2015 Occupant Protection Standing Review Panel

Research Plan Review for:
The Risk of Injury from Dynamic Loads

Final Report

I. Executive Summary and Overall Evaluation

The 2015 Occupant Protection (OP) Risk Standing Review Panel (from here on referred to as the SRP) participated in a WebEx/teleconference with members of the Space Human Factors and Habitability (SHFH) Element, representatives from the Human Research Program (HRP), NASA Headquarters, and NASA Research and Education Support Services on November 3, 2015 (list of participants is in Section VII of this report). The SRP reviewed the updated research plans for the Risk of Injury from Dynamic Loads (OP Risk).

The SRP agrees that the Gaps are relevant and appropriate to mitigate the injury risk. All the appropriate and relevant Tasks have been identified to fill the Gaps. Depending upon the findings, additional tasks may need to be identified or modified. Excellent progress has been made since the 2014 SRP meeting. Publications in peer-reviewed journals validate the scientific merit of the research findings. As detailed in this report, the SRP has specific comments, guidance, and information in the following areas: human finite element modeling, human vs. surrogate dynamic responses, chest injury risk curves, matched pair testing of Test device for Human Occupant Restraint (THOR) and Hybrid III, and disc herniation risk analysis.

II. Critique of Gaps and Tasks for the Risk of Injury from Dynamic Loads

A. *Have the proper Gaps been identified to mitigate the Risk?*
    a. *Are all the Gaps relevant?*
    b. *Are any Gaps missing?*
B. *Have the gap targets for closure been stated in such a way that they are measureable and closeable?*
    a. *Is the research strategy appropriate to close the Gaps?*
C. *Have the proper Tasks been identified to fill the Gaps?*
    a. *Are the Tasks relevant?*
    b. *Are there any additional research areas or approaches that should be considered?*
    c. *If a Task is completed, please comment on whether the findings contribute to addressing or closing the Gap.*
D. *If a Gap has been closed, does the rationale for Gap closure provide the appropriate evidence to support the closure?*

Gaps and Tasks:

- The SRP thinks all of the Gaps are relevant and appropriate to mitigate the risk.
- The SRP thinks all the Gaps are relevant. The Gaps do not all have the same priority and the team recognizes this and has prioritized them well.
- The SRP thinks the gap targets for closure are measurable and closeable.
- Some of the targets may have to be scaled back if funding and time do not permit. Therefore, the SRP thinks it is important to develop priorities, which it appears, the team is developing.
- The SRP thinks there are good research strategies appropriate to close the Gaps using as

much previous information as possible and employing existing tools.

- The SRP thinks at this stage, all the appropriate and relevant tasks have been identified to fill the Gaps. Depending on the findings from currently planned and approved tasks, additional tasks may need to be identified or modified.
- For the tasks that are completed, the OP group is disseminating through publications. This is excellent progress and the peer review of these publications brings additional confidence in the scientific merit of the findings. This type of peer-reviewed publication is suggested as a continued good practice.
- If spaceflight deconditioning is progressive and dependent on duration of flight or exposure to low-gravity or if deconditioning reaches a steady state after a certain time period could be a critical question.

OP-01: We do not understand the risk of injury associated with Soyuz landings and how this risk relates to the desired acceptable risk. (Formerly OP2)

- The SRP thinks this Gap is relevant and appropriate.

Tasks:

- Definition of Acceptable Risk Summit – Completed Task
- Soyuz Landing Injury Risk Characterization – PI: Jeffrey Somers, Ph.D. – NASA Johnson Space Center
    - The SRP thinks this is an important task and thinks it should be a high priority.
    - There is a tremendous potential for valuable information from the Soyuz landings to guide the OP team in validating some of their assumptions from the first task in this Gap and to help guide appropriate human testing later.
    - Once a validated model of the Soyuz seat exists, the SRP thinks it would be worth reconstructing injury producing events with parametric FE models that have been morphed to have geometry that is representative of the astronauts exposed to such events. This approach would allow for better estimation of the acceleration histories needed to produce fracture and could thus create a design target for energy absorbing structures in space vehicles.

