ORION SPACE CRAFT WATER AND LAND LANDING SYSTEM SIMULATION; AN INJURY CASE STUDY

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Abstract

NASA's return to moon program had kept the NESC (NASA Engineering and Safety Center) busy for the past several years. The NESC was charged to come up with a safe landing for the Orion capsule. Water and land landing is considered for the Orion capsule. The NESC took major initiative to come up with recommendation to the program. Part of this initiative is to come up with Injury criteria recommendation during the landing of the Orion capsule. Impact simulation is used to assess the injury and pulse responses of the Orion during landing. Major tasks were under taken to validate the steps of the impact simulations. The models used in water landing, soil landing, and the finite element dummies were validated through experimental testing. In here some of the validation is presented. The paper finally compares the injury values of the astronauts during water and land landing.

Introduction

During the landing of the Orion crew vehicle on hard surfaces, significant impulse loads could be transmitted to the astronauts through the vehicle-occupant interfaces such as the floor and seat. If these loads are not attenuated to survivable levels, they could lead severe injuries or fatality of the occupants. Simple seat structures are not sufficient to protect the occupant against hard landing, and thus further protective techniques need to be investigated.

The original recommendation was for water landings with parachutes and retro rockets. Once landing systems were validated, transitions to land landing. Residual landing velocities and requirement for vehicle re-usability led to need for crushable material on bottom of vehicle. Retro rockets and crushable material is less efficient design than deployable airbags for land landings. Vehicle weight exceeded launch vehicle capacity so all landing systems removed and water landing set as baseline. However the vehicle design must meet crew safety requirements for contingency land landing (Figure 1).

The parachutes lower landing velocity to under 30 fps and provide primary mode of crew protection. Water, and to a certain extent land, provide landing load attenuation. Crushable structure between heat shield and vehicle were added to provide further crew protection and vehicle reusability. Crew seat pallet struts were also added to provide stroking for extreme off-nominal load cases. Crew seats, helmets, suits, and harnesses provide additional layer of final crew protection.

Figure (1) water and land landing

In here the water and land landing is evaluated through the explicit dynamic finite element system simulation using LSDYNA. The Orion finite element model is considered with six astronauts placed in their seats for the impact simulations. The LSDYNA dummy models are used in the simulations. In order to determine the effectiveness of the finite element models a validation is performed using test data. A

set of experiments are conducted at the Wright-Patterson Air Force Base in Dayton Ohio. These tests are used to validate the finite element crash test dummy models. Occupant crash data such as forces, moments and accelerations are collected from simulations and then compared to these injury criteria to assess Occupant Survivability and Human Injury.

Models Validation

Before accepting the results of any simulation validation of the finite element model is necessary. In the case of a system simulation which can cost significant amount of money and effort, components validation is necessary. In the Orion system simulation there exist several sub-models that need validation. Of the major concern is the water landing model, the soil landing model, and the dummy model used in the system simulation. The validation of the LSDYNA model of the system in whole is very costly and next to impossible considering human astronauts. However an effort can be under taken to validate components of the simulation and reduce the potential deviation of the system simulation from the real behavior. In the subsequent sections some of the data used to validate the components is presented.

Water Landing Validation

The LSDYNA code can perform water impact simulation with good accuracy. However, it needs to be validated for Orion water landing system simulation. There exists some data from the Apollo program of one fourth scale model impacted into water. Some acceleration data and some pressure data were taken at that time when it was tested. A finite element model of the one fourth scale Apollo capsule is developed for the water impact validation. Figure (2) depicts the finite element simulation with one of the landing cases validated. Table (1) summaries the predication of the finite element model and one of the tests conducted. Reasonable prediction is obtained and the water landing is validated.
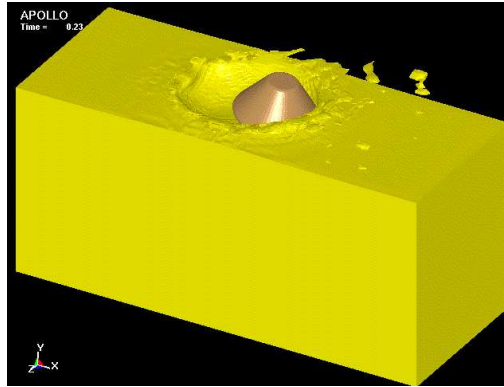
Figure (2) ¼ Scale Apollo Water Impact @ 11 degrees

Table (1) Water Landing Validation

Data	Lateral acceleration	Vertical acceleration	Resultant acceleration	Local lateral	Local vertical	Pressure
Experimental				7.1 g's	36.8 g's	586.0e3 N/m^2
Coarse mesh	3.3 g's	42.8 g's	42.85 g's	8.1 g's	42.0 g's	
Fine mesh	2.1 g's	38.7 g's	38.76 g's	7.4 g's	38.04 g's	
Pressure	Obtained	from	DBFSI	File		504.0e3 N/m^2

Soil Validation

Several tests were conducted by NASA on the soil in the potential landing sites. The tests were conducted at several locations in the site and at different seasons. Different moisture content are considered to cover different soils ranging from muddy sift soil to dry hard soil. One of the tests conducted is the half sphere drop tests shown in Figure (3). In here one of the test cases that is conducted during the month of August is considered for the validation. This test case is a representative of dry hard soil. Figure (4) shows the LSDYNA predication versus test. Good correlation between the material

model used in LSDYNA and test is obtained.

