	98.52%	*100.00%*	100.00%	n/a
Space Shuttle Low[ß]	USA	28.8	$10.42	*10.30%*	98.52%	*100.00%*	100.00%	n/a
Corr with Insurance Rate		-0.31	-0.75[††]	*-0.75*[**]	-0.44	*-0.77*	0.25	1.00

<u>SpaceX's Falcon 9 Insurance Rate</u>

Using the data gathered above, we can make an estimate first of what the insurance rate for the Falcon 9 launch system would have been in 1998 using linear regression and then project

[*] The negative correlation indicates that **higher** *success rates/launcher % of total mission cost* are correlated to **lower** *insurance premiums*

[†] LEO = Low Earth Orbit, Metric Tons to Low Earth Orbit is used to compare the size of the rockets in launch capacity. There is a high correlation between the tonnage to LEO and other orbits

[‡] Inflation adjusted, where necessary, to 2010 dollars

[§] SR = Success Rate

[**] The true cost of the Space Shuttle has been highly debated. High and low estimates are given.

[††] These correlations are identical because these columns are effectively measuring the same things — there is a 1:1 correlation between the cost per metric ton and the percentage of the total mission costs that pay for the launch

forward to what it would be today and how that rate will drop as the launcher's success rate improves.

Family SR	Predicted 1998 Rate*			Projected 2010 Rate			Cycle Peak Rate		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
55%	35.92%	**59.87%**	113.75%	77.83%	**89.81%**	107.77%	119.74%	**149.68%**	185.60%
65%	29.81%	**49.69%**	94.40%	64.59%	**74.53%**	89.43%	99.37%	**124.21%**	154.03%
75%	23.70%	**39.50%**	75.05%	51.35%	**59.25%**	71.10%	79.00%	**98.75%**	122.45%
85%	17.59%	**29.32%**	55.70%	38.11%	**43.97%**	52.77%	58.63%	**73.29%**	90.88%
95%	11.48%	**19.13%**	36.35%	24.87%	**28.70%**	34.44%	38.26%	**47.83%**	59.31%
100.00%	8.42%	**14.04%**	26.67%	18.25%	**21.06%**	25.27%	28.08%	**35.10%**	43.52%
$5.60m / MT	13.15%	**21.92%**	41.64%	28.49%	**32.87%**	39.45%	43.83%	**54.79%**	67.94%

The biggest lesson we see here is that SpaceX must have reliable launchers if it is going to be able to be affordable (and, given its lack of history, this must be proven quickly). SpaceX will have to have a better than 85% weighted success rate for its Falcon Rockets to be able to achieve an insurance rate that is even possibly competive. We saw already that SpaceX's Falcon 9 rocket is priced low compared to the market. But how low do insurance premiums need to be for low price to be relevant?

Let us look at what the cost premium to use a launcher over the Falcon 9. The table below looks at this amount (so, it would cost a commercial satellite customer 127.74% more to use the Ariane 5 rocket than the Falcon 9, adjusted for payload size). We also look at the cost premium including insurance. This is effectively what the insurance rate on the Falcon 9 would have to be for the total cost of the launcher, including insurance, to be the same as the launcher under comparison (or you could insure the Falcon 9 1.64 times over before the total cost would be the same as the Ariane 5). However, when we consider the cost of insuring the satellite onboard†[35], we see there isn't quite as much room for exorbitant insurance rates (including insuring the satellites, it costs 30.31% to launch using the Ariane 5 than the Falcon 9).

	Nationality	Cost Premium		
		Launcher	+Insurance	+Satellite+Insurance
Long March 2C	China	25.56%	56.95%	28.09%
Ariane 5	Europe	127.74%	164.18%	30.31%
Atlas 2AS	USA	102.03%	134.35%	27.43%
Proton M	Russia	-9.63%	8.44%	18.88%
Delta II	USA	178.10%	222.60%	35.95%
Space Shuttle High	USA	985.07%		95.14%‡
Space Shuttle Low	USA	86.01%		8.31%†
Average w/o Space Shuttle		84.76%	117.31%	28.13%

* 1998 rates are not substantially different from the low point of the insurance cycle
† Satellite costs are assumed to be the projected 2010-2020 average of $52.38m / MT
‡ Does not include insurance as data was unavailable

Discounting the Russian Proton M launcher, SpaceX has a reasonable margin here to work with. If SpaceX can achieve a weighted success rate of 90%, it ought to be able to be able to be cheaper after insurance than any launcher except the Proton M[*].

