1 Introduction

This PM is applicable for analysis of metallic structures on new programs initiated after December 1998. Programs may supplement and tailor the content with program-specific guidance such as that found in References 1-7, 1-8 and 1-12, and customer-generated guidance such as 1-6 and 1-9 through 1-11. In general, this PM is not intended to supersede heritage structures manuals (e.g., References 1-1 or 1-2) used on legacy LM Aero programs initiated prior to December, 1998, since such programs are subject to a separate AeroCode policy document. If major modifications are made to legacy aircraft, it is recommended the new design be consistent with the methods contained herein.

Other aspects of structural analysis, such as stress analysis of composite structures, fatigue life methods, durability and damage tolerance, internal and external loads development, and dynamics are covered in other Process Manuals, program-level, and/or customer-provided guidance material.

Table of Contents

1.1 References

Each major section of this handbook will have a list of references specific to the material located in that section. Some of the general references used in preparing this document are listed below.

1-1. anon., *Lockheed Martin Engineering Stress Memo Manual*, Lockheed Martin Aeronautical Systems, Marietta, GA (October 1998 Release; April 2002 Revision).
1-2. anon., *Structures Analysis Manual, Volume 1* and Volume 2, General Dynamics Convair and Space Systems Division (1988).
1-3. Staff, *LTV Structures Manual*, LTV Aircraft Products Group, Grand Prairie, TX (June 1989 Revision).
1-4. Norwood, D and Selvarathinam, A, "LM Aero Procedures Manual, PM4056 Composite Structural Analysis Manual," Lockheed Martin Corporation, Fort Worth, TX, 2014
1-5. anon., "Metallic Materials Properties Development and Standardization," *MMPDS-XX*[1], Battelle Memorial Inst., Secretariat (200X).
1-6. Anon, "General Guidelines For Aircraft Structural Integrity Program," MIL-STD-1530C, United States Air Force, Wirght Patterson AFB, OH, 2005
1-7. E. Kelley, "F-22 Structures Policies and Analysis Methods," 5PD00132, Rev D, Lockheed Aeronautical Systems Co., Marietta, GA (January, 1996).
1-8. anon., "Structural Design Criteria for Block 50 F-16C/D Aircraft," 16PS135, General Dynamics Fort Worth Division, Ft. Worth, TX (1 August, 1989).
1-9. anon., "USAF Guide Specification for Aircraft Structures", *AFGS-87221A*, June 1990.
1-10. anon., "Damage Tolerance and Fatigue Evaluation of Structure (Acceptable Means of Compliance)," AC25.571(a), Federal Aviation Administration (Dec. 18, 1985).

[1] MMPDS revisions are designated by a 2 digit number, for instance MMPDS-03 was published in October 2006. Reference is left generic as MMPDS-XX.

1-11. anon., “Department of Defense Joint Services Specification Guide, Aircraft Structures, JSSG-2006,” Department of Defense, ASC/ENSI, Wright Patterson Air Force Base, Ohio (2006)
1-12. B.E. Mueller, N.G. MacKaron, “Structural Analysis Methods and Design Criteria,” 2ZSB00001 Rev E, Lockheed Martin Aeronautics, Northrop Grumman, BAE Systems, Fort Worth TX (2006)

1.2 Purpose

The purpose of this Process Manual (PM) is to provide general structural analysis methodologies and guidance for metallic materials applications to fulfill the analysis requirements of Tasks I-V of Reference 1-6, Reference 1-11 and FAR 25.

Figures 1.2-1 through 1.2-4 is a flow chart describing the entire design/analysis/test effort for the aircraft structure from concept to retirement. The stress analysis is only a portion of this total effort and this flow chart is provided here to give context to the analysis effort in aircraft design.

