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Final NASA Panel Recommendations for Definition of Acceptable Risk of Injury due to Spaceflight Dynamic Events

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1.0 Introduction

A panel of experts was convened in 2010 to help define acceptable injury risk levels for space vehicle launches, landings, and abort scenarios. Classifications of spaceflight-relevant injuries were defined using four categories ranging from minor to severe injury. Limits for each injury category were agreed to, dependent on the expected number of crew exposures in a given vehicle and on whether the flight was considered nominal or off-nominal. Somers et al. captured the findings of this summit in a NASA technical memorandum.[1]

This panel was recently reconvened (December 1, 2014) to determine whether the previous recommended injury limits were applicable to newly designed commercial spaceflight vehicles. In particular, previous limits were based in part on the number of crew exposures per vehicle and also were sensitive to a definition of nominal and off-nominal vehicle performance. Reconsideration of these aspects led to a new consensus on a definition of injury risk.

2.0 Summary of 2010 Panel Findings

Examining the Orion vehicle's probabilistic risk assessment for landings, the panel previously assigned acceptable risk levels to four different landing modes. One nominal water landing condition (predicted to occur $\geq$ 95%) and three off-nominal possible landing conditions were considered (Table 1). Expected injury numbers were based on 80 vehicle flights with 4 crewmembers on each, for a total of 320 crew exposures. Since off-nominal events are expected to occur so rarely, tolerance for injury risk can increase for these types of landings.

Table 1: Determination of Acceptable Orion Landing Injury Risk (Nominal/Off-Nominal Landing Cases)

Assumes: 80 Landings over Program Life – 4 Crewmembers per Landing, 320 Total Crew Landings 95% Confidence		Nominal		Off-Nominal^					
		End of Mission Nominal Water Landing or Pad Abort Water Landing		Ascent Abort Water Landing		End of Mission Water Landing with Parachute Failure, High Winds, High Sea State		Pad Abort Land Landing	
P(Landing)		99.6%		<1%		<1%		<1%	
Injury Class		Expected Number of Injuries	Probability of Injury	Expected Number of Injuries	Probability of Injury	Expected Number of Injuries	Probability of Injury	Expected Number of Injuries	Probability of Injury
Minor	I	18	4%	3	56%	3	56%	4	100%
Moderate	II	3	0.42%	2	39%	2	39%	3	70%
Severe	III	0	0.1%	0	17%	0	17%	0 (2)*	10% (30%)*
Life-Threatening	IV	0	0.02%	0	6%	0	6%	0	10%
All Classes	I-IV	21	4.71%	5	100%	5	100%	9	100%

*Acceptance of this injury risk assumes Search and Rescue forces will get access to the crewmembers within 30 minutes of the mishap occurrence.

^Number of expected injuries for off-nominal was determined using 1% probability of occurrence. The current design probabilities are much lower.

The 2010 panel then decided that it would be best to define a total overall risk of injury, rather than discriminate between nominal and the rarely occurring off-nominal events. However, the Table 1 ratios were deemed important to preserve. Table 2 shows the final ratios for each injury category. The percentages are based on a 95% confidence interval of a binomial distribution based on 320 crew exposures.

Table 2: Recommendation for Acceptable Orion Landing Injury Risk (All Landing Cases)

Injury Description	Injury Class	Expected Number of Injuries	Probability of Injury
Minor	I	23/320	5%
Moderate	II	6/320	1%
Severe	III	0/320 [2/320]*	0.02% [0.25%]*
Life-Threatening	IV	0/320	0.02%
All Classes	I-IV	29/320 [31/320]*	6.8% [7.4%]*

*Acceptance of recommendations in brackets assumes Search and Rescue forces will get access to the crewmembers within 30 minutes of the mishap occurrence.

For commercial space vehicles, the total number of crew exposures could be quite different from expectations for Orion. Therefore, Table 3 was developed to examine injury rates for various numbers of crew exposures. Table 3 shows that the injury risk does not vary significantly based on the number of exposures. The median values are in the 160 to 200 exposure range.

Table 3: Maximum Nominal Risk Levels for each Injury Class Based on Number of Crewmembers Flown Over the Course of a Program

	Number of Crew Exposures								
	40	**80**	**120**	**160**	**200**	**240**	**280**	**320**	**Median**
Class I	3.49%	4.18%	4.59%	4.87%	4.68%	4.90%	5.08%	5.23%	4.8%
Class II	0.90%	1.03%	0.68%	0.86%	0.99%	1.09%	0.94%	1.03%	1.0%
Class III	0.13% [0.12%]	0.45% [0.44%]	0.30% [0.29%]	0.22% [0.22%]	0.18% [0.17%]	0.34% [0.34%]	0.29% [0.29%]	0.26% [0.25%]	0.27% [0.27%]
Class IV	0.13%	0.06%	0.04%	0.03%	0.03%	0.02%	0.02%	0.02%	0.03%

3.0 Final 2014 Panel Recommendations

The reconvened panel agreed that the median values would be a sound basis for a final update to the definition of acceptable risk. However, with only risk guidelines for overall vehicle life cycle, it was somewhat concerning that vehicle designers could potentially ignore any risk associated with off-nominal performance. The panel wanted to ensure the final recommendations required not-to-exceed injury limits in off-nominal conditions as well. To avoid confusion over defining off-nominal versus nominal performance, the panel decided to specify injury limits for ≥ 95% of all possible vehicle dynamic events, and a set of separate not-to-exceed injury limits for the remaining 5% of cases.

