Occupant Protection at NASA

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Goals & Objectives

- **Background**
  - Give a brief background on NASA's work on the NORIS, analogous operational environments, and the Definition of Acceptable Landing Impact Injury Risk
- **Collaboration**
  - NORIS / MORIS development and validation
  - Data sharing agreement
  - Next generation aerospace ATD development
  - Human tolerance testing facilities usage and data sharing
- **Human Tolerance / Injury Data Mining**
  - Determine what data exists to assist in validating ORIS and developing refined injury criteria
  - Determine forward plan for sharing and analyzing data
- **Next Generation Aerospace ATD Development**
  - Determine USAARL and NASA requirements for new ATD
  - Develop proposal for funding
- **Human Tolerance Testing**
  - Determine what testing would be beneficial to NASA and USAARL
  - Determine forward plan

Background

Operationally-Relevant Injury Scale

- **What is the AIS?**
  - "The AIS is an anatomically-based, consensus-derived, global severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale"
- **Severity vs. Mortality**
  - AIS dimensions include: Threat to life, mortality, Length of hospitalization, Cost, Amount of energy dissipated, Temporary/Permanent impairment, Quality of Life, and other factors.
  - AIS severity is well correlated with mortality/survival, but mortality is not a sole determinant of AIS severity.
- **Other Injury scales exist for specific injury areas, but AIS is universal**
- **Why we need something that is "operationally-relevant"**
  - AIS tells us severity with regard to survival, but not SIGNIFICANCE within a certain operational context
- **What does "Operationally-Relevant" mean? For Orion:**
  - What does the crew have to DO during and immediately after the landing?
  - How will a given injury affect the crews ability to perform post-landing and egress tasks?
  - How will a given injury affect the crews long-term health and flight status?

Operationally Relevant Injury Scale

Injury Severity (IS)

0	1	2	3	4	5	6
None	Minor	Moderate	Serious	Severe	Critical	Maximal

Self-Egress Capability (SE)

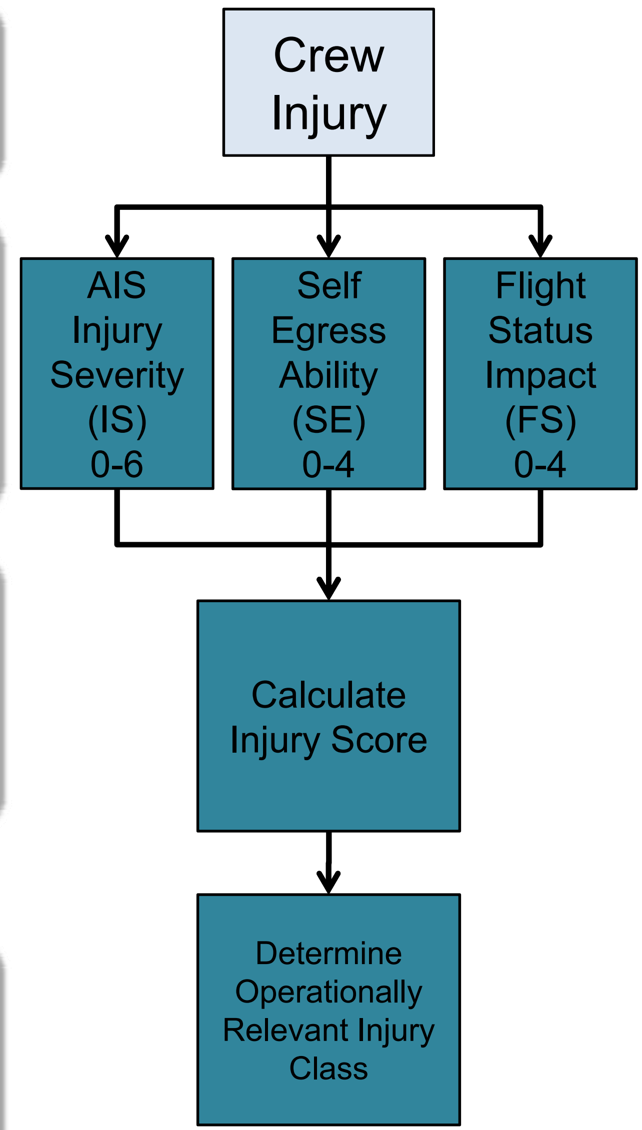
0	1	2	3	4
No Impact	Able with Minor Impact (within 3min req)	Able with Major Impact (not within 3min req)	Unable without assistance	Unable, requires rescue and/or stabilization

Return to Flight Status Estimate (FS)

0	1	2	3	4
No Delay in Return	Short Delay in Return (<3mo.)	Intermediate Delay in Return (<1y)	Long Delay in Return (>1y)	Ended Flight Status/ DQ'd

Operationally Relevant Injury Class

0	1	2	3	4
No Injury	Minor Injury	Moderate Injury	Severe Injury	Life-Threatening or Fatal Injury



Final Injury Scoring Calculation Method

- **Calculate Injury Score based on the following equation:**

$$Score = \sqrt{0.25 \cdot IS^2 + 0.5 \cdot SE^2 + 0.25 \cdot FS^2}$$

- **Where:**
  - IS is Injury Severity
  - SE is Self-Egress ability (weighted to greatest contribution)
  - FS is the Return to Flight Status Estimate
- **Assume any IS 4 or greater results in a Class IV injury**
- **Assume any IS 3 or greater results in at least a Class III injury**

		IS					
SE	FS	1	2	3	4	5	6
0	0	100	200	300	400	500	600
0	1	101	201	301	401	501	601
0	2	102	202	302	402	502	602
0	3	103	203	303	403	503	603
0	4	104	204	304	404	504	604
1	0	110	210	310	410	510	610
1	1	111	211	311	411	511	611
1	2	112	212	312	412	512	612
1	3	113	213	313	413	513	613
1	4	114	214	314	414	514	614
2	0	120	220	320	420	520	620
2	1	121	221	321	421	521	621
2	2	122	222	322	422	522	622
2	3	123	223	323	423	523	623
2	4	124	224	324	424	524	624
3	0	130	230	330	430	530	630
3	1	131	231	331	431	531	631
3	2	132	232	332	432	532	632
3	3	133	233	333	433	533	633
3	4	134	234	334	434	534	634
4	0	140	240	340	440	540	640
4	1	141	241	341	441	541	641
4	2	142	242	342	442	542	642
4	3	143	243	343	443	543	643
4	4	144	244	344	444	544	644

Score Range	Injury Class
>0 – 1	Class I
>1 – 2	Class 2
>2 – 3	Class 3
>3	Class 4

Classification Methodology

- **Using Scoring table in previous slide, assign each injury an Operationally Relevant Injury Score**

SE	FS	IS 1	2	3	4	5	6
0	0	100	200	300	400	500	600
0	1	101	201	301	401	501	601
0	2	102	202	302	402	502	602
0	3	103	203	303	403	503	603
0	4	104	204	304	404	504	604
1	0	110	210	310	410	510	610
1	1	111	211	311	411	511	611
1	2	112	212	312	412	512	612
1	3	113	213	313	413	513	613
1	4	114	214	314	414	514	614
2	0	120	220	320	420	520	620
2	1	121	221	321	421	521	621
2	2	122	222	322	422	522	622
2	3	123	223	323	423	523	623
2	4	124	224	324	424	524	624
3	0	130	230	330	430	530	630
3	1	131	231	331	431	531	631
3	2	132	232	332	432	532	632
3	3	133	233	333	433	533	633
3	4	134	234	334	434	534	634
4	0	140	240	340	440	540	640
4	1	141	241	341	441	541	641
4	2	142	242	342	442	542	642
4	3	143	243	343	443	543	643
4	4	144	244	344	444	544	644

Class I
Class 2
Class 3
Class 4

Example

- **Describe the injury:**

  Grade 3 Concussion, Brief LOC

- **Rate injury severity (IS) based on definitions 0-6**

  2

- **Rank impact on self-egress (SE) based on definitions 0-4**

  2 (LOC classified as <5 min)

- **Rank impact on future return to flight status (FS) 0-4**

  1

- **Injury Score**

  1.80

- **Overall classification scale is**

  Class 2

Injury Database

- **The following charts detail the results of applying this Operationally-Relevant Injury Scale (ORIS) to the injury databases**
- **Injuries from causes such as inhalation, burns, etc that are not caused by impact are not currently included, even though they may be a risk during the landing phase**
  - These types of injuries cannot be modeled with our methods, and therefore cannot be applied in our technical approach
  - Non-impact injuries should be considered in other analysis involving landing risk

NASCAR Injury Classification (1/2)

