Occupant Protection During Orion Crew Exploration Vehicle Landings

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Introduction The Constellation Program is evaluating current vehicle design capabilities for nominal water landings and contingency land landings of the Orion Crew Exploration Vehicle. The Orion Landing Strategy Tiger Team was formed to lead the technical effort, for which associated activities include the current vehicle design susceptibility to roll control and tip over, reviewing methods for assessing occupant injury during ascent/aborts/landings, developing an alternate seat/attenuation design solution which improves occupant protection and operability, and testing the seat/attenuation system designs to ensure valid results. The EVA Physiology, Systems, and Performance (EPSP) Project is leading the effort under the authority of the Tiger Team Steering Committee to develop, verify, validate and accredit biodynamics models using a variety of crash and injury databases, including NASCAR, Indy Car, and military aircraft. These validated biodynamics models will be used by the Constellation program to evaluate a variety of vehicle, seat, and restraint designs in the context of multiple nominal and off-nominal landing scenarios. These models will be used in conjunction with Acceptable Injury Risk definitions to provide new occupant protection requirements for the Constellation program.

Biodynamics Modeling Race car and military aircraft occupant protection experience suggests significant benefits can be gained from improved seat and restraint systems. Existing NASA occupant protection requirements are tied to the Brinkley injury risk model, which cannot adequately account for seat/restraint systems and their associated injury responses to a range of landing loads. The EPSP team is coordinating a panel of subject matter experts from auto, racing and military occupant protection backgrounds. The acquisition, processing and modeling of statistical and biodynamic data will be undertaken by the team and reviewed with this expert panel. In addition, the team is responsible for sharing knowledge captured within the project data analysis with the Steering Committee and the Orion project for design and requirements impacts. The team will organize the final project deliverables, validated biodynamics models and report to the Constellation program in time to support critical design review milestones for the Orion project.

Definition of Acceptable Risk After defining probability of injury associated with critical biodynamic responses, it is necessary to systematically define the highest level of acceptable injury risk during landings consistent with a successful program. This definition is based on key mission drivers such as crew health, safety and performance considerations in the immediate landing environment, long-term crew health considerations including medical policy and future flight status, programmatic success criteria e.g. overall Loss of Crew (LOC) requirement in context of all mission phases, public opinion and ethical considerations, and balancing the risk vs. reward (Utility) for landing environment in context of all mission phases. To put Orion landing risk in perspective, the team is providing a context of injury risk compared with other military and civilian vehicle operations based on overall risk of injury, probability of an off-nominal event, and the risk of injury in an off-nominal event. To accomplish this task, an Operationally Relevant Injury Scale is being defined to allow classification of injuries based on impacts to crew performance and egress.

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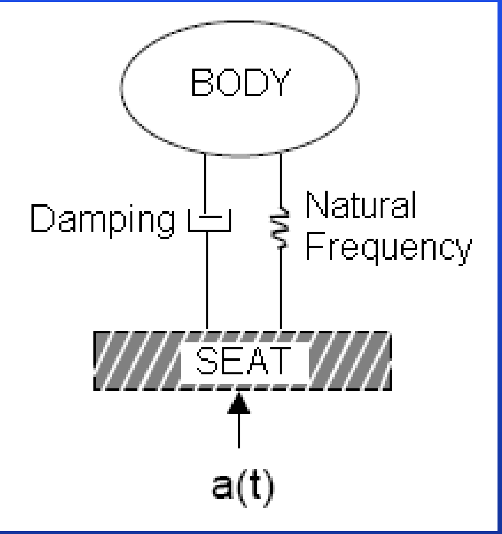
Origination