Figure (3) Soil Testing in The Potential Landing site
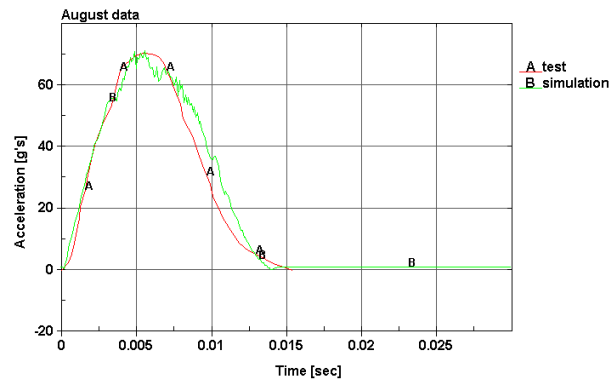
Figure (4) Soil Drop Test Validation

Dummy Validation

Major sets of experiments are conducted at Wright-Patterson Air Force Base (WPAFB) in Dayton, Ohio. These tests consisted of a belted Hybrid III dummy in several configurations and various pulses. The tests consisted of 10-20 g's in the +x-direction, -x-direction, y-lateral-direction, and the z-spinal-direction. The tests also considered for various rise-to-peak duration. Three tests are conducted for each case to show

repeatability. In addition, the Hybrid III dummy is clothed in a proposed astronaut suit and tested in several configurations as shown in Figure (5). In the present paper only one of the tests is considered for validation and data extraction. The considered test is the 10 g's pulse in the +x-direction. Figure (6) depicts the head acceleration of the three repeated tests and the prediction of the simulation. Good validation is obtained in this case as well.

Figure (5) One of The Tests Conducted at The WPAFB Facilities
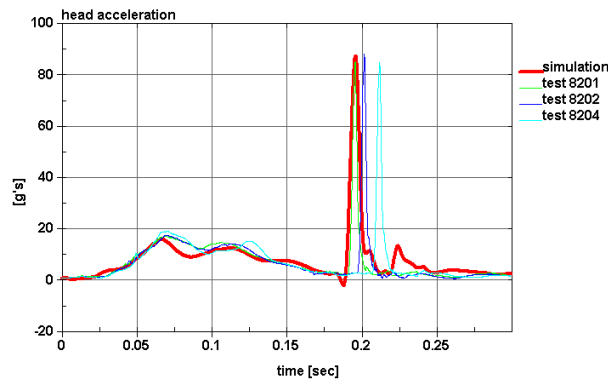
Figure (6) Head Acceleration From The 3 repeated Test and Simulation

System Simulations

The finite element model of the Orion with the seats and six dummies is developed and simulated. Figure (7) shows the water and soil landing model with the six restrained astronauts in position in their seats. The six astronauts are numbered as shown in the figure. The two models are considered for the equal lading conditions. The landing conditions consists of the following velocities: Vx=429.9, Vz=-552.00 [in/sec]. The Orion landing orientation considered is as follows: Pitch=20.0, Yaw=-4.1, Roll=30.0 degrees. The initial orientation of the water landing and land landing and the final orientation of the Orion is shown in Figure (8) at time 160 ms. One can observe that even though the initial orientation and landing condition is the same, the final orientation of the capsule is totally different. Figure (9) depicts the water lading situation. Injury numbers are extracted for the two cases and compared.
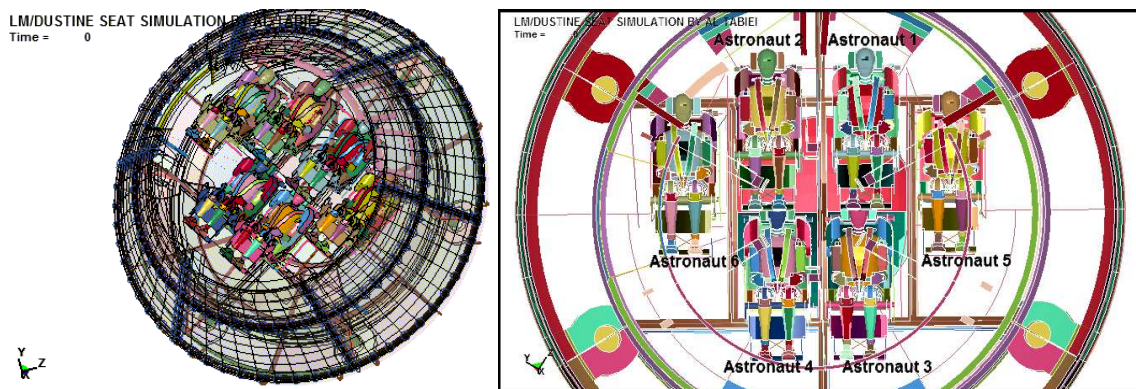
Figure (7) The Orion System Finite Element Model
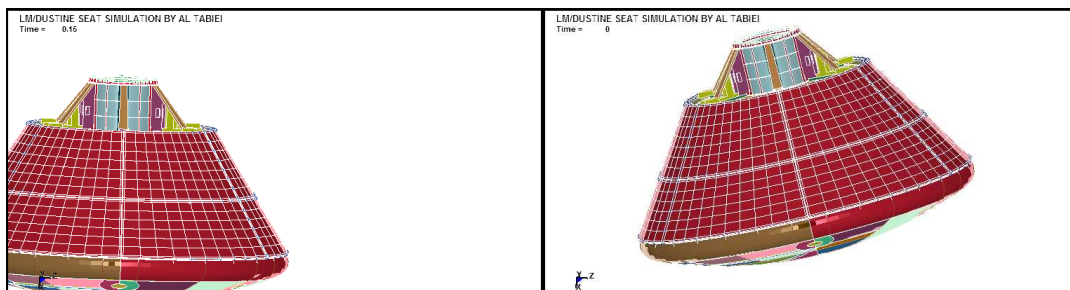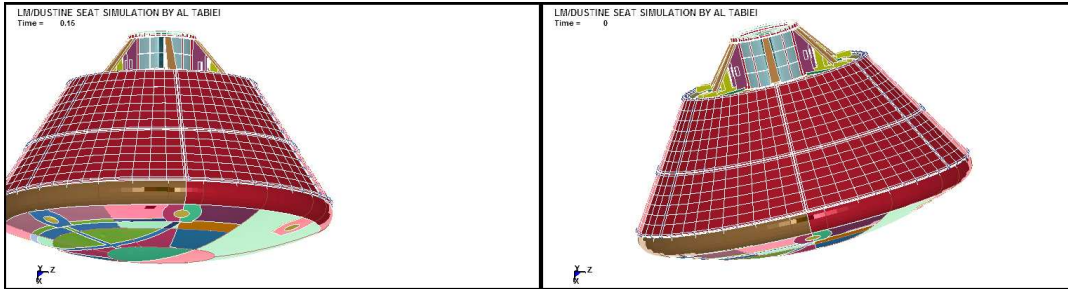
Figure (8) Orion Initial and Subsequent Orientation During Water Landing (Top) and Land Landing (bottom)
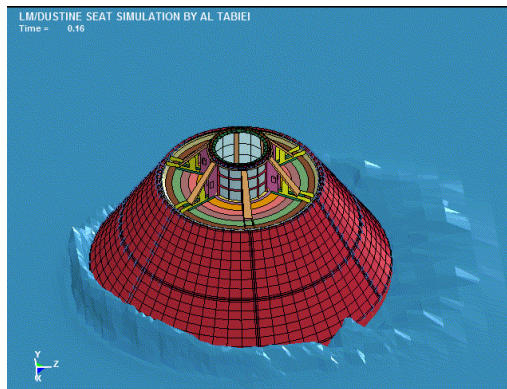
Figure (9) Water Landing System Simulation

