Abstract

Our current International Space Station Probabilistic Risk Assessment (ISS PRA) model assumes all collisions between a visiting vehicle (VV) and the ISS result in worst case loss of the ISS crew and the vehicle (LOCV). Drawing results from the Mir-Progress collision, we know this assumption is inaccurate because that collision did not lead to LOCV. Therefore the PRA team is conducting a study to determine the likelihood of LOCV when a collision occurs between a VV and the ISS. Kinetic energy is calculated and converted to pounds of TNT for the moving VVs when they collide with the ISS. Different scenarios are evaluated to obtain collision related data such as translational kinetic energy and rotational kinetic energy. These calculated data are integrated into the results from the expert elicitation performed on the Mir-Progress collision. As a result of this study, the PRA model will now calculate the probability of a VV collision with ISS, the probability that collision will result in Loss of Soyuz Crew (LOC) or Loss of ISS Crew and Vehicle (LOCV)



Exit Presentation Fall 2013

Qi Rong (Bruce) Yang









Agenda

- My background and education
- Organization
- Projects
  - Determining the likelihood of LOCV due to collisions
  - Assisting OE website maintenance/updating
- Developments during the internship
- Extracurricular activities at JSC
- Future Plans
- Acknowledgments

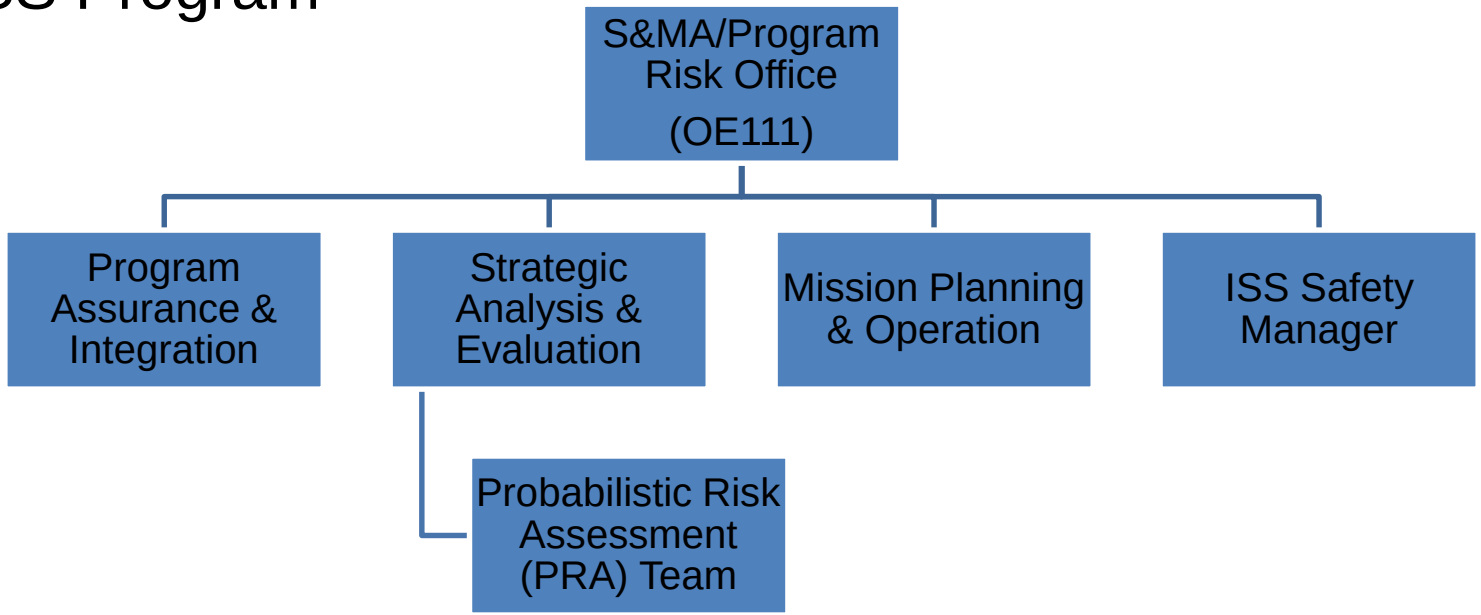
Background

- Qi Rong (Bruce) Yang | 杨启荣
- Born in China, live in York, PA
- Shippensburg University of Pennsylvania
  - -Applied Mathematics
  - -Physics
- Expected Graduation, December 2014
- Member of Sigma Pi Sigma-National Honor Society for Physics
- Professor's Assistant
- Involved in Math Club, Physics Club, Quiz Bowl, Science Bowl



Organization

- Internship August 26, 2013 - December 19, 2013
- ISS Program



- Branch Manager: Willie Lyles
- Deputy: Scott Seyl
- Mentors: Theresa (Terri) Castillo, Philip Mortillaro, Rachael Hayes, Megan Haught, and Gary Duncan

PRA Overview

- Probabilistic Risk Assessment
- Used to model systems and determine the likelihood of end states for the International Space Station Program
  - EVAC3, EVAC6, LOC, LOCV
- Provide quantitative solutions to questions such as:
  - What is the likelihood of risk associated with the ISS?
  - What is the probability of a hardware failure?
- Use system knowledge to create event trees and fault trees
- There is always uncertainty associated with PRA modeling
- Assumptions are required to bound the scope of the analysis

Mir Station

- Current ISS PRA model assumes every collision between a visiting vehicle (VV) and the International Space Station (ISS) results in loss of crew and vehicle (LOCV)

- Inaccurate assumption
  - Progress-Mir Station collision
    - Spektr Science Module
    - Decompression
    - 3.5 m/s, 7100kg, 0.02 lb TNT

NOT LOCV!



