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# Standard Test Method for Assessing the Safety of Small Unmanned Aircraft Impacts[1]

This standard is issued under the fixed designation F3389/F3389M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method is applicable to small unmanned aircraft (sUA) that are limited in the United States in accordance with 14 CFR § 107.3 to be less than 55 lbf. The test method provides a standardized method for assessing the safety of sUA impacts with a person on the ground. Results from testing using Methods A, B, C, or ~~C~~D are intended to be used to support an applicant in obtaining permission from the governing Civil Aviation Authority (CAA) for flight over people. Approval of reports for the conduct of tests and the decision to grant permission rests with the governing CAA based upon adherence to the methodologies outlined in this test method.

1.2 This test method is based on methods researched by the FAA Center of Excellence for Unmanned Aircraft Systems (UAS) supported by the Alliance for System Safety of UAS through Research Excellence (ASSURE). These methods expand on extensive research and testing conducted by the automotive industry to support quantitative automotive passenger safety standards and testing and test data on sUA collected by ASSURE.



1.3 The purpose of this test method is to define a method to establish confidence in the overall injury potential of a particular sUA configuration under probable failure conditions. This testing is not meant to simulate the worst possible impact for the most conservative set of the population. It is expected that CAAs should determine what injury thresholds are acceptable under their public policy and determine operational limitations for various operations by using the data from this testing in conjunction with the specific concept of operations proposed by the applicant.



1.4 The test method provides ~~three~~four methods for evaluating the potential for impact injury: a simple analytical method, a simplified test, ~~and~~ a more rigorous ~~test~~ test, and a test method normed to approximate energy transfer values with appropriate safety margins applied to each approach to address uncertainty in each of the approaches.

1.5 The applicant should understand the actual operating characteristics of their sUA before starting the process outlined in this test method. It is assumed that the applicant is able to substantiate the most probable, ~~worst case~~ worst-case (MPWC) impact orientation of the sUA; typical and maximum operating heights and speeds; and terminal velocity of their sUA as a function of altitude to compare the results of the impact analysis with the proposed operation for the sUA. This test method is intended to supplement the verification requirements of Specification F3298 and Specification F3322, as well as a supplement to Specification F2910. This test method should not be used as a stand-alone document without consideration of other ASTM UAS standards.

1.6 These methods assume that a blunt force head impact is the most likely injury mechanism leading to serious injury or fatalities. The level of blunt force injury to the head may be adjusted for various applications (such as sUA operations around first responders with helmets) and compared with the amount of force or load factor that the sUA transfers during a collision.

[1] This test method is under the jurisdiction of ASTM Committee F38 on Unmanned Aircraft Systems and is the direct responsibility of Subcommittee F38.01 on Airworthiness.

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1.7 Method B is not appropriate for foam-built fixed-wing sUA due to the stiffness of the FAA Hybrid III ATD Head and Neck. Until a different impactor can be developed for Method B, these sUA should use Method C or D for evaluation.

1.8 *Units*—The values stated in either International System (SI) units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

F2910 Specification for Design and Construction of a Small Unmanned Aircraft System (sUAS)
F3060 Terminology for Aircraft
F3298 Specification for Design, Construction, and Verification of Lightweight Unmanned Aircraft Systems (UAS)
F3322 Specification for Small Unmanned Aircraft System (sUAS) Parachutes
F3341/F3341M Terminology for Unmanned Aircraft Systems

2.2 *Code of Federal Regulations:*[3]

14 CFR § 107.3 Definitions
~~14~~49 CFR ~~Part~~Section 571.208 Occupant crash protection
49 CFR Part 572 Subpart E Anthropomorphic Test Devices Subpart E - Hybrid III Test Dummy (§§ 572.30 - 572.36)

2.3 *FAA Documents:*[4]

DOT/FAA/AR-09/41 Neck Injury Criteria for Side-Facing Aircraft Seats
FAA AC ~~25.562~~25.562-1 Rev B Dynamic Evaluation of Seat Restraint Systems and Occupant Protection on Transport Airplanes
FAA Docket Number FAA-2018-1087 Operation of Small Unmanned Aircraft Systems Over People

2.4 *NHTSA Standards:*[5]

FMVSS 208 Federal Motor Vehicle Safety Standard 208 - Defined in 49 CFR Part 571.208
TP-208-14 Appendix A Part 572E (50th Male) Dummy Performance Calibration Test Procedure

2.5 *SAE Standards:*[6]

SAE J211/1 Instrumentation for Impact Test—Part 1: Electronic Instrumentation
SAE J211/2 Instrumentation for Impact Test—Part 2: Photographic Instrumentation
SAE J1727 Calculation Guidelines for Impact Testing
SAE J1733 Sign Convention for Vehicle Crash Testing

2.6 *UN Regulation:*[7]

UN Regulation No. 94 Occupant Protection in Frontal Collisions: Uniform Provisions Concerning the Approval of Vehicles with regard to the Protection of the Occupants in the Event of a Frontal Collision



## 3. Terminology

3.1 *Unique and Common Terminology*—Terminology used in multiple standards is defined in F3341/F3341M, UAS Terminology Standard, and F3060, Aircraft Terminology Standard. Terminology that is unique to this test method is defined in this section.