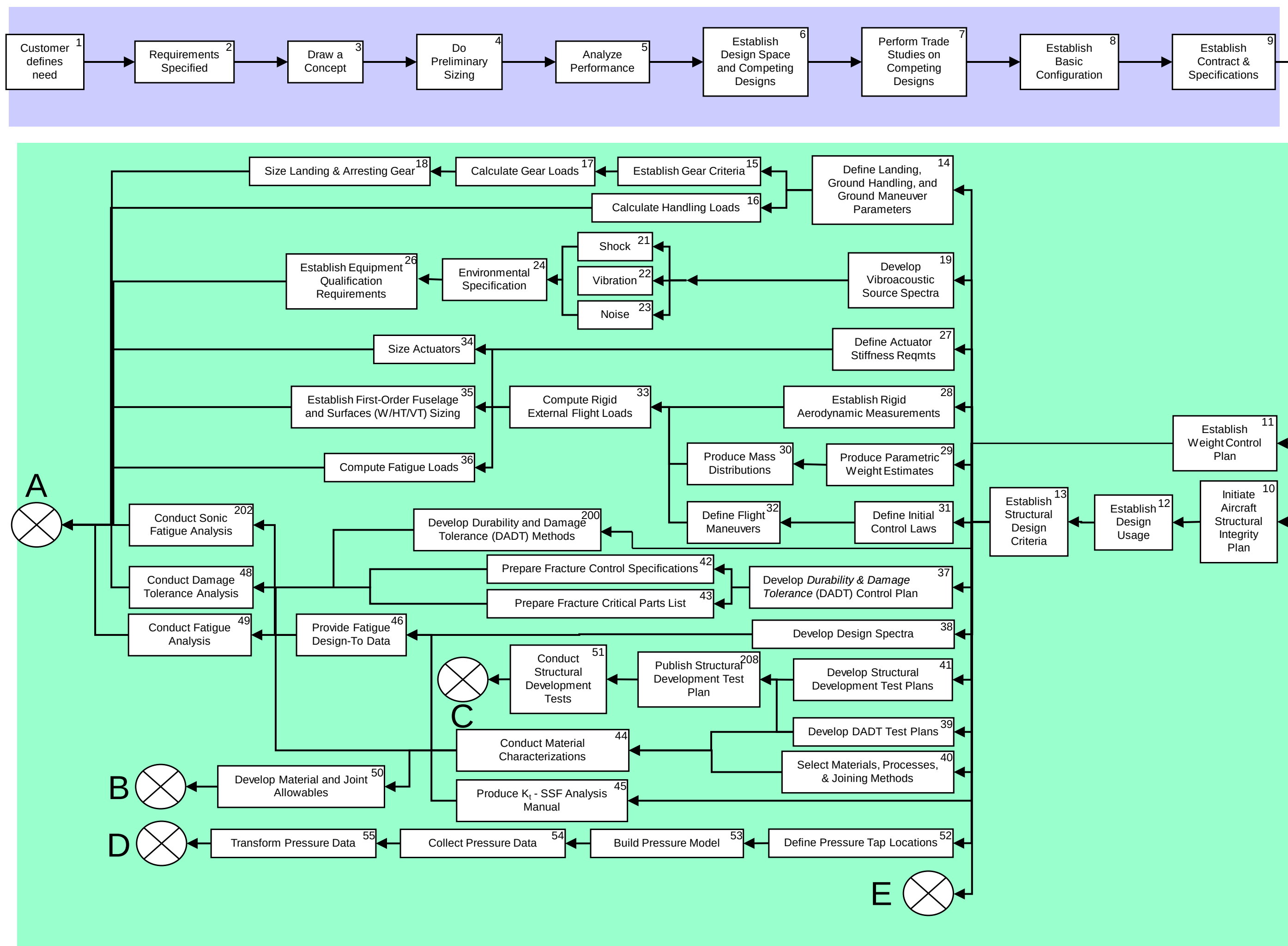

Figure 1.2-1 Aircraft Design Flowchart Part 1

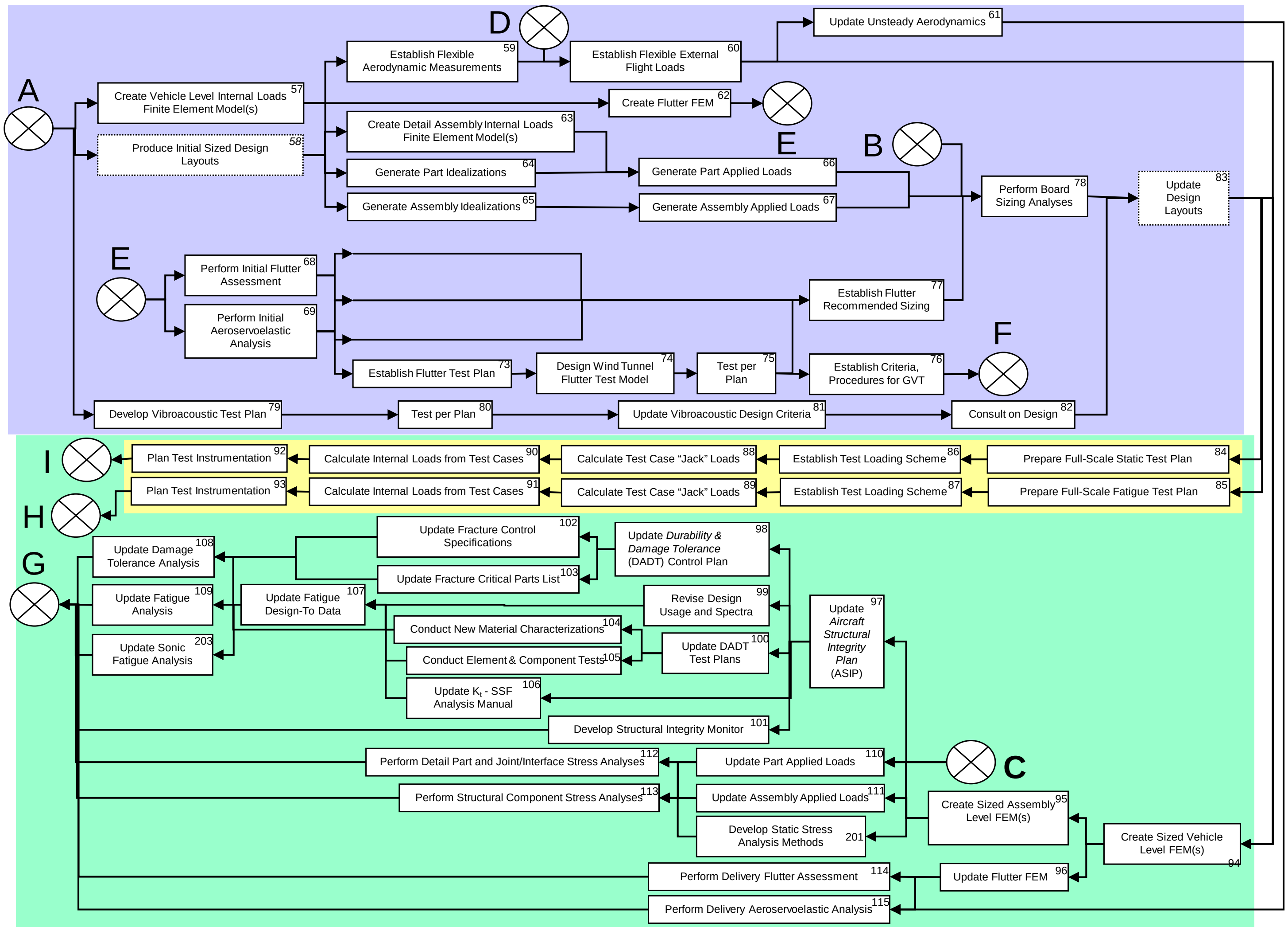

Figure 1.2-2 Aircraft