DATA MINING OF HISTORICAL HUMAN DATA TO ASSESS THE RISK OF INJURY DUE TO DYNAMIC LOADS

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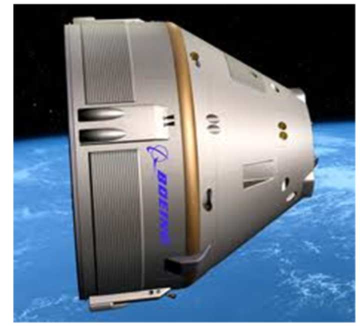
- **NASA, along with the Commercial Crew Program, is developing new crewed vehicles**
  - Designs include both capsule and winged/lifting body
  - Each design has various launch, abort and landing orientations
- **The Occupant Protection team has been tasked with developing requirements to ensure the crew is protected from injury due to dynamic loads during all phases of flight**

Orion / MPCV 4 crew, 316 ft^3



Boeing CCT-100 7 Crew

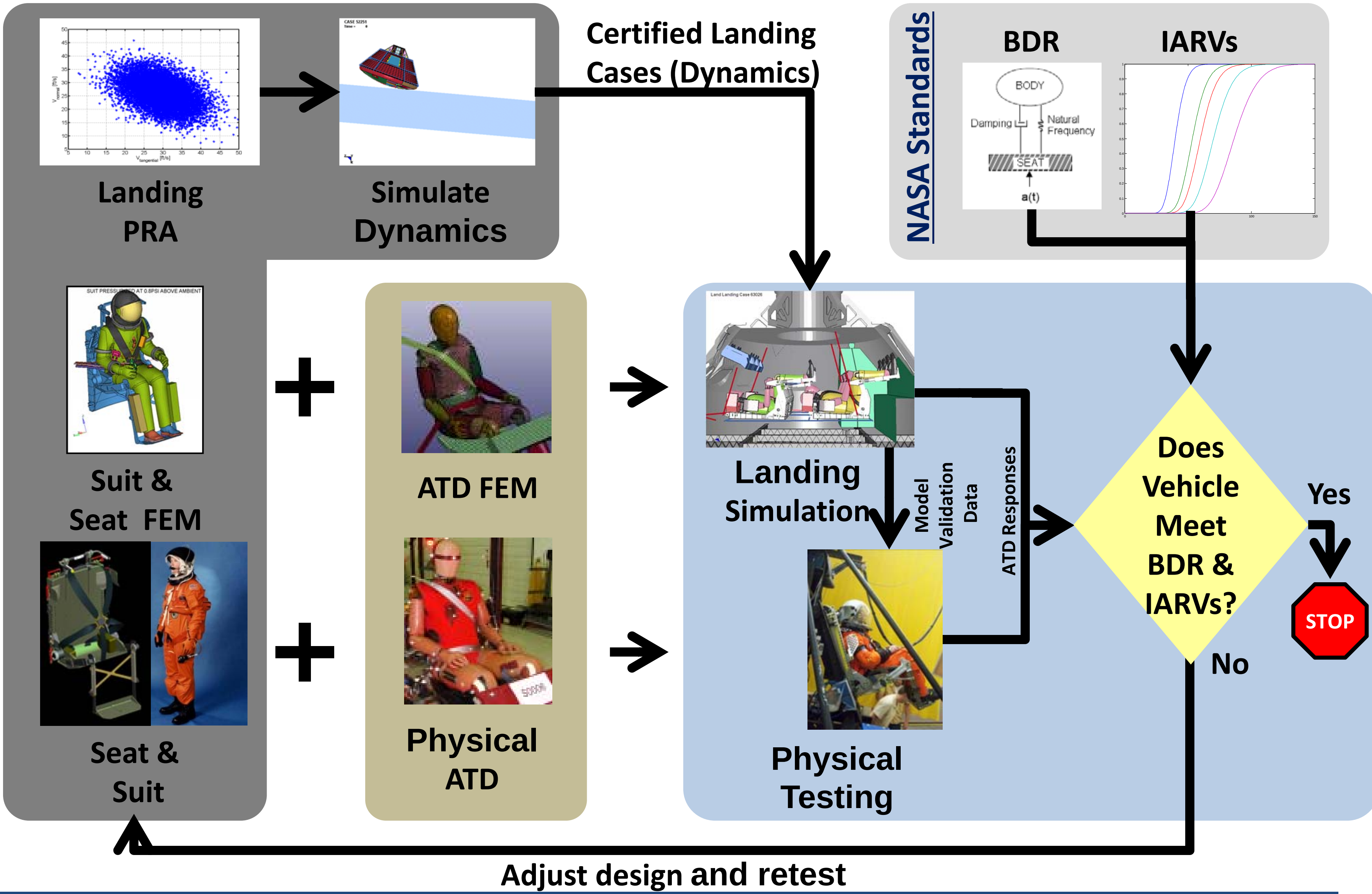
SpaceX Dragon 7 Crew, 353 ft^3

Blue Origins New Shepard 7 Crew?

Sierra Nevada DreamChaser 6 Crew, 565 ft^3

Soyuz TMA-M 3 Crew, 300 ft^3

Proposed Occupant Protection Standardized Test Methodology



Defining Acceptable Injury Risk

- **OP Convened a technical interface meeting (TIM) with experts from within and outside of NASA including military, automotive, and academic injury biomechanics experts.**
- **Systematically defined the highest risk which would be acceptable for each injury level.**
- **Bought down the risk levels using programmatic, political, ethical, and medical considerations.**
- **Unanimous consent from the panel of experts.**
- **Approved by the SLSD community (MOB, SMCCB, and FACB).**

	Nominal	*Off-Nominal*
Class I (AIS1+)	5%	19%
Class II (AIS2+)	1%	4%
Class III (AIS3+)	0.3%	1%
Class IV (AIS4+)	0.03%	0.1%

Validating Risk

