NASA Occupant Protection Standards Development

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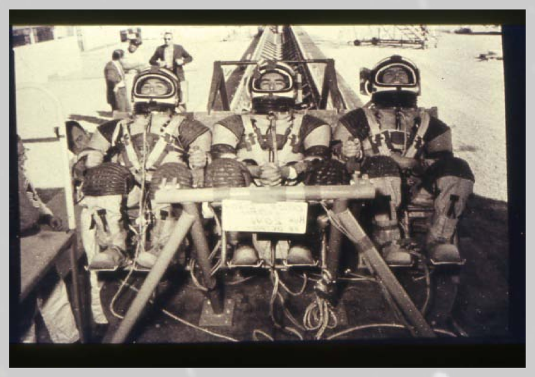
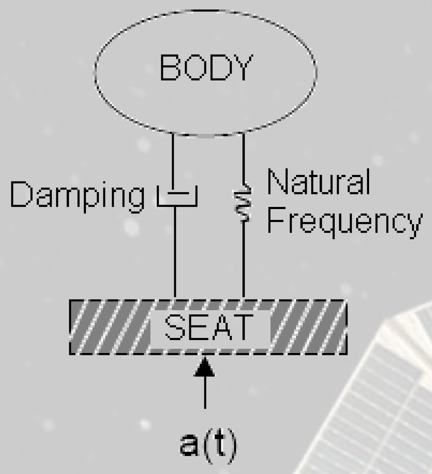
Background

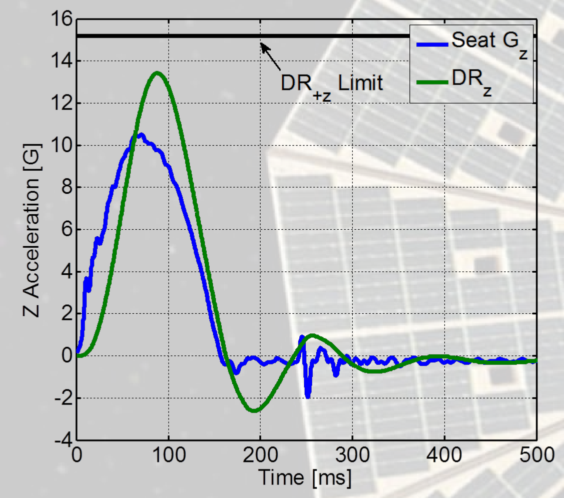


Historically, spacecraft landing systems have been tested with human volunteers, because analytical methods for estimating injury risk were insufficient. These tests were conducted with flight-like suits and seats to verify the safety of the landing systems.



Currently, NASA uses the Brinkley Dynamic Response Index to estimate injury risk, although applying it to the NASA environment has drawbacks:

- Does not indicate **severity** or **anatomical location** of injury
- Unclear if model applies to NASA applications



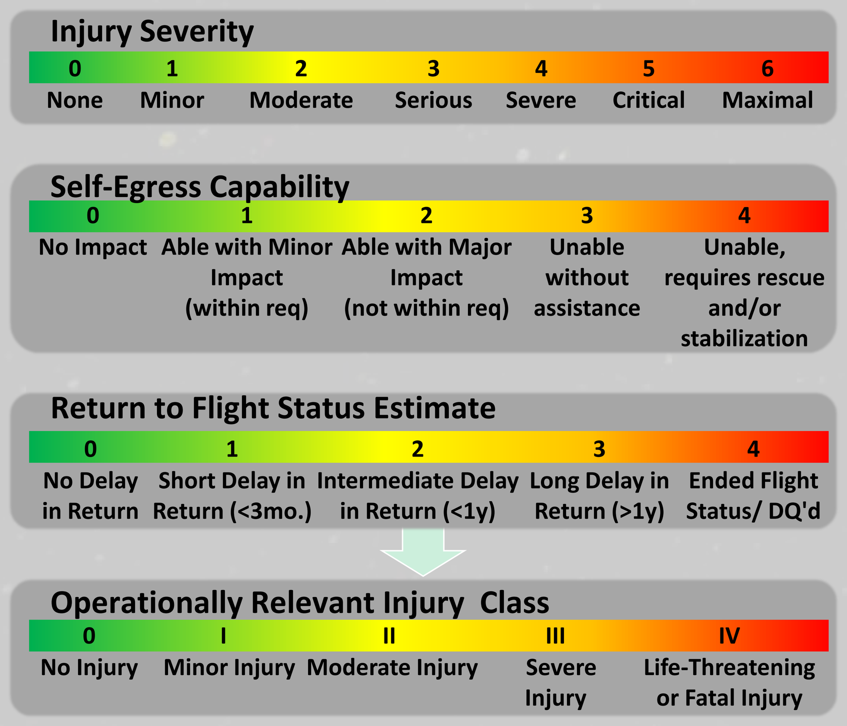
Because of these limitations, a new validated, analytical approach was desired.