LOCV Collision

- Determine the probability of LOCV given a collision occurs between a VV and the ISS



LOCV Collision

- 3.5m/s, 7100kg, 0.02 lb. TNT (did not result in LOCV)
- Relate it to the velocity and mass of current VVs; kinetic energy = $\frac{1}{2}mv^2$
- We also have probability of collision for each VV with the ISS in 6 months of operation
- If we know how the kinetic energy for the Progress-Mir collision relates to kinetic energy for the current VVs and the probability of ISS collision, then we can estimate the probability of LOCV for a current VV and the ISS

LOCV Collision

Current VVs' masses

- ATV (20,750 kg)
- Cygnus (7,350 kg)
- Dragon (7,510 kg)
- HTV (16,500 kg)
- Progress (7,100 kg)
- Soyuz (7,120 kg)







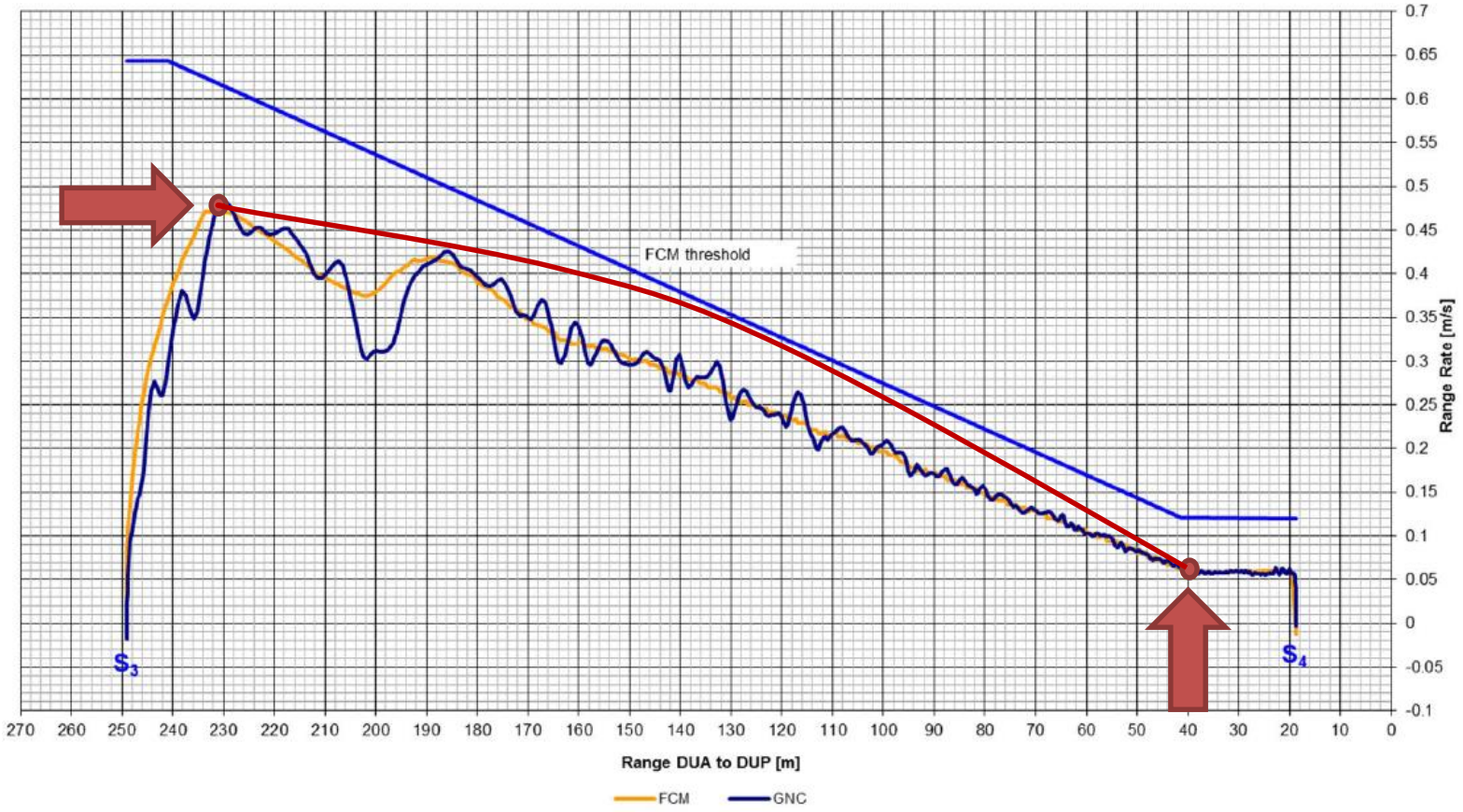






LOCV Collision

- Current VVs' Velocities vary in the final approach



LOCV Collision

- Kinematic Equations:

$$x(t) = \frac{1}{2}at^2 + v_0 t + x_0$$

$$v(t) = at + v_0$$

$$x(t) = \frac{v_0 + v}{2}t$$

- Spreadsheet

v_0	4.8E-01
a	-6.0E-04
x_{total}	250





	Breakdown occurs between 230-40m			
	input (230,40) dis from ISS	x1 (m) dis traveled	v (m/s) velo at x1	t2 (s) est to ISS
ENTER-> (230,40)	230	0	0.48	479

LOCV Collision

The final result:

Vehicles Mass (kg)	Zone	Maximum Expected Velocity	Translational Kinetic Energy (J)	TNT (lb.)
Progress 7,100 kg	250-20	0.48	817.92	4.30E-04
	20-10	0.066	15.46	8.13E-06
	10-dock	0.074	19.44	1.02E-05
Soyuz 7120 kg	250-20	0.48	820.22	4.31E-04
	20-10	0.066	15.51	8.15E-06
	10-dock	0.074	19.49	1.03E-05
ATV 20750 kg	250-20	0.48	2390.4	1.26E-03
	20-10	0.066	45.19	2.38E-05
	10-dock	0.074	56.81	2.99E-05
Cygnus 7350 kg	250 - 220	0.3333	408.33	2.15E-04
	220 -100	0.4	588	3.09E-04
	100 - 30	0.4333	690.08	3.63E-04
	30 -10	0.0741	20.16	1.06E-05
Dragon 7510 kg	250 - 30	0.13	63.45	3.34E-05
	30 - 10	0.037	5.15	9.27E-06
HTV 16500 kg	250-30	0.249	511.55	2.69E-04
	30 - 10	0.0323	8.58	4.51E-06

Possible rotational velocity is also calculated but is not implemented in this study

LOCV Collision

If we know how the kinetic energy for the Progress-Mir collision relates to kinetic energy for the current VVs and the probability of ISS collision, then we can estimate the probability of LOCV for a current VV and the ISS.





