Estimating the Reliability of a Soyuz Spacecraft Mission

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Abstract: Once the US Space Shuttle retires in 2010, the Russian Soyuz Launcher and Soyuz Spacecraft will comprise the only means for crew transportation to and from the International Space Station (ISS). The U.S. Government and NASA have contracted for crew transportation services to the ISS with Russia. The resulting implications for the US space program including issues such as astronaut safety must be carefully considered. Are the astronauts and cosmonauts safer on the Soyuz than the Space Shuttle system? Is the Soyuz launch system more robust than the Space Shuttle? Is it safer to continue to fly the 30 year old Shuttle fleet for crew transportation and cargo resupply than the Soyuz? Should we extend the life of the Shuttle Program? How does the development of the Orion/Ares crew transportation system affect these decisions?

The Soyuz launcher has been in operation for over 40 years. There have been only two loss of life incidents and two loss of mission incidents. Given that the most recent incident took place in 1983, how do we determine *current* reliability of the system? Do failures of unmanned Soyuz rockets impact the reliability of the currently operational man-rated launcher? Does the Soyuz exhibit characteristics that demonstrate reliability growth and how would that be reflected in future estimates of success?

NASA's next manned rocket and spacecraft development project is currently underway. Though the projects ultimate goal is to return to the Moon and then to Mars, the launch vehicle and spacecraft's first mission will be for crew transportation to and from the ISS. The reliability targets are currently several times higher than the Shuttle and possibly even the Soyuz. Can these targets be compared to the reliability of the Soyuz to determine whether they are realistic and achievable?

To help answer these questions this paper will explore how to estimate the reliability of the Soyuz Launcher/Spacecraft system, compare it to the Space Shuttle, and its potential impacts for the future of manned spaceflight. Specifically it will look at estimating the Loss of Mission (LOM) probability using historical data, reliability growth, and Probabilistic Risk Assessment techniques.

Keywords: PRA, Reliability, Probability, Risk, Failure, NASA, ISS, Space Station, Shuttle, Constellation, Samar, Loss of Mission, Loss of Crew, Soyuz, Launcher, Stage, Fregat, Ikar, Blok

1. INTRODUCTION

It is necessary to have an understanding of the reliability of the Soyuz Launcher, the Soyuz Spacecraft vehicle, and the reliability of the end-to-end Soyuz system of ascent, on-orbit operations, and entry. Then it is necessary to compare the Soyuz system to empirical and reliability models of the Space Shuttle and Ares I/Orion systems, which are part of NASA's Constellation Program. Due to data availability and resource constraints the following reliability study is only intended as a *starting point*, not an exhaustive or comprehensive reliability study. There are a lot of questions left unanswered and significant research could and should be done.

It is the hope of the authors that this initial study give the reader a *feel* for the orders of magnitude of reliabilities achieved today, and what is possible and realistic to expect given our current state of technology in 2010.

NASA's Constellation Program set reliability requirements for the Loss of Mission (LOM) and Loss of Crew (LOC) for the mission to the International Space Station (ISS). These reliability requirements were put in place prior to the launcher and spacecraft design phases, and were intended as design drivers to develop improved reliability and safety over previous spacecraft systems. Probabilistic risk analyses (PRA) were performed during iterative systems engineering design cycles to estimate the failure probabilities for the ISS mission and identify areas for improvement. As the program evolved, it became evident that while significant improvements for safety and reliability were being identified and implemented on the baseline design configuration, there was a disparity between the reliability targets assigned and what seemed to be theoretically achievable. It also seemed clear that there were no design or "game changing" technologies that could close the gap, given available design commodities and projected performance. The early requirements had been set using incomplete and preliminary PRA. There was not strong rationale for the values defined in terms of mission need or achievability. Accordingly, the Constellation sought guidance from the ISS team to determine what reliability was actually needed in order to fulfill the ISS lifeboat mission. ISS program managers responded that the new systems should at least as reliable as the Soyuz.

Comparison with Soyuz provided a benchmark to determine if the reliability goals were realistic and attainable. No other benchmarks for this type of mission exist. And in order to create a new benchmark, much more data would be required than was available in any space program. A methodology to produce a representative and believable baseline would need to be developed. However, due to the relatively limited experiential data available, such a methodology would require a combination of experience and a logical means of theoretical prediction.

Some people believe the Soyuz spacecraft is more reliable human spacecraft because of its simplistic design when compared to the Space Shuttle as well as its successful launch history over the last 40 plus years. The ISS PRA team already had a PRA model established for the Soyuz spacecraft while in orbit. The Constellation Program asked the ISS PRA team to calculate a Loss of Mission (LOM) probability for a Soyuz mission (from launch to reentry) and compare it to the reliability target of 1 in 200 (5.0E-3) for a Constellation Mission failure.