New Approach

Leveraging off of the current state of the art in automotive safety and racing, a new approach was developed. The approach has several aspects:

- Define the acceptable level of injury risk by injury severity
- Determine the appropriate human surrogate for testing and modeling
- Mine existing human injury data to determine appropriate Injury Assessment Reference Values (IARV).
- Rigorously Validate the IARVs with sub-injurious human testing
- Use validated IARVs to update standards and vehicle requirements

Operationally Relevant Injury Scale



The Operationally Relevant Injury Scale (ORIS) was developed to address NASA's unique operational environment. Because the Abbreviated Injury Scale (AIS) was developed for passenger car incidents, it was determined that a new injury classification system was needed for NASA. The new scale combines the injury severity from the AIS, a measure of a crewmember's ability to self-egress, and a measure to estimate the time to return to flight status. All three factors are used to calculate the final classification of the injury.

Example: A clavical fracture (AIS=2) could prevent crewmembers from egressing (SE = 3), so it would be classified as a Class III Injury using the ORIS

Acceptable Risk Definition

An expert panel was convened to determine what level of injury would be acceptable for NASA. The team used a systematic approach to buy down the risk to an acceptable level for nominal and off-nominal scenarios. To provide context, the team considered other analogous environments such as previous spaceflight, military aircraft, and automotive race cars. To assist in understanding the consequences of injury, the team considered generic tasks that crewmembers would be required to perform after landing.

Once the team reviewed this information, the highest risk that would be acceptable was determined. This risk was then bought down using driving criteria, such as: ethical, medical, political, and programmatic considerations

Injury Description	*Injury Class*	*Nominal Probability of Injury*	*Off-Nominal Probability of Injury*
Minor	I	4.8%	19.1%
Moderate	II	1.0%	3.9%
Severe	III	0.27%	1.1 %
Life-Threatening	IV	0.03%	0.11%

Critical Injury Definition

Working with experts within NASA, the team developed a list of "critical" injuries. This list of injuries is not all inclusive, nor is it a list of "expected" injuries.

Instead, the list is intended to be comprehensive, such that if the risk for each injury is mitigated, then the risk for other related injuries would also be mitigated.

The list of injuries was also divided anatomically to ensure that every region of the body was represented.

Region	*Injury*
Head	Concussion w/o LOC Concussion w/ LOC Skull Fracture TBI
Face	Eye Ear Fracture
Chest	Lung Contusion Rib Fracture Hemothorax Pneumothorax Hemopneumothorax
Upper Extremity	Shoulder Dislocation Joint Injury Skeletal Fracture
Lower Extremity	Joint Injury Fracture
Spine	Brachial Plexus injury Cord Contusion Fracture Herniated Disc Disc Rupture