Design Flowchart Part 2

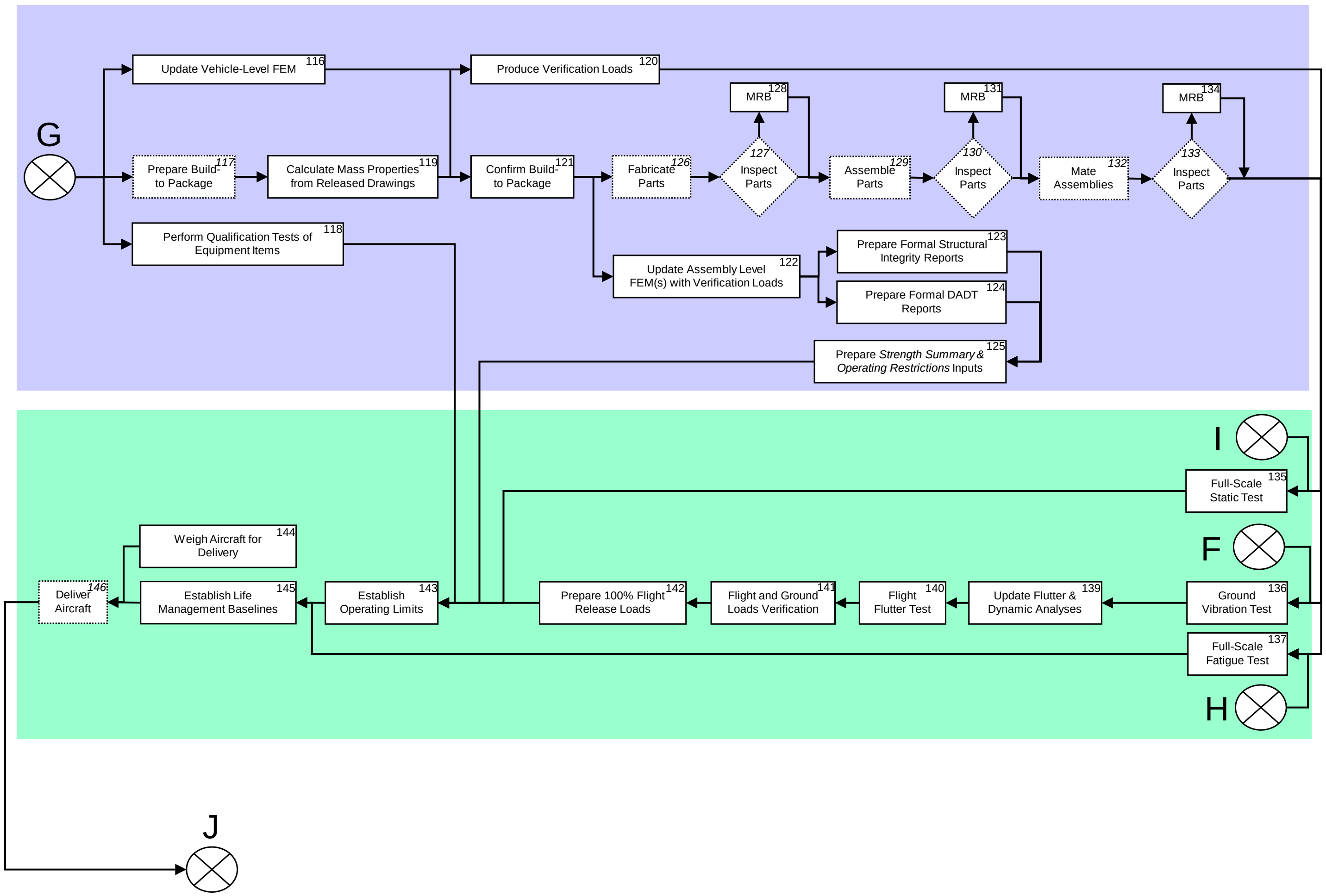

Figure 1.2-3 Aircraft Design Flowchart Part 3

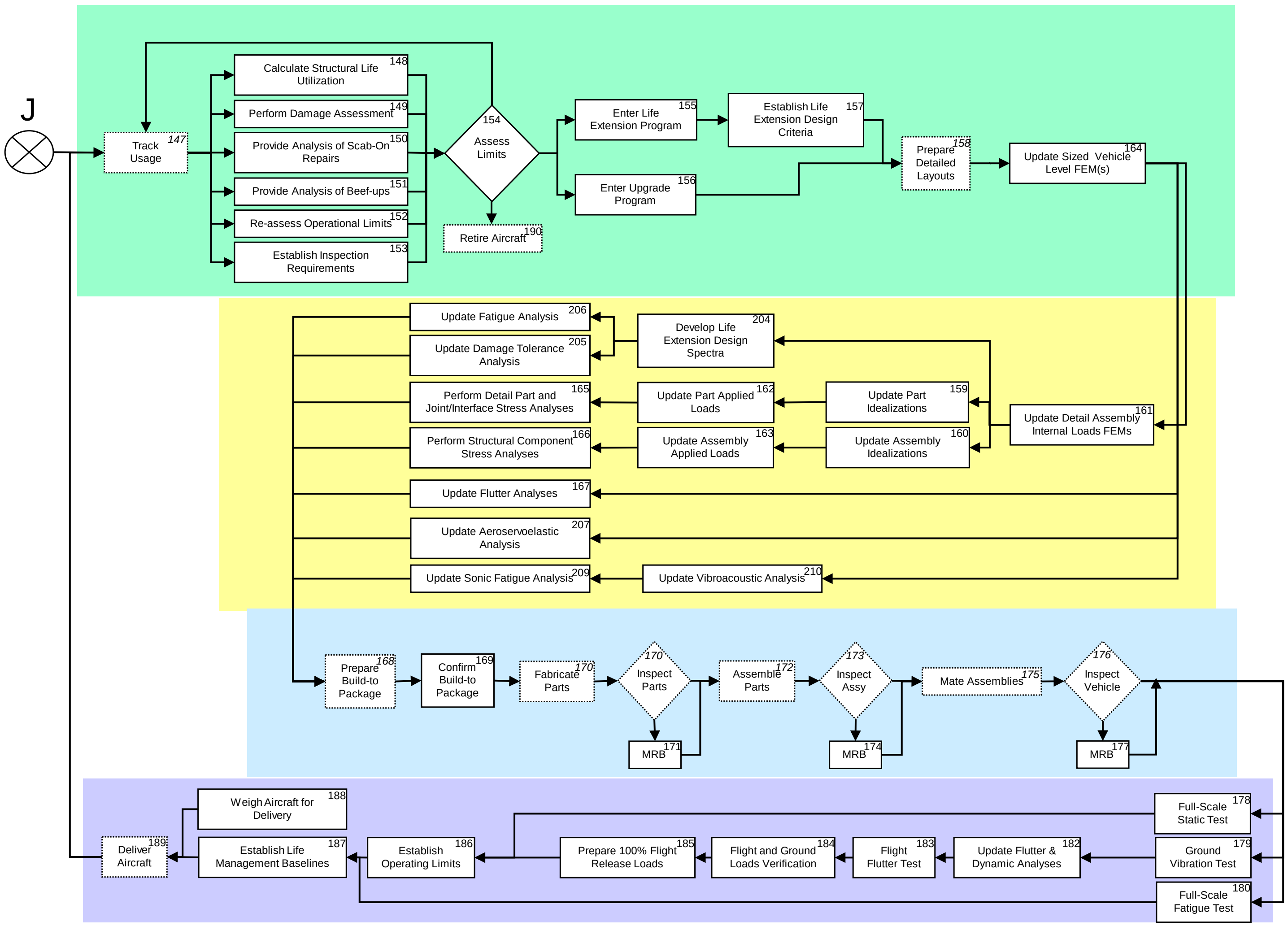

Figure 1.2-4 Aircraft Design Flowchart Part 4

1.3 Symbols and Abbreviations

Each major section of this manual contains symbols and abbreviations appropriate for the material covered in that section. Symbols listed here are of the most generic nature related to stress analysis and can be context dependent.

