Safety Measures in Aerospace Ground Tests

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Abstract

The article presents the various levels of safety measures used in aerospace ground tests. The tests were done on the ground to use new material in an aircraft and qualify it for flight. The various test levels include specimens, features, component and a full-scale aircraft. During these tests, various safety measures needs to be accounted for safe and efficient execution of the test. Safety and efficiency in test activity are related i.e., improved efficiency bring in safety. The indispensable modelling and simulation DMU (Digital Mock-up) give a lot of input for the safe execution of tests. The EMU (Engineering Mock-up) from the manufacturer side and all the above mentioned aspects are presented in this article with figures.

Keywords: Safety; Testing; Aircraft; Material; Experiment

1. Introduction

Safety measures are vital factor in any level of tests or experiments being performed. Some of the safety measures described in this paper refers to different levels of testing viz., specimen, feature, component/part and full-scale aircraft testing (Figure 1). Figure 1 also indicates the type of event and its frequency. The minor incidents and near accidents occur frequently. The major accidents with damage and injury occur infrequently. The serious accident event causing catastrophic failure is a rare occurrence (Operator’s Flight Safety Handbook, Issue 2, 2001). Since 1945 to the year 2000 it is observed that the cause of accidents has reversed. In 1945 the cause of an accident was a technical factor but in the year 2000 it is a human factor (Boeing, 2016), (Abbas and Heinz 2006). Ground testing is a prerequisite before any flight-test program can begin. Early development of a new aircraft the design life in flight cycles (takeoffs and landings) or flight hours is established. Fighter aircraft due to their extreme maneuvering and operating environments have design life in thousands of flight hours. Transport aircraft, the design life is typically tens of thousands of flight cycles. Knowledge of the anticipated flight load spectrum for an aircraft enables pressure cycling of the fuselage, as well as hydraulic loading of the wings, empennage, and other principal structures.

A proactive approach for managing safety developed that concentrates on the control of processes and not solely relying on inspection and remedial actions on end products. This innovation in aviation industry system safety called a safety management System (SMS), an expression indicating that safety factors are most effective when made a fully integrated part of the business operation (F2245-16a 2016). It is now generally accepted that most aviation accidents result from human error. Various factors influencing aircraft have been found out by many researchers after in depth study of many major aircraft accidents. These factors include internal factors of the aircraft or external conditions of the environment in which the aircraft operates. Though the accidents cannot be completely avoided, it is possible to reduce it by carefully knowing the factors causing it and take prior precautions to avoid an accident. This article focuses on these precautionary safety measures.
2. Different Levels of Tests

All tests done at four different levels first is the specimen level, the second is the feature level, third is the component level, and fourth being the full aircraft level. The size of component/part and load magnitude of the test keeps increasing as the level of test increases.

![Diagram](image)

**Figure 1. Triangle representation of Tests and accident statistics profile**

2.1 Specimen level tests

An experiment is a scientific test conducted to discover what happens to something (material) in particular condition. As Griffith (1921), Gdoutos (2005) did a large number of experiments to discuss the issue of fracture toughness. Now we have an ASTM E1820-09, standard to determine the fracture toughness of a new material (ASTM E1820-09). A test is a deliberate action or experiment to find out how well something works. Most of the tests are performed based on standards like ASTM (American Society for Testing and Materials), ANSI (American National Standards Institute), DIN (Deutsches Institut für Normung, meaning German institute for standardization), etc.