Standards Framework

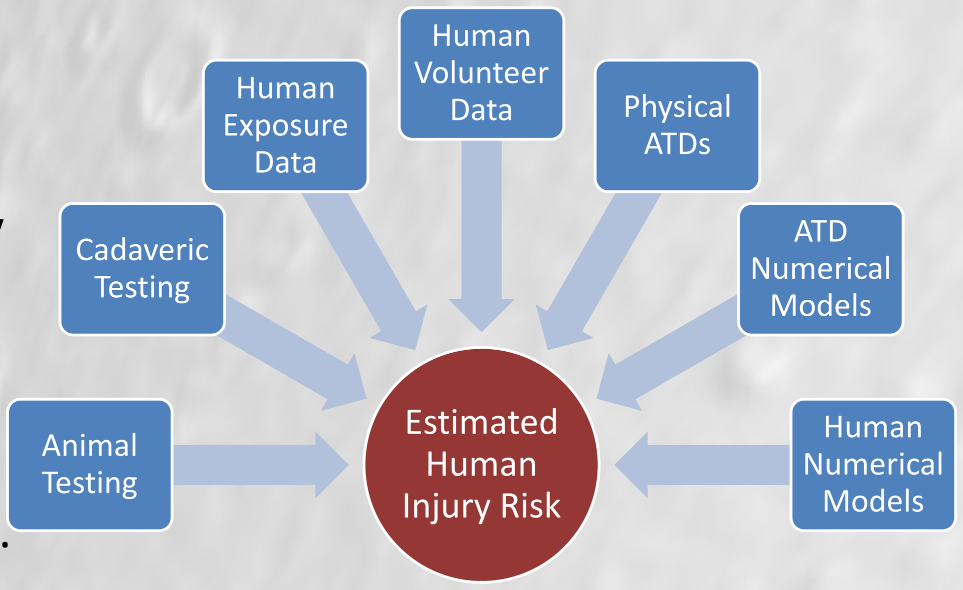
Collaborating with experts within NASA, the FAA, and NHTSA, the team developed a table mapping critical injuries to various injury metrics available for Anthropomorphic Test Devices (ATDs or crash test dummies). Using this framework, the THOR-NT ATD was selected for use.

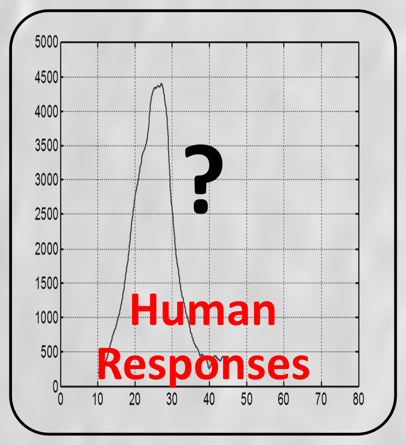
H – Hybrid III
T – THOR-NT
W - WorldSID
X – Design Constraint

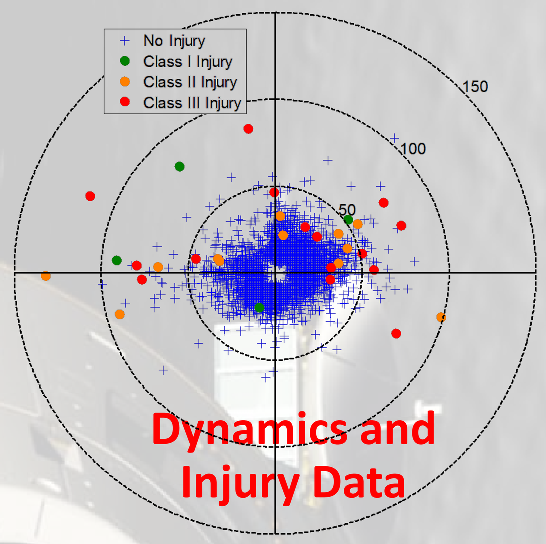
	Head Injury	Facial Trauma	Cervical Spine Trauma	Blunt Trauma	Lung Contusion	Rib Fracture	Hemo/Pneumo-thorax	Upper Extremity Joint Injury	Upper Extremity Fracture	Thoracic Spine Trauma	Lumbar Spine Trauma	Lower Extremity Joint Injury	Lower Extremity Fracture
HIC36	T/H												
BRIC	T/H												
Neck Axial Tension			T/H										
Neck Axial Compression			T/H										
Max Chest Deflection					T	T	T						
Lateral Shoulder Force (Deflection)					T/W	T/W	T/W	T/W	T/W				
Lumbar Axial Compression										T/H	T/H		
Ankle Moments												T	
Contact Limits / Restraints (Design Constraint)		X		X				X	X			X	X

Data Mining

Human surrogates (e.g. ATDs) are used to estimate risk since injury risk often cannot be measured directly with live humans. For this study, we have chosen to focus on human data from multiple sources, and numerical and physical ATDs.