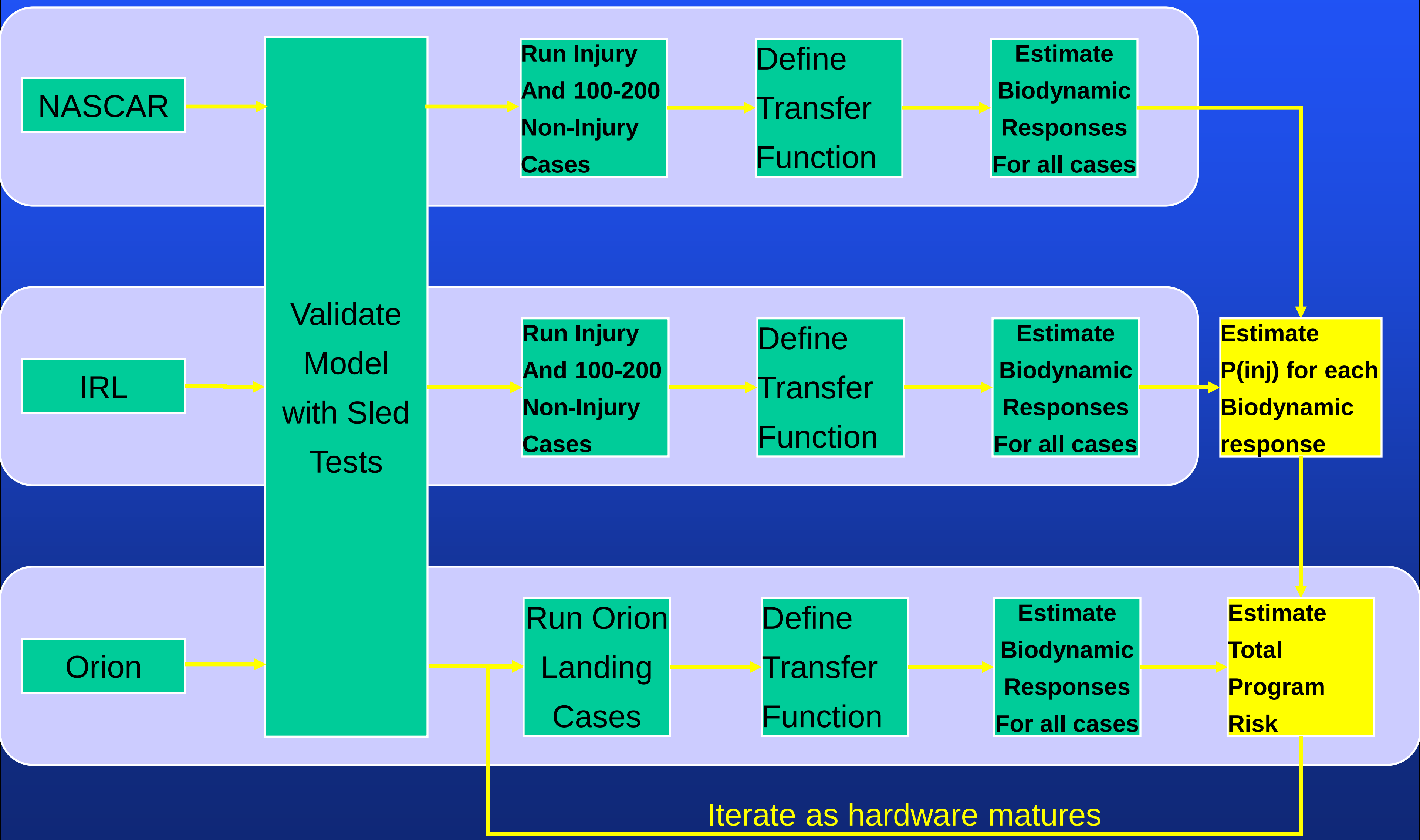
- **The Constellation Program is evaluating current vehicle design capabilities for nominal water landings and contingency land landings of the Orion Crew Exploration Vehicle.**
- **The Orion Landing Steering Committee (LSC) Tiger Team was formed to lead the technical effort, including:**
  - Evaluating current vehicle design susceptibility to roll control and tip over
  - Reviewing methods for assessing occupant injury during ascent/aborts/ landings
  - Developing an alternate seat/attenuation design solution which improves occupant protection and operability
  - Testing the seat/attenuation system designs to ensure valid results
- **The Occupant Protection Project was formed to develop, verify, validate and accredit biodynamics models using a variety of crash and injury databases that include NASCAR, Indy Car, and military aircraft.**