In the testing of specimens and feature level components, the various capacities of machines used include 3kN, 25kN and 100Nm, 50kN, 150kN, 250kN, and a four column 1500kN. Various tests done in the case of metallic materials include: (i) Tensile tests (Figure 2, to determine the property of adhesive) (ii) Compression (iii) Notched bar impact (iv) Constant amplitude Fatigue tests, (v) Fracture Toughness tests, (vi) Strain- controlled Fatigue tests, and (vii) Fatigue Crack Growth Rate Test. In the case of Composite Materials, the material properties generation carried out using following tests. (i) Tensile Longitudinal and Transverse Tests (Figure 3, UD – Uni-directional, BD – Bi-directional lamina, T – Thickness, GFRP – Glass Fibre Reinforced Plastic)) (ii) Compressive Longitudinal and transverse tests, (iii) In- Plane Shear Test, (iv) Bearing strength test, (v) Flexure test, (vi) Inter-Laminar
Shear Strength Test, (vii) Open hole tension test, (viii) Open hole compression test, (ix) Open hole shear test, (x) Resistance to aircraft fluid test, (xi) Compression after impact test, (xii) Fracture toughness test, (xiii) Tension-Tension Fatigue Test, (xiv) Mixed Mode Bending test. In this category especially when we do high-temperature tests it is mandatory to wear appropriate spectacle, overcoat, gloves, and safety shoes. Primarily a test performed either by displacement control or force control. Depending on the control the safety limits entered into the software. For hardware, the limits set and configured with the test.

**Figure 2. Form and dimensions (mm) of the test specimen**

Moog Test Aerospace Test Software Safety: Dual Safety (i) accidental loads and (ii) Unforeseen test shutdown. Moog (Aerospace Test Software 2016) provides software thresholds and hardware integrity. Increased use of safety systems: Overloading of test article supported by a comprehensive set of safeguarding parameters. For each type of limit, three error bands set up viz., (i) triggering either an alarm, (ii) a user-defined action or (iii) hard shutdown.

Drive Limits tab displays the drive limits options. Setting of the drive limits done before setting up your test system which reduces the risk of damage to the specimen being tested and the testing system.

Operating limits included within your testing system to limit actuator movement. In case one fails to set these limits appropriately would result in injury to personnel or damage to equipment. Setting excessive gain values for your system can make the actuator response unstable and leave the actuator uncontrollable. If the actuator becomes unstable, strike the emergency stop button. Allowing an actuator to remain in an unstable condition could cause injury to personnel or damage to equipment.

**Figure 3. Tension test specimen geometry and dimension in mm**
Either in the Linear or the Rotary actuator, the options button displays the selected symbol. Enter the actuator dynamic rating for the actuator being connected (100kN), information about your system is entered into the controller so that calculations can be performed. Enter the total working stroke for the actuator being connected (100mm), information about your system entered into the controller so that calculations can be performed. Enter the working pressure for your system (207bars), system information is entered, allowing calculations to be performed. Calculated Actuator stiffness = 141.304kN/mm. Click the Apply button. The actuator stiffness calculations are carried out. Click the OK button, the settings are entered into memory and the window is removed from the screen.

Servo-valve Current Limits: The current drive to the servo-valves has different limit states, expressed as a percentage of the full drive, corresponding to the hydraulics LOW and HIGH states (Instron 2003). In the hydraulics LOW state, the solenoid is not energized. A connection (also referred to as a ‘shunt’) provided across the actuator control ports which limits the differential pressure. This, with the LOW current limits, restricts the force and velocity the actuator can achieve. When the hydraulic HIGH state selected, the solenoid energized and the connection across the control ports is closed. The stall force of the actuator at full system pressure can be achieved. At this time, the servo-valve current limits are changed from the LOW values to the HIGH values.

2.2 Feature level experiments

The feature level components are the second category in the test level. The typical components are as shown in Figure 4 are their cross-sectional details. The components are made from sheet metal fabrication or from integrally stiffened panels. In the integrally stiffened panels, there are no rivets, the material scooped out to form the shape and form. Due to this reason, the integrally stiffened panel have higher strength and durability compared to sheet metal components. The critical part choice, described in the MIL-STD-1530C (Department of Defense 2005).

The specimen and feature level specimens operator should use safety spectacles especially during fabrication and testing process. Appropriately use safety gloves especially while handing high temperature and chemicals.