LOCV Collision

Expert Elicitation - A method of estimating failure probabilities when better sources (field data, test data, surrogate data, etc.) are unavailable.

8 Experts responded:

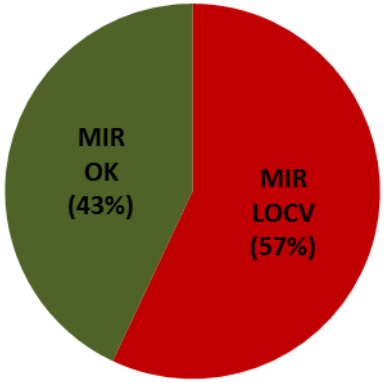
- Flight Dynamics Division (DM)
- Operation Division (DO)
- System Engineering and Integration (OM)
- Human Exploration Science (KX)
- Structure Engineering (ES)
- ISS Program - Viper Team members from the Mission and Program Integration (OP)

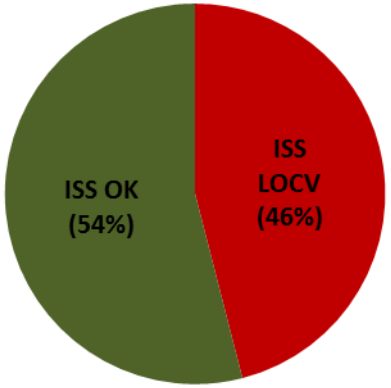
LOCV Collision

- Experts were asked to determine whether or not LOCV was likely to have occured after the Progress-Mir Collision
- What if the collision had happened to the ISS?



- Give a numerical values to their answers





LOCV Collision

Experts' answers:

Expert ID	P(MIR LOCV)		P(ISS LOCV)		ISS/MIR Ratio
Expert 1	Likely	0.30	Likely	0.30	1.00
Expert 2	Likely	0.60	Likely	0.70	1.17
Expert 3	Possible	0.25	Unlikely	0.10	0.40
Expert 4	Likely	0.60	Likely	0.60	1.00
Expert 5	Likely	0.52	Likely	0.60	1.15
Expert 6	Likely	0.05	Likely	0.05	1.00
Expert 7	Likely	0.60	Very Likely	0.90	1.50
Expert 8	Possible	0.34	Possible	0.28	0.82
Mean					1.01
Variance					0.10

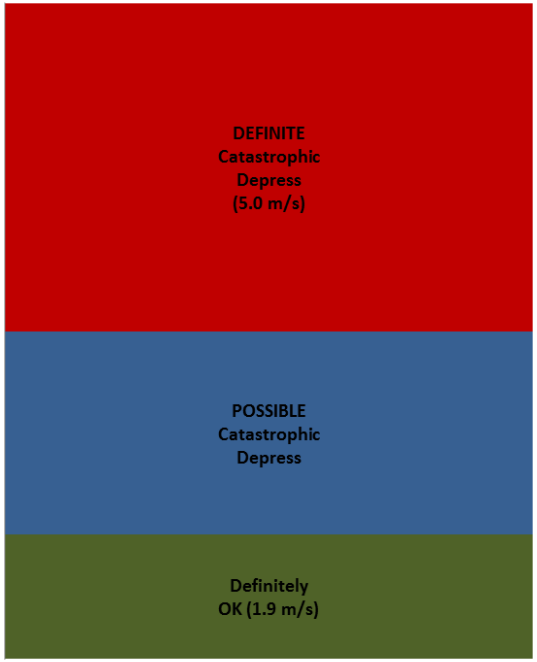
The ISS/MIR ratio tells us how much more likely a collision is to result in LOCV for the ISS as compared to Mir.

The mean of this ratio is 1.01, with a variance of 0.10. The variance reflects the difference in expert responses.

LOCV Collision

Given a fixed mass (7,100 kg), experts established the bounds for velocities that would definitely (or definitely would not) cause LOCV given a collision with MIR.

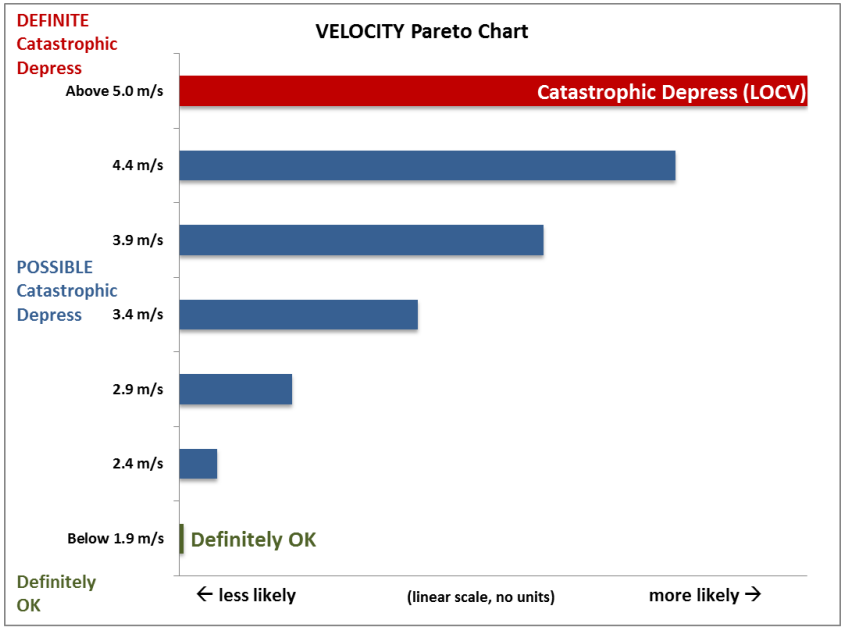
Given a fixed velocity (3.5 m/s), experts established the bounds for masses that would definitely (or definitely would not) cause LOCV given a collision with MIR.