OP-02: We do not know how load dynamics and sex differences affect injury risk in spaceflight conditions and how to mitigate the increased risk of injury. (Formerly OP3)

- The SRP thinks this Gap is relevant and appropriate.
- This Gap mentions sex differences and the SRP questions whether occupant size is encompassed in the sex difference characterization. Do we need to get as detailed to know if sex differences are mostly dependent on size difference, or are there truly risk differences by sex for the same occupant size?
- In the Approach section of OP-02 in the Human Research Roadmap, it is stated that "Even though the surrogate responses may not reflect the actual human responses (i.e., neck tension in the surrogate and human may be different in identical loading conditions), this approach works if the surrogate response is sensitive to changes in the configurations that induce injury (either seat design or loading conditions)." The SRP thinks this statement is not always true and the OP team should be aware of the conditions under which it is violated in making design decisions. Specifically, an Anthropometric Test Device (ATD) can be sensitive to a particular type of loading, but can still interact with

the environment in a manner different from the human and this non-humanlike interaction can lead to inappropriate injury assessment. For example, if the THOR pelvis was stiffer in lateral compression and had greater effective mass than that of a human in lateral impact then it could bottom through compliant structures intended to attenuate loading into the stiffer underlying supporting structures. As a result, the THOR pelvis load cells would measure high loads. In contrast, a human, under similar lateral impact loading conditions would not bottom through compliant structures and would not experience the same higher loads. So, in this case, even if a relationship between force measured by ATD and human is developed with matched pair testing, the human will not engage the same structures as the ATD and thus the risk assessment based on ATD force will not be accurate.

Task:

- Occupant Protection Data Mining and Modeling Project – PI: Michael Gernhardt, Ph.D., NASA Johnson Space Center
  - The SRP thinks findings from this task will contribute to closing the Gap.
  - The SRP is unsure why the Kroell data were used to develop risk curves for chest injury. These data were collected using pendulum impacts to the chest, which are not representative of the type of loading experienced during landing. Risk curves based on more distributed loading of the anterior chest would be more appropriate. Also, is anterior to posterior loading the expected mechanism for chest injury for future vehicles?
- ATD Injury Metric Development – PI: Jeffrey Somers, Ph.D. – NASA Johnson Space Center
  - For the ATD injury metric development, matched pair testing of the THOR and Hybrid III will be performed in the same conditions as prior human cadaver tests. Priority areas will include neck injury (sagittal plane and lateral plane), lateral acetabular force, and lateral thorax displacement. Understanding the neck injury biomechanics is a priority area. It is not clear why hip and torso injuries are prioritized over head and lumbar spine injuries. Do the epidemiological data indicate that the hip and torso injuries are more significant and pose greater risk than the head and lumbar spine injuries? Alternatively, are the hip and torso injuries prioritized due to the availability of pre-existing cadaver data? It is recommended to prioritize the ATD injury metric development based upon the specific anatomic injury locations and injury severities identified in the prior epidemiological studies of astronauts.
  - Further, it is not clear whether the load directions, rates, and magnitudes used in the prior cadaver studies adequately represent those that the astronauts are exposed to. The SRP suggests to first identify prior cadaver studies that have been performed with dynamic load directions, rates, and magnitudes similar to those during space launch, abort, and/or landing and focus the matched pair comparisons using those studies. These analyses may indicate further cadaver testing that may need to be done to better model the dynamic loads during space launch, abort, and landing.
  - It should be noted that the matched comparisons of the THOR and Hybrid III to the prior cadaver data are limited by the existing designs of the crash dummies. For example, THOR's neck in neutral posture is aligned vertically and does not mimic the natural lordosis of the human cervical spine. In multiple prior studies, the Hybrid III

neck has been found to be far too stiff as compared to human. Lastly, the human cadaver database is limited by the lack of a helmet in the previously published cadaver work. The dynamic injury responses including neck loads and motions and injury sites and severities will differ among cadaver tests performed with and without the helmet.