![Figure 4. Feature Level Panels Stiffened with L and T Stringers](image)

2.3 Component level experiments

Bigger size components do not fit in the Universal Testing Machines (UTM). The component level testing of a wing is shown in Figure 5. For safety purpose trip units installed. A trip unit is the part of a circuit breaker that opens the circuit in the event of a thermal overload, short-circuit, large load/ displacement or ground fault. An open-circuit will not conduct electricity because either air or some other insulator has stopped or broken the flow of current in the loop.

A trip unit is for software or hardware. The photograph of a trip device used in the component level test is shown in Figure 6. Euchner Company's slogan is ‘More than Safety’ (Teknic Euchner Electronics 2016). The company provides high-quality switching systems for mechanical and system engineering for more than 60 years.
Recommended to make use of this safety device in testing activities, to save costly components. If not results in the loss of costly components. The cost of a typical wing root fitting box, component is around 80 lakhs in Indian Rupees.

In all the experiments/tests human should not go near the component being tested. It is significant especially when the component breaks it may harm the human near the component. All the test need be carried out in remote place using cameras placed at proper places, one can watch the displacement, force and other parameters by sitting in his cabin. It is good to partition the test system from other areas.

For vibration type test for example a shake table test facility. It is recommended in the BS 5228-2:2009 standard (British Standard BS 5228-2:2009) that the vibration level should be below 0.3 mm/s. In another literature reference (Yong and Neil 2014) the limit of acceptance for an office building is quoted as 0.4 mm/s.

2.4 Full aircraft level experiment

Here it is essential to sector the wing area for load distribution. In Figure 7, four sectors have been made in each wing. The colours of each sector are Yellow, Green, Orange and Red. At the bottom, all are blue coloured. This colouring aid in distinguishing the type of load and its magnitude.

Load calibration tests done with approximately 60 percent of each lower wing surface covered with load pads. This method allows both tensile and compressive loads application at all load zones on each wing (Andrew et al). A single load zone consisted of a hydraulic jack, a load cell to measure the applied load, and a whiffletree mechanism to distribute the load to two, three, or four, load pads. Figure 7 is a photograph of the full-scale fatigue test setup on the airframe of an aircraft. Left and right-wing loads applied at the same respective locations so that the aircraft was symmetrically loaded. A similar type of tests carried out F/A-18 aircraft (Timothy N and Callihan 2007), (Simpson et al 2002), the wing design was structurally complicated by seven inboard and six outboard spars and span wise load-path interruption at the wing fold.

During the part/component and full-scale tests the operators should wear safety helmet and boots as safety measure. DGFASIL (http://www.dgfasli.nic.in 2017)(Directorate General, Factory Advice Service and Labour Institute) give various links for selected health and safety resources. Six tips to building a strong safety culture is available in reference (www.selectiernational.com 2014).

As in the case of full-scale aircraft the safety technologies include CAPS (Cirrus Airframe Parachute System) for safer skies, such that it can land safely in case of emergency. CAPS provides the ultimate safety advantage—an exclusive Cirrus (https://cirrusaircraft.com/aircraft/ 2016) technology that has saved around 90 lives...
as in the Cirrus aircraft (SR20 and SR22). Other features include like ESP (Electronic Safety and Protection), and Crashworthiness.

Preferred to have at least one of the accreditation to laboratories, National Accreditation Board for Testing and Calibration Laboratories (NABL) (http://www.nab1-india.org/to-the-lighthouse 2017) or National Aerospace and Defense Contractors Accreditation Program (NADCAP) (http://www.expertresource.com/NadcapAuditChecklistListing.html 2017) to boost in safety by following standard practices. This will also help in business, a good catalyst for return on investment.

![Figure 7. Full-scale aircraft test facility](image)

### 3. Safety & Efficiency

Safety and efficiency are so closely interrelated that in many cases their influences overlap and factors affecting one may also affect the other. Human Factors have a direct impact on those two broad areas.