Injury Criteria (txt taken from the NASA report, please modify as you think is fit)

The core of the occupant protection criteria is based on the Brinkley Dynamic Response Index (DRI) model. This model has been and is currently used by NASA and the military to determine the risk of injury or adverse physiological response to vehicle occupants based on seat acceleration. While this model is useful for generating an overall estimate of the probability of injury, the model has limitations. The model assumes a basic seat geometry, restraint, and head protection and is therefore only an approximation for other seat designs and protection systems. Furthermore, the model cannot be used to predict risk when improvements are made to the seated environment. Risk can only be lowered by reducing the driving loads into the seat.

To complement the Brinkley DRI, additional injury criteria, specific to the head, neck and legs have been incorporated into the Human System Interface Requirements (HSIR).

These injury criteria were developed primarily for the automotive industry and are regularly used to insure automotive safety. The injury criteria used by the automotive industry are designed for automobile accidents and considerably higher allowable probability of injuries than are acceptable for NASA and manned vehicle landings so judgment was used to extrapolate the criteria for use for manned space flight. The criteria provide more understanding of the location and type of occupant injury and the effect of seating conditions and occupant protection and when used in conjunction with the Brinkley DRI provide a more complete assessment of occupant protection. In here some of the Injury criteria adopted by the HSRI is presented and compared for the two landing situations.

Comparison

The two system simulations are carried out with LSDYNA version 971-R4. The water landing simulation was much more CPU intensive than the land landing because of the fluid structure interaction algorithm. The two simulations are post processed to obtain the injury parameters and compared to each other. Figure (10) depicts the positions and movements of the dummies at time 160 ms for both the water landing and land landing cases. Once can observe that the land landing case yield higher movements in the dummies. The injury values and compared graphically for all six astronauts. However, for the purpose of peak value comparison only two injury parameters are presented. Tables (2) and (3) show the Head Injury Criterion (HIC) and the neck x-force for the sin astronauts during land and water landing. The following injury parameters are extracted and compared for all six astronauts; Head acceleration, chest acceleration, chest deflection, pelvis acceleration, all neck forces, and all lumbar forces. Figures (11)-(19) depicts all these injury parameters during the water and land landing event.

LM/DUSTINE SEAT SIMULATION BY AL TABIEI
Time = 0.16
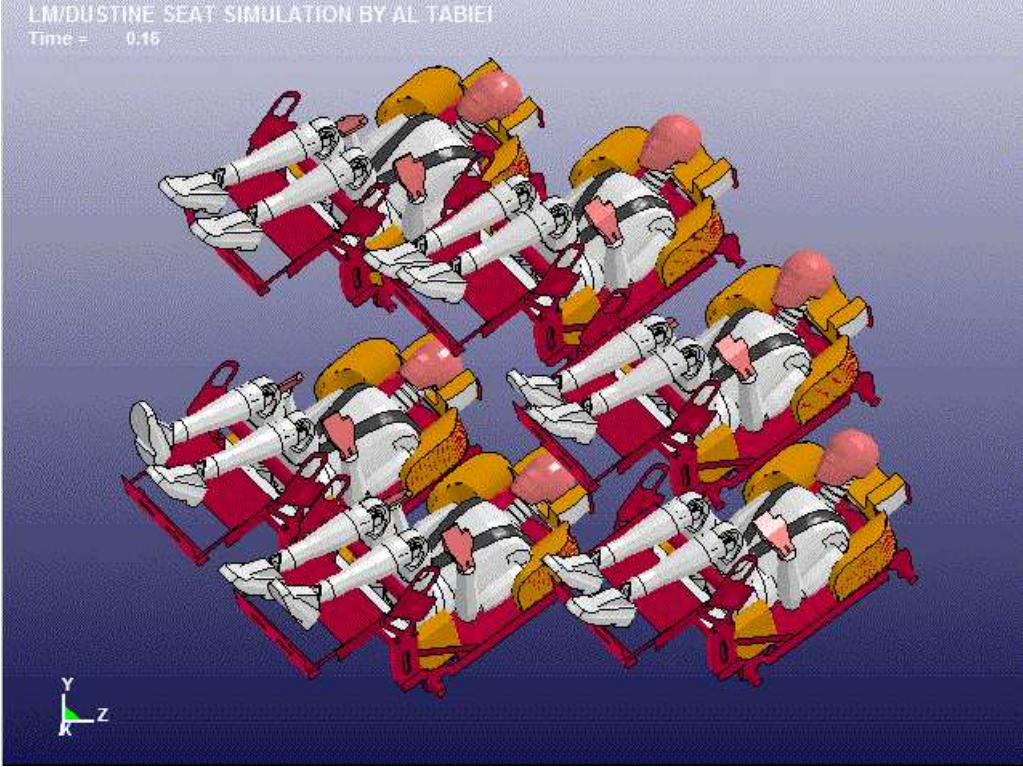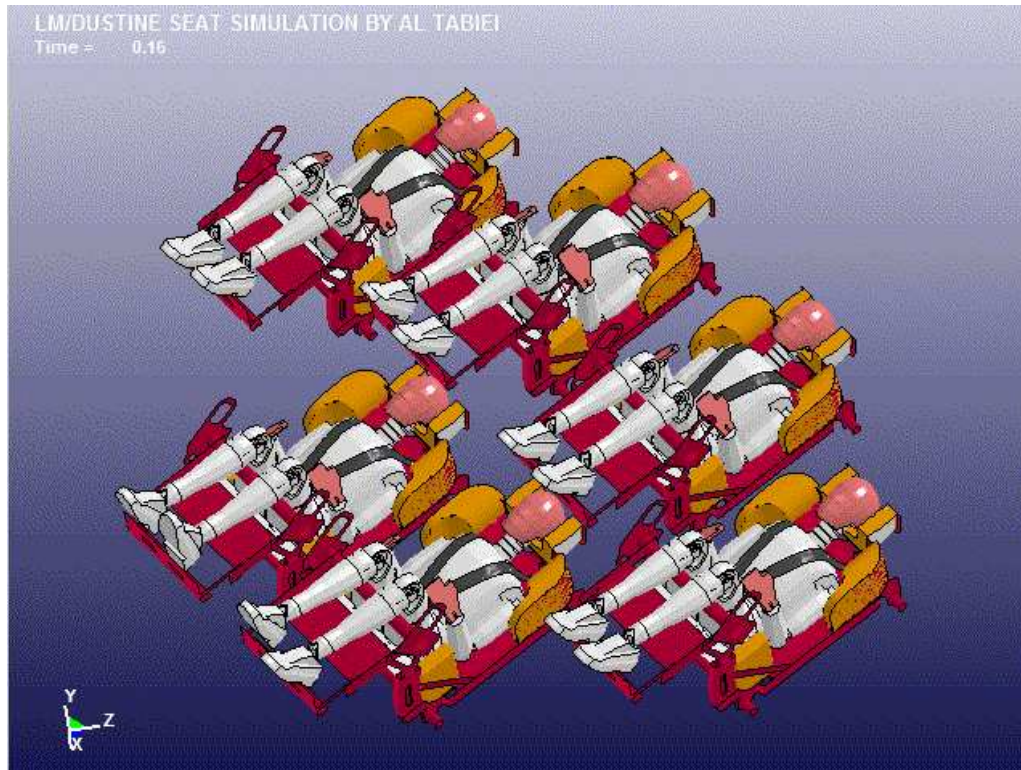
Figure (10) Comparison of The Dummies Behavior During Water (bottom) and Land (top) Landing at 160 ms.