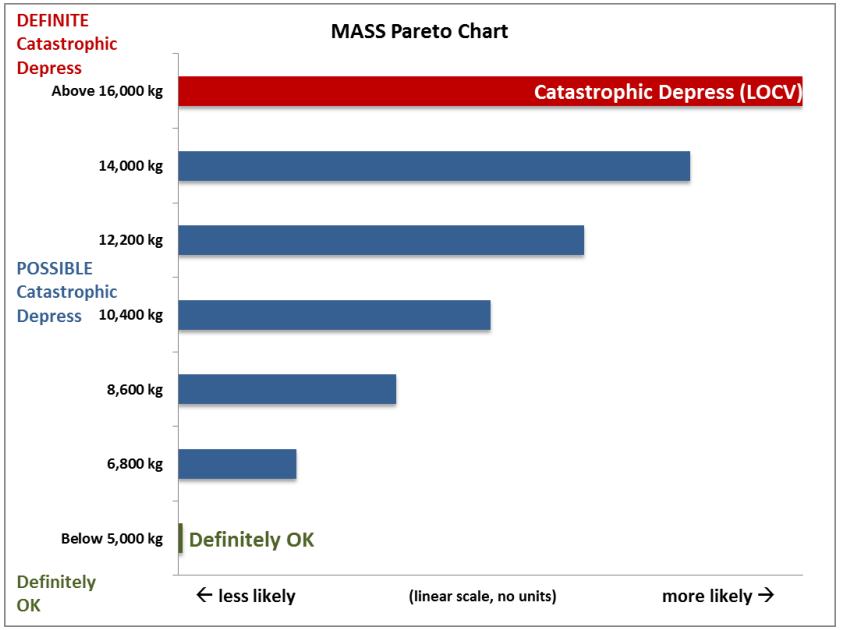




LOCV Collisions

- Experts provided the relative likelihood of LOCV due to collision with MIR for masses and velocities between their given bounds.





LOCV Collisions

The masses and velocities considered by the experts were converted into kinetic energy (joules).

	Velocity	Energy	P(MIR LOCV)	m	Mass	Energy	P(MIR LOCV)	m
Expert 1	4.5	71,888	1.00	1.4E-05	8,500	52,063	1.00	1.9E-05
	3.7	48,600	0.63	1.3E-05	7,100	43,488	0.49	1.1E-05
	3.0	31,950	0.52	1.6E-05	5,700	34,913	0.34	9.7E-06
	2.3	18,780	0.36	1.9E-05	4,300	26,338	0.23	8.7E-06
	1.6	9,088	0.19	2.1E-05	2,900	17,763	0.14	7.9E-06
	0.9	2,876	0.07	2.4E-05	1,500	9,188	0.10	1.1E-05
	0.2	142	0.00		100	613	0.00	
Expert 2	4.0	56,800	1.00	1.8E-05	9,900	60,638	1.00	1.6E-05
	3.2	36,352	0.66	1.8E-05	8,500	52,063	0.94	1.8E-05
	2.6	23,998	0.42	1.8E-05	7,000	42,875	0.78	1.8E-05
	2.0	14,200	0.24	1.7E-05	5,500	33,688	0.57	1.7E-05
	1.4	6,958	0.10	1.4E-05	4,000	24,500	0.33	1.3E-05
	0.8	2,272	0.05	2.2E-05	2,500	15,313	0.19	1.2E-05
	0.2	142	0.00		1,000	6,125	0.00	
Expert 3	8.0	227,200	1.00	4.4E-06	13,000	79,625	1.00	1.3E-05
	7.0	173,950	0.77	4.4E-06	11,500	70,438	0.74	1.1E-05
	6.2	136,462	0.56	4.1E-06	10,000	61,250	0.56	9.1E-06
	5.4	103,518	0.39	3.8E-06	8,500	52,063	0.41	7.9E-06
	4.6	75,118	0.25	3.3E-06	7,000	42,875	0.21	4.9E-06
	3.8	51,262	0.15	2.9E-06	5,500	33,688	0.08	2.4E-06
	3.0	31,950	0.00		4,000	24,500	0.00	
Expert 4	4.0	56,800	1.00	1.8E-05	9,500	58,188	1.00	1.7E-05
	3.5	43,488	0.84	1.9E-05	8,600	52,675	0.75	1.4E-05
	3.0	31,950	0.78	2.4E-05	7,800	47,775	0.50	1.0E-05
	2.5	22,188	0.61	2.7E-05	7,000	42,875	0.40	9.3E-06
	2.0	14,200	0.19	1.3E-05	6,200	37,975	0.29	7.6E-06
	1.5	7,988	0.05	6.3E-06	5,400	33,075	0.19	5.7E-06
	1.0	3,550	0.00		4,600	28,175	0.00	