Head/Facial Injury	AIS Score	Injury Severity	Self-Egress Ability	Flight Status	Score	Class
Cerebral Concussion, NFS	161000.1	1	1	1	1	1
Mild Concussion, No LOC	161001.1	1	1	1	1	1
Cerebral Concussion, Brief LOC	161002.2	2	2	1	1.8	2
Cerebral Concussion, LOC < 1 hr NFS	161003.2	2	2	1	1.8	2
Cerebral Concussion, LOC ≤ 30 min	161004.2	2	2	1	1.8	2
Minor Facial Laceration	210602.1	1	0	1	0.71	1
Neck Injury	**AIS Score**	**Injury Severity**	**Self-Egress Ability**	**Flight Status**	**Score**	**Class**
Neck Contusion	310402.1	1	0	0	0.5	1
Cervical Spine Stenosis	640200.3	3	2	2	2.29	3
Cervical Spine Strain, No Fx, No Dislx	640278.1	1	1	1	1	1
Bulging Cervical Disc	650202.2	2	1	1	1.32	2
Traumatic Cervical Spine Disruption	650205.3	3	2	2	2.29	3
Cervical Spine Fx	650216.2	2	4	3	3.35	4
Chest Injury	**AIS Score**	**Injury Severity**	**Self-Egress Ability**	**Flight Status**	**Score**	**Class**
Chest Abrasion	410202.1	1	0	0	0.5	1
Chest Contusion	410402.1	1	0	0	0.5	1
Rib Fracture	450201.1	1	2	2	1.8	2
Multiple Rib Fracture	450203.3	3	2	2	2.29	3
Abdominal Contusion	510402.1	1	0	0	0.5	1
Thoracic Spine Strain	640478.1	1	1	1	1	1
Thoracic Spine Compression Fx	650616.2	2	2	2	2	2

Injury Class	1	2	3	4
Description	Minor	Moderate	Severe	Life-Threatening or Fatal

NASCAR Injury Classification (2/2)

NASA Occupant Protection

Upper Extremity Injury	AIS Score	Injury Severity	Self-Egress Ability	Flight Status	Score	Class
Abrasion	710202.1	1	0	0	0.5	1
Contusion	710402.1	1	0	0	0.5	1
Clavical Fracture	750500.2	2	2	1	1.8	2
Scapula Fracture	750951.2	2	2	2	2	2
Shoulder Dislocation	770730.2	2	2	1	1.8	2

Lower Extremity Injury	AIS Score	Injury Severity	Self-Egress Ability	Flight Status	Score	Class
Abrasion	820202.1	1	0	0	0.5	1
Contusion	810402.1	1	0	0	0.5	1
Leg Fx	852002.2	2	2	1	1.8	2
Fibula Fx	854441.2	2	2	1	1.8	2
Ankle Fx	852004.2	2	2	1	1.8	2
Tailbone Fx	856151.2	2	1	1	1.32	2

Injury Class	1	2	3	4
Description	Minor	Moderate	Severe	Life-Threatening or Fatal

Analog Operational Environments

- **We want to provide a context for the level of risk inherent in the Orion landings in terms that people understand and have a sense for**
- **Risk comparison is primarily subjective and qualitative since the actual risk is determined by operational differences, seating and occupant protection differences, and other factors.**
- **For example, is the risk of injury during an Orion landing roughly the same, better or worse than:**
  - An aircraft carrier landing,
  - a NASCAR crash,
  - a helicopter crash, etc?

Data Reviews

- **We conducted reviews of injury and crash statistical data from "analogous operational environments"**
- **While clearly different in many key aspects, these analogs share some common traits with the Orion landings:**
  - Multi-point (at least 5pt) harness seating systems
  - Suited/helmeted occupants
  - Considerations for flail and head/neck protection
  - Aviation landings and/or high speed collisions (racing)
  - Dynamic landing/impact environments and orientations
- **A few key differences include:**
  - Data categorized as mishaps often not attributable directly to injury/severity
  - Racing is a competitive environment
  - Military aviation may be in a hostile environment
  - Vehicle configurations and impact vectors differ from Orion
  - Land vs. Water landings, Controlled parachuted landing vs. Hard land landings

NASCAR Risk

- **NASCAR crash and injury data provided for years 2003-2008**
  - 41 total injuries/4015 impact events
- **NASCAR crash data recorder data provided as well as narrative descriptions of the crash event (for injury cases)**
- **Injury data including general descriptions and AIS codes provided**
- **Data prior to 2003 is less reliable**
  - Inconsistent measures and recording practices
  - Incomplete records of crash events and data
  - Vehicle configurations less consistent
- **Definitions for NASCAR**
  - Injury – Reported, known injury with AIS coding
  - Crash – Any impact event that triggered recorder
  - Sortie – Any time the driver enters the car during an event
    - Assumed 4-5 sorties per car per race event
    - Includes practice laps, qualification, and the race event

IRL Risk

- **Indy Racing League (IRL) crash and injury statistics provided for years 2003-2008**
  - 38 total injuries/570 crashes
- **Crash recorder data provided 2006-2008 in standardized format. Data prior to 2006 may be available but in different formats.**
- **Injury descriptions provided**
- **Definitions for IRL**
  - Injury – Reported injury with descriptions
  - Crash – Any impact event that triggered recorder
  - Sortie – Any time the driver enters the car during an event
    - ~3 sorties per car per race event (based on IRL database)
    - Includes practice laps, qualification, and the race event

Air Force Risk

- **Air Force crash and injury data provided for years 1996-2007**
- **Mishap severities categorized by Class I – IV for Fixed and Rotary Wing Crashes (multiple aircraft types)**
- **85 ejections in dataset**
- **Flight Hour Data and Ejection Injury Descriptions provided**
- **Fatalities/Injuries distinguished in some data but not injury severities**
- **Ejection injuries are often from exiting or windblast, rather than landing impact**
- **Definitions for Air Force**
  - Injury – A known ejection injury or a mishap class A-D
  - Crash – An ejection (fixed-wing) or mishap (rotary-wing)
  - Sortie – Total Flight Hours/Average Sortie length (assumed 8 hr average)

Navy Risk

- **Navy crash and injury data provided for years 1980-2009**
- **Mishap and Crash statistics provided by Class A-C for Flight/Ground and Fixed/Rotary Wing Crashes (multiple aircraft types)**
- **Fatality rates and statistics provided**
- **Provided Flight Hour and Crash data**
- **Definitions for Navy**
  - Injury – Mishap Class A-C (not a true indication of injury)
  - Crash – A mishap
  - Sortie – Total Flight Hours/Average Sortie length (assumed 8 hour average)

Army Risk

- **Army crash and injury data provided for years 2003-2008**
- **Mishap statistics provided by Class A-D, rates per 100k flight hours and per 100k landings.**
- **Fixed and Rotary Wing data provided**
- **Fixed-Wing: Assumed Average Sortie Length of 4 hours**
- **Rotary-Wing: Number of Landings Provided**
- **Army team is trying to access more detailed information on injuries to more accurately reflect injury rates and statistics per crash and flight hours.**
- **Definitions for Army:**
  - Injury – Mishap Class A-D (not a true indication of injury)
  - Crash – A mishap
  - Sortie – Fixed-Wing: Total Flight Hours/Average Sortie length (assumed)
    Rotary-Wing: Landing

Shuttle Risk

- **Total Number of flights known**
- **Very small number of minor injuries possibly attributable to landing impact forces**
- **Small number of off-nominal landings within design limits of the vehicle, not considered a crash**
- **No crashes, but landings are taken as the denominator**
- **Sorties are a launch/landing mission**
- **Definitions for Shuttle:**
  - Injury – Injury descriptions
  - Crash – Exceedance of vehicle landing performance limits
  - Sortie – Number of Missions
- **Challenger and Columbia excluded from crash/landing analysis (prior to landing event) but not from sortie calculations**

Soyuz Risk

- **Most closely related current analog to Orion landing system**
- **There are differences in design and functionality but the similarities are more significant**
- **Deaths due to failure of vehicle systems may be better attributed to a rate/sortie rather than a rate/crash since a system failure was the cause**
- **Hard land landings are a key factor in Soyuz landing risk, raising level of minor injuries observed**
- **Definitions for Soyuz:**
  - Injury – Injury descriptions
  - Crash – Off-nominal landings
  - Sortie – Number of Missions

Mercury, Gemini, Apollo Risk

- **Not currently included in comparative analysis**
- **Injury data not readily available**
  - Apollo 12 injury due to improper stowage of hardware coming loose and striking crewmember

