GAMA PUBLICATION NO. 13

ACCEPTABLE PRACTICES DOCUMENT, CABIN INTERIOR MONUMENT STRUCTURAL SUBSTANTIATION METHODS

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FOREWORD

The GAMA Publication No. 13 – Acceptable Practices Document, Cabin Interior Monument Structural Substantiation Methods was made possible by the dedicated efforts of a broad aviation industry coalition of both GAMA and non-GAMA member manufacturers and the Federal Aviation Administration (FAA).
The guidelines in this Acceptable Practices Document (APD) were contributed by various members of the aviation community to assist in the preparation of documents considered necessary to substantiate the installation of interior cabin monuments. The recommendations address certification of Transport Category Airplanes certified to 14 Code of Federal Regulations, Part 25, but the principles are applicable to other aircraft programs.

The intent is to present clearly defined methods and procedures to standardize and clarify the presentation of the required information and thereby reduce the ambiguity and time to certify the products, and insure consistency across FAA regions.

Future revisions of this document will further expand the scope and detail of the work. Questions on interpretation, proposed changes to this publication and contributions of specific examples of accepted practices should be submitted to the General Aviation Manufacturers Association where they will be reviewed by a working committee and considered for future incorporation.

Sincere thanks are hereby extended to the following organizations for their contributions and participation in the various meetings toward the development of this publication:

- Aero Design Inc.
- BE Aerospace
- Boeing Commercial Aircraft Co.
- C & D Aerospace
- Cessna Aircraft Company
- Dassault FalconJet
- DeCrane Aircraft Cabin Mgmt.
- Delta Engineering
- Federal Aviation Administration
- General Aviation Manufacturers Association
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- Halvorson Engineering
- JAMCO America
- McGettrick Structural Engineering
- Northwest Composites
- Perrella & Associates
- Threshold Engineering Co.

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CHAPTER 1. INTRODUCTION

1. Background

This document was developed by the General Aviation Manufacturers Association (GAMA), Cabin Monuments Subcommittee. The Cabin Monuments Subcommittee was formed at a meeting hosted by GAMA on April 4-5, 2001. The meeting included participants from the business aviation industry, the FAA, and GAMA. The GAMA Business Aircraft Interiors (BAI) Ad Hoc Committee was formed to resolve certification issues and disparity within industry impacting cabin interiors. A member's roster of the BAI Ad Hoc - Interior Monuments Subcommittee is included in Appendix A.

2. Purpose

(1) The guidelines in this document were contributed by various members of the aviation community to assist in the preparation of documents considered necessary to substantiate the installation of interior cabin monuments. The recommendations address certification of Transport Category Airplanes certified to 14 Code of Federal Regulations, Part 25, but the principles are applicable to other aircraft programs.

(2) The intent is to present clearly defined methods and procedures to standardize and clarify the presentation of the required information and thereby reduce the ambiguity and time to certify the products, and ensure consistency across FAA regions.

(3) Future revisions of this document will further expand the scope and detail of the work. Specific examples of accepted practices are included in attached Appendices to this document, and will continue to be incorporated. Questions on interpretation, proposed changes to this publication and contributions of specific examples of accepted practices should be submitted to the General Aviation Manufacturers Association where they will be reviewed by a working committee and considered for future incorporation.

<u>COMMENTS on GAMA ACCEPTABLE PRACTICES DOCUMENT for MONUMENTS</u>

Submit to:	GAMA Pub 13 Monument APD Comments Attn: Gregory J. Bowles
By Mail:	General Aviation Manufacturers Association 1400 K Street NW, Suite 801 Washington, DC 20005-2485
By Fax:	(202) 842-4063
By E-mail:	comments@GAMA.aero

(4) All contributions will be reviewed by a working committee and considered for future incorporation.

(5) This is a significant step towards creating a resource that will not only enhance the relationships within the aviation industry, but also promote the spirit of professional cooperation that is vital to continued improvement in quality and safety of our products. Contributions, suggestions, and questions are encouraged and requested from all interested parties.

3. Applicability

The methods described in this document on the structural substantiation of interior monuments are applicable to Transport Category Airplanes certified to 14 Code of Federal Regulations, Part 25.

4. General Requirements

A Structural Certification Plan is developed by the applicant to define the monument design characteristics, materials & processes, and the substantiation methods the applicant will be using. The FAA accepted plan offers an advanced notice of all new materials and designs as well as being a documented working agreement between the applicant and the FAA. The Structural Certification Plan should include the following:

(1) The airplane certification basis (detailed on the Type Certificate Data Sheet).

(2) A brief description of the monument/s structure including: the monument/s part number/s, the basic construction materials, critical processes, castings, major fittings, and the joint design details. Provide detailed figures with dimensions.

(3) A compliance checklist of the applicable regulations.

(4) Proposed method/s of structural substantiation (e.g. structural testing, analysis supported or validated by test, analysis and partial test, analysis only, and/or by comparison analysis).

(5) A listing of the structural substantiation documents to be submitted.

(6) A weight estimate table including the monument structure weight, the installed equipment weights, and compartment contents weights.

(7) Loads table/s including: design load factors, flight load factors, fitting factors, and other applicable loads and/or factors.

(8) Method/s of calculation of interface loads. For finite element modeling, identify the name and version of FEM code to be used.

(9) A listing of applicable design values including FAA "A" & "B" Design Allowables, and all design value allowable source documents.

(10)A listing of the material and process specifications with revision levels used in the construction of the monument/s, and confirmation that the specifications are FAA approved for the aircraft which the monument is intended to be installed.

(11)A listing of the names of those to be involved in the preparation of documents (e.g. engineering documents, quality assurance documents, and the certifying agency documents).

(12)A proposed program schedule.

5. Applicable Federal Aviation Regulations

Note: Specific FAA regulations can be found at www.faa.gov.

Article 14 Code of Federal Regulations, Chapter 1, Subchapter C and Aircraft, Part 25 Airworthiness Standards: Transport Category Airplanes:

Sub-part C – Structure

- Section 25.301 *Loads* (as amended by Amendment: 25-23, 35 FR 5672, Apr. 8, 1970)
- Section 25.303 *Factor of Safety* (as amended by Amendment: 25-23, 35 FR 5672, Apr. 8, 1970)
- Section 25.305 *Strength and Deformation* (as amended by Amendment: 25-86, 61 FR 5220, Feb. 9, 1996)
- Section 25.307 *Proof of Structure* (as amended by Amendment: 25-72, 55 FR 29775, July 20, 1990)
- Section 25.365 *Pressurized Cabin Loads* (as amended by Amendment: 25-87, 61 FR 28695, June 5, 1996)
- Section 25.561 *General* (as amended by Amendment: 25-91, 62 FR 40706, July 29,1997)

- Section 25.562 *Emergency Landing Dynamic Conditions* (as amended by Amendment: 25-64, 53 FR 17646, May 17, 1988)

Subpart D – Design and Construction

- Section 25.601 *General*
- Section 25.603 *Materials* (as amended by Amendment: 25-46, 43 FR 50595, Oct. 30, 1978)
- Section 25.605 *Fabrication Methods* (as amended by Amendment: 25-46, 43 FR 50595, Oct. 30, 1978)
- Section 25.607 *Fasteners* (as amended by Amendment: 25-23, 35 FR 5672, Apr. 8, 1970)
- Section 25.613 *Material Strength Properties and Design Values* (as amended by Amendment: 25-72, 55 FR 29775, July 20, 1990)
- Section 25.619 *Special Factors* (as amended by Amendment: 25-23, 35 FR 5672, Apr. 8, 1970)
- Section 25.625 *Fitting Factors* (as amended by Amendment: 25-72, 55 FR 29775, July 20, 1990)
- Section 25.787 *Stowage Compartments* (as amended by Amendment: 25-51, 45 FR 7755, Feb. 4, 1980)
- Section 25.789 *Retention of Items of Mass in Passenger and Crew Compartments and Galleys* (as amended by Amendment: 25-46, 43 FR 50596, Oct. 30, 1978)

Subpart G – Operating Limitations and Information (Markings and Placards)

- Section 25.1541 *General*
- Section 25.1557 *Miscellaneous Markings and Placards* (as amended by Amendment: 25-72, 55 FR 29786, July 20, 1990)

6. Related Documents

(1) FAA Presentation (Power Point® CD) entitled: Overview of Aircraft Interior Monument Structural Substantiation Requirements/Guidelines/Practices, given by FAA/Transport Airplane Directorate/Standards Staff/Cabin Safety-Airframe Branch/ANM-115-GLS. Note: This document is available through GAMA.

(2) FAA Presentation entitled: Application of Finite Element Analyses (FEA) – Aircraft Interior Structures given by FAA/Transport Airplane Directorate/Standards Staff/Airframe Branch/ANM-115-GLS. Note: This document is available through GAMA.

(3) FAA Presentation entitled: Material Strength Properties and Design Values presented by Seattle ACO Airframe Branch / ANM-120S July 25, 2002. Note: This document is available through GAMA.

(4) FAA MEMORANDUM entitled: Static Strength Substantiation of Composite Airplane Structure, from the Manager, Small Airplane Directorate, Aircraft Certification Service, ACE-100, dated July 30, 2001. Note: This document is available through GAMA.

(5) Niu, Michael, Airframe Structural Design, Conmilit Press, 1988.

(6) Roark RJ, Young WC, Formulas for Stress and Strain, Fifth Ed, McGraw Hill.

(7) Bruhn, E.F., Analysis and Design of Flight Vehicle Structures, Jacobs Publishing, Inc., Carmel, Indiana, 1973.

(8) MIL-HDBK-5H(1) Metallic Materials and Elements for Aerospace Vehicle Structures. Dated Oct.1, 2001. Department of Defense Handbook. Replaced by DOT/FAA/AR-MMPDS-01, available from the US Department Commerce Technology Handbook Administration, National Technology Information Service.

(9) MIL-HDBK-17 Website: http://www.mil17.org. (Click on Resources/Software/STAT17 MS EXCEL Spreadsheet File is downloadable, and approved for use in Mil-17 material allowable development)

(10) MIL-HDBK-17B(1) Polymer Matrix Composites, Volume 1, Guidelines. Dated Oct. 1, 2001. Department of Defense Handbook.

(11) MIL-HDBK-17/2E Polymer Matrix Composites Materials Properties, Volume 2. Dated May 24, 1999. Department of Defense Handbook.

