Investigation into the Injury Severity of Unmanned Aerial System (UAS) Impacts on Non-Participating Public

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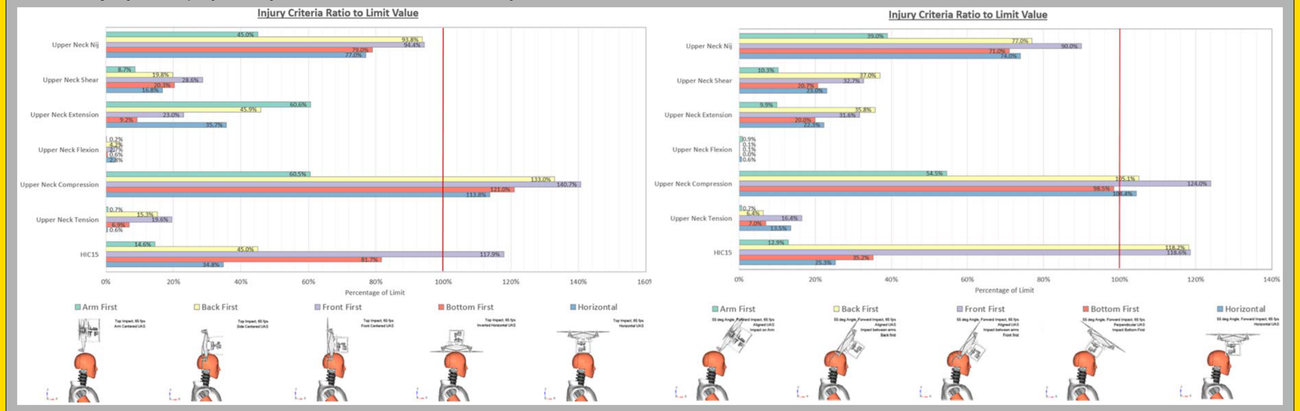
A series of injury criteria were collected for automotive and aviation industry regulation at the beginning of virtual & physical ATD testing. These focused on head & neck injuries and were used to assess injury potential of impact variations. Impact speeds and orientations possible for the sUAS in an impact event were varied in virtual testing of ATD impacts. These variations identified the injury severity at different speeds and helped to identify the worst case orientations. Variations on how the sUAS could impact from the top, side, forward, side, back, and angled directions were virtually tested. Impact speeds ranged from 10 to 71 ft/s. Physical testing of the H-III took the most critical orientations identified for each impact direction and tested the full speed range to confirm injury severity.

These critical cases and range of speeds were then also virtually tested with the THUMS HBM. Additional injury criteria were used to further evaluate skull fracture and head injury in general. Specifically, these criteria examined injuries for AIS1+ concussion, 30% chance of an AIS2+ skull fracture, and 30% chance of an AIS3+ head & neck injury. With the more biofidelic FE model, properties like skull bone strain could also be evaluated and compared to literature for fracture limits. These simulations identified which of the critical cases for the ATD were critical for the HBM.

Finally, physical PMHS testing was conducted at the Injury Biomechanics Research Lab at OSU. A similarly wide range of impact speeds & orientations were planned for PMHS testing and a subject would no longer be useful for testing if too high of injuries were sustained. This is where the virtual & physical ATD and THUMS data became useful in helping to sequence the PMHS tests. A tetrahedron accelerometer package was used to obtain head c.g. acceleration and strain gages were placed at key locations around the skull to identify peaks in strain rate when a bone fracture occurred. The PMHS were x-ray scanned and examined by necropsy after a severe injury was physically observed or indicated by the sensors.

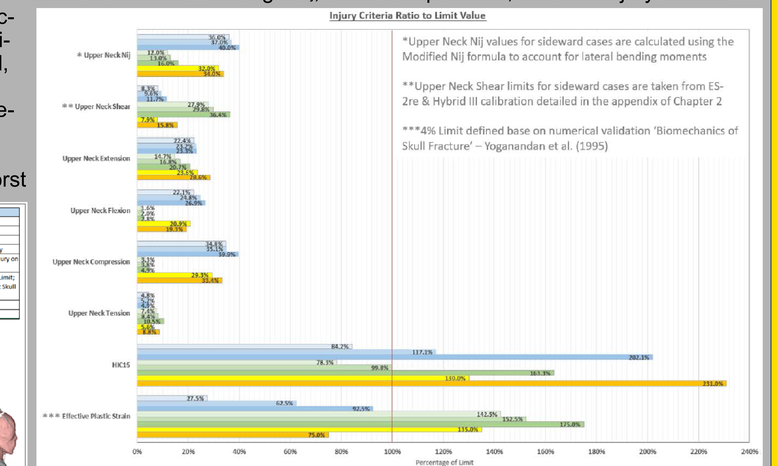


Results & Discussion

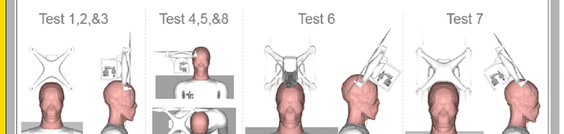
The sUAS to ATD simulations showed that the “front first” orientation resulted in the highest injury potential for most impact simulations. They also gave insight into possible injury mechanisms of concern. The high N_{ij}, Neck Compression, and HIC injury criteria scores indicated possible skull and vertebral bone fractures. The critical case was identified as the sUAS oriented front first, coming in at a 58° from the horizontal, and impacting the frontal bone region. Injury criteria started surpassing thresholds at the 65ft/s speed increment. These results were confirmed by physical ATD testing.