Conclusion

The impact simulation is used to assess the injury and pulse responses of the Orion during landing. Both water and land landing is considered. Major tasks were under taken to validate the steps of the Orion impact system simulations. The models used in water landing, soil landing, and the finite element dummies were validated through experimental testing. In here some of the validation is presented. The paper finally compares the injury values of the astronauts during water and land landing. As expected the land landing situation leads to a much higher injury values in almost all injury criteria. These simulations provide the level of accelerations, forces, and moment differences between the land and water landing.

References

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2. Lawrence, Charles; Littell, Justin D.; Fasanella, Edwin L.; Tabiei, Ala, "Orion Crew Member Injury Predictions during Land and Water Landings", NASA/TM-2008-215171, 2008.
3. Lawrence, Charles; Fasanella, Edwin L.; Tabiei, Ala; Brinkley, James W.; Shemwell, David , "The Use of a Vehicle Acceleration Exposure Limit Model and a Finite Element Crash Test Dummy Model to Evaluate the Risk of Injuries During Orion Crew Module Landings", NASA/TM-2008-215198, 2008.

Disclaimer

The results presented herein are the views and analysis performed by the authors. All data are solely the opinions of the authors and in no way represent the views and policies taken by NASA.

Table (2) Head Injury Data Comparison For The six Astronauts Positions During Water and Land Landing

Astronaut	Water landing (HIC)	Soil landing (HIC)
#1	15	294
#2	42	282
#3	47	85
#4	55	65
#5	50	223
#6	47	174

Table (3) Neck Injury Data [lb] Comparison For The six Astronauts Positions During Water and Land Landing