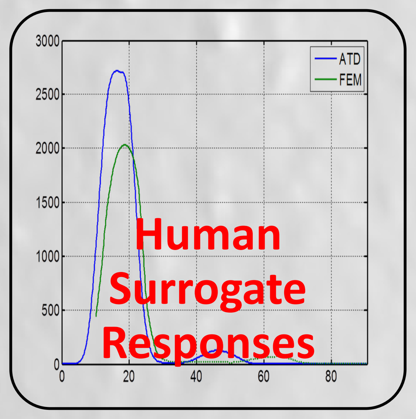


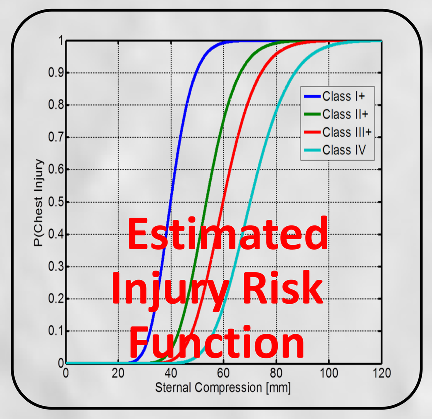


The goal of this task is to develop injury risk functions for each of the injury metrics for the THOR-NT ATD. Several datasets are available to us:

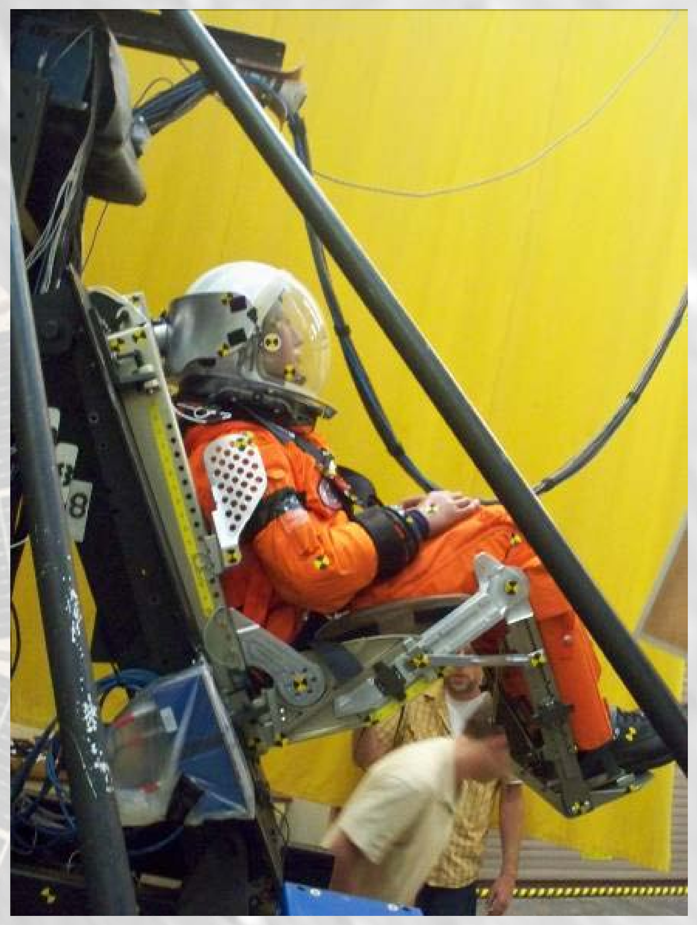
- NASCAR
- IndyCar
- Historical Human Volunteer Testing
- Data available in the Literature

These injury risk functions will then be combined with the acceptable risk levels to determine Injury Assessment Reference Values (IARVs)





Human Volunteer Testing



Once the IARVs are determined, they will still need to be validated in the spaceflight configuration. Because each of the datasets used to develop the IARV sets are not exactly analogous to spaceflight, rigorous validation by sub-injurious human testing is needed.

Human subjects will be recruited to allow a 95% confidence of a less than 5% risk of any injury. Given no injuries during testing (as anticipated), approximately 60 subjects would be needed. Subjects will be selected to represent the astronaut corps (height, weight, gender, age)

Subjects will be tested at several acceleration levels culminating in testing at expected Orion nominal landing loads. The testing will be conducted with flight-like Orion seats and suits, and each subject will be tested with and without suits to allow investigation into the effects of the suit on the human response.

Finally, each test will have a matched ATD run to allow a correlation between the subject responses and the ATD responses.