NASA History of Landing Injury Risk

- **The Brinkley Model is currently used by NASA and the military to determine the risk of injury to vehicle occupants based on seat acceleration**
- **The model calculates a Dynamic Response (DR) using a lumped mass modeled with a spring and damper attached to the seat**
- **An injury classification based on injury probability is then determined using pre-defined DR limits for each axis**
  - Very Low: <0.05%
  - Low: 0.05 - 0.5%
  - Medium: 0.5 – 5%
  - High: 5 – 50%
  - Very High: >50%
- **Disadvantages of the Brinkley Model**
  - The model assumes a basic seat geometry and so probability of injury is not reduced with seat or safety equipment improvements
  - With the Brinkley model, the only way to reduce injury risk is to attenuate energy
  - Brinkley model only predicts if an injury occurs
  - Brinkley model does not predict injury severity, or anatomical location



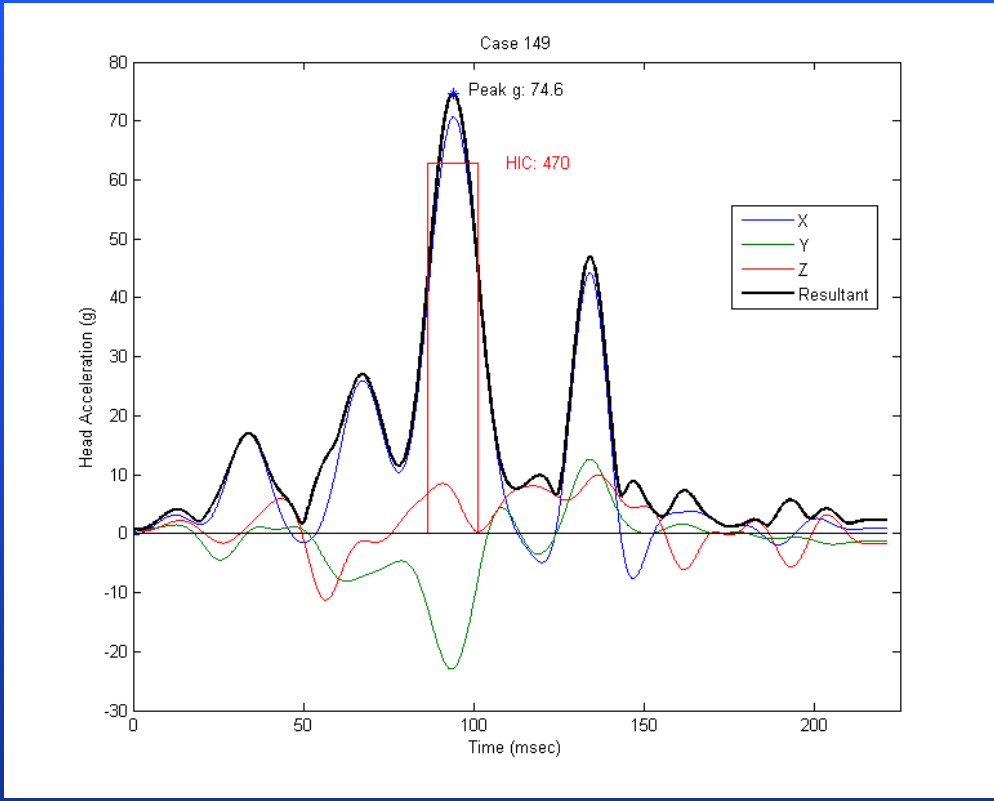
Modeling Road Map



Relating Race Car Crash Data to Orion

- **How do we relate NASCAR and Indy Racing League (IRL) crash data to Orion?**
  - Use numerical models with Hybrid-III manikin
  - Use actual crash data to relate biodynamic responses to injuries
  - Relate NASCAR / IRL biodynamic manikin responses to biodynamic manikin responses from CEV cases

