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Development of the Operationally Relevant Injury Scale for Exploration ($ORIS_x$) to Identify High-Consequence Suited Injuries

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INTRODUCTION

The National Aeronautics and Space Administration (NASA) has a responsibility to adequately manage and mitigate the risk of crew injury during upcoming manned missions to the moon. It is a priority to return the crew back to Earth safely, but also to ensure a successful mission with the completion of all planned objectives. Throughout lunar missions, crewmembers will be scheduled to complete Extravehicular Activities (EVAs), which will require crewmembers to leave the lunar lander and complete tasks on the lunar surface while in an EVA suit. It is important that there is consideration of possible injuries that could occur during EVAs and their effect on crew health and mission success.

Based on data collected in prior missions in the U.S. spaceflight program, 0.26 injuries were reported per EVA. Hand injuries due to the EVA suit were the most commonly reported, followed by foot and shoulder injuries. A more focused analysis was also completed on injuries that occurred during the Apollo program, with a total of nine suited injuries reported during lunar EVAs. Five of the nine documented were hand injuries due to the EVA suit glove. Astronauts reported significant fatigue and soreness in their hands and fingers during and following EVAs. Other injuries were due to repetitive rubbing of suit components over the wrist joint, muscle fatigue during ambulation, and two acute events while using drilling equipment [1].

A new EVA suit is being developed, currently known as the Exploration Extravehicular Mobility Unit (xEMU). The intention of this suit is to allow crew to explore the lunar surface with more capability than seen previously with the Extravehicular Mobility Unit (EMU) suits used during the Apollo missions. Due to the desire for increased exploration ability and ease of movement, the xEMU allows for greater mobility and is specifically designed for microgravity and lunar surface operations. This includes a Hard Upper Torso (HUT) and a rear-entry hatch, with the rest of the suit being soft goods, and an Exploration Portable Life Support Subsystem (xPLSS). In designing the xEMU, potential injury mechanisms must be considered to ensure that the suit adequately mitigates injury risk to the crewmember.

It is important to quantify the severity of each possible suited injury for analysis. There are many terrestrial injury scales used to score injury severity. In the automotive industry, the Abbreviated Injury Scale (AIS) is widely used [2, 3]. The AIS measures injury severity based off of the survivability of an injury, but it does not address any operational impacts. The assumption is that in an automotive accident, the occupant will not have to perform any operational duties, and first responders will be able to treat the occupant. In a spaceflight setting, the crewmember may have to traverse back to the lunar lander to safety. Beyond survivability, an injury could cause mission impacts, such as unplanned EVA downtime or an emergency evacuation from the lunar surface. This warranted the creation of a new injury scale to address injury severity in the spaceflight environment.

An Operationally Relevant Injury Scale (ORIS) was previously developed to evaluate injuries resulting from launch, abort, and landing [4]. Based on this ORIS, a new scale was developed to assess suited injuries on the lunar surface, the Operationally Relevant Injury Scale for Exploration ($ORIS_x$). The $ORIS_x$ is intended to evaluate suited injuries such as those due to lunar landing, rover activities, EVA repetitive tasks, falls on the lunar surface, etc. The $ORIS_x$ scores individual injuries based on their survivability, mission impacts, and long-term impacts to give an overall consequence score between 0 and 4. The purpose of this report is to detail the development and rationale behind the $ORIS_x$ scoring system and methods that will be used for scoring individual injuries.

METHODS

The $ORIS_x$ was developed based off the previous ORIS for launch, abort, and landing. This ORIS addresses injury severity, self-egress ability, and return to flight status [4]. The scale was developed to address injuries that may occur during dynamic phases of flight that could affect egress ability and long-term health. The inability to self-egress could be life-threatening in an emergency situation. Return to flight status captures the long-term health consequences of an injury and scores the injury based on the time to return to duty.

Using the ORIS scoring system as a starting point, the $ORIS_x$ was adapted to address consequences in a lunar environment. New components were developed and vetted with the appropriate stakeholders to be finalized. Then, a medical conditions list was developed using the Lunar EVA Incapacitation Condition List and the IMPACT 1.0 Medical Conditions List (ICL 1.0). These lists were combined and refined to remove repeated conditions and conditions that were not injury or trauma related. Additionally, some injuries were added per subject matter expert (SME) opinion.

With a finalized conditions list, individual injuries will be scored. The well-documented AIS scoring system will determine the injury severity score. The other components will be scored using NASA flight surgeon expertise. After individual scoring is complete, final scores will be calculated and high-consequence injuries identified.

OPERATIONALLY RELEVANT INJURY SCALE FOR EXPLORATION

The new $ORIS_x$ was developed to evaluate an injury's severity on the lunar surface. It is intended to be used to identify high-consequence injuries that would adversely impact crew health and mission success. A main purpose of the $ORIS_x$ is to aid in the design process of the xEMU to prevent injuries. The $ORIS_x$ score consists of three sub-components.

Injury Severity (IS)

The injury severity score measures the survivability of an injury. This will be scored using the AIS, a widely used and accepted evidence-based scoring system developed for the automotive industry [1, 2]. The traditional AIS has a maximum score of 6, while the $ORIS_x$ has a maximum score of 4. The severity scores of 5 and 6 are included in the $ORIS_x$ score of 4. It is assumed that in this environment a score of 4 will potentially be life-threatening and require evacuation when considering lack of treatment available on the lunar surface. This severity of an injury should never occur and will require strong, thorough mitigations for prevention. A score of 0 was also added to indicate no injury, which is not included in the AIS.

