Structures Bulletin

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Number: EZ-SB-22-01

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Subject: Joint USAF/USN Methodology to Establish the Aircraft Allowable Load Limit Related to Static Strength Capability

References:

1. MIL-STD-1530D Change 1, “Department of Defense Standard Practice, Aircraft Structural Integrity Program”, 13 October 2016 (applicable to USAF only)
2. JSSG-2006, “Department of Defense Joint Service Specification Guide, Aircraft Structures”, 30 October 1998
3. EZFS-SB-05-002R1, “Joint USAF/USN Aircraft Strength Flight Release Methodology”, 20 October 2006
4. EN-SB-10-001, “Revised Design Criteria for Pressurized Structure”, 3 February 2012 (applicable to USAF only)
5. EN-SB-11-001 Revision A, “Guidance on Correlating Finite Element Models to Measurements from Structural Ground Tests”, 4 February 2020 (applicable to USAF only)

Purpose:

The purpose of this Structures Bulletin (SB) is to document the methodology for defining the aircraft allowable load limit (ALL) related to static strength capability.

Discussion:

Note that some References are applicable to USAF only, see above. References 1 and 2 provide some requirements and guidance related to establishing the appropriate ALL based on static strength capability. Reference 3 provided detailed requirements for establishing strength flight release limits. However, many issues and shortcomings in Reference 3 were identified during program implementation efforts that revealed the need for a comprehensive revision. To minimize the potential for confusion between Reference 3 revisions, this new SB is a replacement of Reference 3 and supersedes it. This SB applies to non-FAA certified USAF/USN fixed wing aircraft only.

1.0 Methodology to Establish the Initial ALL.

1.1 Methodology.

Table 1 shall be used to establish the initial ALL only if all of the additional requirements specified in paragraph 1.2 are achieved. These limits apply to aircraft ground and flight operations. See Appendix 1 for descriptions of the key terms used in Table 1.

#	Aircraft Has Strength Proof Test (SPT)?	Full-Scale Static Test (FSST) ?	Aircraft Has Loads Calibration to 80% Design Limit Load (DLL) and Real-Time Loads Monitoring?	Initial ALL	Maximum Initial ALL (%DLL)
1	No	No	No	40% Design Limit Load (DLL)	40
2	Yes to ≤100% DLL	No	No	%DLL = (SPT Load %DLL / 1.15) * 0.8	70
3	Yes to 100% DLL	No	Yes	80% DLL	80
4	Other Aircraft to ≤100% DLL	No	No	%DLL = (SPT Load %DLL / 1.5) * 0.8	53
5	Other Aircraft to 100% DLL	No	Yes	60% DLL	60
6	No	Yes	No	%DLL = (FSST Load %DLL / 1.5) * 0.8 * 0.8	64
7	No	Yes	Yes	%DLL = (FSST Load %DLL / 1.5) * 0.8	80
8	Yes	Yes	No	Use Higher of #2 and #6	
9	Yes	Yes	Yes	Use Higher of #3 and #7	
10	Other Aircraft to ≤100% DLL	Yes	No	Use Higher of #4 and #6	
11	Other Aircraft to 100% DLL	Yes	Yes	Use Higher of #5 and #7	

Table 1. Methodology to Establish the Initial ALL

1.2 Additional Requirements.

All of the following additional requirements must be satisfied for Table 1 to apply and the resulting documentation, test plans, test requirements, test data, etc. are subject to review and approval by the procuring agency. In addition, test data shall be used to validate/correlate/correct the relevant analyses.

1.2.1 Structural design criteria are based on requirements and guidance in References 1 and/or 2.

1.2.2 Loads analysis is completed and based on up-to-date structural design criteria, wind tunnel data, flight control laws, mass properties, etc.

1.2.3 Static strength analysis is completed and based on up-to-date structural design criteria, finite element model, loads, etc. and results in margins of safety equal to or greater than zero.