- ATD Injury Metric Sensitivity and Extensibility – PI: Jeffrey Somers, Ph.D. – NASA Johnson Space Center
- Human Volunteer Testing – Planned Task
  - The SRP thinks it would be very beneficial to convene an expert panel prior to beginning the human volunteer testing.
  - Need to be sure to well characterize human body shape and seated posture for subsequent model validation or efforts to better understand reasons for variability in human response.
- Dynamic Load Definition Workshop – Planned Task
- Comparison of Biodynamics Models Using Automotive Racing Crash Data – Completed Task
  - There is not enough information available to determine if this task will contribute to closing the Gap. If NASCAR seat accelerations are in the range of those expected during future missions and are in the same directions, then this will contribute to closing the Gap.
- Human Surrogate Risk Characterization – Planned Task

OP-03: We do not have a set of analytical tools to inform design decisions for new programs and reduce required human testing for validation of initial or modified designs. (Formerly OP4)

- The SRP thinks this Gap is relevant and appropriate.
- The SRP thinks it will be important to define what the threshold for an adequate tool will be. The OP SRP understands that certain responses of the test surrogates are more important than others. Model validation is a continuum and as the OP team progresses through tools characterization they will need to more precisely define the end point of the task and realize that certain tools that they considered may just not be adequate enough for the intended purpose.
- For the human finite element (FE) modeling tasks, if not already being considered, the SRP would suggest the use of whole body FE models with geometry that is parametric with occupant characteristics such as age, sex, body mass index (BMI), and stature, should be considered. Parametric versions of the Total Human Model for Safety (THUMS) and Global Human Body Model Consortium (GHBMC) have been developed (see Schoell et al. 2015 Stapp and Shi et al. 2015). Simulations with such models can account for how crew member anthropometry differs from that of the midsize male and the effect of this difference on biomechanical response and injury. Such models can also be used to estimate the effects of design changes on population response and injury. They can also accurately identify subsets of the population that are most vulnerable and assess the effects of customized countermeasures (e.g., custom seats for each crew member as is done in the Indy Racing League (IRL) or the National Association for Stock Car Auto Racing (NASCAR)).

Shi, X., Cao, L., Reed, M.P., Rupp, J.D., and Hu, J. (2015). Effects of obesity on occupant responses in frontal crashes: a simulation analysis using human body models. Computer Methods in Biomechanics and Biomedical Engineering. 18(2):1280-1292. 10.1080/10255842.2014.900544.

Schoell, S., Weaver, A., Urban, J., Jones, D.A., Hwang, E., Hu, J., Reed, M.P., Rupp, J.D., and Stitzel, J.D. (2015). Development and Validation of an Older Occupant Finite Element Model of a Mid-Sized Male for Investigation of Age-related Injury Risk. Stapp Car Crash Journal. In Press.

Tasks:

- NESC/Hybrid III Testing & Model Characterization – Planned Task
  - The SRP thinks the OP team should consider using the THOR small female in addition to the Hybrid III small female depending on timing. The THOR 5th is in development, but should be ready for testing in approximately 1.5 years.
- NESC/Suit Characterization – Planned Task
- Surrogate Model Validation – Planned Task
- Occupant Protection Data Mining and Modeling Project – PI: Michael Gernhardt, Ph.D., NASA Johnson Space Center

OP-04: We do not know the extent to which spaceflight deconditioning decreases injury tolerance for dynamic loads. (Formerly OP5)

- The SRP thinks this Gap is relevant and appropriate.
- The SRP thinks the gap targets for closure are measurable and closeable.

Tasks:

- Vertebral Strength and Fracture Risk Following Long Duration Spaceflight – PI: Mary Bouxsein, Ph.D., Harvard Medical School
- Disc Herniation Risk Analysis – Completed Task
  - For the disk herniation risk analysis study, a sample size of 330 U.S. astronauts was used. These astronauts took part in 745 space missions over 55 years. Statistical analyses identified strong evidence that spaceflight contributed to the risk of disk herniation. This study should identify the spinal level(s) where the herniation(s) occurred. It is unclear how disc herniation was diagnosed prior to MRI. This should be clearly explained. The discussion of confounding factors should also be expanded. The length of time between the flight and the clinical diagnosis of herniation should be reported. Attempts should be made to classify and define the herniation severity using consistent nomenclature and a classification system (e.g., Fardon et al., Spine 39 (24):E1448–E1465).
- Pre/Post Flight Imaging Study – Planned Task
  - The SRP recommends adding Raman Spectroscopy of sufficiently superficial skeletal structures to assess bone quality (not sure if this is yet approved).
  - Also, the SRP thinks the OP team should use subject specific FE models to account for effects of spine geometry.
  - Lastly, imaging in seated postures and under load (rather than supine computed tomography (CT)) would be useful so that the effects of posture could be

incorporated in the FE model.