Astronaut #	Neck Force Parameters	Water landing	Soil landing
1	Peak Neck Lateral (± Fx)	59	120
2	Peak Neck Lateral (± Fx)	74	105
3	Peak Neck Lateral (± Fx)	96	117
4	Peak Neck Lateral (± Fx)	100	97
5	Peak Neck Lateral (± Fx)	76	115
6	Peak Neck Lateral (± Fx))	98	98
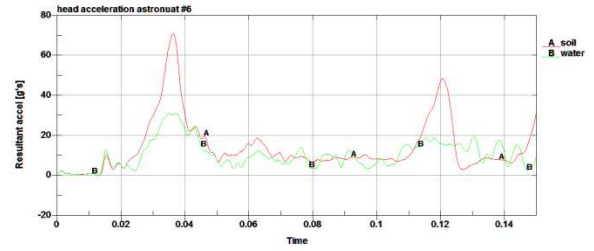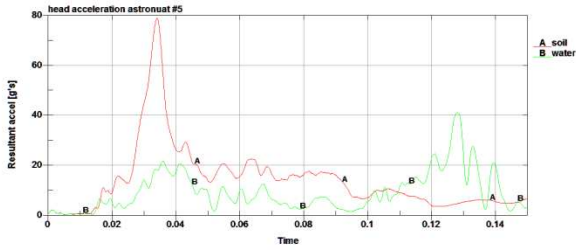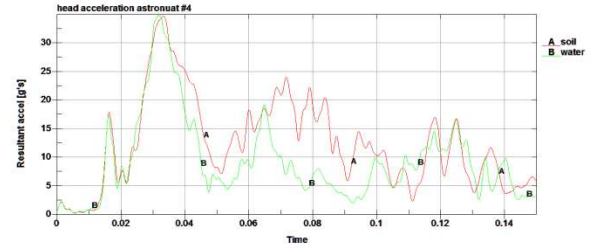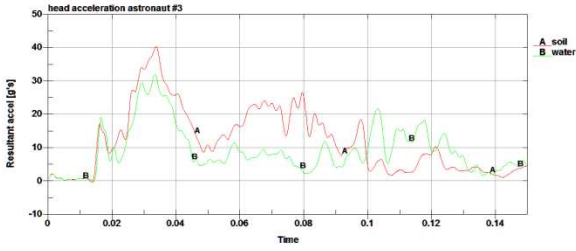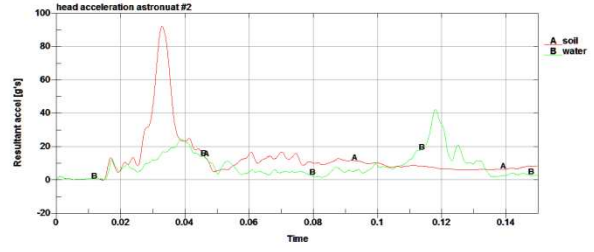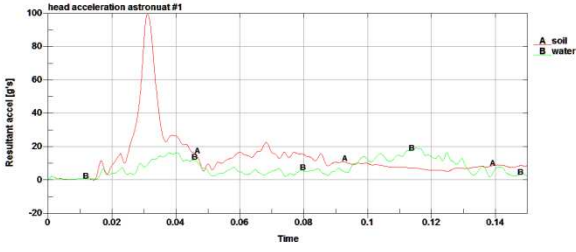
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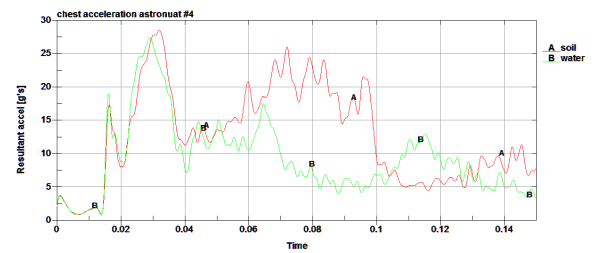