1.2.4 Design development test requirements established in Reference 1 or the contracted effort related to static strength are completed.

1.2.5 First flight verification ground test requirements established in Reference 1 related to loads and static strength are completed. The specific test requirements are shown in Table 2 for each case described in Table 1 where DLL for pressurized structure is described in Reference 4. Note that Reference 1 also requires additional ground testing be completed prior to first flight related to structural dynamics. For the USN, these requirements, including structural dynamics tests, are established by the procuring agency for the subject aircraft.

1.2.6 Aircraft “as built” configurations verified to be “as designed” and any deviations are properly dispositioned.

1.2.7 If an SPT is selected to achieve a desired initial ALL, the maximum applied test loads shall be 100% DLL and the SPT article shall be instrumented for strain measurements. Strain measurements shall be correlated to Finite Element Model (FEM) predictions (per Reference 5 for USAF). The test plan shall specify instrumentation, data collection, load cases, load application method, analysis validation criteria, etc. to include subsystems as selected.

1.2.8 If a FSST is selected to achieve a desired initial ALL, the FSST shall be conducted in accordance with Reference 1 and/or approved test plans. Strain measurements shall be correlated to Finite Element Model (FEM) predictions (per Reference 5 for USAF).

1.2.9 If an aircraft loads calibration test is selected to achieve a desired initial ALL, the test plan shall specify the loads calibration instrumentation, load cases, load levels, etc.

1.2.10 For all cases in Table 1, flight testing using an incremental build-up approach shall be conducted beginning with test conditions whose loads are predicted to be less than the maximum initial ALL. Flight test envelope expansion (e.g., symmetric maneuvers with increasing dynamic pressure, asymmetric maneuvers with increasing roll rate)

and flight test continuation criteria shall be established and approved by the procuring agency (System Program Office (SPO) and Responsible Test Organization (RTO) for USAF). Evaluation of flight test data that demonstrates criteria established by the procuring agency (SPO and RTO for USAF) are achieved, shall be completed prior to releasing the same incremental capability to other aircraft. Flight test envelope expansion up to the next build-up increment shall only proceed when the current increment satisfies the approved criteria.

1.2.10.1 For cases 1, 2, 4, 6, 8, and 10 in Table 1 (no basis for loads measurements or monitoring), the incremental build-up approach shall compare loads derived from recorded/measured parameters (e.g., Mach, altitude, pitch rate, roll rate, control surface positions) at specific conditions to predicted loads for the as-flown conditions.

1.2.10.2 For cases 3, 5, 7, 9, and 11 in Table 1 (loads calibration and real-time loads monitoring), the incremental build-up approach shall compare measured and predicted loads for the as-flown conditions.

#	SPT ?	FSST ?	Loads Cal. & Mon. ?	Maximum Initial ALL (%DLL)	Verification Ground Test Requirements Prior to First Flight for Each Applicable Aircraft
1	No	No	No	40	**Each Aircraft:** Mass Properties Tests, cockpit & fuel tanks Pressure Proof Tests at 100% DLL, SPTs of selected components, and Functional Proof Tests of control surfaces (no loading). **First Flight or Flutter Flight Test Aircraft:** Ground Vibration Test.
2	Yes to ≤100% DLL	No	No	70	**Each SPT Aircraft:** Mass Properties Tests, cockpit & fuel tanks Pressure Proof Tests at 100% DLL, SPTs , and Functional Proof Tests of control surfaces at maximum SPT loading. **First Flight or Flutter Flight Test Aircraft:** Ground Vibration Test.
3	Yes to 100% DLL	No	Yes	80	**Each SPT & Loads Calibration Aircraft:** Mass Properties Tests, cockpit & fuel tanks Pressure Proof Tests to 100% DLL, SPTs at 100% DLL, Functional Proof Tests of control surfaces at 100% DLL, and Loads Calibration Tests to 80% DLL minimum. **First Flight or Flutter Flight Test Aircraft:** Ground Vibration Test.
4	Other to ≤100% DLL	No	No	53	Same as #1
5	Other to 100% DLL	No	Yes	60	Same as #1 plus **Each Loads Calibration Aircraft:** Loads Calibration Tests to 80% DLL minimum.
6	No	Yes	No	64	**Each Aircraft:** Mass Properties Tests, cockpit & fuel tanks Pressure Proof Tests until representative 150% DLL FSST cases completed, and SPTs of selected components until representative 150% DLL FSST cases completed. **FSST:** Functional Proof Tests of control surfaces at 100% DLL prior to first flight. **First Flight or Flutter Flight Test Aircraft:** Ground Vibration Test.
7	No	Yes	Yes	80	Same as #6 plus **Each Loads Calibration Aircraft:** Loads calibration tests to 80% DLL minimum.