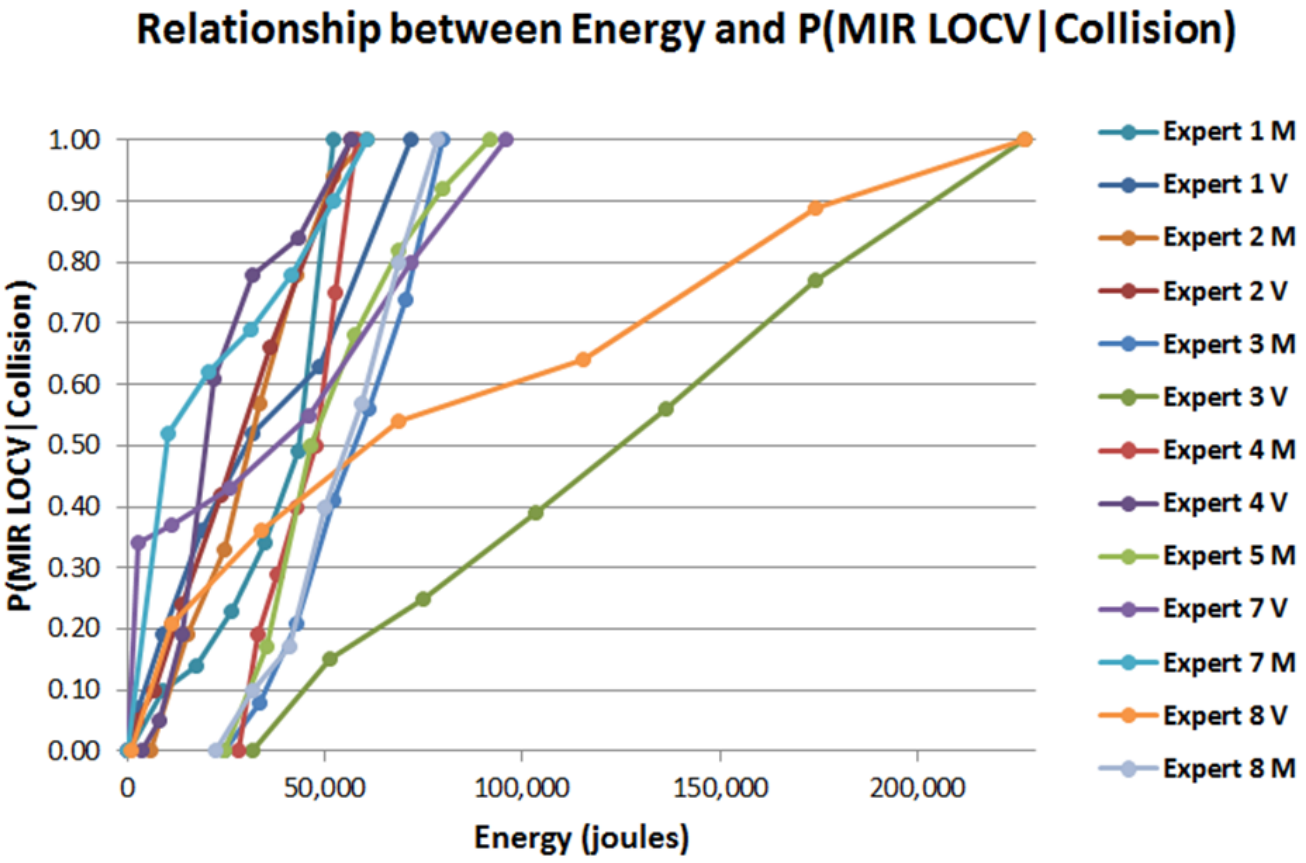
LOCV Collisions

The term *m* represents the ratio between P(MIR LOCV) and the kinetic energy for each response

	Velocity	Energy	P(MIR LOCV)	m	Mass	Energy	P(MIR LOCV)	m
Expert 5	Respondent did not comply with survey				15,000	91,875	1.00	1.1E-05
					13,000	79,625	0.92	1.2E-05
					11,200	68,600	0.82	1.2E-05
					9,400	57,575	0.68	1.2E-05
					7,600	46,550	0.50	1.1E-05
					5,800	35,525	0.17	4.8E-06
					4,000	24,500	0.00	
Expert 6	Respondent did not comply with survey				Respondent did not comply with survey			
Expert 7	5.2	95,992	1.00	1.0E-05	9,900	60,638	1.00	1.6E-05
	4.5	71,888	0.80	1.1E-05	8,500	52,063	0.90	1.7E-05
	3.6	46,008	0.55	1.2E-05	6,800	41,650	0.78	1.9E-05
	2.7	25,880	0.43	1.7E-05	5,100	31,238	0.69	2.2E-05
	1.8	11,502	0.37	3.2E-05	3,400	20,825	0.62	3.0E-05
	0.9	2,876	0.34	1.2E-04	1,700	10,413	0.52	5.0E-05
	0.0	0	0.00		0	0	0.00	
Expert 8	8.0	227,200	1.00	4.4E-06	12,800	78,400	1.00	1.3E-05
	7.0	173,950	0.89	5.1E-06	11,200	68,600	0.80	1.2E-05
	5.7	115,340	0.64	5.5E-06	9,700	59,413	0.57	9.6E-06
	4.4	68,728	0.54	7.9E-06	8,200	50,225	0.40	8.0E-06
	3.1	34,116	0.36	1.1E-05	6,700	41,038	0.17	4.1E-06
	1.8	11,502	0.21	1.8E-05	5,200	31,850	0.10	3.1E-06
	0.5	888	0.00		3,700	22,663	0.00	

LOCV Collision

Graphical representation of the relationship between kinetic energy and P(MIR LOCV) for each response; in this graph *m* represents the slope of the line of best fit.



LOCV Collision

- The mean and variance for the ISS/MIR ratio and *m* are assumed to be distributed lognormally.

	Distribution	Mean	Variance
ISS/MIR Ratio	Lognormal	1.01	0.10
m	Lognormal	1.6E-05	2.2E-10

- The equation for a line is y = mx + b

  y = P(MIR LOCV|Collision)

  x = Energy

  m = slope

  b = y-intercept

LOCV Collision

- Assuming that the line of best fit has a slope of *m* and a y-intercept of zero, its equation is:

P(MIR LOCV|Collision) = (*m*)(Energy)

- The probability that a collision with ISS would result in LOCV is:

P(ISS LOCV|Collision) = (MIR LOCV|Collision)(ISS/MIR Ratio)

- This equation relates a given vehicle's energy to the probability that a collision with MIR would result in LOCV, then proportions it to the probability of LOCV if the collision had been with ISS.

LOCV Collision

P(ISS LOCV|Collision) was calculated for each phase of each vehicle using the sampled ISS/MIR ratio and *m* as shown in the previous slide.