Injury Risk by Program

NASA Occupant Protection

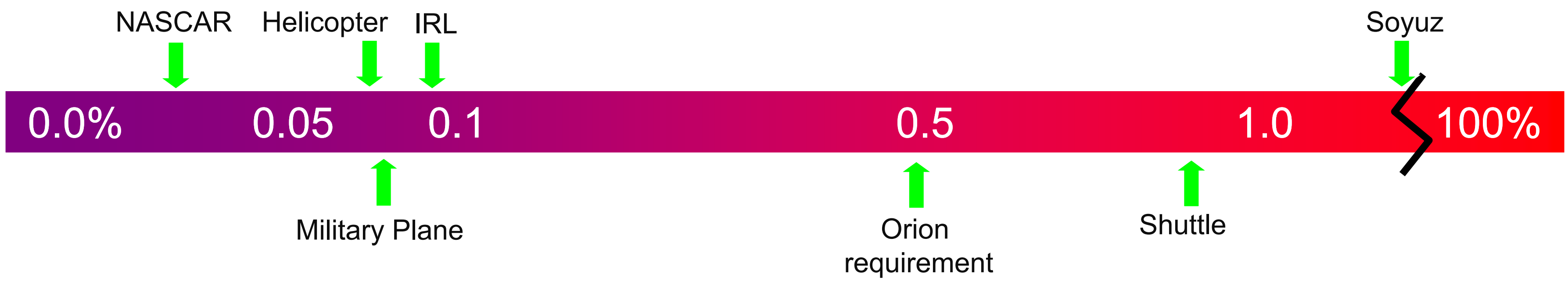
Program	Injuries Per Crash or Off-Nominal Landing: Class I	Class II	Class III	Class IV	Injuries Per Sortie (Exposure Risk): Class I	Class II	Class III	Class IV
NASCAR	0.36%	0.58%	0.39%	0.04%	0.02%	0.03%	0.02%	0.00%
IRL	1.58%	2.28%	2.46%	0.35%	0.07%	0.09%	0.10%	0.01%
USAF Fixed Wing	57.0%	5.6%	7.0%	8.5%	0.006%	0.001%	0.001%	0.001%
USN Rotary Wing	59.27%		17.16%	23.57%	0.054%		0.015%	0.021%
USN Fixed Wing	68.4%		12.3%	19.3%	0.09%		0.02%	0.03%
USA Rotary Wing	36%	40%	9%	16%	0.0027%	0.0029%	0.0007%	0.0012%
USA Fixed Wing	48%	35%	14%	3%	0.040%	0.030%	0.012%	0.002%
Shuttle	N/A	N/A	N/A	N/A	0.75%	0%	0%	0.88%
Soyuz	15.9%	1.6%	0%	1.6%	4.1%	0.4%	0%	0.4%

- **Using data from other programs, a basis of risk can be established to allow Task 1 to relate Orion risk**
- **The idea here is to help relate probability numbers to real risks that team members have experience with and understand (Shuttle, NASCAR, Rotary Wing, etc.)**

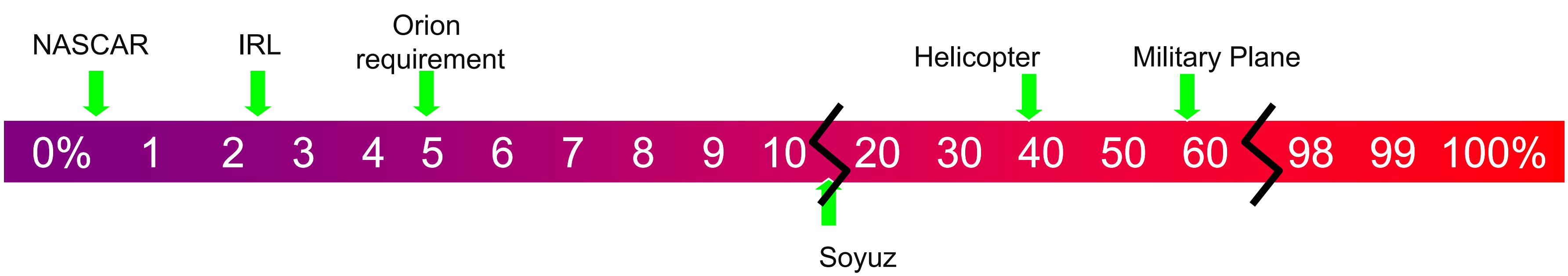
- ***Assumes a probability of off-nominal landings of <1% (land-landing case shown)**
- **^Calculated by proposed expected number of injuries divided by assumed number of crew landings**

Study Products: Injury Context

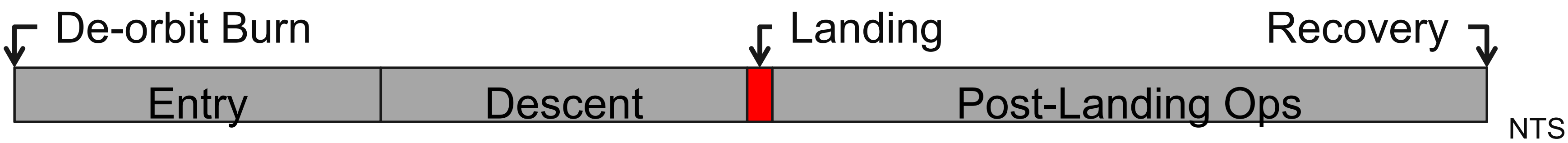
What is the overall risk of minor/moderate/severe impact related injury every time a person gets in the vehicle?



What is the risk of minor/moderate/severe injury during ejections/crashes/off-nominal landings in the vehicle?



Definition of Acceptable Landing Injury Risk



- **What this meeting was not about:**
  - Improved seat/restraint attenuation systems (Design independent!)
  - Biodynamics models
  - Specific injury response parameters
  - Any Orion-based testing (sled tests, drop tests, suit tests)
  - Suit design and Suit-Occupant interactions
- **What this meeting did not cover:**
  - Injury risk during the following mission phases:
    - Launch and Ascent
    - On-orbit ops
    - Entry and Descent
    - Post-Landing
  - Injuries (burns, inhalation, etc) unrelated to landing impact
- **Goal:**

  The goal of this meeting was to formulate a recommendation to the Orion Project for an acceptable level of injury risk associated with Nominal and Off-Nominal landing cases.

Define Highest Level of Injury Risk Consistent with Successful Program

- **Everyone has an opinion on what acceptable injury risk is**
- **Start with defining the highest level of injury consistent with a successful program**
  - Currently Brinkley low for nominal & Brinkley moderate for off-nominal. Question: What if we find out that 30% of the time we will have off-nominal landing? Is Brinkley moderate the right criteria (less than 5% risk)?
- **This is not a simple task.**
  - Team of medical, scientific, operational, flight crew, statisticians and outside experts, i.e. military, to systematically review mission and medical drivers and come to a consensus on the highest risk of injury consistent with a successful program.
    - Are five cases of crewmembers with minor injury, which don't impede egress, and don't lose flight status over the 10 year program acceptable? Are 10 cases?
    - Is one case of a crewmember that has a successful egress, but has long-term health impacts, acceptable over the course of the 10 year program?
- **To properly do this task, need to understand both injury response to landing loads and probability distribution of landings**
- **Once the highest level of injury risk consistent with a successful mission is determined, then we look at other medical, operational and ethical considerations that would warrant further reduction of the injury risk levels**
- **This is a long, systematic effort to define acceptable injury risk within programmatic and operational constraints**

Refinement Process

- **Ethical**
  - Whatever the risk, each crew should know up front what they are accepting or be given opportunity to decline. Disclosure is the key.
  - Some moderate risk may be acceptable, but not undue risk
- **Political**
  - Given the loss of life from the Shuttle program (unacceptable for low-earth exploration), the Constellation program should be 10 times safer than Shuttle during ISS operations.
  - Is the Soyuz risk level an appropriate level for US crews (current accepted by NASA)
  - How much risk is acceptable for low-earth operations (ISS) vs. Lunar operations? Ref. CARD LOC/LOM
  - Reduced funding or redirection of funds and priorities
- **Public Opinion**
  - Public opinion drives political will
  - Interest in space exploration and scientific endeavors
  - Impact on future generations
- **Medical/Flight Status**
  - Available Medical Supplies aboard the vehicle (limited treatment ability)
  - Non-deconditioned Crews should be given the best possible opportunity to return to flight status, even for off-nominal events
  - Deconditioned crew experiencing nominal landings should be able to return to flight status following a nominal rehabilitation period, what about for off-nominal landings?
- **Programmatic**
  - Assuming the mission was successful prior to the landing event, other considerations include loss of crew medical data due to landing injury and opt-out or unavailability of specimen collections (science financial and technical loss)
  - Impact to Astronaut corps (recruitment, assignment, morale, etc.)
  - Financial losses to vehicle and systems

Injury Scale Classification Definitions

- **For the purposes of this meeting, the following definitions were be used for the Injury Classes:**
  - Class I - minor injury that would not impede performance or egress, no long term health risks.
  - Class II - moderate injury that may delay self-egress, possible short-term health risks.
  - Class III – significant injury that would require assisted egress and subsequent survival operations; possible long-term health risks
  - Class IV – severe injury and possible threat to life, probable long-term health impacts

Proposed Acceptable Limits

Assumes: 80 Landings over Program Life; 4 Crewmembers per landing; 320 Total Crew Landings; 95% Confidence		Nominal		Off-Nominal^					
		EOM Nominal Water Landing Or Pad Abort Water Landing		Ascent Abort Water Landing		EOM Water Landing with Parachute Failure, High Winds, High Sea State		Pad Abort Land Landing	
P(Landing)		99.6%		<1%		<1%		<1%	
Injury Class		320 Total Crew Landings							
		Exp # Injuries	P(Injury)	Exp # Injuries	P(Injury)	Exp # Injuries	P(Injury)	Exp # Injuries	P(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	0.016%	0	17%	0	17%	0 [2]*	10% [30%]*
Life-Threatening	IV	0	0.016%	0	6%	0	6%	0	10%
All Classes	**I-IV**	**21**	**4.71%**	**6**	**100%**	**6**	**100%**	**9**	**100%**

*Acceptance of recommendations in brackets requires SAR forces will get access to the crewmembers within 30 minutes of the mishap occurrence.