2. APPROACH

There was insufficient design data to build a complete Soyuz PRA model from launch to reentry, as was developed for the Space Shuttle, in order to determine the probability of a failed Soyuz mission. However, the Soyuz mission can be broken up into 3 different quantifiable phases for the modeling of a mission failure. Through NASA's international partnerships for the ISS there is information on the Soyuz spacecraft while in orbit, and therefore a traditional PRA model already exists for Soyuz while in space. Other analysis methodologies using Russian empirical data would need to be used for the other two remaining mission phases; namely ascent of the Soyuz rocket and spacecraft and the reentry of the Soyuz descent module.

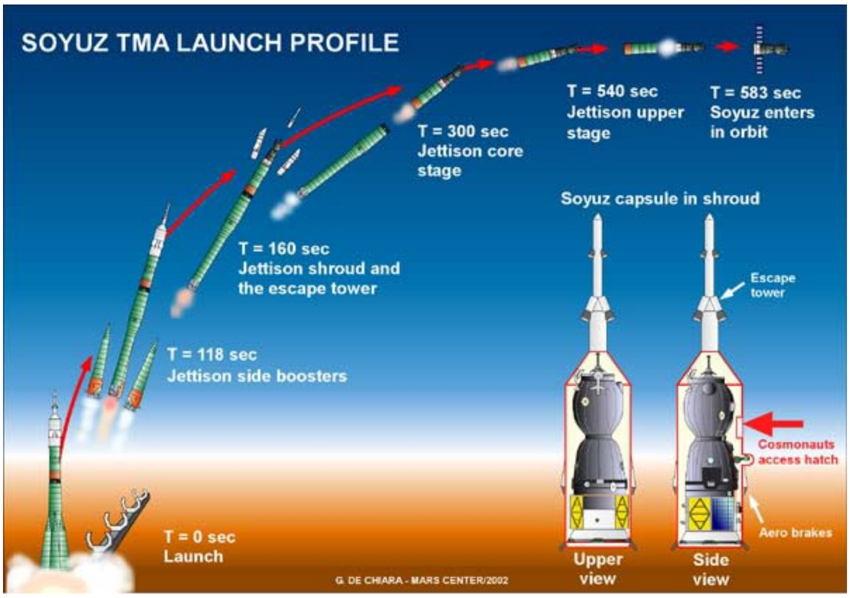
When evaluating the other methodologies for ascent and reentry, questions arose regarding which empirical data should be used. Should only Manned spacecraft mission data be used or should unmanned spacecraft mission data be used also? How are these difference missions comparable? Or should the launch data be divided into the different rocket stages? If rocket stage data is used, should all the data on unmanned rocket stages that are used for manned missions be evaluated?

When examining the data, the design changes and procedural changes impact the experiential data, such that changes have to be accounted for. How are these changes accounted for and do they affect the failure predictions?

Sections 3 and 5 will discuss the options that we considered for calculating probabilities for Ascent and Reentry based on the historical data available, including some "estimation techniques." We found three accepted "estimation techniques" for calculating probabilities with the failure data: Discounting of Failures, Incipient Failure Probability, and Jeffreys Non-informed Prior applied to a Beta Distribution. Section 4 will discuss the ISS PRA model for the Soyuz spacecraft while in orbit.

3. ASCENT PHASE

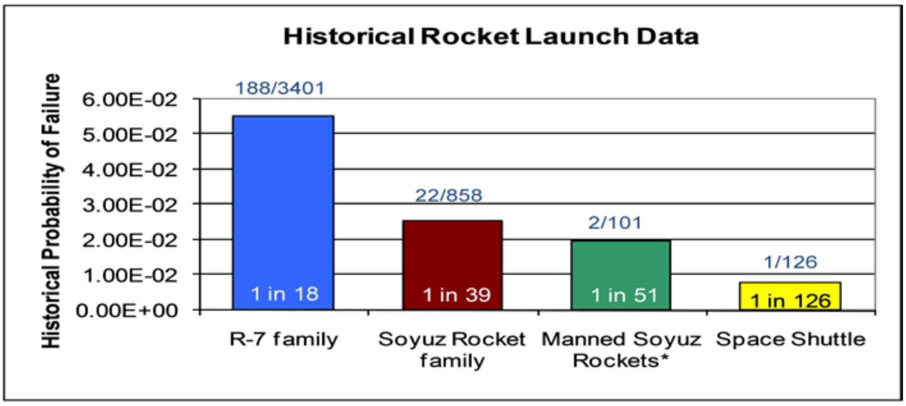
Figure 1: Soyuz TMA Launch Profile



3.1. Historical Rocket Launch or Ascent Data

First, we collected the history on all the Russian launches. Multiple references were cross-referenced to produce the experiential launch data [1] [2]. We divided the launch data into three groups: the R-7 family, the Soyuz Rocket family, and manned Soyuz Rockets. Figure 2 captures these groups and has the Space Shuttle historical launch data added as a reference. There have been two successful launch aborts (Soyuz 18a in 1975 and Soyuz T-10a in 1983) on the 101 manned Soyuz Rockets, these failures did not cause a Loss of Crew (LOC) but are considered an LOM. This data was current as of April, 2009.