Vehicle	Zone (m)	Mass (kg)	Velocity (m/s)	Energy (J)	P(ISS LOCV|Collision)
ATV 1	250 - 20	20,750	4.8E-01	2,390	3.9E-02
ATV 2	20 - 10	20,750	6.6E-02	45	7.3E-04
ATV 3	10 - dock	20,750	7.4E-02	57	9.2E-04
Cygnus 1	250 - 220	7,350	3.3E-01	408	6.6E-03
Cygnus 2	220 - 100	7,350	4.0E-01	588	9.5E-03
Cygnus 3	100 - 30	7,350	4.3E-01	690	1.1E-02
Cygnus 4	30 - 10	7,350	7.4E-02	20	3.3E-04
Dragon 1	250 - 30	7,510	1.3E-01	63	1.0E-03
Dragon 2	30 - 10	7,510	3.7E-02	5	8.3E-05
HTV 1	250 - 30	16,500	2.5E-01	512	8.3E-03
HTV 2	30 - 10	16,500	3.2E-02	9	1.4E-04
Progress 1	250 - 20	7,100	4.8E-01	818	1.3E-02
Progress 2	20 - 10	7,100	6.6E-02	15	2.5E-04
Progress 3	10 - dock	7,100	7.4E-02	19	3.2E-04
Soyuz 1	250 - 20	7,120	4.8E-01	820	1.3E-02
Soyuz 2	20 - 10	7,120	6.6E-02	16	2.5E-04
Soyuz 3	10 - dock	7,120	7.4E-02	19	3.2E-04

LOCV Collision

The zones were combined for each vehicle to obtain a total per-approach probability that, given a collision has occurred, that collision will result in LOCV. For example, the probability for ATV would be calculated as follows:

$$P(\text{ISS LOCV} \mid \text{ATV Collision}) = P(\text{ATV 1}) + (1 - P(\text{ATV 1}))P(\text{ATV 2}) + (1 - P(\text{ATV 1}))(1 - P(\text{ATV 2}))P(\text{ATV 3})$$

That is, ATV either fails in Zone 1, or succeeds in Zone 1 and fails in Zone 2, or succeeds in Zones 1 and 2 and fails in Zone 3.

Vehicle	P(ISS LOCV|Collision)
ATV	4.0E-02
Cygnus	2.7E-02
Dragon	1.1E-03
HTV	8.4E-03
Progress	1.4E-02
Soyuz	1.4E-02

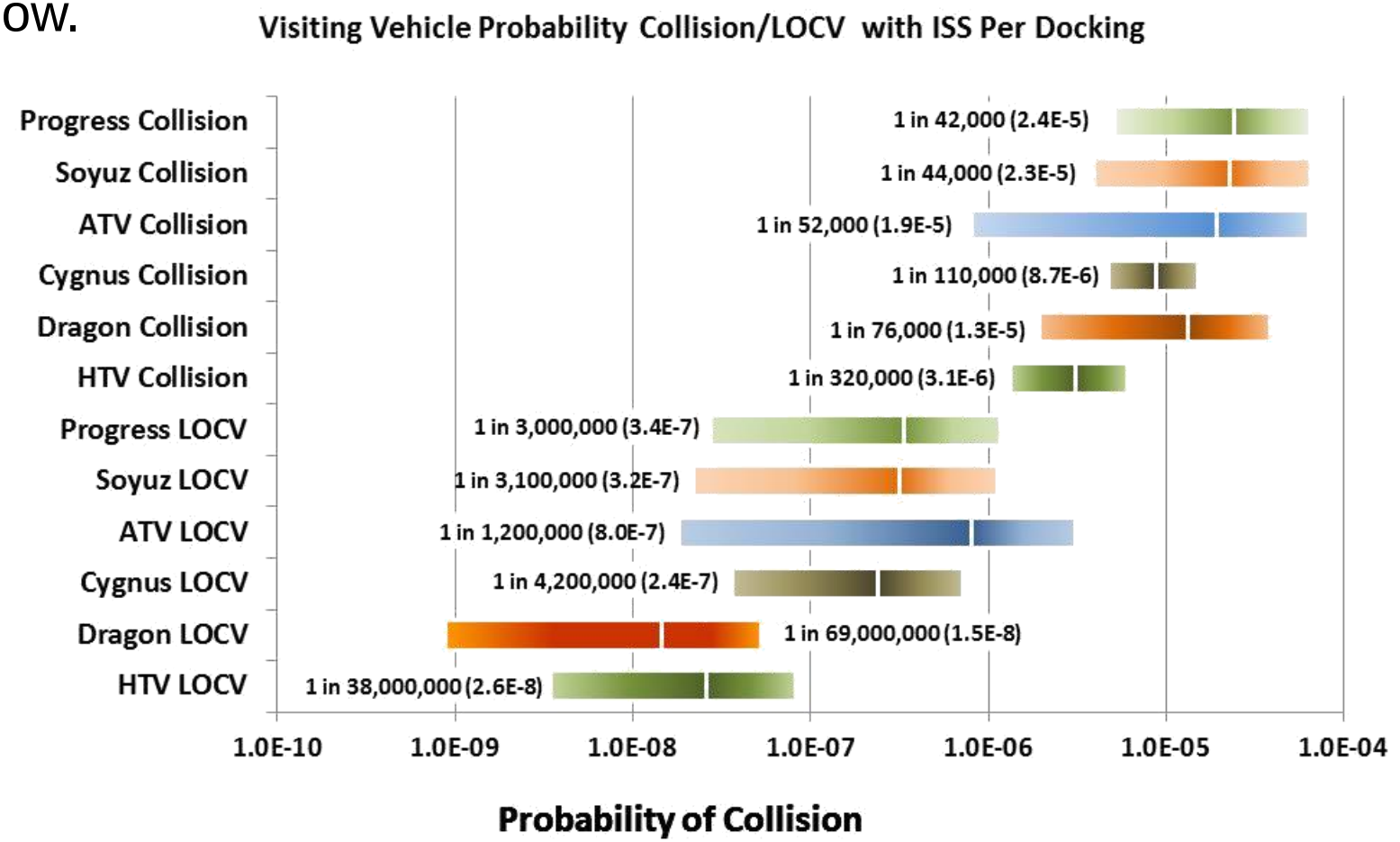
LOCV Collision

ModelRisk, a spreadsheet-based Monte Carlo simulation tool, was used to sample each variable (100,000 reps) to obtain uncertainty about the final results.