- Retrospective Animal Flight Study – Planned Task
  - The SRP thinks this study is a good addition to the planned tasks.
- Quantification of In-flight Physical Changes - Anthropometry and Neutral Body Posture (NBP) – PI: Sudhakar Rajulu, Ph.D., NASA Johnson Space Center
  - The SRP recommends using methods other than measurement of skeletal landmark locations and body circumferences. For example, all of this information except range of motion can be extracted from scans of external body geometry with structured light scanners.
- Deconditioning Summit – Completed Task
- Risk of Intervertebral Disc Damage After Prolonged Spaceflight – PI: Alan Hargens, Ph.D., University of California, San Diego
- Sonographic Astronaut Vertebral Examination – PI: Scott Dulchavsky, M.D., Ph.D., Henry Ford Health System
- Animal Study Assessment – Planned Task

III. Discussion on the strengths and weaknesses of the IRP and identify remedies for the weaknesses, including answering these questions:

A. Is the Risk addressed in a comprehensive manner?
   - The SRP thinks the Risk is addressed in a comprehensive manner and the OP discipline is doing a good job at trying to alleviate the Risk.

B. Are there areas of integration across HRP disciplines that are not addressed that would better address the Risk?
   - During the WebEx presentation, the OP team identified good collaborations with other HRP disciplines.

IV. Evaluation of the progress on the Occupant Protection Risk Research Plan since the 2014 SRP meeting

- The SRP thinks excellent progress has been made with peer-reviewed publications emanating from the tasks. This type of dissemination is encouraged going forward.

V. Additional Comments

- The SRP encourages collaboration with our Russian colleagues (e.g., Roscosmos, Institute of Biomedical Problems) to enable gathering of a large data set for injuries sustained.
- The SRP would continue to encourage the OP group to gather data from any future test flights either by NASA or by other contractors, if allowed. There are low-profile, low-mass, six-degree-of-freedom sensors and data acquisition unit all-in-one packages that could easily be mounted to any seat structure on any test flight.

VI. 2015 Occupant Protection Risk SRP Research Plan Review: Statement of Task for the Risk of Injury from Dynamic Loads

The 2015 Occupant Protection (OP) Risk Standing Review Panel (SRP) is chartered by the Human Research Program (HRP) Chief Scientist. The purpose of the SRP is to review the Risk of Injury from Dynamic Loads section of the current version of the HRP's Integrated Research Plan (IRP) which is located on the Human Research Roadmap (HRR) website (http://humanresearchroadmap.nasa.gov/). Your report, addressing each of the questions in the charge below and any addendum questions, will be provided to the HRP Chief Scientist and will also be made available on the HRR website.

The 2015 OP Risk SRP is charged (to the fullest extent practicable) to:

1. Based on the information provided in the current version of the HRP's IRP, evaluate the ability of the IRP to satisfactorily make progress in mitigating the Risk by answering the following questions:

   A. Have the proper Gaps been identified to mitigate the Risk?
   i) Are all the Gaps relevant?
   ii) Are any Gaps missing?

   B. Have the gap targets for closure been stated in such a way that they are measureable and closeable?
   i) Is the research strategy appropriate to close the Gaps?

   C. Have the proper Tasks been identified to fill the Gaps?
   i) Are the Tasks relevant?
   ii) Are there any additional research areas or approaches that should be considered?
   iii) If a Task is completed, please comment on whether the findings contribute to addressing or closing the Gap.