- **Two methods to validate probability of injury for a given vehicle:**
  1. **Perform impact tests with human volunteers under projected nominal landing loads for a given vehicle.**
     - This method would require a large number of tests to show with 95% confidence that the risk of injury is within the DAR.
  2. **Mine data from existing databases of human response to impact, then compare that data to ATD test data performed under the same conditions.**
     - With this method Injury Assessment Reference Values (IARVs) would be defined for a given ATD which meet 95% confidence that the risk of injury is within the DAR.
     - This method could reduce the number of human volunteer testing required for vehicle validation.

Developing Injury Assessment Reference Values

H – Hybrid III
T – THOR-K
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
HIC 15	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

- **Collaborative Biomechanics Data Network (CBDN)**
  - The U.S. Air Force has conducted hundreds of sub-injurious human impact tests at Wright Patterson Air Force Base (WPAFB)
  - Tests performed in frontal, lateral and spinal directions, for various impulse levels and durations
  - OP team performed impact testing of THOR ATD at WPAFB under similar conditions as 5 frontal and 3 spinal loading conditions from the CBDN
- **Other data sets**
  - Additional sub-injurious and injurious data was collected from NASCAR and Indy Racing League (IRL) crashes
  - Recreation of crash pulses using digital ATD and seat configuration can provide additional data points