(12) MIL-HDBK-17/3E Polymer Matrix Composites Volume III. Materials Usage, Design, and Analysis. Dated Jan. 23, 1997. Department of Defense Handbook.

(13) MIL-HDBK-17/4 Composite Materials Handbook. Volume 4. Metal Matrix Composites. Dated Sep. 21, 1999. Department of Defense Handbook.

(14) Material Qualification and Equivalency for Polymer Matrix Composite Material Systems – DOT/FAA/AR-00/47.

(15) AGATE statistical analysis program entitled: Material Qualification Methodology for Epoxy-Based Prepreg Composite Material Systems. Note: This document is available through GAMA.

(16) Handbook: Manufacturing Advanced Composite Components for Aircraft, DOT/FAA/AR-96/75.

(17) Fiber Composite Analysis and Design: Composite Materials and Laminates, Vol. 1 and 2, DOT/FAA/AR-95/29, I and II.

(18) Certification Testing Methodology for Composite Structure, Volumes I and II, DOT/FAA/CT-86/39.

(19) Federal Aviation Administration, Designee Newsletter, Aircraft Certification Division, Transport Airplane Certification Directorate, Edition 6; December 7, 1987.

(20) Peery, David J., and Azar, J.J., Aircraft Structures, McGraw-Hill Book Company, New York, 1982.

(21) Baumeister, Theodore, and Marks, Lionel S., Standard Handbook for Mechanical Engineers, Seventh Edition, McGraw-Hill Book Company, New York, 1967.

(22) Hexcel Corporation, Mechanical Properties of Hexcel Honeycomb Materials, TSB120.

(23) Hexcel Corporation, Bonded Honeycomb Sandwich Construction, TSB124.

(24) NASA Technical Memorandum TM X-73305, "Astronautics Structures Manual", Volume I, George C. Marshall Space Flight Center, Alabama, August 1975.

(25) NASA Technical Memorandum TM X-73306, "Astronautics Structures Manual", Volume II, George C. Marshall Space Flight Center, Alabama, August 1975.

(26) NASA Technical Memorandum TM X-73307, "Astronautics Structures Manual", Volume III, George C. Marshall Space Flight Center, Alabama, August 1975.

CHAPTER 2. DEMONSTRATION BY STATIC TEST

This section describes acceptable methods to fulfill the requirements for cabin monument substantiation by full scale static testing, and outlines the key elements required for the development of a static test plan including: a static test proposal and a static test results report.

1. General Requirements

A Static Test Proposal is developed by the applicant to define the monument design characteristics, materials and processes, and the testing methods the applicant will be using. The approved Proposal offers the FAA an advanced notice of all new materials and designs; it is also a documented working agreement between the applicant and the agency. If the test article, after testing, is to be used as a production unit for installation in a production airplane, the procedures for ensuring that the delivered unit is airworthy, that includes quality control requirements, refurbishment and overhaul, and completion, shall be defined as part of the certification plan. Cost and risk is minimized by limiting and simplifying the test article and the test setup, including test article refurbishment between tests or multiple test articles, simplification of fixture design, simplification of load application system and simplification of instrumentation.

2. Purpose

The cabin interior monuments shall be static tested for structural substantiation in accordance with the requirements of a test proposal approved by the FAA. The unit shall sustain ultimate loading for all critical design load conditions as defined by the test proposal, for a minimum of 3 seconds as required by 14 CFR, 25.305. Design load conditions not deemed critical need not be tested; however, documentation shall be provided to demonstrate that compliance with strength requirements for all required design loading conditions is proven by other tested load conditions, or by complementary analyses (see Chapter 4.).

3. Documentation

The applicant's submittal documents, which include drawings, should be in English. English units shall be pounds-force and inches; S.I. units should be newtons and millimeters. When S.I. units are used, summary tables, totals, etc. should also include English units. The test plan shall also include test fixture and test jig descriptions, as well as descriptions of the load measurement/test equipment to be used during the test. The test plan shall also reference applicable design data and revision level. A brief description of the monument structure should include the basic construction materials, critical processes, major fittings, and joint design details.

The structural documentation of the static test shall be submitted in two parts, Static Test Proposal and Static Test Results as follows:

Static Test Proposal Contents (Key Elements)

A Static Test Proposal should be used to inform the FAA of the intent to perform a test. The Test Proposal would contain a Test Plan as well as schedules for completion of various portions of the test (see item 19). A Static Test Plan should include only the details of what to do during the test and how to do them (see items 1 through 18). The Test Plan should not include any schedules. The Test Plan, once approved by FAA, could be reused for other tests.

(1) Identify the Certification Basis (Type Certificate Data Sheet per FAA, CAA, JAA, etc.)

(2) The test proposal shall include test article description, weight estimates, compartment contents and center of gravity calculations, tests loads, test procedures, and deflection measurement points. Detailed sketches with dimensions and a list of the test article part numbers should also be included. The monument test article need only be structurally complete. Parts, components and features that do not substantially affect structural integrity do not need to be installed. Omission of these details must be listed in the test plan or noted in the test article drawing.

(3) The monument test article design data should include:

a. The test article assembly drawing

b. The applicable sub-assembly and detail drawings

c. The monument installation drawing including installation hardware details and assembly drawings

d. The monument FAA-approved design allowables document when available. This should include the required data for newly developed design allowables or evidence of prior approval document when available.

e. The airframe structure drawings and/or maximum allowable interface load and strength data applicable to monument installations if available.

f. Test fixture drawing

g. List of applicable material and process specifications with respective revision levels used in the construction of the monument test article. If the specifications are newly developed, the data necessary for approval shall be provided. If the specifications have been previously used, include evidence of previous approval.

(4) Test fixture validation including airframe attachments with representative airframe structural members, or supporting analyses defining airframe stiffness.

(5) Definition of the test load cases. Qualitative, comparative or quantitative analyses may be used to limit the number of tests to those load cases deemed critical test conditions.

(6) Design load factors

a. Landing conditions.

b. Flight Conditions.

(7) Fitting factors if required.

(8) Other loads or load factors where applicable.

(9) Indicate the locations on the monument test article where deflections are to be measured, how deflections will be measured, and when to obtain the measurement during the test.

(10) The monument dry weight and center-of-gravity (C.G.)

(11) The contents weights and C.G.

(12) The method used to calculate the monument interface loads when required. The static test substantiates the monument side of the airframe attachments. Unless the test fixture duplicates the airframe interface structure, one is left with the task of substantiating that side of the structure. Unless the reactions were measured during the static test, provide methods used for calculating the reactions in the redundant structures. If an FEA is used to calculate the reactions, provide validation documentation.

(13) List FAA conformity inspections that include:

c. The FAA conformity inspections for the monument test article assembly

d. The monument installation on the test fixture

e. The test set-up design including a verification of the test fixture stiffness (where required)

f. Completed FAA conformity records are required prior to testing.

(14) Indicate the temperature and humidity conditions when and/or if required for testing.

(15) Indicate load application methodology/s: whiffletree design, contents load distribution, and equipment/component installation method representing the actual unit.

(16) Include a listing of the test instrumentation and calibration requirements (e.g. load cells / strain gages, weigh scales and measurement tools).

(17) Define the monument testing protocol (e.g. test condition sequence, step by step testing instructions, signage requirements, photo/video documentation and etc.).

(18) Establish the monument “pass/fail” criteria.

(19) Establish a testing schedule that includes:

a. Completion of test article drawings (e.g. details, sub-assembly, assembly and installation)

b. Completion of test set-up drawings

c. Completion of test plan/proposal (may be submitted to FAA by DER with recommended approval)

d. Completion of FAA Form 8120-10 *Request for Conformity*

e. FAA approval of the test plan/proposal

f. Completion of the fabrication of the test article

g. Completion of FAA Form 8130-9 *Statement of Conformity.*

h. FAA conformity of the test article including FAA Form 8100-1 *Conformity Inspection Record*, and FAA Form 8130-3 *Airworthiness Approval Tag* (when required)

i. Installation of test article in testing fixture

j. FAA conformity of the test set-up

k. Testing date/s

l. Completion of testing results report

Static Test Results Report Contents

Upon completion of the monument or interior furnishing static tests a test results report including the following items shall be prepared:

(1) The date and location of the testing

(2) A brief description of the test article and the materials utilized

(3) The loads, load factors, and direction actually achieved for a three (3) second minimum requirement

(4) Measurement of monument deflections at the critical locations under load specified in the approved test proposal

(5) A statement by the FAA test witness and/or FAA authorized designee confirming the testing was completed and in accordance with the test proposal, and any exceptions noted

(6) A table indicating whether each test condition was a success or failure according to the pass/fail criteria in the test proposal

(7) Photos and/or movies of the testing

(8) Environmental conditions (temperature and relative humidity) at the time of the testing when required

(9) List of testing witnesses including FAA test witness and/or FAA authorized designee

(10) A post-test inspection report including descriptions and photos/video of any damage incurred

(11) A copy of the FAA/FCAA or CAA or equivalent foreign regulatory agency approved statement of conformity inspection records:

a. Manufacturer's inspection records

b. FAA Form 8130-9 Statement of Conformity

c. FAA Form 8130-3 Airworthiness Approval Tag (when required)

d. FAA Form 8100-1 Conformity Inspection Record

(12) Equipment Calibration records (e.g. load cells, strain gages, weigh scales, etc.)

One document covering all units or separate documents for each unit may be submitted. This should be specified in the Structural Certification Plan.
The test proposal shall be submitted for approval to the FAA in accordance with the negotiated schedules. The test results report can be submitted as approved by the DER if delegated by the certifying agency.

4. Test - General

All testing will require a conformity inspection and an authorized test witness. If a test failure should occur, the controlling certifying authority, and the applicant shall be notified within 24 hours. This will allow the controlling authority, along with the applicant, to evaluate the impact of the failure and the repair on the test article certification program.

5. Conformity Inspection

An authorized representative from the supplier quality assurance shall inspect the test article including set-up, and provide a statement of conformity (FAA Form 8130-9). An authorized representative from the certifying agency FAA/FCAA inspector or authorized designee shall check the test article and the test set-up for conformity to the applicable design data prior to static test.