Symbol	Definition	Units
A	Area	in^2
ASAARS	Automated Structural Analysis and Reporting System	--
b	Width	in
D	Diameter	in
E	Tensile Modulus of Elasticity	psi
E_c	Compression Modulus of Elasticity	psi
E_{tan}	Compression Tangent Modulus of Elasticity	psi
e	Material elongation	in/in
e	Material strain	in/in
e	Edge distance from center of hole to edge of part	in
f	Stress	psi
F	Allowable Stress	psi
F_{bry}	Bearing Property Yield Stress	psi
F_{bru}	Bearing Property Ultimate Stress	psi
F_{cy}	Allowable Compression Yield Stress	psi
F_{su}	Allowable Shear Ultimate Stress	psi
F_{tp}	Allowable Tensile Proportional Limit Stress	psi
F_{ty}	Allowable Tensile Yield Stress	psi
F_{tu}	Allowable Tensile Ultimate Stress	psi
G	Modulus of Rigidity or Shear Modulus	psi
I	Moment of Inertia	in^4
IDAT	Integrated Detail Analysis Toolset	--
K or k	Stress amplification or reduction factor	--
m	Applied moment	in-lb
M.S.	Margin of Safety	--
n	Ramberg Osgood number	--
P	applied load	lb
Q	First or Static moment of inertia	in^3
R	Stress Ratio	--
t	Thickness	in
Greek Symbols		
Δ	Change or difference	--
ε	Material strain	in/in
σ	Stress	psi
τ	Shear stress	psi

1.4 Definition of Terms

This section provides some fundamental definitions of terms commonly used in analysis. For a more detailed description, please consult the appropriate section of this manual.

A-Basis – A design material property which is, per Reference 1.0.4 or 1.0.5, the lower of either the material specification minimum or the statistically calculated value that at least 99% of the population is expected to exceed with a confidence of at least 95%. See S-Basis.

Allowable Load – The calculated or experimentally-derived load at which failure is expected to occur; a part or assembly may have several potential failure modes and therefore several corresponding allowable loads.

B-Basis – A design material property which is, per Reference 1.0.4 or 1.0.5, a statistically calculated number that at least 90% of the population of values is expected to exceed with a confidence of at least 95%. See S-Basis.

Compact structure – Structural element which has no long thin flanges. The width of the flange divided by its thickness should be less than 7.

Design Limit Load – See Limit Load

Design Ultimate Load – See Ultimate Load

Engineering strain is the ratio of the change in length of a structural element under load to its original length. Strain is non-dimensional.

Equivalent Strength Analysis – Analysis performed in the absence of specific aircraft design loads and based on the existing capability of the part design.

Factor of Safety – The factor applied to limit loads to obtain the corresponding ultimate loads. This factor accounts for uncertainty in the analysis, including uncertainty in the loads, material properties, structural model and analysis methodologies, uncertainty in the fabrication process including artisan skills, etc. It is generally 1.5 for manned flight although certain exceptions may apply. The factor of safety is also referred to as the factor of uncertainty or the safety factor.

Factor of Uncertainty – See Factor of Safety

FEA – Finite Element Analysis - A numerical structural analysis method in which the structure is divided into numerous simple "finite elements" for which the load-displacement relationships are known allowing the overall load-displacement relationships for the structure to be determined through matrix methods. For a specified applied loading, the displacements, strains, stresses and internal loads in the elements can then be determined allowing for structural sizing and the calculation of margins of safety.