3.2 This test method uses terminology contained in Specification F3298 and Specification F3322. These terms are not duplicated in this test method.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from U.S. Government Publishing Office (GPO), 732 N. Capitol St., NW, Washington, DC 20401, http://www.gpo.gov.

[4] Available from Federal Aviation Administration (FAA), 800 Independence Ave., SW, Washington, DC 20591, http://www.faa.gov.

[5] Available from National Highway Traffic Safety Administration (NHTSA), 1200 New Jersey Ave., SE, Washington, DC 20590; described in http://www.nhtsa.gov/cars/rules/import/FMVSS/#SN208.

[6] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

[7] Available from GlobalAutoRegs, https://globalautoregs.com/rules/105-occupant-protection-in-frontal-collisions.

3.3 ~~*Definitions:*~~*Definitions of Terms Specific to This Standard:*

~~3.1.1 *applicant, n*—the person or organization responsible for seeking the approval to operate, and operating, an unmanned aircraft (UA). The applicant may be one of the following entities: manufacturer, operator, or original equipment manufacturer.~~

~~3.1.2 *as flown* or *as to be flown, n*—these terms represent the configuration under test and describe the mass and structural properties of the sUA and its payloads. During test, the *as flown* or *as to be flown* configuration structure and impact characteristics shall be representative of the flight configuration being considered for use.~~

~~3.1.3 *category 2 operations, n*—under the Micro UAS Advisory Rulemaking Committee (ARC), a Category 2 operation is an sUA permitted to operate over people if it weighed more than 0.55 lb, but still presented a 1 % or less chance of "serious injury" (Abbreviated Injury Scale (AIS) level 3 or greater) upon impact with a person.~~

~~3.1.4 *category 3 operations, n*—under the Micro UAS ARC, a Category 3 operation is an sUA permitted to operate over people if it presented a 30 % or less chance of causing an AIS level 3 or greater injury upon impact with a person. The manufacturer of the small UAS would be required to certify to the FAA that the small UAS did not, in the most probable failure modes, exceed the typical or likely impact energy threshold.~~

3.3.1 *critical* ~~*speed,*~~*speed* ~~*n*—~~*for Method D—*the ~~speed at which the sUA is capable~~critical speed for Method D testing varies from the definition in Terminology F3341/F3341M~~of its maximum kinetic energy (KE) considering both powered flight as well as failure conditions. -~~. The critical speed for ~~fixed-wing sUA is the maximum cruise speed. The critical speed for rotor-wing sUA is the speed~~Method D testing is either the highest ground speed achievable in powered flight, including the proposed environmental conditions (that is, wind), or the maximum resultant speed based on an unpowered free-fall from the maximum attainable altitude, whichever is higher. If parachutes are used as a mitigation, the critical speed is defined in Annex A1~~of the rotorcraft at terminal velocity.~~.



~~3.1.6 *manufacturer, n*—the person or organization who causes production of a product or article. A manufacturer may also be an operator.~~

~~3.1.7 *most probable, worst case (MPWC), n*—the sUA orientation used in impact testing. The orientation is found by first using operational data, failure modes, and engineering judgment to determine the most probable impact orientations. Testing is conducted to determine the worst case (most damaging) orientation among the most probable impact orientations.~~

~~3.1.8 *operational speed, n*—the maximum speed at which the sUA can normally operate (considering the usage expectations and limitations within the flight manual).~~

~~3.1.8.1 *Discussion*—~~

~~Test articles should not be used for more than one test. For example, visual inspection of composite material may be found to be mechanically equivalent to the original configuration, but they are not. Test articles should only be reused if they are found to be mechanically and structurally equivalent to the original configuration. Use of inspections to determine mechanical and structural equivalency should be included in the final report to the governing CAA for concurrence on reuse of test articles. Nonfunctional payloads and internal electronic components that are structurally intact should be deemed acceptable for testing the *as flown* configuration. Mockups or surrogates for payloads and electronic components may be acceptable if their stiffness and impact dynamics can be shown to be similar. The use of nonfunctional components and mockups/surrogates is intended to reduce testing costs without impacting the assessment of injury potential. Modifications of the tested configuration should be reviewed with the governing CAA and compared with the sUA originally tested to determine if additional impact testing is required to determine the injury potential of the new configuration. Only modifications that affect the collision dynamics and energy transfer of the sUA when colliding with a human should require additional testing.~~

~~3.1.9 *operator, n*—the person or organization who applies for CAA approval to operate an sUAS or who seeks operational approval for types of flight operations prohibited by a CAA for that sUAS.~~

~~3.1.10 *original equipment manufacturer (OEM), n*—the person or organization who first produced that product or article. An OEM may also be an operator.~~

3.1.11 *shall versus should versus may, n*—use of the word *shall* means that a procedure or statement is mandatory and must be followed to comply with this test method, *should* means recommended, and *may* means optional at the discretion of the applicant/proponent.

3.1.11.1 *Discussion*—
*Shall* statements are requirements, and they include sufficient detail needed to define compliance (for example, threshold values, test methods, oversight, and reference to other standards). *Should* statements are provided as guidance towards the overall goal of improving safety and could include only subjective statements. *Should* statements also represent parameters that could be used in safety evaluations or could lead to development of future requirements, or both. *May* statements are provided to clarify acceptability of a specific item or practice and offer options for satisfying requirements.