Safety affected by the Live-ware-Hardware interface. Any changes that affect such interface the result might be catastrophic. In a particular aircraft accident, one causal factor cited in the report was that “variation in panel layout amongst the aircraft in the fleet had adversely affected crew performance”.

Efficiency is also directly influenced by Human Factors and its application. In turn, it has a direct bearing on safety (Smart Testing Bombardier Thoughts 2015)[20].

(i) For instance, motivation constitutes a major boost for individuals to perform with greater effectiveness, which will contribute to a safe operation.

(ii) Properly trained and supervised crew members working in accordance to SOPs are likely to perform more efficiently and safely.

(iii) Cabin crew understanding of passengers’ behavior and the emotions they can expect on board is important in establishing a good relationship which will improve the efficiency of service but will also contribute to the efficient and safe handling of emergency situations.

(iv) The proper layouts of displays and controls in the cockpit enhances Flight Crew efficiency while promoting safety.
Indu Bala et al., (2014) have distributed the articles in five (5) major perspectives of aviation safety namely Environmental, Human, Airspace & Airport, Technical, and Miscellaneous. In this, the maximum number of articles contributing towards failure is Technical Factors followed by Airspace and Airport.

4. Flight Safety Starts on the Ground

The aircraft flight safety shall be designed with the following minimum required instrumentation and equipment (F2245-16a 2016):

(a) Flight and Navigation Instruments: (i) Airspeed indicator, and (ii) Altimeter.

(b) Powerplant Instruments: (iii) Fuel quantity indicator (or equivalent for EPU), (iv) Tachometer (RPM), (v) Engine “kill” switch (or equivalent for EPU), and (vi) Engine instruments as required by the engine manufacturer.

(c) Miscellaneous Equipment—Other Than EPU: (vii) If installed, an electrical system shall include a master switch and overload protection devices (fuses or circuit breakers). (viii) The electric wiring shall be sized according to a load of each circuit. (ix) The battery installation shall withstand all applicable inertia loads. (x) Battery containers shall be vented outside of the airplane (Protection of the structure against weathering, corrosion, and wear, as well as suitable ventilation and drainage, shall be provided as required).

(d) Safety Belts and Harnesses—(xi) There a lap belt and at least one shoulder harness for each occupant and adequate means to restrain the baggage.

Educate about the benefits of flying an aircraft equipped with technologies that help in collision avoidance. Either flying in congested airspace or not, a cockpit display or alert of traffic information will increase awareness of surrounding traffic.

Pre-flight planning: Pilot should review Notice to Airmen (NOTAM), terrain information along their route of flight during pre-flight planning (NTSB 2016).

5. Modelling and Simulations

Complete modelling and simulation of an aircraft is the need for smart testing. From the modelling and simulation activities arrive at the safety limits for the given set of loading conditions. From the simulation arrive at the component to be tested for verification. Essentially analyses drives the selection of test articles in terms of loading (mechanical and thermal), complexity and novelty of design features, recognized failure modes, anticipated utilization, hybrid structure considerations etc. (Advisory Circular No. 90-48D).

From the simulation results, it is possible to arrive at the hot spots and monitor these locations using strain gages and displacement sensors. Digital / Design Mock-up (DMU) is the state of art towards digitization. DMU is a computer-based product definition of a real product. It consists of 3D geometry, product structure, attributes, and documents. All the components, digitized so that a prior information about the maximum structure deformation and its associated parameters computed. Engineering Mock-up (EMU) built by manufacturing team upon a later and more advanced design (Walter 2008) phase.

6. Concluding Remarks

This article presents various safety measures necessary for the successful and efficient performance of a test at all the four levels. All the four levels of tests viz., specimen, feature, component/part and full-scale. The vital factor of safety measure is to define the limits depending on the type and size of the test being carried out. Efficiency and safety issues are related, if safety exist, the efficiency will surge. Modelling and simulations show the hot spots in a component/part, enables in
monitoring these hot spots more effectively during real test. Usage of DMU and EMU aid in the arriving at the safety limits.

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