THUMS simulations gave similar predications of worst case orientation. The additional injury criteria and skull strain evaluation showed a high probability of skull fracture for the front first, angled forward impact. There were some high strains and fracture potential also noted for the front first, 0° to side of head, impact. However, the specific modeling method of the ear structure for the THUMS was considered to be unrealistically enduring this fracture.

With the virtual & physical ATD data and THUMS simulations, the PMHS tests were ordered. Severe injury to a subject was avoided before the cases which predicted fracture were tested. For the front first, angled forward, 71 ft/s impact, the PMHS suffered a hairline fracture along the frontal bone. This was confirmed though necropsy and validated the previous simulation efforts.



Test	PMHS	Aircraft	Impact Orientation with Respect to Head	Aircraft Impact Orientation	Impact Velocity/KE	Remark
1	#1	DJI Phantom 3 (2.69 lbs)	Vertical to top of Head	Forward - Impact Point Between Arms	55 ft/s (124 ft-lb)	
2	#1	DJI Phantom 3 (2.69 lbs)	Vertical to top of Head	Forward - Impact Point Between Arms	61 ft/s (150 ft-lb)	
3	#1	DJI Phantom 3 (2.69 lbs)	Vertical to top of Head	Forward - Impact Point Between Arms	71 ft/s (200 ft-lb)	
4	#1	DJI Phantom 3 (2.69 lbs)	Horizontal to Side of Head	Forward - Impact Point Between Arms	58 ft/s (124 ft/s)	Assess neck injury
5	#1	DJI Phantom 3 (2.69 lbs)	Horizontal to Side of Head	Forward - Impact Point Between Arms	61 ft/s (150 ft-lb)	Only complete if no injury on previous test
6	#2	DJI Phantom 3 (2.69 lbs)	58 Deg to Front of Skull	Forward - Impact Point Between Arms	61 ft/s (150 ft-lb)	Above Skull Fracture Limit; Objective is to Bracket Skull Fracture Limit
7	#2	DJI Phantom 3 (2.69 lbs)	58 Deg to Rear of Skull	Forward - Impact Point Between Arms	71 ft/s (200 ft-lb)	
8	#2	DJI Phantom 3 (2.69 lbs)	Horizontal to Side of Head	Forward - Impact Point Between Arms	71 ft/s (200 ft-lb)	



Introduction

With the expanding use of many small UAS, the possibility for impacts onto non-participating public becomes more likely. The FAA center of excellence sought to understand the injury potential from these impacts.

Physical testing with post mortem human subjects (PMHS) was desired for final testing. However, there were a limited number of subjects available. Virtual finite element (FE) simulations with a human body model (HBM) were used to estimate injury potential and determine worst case impacts, as to inform physical PMHS testing. Physical & virtual H-III ATD testing was also completed to inform PMHS testing, as well as to establish a common test method for sUAS of the future. The ATD would also allow for assessing a wider range of injury criteria throughout the head & neck.

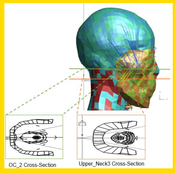
Code	Material
	Polycarbonate
	Nylon
	Cast Aluminum 520-F
	Steel 4030
	G-10 Fiberglass (PCB)
	Li-Po Battery Cell
	Aluminum Film 1145-O

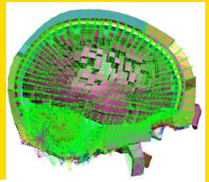
One of the vehicles chosen was the DJI Phantom III, for its high percentage of the sUAS market share. NIAR reverse engineered the Phantom III to created a virtual FE model.

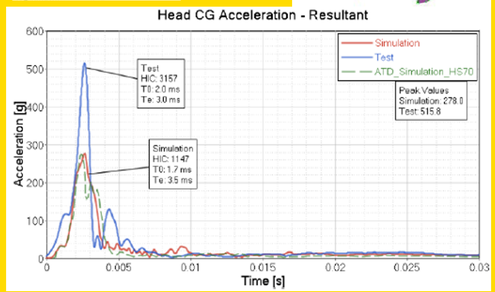
Each sub-component & material model was validated though the building block approach for certification by analysis.

Methods

The Humanetics H-III was used for the physical and virtual ATD. These used their respective built in sensors for head and neck instrumentation. The THUMS was chosen as the HBM for replicating the PMHS impacts. Virtual instrumentation was developed to compare to the built in ATD instrumentation and the accelerometer package used for the PMHS tests. The head c.g. acceleration was captured by a dependent interpolation element placed at the c.g. of the HBM that output the averaged movement of all the nodes of the skull. This gave a head acceleration that compared well with the physical & virtual ATD results. Cross sections were used to capture the neck loads & moments in the THUMS. While the magnitude of the this load sensor was always less than what was read by the ATD, the impulse compared well.







Conclusions

The advantages of virtual testing proved helpful in running a large number of variations, also providing an estimate for worst case scenario. This was confirmed in both forms of physical testing where the physical ATD results compared well and the PMHS subject suffered a similar fracture as the THUMS simulation. This last comparison also shows the benefit of HBM in injury analysis, offering a more realistic biofidelic response.