Any unsatisfactory condition identified during conformity inspection must be coordinated with the authorized designated engineering representative (when authorized by the certifying agency), or responsible certifying agency project manager, and a disposition determined. After the inspection has been performed, a properly executed conformity inspection record (FAA Form 8100-1) shall be signed, available for viewing prior to testing, and provided as part of the static test results.

The Static Test Proposal must be approved by the responsible certifying agency prior to the conformity inspection and the test witnessing.

6. Witnessing Procedure

The responsible certifying agency and/or authorized designated representatives shall witness the static testing. The test witness should validate that the test plan/supporting engineering drawings are FAA approved and FAA conformity paperwork is complete prior to testing. The test witnesses shall verify that the tests were conducted in accordance with the approved test plan. A test witness listing for each test condition shall be included as part of the Static Test Results Report.

The responsible certifying agency shall be notified of the test schedule 30 days prior to the test (or a mutually agreed upon schedule) to allow time to request attendance of the agency engineering representative or designee (this is imperative if the test is to be witnessed on behalf of the applicant, especially by a foreign authority). The responsible certifying agency or delegated representative should be provided with copies of all conformity paperwork prior to test.

7. Criteria for Successful Test

A static test shall be considered successful, and the monument acceptable for installation in the aircraft, if the following conditions are met:

(1) For monument assembly certification –

a. All limit loads (if applicable) must be reached and held with no detrimental, permanent deformation or structural failures.

b. The test article must be subjected to the required ultimate loads, held for three (3) seconds. The test article can't break free from its supports or restraints, and can't release its contents into the surrounding area.

c. Internal structure failures at ultimate loads may be acceptable providing that they do not impact the unit's ability to meet the criteria outlined in "b." above.

(2) For monument installation certification:

a. Interface load distribution to airplane attachment points, as defined by the approved interface loads document, is not significantly altered by any damage or detrimental, permanent deformation sustained by the monument's major load carrying details during the testing.

1. Major load carrying details are defined as floor fittings and surrounding structure, overhead attachment fittings and surrounding structure, and any major panels or panel joints, split line joints, etc.
2. Examples of damage that may significantly affect the interface load distributions would include complete fracture or severe yielding of major load carrying details, extensive cracking or buckling in composite panels or metal parts in major load carrying details, etc.

b. Permanent deformations at the ultimate loads must be of the magnitude where they do not impede passenger egress from the airplane. Deflections at ultimate load must be of the magnitude where they do not contact adjacent structures that have not been designed for such a condition. Maximum deflections allowed during ultimate loads should be decided between the applicant and the certifying authority prior to testing.

8. Test Article

The test article shall be representative of the production unit; however, the test article need only be structurally complete representing a production unit having the same structural shell and attachment design (ensuring the test article is a "worst-case" configuration). Parts, components and features that do not affect structural integrity need not be installed (i.e. Plastic laminates over aluminum structure, and doors that do not have structural latches and hinges). The test article description, airplane location, and construction methods shall be documented in the test proposal or in applicable design data. The test proposal shall reference all applicable design data (e.g. process specifications, sub-tier drawings, related reports, and etc.) including revision levels (if this is not documented in the reference drawings).

If the tested article will be used in a production aircraft installation, then a statement shall be included in the certification plan. The method of post-test inspection, required refurbishment, and completion procedures shall be coordinated with and approved by the responsible certifying agency.

The following is the requirement for refurbishment of monuments and interior furnishings that have been subjected to structural testing to flight loads and FAR 25.561 emergency landing requirements:

> After the test, the unit shall be shown to conform to design data including the applicable specifications after FAA conformity inspection. The monument manufacturer and/or applicant shall post-test inspect the unit for 1) overall dimensions and tolerances from a datum as established by

the design data, applicable specifications and 2) for structural condition. All deviations shall be noted and corrected. The responsible engineer shall approve the inspection results and all rework, and record these results/rework in the applicant's Quality Assurance records.

9. Test Fixture

(1) A test fixture or an airplane fuselage test article may be utilized. The test fixture design data shall be submitted to the FAA or agency representative for review and approval. Design data including revisions must be released and controlled in accordance with standard engineering practice.

(2) The applicant or responsible engineer shall ensure that the stiffness of the test fixture is appropriate to the test and if necessary to demonstrate compliance with 25.301 and 25.305 is representative of the aircraft support structure. The test fixture and the test set-up shall be included in the test plan and be conformed by the responsible certifying agency prior to testing, for design and configuration compliance.

(3) Test fixtures are typically constructed from either beam representations of the airplane floor or spring plates at the attachment locations that provide the appropriate local stiffness. Validation of exact representations of the airplane floor can typically be accomplished by review of the test fixture drawings. For test fixtures that do not duplicate this structure, a common approach to validate the test fixture is to replace the airplane floor and tie rod attachments in the finite element model with the test fixture structure. If the resulting interface loads and deflections are approximately equivalent to the analytical results of the original airplane representation, then the test fixture is acceptable. It has been generally accepted that a ± 10% difference in large magnitude interface loads, or ± 100 lbs for small magnitude interface loads is a basis of equivalency.

(4) The requirement for simulated airplane stiffness is a function of the complexity of the unit being structurally substantiated.

a. For statically determinate structures, the influence of the airplane support structure stiffness is minimal with regard to interface loads and therefore, a simple (rigid) test fixture is satisfactory. However, the effect of deflection must be considered. For example, the hard point floor fitting design must be duplicated in order to test the unit for the effect of the moment input by the fitting.

b. For multi-load path, indeterminate structures, the airplane support structure stiffness can have a strong influence and therefore, the stiffness as well as the geometry should be simulated. The applicant or responsible engineer is responsible for obtaining the information necessary to design and manufacture the test fixture to meet the stiffness requirements.

c. For deflection critical monuments and interior furnishings such as clearances for emergency egress, clearances for control cables or door actuation systems, and interference with adjacent installations, the airplane support structure stiffness must be approximately simulated so that deflection measurements can be taken to verify acceptable deformations.

(5) The test fixture shall be inspected after test to verify structural integrity. Any modification or major refurbishment made after testing shall be documented and coordinated with the responsible certifying authority, and responsible engineer.

10. Test Fixture Mounting Procedure

The unit shall be mounted to the test fixture using locations shown in the applicable design data. It is the responsibility of the FAA authorized inspector to verify the unit is properly installed in the test fixture and that its attachment to the fixture has the correct fittings and/or fasteners per the applicable installation or assembly drawings. All fasteners should be per the applicable fastener specifications.

11. Test Jigs

(1) Test jigs include such items as dummy equipment articles, or fixtures which simulate equipment and accessory installations, etc., and plywood panels, plywood boxes, etc., used to apply distributed load to the monument or interior furnishing unit.

(2) Each test jig to be used for static testing shall be described in detail in the test proposal or in a test set-up document so that the person/s approving the test proposal can verify that the jig realistically simulates actual loading of the equipment article. Dimensioned sketches or drawings of each test jig shall be included in the test proposal or test–up document.

(3) Plywood (or similar acceptable substrate) panels used to simulate load on compartment doors or monument/interior furnishing interior structure shall be described in the test proposal in terms of size and thickness. Plywood panels shall cover no more than 50% to 75% of the intended load area of the compartment door or wall. The plywood panel stiffness should be less than that of the compartment or panel being loaded, which allows simulation of loose contents and prevents unrealistic loading on the compartment/panel periphery.

(4) The use of steel/aluminum extrusions shall be limited to large areas requiring load distribution, and shall not result in unrealistic stiffness of a loaded compartment or panel.

12. Detail Tests

(1) Certain components of a monument or interior furnishing can be substantiated by a specific test of that component. Such detail tests shall be described in a test proposal, and can usually be included within the main test proposal for the monument or interior furnishing structure.

(2) For items not provided by the monument or interior-furnishing applicant (e.g. equipment and accessory installations, etc.), the provisions for attaching these items to the monument or interior furnishing unit may be substantiated by detail test or analysis to simplify the unit test. Test jigs used to simulate equipment and accessory installations, etc., shall be described within the test proposal. The test proposal shall also include a description of the test set-up for detail tests.

(3) Test proposals for detail tests shall be submitted to the responsible certifying agency for approval prior to actual testing.

13. Unit Estimated Weight and Center of Gravity

(1) The weight terminology shall be defined and reported as follows:

a. <u>Gross Weight</u>: The weight of the unit as installed in the airplane with all compartments loaded to their placard weight or maximum capacity if no placard is provided. This weight includes items that are to be installed by the end customer.

b. <u>Structure Weight</u>: The gross weight minus the weight of fixed items, and the weight of removable or consumable items installed by the end customer. If decorative finishes or trim is left off the test specimen, the associated weight will be included in the calculations of the test loads.

c. <u>Fixed Equipment Weight</u>: The weight of all fixed equipment items and miscellaneous items at their loaded or full weight, as supported or restrained by the monument shell. This includes ovens, coffee makers, stove-tops, water heaters, lines, electrical wiring, etc.

d. <u>Removable or Consumable Weight</u>: Items that are stored in the monument, along with the associated placarded weight limits for each compartment. This includes dishes, glasses, napkins, food or drink items, water, ice, etc.

e. <u>Tare Weight</u>: The weight of the test article including materials used to protect surfaces and to distribute loads during testing. For certain tests where the weight of the test equipment may have an effect on the applied loads, the tare weight includes the test equipment, such as whiffle trees, cables, hardware, load pads, etc.

f. Total Test Weight: The total weight of the unit upon which the design test loads are based. This weight shall be equal to or greater than the gross weight.

(2) The calculations of combined center of gravity, including the effect of structure weight and customer installed items, will be included in the test plan. Also included in the test plan shall be a sketch showing the interior furnishing envelope and corresponding center of gravity.

(3) The airplane XYZ reference axes should be utilized to orient the monument location with the airplane. For example: "X" being the {forward aft} axes expressed as a Fuselage Station (FS), "Y" being the {left right} axes expressed as a Right Buttock Line (RBL) or a Left Buttock Line (LBL), and "Z" being the {up down} axes expressed as a Waterline (WL). The coordinate system should be identified.

14. Monument Compartment Fixed Equipment Items

(1) A description of each fixed equipment item, including the contents weights, shall be included in the test proposal. If any are omitted during the test, this should be stated along with any finishes left off that would not contribute to the strength of the monument.

(2) A sketch of the compartments and their restraint devices shall be included in the test proposal. Provide an explanation of the method to be used to substantiate both primary and secondary latches (when secondary latches are required).