Figure 2: Historical Rocket Launch Data



3.2. Historical Manned Soyuz Rocket Stages on All Vehicles

There have been significant design changes to the rockets since the last launch abort in 1983. Currently, the Soyuz spacecraft is launched on the Soyuz FG rocket. There have only been 14 Manned Soyuz FG launches at the time of data collection. 14 data points is not sufficient to provide a mission probability without a high level of uncertainty. We decided to examine the data further and found that some of the stages used on the 14 Soyuz FG launches were also used on other manned Soyuz rockets. We only included data on stages back to the last launch abort in 1983, with the belief that the failure in 1983 caused numerous design and procedural changes and Soyuz Rocket stage data before 1983 would not be indicative of the current design stages. We separated and evaluated the stages of the manned Soyuz rockets and determined that the rockets have these stages [1] [2]:

Soyuz FG – Stage 0 (4 boosters): Blok-B, V, G, D / RD-117
Stage 1: Blok-A / RD-118
Stage 2: Blok-I / RD-124
Stage 3: Fregat
Soyuz 11A511U - Stage 0 (4 boosters): Blok-B, V, G, D / RD-107-11D511
Stage 1: Blok-A / RD-108-11D512
Stage 2: Blok-I / RD-110
Stage 3: Fregat/Ikar
Soyuz 11A511U2 - Stage 0 (4 boosters): Blok-B, V, G, D / RD-107-11D511P
Stage 1: Blok-A / RD-108-11D512P
Stage 2: Blok-I / RD-110

The number of stages launched on manned Soyuz Rockets since 1983 are in Table 1. In Tables 1-5 the "Total" row is not the total number of stages that have launched, but is the total number of launches that have included one or more of the above stages.

Table 1: Manned Soyuz Rocket Stages (Since 1983)

Soyuz Manned Stages since 1983	Launches	Failures	Stage
Blok-B,V,G,D / RD-117	14	0	0
Blok-B,V,G,D / RD-107-11D511	14	0	0
Blok-B,V,G,D / RD-107-11D511P	25	0	0
Blok-A / RD-118	14	0	1
Blok-A / RD-108-11D512	14	0	1
Blok-A / RD-108-11D512P	25	0	1
Blok-I / RD-0124	14	0	2
Blok-I / RD-0110	39	0	2
Fregat/Ikar	28	0	3
Total	53	0	

Researching the rocket stage data, we learned that many of the stages used for manned Soyuz rockets are also used for unmanned Soyuz rockets (e.g. Progress missions). We expanded the stage data listed in Table 1 to include identical stages that were launched on unmanned Soyuz rockets. Unmanned Soyuz rockets with identical stages include: Soyuz 2-1a, Soyuz 2-1b, Molniya 8K78M-2BL, Molniya 8K78M-ML, and Molniya 8K78M-SOL. This expanded data includes 634 launches since 1983. A total of 11 failures have occurred on these 634 flights. Some failure modes are known and are attributed to a specific rocket stage; however, some failures modes are unknown and therefore may or may not be attributed to one of the manned Soyuz rocket stages from Table 1. 5 failures can be identified and traced to a stage that is identical to a stage used on a manned Soyuz rocket. Of the 634 flights, 6 failures cannot be attributed to a particular stage. These 6 failures may or may not have impacted manned Soyuz rockets causing this data to have a high uncertainty. 2 shroud failures occurred in 1996 on the Soyuz 11A511U Stage 3 (Fregat stage). Normally data for the Fregat stage would not contribute to Soyuz Spacecraft launch data but these two failures were attributed to the shroud covering and we assumed that the shroud covering can be directly related to the shroud covering of the Soyuz Spacecraft. In 1987 a Soyuz 11A511U Stage 0 Booster exploded on the pad (Spacecraft Resurs, Earth observation satellite). In 2002 a Soyuz 11A511U Stage 0 Booster exploded 29 seconds after launch (Spacecraft Foton-M1). In 2005 a Molniya 8K78M-ML Stage 2 failed; this rocket stage, Blok-I, is the same stage that is used on the Soyuz 11A511U launcher. The subsequent Soyuz Spacecraft launch was delayed while root-cause analysis was performed. Using only the 5 failures instead of the 11 failures does not drastically improve the reliability of the manned Soyuz rocket, see Table 2.