FEM – Finite Element Model – An assemblage of "finite elements" used to represent a structure for use in finite element analysis (FEA). Finite element models run the gamut from representing single parts to small subassemblies to the full aircraft. The model may vary from a very coarse representation to a very fine representation of the structure, as needed.

Grain Direction is the orientation of the primary grain structure in a metallic material or part. There may be up to three grain directions, usually orthogonal, depending on material and material form.

Life Enhancement Techniques – Manufacturing techniques, such as shot or laser peening and cold working, which provide life improvements to certain details within a part.

Limit Load – A maximum load or critical combination of loads any part of the aircraft is realistically expected to experience during its lifetime of service under normal operation within specification limits. Also called Design Limit Load.

Load Ratio – ratio of applied load to allowable load used in margin of safety interaction calculations.

Margin of Safety – A quantitative measure of the strength of a part at a particular location on the part at ultimate applied load. In its simplest form it is calculated as the allowable load divided by the factored applied load, minus one. For no failure, the margin of safety shall be greater than or equal to zero.

Modulus of Elasticity – Slope of the straight line portion of a stress-strain curve. It represents a relative measure of the stiffness of the material. See Young's Modulus.

Multiple Loadpath Structure (Redundant Structure) – A group of structural components sharing a common load, such that a single component failure would result in redistribution of load to the remaining undamaged components and not compromise a mission or lead to catastrophic failure.

Non-structural shim – Shims having insufficient attachment provisions to effectively transfer load into and out of the shim to make it act as a part of the structure.

Normal Stress - The load divided by the original area.

Pitch Distance – Fastener spacing.

Plasticity Correction - A reduction in the buckling stress in metallic plates when the stress exceeds the proportional limit. It can be estimated by substituting a reduced modulus for the Young's modulus: $\eta = \sigma_{cr\text{-}plastic}/\sigma_{cr\text{-}elastic} = E_t/E$ or E_s/E:

Poisson's Ratio - The ratio of strain perpendicular to an applied axial force relative to strains parallel to it. It is a fundamental property of the material characterizing a phenomenon exhibited in the distortion of a part under load, wherein the cross-section contracts or expands as the length increases or decreases, respectively. Values for many materials can be found in References 1.0.4 or 1.0.5. For most metals, in the elastic range, it is approximately 0.29 to 0.35. As the material becomes increasingly plastic in behavior the value approaches 0.5.

Proportional limit – The point at which the stress versus strain in a material deviates from a straight line. Since the concept of a constant linear value for Modulus of Elasticity, E, is a matter of theoretical and computational convenience, the stress or strain level at which the stress-strain curve deviates from a straight line is somewhat arbitrary. In tension it is generally set at 0.0001 in/in strain or 0.01% offset from the straight line portion of the stress-strain curve. Sometimes it may be appropriate to adjust this value.

Ratio to Requirement – A ratio calculated by dividing the applied load or deflection by the required load or deflection. Generally used for stability or deflection criteria analysis.

Safety Factor – See Factor of Safety

S-Basis – This design property represents the specification minimum for a material, which has a limited statistical basis.

Secant Modulus - The slope of a line from the origin to a specific point on the stress-strain curve as shown in Figure 1.5-1. There is a different secant modulus for each stress-strain pair above the proportional limit. Below the proportional limit the secant modulus is equal to the Modulus of Elasticity.

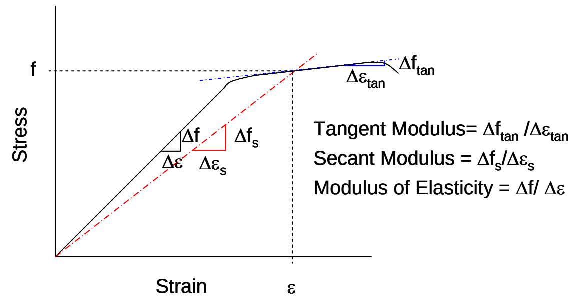

Figure 1.5-1 Stress-Strain Curve

Single Loadpath Structure – Structural component where a single failure could compromise the load carrying ability of the aircraft and lead to catastrophic failure or compromise of mission.