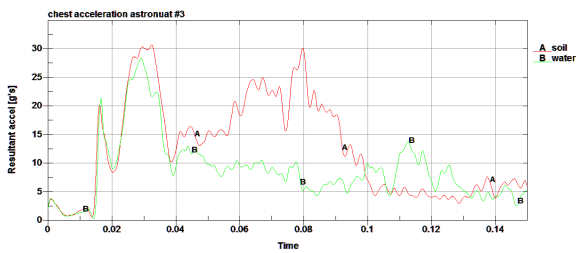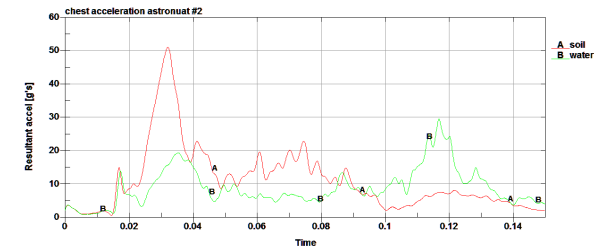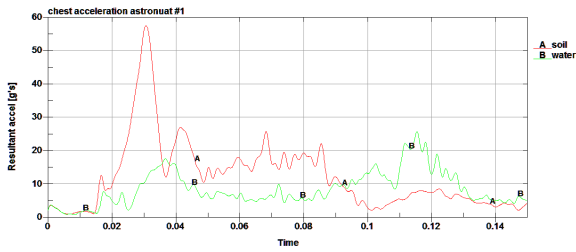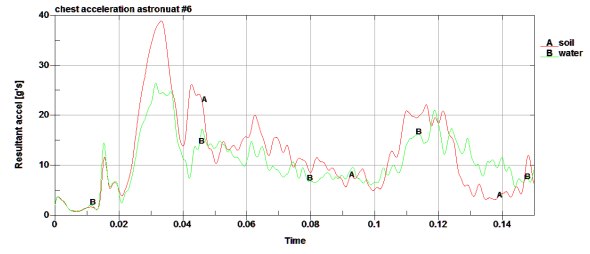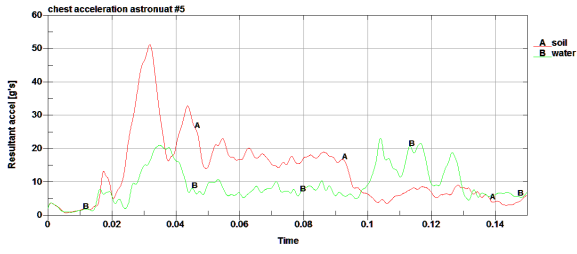
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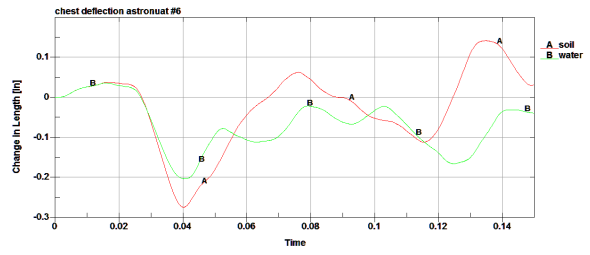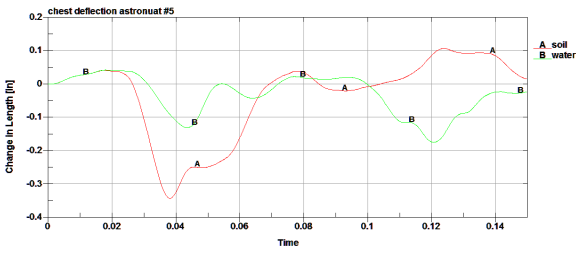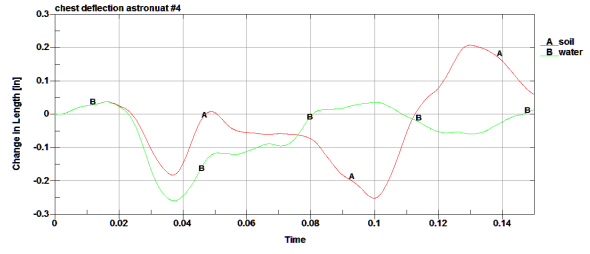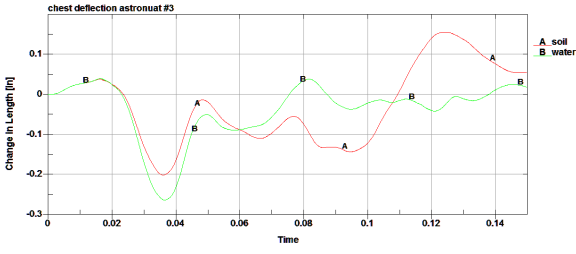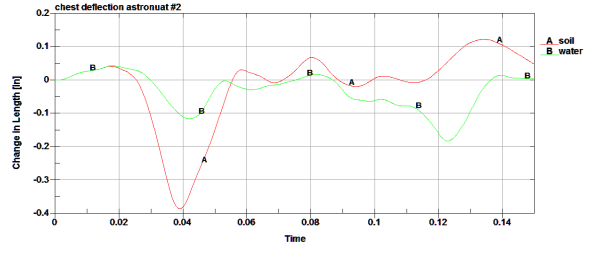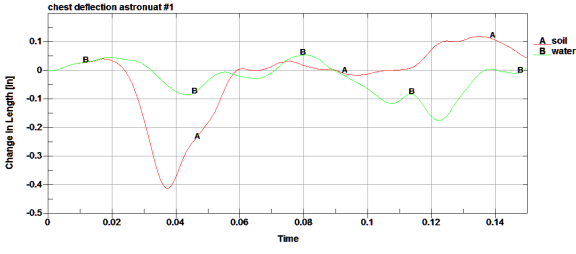
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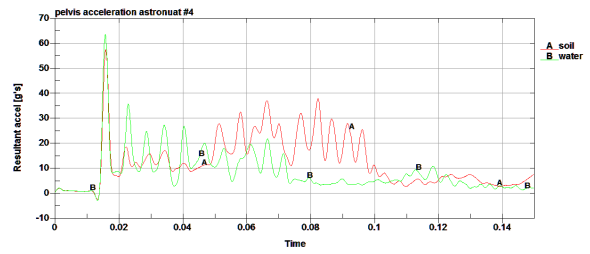