Table 2. Verification Ground Test Requirements

1.3 Rationale for the Methodology to Establish the Initial ALL.

Method 1: The initial ALL is based on a statistical evaluation of historic data of unexpected failures during FSST as a result of insufficient analysis methods or errors in the static strength analysis.

Method 2: The initial ALL equation includes a factor of 1.15 to account for uncertainty in the static strength capability due to the potential for insufficient methods or errors in the design analyses that would be uncovered during a FSST. The equation also includes a 0.8 factor which is the “loads factor” (LF) applied since flight and ground loads analyses have not been validated via flight test measured loads correlated with analysis predictions or corrected as necessary prior to the initiation of flight testing.

Method 3: The initial ALL is similar to method 2 and considers the additional benefit of loads calibration and real-time loads monitoring.

Method 4: The initial ALL equation includes a factor of 1.5 which is the standard factor of safety (FS) applied to DLL for the ultimate strength analysis check. The FS accounts for variability in the static strength capability of each aircraft considering statistical distributions of part geometries during manufacturing, material properties, assembly tolerances, etc.; and the potential for insufficient methods or errors in the design analyses. In other words, the SPT is treated as a FSST for non-SPT aircraft. The equation also includes the 0.8 LF.

Method 5: The initial ALL is similar to method 4 and considers the additional benefit of loads calibration and real-time loads monitoring.

Method 6: The initial ALL equation includes the 1.5 FS and the 0.8 LF. The equation also includes an additional 0.8 factor to account for unmonitored aircraft.

Method 7: The initial ALL equation is similar to method 6 except the additional 0.8 factor for unmonitored aircraft is removed.

The rationale for including both a FS and LF separately in the equations is based on probability of failure (PoF) calculations for various loads exceedance probability distributions combined with various strength probability distributions using the convolution integral method. The example calculations show that a 20% error in loads analysis or overload can increase the PoF by ~30 to ~300 times the baseline, a 15% error in strength analysis can increase the PoF by ~10 to ~100 times the baseline, and the combined errors can increase the PoF by ~300 to ~24,000 times the baseline. Ground and flight testing combined with analyses correlation and updates as necessary are required to mitigate the risk of errors jeopardizing structural integrity during aircraft operations.

2.0 Methodology to Establish the Maximum ALL.

2.1 Methodology.

Table 3 shall be used to establish the ALL based upon ground testing, %DLL achieved during loads flight testing, and correlation between measured and predicted loads. Table 3 applies to aircraft ground and flight operations after all development testing and analysis updates applicable to the case are completed. Only cases 3, 7, 9, and 10 in Table 3 have the potential for increasing the ALL beyond the maximum initial value. The incremental build-up approach described in 1.2.10 shall be continued to the maximum ALL. In Table 3, an LF equal to 1.0 may be approved if loads are validated to 80% DLL and real-time loads monitoring is performed, or with loads validated up to 100% DLL; otherwise the LF shall be 0.8.