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

Proposed Acceptable Limits For All Landings

Injury Description	Injury Class	Expected Number of Injuries	P(injury)
Minor	I	23/320	5%
Moderate	II	6/320	1%
Severe	III	0/320 [2/320]*	0.016% [0.25%]*
Life-Threatening	IV	0/320	0.016%
All Classes	**I-IV**	**29/320** [31/320]*	**6.8%** [7.4%]*

Assumes:

- 80 Landings over Program Life
- 4 Crewmembers per landing
- 320 Total Crew Landings
- 95% Confidence (of not observing more than defined # of injuries)

*Acceptance of recommendations in brackets requires SAR forces will get access to the crewmembers within 30 minutes of the mishap occurrence.

Comparison to Current Requirements

Injury Description	Injury Class	Expected Number of Injuries	P(injury)	Current Requirements Expected # of Injuries	Current Requirements P(Injury)
Minor	I	23/320	5%	6	0.83%
Moderate	II	6/320	1%	4	0.57%
Severe	III	0/320 [2/320]*	0.016% [0.25%]*	3	0.26%
Life-Threatening	IV	0/320	0.016%	1	0.09%
All Classes	**I-IV**	**29/320** [31/320]*	**6.8%** [7.4%]*	**10**	**1.76%**

^Assuming current injury statistical distribution of injuries, the total current risk was broken down into separate probabilities of each injury type

*Acceptance of recommendations in brackets requires SAR forces will get access to the crewmembers within 30 minutes of the mishap occurrence.

Comparisons of Recommendation to Soyuz, etc

Injury Description	Injury Class	Expected Number of Injuries	P(injury)	Soyuz	NASCAR	IRL
Minor	I	23/320	5%	19 (4.1%)	1 (0.02%)	1 (0.07%)
Moderate	II	6/320	1%	3 (0.4%)	1 (0.03%)	1 (0.09%)
Severe	III	0/320 [2/320]*	0.016% [0.25%]*	0 (0%)	1 (0.02%)	1 (0.10%)
Life-Threatening	IV	0/320	0.016%	3 (0.4%)	0 (0%)	0 (0.01%)
All Classes	**I-IV**	**29/320 [31/320]***	**6.8% [7.4%]***	**25 (5.8%)**	**3 (0.42%)**	**3 (0.42%)**

This chart provides a comparison between the recommendation and the applied risk probabilities to current analogous environments

*Acceptance of recommendations in brackets requires SAR forces will get access to the crewmembers within 30 minutes of the mishap occurrence.

Risk Determination Assumptions (1/2)

- **Up front assumptions made to drive risk determination discussions:**
  - 95th percentile based on 320 exposures, 80 landings (4 crew each)
  - Full scale/drop testing to be conducted in water, land or both to validate assumptions and performance from modeling and risk definition processes and will tell if impact into occupant volume will change risk posture
  - Injury criteria and requirements will be validated with 5, 50th, 95th percentile models, may need to be revised later for other mannequins (Note: current requirements based only on 50th percentile metrics)
  - Static fit tests with engineering/human factors controls in place
  - Safety factors for engineering design are similar to those used in experiences of panel participants from NASCAR and military aviation industries
  - Hazards such as sharp edges, fire controls etc that will cause other landing and post-landing related injuries and risk will be properly mitigated
  - Ground based response and access to crew varies by scenario. These assumptions need to be validated with help of ground crews and recovery personnel
    - Off-nominal land landing will have ACLS medical care to crew in 30 minutes or less (pad abort)
    - Off-nominal water landings will not have ACLS medical care to crew in 30 min or less

Risk Determination Assumptions (2/2)

- **Up front assumptions made to drive risk determination discussions:**
  - Injury categories will be based on consensus of Space Medicine and Flight Surgeon communities, to be expressed in terms of biodynamics parameters
  - Deconditioning factors to be applied for cases where biodynamics responses and injury likelihoods would be affected by spaceflight
  - Analysis assumes the crew will perform independently during egress tasks (conservative approach) which focuses on the “weakest link” crewmember most injured
  - Discussions considered projected probabilities of landing cases, but determinations were made relative to “worst-case” likelihoods rather than current analysis.
  - Recommendations are process-based and are therefore expected to be independent of vehicle design and program mission rates.
  - Assuming that vehicle is not designed primarily for land landing and that the design for attenuation and protection systems will consider these cases to be off-nominal - therefore inherently more risk will be accepted for their actual occurrence
  - Application of more conservative (i.e. worst) of number of injuries or probabilities of injuries should be bounding.

Injury Risk by Program

Program	Injuries Per Crash or Off-Nominal Landing: Class I	Class II	Class III	Class IV	Injuries Per Sortie (Exposure Risk): Class I	Class II	Class III	Class IV
NASCAR	0.36%	0.58%	0.39%	0.04%	0.02%	0.03%	0.02%	0.00%
IRL	1.58%	2.28%	2.46%	0.35%	0.07%	0.09%	0.10%	0.01%
USAF Fixed Wing	57.0%	5.6%	7.0%	8.5%	0.006%	0.001%	0.001%	0.001%
USN Rotary Wing	59.27%		17.16%	23.57%	0.054%		0.015%	0.021%
USN Fixed Wing	68.4%		12.3%	19.3%	0.09%		0.02%	0.03%
USA Rotary Wing	36%	40%	9%	16%	0.0027%	0.0029%	0.0007%	0.0012%
USA Fixed Wing	48%	35%	14%	3%	0.040%	0.030%	0.012%	0.002%
Shuttle	N/A	N/A	N/A	N/A	0.75%	0%	0%	0.88%
Soyuz	15.9%	1.6%	0%	1.6%	4.1%	0.4%	0%	0.4%
Orion (Proposed)	100%*^	75%*^	0%*^	0%*^	7.2%^	1.9%^	0%^	0%^

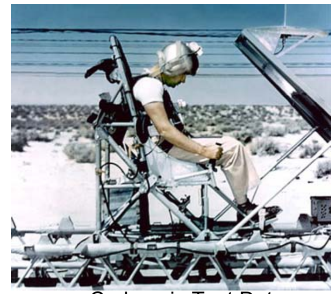
- **Using data from other programs, a basis of risk can be established to allow Task 1 to relate Orion risk**
- **The idea here is to help relate probability numbers to real risks that team members have experience with and understand (Shuttle, NASCAR, Rotary Wing, etc.)**

- ***Assumes a probability of off-nominal landings of <1% (land-landing case shown)**
- **^Calculated by proposed expected number of injuries divided by assumed number of crew landings**

Human Injury Data Mining

Human Impact Injury Database

- **Approach**
  - Mine Existing Human Injury datasets
    - Determine available and applicable injury datasets
      - Nation Assn. For Stock Car Auto Racing (NASCAR)
      - Indy Racing League (IRL)
      - Crash Injury Research Engineering Network (CIREN)
      - Human volunteer testing
      - Cadaveric testing
      - Department of Defense historical testing
    - Obtain injury data
  - Model data to obtain “normalized” data
    - Use analytical tools to model data to “normalize” biodynamic responses relative to test setup
    - Develop injury criteria risk curves based on database information
- **Products**
  - Revised Injury Criteria limits and rationale
- **Team**
  - Chuck/Brad/Jeff (NASA)
  - TBD



Cadaveric Test Data

IndyCar Database

NASCAR Database

CIREN Database

Air Force (Stapp) and Navy Human Sled Tests

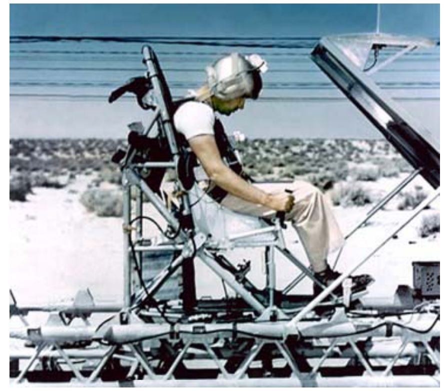
Data Uses

- **Validate NASA Operationally-Relevant Injury Scale (NORIS) / Military Operationally-Relevant Injury Scale (MORIS)**
  - Create list of know injuries and score them using operational impact (i.e. egress ability) and long-term outcome (i.e. return to flight status) data
  - Use information to validate scale and algorithm

- **Develop Injury Risk Criteria**
  - Use numerical models to simulate impact conditions and estimate ATD responses
  - Use injury data to correlate human injury to ATD response

Developing Injury Risk Criteria

- **Testing Approach**
  - Run human and ATD in same test conditions
  - Relate human tolerance / injury to ATD responses
  - Additional info on setup not needed since ATD responses are directly related to human exposure



Human Data to give Injury thresholds

ATD data to give Biodynamic responses

- **Exposure Approach**
  - Use human exposure data to drive numerical models of occupant
  - Relate real-world injury to ATD estimated responses from model
  - Requires acceleration time histories of impact event (estimates OK)
  - Requires details of occupant protection system and material properties
  - Not as accurate, but allows evaluation of ATD responses at higher exposures