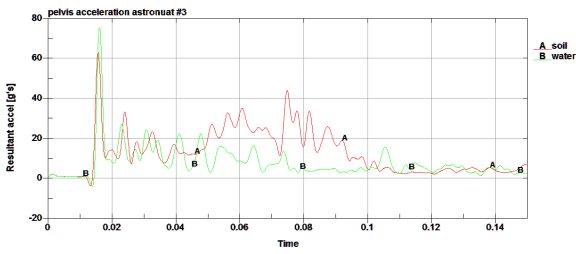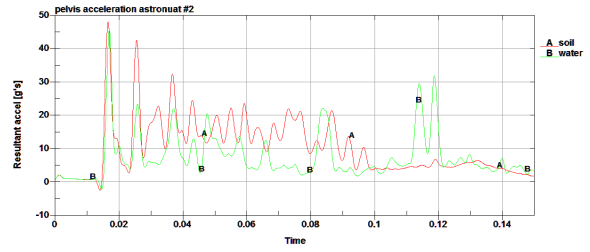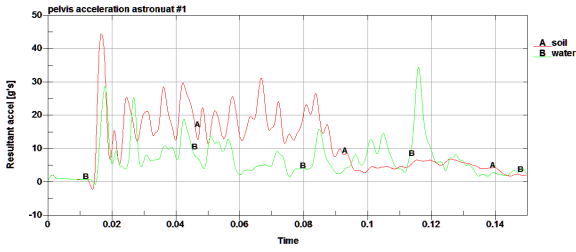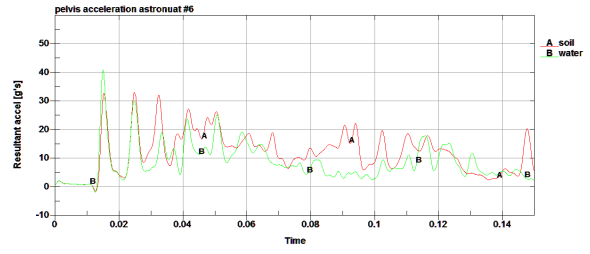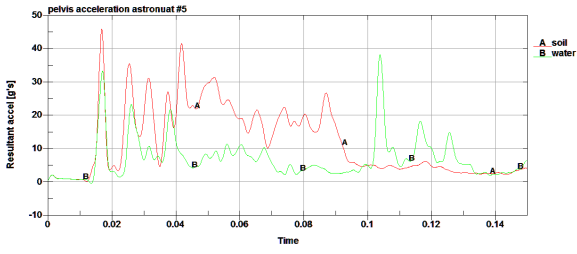
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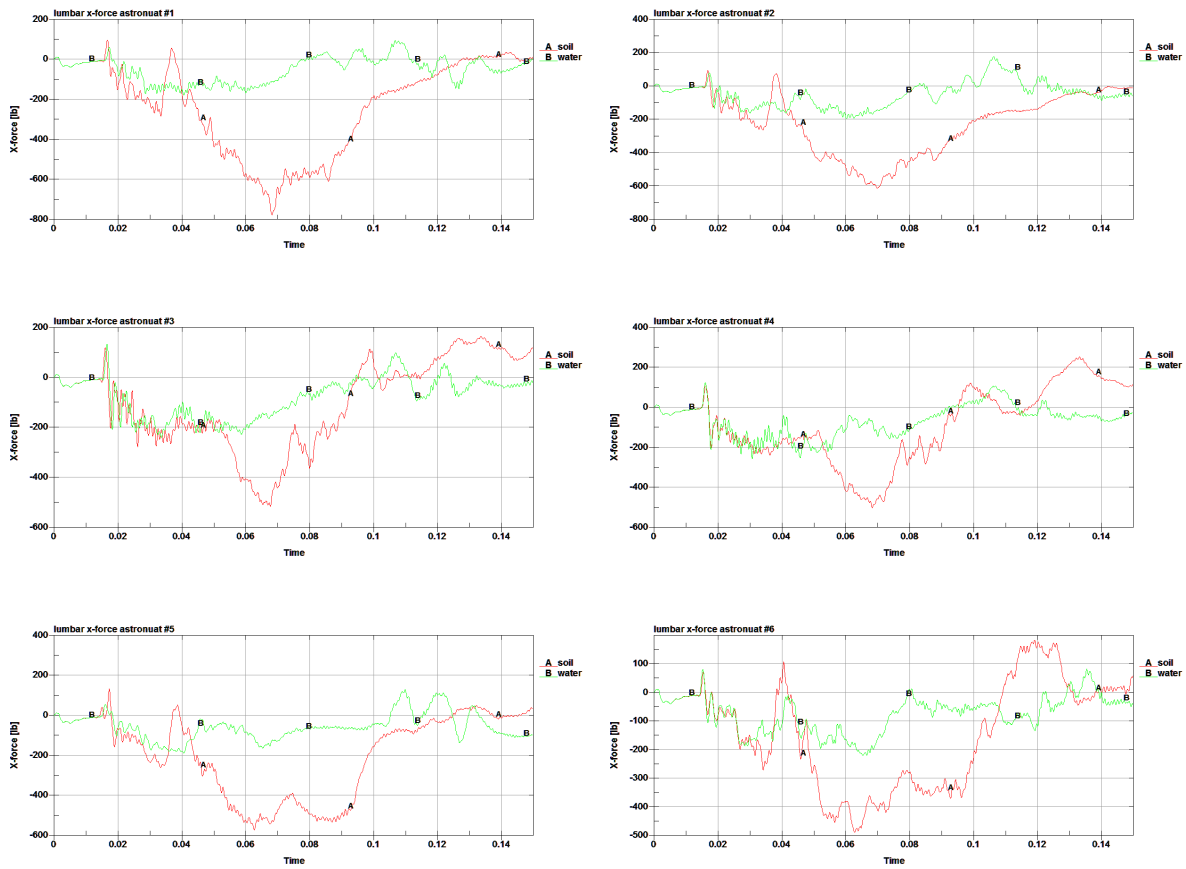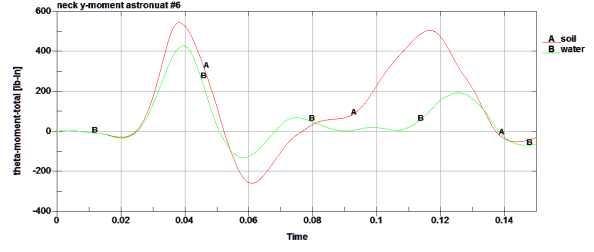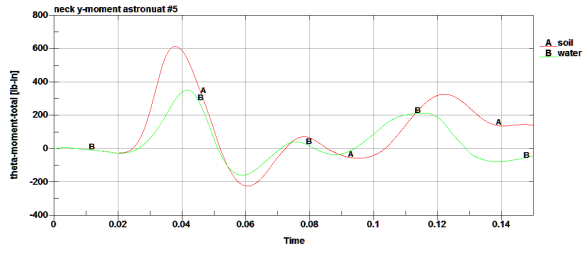
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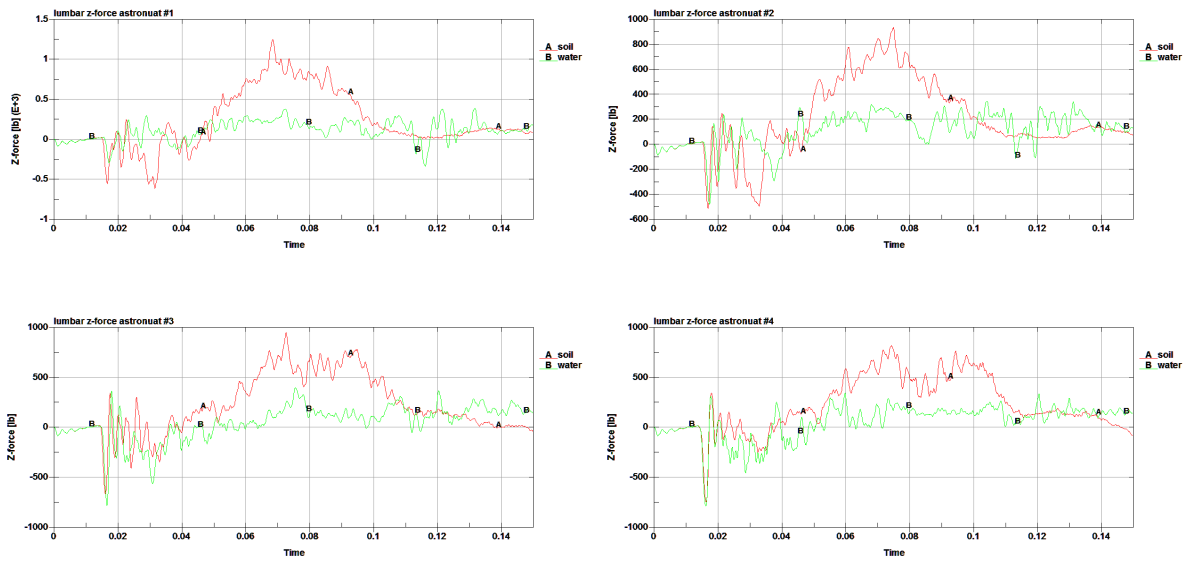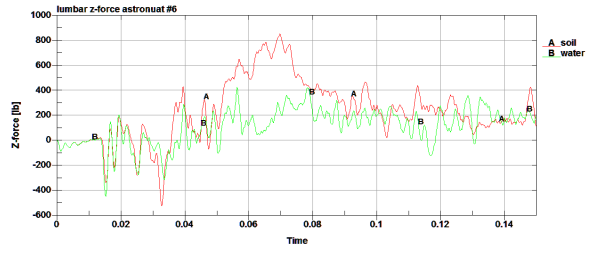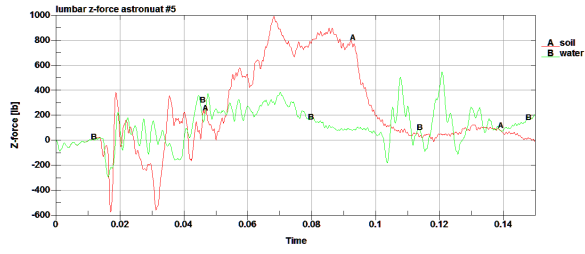