THOR Test Data

		Peak THOR Values								
		Frontal				Spinal				
		8G, 100ms	10G, 100ms	10G, 70ms		10G, 40ms	8G, 100ms	10G, 100ms	12G, 100ms	10G, 70ms
	THOR Test	8681	8682	8700	8701	8660	8676	8673	8675	8665
	Number of Human Subjects	29	26	20		13	11	11	11	12
	Nij - filtered	0.3130	0.3964	0.5926	0.5779	0.3670	0.2986	0.3135	0.3676	0.3401
	HIC 15	9.63	17.78	20.23	24.77	29.60	8.85	19.53	33.26	18.25
	BRIC	1.07	1.03	3.43	2.86	0.84	0.93	1.03	1.31	0.95
	Neck Axial Tension Force [N]	898.34393	1271.10251	2250.28	2238.61	x	x	x	x	x
	Neck Axial Compression Force [N]	x	x	x	x	-2126.18	-1150.69	-1733.70	-2187.01	-1630.28
	Max Chest Deflection, x [mm]	156.01	154.27	154.09	155.79	156.13	157.04	156.44	158.37	157.03
	Max Chest Deflection, z [mm]	x	x	x	x	20.55	14.46	17.51	19.35	14.44
	Thoracic Spine Axial Compression Force [N]	x	x	x	x	-2695.41	-1714.08	-2162.41	-2777.09	-2555.30
	95% conf	9.8210	10.8911	13.9114	13.9114	20.5821	23.8424	23.8424	23.8424	22.1022
	p(Inj) = 5%	77.4099	73.6516	64.1552	64.1552	48.6693	43.1233	43.1233	43.1233	45.9674
	Additive									
# Subjects	Nij	122	46	20		70	133	93	57	82
	HIC	122	67	44		24	133	55	11	67
	BRIC	60	109	20		133	120	109	31	97
	Neck Axial Tension Force	75	46	20		x	x	x	x	x
	Neck Axial Compression Force	x	x	x	x	24	58	35	11	47
	Max Chest Deflection, x	29	55	49		58	22	45	11	34
	Max Chest Deflection, z	x	x	x	x	13	46	35	24	58
	Thoracic Spine Axial Compression Force	x	x	x	x	24	58	47	11	36

Example - HIC 15

$$HIC_{15} = \max_{0 \le t_2 - t_1 \le 0.015} \left((t_2 - t_1) \left[\int_{t_1}^{t_2} a(t)dt \, \frac{1}{t_2 - t_1} \right]^{2.5} \right)$$

- **Head Injury Criteria (HIC) is an industry standard for head injury due to translational acceleration**
- **Using the NHTSA curves, the following values can be derived**

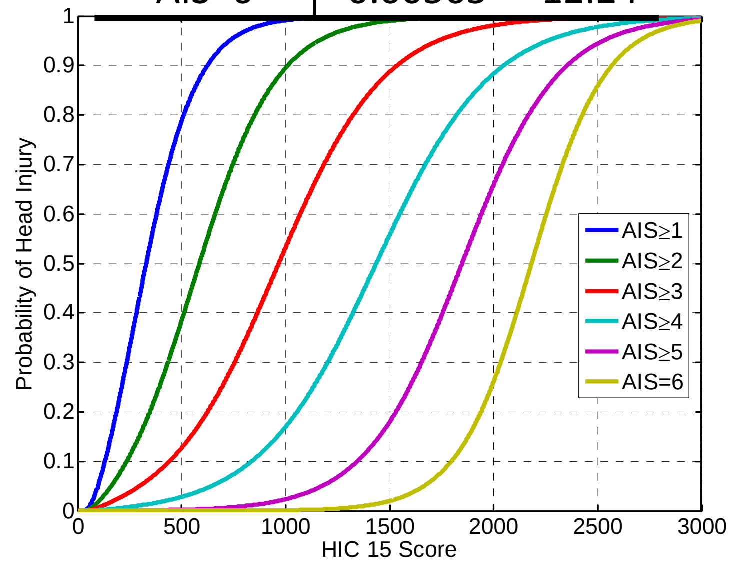
HIC 15	Nominal	Off-Nominal
AIS≥1	98	182
AIS≥2	58	144
AIS≥3	74	121
AIS≥4	59	87