(3) Secondary restraints (when required) may be tested separately for the compartment loads or tested simultaneously by conducting another full-scale test with secondary restraints engaged and primary restraints disengaged. An alternative procedure is to select the most critical of either the primary or secondary latch of a given part number, and use that in the test. Comparison to previous tests using identical latches that might have been loaded to higher loads can also be employed in making the selection. If this method is not feasible, a separate door or drawer component test might be preferred to a second full-scale test.

15. Loads Determination

A table listing the loads and the applicable load factors to be used shall be included in the test plan. The loads must be placed in equilibrium with the inertia forces.

(1) External Loads

a. Flight Loads, including Maneuver Loads and Gust Loads - defined as Limit Design Load. These loads are generally specified as load factors, to be applied to the critical mass of the monument, but may also include secondary loads, interface loads, operating loads and other sources of loading.

b. Landing and Ground Loads - defined as Limit Design Load. These loads are generally specified as load factors, to be applied to the critical mass of the monument, but may also include secondary loads, interface loads, operating loads and other sources of loading.

c. Emergency Landing Loads - defined as Ultimate Design Load. These loads are generally specified as load factors, to be applied to the critical mass of the monument, but may also include secondary loads, interface loads, operating loads and other sources of loading.

d. Special Loads:

1. Rapid Decompression Loads
2. Forced Vibration – If failure of the monument could preclude continued safe flight or landing or if forced vibration of the monument could induce failure in primary structure to

which it may be attached, then the monument should be designed for the sustained engine imbalance loads of 25.903(c) (ref: AC 25-24, Sustained Engine Imbalance).

3. Operating Loads - Structural loading caused by use or operation of the monument should be considered and combined with the flight loads appropriate to the operating condition.

4. Abuse Loading - Where a monument has the capability to have loads applied, either through deliberate use of hand holds, steps or operating interfaces, or accidentally applied loads because of location or configuration, abuse loads should be defined that will ensure a level of structural integrity such that the monument will continue to function safely after the application of the abusive loading. In the absence of a rational abuse load definition, an applied load of 300 pounds is generally considered an appropriate abuse load value.

e. Limit or Applied Loads are the maximum loads anticipated on the airplane during its lifetime of service. The monument structure shall be capable of supporting the limit loads without suffering detrimental permanent deformation so as not to interfere with the safe operation of the airplane.

1. Ultimate Loads are equal to the Limit Loads multiplied by a factor of safety (F.S.) of 1.5. Any additional factors should also be included (see Section 16 of this Chapter).

(2) The loading shall include forces caused by all externally mounted items and loading effects from items which are located adjacent to the unit which will impose load on the unit under inertia loading as shown in the design data. Applicable items include magazine racks, stowage units, emergency equipment, attendant seats, people, adjacent monuments, airplane interior panels, etc.

(3) Airplane induced loads including airframe and/or floor beam deflections should be considered in the monument installation design and included in the test set-up design (e.g. soft mounts, slip mounts, etc.).

(4) The rapid decompression loads shall be considered in addition to the flight and/or emergency landing loads.

(5) The static loads shall be applied by means of weights, electro-mechanical or hydraulic cylinders, or by “whiffle tree” loading. Test loads may also be applied by “centrifuge” method.

16. Load Factors

Load factors may be applied at the customer’s request, at the supplier’s option, and/or per the requirements of a foreign authority. However, these additional load factors shall be clearly defined.

PER 14 CFR, PART 25 REQUIREMENTS

(1) Material Variability Factor

a. 25.601, 25.603, 25.605 and 25.613 establish that materials used for the manufacture of parts, the failure of which could be hazardous or affect safety, shall have consistently sound structural characteristics and capability, and design strength values established by tests. The design values chosen must be selected to minimize the probability of structural failure due to material variability. Monument installations are required to demonstrate compliance to 25.789, “Retention of Items of Mass in Passengers and Crew Compartments and Galleys” since they are considered items whose structural failure is considered hazardous and affects safety. As such, compliance with the material and process requirements must be demonstrated. In particular, it must be established that the probability of structural failure due to material variability must be minimized.

b. It has been established that, for structure of conventional metallic construction, whose strength is demonstrated by structural testing only, and for which the failure of individual elements would not result in loss of structural integrity of the monument [25.613(b)(2)], testing to ultimate load has been accepted as demonstration of compliance to the strength requirements of the regulations. This is based upon the test article being fabricated using traditionally accepted, specification controlled, materials and processes standard in the aerospace industry. The actual strength of the material used in the construction of the test article need not be known. It is accepted that, using fabrication and manufacturing process standard in the aerospace industry, the proven and demonstrated strength variability inherent in these units meets the safety requirements of the regulations and results in minimization of the probability of structural failure due to material variability. For these materials, the Coefficient of Variation (CV, the standard deviation expressed as a fraction of the mean) of the material strength properties falls in the range of 0.03 to 0.07.

c. Modern non-metallic materials, such as fibrous reinforced composite laminate structures, afford manufacturing economies, light-weight, high strength, and fabrication flexibility. However, the material strength properties of parts made from these materials, such as fiberglass/epoxy or carbon fiber epoxy, have material strength CV's that are significantly greater than traditional metallic materials, ranging to 0.13 and higher for loosely controlled fabrication process specifications. For the manufacturer that is demonstrating compliance with the regulations by a structural test to ultimate load of a fabricated monument test article only, the question of compliance with the requirement to assure that the probability of structural failure due to material variability is on the same order of that for traditional materials and processes must be addressed. One method that has been developed has been to apply an overload factor to the test. The intent of the application of an overload factor to a structure substantiated by test only, where the actual strength of the material used to fabricate the test article is not known, would be to ensure that the confidence in the strength of the design is approximately the same as that obtained from a component substantiated by analysis, using minimum guaranteed properties, validated by test.

d. Overload factors for the material and process variability may be based on a ratio between the mean and the "B" basis values for the significant material properties. This overload factor may be reduced to account for the acceptable material property variability of metal structure. A typical way to treat this could be as follows:

e. If P_D is the design load level, and P_A is the test applied load, and you wish to ensure that the test demonstrates that any product made from material whose actual properties are as low as B-basis will support P_D, an overload factor, LF, can be applied to accomplish this.

f. If one has determined the strength of a test article by testing to failure, to reduce the test results to a B-basis design allowable, the test results can be adjusted based upon actual material strength compared to B-basis strength. If the actual strength of the material is F_A, and the B-basis strength of the material is F_B, then the relationship will be:

$$P_D = P_A \, (F_B / F_A)$$

g. Conversely, if we wish to ensure that the test applied load is high enough so that when the test results are reduced to a B-basis value, it will be greater that P_A. Thus: $P_A = P_D \, (F_A / F_B)$

h. Expressing this in terms of a load enhancement factor, LF:

$$P_A = LF * P_D, \text{ from which}$$
$$LF = F_A / F_B$$

i. For a normal distribution of material properties, with the mean strength defined as X, the one-sided tolerance limit factor defined as k, and the standard deviation defined as s, this can be written:

$$LF = F_A / (X\text{-}ks)$$

j. If we further assume that the test article as fairly representative of the material properties, then:

$$F_A = X$$

k. Recognizing that the Coefficient of Variation, CV is:

$$CV = s/X$$

l. Substituting:

$$LF = 1 / (1 - k * CV)$$

m. Letting CV be the coefficient of variation of the material properties used in construction, and CV_B be the coefficient of variation of the traditional metallic properties, and accounting for the acceptable material variability of metallic structures, then:

$$LF = 1/ \{1- [k * (CV - CV_B)]\}$$

n. This expression is valid when both the construction material and the baseline material properties are normal distributions.

o. The following conditions and assumptions can be used in determining an overload factor:

1. An acceptable CV for baseline aluminum material may be computed from DOT/FAA/AR-MMPDS-01 data. In determining a one-sided tolerance factor, it is acceptable to assume that the B-basis data presented in the handbook is supported by at least 100 coupon tests. An acceptable value for the CV of baseline aluminum sheet metal is 0.03.
2. For glass or carbon fiber based epoxy matrix laminates, the material property mean values and "quasi-B-basis" design allowables used to compute CV may be obtained using the methods from DOT/FAA/AR-MMPDS-01 for a normal distribution. While this does not necessarily provide design data that complies with 25.613 requirements, is considered sufficient for use in the determination of an overload factor. The application of this to other materials depends upon the material property statistical distribution. It must be determined that a normal distribution is a reasonable approximation, and some engineering judgment may be required.
3. Material data for the determination of an overload factor may be obtained from the coupon testing used to qualify, validate and control the materials and process being used. Experience has demonstrated that such coupon data is usually adequate, and often conservative in quantifying variations at structural scales. These coupons should represent several material batches and several process batches for each material batch.
4. The materials and fabrication processes used to make the test samples must be sufficiently controlled, and must flow into the manufacturing processes, such that the material property variations expected in the manufactured structure is adequately or conservatively represented by the coupon data.

p. In the absence of a rationally derived overload factor, for glass and carbon fiber, epoxy matrix laminates, fabricated using material and process specifications that meet the standard of the aerospace industry, an overload factor of 1.33 may be assumed.

q. The material variability overload factor must be combined with other factors, such as environmental factors (temperature and humidity) and Special Factor required by 25.613. This is because the overload factor for material variability is not a special factor, but is an alternate means of achieving the same structural reliability as compliance by structural test where the test results have been adjusted to a B-basis design allowable or compliance by reliable analysis with margins of safety based upon B-basis allowables.

(2) Quick Change Factor

Monuments and interior furnishings subject to wear and tear due to frequent removal and re-installation (e.g. "Quick Change" interior) shall apply a factor to the wear surfaces of local attachments per the requirements defined in Section 25.561(c)(2) *General.*

(3) Casting Factor

Each critical casting must have a casting factor applied per the requirements of Section 25.621.

(4) Bearing Factor

Per the requirements of Section 25.623 each part that has clearance (free fit), and is subject to pounding or vibration must have a bearing factor large enough to provide for the effects of normal relative motion.

(5) Fitting Factor

A fitting factor of 1.15 per the requirements of Section 25.625 must be applied to the limit and ultimate loads unless proven by actual testing or if the joints are made under approved practices and based on comprehensive test data.