Human Exposure Data with injuries

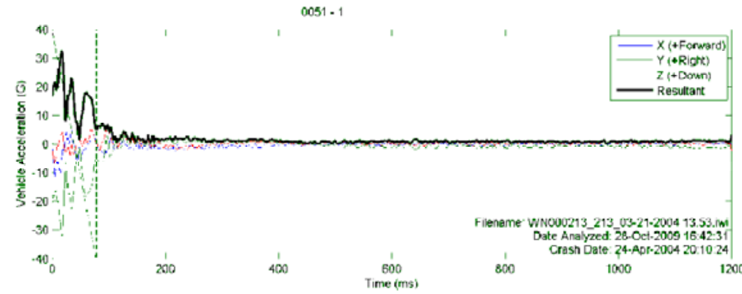
ATD model to give Biodynamic responses

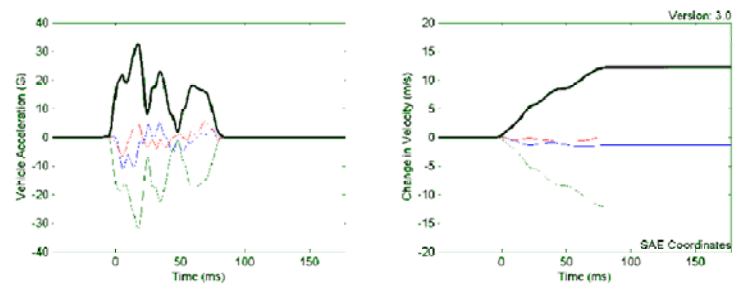
Data Needs

- **For data where ATD responses were not collected with the same conditions, the following info is needed:**
  - Test Setup
    - Dimensions of occupant protection system (seat, restraints, helmets, padding, etc.). CAD files are best if available
    - Material properties of occupant protection system (foam properties, material types, etc)
    - If seat accelerations not available, additional info regarding the energy attenuation system between the seat and vehicle are needed (dimensions, dynamics, etc.)
    - Any pictures to help position ATD correctly
  - Acceleration Time Histories
    - These are used to drive the model. Estimates of time history are OK, but results are dependent on fidelity of the estimates
    - High-Speed Photography (not essential) can help verify whole body kinematics
  - Injuries
    - Any information on injuries is needed
      - Detailed description
      - AIS codes
      - Operational impacts of injuries
      - Long-term outcome

NASCAR Modeling Techniques

- **NASCAR and IRL provided measured vehicle accelerations from on-board crash recorders**
- **Outside Collaborators developed custom model of racing seats and restraint systems**
- **First Technology Safety Systems (FTSS) commercial Hybrid-III Automated Test Dummy (ATD) model integrated into setup for determining biodynamic responses**
- **Simulate crash using recorder data and custom models to predict responses for driver**

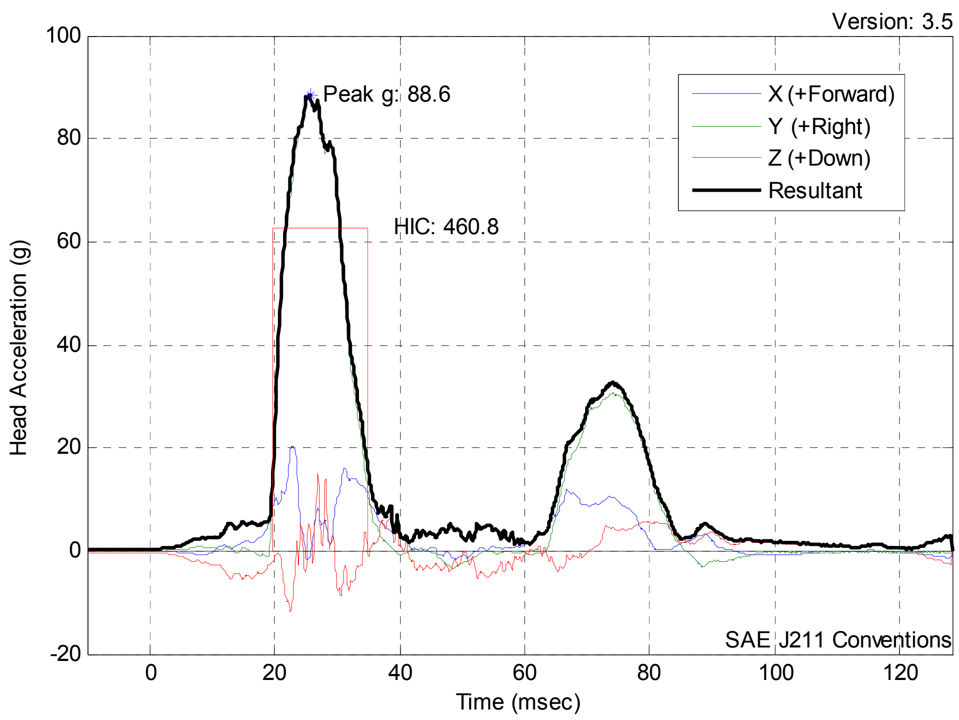


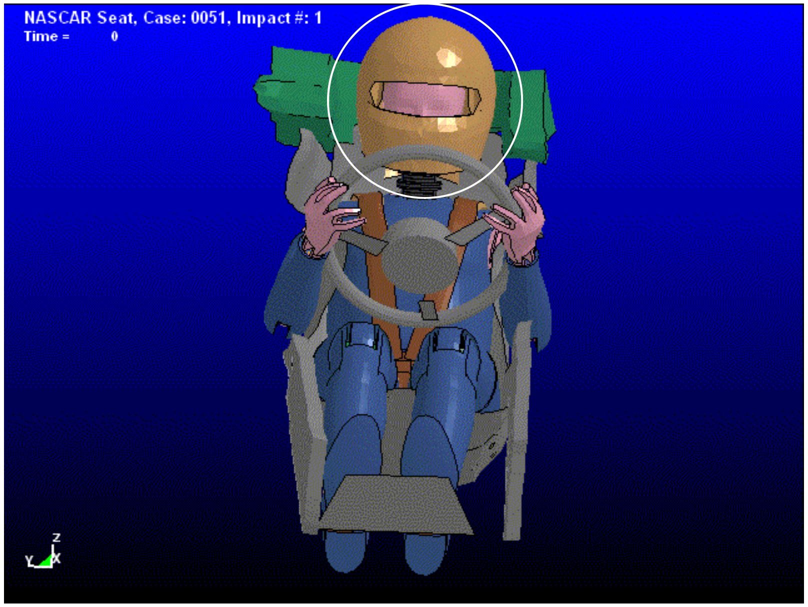


Biodynamic Response Example: Head Acceleration

- **Peak Head Acc: 88.6G**
- **HIC: 461**

- **NASCAR Side Impact Case (+Y)**
- **36.4 G Impact**
- **26.2 mph ΔV**





NASCAR Crash Data

- **NASCAR provided all crash data from 2002-2008**
  - 4015 crash incidences
  - 4071 separate usable crash events (some contained more than 1 crash event)
- **43 total Injury cases**
  - 11 cases were excluded because injury not attributed to inertial accelerations (due to vehicle intrusion, nature of the injury, etc.)
  - 32 usable injury cases
  - 27 head injury cases
- **4039 Non-injury cases**

NASCAR Injury Breakdown (2002-2008)

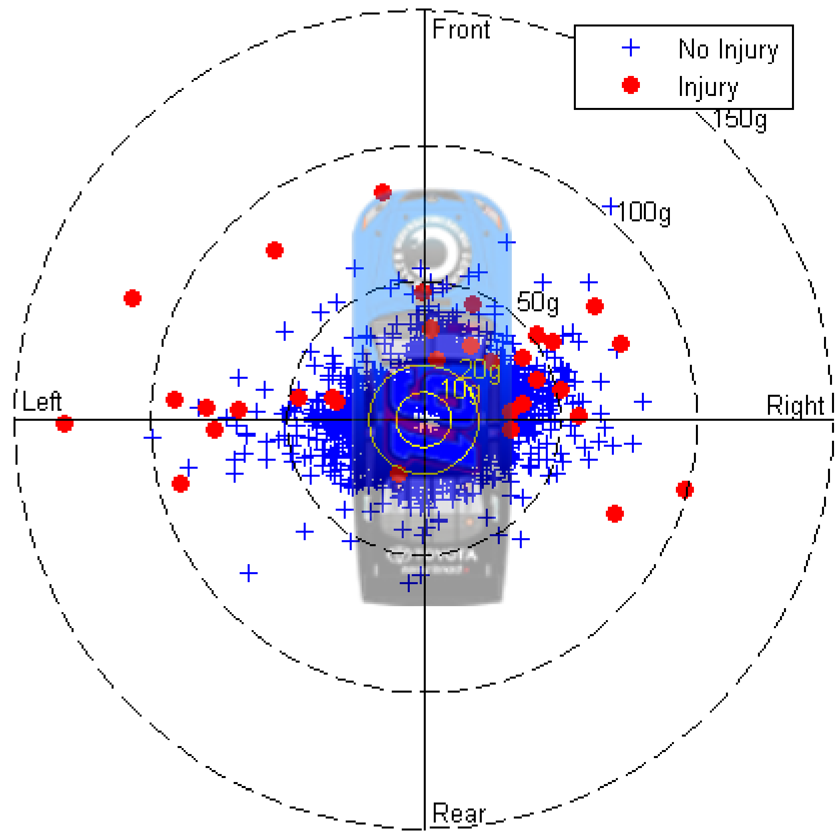
Breakdown of NASCAR injuries by anatomical region and severity (32 injurious crashes)