Table 2: Manned and Unmanned Soyuz Rocket Stages (Since 1983)

Manned Soyuz Stages on all Vehicles	Launches	Failures	Stage
Blok-B,V,G,D / RD-117	31	0	0
Blok-B,V,G,D / RD-107-11D511	383	2	0
Blok-B,V,G,D / RD-107-11D511P	93	0	0
Blok-A / RD-118	31	0	1
Blok-A / RD-108-11D512	381	0	1
Blok-A / RD-108-11D512P	93	0	1
Blok-I / RD-0124	31	0	2
Blok-I / RD-0110	601	1	2
Fregat/Ikar	412	2	3
Total	634	5	
with 6 unknown failures	634	11	

Table 2 can be narrowed to only include data specific to the current manned Soyuz rocket stages, which is the Soyuz FG.

Table 3: Soyuz FG Rocket Stages (Since 2002)

Soyuz FG Stage since 2002	Launches	Failures	Stage
Blok-B,V,G,D / RD-117	31	0	0
Blok-A / RD-118	31	0	1
Blok-I / RD-0124	31	0	2
Total	31	0	

The data in Table 1 can additionally be expanded to include the stages of all the manned Soyuz spacecraft launches since 1967, see Table 4.

Table 4: Manned Soyuz Rocket Stages (Since 1967)

Direct Soyuz Manned Total since 1967	Launches	Failures	Stage
Blok-B,V,G,D / RD-117	14	0	0
Blok-B,V,G,D / RD-107-11D511	62	1	0
Blok-B,V,G,D / RD-107-11D511P	25	0	0
Blok-A / RD-118	14	0	1
Blok-A / RD-108-11D512	61	0	1
Blok-A / RD-108-11D512P	25	0	1
Blok-I / RD-0124	14	0	2
Blok-I / RD-0110	86	1	2
Fregat/Ikar	74	0	3
Total	101	2	

The data in Table 4 can also be expanded to include the stages of all the manned and unmanned Soyuz spacecraft launches (which include test flights and unmanned Soyuz spacecraft).

Table 5: Un/Manned Soyuz Rocket Stages (Since 1966)

Direct Soyuz Un/Manned Total since 1966	Launches	Failures	Stage
Blok-B,V,G,D / RD-117	14	0	0
Blok-B,V,G,D / RD-107-11D511	84	2	0
Blok-B,V,G,D / RD-107-11D511P	26	0	0
Blok-A / RD-118	14	0	1
Blok-A / RD-108-11D512	82	0	1
Blok-A / RD-108-11D512P	26	0	1
Blok-I / RD-0124	14	0	2
Blok-I / RD-0110	122	1	2
Fregat/Ikar	95	0	3
Total	124	3	

By separating and grouping the historical stage data we learned that stage probability based on historical data is always in the same magnitude when there is significant historical data. However, using historical stage data seemed to raise more questions than it answered, like: How similar are the stage upgrades? e.g. RD-107-11D511 and RD-107-11D511P. How do you account for the unknown design and procedural changes within the same stage? e.g. RD-107-11D511 stage was first launched in 1974 and is still being launched as of 2009, surely there has been some design changes.

3.3. Failure Discounting Methodology on Historical Manned Soyuz Rockets

The first "estimation technique" evaluated is the Failure Discounting Methodology. Once a failure has been analyzed and corrective actions for that specific failure mode have been implemented, the probability of the failure's recurrence is diminished. Failure Discounting is a method of applying a reduction factor to a specific failure. It is arbitrary as to how much of a reduction factor is applied to a specific failure and it is dependent on how much is know about the failure and the corrective action(s). Corrective actions can also introduce new failure modes that were not a part of the original design.

3.3.1 Discounting Failures

Typically a failure is discounted by 50%, and if there is justification, failures can be discounted by 66% or more. A sensitivity assessment of different failure discounting factors is applied to the 2 launch failures (Soyuz 18a and Soyuz T-10a) in Table 6. It is difficult to determine Russia's failure mode analysis and corrective actions for past failures (even today it is difficult because of the sensitivity of the information), so public knowledge sources must be used which is often incomplete and contradictory. High Failure Discounting factors are neither defendable nor are they conservative; therefore, a low Failure Discounting factor must be utilized.

Table 6: Failure Discounting Sensitivity on Soyuz Rockets

Discount	Failures	# Launches	Failure Probability	1 in
0.00	2.00	101	1.98E-02	51
0.50	1.00	101	9.90E-03	101
0.67	0.67	101	6.59E-03	152
0.80	0.40	101	3.96E-03	253
0.90	0.20	101	1.98E-03	505
0.99	0.02	101	1.98E-04	5050

3.3.2 Incipient Failure Probability Methodology

The second "estimation technique" evaluated is the Incipient Failure Probability Methodology. The calculation of Incipient Failure Probability assumes that the next Soyuz flight is a failure. For this method we considered only the "modern" Soyuz launchers since the beginning of the Mir Program (Soyuz FG, Soyuz 11A511U, and Soyuz 11A511U2). This data accounted for 47 launches with no failures on ascent. The incipient failure probability for these 47 launches provides a failure probability of 2.08E-02 or 1 in 48.