3.4 *Acronyms and Abbreviations:*

3.4.1 *AIS*—abbreviated injury scale

3.4.2 *ARC*—advisory rulemaking committee

3.4.3 *ASSURE*—Alliance for System Safety of UAS through Research Excellence

3.4.4 *ATD*—anthropomorphic test device; a crash test dummy

3.4.5 *CAA*—civil aviation authority

3.4.6 *CFC*—channel frequency class

3.4.7 *CONOPS*—concept of operations

3.4.8 *DAQ*—data acquisition

3.4.9 *IARV*—injury assessment reference values

3.4.10 *KE*—kinetic energy

3.4.11 *MPWC*—most probable, worst case

3.4.12 *NHTSA*—National Highway Traffic Safety Administration

3.4.13 *NIAR*—National Institute for Aviation Research at Wichita State University

3.4.14 $N_{ij}$—neck injury criteria

3.4.15 *NPRM*—notice of proposed rulemaking

3.4.16 *OEM*—original equipment manufacturer

3.4.17 *PMHS*—post mortem human surrogate

3.4.18 *PPE*—personal protective equipment

3.4.19 *sUA*—small unmanned aircraft; the flying aircraft only

3.4.20 *sUAS*—small unmanned aircraft system; an sUA and its associated elements (including communication links and the components that control the sUA) that are required for the safe and efficient operation of the sUA in a national airspace system.

3.4.21 *UAH*—The University of Alabama in Huntsville

## 4. Summary of Test Method

4.1 This test method describes ~~three~~four methods for assessment of the safety of an sUA to assess injury potential associated with an impact. The applicant can choose the method that is appropriate for their sUA based on mass and speed, or based on the rigor required.

4.2 Method A requires the applicant to use the sUA mass and operating characteristics to define an operating envelope that shall keep the sUA below a safe KE threshold. This is intended for lightweight or slow falling sUA that present little or no risk to the public.

4.3 Method B uses an instrumented ATD head form and requires the applicant to conduct a series of impact tests using the sUA. Impacts are conducted at the MPWC impact orientation, which is determined through a combination of engineering judgment and experiments. The test allows a characterization of the accelerations that may be experienced at impact as a function of sUA KE. A safe threshold value of KE is identified using a level of acceleration that corresponds to a low risk of an AIS 3 skull fracture. The weight limit for this method is 8 lbf for sUA and larger sUA up to 55 lbf being tested at parachute speeds. Method B is not appropriate for the testing of foam fixed-wing sUA due to the increased rigidity of the test setup.

4.4 Method C uses an instrumented ATD and requires impacts at multiple energies and three different impact angles. Data is collected that give insight to possible head and neck injuries based on FMVSS 208. These test results can be compared to automotive injury risk metrics associated with 30 % probability of an AIS 3 or greater injury or against defined injury metrics developed and used by the governing CAA. The weight limit for this method is 8 lbf for sUA and larger sUA up to 55 lbf being tested at parachute speeds.



4.5 Method D uses an instrumented ATD head form and neck and requires the applicant to conduct a series of impact tests using the sUA and a rigid object. Impacts are conducted in three different trajectories with respect to the ATD head using the MPWC orientation. MPWC orientation is determined based on analysis of the CONOPS and potential failure modes of the aircraft. If parachutes are used as a mitigation, the MPWC should be determined with the mitigation applied. The test results of the sUA are compared with the head injury criteria ($HIC_{15}$), peak acceleration, the $N_{ij}$ neck injury criteria, and neck compression results for rigid object impacts at each orientation. This method allows the tailoring to an energy transfer requirement, which may be requested by some CAAs.

## 5. Significance and Use

5.1 The test method is intended to be used by sUAS manufacturers, sUAS operators, and CAAs to assess the safety of sUA impacts to people on the ground during operations involving flight over people.

5.2 The test method provides a framework for creating new designs and evaluating existing designs to determine the sUA's blunt force trauma injury potential to the head or neck, or both, during a collision with a person on the ground.

5.3 Applicants can determine whether to use Methods A, B, C, or ~~C~~D based upon their specific sUA ~~characteristics and flight operations. In many~~characteristics, flight operations, and CAA requirements. In some cases, sUA with low impact KE below 54 ft-lbf [73 J] ~~(see~~may ~~Appendix X1) do~~ not require rigorous testing to ensure safety to the nonparticipating public and can use Method A. Vehicles with higher impact KEs should conduct impact testing using Method ~~B~~ B, Method C, or Method ~~C.~~D. Method B is simpler than Method C and, therefore, less costly for the applicant. Method B results may be more conservative since the test setup is more rigid and can result in an increase in the amount of energy transferred during the impact than the injury metrics established using a full ATD. Method C testing is costlier and schedule-intensive, but provides a higher level of certainty of the injury potential of the sUA and is more directly comparable to established automotive injury metrics and injury metrics derived from ATD testing and used by the governing CAA. Method D allows for the direct comparison to energy-based requirement of some CAAs.