Severity	Head	Neck	Chest	Lumbar	Pelvic	Arm	Leg
Class I	7	2	3	0	2	2	4
Class II	9	2	8	1	0	4	0
Class III	8	2	2	0	0	1	0
Class IV	0	0	0	0	0	0	0
Total	**27**	**7**	**16**	**4**	**3**	**4**	**7**

Total may exceed total number of injury cases since some cases may involve injuries in more than one anatomical region

NASCAR Injury Statistical Methods

- **Modeled 274 out of 4071 of cases**
- **Use *logistic regression* analysis to calculate the probability of injury associated with each biodynamic response related to head injury**
- **This is accomplished by relating the estimated biodynamic responses in race car crashes to the actual injuries observed**



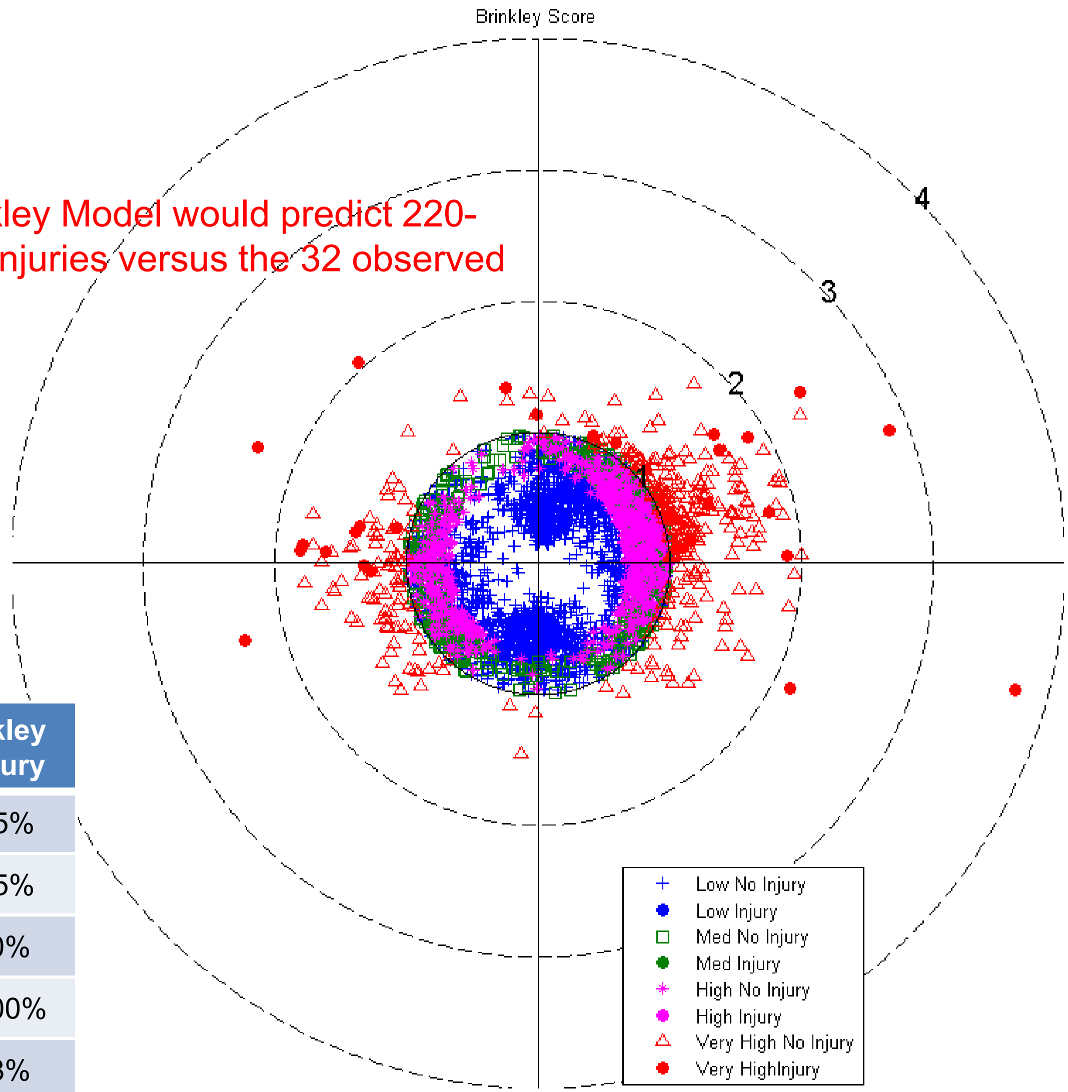
NASCAR Injury Distribution

Brinkley Model Comparison

- **Calculated Brinkley Injury Criteria Scores for all NASCAR crashes**
- **Brinkley Low**
  - Corresponds to 0-0.5% Risk of Injury
  - Expect up to 12 injuries
  - Observed 2 Injuries (0.08%)
- **Brinkley Medium**
  - Corresponds to 0.5-5% Risk of Injury
  - Expect 4-36 injuries
  - Observed 1 Injury (0.14%)
- **Brinkley High**
  - Corresponds to 5-50% Risk of Injury
  - Expect 34-345 injuries
  - Observed 1 Injury (0.15%)
- **Brinkley Very High**
  - Corresponds to 50-100% Risk of Injury
  - Expect 182-364 injuries

Brinkley Criteria	No Injury	Injury	Total	Calc % Injury	Brinkley % Injury
Low	2404	2	2406	0.08%	0-0.5%
Medium	710	1	711	0.14%	0.5-5%
High	688	1	689	0.15%	5-50%
Very High	336	28	364	7.69%	50-100%
Total	4138	32	4170	0.77%	5-18%