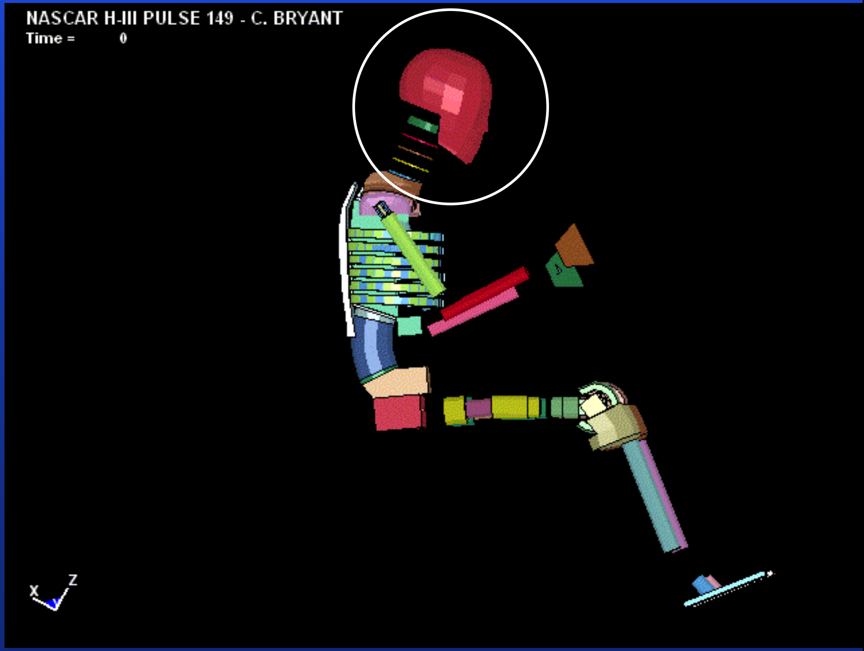
Biodynamic Response Example: Head Acceleration



NASCAR Rear Impact Case (+X)

56.5 g Impact

63.2 mph ΔV



Definition of Biodynamic Responses

- **Using military, passenger vehicle and race car published research and requirements, we worked with industry experts to identify biodynamic responses and determine the limits that would best protect the crew**

		0.5% risk			2% risk			5% risk		
	Parameter **(Deconditioned)**	Small Female	50th% Male	Large Male	Small Female	50th% Male	Large Male	Small Female	50th% Male	Large Male
Head	Head Injury Criteria (HIC 15)	300			500			700		
	Peak Head Acceleration (g)	119	112	109	151	142	138	166	155	151
Neck	Peak Neck (cervical) flexion bending moment (Nm)	42	83	83	57	108	125	89	163	222
	Peak Neck (cervical) lateral bending moment (Nm)	33	65	65	41	82	82	62	123	123
	Peak Neck (cervical) extension bending moment (Nm)	15	34	42	27	49	67	28	56	75
	Peak Neck (cervical) axial tension (N)	631	943	1138	1753	2781	3363	2161	3440	4326
	Peak Neck (cervical) compression (N)	596	946	1142	1067	1694	2046	2167	3440	4154
	Peak Neck (cervical) shear force (N)	593	946	1142	919	1462	1766	1680	2666	3219
Lumbar	Lumbar resultant force	TBD			TBD			TBD		
Leg	Peak Tibial Axial Compression	1914	3000	3690	2490	3900	4800	3825	6000	7380
	Peak Femur Axial Compression	1914	3000	3690	2498	3801	5013	3862	5670	8100
Chest	Chest Sternal to Spine Deflection (mm)	28	31	35	36	44	49	41	50	55

Per CxP 70024 (HSIR revC)

Relating Injury Risk

- **Abbreviated Injury Scale (AIS) describes injuries anatomically**
  - Standardize injury terminology
  - Rank injuries by severity
  - Facilitate comparisons of injury studies
- **Using an operationally relevant injury scale, we can classify AIS injury codes into several categories**
- **Using these injury severities and anatomical location, we can determine probability of injury occurrence and severity for each region of the body**

