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.

Designation: F3389/F3389M – 21

# 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 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 four methods for evaluating the potential for impact injury: a simple analytical method, a simplified test, a more rigorous 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 (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.

1.7 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.*

[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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## 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

49 CFR 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 25.562-1 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.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *critical speed for Method D*—the critical speed for Method D testing varies from the definition in Terminology F3341/F3341M. The critical speed for 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.

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 four methods for assessment of the safety of an sUA to assess injury potential associated

[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.



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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 D based upon their specific sUA characteristics, flight operations, and CAA requirements. In some cases, sUA with low impact KE below 54 ft-lbf [73 J] may 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, Method C, or Method 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.[8] By evaluating sUA KE in the MPWC orientation and a variety of ATD impacts, the applicant should assess the sUA for injury potential using 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 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 D may be used in conjunction with governing CAA's metrics for certifying the sUA for flight over people.

[8] Mertz, H. J., "Biofidelity of the Hybrid III Head," SAE Technical Paper 851245, 1985.

[9] 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.



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## 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). Testing shall be conducted with an FAA Hybrid III 50$^{th}$ 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 50$^{th}$ 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 50$^{th}$ 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 50$^{th}$ 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.$^2$.

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

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