Brinkley Model would predict 220-756 injuries versus the 32 observed

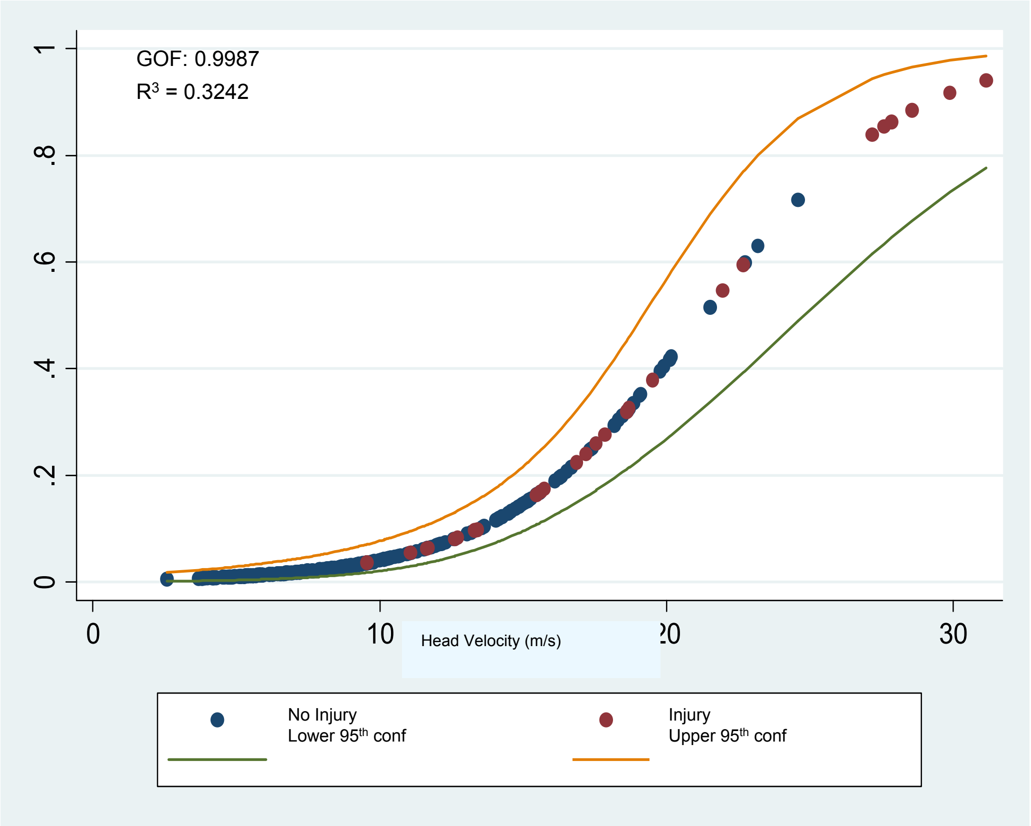


Developing Injury Risk Curves

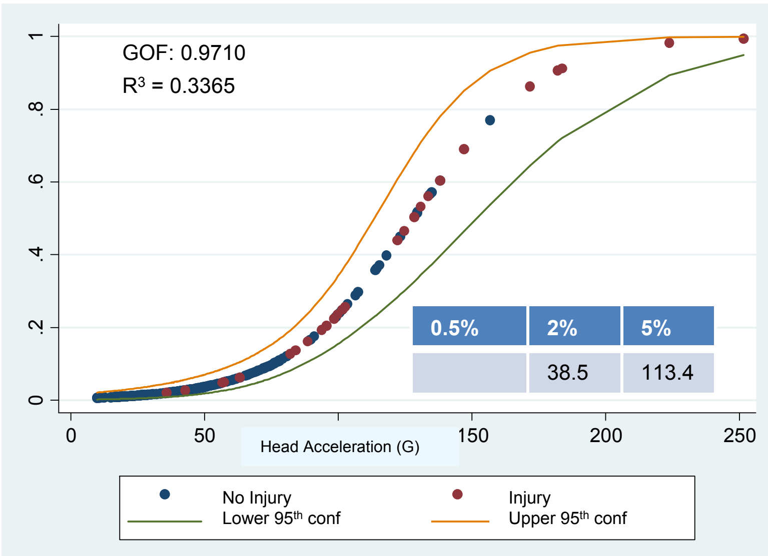
- For each biodynamic response parameter, individual injury risk curves will be established

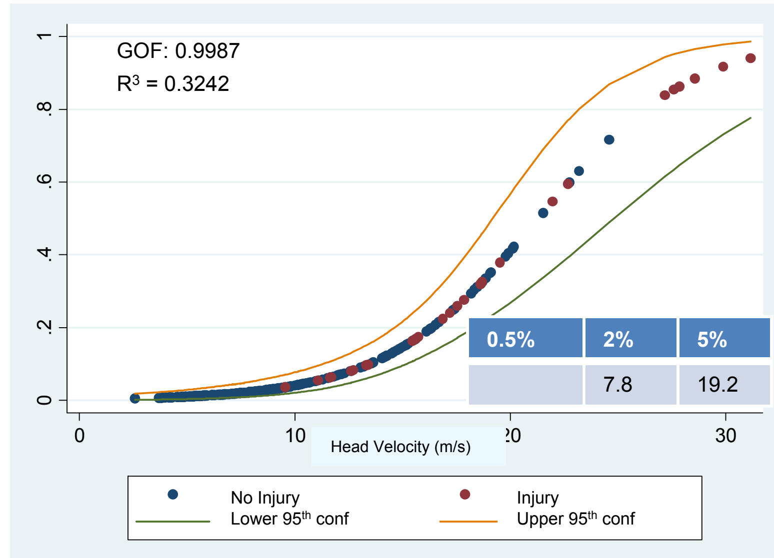
- Using these probability distributions and the accepted risk limit for each anatomical region, HSIR threshold will be updated as indicated

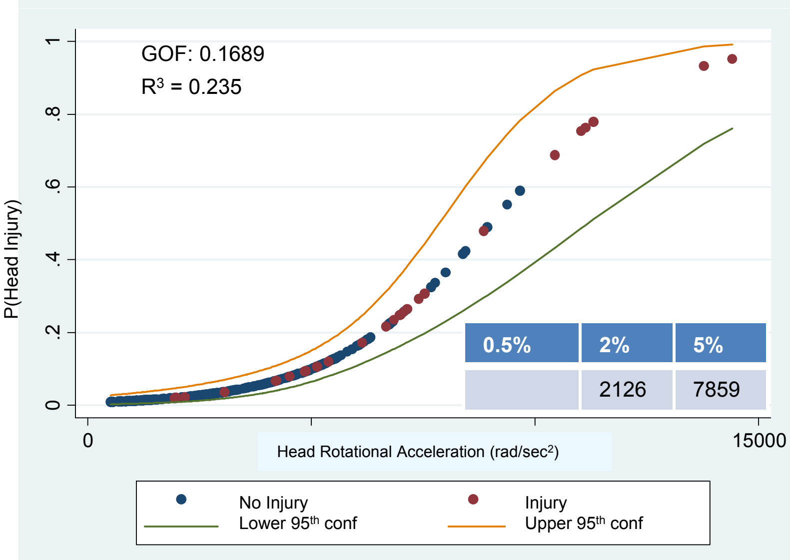
- These data will then be applied to Orion landing cases to determine injury risk