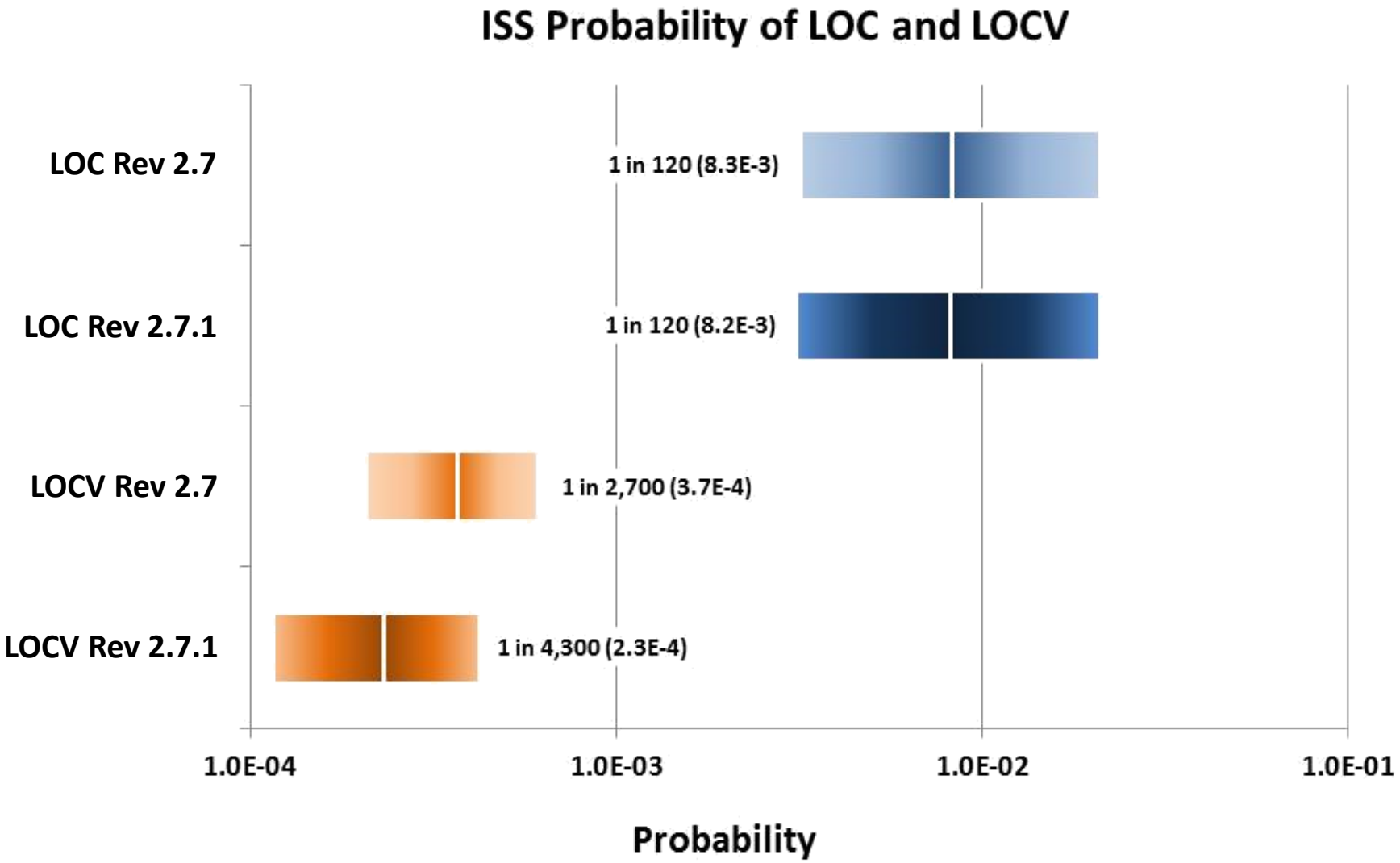
Variable	5th percentile	Mean	95th percentile	1 in X	EF
m	3.2E-06	**1.6E-05**	4.3E-05		3.6
ISS/MIR Ratio	5.8E-01	**1.0E+00**	1.6E+00		1.7
ATV	7.1E-03	**4.0E-02**	1.1E-01	**1 in 25**	4.0
Cygnus	4.8E-03	**2.7E-02**	7.6E-02	**1 in 37**	4.0
Dragon	1.9E-04	**1.1E-03**	3.1E-03	**1 in 900**	4.0
HTV	1.5E-03	**8.4E-03**	2.4E-02	**1 in 120**	4.0
Progress	2.4E-03	**1.4E-02**	3.9E-02	**1 in 73**	4.0
Soyuz	2.4E-03	**1.4E-02**	3.9E-02	**1 in 72**	4.0

LOCV Collision

The results were incorporated into the ISS PRA Model. The overall probability of collision and LOCV for each vehicle is shown below.