3.3.3 Jeffreys Non-informed Prior applied to a Beta Distribution

The last "estimation technique" evaluated is the Jeffreys Non-informed Prior applied to a Beta Distribution. When the Jeffreys Non-informed Prior is applied to a Beta Distribution the Mean Failure Probability becomes:

$$\boldsymbol{Mean} = \frac{\mathbf{0.5}}{\boldsymbol{n+1}} \tag{1}$$

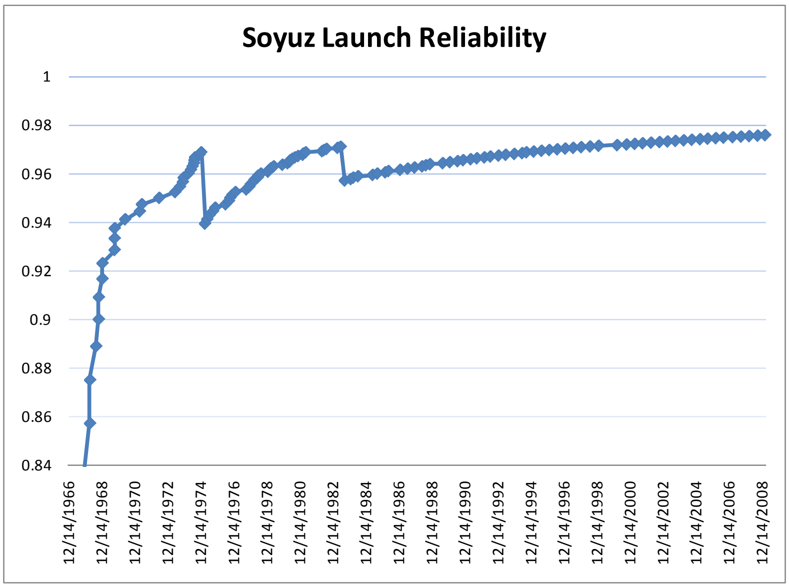
The same "modern" launch data of 47 launches that is used for Incipient Failure Probability Methodology is used as the demand (n) for the Jeffreys Non-informed Prior applied to a Beta Distribution. The Beta distribution calculates a launch failure probability of 1.04E-02 or 1 in 96.

3.4. Reliability Growth

Initial designs and prototypes are never perfect. Reliability can be improved via an extensive testing program to identify flaws and make corrections. Reliability also grows from operating a system and learning from the performance, the anomalous behavior, and failures. The process of finding and tracking reliability issues and subsequent improvements throughout the design process and operational life is known as reliability growth.

Figure 3 plots the reliability of the Soyuz vehicle using historical data and demonstrates that the vehicle has experienced reliability growth over the period analyzed. At each failure point there is a sharp drop on the curve that becomes lesser in magnitude as more data – and successes – became available. After a sufficient number of launches, the curve would be expected to approach the actual vehicle success rate. This supports observations for other rocket launchers that indicate reliability tends to increase over time and failures become more isolated as opposed to generic in nature for the early stages of flight where changes in the design are enacted [3].

Figure 3: Launch Reliability of a Soyuz Rocket Using Historical/Empirical Information