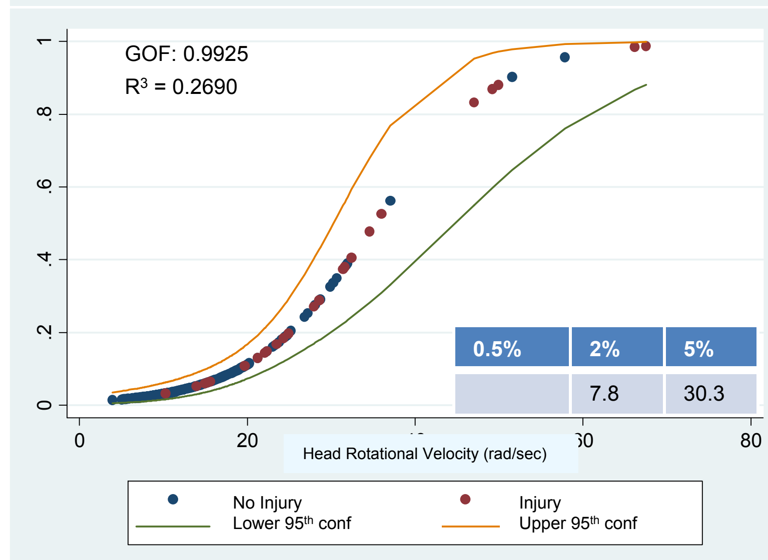


Head Injury Risk



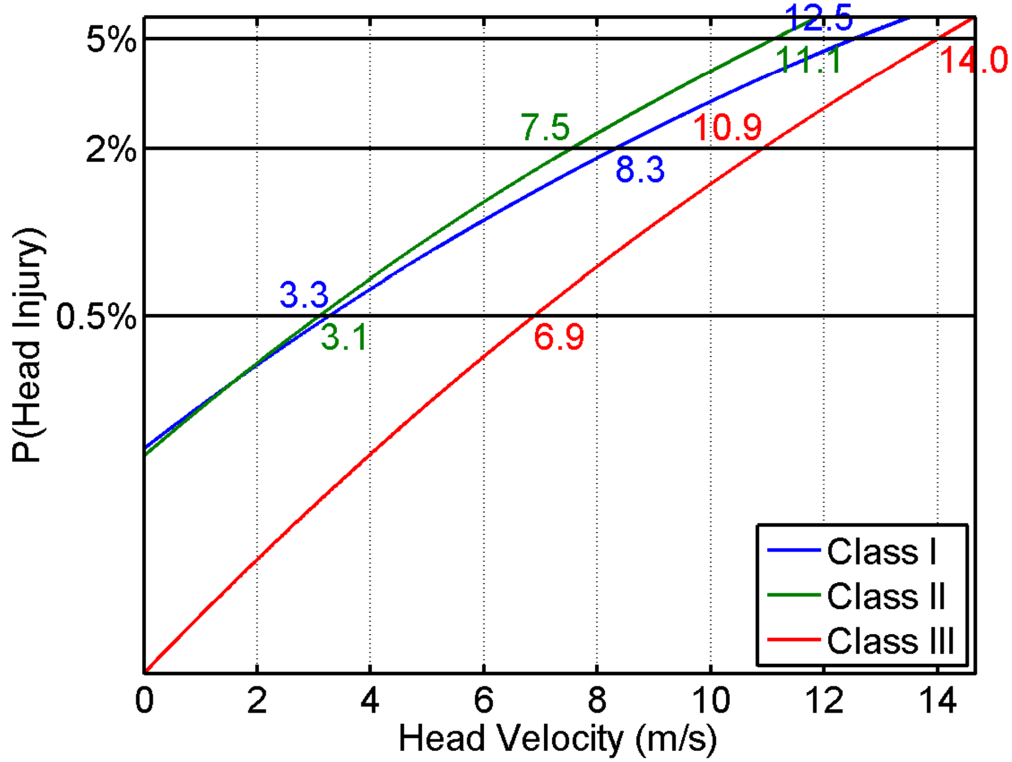




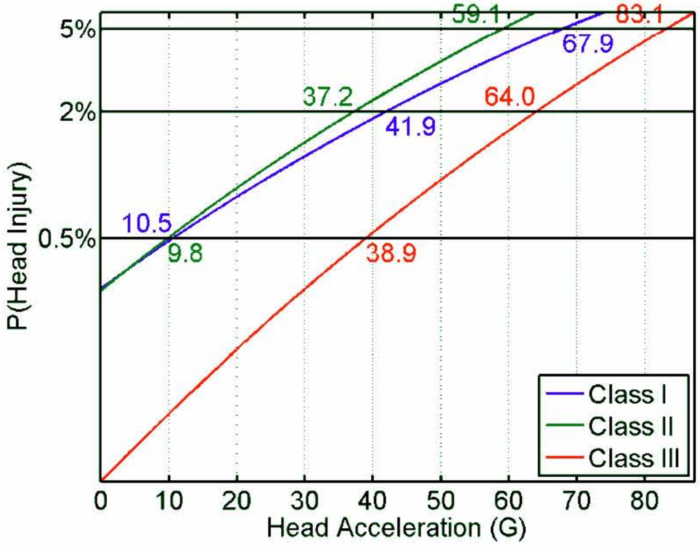


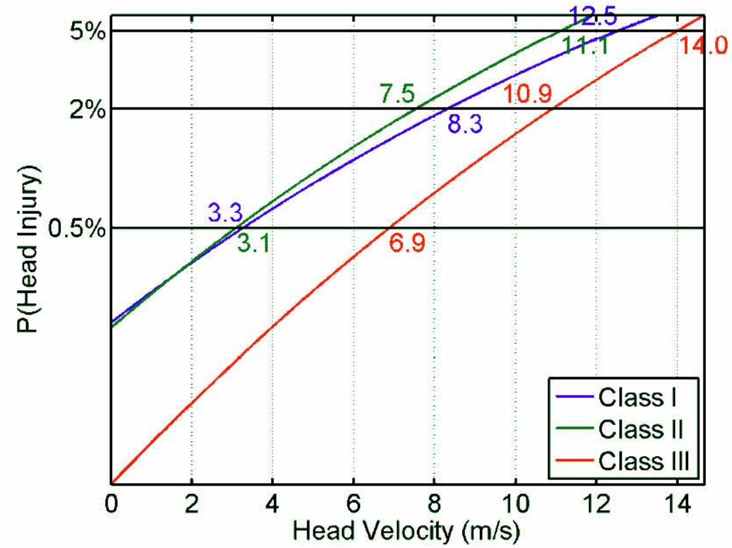
Head Injury By Severity

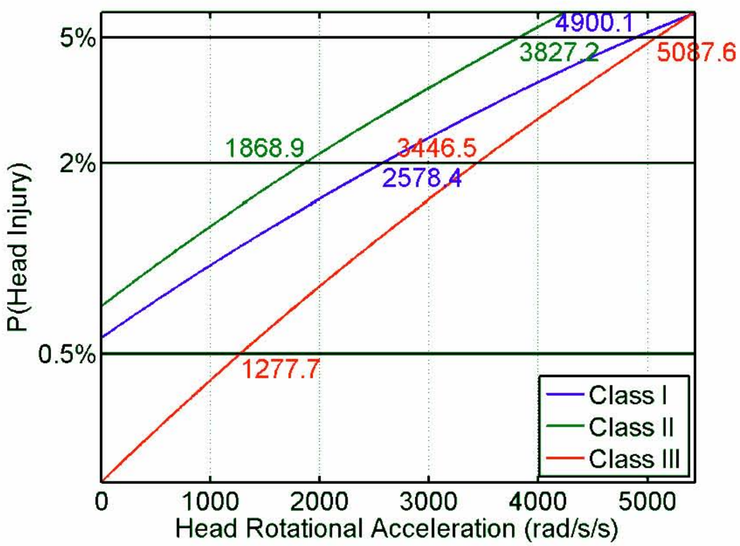
- **Using the ORIS, each head injury was classified by severity**
- **Using *ordered probit* analysis, injury probability curves were calculated for each class of injury (Class I-III. There were no Class IV head injuries in the dataset)**

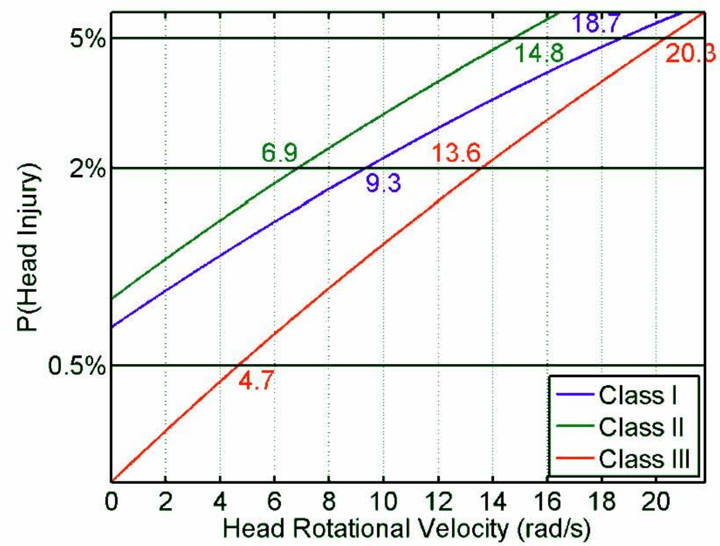


Head Injury Risk By Severity









Next Generation Aerospace ATD Development

Next Generation Aerospace ATD Development

- **Approach**
  - Determine existing ATD components that meet NASA needs
  - Integrate components together
  - Develop new components as needed
  - Test new ATD
- **Products**
  - ATD design specs and prototypes
- **Team**
  - Chuck/Brad/Jeff (NASA)
  - TBD

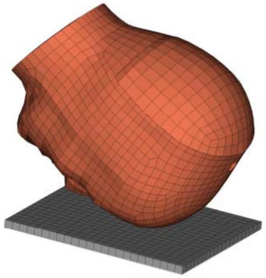
Bio_RID II Spine

ES2re Shoulder and ribs

ADAM Joints

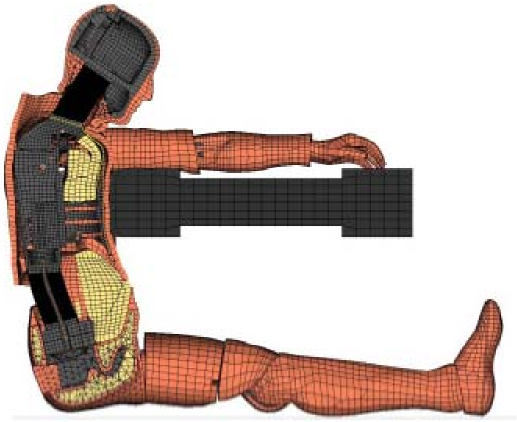
Next Generation Aerospace ATD Numerical Model Development

- **Approach**
  - Identify models of existing ATD components used
  - Develop numerical models of new components
  - Integrate components into new model
  - Validate model using physical test data
- **Products**
  - Validated model of new ATD and validation data
- **Team**
  - Chuck/Brad/Jeff (NASA)
  - TBD



Sub-Assembly Validation

Full Model Development



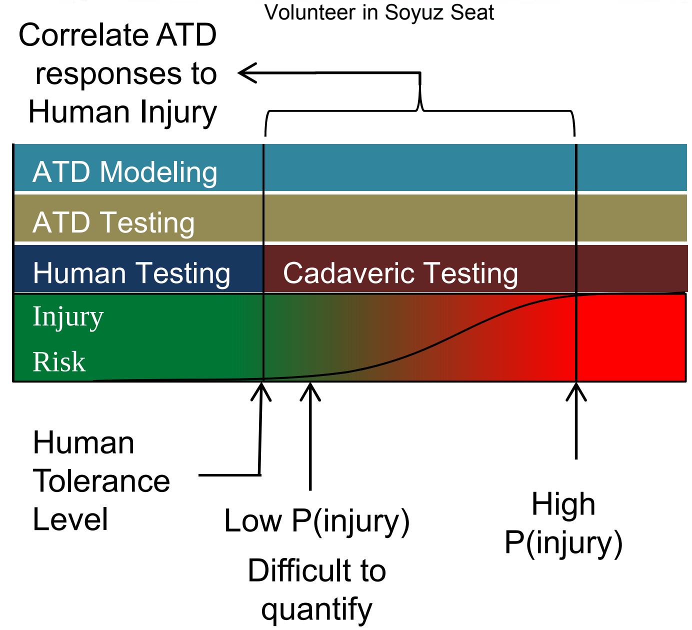
Full Model Validation

Human Tolerance Testing

Human Tolerance Testing

- **Approach**
  - Human Tolerance Testing is most direct approach to determine Human tolerance to actual spacecraft landing loads in an actual vehicle mechanical environment (i.e. seat, harness, suit)
    - Measures tolerance limits directly
    - Eliminates complexity and limitations of using numerical models and/or ATD's.
    - Humans
      - Determine human tolerance levels to test humans below
    - ATDs
      - Test across entire range
    - Cadavers
      - Test cadavers above human tolerance levels
    - Relate ATD responses to injury and human tolerance levels to determine injury criteria limits
    - Determine facilities / multi-center approach
- **Products**
  - Testing Protocol and facilities lists
  - Test data
- **Team**
  - TBD

Volunteer in Soyuz Seat



Forward Plan

Forward Plan

- **Fill in there as we go.**