PER APPLICANTS REQUIREMENTS

(1) Vibration and Buffeting Factor

(2) Gross Weight Increase Factor

(3) Abuse Load Factor

(4) Material Degradation Factor

(5) Durability Factor

NOTE: Special factors used in compliance with 25.619 need not be combined. The largest applicable factor is adequate. Other factors, such as a material variability overload factor, or a material property environmental factor, that represent a means to demonstrate compliance to the material and process sections of the regulations and would normally be applied as a statistically derived design allowable (such as B-basis), or a material properties Knock-down factor, in determining analytical margins of safety, would be combined with other factors. The factors defined by the applicant would be treated per the applicant specification.

17. Test Procedure / Test Set-Up

The testing procedure shall be fully outlined including test location and date, as well as a written description of the test set-up and the test steps. The set-up shall explain how the unit is being tested and what testing equipment is to be used. Test equipment calibration shall be current, and equipment calibration dates shall be verified during the conformity process. The steps should list the number of tests and the name of each test.

18. Deflection Measurements

(1) Deflection limits will be based upon the specific monument or interior-furnishing configuration and shall be coordinated at the initial certifying agency technical coordination meeting.

(2) As a minimum, the following suggested deflection measurements should be recorded. During testing of forward and side load conditions, deflection measurement should be recorded for the locations specified below at both the ultimate load and after removal of test load. The test results report should record the resulting deflections measured in the direction parallel to that of the applied load.

(3) Forward load condition:

a. <u>Unit with upper support(s)</u> - Forward inboard and forward outboard vertical edges at the middle of the panel from base of unit, forward inboard and forward outboard top corners of the unit (Upper support is understood as upper forward-aft support. If so, then measurement at the top corners is optional).

b. Unit without upper support(s) - Forward inboard and forward outboard top corners of unit

(4) Side load condition:

Unit with or without upper support(s) - Forward inboard, and aft inboard edge at top of unit. When the unit has upper lateral support, measuring deflection at the middle points may be considered more practical.

(5) For large monument compartment doors and for all monument fixed equipment doors, door deflections shall be measured at ultimate loading.

(6) All deflection measurements shall be recorded and provided within the test results report. For both monument compartment doors and monument fixed equipment doors, deflections that would allow spillage of contents at ultimate load are to be considered test failures, requiring the redesign and re-substantiation of the unit. Magnitudes of such deflections should be established in consideration with the size of the contents materials being restrained, and should be specified in the test plan.

The previously stated definitions of deflection measuring point location are general. Actual critical measuring point location depends on the unit structure, its installation, and airplane support structure, etc. The key concept is to select points at locations where maximum deflections will occur or most probably will occur, where deflections may interfere with adjacent structure, or where excessive deflection would indicate failure to comply with the regulations.

CHAPTER 3. DEMONSTRATION BY ANALYSIS

1. Introduction

(1) This section outlines the requirements and format for substantiating cabin monuments and interior furnishings by stress analysis. In determining the suitability of structural analysis in demonstrating compliance with the strength requirements of the regulations, the following criteria should be met:

a. The structural analysis methods must have been shown to be reliable in predicting the strength of the structure and are applicable to the structural configuration, materials and fabrication methods used in the structure [25.307(a)].

b. The demonstration of reliability of the analysis, including calculation of failing strength should be traceable back to testing.

   1. The analytical methodology should be shown to be capable of reliably and accurately or conservatively predicting the appropriate strength: i.e. stress, strain, internal loads, interface loads, deflections, etc.

   2. The analytical methodology must be capable of identifying all potential failure modes for the structure being analyzed.

(2) Structural substantiation of an interior item may be accomplished using combinations of both Stress Analysis and Static Test. One method that makes use of both methods is Stress Analysis, supported by Static Test. With this method, the principle means of substantiation is by stress analysis, but testing is used to verify the structural adequacy of the specific items (or questionable design details) or to verify a behavior or boundary condition assumed in or resulting from the stress analysis. The regulations require test confirmation of design suitability and the use of reliable analytical techniques (Ref. 25.307, 25.601, 25.603). Such a need for verification by static test occurs for a variety of reasons: when new parameters for semi-empirical analytical methods must be developed or extension of the method to new designs or requirements is needed, when assumptions made in the stress analysis are in dispute, when there is some question of the creditability of design allowable data used, or when the predicted deflection of an interior item is uncertain.

(3) Two areas that consistently must be evaluated in this light are the validation of Finite Element Models used in the stress analysis and the determination or verification of failure modes and values for complex design details.

(4) Often the static test is not performed according to a FAA approved test plan but is an “engineering” test. Although the data collected does not have to be FAA approved, the methods and procedures for documenting the data should be the same level of rigor in regard to inspections, calibrations and etc. This is considered acceptable because the method of certification is 100% stress analysis and the test corroborates the stress analysis conclusions. This evaluation may be necessary because:

a. The analytical methodology has to be proven to be applicable and reliable

b. Failure modes or failure theories have to be validated

c. Structural analytical models have to be validated

d. Assumptions and the effects of boundary conditions have to be validated, or

e. There is uncertainty in the strength due to structural optimization, weight minimization or secondary effects. The means for determining the failing strength or the loading at failure must be reliable and accurate or conservative, and account for structural load interactions.

2. Stress Analysis – General

(1) A stress analysis report shall be prepared in accordance with standard engineering form and practice (defined below) to substantiate the cabin monument or interior furnishing as defined in the Structural Substantiation Proposal.

(2) Detail drawings that are not relevant to the structural design of the unit are not required for submittal.

3. Minimum Analysis Requirements

The stress analysis report shall contain as a minimum the following analysis data for each unit.

(1) Panels, including countertops and shelves

(2) Joints, including split lines

(3) Floor fittings (Maximum allowable shim stack-up should be considered in the substantiation.)

(4) Overhead ties, fittings, and upper support structure

(5) Cart restraints, including primary and secondary retaining devices

(6) Doors and latches, including hinges

(7) Monument equipment retention (coffee makers, boilers, ovens, chillers, etc.)

(8) Crew seat attachments (if applicable)

(9) Attachment of all other equipment mounted to the unit

(10) Pullout tables, assist handles, etc.

4. Analysis Procedure

(1) A sketch with dimensions, section properties, and drawing part numbers

(2) All forces and reactions per referenced Interface Loads Report shall be shown in equilibrium

(3) All material designations, design values, and FAA-allowables called out and referenced

(4) Critical design condition(s) identified

(5) Applicable special factors per Chapter 2, Section 16

(6) All assumptions and calculations (Where special tools/software [e.g. computer spreadsheets] are used to develop an analysis, all equations and methods used in the analysis shall be defined)

(7) Margins of safety

5. Deflection Analysis

A deflection analysis shall be performed at ultimate loads, and the following data should be evaluated:

(1) The maximum deformed shape to determine if the load distribution has changed from the non-deformed shape

(2) The deformed shape interacts and/or loads adjacent monuments, bulkheads and/or equipment

(3) The permanent deformation effects cannot be predicted with FEM. Deflection analysis from FEM is acceptable in the elastic range.

Note: It is acceptable to provide deflection results from interface load FEM analysis if available.

6. Report Format

The stress analysis report should contain but not be limited to the following sections:

(1) Cover Page with provisions for signatures

a. Written by

b. Checked by

c. Approved by

(2) Revision Page

(3) Table of Contents Section

(4) References Section

a. Reports texts

b. Drawings

(5) Introduction including reason and brief description

(6) Certification Basis including Make, Model, Effective Serial Nos., Regulation with date and Amendment Level

(7) Margin of Safety Summary Table

(8) Description of Structure (Monument)

(9) Applied Loads Section (including effects of dynamic loads, e.g. from seats, decompression etc.)

(10) Internal loads distribution

(11) Detail Stress Analysis Section

(12) Conclusion

(13) Appendices

The report format may as outlined in Section 7, which includes the following: Introduction, Materials, Margins of Safety, Detail Analysis, and Conclusions sections.

7. Introduction Section

The introduction shall contain the following information as a minimum:

(1) Unit description - Listing of the specific part number(s) and name(s) of assemblies and parts being analyzed with references to applicable drawings, revision levels, and dates, including top assembly and major sub-assemblies. A sketch shall be provided showing location of unit in the airplane.

(2) Method of attachment to the airplane - Shall be shown in sketch form and shall include attachment types, i.e. seat track or hard-point and overhead ties if applicable. The sketch shall identify load restraint direction. Part numbers for standard attachments and/or vendor parts shall be included.

(3) Method of basic construction - Shall include a description of:

a. Panel construction such as sandwich panel, face sheet and core, material and thickness, machined and/or welded panels, material and thickness, etc.

b. Joint construction, including types of fasteners, adhesive bonding, or welding, if applicable.

c. Method of primary and secondary restraint for carts, inserts, and doors, if applicable.

(4) Procedure - Statement shall identify which units or components will be analyzed. All units/components shall be analyzed unless justification for selected critical items is provided.

(5) Load factors - Shall be listed based on intended usage (location in airplane, which airplane(s), etc.).

8. Materials

A list of materials used in construction shall be provided which includes material specification designations. Where material properties are process sensitive (e.g. sandwich panels), manufacturing process specifications shall also be specified. Material allowables/design values shall be referenced including fastener allowables.

9. Margins of Safety Summary

A summary shall be prepared to include the following:

(1) List of items analyzed

(2) Critical condition(s)

(3) Type of stress condition (i.e. bending, shear, tension, etc.)

(4) Page number (location in analysis)

(5) Margin of safety

10. Interface Load Calculation by Finite Element Methods (F.E.M.)

This section is intended to provide information for using FEM to produce interface loads. Note: While current finite element modeling programs are adequate to determine interface loads, they are not capable of performing detailed stress analysis of interior monuments. The distinction between determining interface loads and detailed stresses should be emphasized.

<u>Introduction</u> - Finite Element methods are becoming ever more popular for the stress analysts. When properly employed, Finite Element Models' (F.E.M.) are powerful tools complimenting the traditional skills of the stress analysts. In recent years, because of advances in meshing algorithms and increase of computer power, we are witnessing the start of replacing traditional analysis with F.E.M.

<u>Recent Developments</u> - F.E.M. have been used as sources of internal loads within the aerospace industry for many years. Fuselage and wing models, which are highly idealized, fall into this class. These models would have been constructed with many thousands of load cases also. Information from these models would then be passed onto the stress analysts who would extract the internal loads and use them for traditional analysis. It was not long ago that complete fuselage and wing models took a long time to solve. Today, many of these tasks can be performed very quickly on a workstation. This is a well-accepted role for F.E.M., and in many organizations this is the only role.