Mission Operation Capability (MOC)

The mission operation capability (MOC) score measures the functional impacts of an injury. Because this is designed to evaluate consequences during lunar missions, functional impacts are measured based on EVA capability and EVA downtime. The capability score assesses the ability of the crewmember to complete an EVA and to what extent. The downtime score assesses how much unplanned downtime a crewmember would need to recover from the injury on the lunar surface before another EVA can be completed at full capacity. These two scores were implemented as an 'and/or' measure for functional impacts, with the highest scoring used as the overall MOC score. In other words, ff an injury would receive different scores for EVA capability and EVA downtime, the highest score will be chosen for the overall MOC score to remain conservative. Scoring for the MOC score, for any particular injury, will be decided with flight surgeon expertise.

Long-Term Health Consequence (LTC)

This score measures the long-term health consequences of an injury. This largely addresses post-mission consequences, assessing quality of life post-mission and ability to return to duty. Scoring for the long-term health consequence (LTC) score will be decided with flight surgeon expertise.

Table 1. Operationally relevant injury scale for exploration scoring system for suited injury.

Score	Injury Severity (IS)	Mission Operations Capability (MOC) *EVA capability & downtime*	Long-Term Health Consequence (LTC)
0	None*	No impact	No recovery time
1	Minor	Minor reduction of EVA task performance or short delay in return (≤ 1.5 days)	Short recovery time (<3 month)
2	Moderate	Major reduction of EVA task performance or intermediate delay in return (≤ 1 week)	Intermediate recovery time (< 1 year)
3	Serious	Unable to perform some EVA tasks, may require assistance to return to lander or long delay in return (≤ 1 month)	Long recovery time (>1 year)
4	Severe	Unable to complete EVA, requires rescue or will not return (> 1 month)	Never fully recover/DQ'd from future missions

*not included in AIS definition

ORIS$_x$ Score Calculation

The three components of the ORIS$_x$ score are combined using Equation 1 to determine an overall score. The final score is rounded up to make the scale more conservative.

Equation 1. ORIS$_x$ score calculation

$$Score = \sqrt{0.25 * (IS)^2 + 0.5 * (MOC)^2 + 0.25 * (LTC)^2}$$

Weighting factors are used to weight the importance of the component to the overall score; these weighting factors were designed to sum to 1. MOC was given the highest weighting, 50% of the overall score, because in the case of lunar missions, functional impacts are considered to be of highest importance. Mission success requires EVAs and other operations to be completed. Many injuries that are not terrestrially considered severe could greatly impact EVA operations, therefore making this a conservative measure. IS and LTC are both weighted as 25% of the overall score.

A score of 0 indicates no injury. A score greater than 0 and less than or equal to 1 is a Class I injury; a Class II injury is a score greater than 1 and less than or equal to 2; a score greater than 2 and less than or equal to 3 is a Class III injury; and a score greater than 3 is a Class IV injury. For simplicity of use, each class was generalized and defined as follows: Class 0 is no injury; Class I is a minor injury that may cause a minor reduction of EVA task performance with a short recovery time; Class II is a moderate injury that may cause a major reduction of EVA task performance with an intermediate recovery time; Class III is a serious injury that may leave a crewmember unable to perform some EVA tasks and a requires a long recovery time; and Class

IV is a severe injury that may leave a crewmember unable to complete an EVA and possibly never fully recover.

ASSUMPTIONS AND LIMITATIONS

It is important to note that this scale is not intended for operational use or to decide treatment real-time, but to assess the design of the xEMU and concept of operations to ensure the appropriate mitigation of crew injury. Only injuries due to dynamic events (i.e. lunar landing, falls, etc.) and the expected suited operations (i.e. EVA tasks, rover use, etc.) are considered in this analysis. Other sources of injury not related to the suit, including burns, inhalations, etc., must be addressed elsewhere.

In the scoring of injuries, it is assumed minimal treatment would be available on the lunar surface. For most injuries, only treatment of symptoms would be available with pain medication, where the source of the problem may not be able to be addressed. In the scoring of MOC, injuries will be considered as untreated to define recovery times. LTC recovery times are scored based on terrestrial availability of treatment.

The AIS scoring system is used to score the IS of each injury. This system is widely accepted and based on terrestrial severity of injuries. There are some limitations using this to assess survivability of injuries on the lunar surface. On the lunar surface, limited treatment will be available which may decrease the survivability of certain severe injuries. Even in an emergency evacuation, a crewmember may be days away from adequate treatment. It is assumed that these limitations are addressed by the addition of the more conservative and higher weighted MOC score.

CONCLUSION

The $ORIS_x$ was developed to define consequence scores of suited injuries that could occur during future lunar missions. High-consequence cases will be identified using this new scale. The development of the $ORIS_x$ is only one step towards ensuring the xEMU adequately mitigates injury to the crew. Forward work includes defining the likelihood of each injury to occur on the lunar surface and identifying driving injury cases. Once driving cases are identified, they can be individually assessed, and the appropriate mitigation steps can be taken for each injury.

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