#	Aircraft Has Strength Proof Test (SPT)?	Full-Scale Static Test (FSST)?	Loads Validated Via Flight Testing or Real-Time Loads Monitoring?	ALL Basis	Maximum ALL (%DLL)
1	No	No	No	Same as Initial	Same as Initial
2	Yes to ≤100% DLL	No	No	Same as Initial	Same as Initial
3	Yes to 100% DLL	No	Yes	%DLL = (SPT Load %DLL / 1.15) * LF or Special Case	Note 1
4	Other Aircraft to ≤100% DLL	No	No	Same as Initial	Same as Initial
5	Other Aircraft to 100% DLL	No	Yes	%DLL = (SPT Load %DLL / 1.5) * LF	67
6	No	Yes	No	Same as Initial	Same as Initial
7	No	Yes	Yes	%DLL = (FSST Load %DLL / 1.5) * LF	100
8	Yes	Yes	No	Use Higher of #2 and #6	70
9	Yes	Yes	Yes	Use Higher of #3 and #7	100
10	Other Aircraft to ≤100% DLL	Yes	No	Use Higher of #4 and #6	64
11	Other Aircraft to 100% DLL	Yes	Yes	Use Higher of #5 and #7	100

Note 1: As approved by the procuring agency (SPO and RTO for USAF)

Table 3. Methodology to Establish the Maximum ALL

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Appendix 1. Descriptions of Key Terms Used

Full-Scale Static Test (FSST): A FSST program is conducted on an instrumented aircraft using simulated loads derived from critical flight and ground handling conditions. The simulated loads include mechanical and thermal environment effects as required. The primary purpose of the static test program is to validate or correct the static strength analyses and to demonstrate DLL and design ultimate strength capabilities of the aircraft structure. A FSST program is conducted on a dedicated ground test article that is never to be operated. Detailed requirements for the FSST program are stated in paragraph 5.3.1 and subparagraphs of Reference 1.

Strength Proof Test (SPT): A SPT program is similar to a FSST program but with significant differences in intent, applied loads, instrumentation, and simulated loads methods explained below:

1. Intent: A SPT program is conducted on an aircraft that will be operated whereas a FSST is conducted on a dedicated ground test article that is never to be flown.

2. Applied loads: SPT applied loads are limited to DLL whereas FSST loads are up to design ultimate, as a minimum.

3. Instrumentation: SPT instrumentation to obtain measurements to validate or correct the FEM, stress, and strength analysis are typically less than for a FSST program.

4. Simulated loads methods: SPT loads simulation methods typically result in lower fidelity of load distributions than for a FSST program.

Paragraph 5.3.1 in Reference 1 states "… a separate full-scale static test is not required if any of the following conditions are met and specifically approved by the procuring agency:". Item c in the list of conditions state "strength demonstration proof tests are performed to sufficient load levels for a sufficient number of conditions on every flight aircraft to be operated. These proof tests shall demonstrate that deformation requirements have been achieved and shall be used to validate or correct the stress and strength analysis."

Loads Calibration: A loads calibration test program is conducted on a flight test aircraft during ground test loading to enable an indirect measurement of aircraft loads (e.g., wing bending, wing torsion) during flight testing for validation or correction of the loads analyses predictions. Paragraph 5.3.3.1 in Reference 1 states "…flight and ground loads survey program shall consist of an instrumented and calibrated aircraft operated within and to the extremes of its limit structural design envelope to measure the resulting loads and, if appropriate, to also measure pertinent temperature profiles on the aircraft structure. Load measurements shall be made in a build-up fashion by the strain gage or pressure survey methods commensurate with the state-of-the-art."

Factor of Safety (FS): The FS is applied to DLL to establish design ultimate loads used in the static strength analysis with ultimate design allowables for the materials. The FS accounts for variability in the static strength capability of each aircraft considering statistical distributions of part geometries during manufacturing, material properties, assembly tolerances, etc.; and the potential for insufficient methods or errors in the design analyses.

Loads Factor (LF): The LF is applied when flight and ground loads analyses have not been validated or corrected via flight testing conducted on a loads calibrated aircraft; except for the initial ALLs that are not based on an equation.