5.4 The output of Method A is a verification that the sUA or sUA with mitigation does not exceed the 54 ft-lbf impact KE throughout its flight envelope based upon flight test data as means of obtaining approval for flight over people for Category 2 or 3 operations for the FAA. Other governing CAAs may only require a weight metric or other impact energy metric in lieu of the 54 ft-lbf impact KE.

5.5 The output from Methods B and C is a characterization of the forces (measured in acceleration of the head form or ATD) expected during an MPWC head impact as a function of sUA KE. For Method B, this result is compared to the minimum impact energy resulting in a skull fracture based solely upon peak acceleration to determine the impact KE associated with this injury based upon energy transfer. Method C testing is more rigorous and may be correlated to other standards for both head and neck injury (such as the FMVSS 208 or other automotive standards) to determine whether the sUA is sufficiently safe to operate in Category 2 and 3 Operations Operations.(1)[8] based upon the injury metrics shown in Table X3.1. By evaluating sUA KE in the MPWC orientation and a variety of ATD impacts, the applicant should assess the sUA for injury potential using Table X3.1 or other the governing CAA injury thresholds. The limiting impact KE may establish the operational limits that correspond to that specific value. This test method proposes the use of the standards called out in Table X3.1 based upon the ASSURE impact tests conducted as part of Task A14.[9]

5.6 The output from Method D is a verification that the sUA does not exceed the comparison metrics associated with the transfer of energy resulting from the impact of a rigid object at a specified impact KE for the rigid impactor. The impact KE of the rigid impactor is determined by the CAA for different categories of operations over people. For example, an sUA meets this standard if its impact test results are lower than the rigid object test results.

5.7 Outputs from Methods A, B, C, and CD may be used in conjunction with governing CAA's injury metrics for certifying the sUA for flight over people.

5.7 This test method does not attempt to address all possible hazards that may arise from sUA impacts. It is designed to measure the injury potential of head impacts, which are likely to be among the most probable, and most hazardous, types of sUA impacts when flying over people. Other safety hazards may include laceration from propellers or fire from the powerplant or batteries. These other safety hazards should be assessed separately.



## 6. Apparatus

6.1 Method A does not require any specific apparatus.



6.2 Method B requires the use of an instrumented head form with three accelerometers (one in each orthogonal axis) (axis). Appendix X2). Testing shall be conducted with an FAA Hybrid III 50th Percentile Male head and neck or other head form approved for use by the governing CAA for vertical impact tests.

6.3 Method C requires the use of an instrumented ATD with three accelerometers and three angular rate sensors in the head form, and neck load cells capable of recording data in accordance with the FMVSS 208 standard to determine peak acceleration, $HIC_{15}$, for assessing head injuries, as well as $N_{ij}$ and neck compression values for assessing neck injuries. Testing may be conducted with an FAA Hybrid III 50th Percentile Male ATD or other ATD approved for use by the CAA for vertical and lateral head impact tests.

6.4 Method D shall use an Anthropomorphic Testing Device 50th Percentile Male FAA Hybrid III ATD head and neck instrumented ATD with three accelerometers and three angular rate sensors in the head form, and neck load cells capable of recording data in accordance with 49 CFR Section 571.208 to determine $N_{ij}$ and neck injury values. The use of a full FAA Hybrid III 50th Percentile Male ATD, or other ATD approved for use by the CAA is acceptable. The selected impactor used should weigh between 1 and 5 lb with an approximate frontal area of 6 to 12 in.$^2$.

[8] The boldface numbers in parentheses refer to the list of references at the end of this standard. Mertz, H. J., "Biofidelity of the Hybrid III Head," SAE Technical Paper 851245, 1985.

[9] DJI, Phantom, and Mavic are trademarks of DJI, 14th Floor, West Wing, Skyworth Semiconductor Design Building, No.18 Gaoxin South 4th Ave, Nanshan District, Shenzhen, 518057, China.

[9] The sole source of supply of the Phantom 3 drone and the Mavic Pro drone known to the committee at this time is DJI, 14th Floor, West Wing, Skyworth Semiconductor Design Building, No.18 Gaoxin South 4th Ave, Nanshan District, Shenzhen, 518057, China. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend. Arterburn, D., Olivares, G., Bolte, J., Prabhu, R., Duma, S., Final Report for the FAA UAS Center of Excellence Task A14: UAS Ground Collision Severity Evaluation 2017-2019, prepared for the FAA under Grant # 15-C-UAS-UAH-07, September 2017.

6.5 The instrumentation, collection of data, and filtering of that data in these tests should meet the requirements of SAE J211/1.

6.6 The speed of the sUA relative to the stationary impactor just prior to the time of impact should be measured for each test point. This test method does not require a specific method. Possible methods include high-speed video of the impact made perpendicular to the fall, with a way of measuring the distance travelled between frames—radar, ultrasonic distance measurements, or other sensors. Applicants may use SAE J211/2, which describes the test and analysis methods for determining velocity from video data. Instrumentation methods must be documented in the test plan and included in the test description/procedure provided with the test report to the governing CAA. The uncertainty of the measurement should be documented.