Falcon 9 Launch Prices

Now that we have a general idea what SpaceX must achieve in order to sell its Falcon 9 launches at its current costs, we can do a sensitivity analysis of costs to the price of launches (recall that the current 2012 cost of the Falcon 9 rocket is $5.6m per metric ton of payload to LEO). The table below lists what the total savings for the customer purchasing a launch would be at different launch costs and insurance rates.

Cost of Launcher in Million $ per Metric Ton for Payload to LEO

Insurance Rate	$0.5	$1.5	$2.5	$3.5	$4.5	$5.5	Slope (%/$m/MT)
7%	9.41%	7.57%	5.72%	3.88%	2.03%	0.18%	-1.85%
12%	9.85%	7.92%	5.99%	4.06%	2.12%	0.19%	-1.93%
17%	10.29%	8.27%	6.26%	4.24%	2.22%	0.20%	-2.02%
22%	10.73%	8.63%	6.52%	4.42%	2.31%	0.21%	-2.10%
27%	11.17%	8.98%	6.79%	4.60%	2.41%	0.22%	-2.19%
32%	11.61%	9.33%	7.06%	4.78%	2.50%	0.23%	-2.28%
37%	12.05%	9.69%	7.32%	4.96%	2.60%	0.24%	-2.36%
42%	12.49%	10.04%	7.59%	5.14%	2.69%	0.24%	-2.45%
47%	12.93%	10.39%	7.86%	5.32%	2.79%	0.25%	-2.54%
52%	13.37%	10.75%	8.13%	5.51%	2.88%	0.26%	-2.62%

What we see is that, even though satellite cost is about one order of magnitude higher than the cost of getting that satellite into orbit at the starting Falcon 9 rate of $5.6m / MT, lowering these launch costs still provide signfiicant savings. Furthermore, these savings become more and more significant as insurance rates increase. When considering a pricing scheme for the Falcon 9, it probably won't be possible for SpaceX to lower its prices enough to make a big enough difference. To decrease the cost to $4.5m/MT, for instance, would be nearly 20% decrease in price but would only decrease the total cost to the costumer by 2%-3%. To decrease the price to $.5m/MT would be more than 90% discount from current prices.

Where the real potential lies, however, is in new technology. SpaceX estimates that their Falcon Heavy will cost on the order of $2m/MT[36]. At that cost, savings to the costumer will be 6%-10%, depending on how high insurance rates are[†][37].

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[*] Comparing to "Predicted 1998 Rate", as the Cost Premiums were determined by these 1998 rates

[†] This is not inconceivable. The Russian Shtil rocket achieves $.5m/MT, though for small payloads. It has also been estimated by experts many times that launch costs could be reduced up to an order of magnitude below what "legacy" launchers cost, which would be in the range of $.5m/MT to $2m/MT

Findings

- The cost of insuring the payload is significantly greater than the cost of insuring the launcher, especially as launch costs decrease. At 2012 rates, the payload costs about ten times as much as launching that payload with SpaceX's Falcon 9 rocket.
- A successful launch record is essential. When space insurance rates are low, there is about a 1:1 relationship between reliability and insurance premium. When rates are high, this climbs to a 1:4 relationship. Since the payload costs ten times what the rocket does, this means that total mission costs can quickly become excessive.
- Space insurance premiums do account for increasing reliability of launch systems. There is not enough data to determine what the weighting scheme for such reliabilities with any real accuracy. But startup launch providers can still possibly pull through even with low reliability rates early in their histories. This is essential for SpaceX, which had three failed rocket launches before any successes.[*]
- Lowering launch costs is still an effective means of decreasing costs for the customer, but are meaningless without insurance premiums being low (which requires a reliable launch system).
- The space insurance market is extremely variable. There is an opportunity here for insurance firms to provide flat rates for several years in the future.
- There is a 10%-20% cost premium to use a non-Russian launch system[†]
- NASA will save money using practically any launch system over the Space Shuttle. However, a reliable, inexpensive launch provider can still make a case for saving NASA money versus other non-Shuttle launchers.
- High satellite-to-launch costs mean that satellite reliability is of high importance. Furthermore, there is an opportuntiy for the development of re-usable spacecraft that have low re-use costs to substantially decrease costs. Such spacecraft may be used to retrieve or repair broken or failed satellites to re-use.

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[*] More analysis can be done here to determine how the insurance market views reliability rates of individual launchers versus launch families. These three failures were all with the Falcon 1. SpaceX is now marketing the Falcon 9 heavily. These two rockets would be considered part of the same rocket family, however.

[†] This finding calls for more analysis. These Russian rocket launchers also have the longest history of service, most established reliability rates, and high reliability rates (especially in recent years). There is no clear immediate reason why they should be discounted versus the rest of the market. SpaceX ought to study what value customers see in non-Russian launchers to ensure that they are capturing that value.

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