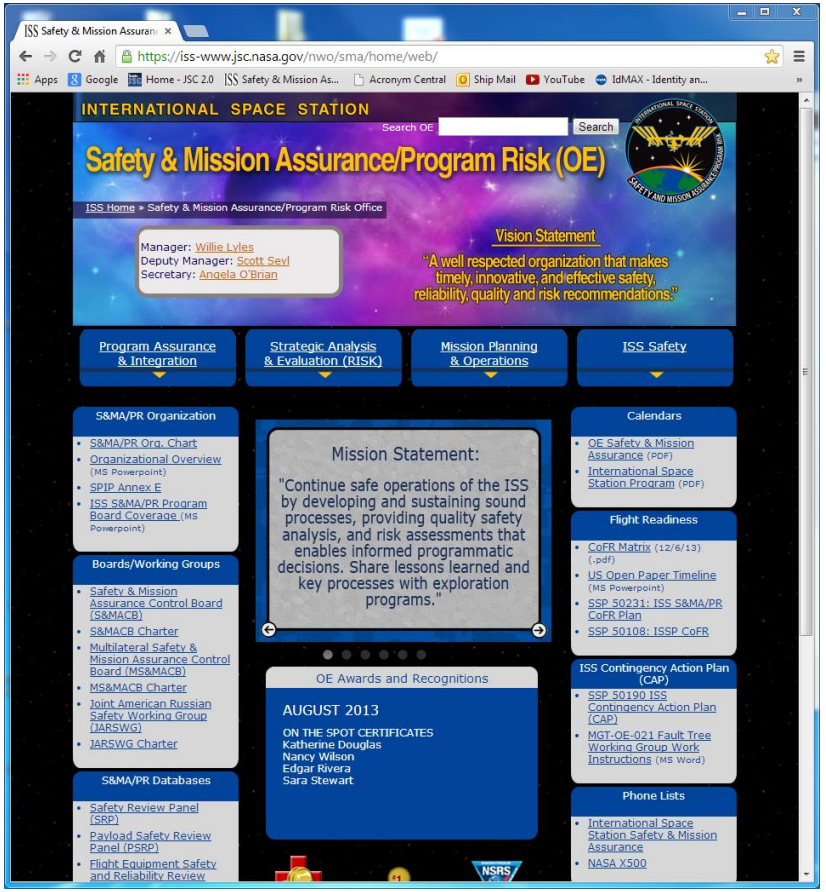


LOCV Collision



OE Website

- Documents are outdated
- Goal: spreadsheet contains
  names and the revision date
- Purpose: monitor the website
  to ensure documents are up to date



OE Website

- Example of the spreadsheet



Original Order	Link	Link	Link	Responsible NASA Official	Latest Update	Notes
1	Computer Safety Work Group (CSWG)	Joint Software Assurance Pannel (JSAP)	Standing Agenda (MS Word)	[redacted]	N/A	
2			JSAP Charter (MS Word)		N/A	
3			S/W Milestone Schedule(MS Excel)		5/16/2013	
4			Ops S&MA Protocol (MS Word)		N/A	
5			Authorized NASA S&MA Representatives and Signature Authorities		4/1/2013	
6		Software Quality Panel (SQP)	Agenda/Minutes/Actions		9/19/2013	
7			SQP (Software Quality Panel) email Link		N/A	
8			SQP Charter (MS Word)		N/A	
9			SQP Action Tracking (MS Excel)		5/22/2006	
10			SPDR/DDR Information		N/A	Cannot find this website
11		Documents	SSP-50645 - (ISS) Command and Telemetry Team (ICATT) Standards		EDMS	
12			SSP 50038 Rev B - Computer-Based Control System Safety		EDMS	
13		Computer Safety Working Group (CSWG)	Agenda/Minutes		9/19/2013	
14			CSWG Charter (MS Word)		N/A	
15			Agenda Index List (MS PowerPoint)		6/1/2006	Not complete
16			Agenda Item Request Form (MS Word)		N/A	
17			CSWG Mailbox		N/A	
18			Generic Hazardous Command Template Form(MS Excel)		2/4/2002	
19			Acronyms List (MS Word)		4/1/2000	
20			Boeing Software Open Paper Safety Assessments		9/16/2013	
21		Database	PVCS		12/11/2002	
22			RIM - Rig Information Management		N/A	
23		Computer Safety Panel (CSP)	CSP Agenda/Minutes		9/19/2013	
24			CSP Charter (MS Word)		N/A	
25			CSP Mailbox		N/A	
26		Useful Links	ISS Program Schedule(PDF)		9/16/2013	
27			ISS QA Team Home Page		9/20/2013	See NASA Quality Assurance (F128)
28			ISS Avionics and Software Office		9/12/2013	
29			SCM Process Page		N/A	Page has been retired
30			SRP - S+-afety Review Panel		UTD	
31			ECW - Early Caution and Warning		4/4/2013	
32			ASCB - Avionics Software Control Board		7/3/2013	
33			S&MACB - Safety & Mission Assurance Control Board		4/22/2013	

- Filters are implemented

Professional Growth

Technical Experiences

- Learned about PRA and its role in supporting the ISS program
- Learned how to implement an Expert Elicitation
- Statistical techniques that are not taught in school

Overall Growth

- Professional interaction with peers as well as supervisors
- Taking notes and setting goals
- Time managements
- More motivated about school

Future Goals

Short-term

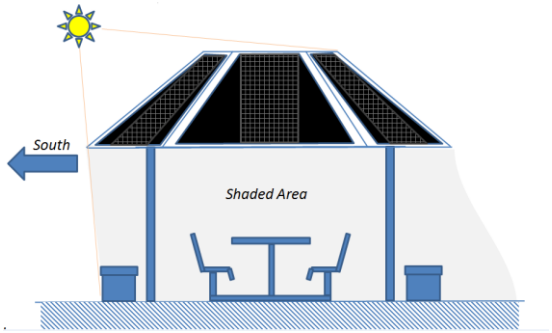
- Return to school for Spring semester
- Apply for summer internship
  - Orbital Mechanics/Flight Dynamics/Applied Mathematic
  - Research

Long-term

- Working in a competitive environment has influenced me to consider Graduate school - engineering?
- Obtain a permanent position with NASA

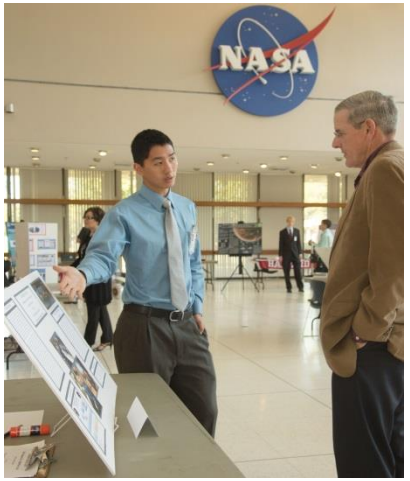
Extracurricular Activities

- Ultimate Frisbee
- Thanksgiving flag football
- Crossfit
- Fancy Dinner
- Attend lectures
- Tours
- NASA on Campus
- Video Committee
- CAPT/SCuM meetings
- SPOCC



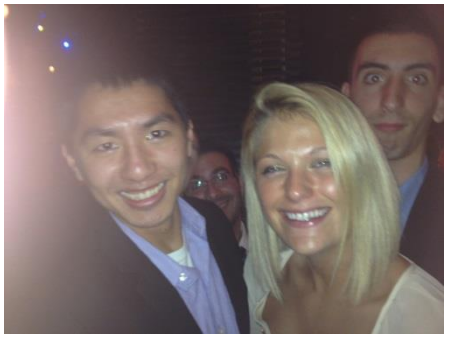












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BACK-UP