6.7 If an FAA Hybrid III Head and Neck is used for the conduct of the Method D test, then consideration should be given to installing gas-damped accelerometers in the head of the ATD. Gas-damped accelerometers are highly desirable for rigid body impacts since the head and neck configuration can be substantially stiffer than a full FAA Hybrid III ATD. Data acquisition devices should use sampling rates of at least 250 kHz when testing with head- and neck-only ATDs to avoid signal aliasing. Applicants are encouraged to conduct sampling studies as part of their means of compliance when using a head- and neck-only target to validate that their data is not being adversely affected prior to the start of testing.

## 7. Hazards

7.1 This test method involves impacts with significant KE. The test apparatus should be set up to control the sUA impact to stay within the test apparatus throughout the impact.

7.2 The impacts may break the sUA. The test apparatus should be designed to prevent flying debris from becoming a hazard. Participants must use appropriate PPE or remain protected during the test.



7.3 When testing an sUA with fuel power plants or lithium batteries, or both, an appropriate fire extinguisher for each application should be within reach. Participants should be made aware of the hazards of lithium batteries, and which fire extinguishers are appropriate for lithium-based fires. Batteries should be tested when they are at their minimum level of charge. Consideration should be made for the amount of fuel contained in the vehicle during the impact to minimize the risk of fire.

## 8. Test Articles



8.1 sUA used in this test shall be mechanically and structurally equivalent to the actual flying configuration. The sUA does not need to be operational or powered, but it shall be the same mass, internal configuration of equipment, the same structural elements, and with the same power plant as the flying configuration. The test article must be representative of the final production article, and test article is selected in order to create the critical case condition for the parameters being measured. It is important that the test is conducted with the approved payload as defined by the manufacturer. If items of any significant mass can become separated during flight, then these payloads, batteries, etc. should be tested separately to assess their injury potential.

8.1.1 Batteries that present a potential for fire during impact should be discharged as much as possible to minimize the risk of a fire. Applicants may consider removing strap-on batteries and use a weight representative mass of similar size and stiffness to mitigate this hazard.

8.2 Test articles may be used for more than one test if they are inspected between tests and found to be mechanically and structurally equivalent to the original configuration. Internal parts must be mounted to the sUA if mounting locations exist, and all mounted components must be present since these structures can change the stiffness of the sUA during collision. Parts that are broken or cracked must be replaced to bring the test sUA into mechanical and structural equivalency with the original configuration. Structurally equivalent and conformance means all load paths remain in place and all masses are located in their respective positions. Visual inspections are sufficient. Repairs/changes to the sUA between tests from the nominal configuration should be documented in the final report.

8.3 The configuration of each sUA used in each impact test should be documented in the test plan and test report.

8.4 For Method D, the selection of the comparative impactor should be chosen to approximate the contact area and weight of the sUA under consideration. The selected impactor used should weigh between 1 and 5 lb with an approximate frontal area of 6 to 12 in.$^2$ in a symmetrical fashion.

## 9. Preparation of Apparatus

9.1 Method B shall use a head form with a minimum of three accelerometers (one in each orthogonal axis). A head and neck from a 50th Percentile Male FAA Hybrid III ATD may be used for this test. Alternate head forms may be used if approved for use by the governing CAA.

9.2 Method C shall use an instrumented ATD with three accelerometers and three angular rate sensors in the head form, and neck load cells capable of recording data in accordance with the FMVSS 208 standard to determine neck compression and $N_{ij}$ values associated neck injury. An Anthropomorphic Testing Device 50th Percentile Male FAA Hybrid III ATD may be used for Method C. The ATD shall be instrumented with accelerometers ~~and rate sensors~~ measuring around three orthogonal axes or a nine-accelerometer array that shall collect linear acceleration about the center of gravity of the head. The upper neck of the ATD shall be instrumented with a six-axis load cell to measure forces and moments about the *x*,*y* and *z*-axes. Alternate ATDs that provide equivalent data may be used if approved for use by the CAA.

9.3 Method D shall use an Anthropomorphic Testing Device 50th Percentile Male FAA Hybrid III ATD head and neck instrumented with three accelerometers in the head form, and neck load cells capable of recording data in accordance with 49 CFR Section 571.208 to determine $N_{ij}$ and neck injury values. Alternate ATDs that provide equivalent data may be used if approved for use by the CAA.

## 10. Calibration and Standardization

10.1 ATD load cells shall be calibrated on an "as needed" basis and a minimum of once every 12 months. ATD and head form accelerometers shall be calibrated on an "as needed" basis and a minimum of once every six months. Need is determined by a pre- and post-test shunt calibration. If bridge balance ~~remained~~remains unchanged and if full-scale shunt calibration results in the same factor, then the transducer characteristics are within calibration. If loads become suspect, linearity of the load cell shall be checked with a universal compression testing machine or other calibration device to determine serviceability. Exact calibration procedure to be found in TP-208-14 Appendix A Part 572E (50th Male) Dummy Performance Calibration Test Procedure.



10.2 All ATDs and associated instrumentation should meet the standards outlined in SAE J211/1 dated 2014-03-31 and SAE J211/2 dated 2008-11-18.