Parameter-Scale	*Injury Magnitude*	*Self-Egress Ability*	*Flight Status*
1	**No Injury**	**No Impact**	**No delay in return**
2	**Minor Injury**	**Minor Impact**	**Short Delay in Return**
3	**Moderate Injury**	**Major Impact**	**Long Delay in Return**
4	**Severe Injury**	**Unable**	**Ended/ DQ'd**

Head Injury

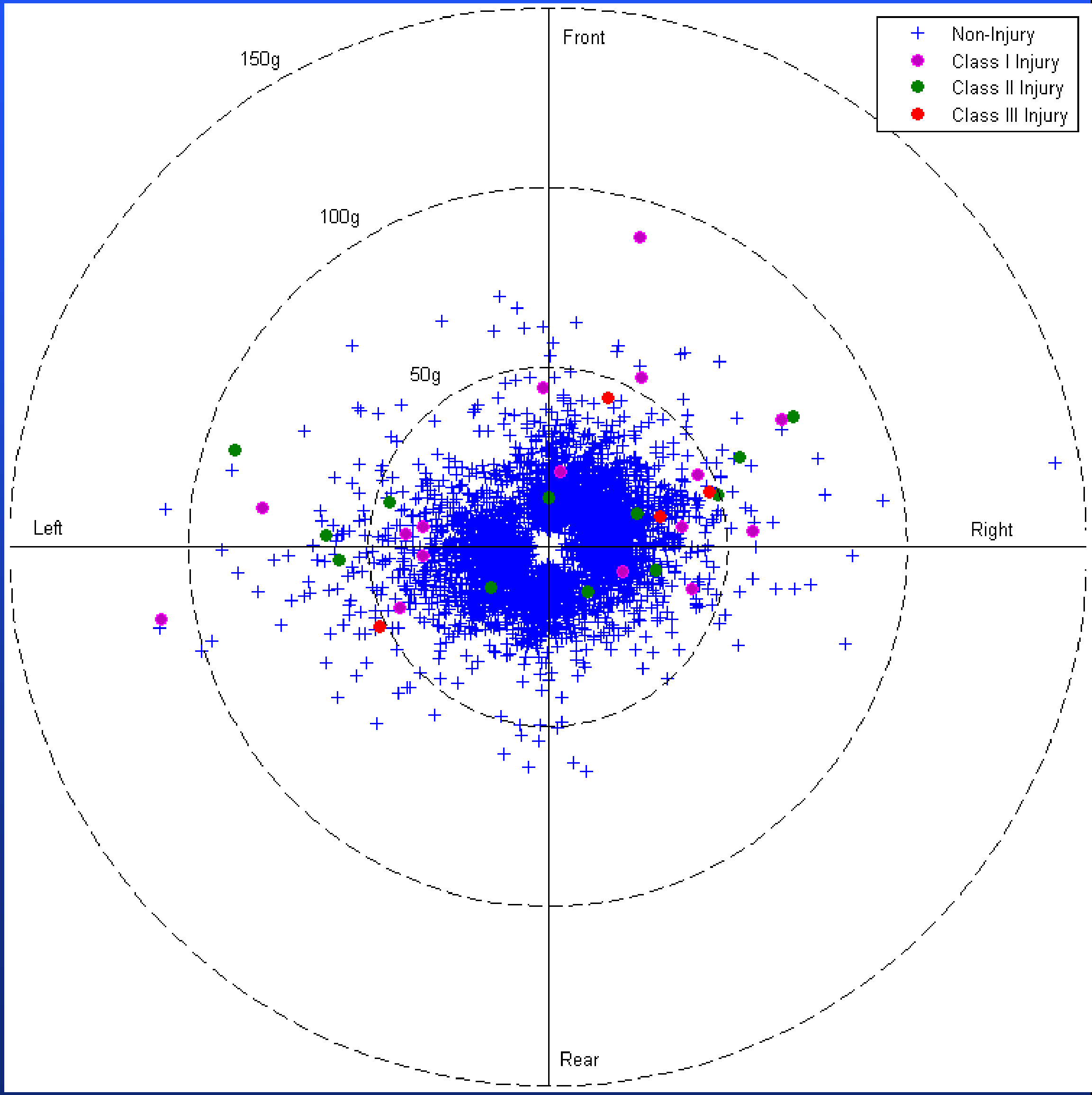
Examples of potential Operationally-Relevant Injuries and associated Biodynamics Response Parameters