- **AIS≥1 is used as it is more reasonable than the other values**

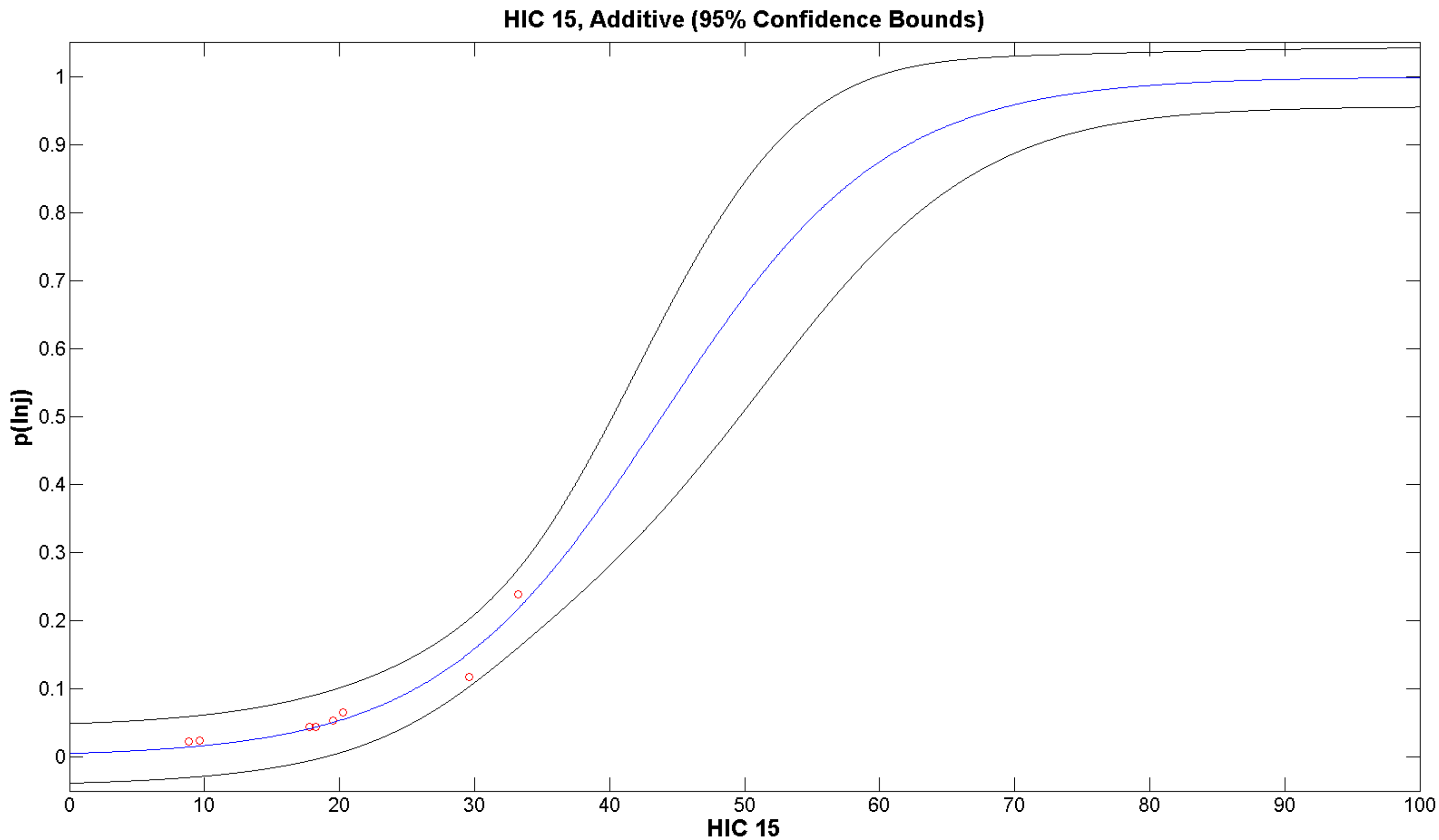
National Highway Traffic Safety Administration. (1995) Final Economic Assessment, FMVSS No. 201, Upper Interior Head Protection.

$$p(inj|AIS \ge n) = \frac{1}{1 + e^{\left(b + \frac{200}{HIC}\right) - a \cdot HIC}}$$

Variable	a	b
AIS≥1	0.0065	1.54
AIS≥2	0.00483	2.49
AIS≥3	0.00372	3.39
AIS≥4	0.00351	4.9
AIS≥5	0.00429	7.82
AIS=6	0.00565	12.24