To calculate these injury percentages, acceptable injury limits were found from a binomial distribution for crew exposures up to 500. The ≥95% of all vehicle dynamic cases bore 75% of the overall risk, with the remaining 25% borne by the ≤5% of all cases. These injury risks were then plotted against crew exposures for each category (Figure 1). Because of the nature of a binomial distribution, the risk fluctuates wildly for a small number of crew exposures; for larger number of exposures, the risk begins to approach an asymptote.

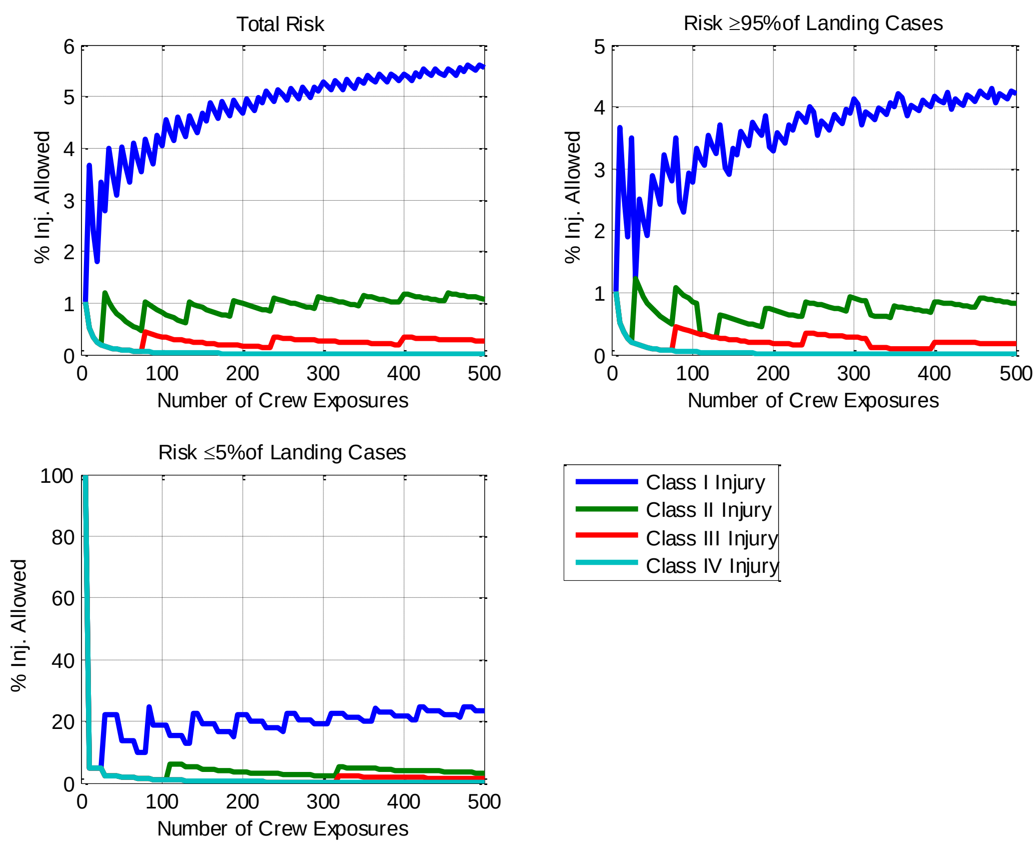

Figure 1: Allowable injury rates for overall, 95%, and 5% of all space vehicle dynamics.

Because of the sensitivity of the numerical model to small numbers of exposures, the panel chose to use the asymptote values for Injury Class I, Class II, and 5% Class III. For Class III and IV, no injuries are expected, so the asymptote approaches zero and is heavily dependent on the number of crew exposures. Rather than using the asymptote values, the panel chose to use the NASA-defined loss-of-crew (LOC) ratio as the basis for this percentage. NASA allows a vehicle to have an LOC of 1/1000 or 0.1%. This LOC calculation is for the entire mission, not just for landing, so the true value for a design will be lower. For Class III, the original definition contained a second probability based on a pad abort land landing. The panel retained this probability for the ≤5% category, shown in parentheses, and estimated its value using the asymptote method. Thus, the panel feels it is an appropriate limit for this context. The final recommendation is shown in Table 4.

Table 4: Acceptable Risk Injury Percentage Limits for Space Vehicles Applicable to 95% of the Probabilistic Dynamic Events and Applicable to the Remaining 5% of all Cases

Injury Class	≥ 95% of all dynamic cases	≤ 5% of remaining cases
I	<4%	<23%
II	<1%	<4%
III	<0.1%	<0.7% [<1%]*
IV	<0.1%	<0.7%

*Acceptance of recommendations in brackets assumes Search and Rescue forces will get access to the crewmembers within 30 minutes of the mishap occurrence.

References

[1] Somers J, Scheuring R, Granderson B, Jones J, Newby N, Gernhardt M. Defining NASA Risk Guidelines for Capsule-based Spacecraft Occupant Injuries Resulting from Launch, Abort, and Landing. Houston, TX: National Aeronautics and Space Administration; 2014. NASA/TM-2014-217383.

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A panel of experts was convened in 2010 to help define acceptable injury risk levels for space vehicle launches, landings, and abort scenarios. Classifications of spaceflight-relevant injuries were defined using four categories ranging from minor to severe injury. Limits for each injury category were agreed to, dependent on the expected number of crew exposures in a given vehicle and on whether the flight was considered nominal or off-nominal. Somers et al. captured the findings of this summit in a NASA technical memorandum. This panel was recently reconvened (December 1, 2014) to determine whether the previous recommended injury limits were applicable to newly designed commercial spaceflight vehicles. In particular, previous limits were based in part on the number of crew exposures per vehicle and also were sensitive to a definition of nominal and off-nominal vehicle performance. Reconsideration of these aspects led to a new consensus on a definition of injury risk.

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