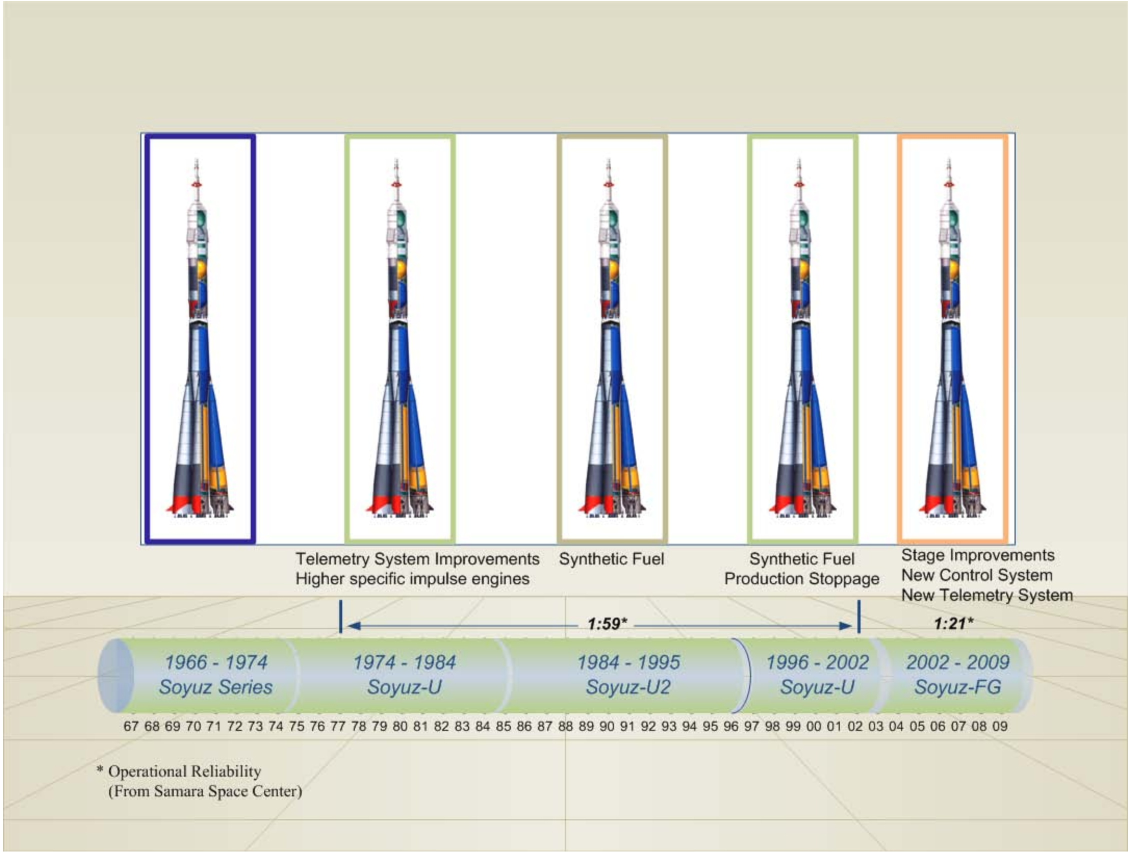
Reliability growth can also be predicted utilizing a variety of methods such the power law model and the exponential model in combination with an established maturity growth model. Such a prediction can be made more representative of actual reliability growth by employing maturity growth, precursor analysis, and if practical via analysis of failed equipment. Additional factors such as complexity, heritage, level of testing, and analysis of specific environments can also provide increased fidelity to the reliability growth estimate.

While it is recognized that by using historical data, the reliability can sometimes provide an optimistic estimate, this study did not employ predictive methods for modelling reliability growth. The growth demonstrated by the historical data does, however, support this study's assertion that discounting of early failures, if applied wisely, provides a more realistic estimate of reliability.

3.7. Samara Operational Reliability

The Soyuz manufacturer, Samara, advertises on their public website "Operational Reliability" numbers for the Soyuz-FG and Soyuz-U of 0.952 and 0.983 [4]. Samara also advertises each launch vehicle's number of launches and failures with a "confirmed serviceability index". See Table 7 for the Samara Launch Statistics. Samara's definition of "Operational Reliability" or "confirmed serviceability index" is unclear, but it is interesting to note that their website uses these figures as a marketing tool for their product. If the "Operational Reliability" is directly related to a launch success rate, then it can be converted into launch failure rates of 4.8E-2 (1 in 21) and 1.7E-2 (1 in 59). Figure 4 is a timeline of the historic Soyuz Rocket with a short description of changes and Samara's assumed launch failure rates.

Figure 4: Samara's Soyuz Reliability Timeline



* Operational Reliability
(From Samara Space Center)

Table 7: Samara's Launch Statistics

Launch vehicle	Total launches	Failure launches	Baikonur		Plesetsk		The confirmed serviceability index
			Total launches	Failure launches	Total launches	Failure launches	
"Soyuz-2"	4	-	2	-	2	-	0.981
"Soyuz-U"	752	**20**	316	**9**	436	**11**	0.984
"Soyuz-FG"	26	-	26	-	-	-	0.984
"Soyuz-U2"	70	-	70	-	-	-	0.984
"Molniya-M"	279	**2**	53	**1**	226	**1**	0.980
"Vostok-2M"	94	**2**	14	-	80	**2**	0.960
"Soyuz-M"	8	-	-	-	8	-	0.950
"Soyuz-L"	3	-	3	-	-	-	0.900
"Soyuz"	32	**2**	32	**2**	-	-	0.960
11A59	2	-	2	-	-	-	0.875
"Voskhod"	299	**14**	138	**3**	161	**11**	0.950
"Vostok-2A"	2	-	2	-	-	-	0.875
"Vostok-2"	45	**5**	39	**5**	6	-	0.980
"Molniya"	40	**11**	40	**11**	-	-	0.830
"Vostok"	26	**8**	26	**8**	-	-	0.810
"R-7A"	28	**2**	25	**2**	3	-	0.940
Satellite	2	**1**	2	**1**	-	-	0.830
Satellite	2	-	2	-	-	-	0.780
"R-7"	26	**9**	26	**9**	-	-	0.780
Total launches	**1741**						