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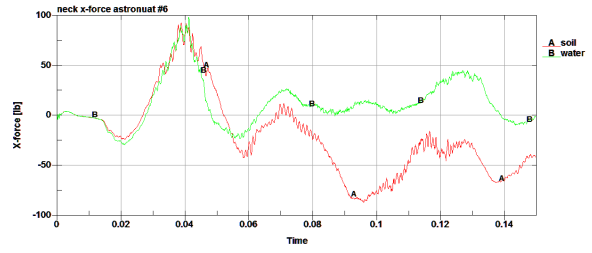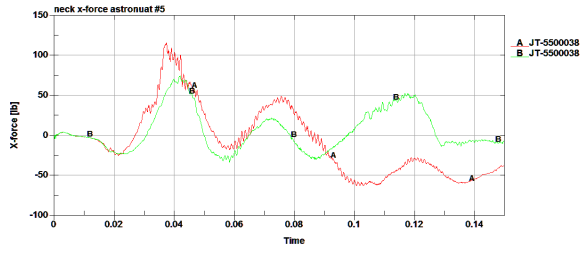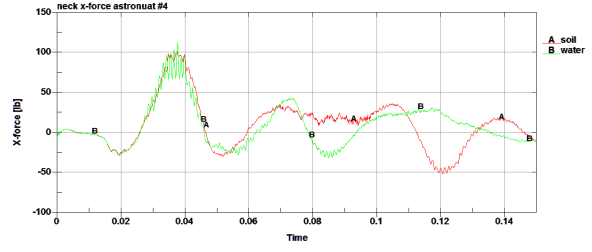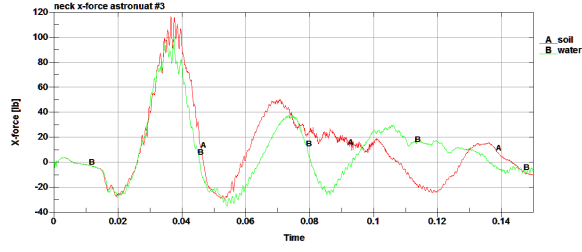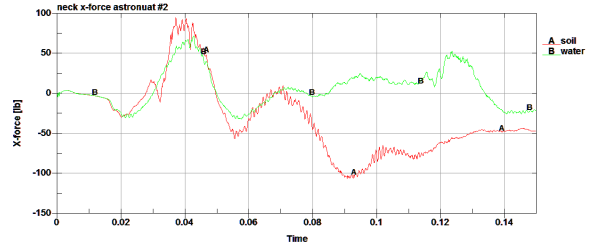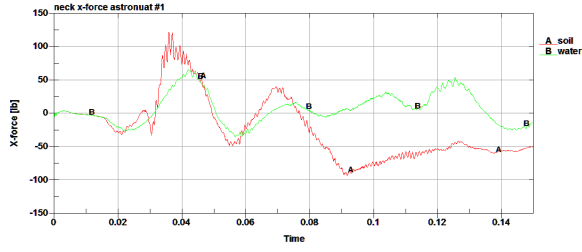
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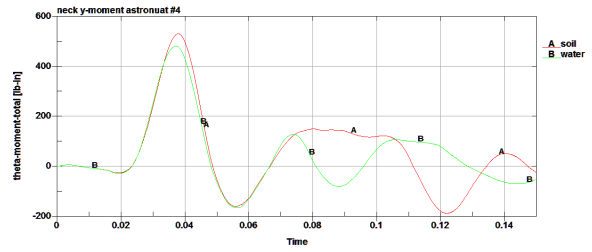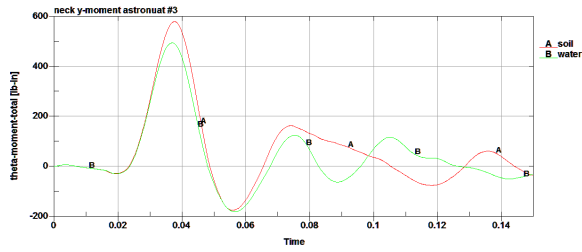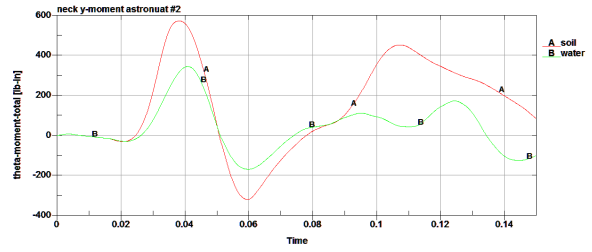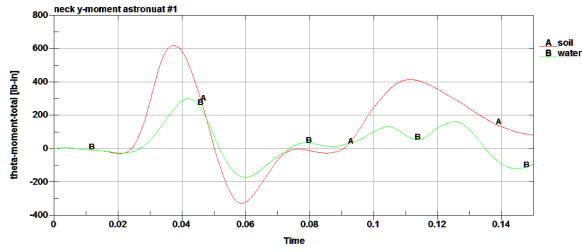
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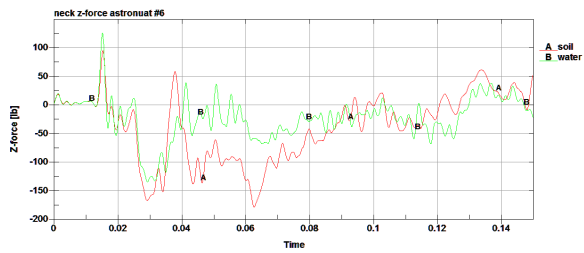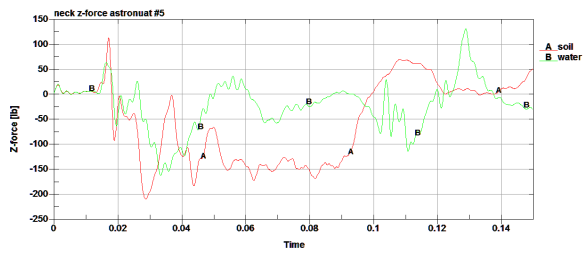Figure (19) Neck z-force