## 11. Method A



11.1 *Method A Procedure:*

11.1.1 Method A allows the applicant to define an operational envelope that shall keep the KE of the sUA below the threshold ($KE_{max}$) of 54 ft-lbf [73 J] at ~~impact (see~~ impact.~~Appendix X1).~~

11.1.2 Defining the operating envelope means the applicant should compare the maximum sUA lateral and vertical impact speeds to a resultant $v_{max}$ defined by the sUA mass and the $KE_{max}$ threshold. If the sUA speeds at impact are greater than resultant $v_{max}$, then the applicant should limit the operating envelope to $v_{max}$. If the sUA speeds are less than $v_{max}$, then the applicant should declare the sUA speeds as the operating envelope. Applicants should include environmental variables such as sUA modes, failure conditions, wind, etc. when substantiating the $v_{max}$ under the provisions of Method A.

11.1.3 The applicant must also consider the case that the sUA falls from altitude. The applicant should measure a curve of falling velocity versus height and use this to construct a curve of falling KE versus height. If the sUA KE is ever greater than $KE_{max}$, then the applicant should limit the maximum operating altitude such that the KE at impact shall be equal to or less than $KE_{max}$.

11.1.3.1 If the applicant does not have a curve of falling velocity versus height, then the applicant may define the maximum operating altitude, $alt_{max}$, associated with 54 ft-lbf [73 J] using potential energy as a function of height. This tends to be very conservative, as this does not consider drag during falling.

11.2 *Method A Calculation and Interpretation of Results:*

11.2.1 Kinetic energy is calculated as: $KE = \frac{1}{2} m \times v^2$.

11.2.2 The maximum safe resultant speed ($v_{max}$), combined horizontal and vertical speed, is calculated as $v_{max} = \sqrt{[(2 \times KE_{max})/m]}$, where $KE_{max}$ is the threshold shown in 11.1.1 and $m$ is the mass of sUA as it would be flown. Care must be taken to ensure the calculation is done with the correct units. While $v_{max}$ is calculated from $KE_{max}$, $v_{max}$ is the resultant speed, $v_{max} = \sqrt{(v_x^2 + v_y^2 + v_z^2)}$ and should be considered when applying this value to the assessments of operational speeds associated with any given operation and associated failure modes.

11.2.3 Maximum altitude ($alt_{max}$) is calculated as either:

11.2.3.1 The falling distance at which the KE of the sUA at the ground equals $KE_{max}$. If the KE of the falling sUA is always below $KE_{max}$ ($v < v_{max}$ always), then there is no altitude limitation to the operating envelope.

11.2.3.2 If the applicant does not know falling KE versus height, calculate $alt_{max} = [KE_{max} / (m \times g)]$.

11.3 *Method A Report:*

11.3.1 A Method A report shall include ~~as~~at a minimum the following information:

11.3.1.1 Results of flight tests showing most probable failure modes and associated descent rates though a minimum of 200 ft above ground level (AGL) following failures.

11.3.1.2 A statement that states that this analysis was conducted in accordance with Method A of this test method.

11.3.1.3 The sUA model considered, with any relevant information about version or configuration.

11.3.1.4 The sUA operational envelope that keeps the KE of sUA impacts below 54 ft-lbf [73 J]. This should include maximum speeds or maximum altitude, or both.

11.3.1.5 The maximum environmental conditions used in the calculation of $v_{max}$.



## 12. Method B

12.1 *Method B Procedure:*

12.1.1 Method B is conducted using a head form containing a three-axis accelerometer.

12.1.2 Applicants should develop a test plan/procedure that describes, at a minimum, the following:

12.1.2.1 The name and address of the test facility performing the tests.

12.1.2.2 The name and telephone number of the individual at the test facility responsible for conducting the tests.

12.1.2.3 A brief description or photograph, or both, of each test fixture. A statement confirming that all instrumentation and data collection equipment used in the test meet the facility's internal calibration requirements, that these calibration requirements are documented and available for inspection upon request, that all calibrations are traceable to a national standard, and that the records of current calibration of all instruments used in the test are maintained at the facility.

12.1.2.4 A statement confirming that the data collection was done in accordance with the detailed description of the actual procedure used and technical analysis showing equivalence to the recommendations of this test method.

12.1.2.5 *Test Articles:*

*(1)* In all cases, the test article (that is, sUA) should be representative of the final production article and should include a structural frame, motors, propellers, electronics, batteries, and payload. The sUA does not necessarily need to be powered. The sUA need not have fully functional electronics if they do not contribute to the structural integrity of the platform. All electronics should ~~be~~ have a mass representative of the production configuration and have the same stiffness and shape. The configuration of each sUA used in each impact test should be documented, and this configuration should conform to the production specification of the sUA for which the applicant is submitting to the governing CAA. Specific modifications to the sUA that are made to support or conduct the tests should be clearly documented, along with their potential impacts on the results of the tests.

*(2)* The payload may be replaced by a representative load made of representative shape, stiffness, and mass. Fuel may be replaced with water or other nonflammable liquid of equivalent mass.

*(3) Items of Mass*—Defined as any part of the sUA that can detach during impact (for example, removable cameras, batteries) and may become a projectile with enough energy to cause a serious injury (see 6.5) to a person. Detachment of these items may be grounds for retest and the means of restraint for these items may need to be improved by changes to design or implementation. Detachment of an item of mass should not leave any sharp or injurious edges. Once retention of an item of mass has been demonstrated using the standard configuration, subsequent tests may be conducted with the item secured by means other than those in the standard operational configuration for the purposes of the test (if required by the governing CAA).