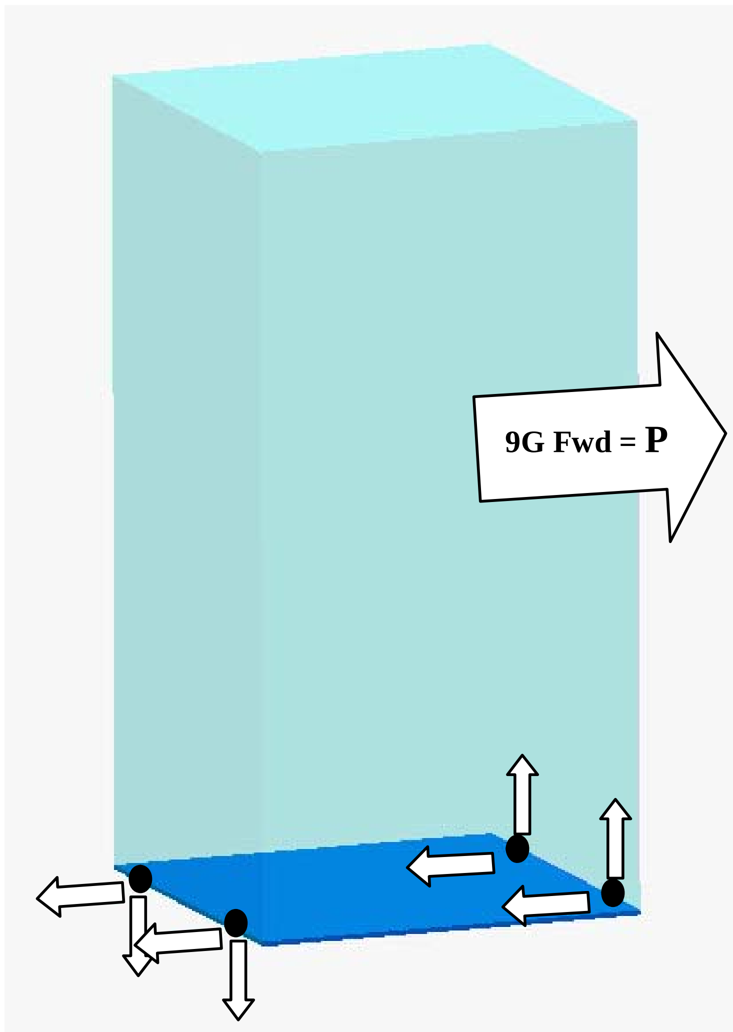
The modeling of complicated parts such as forgings and fittings has eluded those traditional analysts who wanted a better understanding of the behavior of the parts they are analyzing. Advances in meshing algorithms in the last ten years have altered dramatically the F.E.A. landscape. Extraordinarily complex solids can now be meshed with a click of the mouse. Furthermore, vendors of CAD software are leveraging the strength of their products (geometry) and intruding onto their competitors' turf by developing F.E. solvers of their own. A coarse model can produce adequate interface loads, but a more refined model is required to get accurate deflections and further refinement is required to obtain accurate stresses. In the areas of concentrations precise stresses can only be obtained with very fine mesh. A full monument with a fine mesh would take an inordinate amount of time; therefore, a balancing act must be achieved.

<u>Scope</u> - Since we are most concerned with the behavior of interior monuments, we shall use a simple closed commodity as an example. This document will not include detail theory of F.E.A. itself. This section will deal with:

a. Calculating interface loads using F.E.M.

b. Detail analysis of specific components using F.E.M.

The Basic Configuration - Consider this simple and closed monument that is attached either to the seat tracks or some other supporting structure in the airplane at four locations at the bottom. The panels are homogenous. There are no shelves or cutouts. The C.G. lies at the middle of the monument. Without doubt, this configuration can be solved by simple statics. In this case, the height of the C.G. is the determining factor for the vertical floor reactions. The astute user will notice, however, the distribution of the fore/aft reactions, even for this simple configuration, may not be what was expected.



Observation #1

If a problem is statically determinant, the F.E.M. reactions can be checked by statics. If the F.E.M. reactions are different from those calculated by statics, the F.E.M. is not statically determinant.

Corollary - If F.E.M. reactions do not change regardless of how much the properties have changed, the F.E.M. effort may not be required. The problem is statically determinant, and reactions can be calculated by hand.

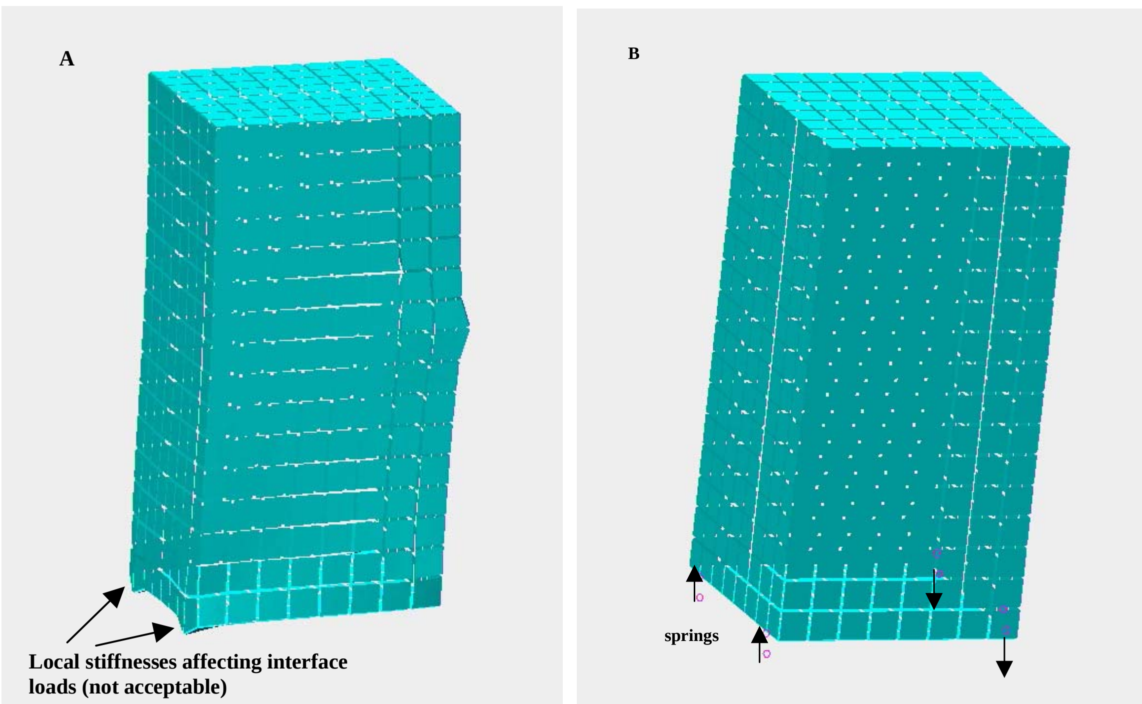
If one had expected the fore/aft reactions at each of the attachments to be P/4, using statics or rigid assumption, it might be tempting to increase the stiffness of the floor panel to get to P/4. As the floor stiffness changes, the directions of the fore/aft reactions will eventually change also. One will begin to discover the stiffness of the monument heavily influences the reactions. Because the vertical reactions are statically determinant, changes in monument stiffness does not change the loads, *in this example*.

Why use F.E.M.? On closer examination of even the simplest monument configurations where we would find at least one overhead tie-rod and four floor fittings, it becomes obvious that there is redundancy in almost all monuments. Together with complex loading, F.E.A. has been adopted for purposes of calculating more accurate interface loads despite numerous attempts in the past to create closed-form solutions for generating interface loads.

Referring back to the basic configuration, if the box is relatively rigid, there are a few things we must do to the F.E.M. in order to arrive at reactions that match values calculated by pure statics.

Observation #2

To arrive at a set of reactions that can be checked by statics, the monument itself has to behave like a rigid body. In this case, the local flexibility effects at the floor interface must be removed. In this case, springs must be added at the floor interfaces. The support structure should not be rigid.



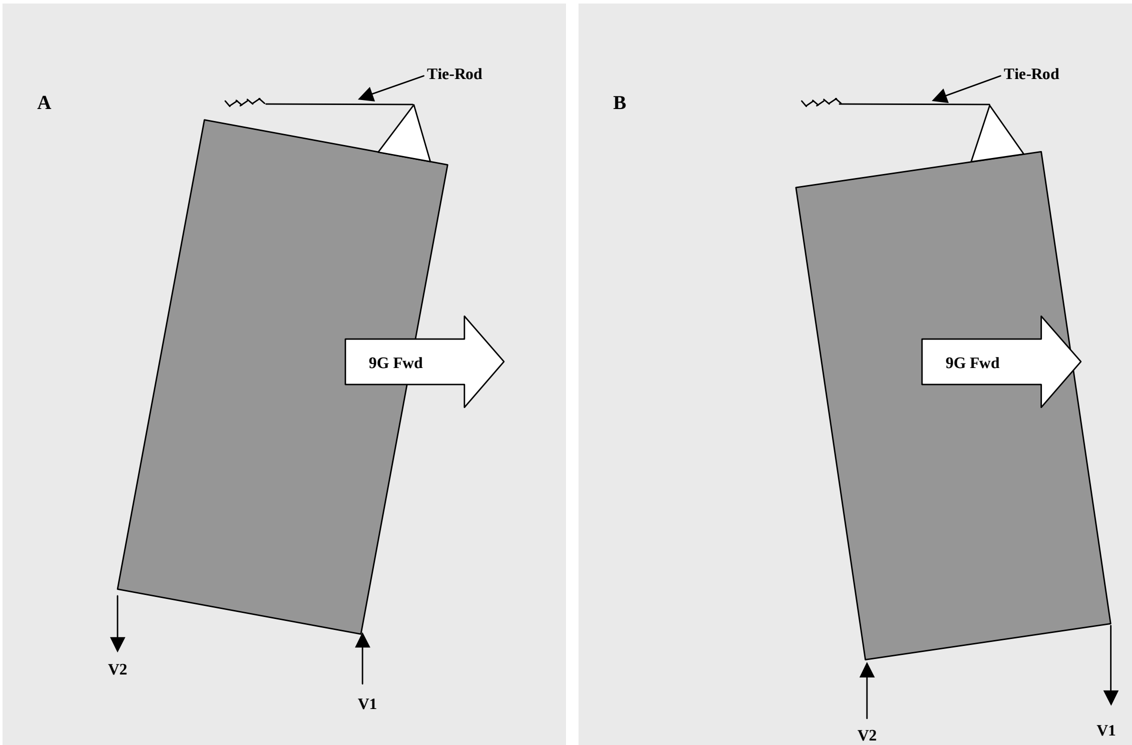
The reactions in case B can now be matched by hand calculations based on rigid assumptions. This is most useful for those who are considering updating old hand calculations with an F.E.M. but who first want to recreate the original interface loads.