Stress – The applied load divided by the area to which the load is applied; the area used is the unstressed area.

Stress-strain curve – A plot of the stress in a material versus the corresponding strain level, generally from a standard specimen test. It demonstrates the elastic and plastic behavior of the material, including ultimate failure level.

Structural Shim – A shim having sufficient attachment provisions, strength and stiffness to effectively act as a splice plate in transferring load in a joint.

Tangent Modulus – Slope of the tangent to the stress-strain curve at a given stress as depicted in Figure 1.5-1. This represents the local rate of change of the stress with strain ($d\sigma/d\varepsilon$). The Tangent Modulus is the same as the Modulus of Elasticity in the elastic range but in the plastic range it gets smaller in magnitude as the stress gets higher, indicating the reduced stiffness of the material. The tangent modulus curve for many materials is provided in Reference 1.0.4 or 1.0.5.

True normal stress – Total load divided by the associated actual sectional area. This accounts for the transverse expansion or contraction under axial load due to Poisson's effect.

Ultimate Load – A maximum load or critical combination of loads used in any part of the aircraft for design and certification. This load level is used in the analysis and ground testing of the aircraft, but, except for unusual circumstances, a typical aircraft is not expected to experience this load magnitude. Design ultimate loads may be the result of limit loads multiplied by a program-specified factor of safety, or of specially defined loads for specific landing or ground handling conditions, crash, ditching, birdstrike, engine rotor seizure, engine fan blade out or other failure conditions. Such specially defined loads arise from extreme conditions which are not considered normal operation and generally do not have a factor of safety applied; the design requirement is no failure under a one-time occurrence. Also called Design Ultimate Load.

Utilization factor – A ratio indicating how much of a given part's strength capacity is utilized by the applied loads. This factor is used in margin of safety interaction calculations.

Yield Stress - Stress at some given amount of plastic strain for use in design. It is generally defined as 0.002 in/in strain or 0.2 % offset as shown in Figure 1.5-2. This value is used in setting a boundary for analysis using purely elastic behavior.

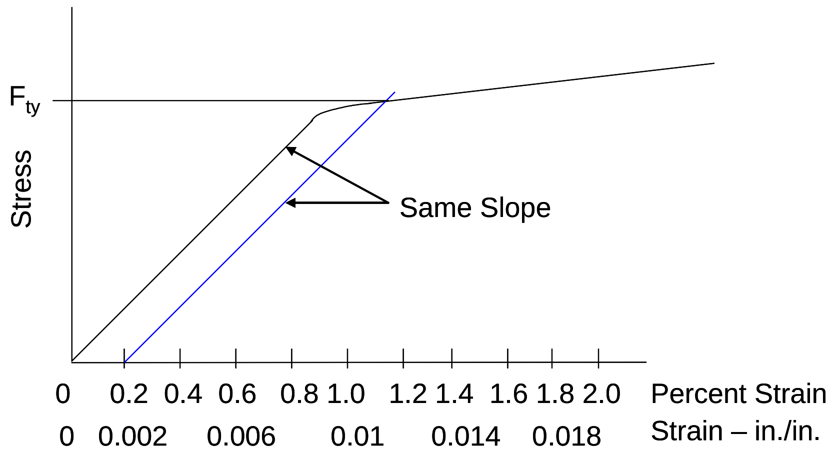

Figure 1.5-2 Stress-Strain Curve Illustrating Development of F_{ty}

Young's Modulus – The Modulus of Elasticity in the linear, or elastic, portion of the stress-strain curve of a material.