Injury	AIS Score	Operationally Relevant Injury Score
Mild Concussion	161001.1	2
Severe Concussion	161006.3	3
Skull Fracture	150000.2	4
Basilar Skull Fracture	150200.3	4
Laceration	110604.1	2

Biodynamic Response Parameters
HIC15
Head Acceleration
Head Movement
Upward Head Movement

NASCAR Injury Distribution

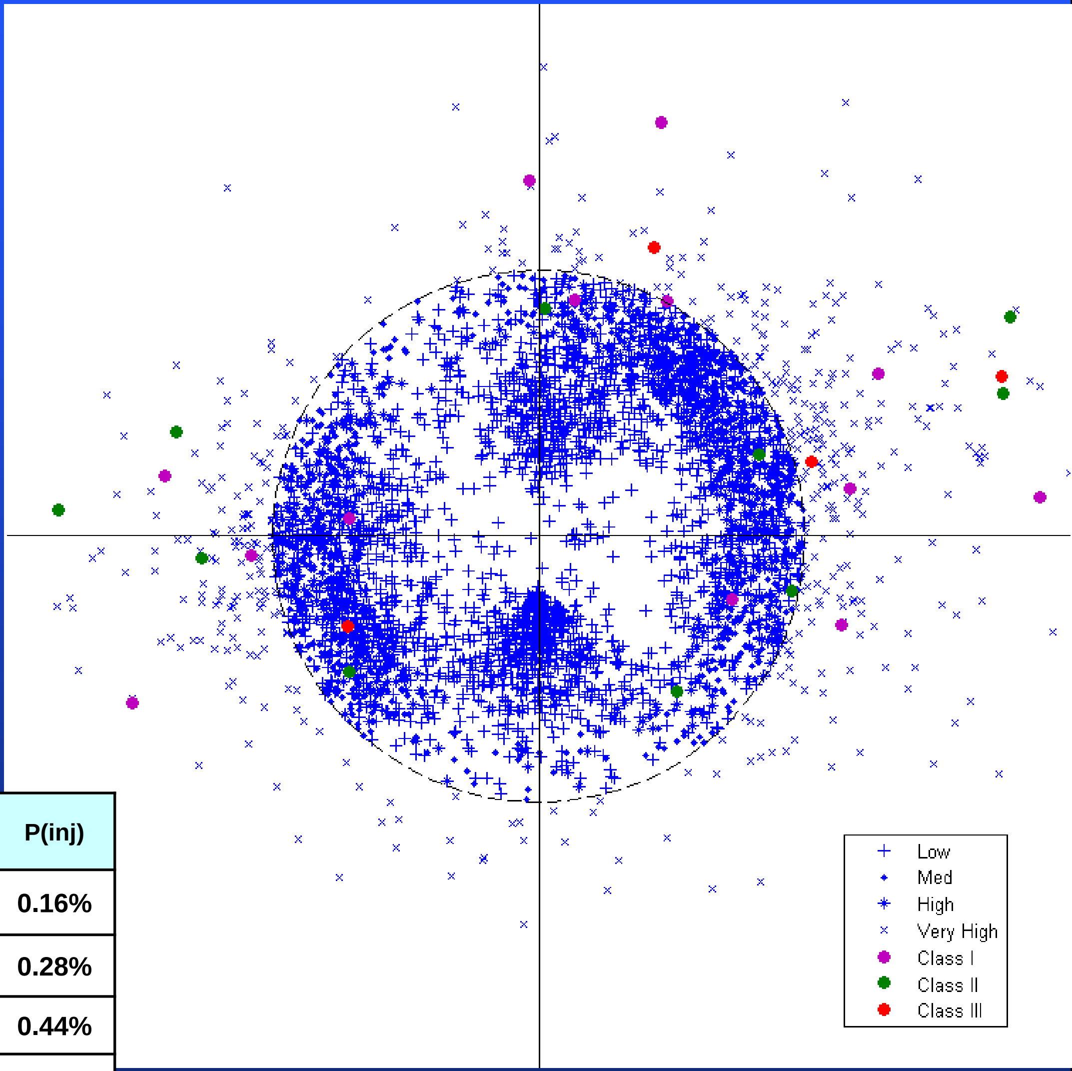
- 4261 Non-Injury Cases
- 16 Class I Injuries
- 15 Class II Injuries
- 4 Class III Injuries