Floor and Overhead Springs - In Observation #2, we stated that support structure should not be rigid. In fact, the stiffness of the main deck floor panel and the floor beam vertical stiffness are modeled by the springs. Springs may also be used to 'filter' out unwanted loads (e.g. because of slots, refer to the OEM documents for the correct spring values).

Off-Centered Loading - For most monuments (even the simplest), it is likely that the C.G. is off-centered. The result is twisting of the monument and lifting of one of the corners. The monument now behaves like a beam in differential bending.

General Configuration and Behavior - Let's consider a more general monument configuration, one that includes an overhead support.

General Behavior of a Monument with a Tie-Rod:



The distribution of the vertical floor reactions in Case A, compression forward and tension aft, is probably the most common. Case B, however, can arise if the tie-rod and support structure stiffness is very high coupled with a low C.G. Tension can then be found in the forward fitting. The monument in Case B behaves like a galley cart during a 9G Forward crash scenario.

<u>Tie-Rod Loading</u> - The magnitude of the tie-rod load is usually governed by the height of the C.G. followed by the support stiffness at the end of the tie-rod. Special consideration should be given to tie-rods that are found to be in compression. Because the basic F.E. analysis is linear, the F.E.M. cannot predict the onset of instability (both local to the tie-rod and general to the monument). There have been instances where F.E.M. predicts that a tie-rod is in compression but the monument fails dynamic testing because the tie-rod swings back into tension. Stability analysis must also be performed on the tie-rod itself.

<u>Floor Grid Models</u> - Monuments for the newer airplanes may be coupled to floor grid models (in place of vertical springs) for interface loads. Floor grid and sometimes sections of the full fuselage model may be used for interface loads whenever they are available. These models usually contain better and more accurate stiffness distributions throughout the fuselage than the simple spring can provide. Care must be taken to ensure that longitudinal and lateral forces taken out by the main deck floor panels must still be represented by springs.

<u>Why Not Model Floor Panels</u>? - Past experiences have shown that including the modeling of floor panels results in an unrealistically high fuselage stiffness, and a tendency to distribute too much load to the outboard fittings.

<u>Super-elements or Boundary Stiffness Matrix</u> - If the actual fuselage was not available to the builder of the monument F.E.M., the full effect of the fuselage can still be obtained from a super-element. Super-elements are stiffness and load matrices for the fuselage reduced to the interface (boundary) locations. Super-element techniques are not usually used for simple monuments that are almost statically determinant and not expected to experience fuselage flight or cabin pressure loads. With the introduction of more

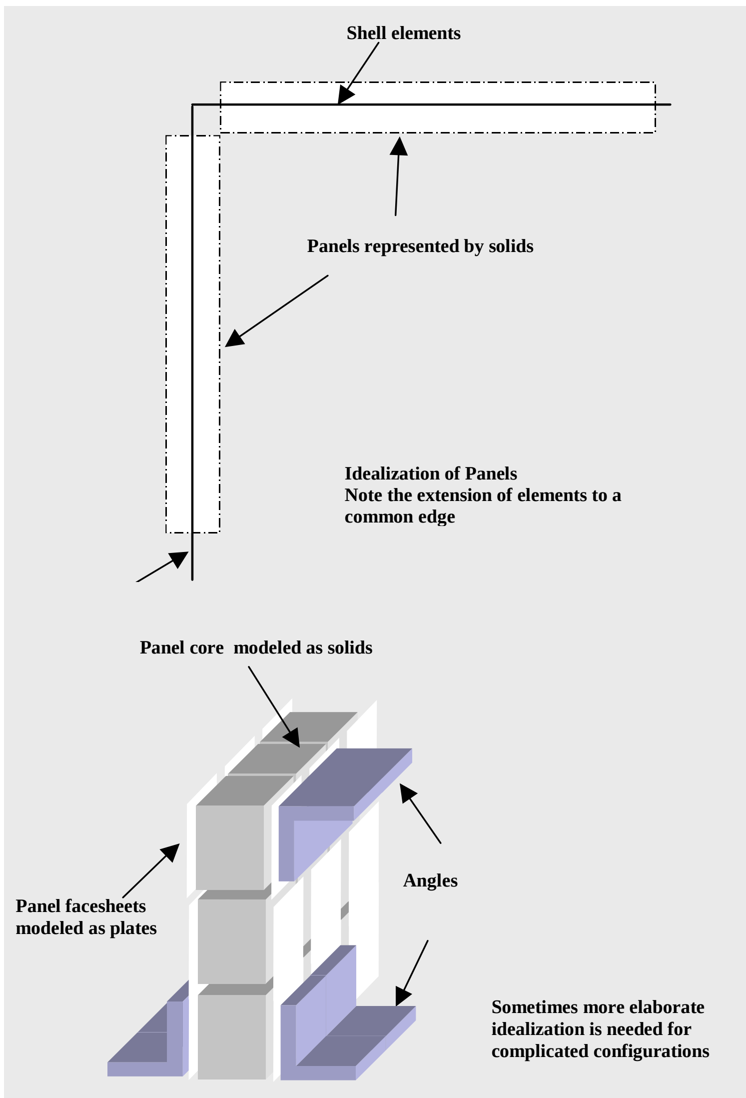
complicated monuments and cooperation between different vendors for a single project, such techniques could become useful in the future.

Now that we have finished discussing the support structure to the monument, we can concentrate on the monument itself.

Modeling Technique - This section will be divided into four parts: Model/element size, element type/idealization, material properties, and restraints and loading.

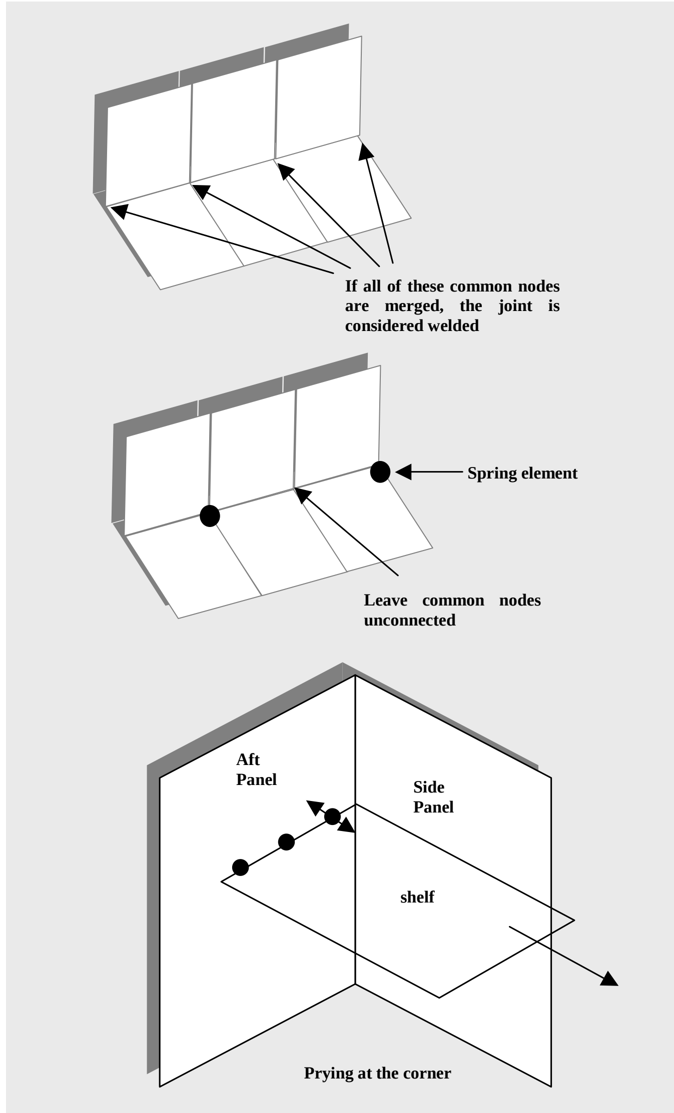
Model/Element Size - The first and most basic question posed often before the first node has been created is: how big is the model going to be? The answer would depend on whether the model will be used for interface loads only, or will it be used for internal loads later, or will it be a full-up stress model. Most panels made for interiors are made of glass/Nomex sandwich construction. Relative to metallic structure, their behavior before failure is fairly linear. On the whole, for a box shaped monument, the panels usually experience shear rather than bending. Glass/Nomex sandwich panels in shear, are usually designed by the panel joints (with exceptions). Therefore, a full-up stress model may sometimes be achievable because unlike thin shell metallic structure, overall load redistribution is not required. A rule of thumb may be an element size of 4”-5” for a model intended for loads only (for a monument the size of a closet). An element size of 1” or less should be used for parts of a model intended for stress purposes.

Element Type/Idealization Panels - In general, panels can be modeled using shell or plate elements that can carry membrane loads and have the ability to withstand out of plane bending from a pressure load, for example. Modern elements can model metallic as well as composite panels with ease. It is common to place the panel at the mid-plane of geometry (usually a solid). Vertical panels should be placed directly over the floor interface locations to avoid unrealistic moments. Sometimes, panel and joint fitting geometry may be so complex, solid elements with actual panel thickness are needed to produce reasonable idealization.