*(4)* The manufacturer, governing specification, serial number, and test weight of the ATDs used in the tests, and a description of any modifications or repairs performed on the ATDs that could cause them to deviate from the governing specification.

*(5)* Batteries that present a potential for fire during impact should be discharged as much as possible to minimize the fire risk. The batteries should be tested separately to demonstrate that there is no risk of fire at impact (many battery manufacturers perform such tests as part of their development process). The manufacturer should maintain a report of the battery impact test, with photographic or video evidence, to demonstrate the battery does not ~~catch fire~~ ignite at impact.

*(6)* Test articles should not be used for more than one test. For example, visual inspection of composite material may be found to be mechanically equivalent to the original configuration, but they are not. Test articles should only be reused if they are found to be mechanically and structurally equivalent to the original configuration. Use of inspections to determine mechanical and structural equivalency shall be included in the test report to the governing CAA for concurrence on the reuse of test articles.

12.1.2.6 A description of the photographic instrumentation system used in the tests.

12.1.2.7 *Test Description*—The description of the test should be documented in sufficient detail, so that the tests could be reproduced simply by following the guidance given in the report. The procedures outlined in the test plan can be referenced in the report but should be supplemented by such details as are necessary to describe the unique conditions of the tests. For example, pertinent dimensions and other details of the installation that are not included in the drawings of the test items should be provided. The placement and characteristics of electronic and photographic instrumentation chosen for the test beyond that information provided by the facility should be documented. This can include special targets, grids, or marking used for interpretation of photo documentation, transducers, etc.



12.1.2.8 Pass Fail criteria used for the tests.

12.1.3 Determine the MPWC impact orientation.



12.1.3.1 The MPWC impact orientation shall be specified by the manufacturer (the sUA manufacturer or the OEM of a payload that shall be carried by a particular sUA). The manufacturer-provided MPWC impact orientation is only valid for the specific sUA configuration tested by the manufacturer.

12.1.3.2 In cases where the MPWC impact orientation is not specified by the manufacturer or for an sUA configuration not tested by the manufacturer, the applicant may determine the most probable impact orientations for the sUA to hit a person's head based on engineering judgment, flight test, any parachute or recovery systems installed, and understanding the operating characteristics of the sUA.

12.1.3.3 Failure flight-testing is essential for evaluating an sUA's post-failure dynamic behavior. Many sUA tumble or stabilize in a predictable orientation while falling. Knowledge of failure dynamics is essential in determining probable impact orientations. The post-failure dynamics can affect the terminal velocity of the sUA and, as such, its impact KE. Longer periods of data logging improve the fidelity of aerodynamic analysis. It is recommended that flight tests be initiated at 800 ft AGL to allow a full 400 ft of fall before initiating recovery via parachute or other decelerative device. Flight tests should allow for a minimum of 200 ft of fall before initiating recovery via parachute or other decelerative device. Flight-testing should be conducted under winds less than 5 kts in order to provide data for aerodynamic analysis. Winds and gusty conditions during flight test can lead to inaccurate estimates of sUA aerodynamic properties. See considerations for parachute recovery systems in Annex A1.

12.1.3.4 For each probable impact orientation, the applicant shall perform a series of drop tests to determine the worst case of these probable orientations. These drop tests should consist of at least three drops in each orientation with a drop height as specified below:

*(1)* For sUA with a mass less than 2.2 lbf [1 kg], the drop height should be at least 10 ft [3 m].

*(2)* For sUA with a mass greater than 2.2 lbf [1 kg], the drop height should be chosen such that the impact KE is at least 20 ft-lbf [27 J].

*(3)* For sUA that employ parachute mitigations for uncontrolled flight, the drop height should be chosen such that the impact speed is at least 8 fps [2.5 m/s].

12.1.3.5 For each impact, the applicant should record the sUA details, sUA impact orientation, speed at impact, the maximum magnitude of maximum resultant acceleration ($a_{mag}$) measured by the alternate head form, and any relevant notes about the impact. Any damage to the sUA shall be noted.

12.1.3.6 Average the measured maximum accelerations for each impact orientation.

12.1.3.7 The MPWC impact orientation is the orientation that resulted in the greatest average measured maximum acceleration over the three drops.

12.1.4 All further impact tests shall be conducted using the MPWC impact orientation. The applicant should conduct a minimum of five (5) impacts each at two (2) drop test heights, for a total of at least ten (10) drop tests. The drop heights should be specified as below:

12.1.4.1 For sUA with a mass less than 2.2 lbf [1 kg], the drop heights should be 10 ft [3 m] and 20 ft [6 m].

12.1.4.2 For sUA with a mass greater than 2.2 lbf [1 kg], the drop heights should be chosen such that the impact KE is 20 ft-lbf [27 J] and 40 ft-lbf [54 J].

12.1.4.3 For sUA that employ parachute mitigations for uncontrolled flight, the drop height should be chosen such that the impact speed is 8 fps [2.5 m/s] and 16 fps [5 m/s]. The mass of the sUA with the associated parachute equipment attached to the sUA should be included in the tests. This test does not define a specific weight since the descent speed and impact energy is depending on the parachute speed and sUA weight.