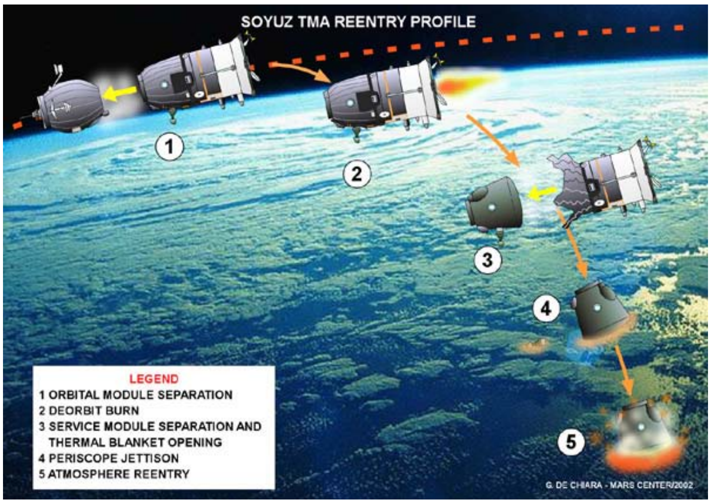
4. ORBIT PHASE

4.1. ISS PRA

The ISS has a complete PRA model to analyze Evacuation, LOC, and Loss of Crew and Vehicle (LOCV) scenarios. One of the dynamic scenarios that affect the ISS is the approach, docking, undocking, and departure of visiting vehicles. For a complete ISS model the Soyuz spacecraft is included and modeled based on information provided by the Russian Space Agency. The Soyuz spacecraft PRA model was used to determine the probability of an LOM while in orbit. This probability is comparable to the Space Shuttle's and other international space vehicles.

5. REENTRY PHASE

Figure 5: Soyuz TMA Reentry Profile



5.1. Historical Soyuz Reentry Data

As of this report, only 98 Soyuz spacecrafts have attempted reentry. Unlike the Ascent phase there is not any other Russian data that can be compared to the reentry of the Soyuz spacecraft. Unmanned Russian spacecraft are design to incinerate on reentry. Of the 98 reentry attempts 2 have failed (Soyuz 1 in 1967 and Soyuz 11 in 1971). There have also been three recent ballistic reentries (one in 2003 and two in 2007).

5.2. Failure Discounting Methodology on Historical Soyuz Reentries

Failure Discounting Methodology as an "estimation technique" may also be applied to the Soyuz reentry data. A higher discount factor should be applied to the reentry data then the launch data. The reentry failures occurred during the early space flight history (Soyuz 1 in 1967 and Soyuz 11 in 1971) and there has not been a catastrophic failure since 1971. After both failures there was a long delay until the next flight because of significant design changes. Also, the first flight had many political pressures to launch before the Soyuz spacecraft was properly prepared causing so many failures that cosmonaut Colonel Vladimir Komarov onboard almost perished on-orbit before even attempting reentry. Presently, the Soyuz reentries have proven to be more robust than past failures would indicate, as demonstrated by the recent ballistic reentries.

Figure 6: Soyuz Decent Module Separation Failure/Ballistic Entry

Table 8: Failure Discounting Sensitivity on Soyuz Reentry

Discount	Failures	# Entries	Failure Probability	1 in
0.00	2.00	98	2.04E-02	49
0.50	1.00	98	1.02E-02	98
0.67	0.67	98	6.80E-03	147
0.80	0.40	98	4.08E-03	245
0.90	0.20	98	2.04E-03	490
0.99	0.02	98	2.04E-04	4900

5.2.1 Incipient Failure Probability Methodology

The second "estimation technique" evaluated in the Reentry Phase is the Incipient Failure Probability Methodology. The calculation of incipient failure probability assumes that the next Soyuz reentry is a failure. For this method we continued to use only the "modern" Soyuz mission data to stay consistent with the Ascent phase. This data accounts for 46 reentries with no catastrophic failures. Applying the incipient failure methodology to these 46 reentries provides a failure probability of 2.13E-02.

5.2.2. Jeffreys Non-informed Prior applied to a Beta Distribution

The last “estimation technique” evaluated in the Reentry Phase is the Jeffreys Non-informed Prior applied to a Beta Distribution. The same “modern” launch data of 46 reentires that is used for Incipient Failure Probability Methodology is used as the demand (n) for the Jeffreys Non-informed Prior applied to a Beta Distribution. The Beta distribution calculates a reentry failure probability of 1.06E-02.