Example – HIC 15

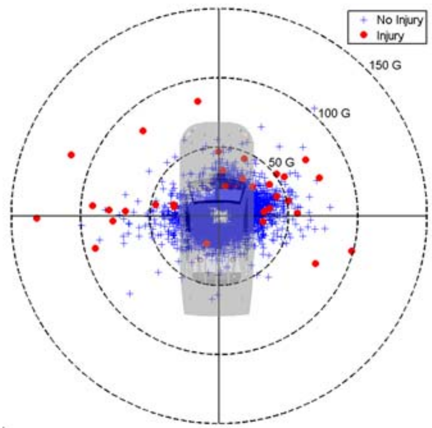


Human Exposure Data Mining & Analysis Example

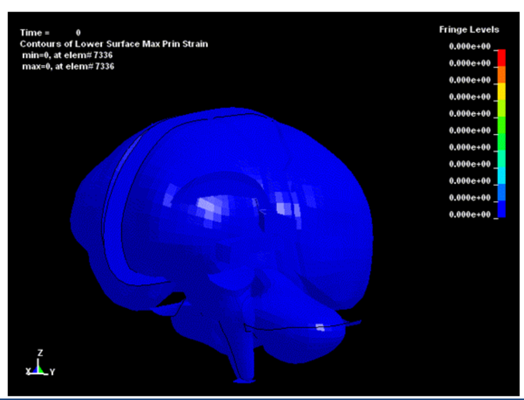
Compile data from various sources with human exposure injury data and recorded accelerations

NASCAR Example

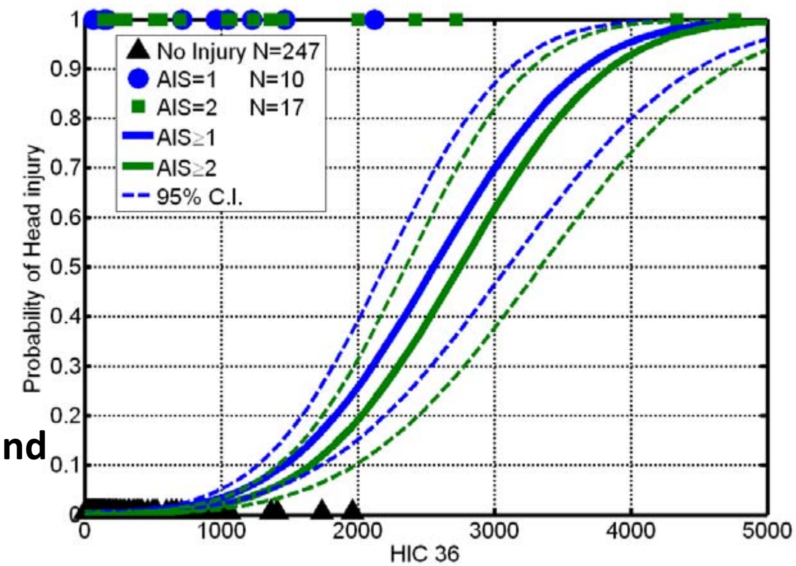
NASCAR records all vehicle impacts and injuries sustained



Using Finite Element models of the seat and restraints and the recorded data, estimate forces, accelerations, strains and deflections experienced by the occupants



- Relate these estimates with actual recorded injuries that occurred to develop injury risk curves



- From these injury risk functions, limits for crew safety can be developed based on desired risk posture
- Use same methodology on additional datasets to get a complete picture of injury risk

Discussion

- **Additional human volunteer testing required to characterize the following**
  - Sex
  - Age
  - Anthropometry
  - Deconditioning
- **Additional THOR testing required to increase the human volunteer data set**
  - Physical ATD testing under similar conditions as historical data from CBDN
  - Physical ATD testing under similar conditions as additional human volunteer testing
  - FE ATD model testing to further develop and refine the FE model
  - FE ATD model testing in same conditions as NASCAR and IRL impacts to increase number of sub-injurious and injurious human volunteer data points

Conclusions

- **Comparison of historical data obtained from CBDN to THOR ATD test data can help define IARVs which meet 95% confidence that the risk of injury is within the DAR.**
- **ATD testing and IARVs established from those tests can help reduce the number of human volunteer testing needed in the future.**
- **Additional testing, both human volunteer and ATD, needs to be completed in order to refine IARVs and validate the DAR.**

Description of What's Next

- **Continue to analyze available NASCAR and IRL crash pulses with the FE ATD and correlate results to human data**
- **Test physical THOR ATD in different test configurations in order to correlate to more historical human test data available on CBDN and use that data to further refine the DAR**
- **Test human volunteers and THOR ATD in configurations in which insufficient data exists to further validate and use that data to further refine the DAR**
  - Sex
  - Age
  - Anthropometry
  - Deconditioning


Questions?