Estimate Results: Brinkley Scores

- **Low (0.5%):**
  - P(inj) = 0.16%
- **Medium (5%):**
  - P(inj) = 0.28%
- **High (50%):**
  - P(inj) = 0.44%
- **Very High**
  - P(inj) = 5.0%

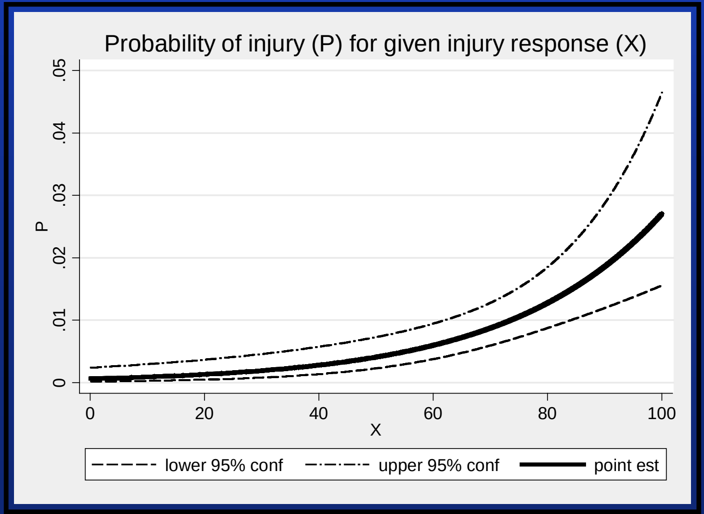
- **Brinkley Model would predict ~608 injuries vs. 32 observed**