12.1.5 For each impact, the applicant should record the sUA details, impact orientation, speed at impact, the maximum magnitude of the resultant acceleration ($a_{mag}$) measured by the alternate head form, and any notes relevant to the impact. Any damage to the sUA should be noted.

12.1.6 sUA can be reused in testing if they are inspected and found to have no mechanical damage after the impact. Damaged sUA components can be repaired or replaced as needed to bring the test article sUA back to the original mechanical and structural configuration.



12.2 *Method B Calculation and Interpretation of Results:*

12.2.1 For each impact, calculate the impact kinetic energy as: $KE = \frac{1}{2} m \times v^2$.

12.2.2 Each impact shall have a 3-axis acceleration time-series measurement of the peak acceleration on each axis. Calculate the resultant acceleration magnitude as: $a = \sqrt{(a_x^2 + a_y^2 + a_z^2)}$ for each point in the time series. Record the greatest value as the resulting $a_{mag}$ for the impact.

12.2.3 Make a linear fit to the data (KE, $a_{mag}$) using the function $a(KE) = S \times KE$. $S$ is the energy transfer slope and shall have the units g/ft-lbf or g/J. The linear fit of the data should use the maximum points for each test condition. The linear fit should be forced to a zero intercept, that is, the resulting acceleration from a zero KE impact is zero.

12.2.4 For Method B, calculate the maximum safe impact energy by $KE_{safe} = G/(S)$, where *G* is a threshold value of *g*s experienced by the head form, and report this value in ft-lbf or J. In the absence of a specific application threshold, the value *G* for skull fracture shall be the peak resultant head acceleration metrics shown in ~~Table X3.1~~Chapter 5 of Report for the FAA UAS Center of Excellence Task A14: UAS Ground Collision Severity Evaluation 2017-2019,[9] or the peak resultant head acceleration metrics specified by the governing CAA. For example, operations over people wearing PPE may utilize a different peak resultant head acceleration threshold to account for the extra protective gear.

12.3 *Method B Report:*

12.3.1 A Method B report shall include, as a minimum, the following information:

12.3.2 A statement that states that this analysis was conducted in accordance with Method B of this test method.

12.3.3 The sUAS model considered, with any relevant information about version or configuration.

12.3.4 Information on the test target, including type of target, configuration, serial number (if applicable), accelerometer serial number(s), and calibration information.

12.3.5 Description of the test location, date performed, and test setup and test procedure including description of test instrumentation.

12.3.6 Results and measurements for each test impact performed, with notes as appropriate.

12.3.7 Results describing how the worst-case orientations that were considered and the data used to substantiate the MPWC; should include flight test results that were used to determine the terminal velocity and MPWC.

12.3.8 Data and calculations resulting in the determination of the slope *S* in g/ft-lbf or g/J as well as the calculation of $KE_{safe}$ and the threshold value *G* used in this calculation.

12.3.9 An assessment of the safe operational envelope proposed including environmental conditions based upon the determination of $KE_{safe}$.

## 13. Method C

13.1 *Method C Procedure:*



13.1.1 Applicants should develop a test plan/procedure that describes, at a minimum, the following:

13.1.1.1 The name and address of the test facility performing the tests.

13.1.1.2 The name and telephone number of the individual at the test facility responsible for conducting the tests.

13.1.1.3 A brief description or photograph, or both, of each test fixture. A statement confirming that all instrumentation and data collection equipment used in the test meet the facility's internal calibration requirements, that these calibration requirements are documented and available for inspection upon request, that all calibrations are traceable to a national standard, and that the records of current calibration of all instruments used in the test are maintained at the facility.

13.1.1.4 A statement confirming that the data collection was done in accordance with the detailed description of the actual procedure used and technical analysis showing equivalence to the recommendations of this test method.

13.1.1.5 *Test Articles:*

*(1)* In all cases, the test article (that is, sUA) should be representative of the final production article and should include a structural frame, motors, propellers, electronics, batteries, and payload. The sUA does not necessarily need to be powered. The sUA need not have fully functional electronics if they do not contribute to the structural integrity of the platform. All electronics should be mass representative of the production configuration and have the same stiffness and shape. The configuration of each sUA used in each impact test should be documented, and this configuration should conform to the production specification of the sUA for which the applicant is submitting to the governing CAA. Specific modifications to the sUA that are made to support or conduct the tests should be clearly documented along with their potential impacts on the results of the tests.

*(2)* The payload may be replaced by a representative load made of representative shape, stiffness, and mass.

*(3)* Items of Mass—Defined as any part of the sUA that can detach during impact (that is, removable cameras, batteries) and may become a projectile with enough energy to cause a serious injury (see 6.5) to a person. Detachment of these items may be grounds for retest and the means of restraint for these items may need to be improved by changes to design or implementation. Detachment of an item of mass should not leave any sharp or injurious edges. Once retention of an item of mass has been demonstrated using the standard configuration, subsequent tests may be conducted with the item secured by means other than those in the standard operational configuration for the purposes of the test (if required by the governing CAA).

*(4)* The manufacturer, governing specification, serial number, and test weight of the ATDs used in the tests, and a description of any modifications or repairs performed on the ATDs that could cause them to deviate from the governing specification.