6. CONCLUSION

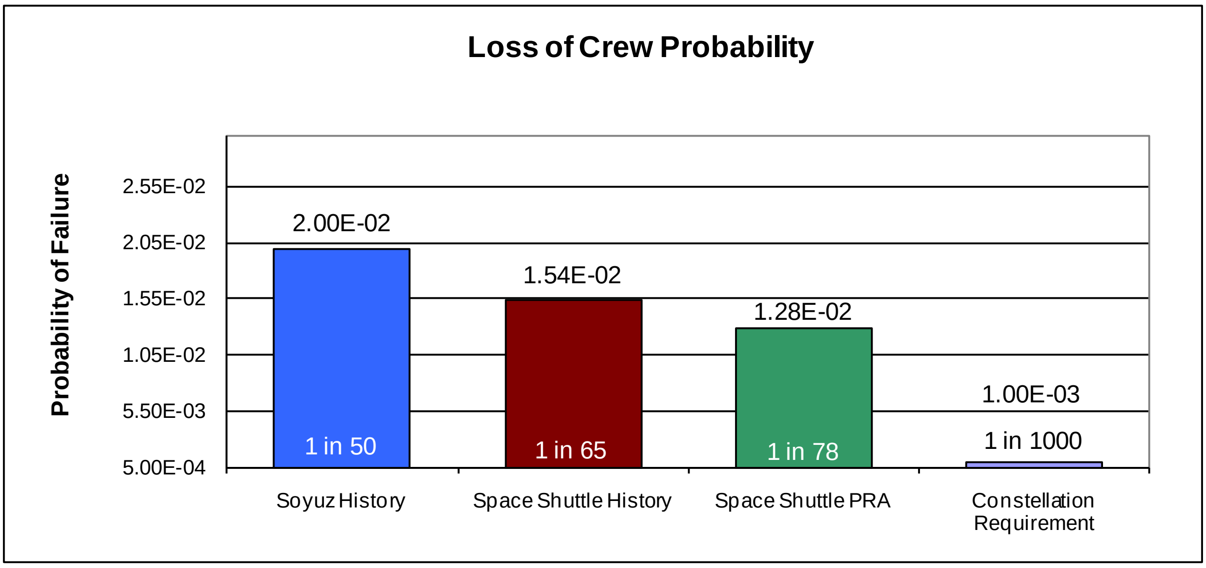
The probability of a Soyuz LOM cannot currently be calculated with great certainty because of the unknown data completeness of Soyuz failures and the lack of available technical design information pertaining to the ascent and reentry of the Soyuz vehicle.

However, the data that has been collected develops a LOM probability for a Soyuz mission between the **ranges of 4.80E-2 (1 in 21) and 1.02E-2 (1 in 98)**. We feel that the Failure Discounting methodology applied to the Ascent and Reentry phases combined with the PRA model in orbit provide the most defendable probability. A discounting factor of 50% for the Ascent phase and a discounting factor of 67% for the Reentry phase are defendable. The difference between the two factors is because of the early time frame on the reentry failures and the long delays after those failures while corrective actions were put in place.

While it would be nice to design the next NASA spacecraft to have a mission failure probability in the 1.0E-3 magnitude range it does not seem feasible with current technology to be able to increase the reliability of spaceflight by an order of magnitude without a new break-through in technology.

For comparison, Figure 6 is the empirical data of LOC for Soyuz and Space Shuttle compared with the Space Shuttle predictive PRA and an early Constellation requirement.

Figure 6: Loss of Crew



So one of the key questions that remain is whether the Constellation Program’s design or the Commercial cargo or crew vehicle could meet such an ambitious requirement. The answer lies in a few key areas. For example, how reliable will the Launch Abort Systems work that essentially transforms what would be a LOC scenario and turn it into a LOM scenario. Also whether you can take credit for the reliability growth of say a 4 segment solid rocket motor when using a 5 segment motor. Certainly the ARES I design is not a totally new launcher, nor is it a typical heritage design you see in aeronautics. There has never been a liquid upper stage mounted on top of a solid first stage. However, NASA has a great deal of experience with solid rocket motors, and believes that this implementation is inherently safer that a traditional liquid core stage with strap-ons..

As for a continuance of the Space Shuttle Program, it does not appear to provide a significant enough improvement in risk to warrant the additional expense in addition to the myriad of other hurdles that must be overcome. Restarting discounted parts manufacture as well as support systems and structure are only a few examples that make extension of the Shuttle Program infeasible.

There are certainly no “game changing” technologies available to transport humans and cargo off and back onto the planet, to utilize an overused phrase. The most significant reliability improvement in the example of the Constellation Program design would be the use of a solid rocket first stage.

As the future of Constellation is unclear, these questions will continue as we debate the role of government and the private sector and how much risk we will accept in putting government or NASA astronauts on launch systems and vehicles that we have little or at least reduced insight into. Will the government or NASA put LOC and LOM requirements on the suppliers of commercial launch services? How would they be verified and who would be responsible for verifying them if they did? The current Nuclear Regulatory Commission model for nuclear power plant operators might be one model to study. The manufacturer of human spaceflight systems whether given the label of “Commercial” or “Contractor” will attempt to build the most reliable systems given the budget, schedule, and available technology and we all hope they will be many times more reliable than what is currently available.

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