   D. If a Gap has been closed, does the rationale for Gap closure provide the appropriate evidence to support the closure?

2. Identify the strengths and weaknesses of the IRP, *and* identify remedies for the weaknesses, including, but not limited to, answering these questions:
   A. Is the Risk addressed in a comprehensive manner?
   B. Are there areas of integration across HRP disciplines that are not addressed that would better address the Risk?
   C. Other

3. Based on the updates provided by the Element, please evaluate the progress in the research plan since the last SRP meeting.

4. Please comment on any important issues that are not covered in #1, #2, or #3 above, that the SRP would like to bring to the attention of the HRP Chief Scientist and/or the Element.

Additional Information Regarding This Review:

1. Expect to receive review materials at least four weeks prior to the WebEx conference call.

2. Participate in a WebEx conference call on November 3, 2015 at 1:30 pm ET.
   A. Discuss the 2015 OP Risk SRP Statement of Task and address questions about the SRP process.
   B. Receive presentations from the HRP Chief Scientist (or his designee), the Space Human Factors and Habitability (SHFH) Element, and participate in a question and answer session, and briefing.

3. Prepare a draft final report (approximately one month after the WebEx conference call) that contains a detailed evaluation of the current IRP specifically addressing items #1, #2, and #3 of the SRP charge. The draft final report will be sent to the HRP Chief Scientist and he will forward it to the appropriate Element for their review. The SHFH Element and the HRP Chief Scientist will review the draft final report and identify any misunderstandings or errors of fact and then provide official feedback to the SRP within two weeks of receipt of the draft report. If any misunderstandings or errors of fact are identified, the SRP will be requested to address them and finalize the 2015 SRP Final Report as quickly as possible. The 2015 SRP Final Report will be submitted to the HRP Chief Scientist and copies will be provided to the SHFH Element that sponsors the OP discipline and also made available to the other HRP Elements. The 2015 SRP Final Report will be made available on the HRR website (http://humanresearchroadmap.nasa.gov/).

VII. OP Risk SRP Research Plan Review WebEx/Teleconference Participants

SRP Members:
Frank Pintar, Ph.D. (Chair) – Medical College of Wisconsin
Paul Ivancic, Ph.D. – Yale University School of Medicine
Michael Kleinberger, Ph.D. – Johns Hopkins University
Jonathan Rupp, Ph.D. – University of Michigan

NASA Ames Research Center (ARC):
Immanuel Barshi, Ph.D.
Brent Butler, Ph.D.
Brian Gore, Ph.D.
Jessica Marquez, Ph.D.

NASA Johnson Space Center (JSC):
Erin Connell, Ph.D.
Kritina Holden, Ph.D.
Nate Newby, Sc.M.
Heather Paul
Jennifer Rochlis, Ph.D.
Mark Shelhamer, Sc.D.
Jeffrey Somers
Susan Steinberg, Ph.D.
Mihriban Whitmore, Ph.D.

NASA Headquarters (HQ):
Steve Davison, Ph.D.
Bruce Hather, Ph.D.

NASA Research and Education Support Services (NRESS):
Tiffin Ross-Shepard

VIII. 2015 Occupant Protection Risk Standing Review Roster

Panel Chair:

Frank Pintar, Ph.D.
Medical College of Wisconsin
VA Medical Center – Research 151
Department of Neurosurgery
5000 W. National Avenue
Milwaukee, WI 53295
Ph: 414-384-2000 x41534
Email: fpintar@mcw.edu

Panel Members:

Paul Ivancic, Ph.D.
Yale University School of Medicine
Department of Orthopaedics & Rehabilitation
P.O. Box 208071
New Haven, CT 06520-8071
Ph: 203-785-4052
Email: paul.ivancic@yale.edu

Michael Kleinberger, Ph.D.
US Army Research Laboratory
12124 Hidden Waters Way
Clarksville, MD 21029
Ph: 410-278-7979
Email: michael.kleinberger.civ@mail.mil

Jonathan Rupp, Ph.D.
University of Michigan
Transportation Research Institute
UMTRI
2901 Baxter Road
Ann Arbor, MI 48109-2150
Ph: 734-936-1112
Email: jrupp@umich.edu