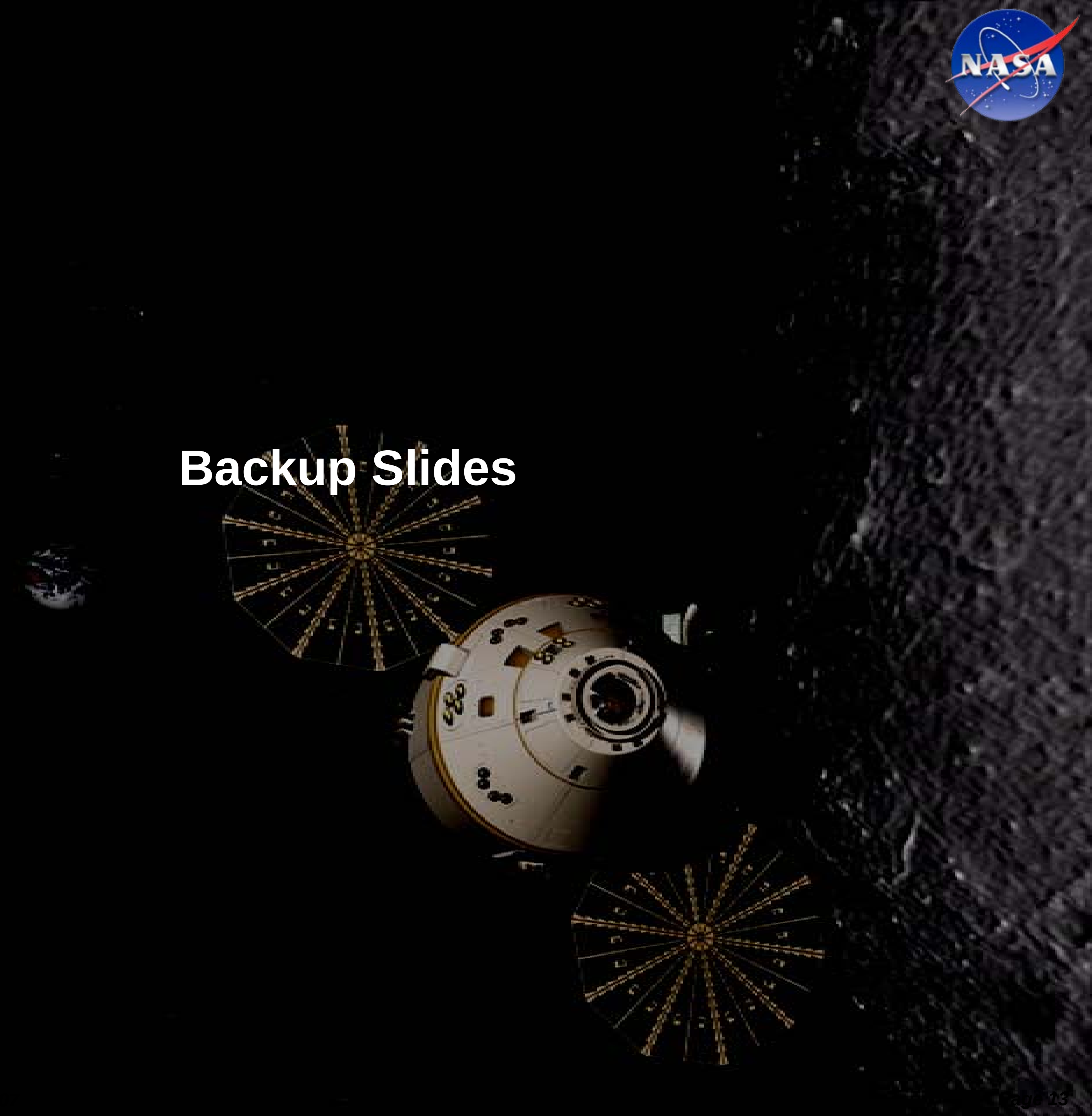
IRC	No Injury	Class I	Class II	Class III	Class IV	Total	P(inj)
Low	2434	2	2	0	0	4	0.16%
Medium	707	1	1	0	0	2	0.28%
High	683	0	2	1	0	3	0.44%
Very High	437	13	7	3	0	23	5.0%

Determining Risk of Injury

- Using the NASCAR data set, statistical modeling techniques will be employed to relate injury predictors (biodynamic responses) with the probability of injury by severity
- Once the each biodynamic response has an associated probability of injury, the Orion landing cases can be assessed to determine the probability of injury
- Using these data, a team of experts will systematically determine what risk is acceptable in an operationally relevant environment
- Using landing probabilities, the goal is to lower total risk over all landing conditions



Backup Slides



Occupant Protection Project Charter

TASK DESCRIPTION:

Determine appropriate methods for modeling and prediction of potential crew injuries. Activities include conducting data mining of injury databases (NASACAR, CIREN, military, etc); assessment of impact simulation and injury prediction methodologies. Recommend techniques / changes to requirements appropriate for Orion including stated limitations.

Data Mining of Injury Databases

- Review automobile, NASCAR, military, and other applicable occupant injury databases

Review limitations and capabilities of analysis tools/techniques

- Review impact simulation techniques appropriate for Orion
- Review occupant injury prediction techniques

Recommend analysis techniques and models appropriate for use by Orion

Recommend appropriate human mass properties data for use by Orion

Provide the necessary mass properties data

Recommend appropriate impact acceleration/occupant injury criteria

Given driving load cases, assess current 606C baseline and alternate designs and recommend potential modifications, if required

PRODUCTS

- Periodic Briefings to Steering Committee/CEV Project Office
- Given driving load cases (from Orion Project Office)

Analyze Orion baseline design (606C) as well as alternate configurations developed by Task #2 team

- Final report to include:
  - Recommendations for standard analysis techniques and models
  - Recommendations for impact acceleration/occupant injury criteria appropriate for use by Orion

Occupant Protection Modeling Forward Plan