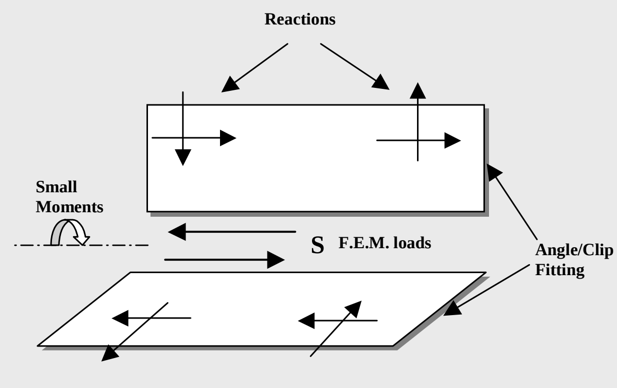


Panel-to-Panel Joints - When meshing different panel surfaces, most preprocessors would create duplicate nodes along common boundaries between adjacent panels. The natural tendency is to merge the two sets of common nodes into one all along the boundary. Such an arrangement would allow full continuity of moments and forces. Depending on the type of joints in the panel, this would not necessarily be correct idealization. To simulate panel pins, beam elements with moments released at one end have been used.

Welded Joints - Two panels joined using mortise-and-tennon joints would be considered welded to each other where moments can be carried from one panel to the next, and may be modeled in such a manner.



Small Hinged Joints - Panels joined by metal angles may be considered hinge joints. There are two schools of thought on how these joints should be modeled. The first advocates spring elements where a stiffness of K approximately equals 1E5 lb./in. be used. The second advocates rigid elements such as those found in NASTRAN to be used. Rigid elements can sometimes give high and unrealistic loads join loads especially when tension loads are present (e.g. corner fitting on a shelf where prying occurs for a 9G forward crash). Adjacent panels should be joined to each other only at those locations where fittings are; the other common nodes should not be connected. The joint loads from the F.E.M. maybe applied to an imaginary cut in the middle of the joint fitting.



Loads in a hinge joint

One of the basic assumptions being made here is that it is easy for the fitting to rotate and the ‘heel-and-toe’ loads on the flanges are small.

Long Hinged Joints - When long angles are used to join two panels, a series of either axial or bending elements may be used.

Summary on Panel Joints - Panel joints are arguably one of the most important features in any monument that directly influence structural integrity. A free-body diagram with all the joint loads can easily be produced for any panel in a modern postprocessor such as PATRAN. It is a good idea to include such information in any stress analysis.

In a highly loaded area such as shelves or dividers behind attendant seats, it may be appropriate to model the joints themselves in greater detail (other than springs) in order to arrive at a more accurate distribution of loads.

CHAPTER 4. DEMONSTRATION BY ANALYSIS AND TEST

(1) Similar to the discussion in the previous Section, structural substantiation of an interior item may be accomplished using aspects of both Stress Analysis and Static Test. In this case, structural substantiation is partially by stress analysis and partially by static test. This can be accomplished when substantiation by stress analysis can be isolated from substantiation by static test. Examples include:

a. Stress analysis of the shell of an interior item, but a static test of some doors, restraints, floor fittings, or other discrete details.

b. Stress analysis of the entire interior item for lateral, aft and vertical load conditions, but static test of the 9G forward load case.

(2) Because the method of certification is not 100% stress analysis or 100% by static test but some portion of each, the FAA review and approval of documents supporting both stress analysis and static test is required according to the previous sections concerning Stress Analysis and Static Test. Care must be taken to ensure each method is mutually compatible in a given structural substantiation. In the case of example a) above, it may be important to use the deflection information of the interior item's shell found in the stress analysis for developing a realistic test fixture support (stiffness) for the detail test of a door or restraint. The significance of this approach is that not all critical conditions need to be tested. The program could be reduced to only one test, selected because it is determined to be the most severe loading case for the overall structure, or because it tests the design condition that has the lowest margin of safety. This approach is beneficial in minimizing program risk and cost when it has been determined that full-scale test validation to ultimate load is necessary.

CHAPTER 5. DEMONSTRATION BY SIMILARITY

1. Comparison Analysis Criteria When Monument is Identical

Substantiation of a monument by comparison analysis is acceptable if both the following criteria are met:

(1) The monument is structurally identical (exterior / interior panels, fittings / fitting installation, fitting locations, etc.)

(2) The monument interior configuration is identical (weight and C.G.)

2. Comparison Analysis Criteria When Monument is Similar

The monument shell structure, the monument installation means, the monument interior configuration, and the weight and C.G. are not identical but similar to a previously substantiated monument may be substantiated by a comparison analysis using the following guidelines:

(1) A drawing is required showing the differences in the structure, the configuration of the monument interior, and the monument installation.

(2) Describe how these differences may affect the internal loading on the monument.

(3) Supply an explanation of how the loads at all the attachment fittings are affected as well as the interface load differences.

(4) Provide a description and explain how the major load-carrying panels are affected (may require showing a comparison in panel loading for each monument).

(5) Perform additional analysis and/or partial detail tests for details that can't be covered by the previous monument substantiation.

(6) Include a conclusion statement as to why the new monument is substantiated based on the similar and previously substantiated monument.

3. Comparison Analysis Criteria When a Component is Identical

When a component is to be substantiated by a statement of similarity to another tested or analyzed component, the two components must be identical and must react the loads in the same manner. This is particularly important in the case of clips or brackets if the applied loads are significantly different.

4. Comparison Analysis Criteria When a Component is Similar

When two components are not structurally identical and/or do not react the loads in the same manner, a comparison analysis is required. All differences in the structure and/or means of reacting load must be shown via a drawing in the report with a description / explanation stating why these differences are not critical, and are covered by the test/ analysis of the previously substantiated component. Otherwise, a full or additional analysis will be required for the new component. The following details need to be addressed when a component is substantiated by comparison:

(1) Component Geometry

(2) Component Material

(3) Component Applied Loads (magnitude and direction)

(4) Component Reaction of Loads (a function of local stiffness)

(5) Component Installation Means

CHAPTER 6. FAA PUBLICATION INFORMATION

1. How can I get this and other FAA publications?

(1) You can get the Federal Aviation Regulations and those APDs for which there is a fee from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. You can view a list of all APDs at:

http://www.gpo.gov/

(2) You can view the FEDERAL AVIATION REGULATION at:

http://rgl.faa.gov/

2. To request free acceptable practice documents, contact:

U.S. Department of Transportation
Utilization and Storage Section, M-443.2
Washington, D.C. 20590

3. To be placed on FAA's mailing list contact:

U.S. Department of Transportation
Distribution Requirements
Section, M-494.1
Washington, D.C. 20590

APPENDIX A. GAMA BAI AD HOC – INTERIOR MONUMENTS SUB-COMMITTEE

Name	Company	Phone	E-mail	Status
Ard, Mark	Gulfstream Aerospace Corp.	912-963-6604	mark.ard@gulfaero.com	Member
Argetsinger, Jack	DeCrane Aircraft Cabin Mgmt.	316-729-2127	jackargetsinger@precision-pattern.com	Chair
Bromm, David	Cessna Aircraft Company	316-517-8664	dbromm@cessna.textron.com	Member
Cheung, Lok	Boeing Commercial Aircraft Co.	425-266-3970	lok-sang.cheung@boeing.com	Member
Cummings, Greg	Greenpoint Technologies	425-739-7142	gcummings@greenpnt.com	Member
Dugelby, Jim	Threshold Eng. Co.	210-490-5386	jdugelby@alum.mit.edu	Member
Etzkorn, Paul M.	Boeing Commercial Aircraft Co.	425-342-2966	paul.m.etzkorn@boeing.com	Member
Gormley, John (Jeff)	Dassault FalconJet	501-210-0368	Jeff.Gormley@DFJCLR.FALCONJET.com	Member
Groutage, DaleAnn	BE Aerospace	360-435-8831	DaleAnn_Groutage@beaerospace.com	Member
Halvorson, Bob	Halvorson Engineering	805-381-1778	BobHDER@aol.com	Member
Howard, Rocky	Aero Design Inc.	512-266-0610	rocky@aerodesigninc.com	Member
Landes, Ross	FAA Standardization Branch ANM-113	425-227-1071	ross.landes@faa.gov	Member
McCarthy, Mike	C & D Aerospace	714-934-0000	mike.mccarthy@cdaero.com	Member
McGehee, Carl	FalconJet	501-210-0273	Carl.McGehee@DFJCLR.FALCONJET.com	Member
McGettrick, Mike	McGettrick Structural Engineering	316-688-5668	michael@mcgettrickengineering.com	Member
Mooney, Joe	Delta Engineering	302-325-9364	jmooney@delta-engineering.com	Member
Offermann, Hank	FAA Transport Directorate ANM-115	425-227-2676	hank.offermann@faa.gov	Member
Powell, Kieron E.	Northwest Composites	360-653-2211	powell@nwcomposites.com	Member
Perrella, William	Perrella & Associates	425-641-6600	w.perrella@attbi.com	Member
Sato, Atuo	JAMCO America	425-347-4735	atuo_sato@jamco-america.com	Member
Schneider, Greg	FAA Transport Directorate ANM-115	425-227-2116	greg.schneider@faa.gov	Member

APPENDIX B. CHECKLIST – STRUCTURAL TESTING

CHECKLIST – STRUCTURAL TESTING

Author: ______________________________ Report No.: ______________________ Revision: __________

Make: ______________________ Model: ________________ Effectivity: __________________________

Monument Part Nos.: ____

Reviewed by: ___________________________ Review Date: __________ Project No.: ____________________

NOTE: This checklist provides guidance only. Acceptable practices are contained in the APD document, and the requirements in the applicable FAR's.
E = Essential for Structural Test Report I = Informational

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	COMPLIANCE TO REQUIREMENTS					
	1. Does the test plan list all the applicable FARs intended for showing compliance?					
	2. If demonstration to other requirements is intended (UK-CAA, JAR) are these listed?					
	3. Does the test procedure state the Ultimate static load will be held for a minimum of three (3) seconds for all load cases per FAR 25.305(b)?					
	4. Does the test plan summarize all applicable process specs., and material specs. used in test article construction? Are the revision levels correct (latest approved)?					
	5. Is testing of this article per the Certification Plan					
	6. Is the name and address of the test facility provided? If the test article and test set-up conformity inspections will be at different business locations then two(2) separate FAA Form 8120-10's will be required, and both locations listed. List the name of the preferred DMIR/DAR delegated to perform conformities.					
	7. Is there a description of the test fixture? Are all the reaction points and locations identified and dimensionally located? List either a drawing or a reference to a drawing.					
	8. Is there a narrative justifying the test fixture? (stiffness or representing aircraft support)					
	VERIFICATION					
	9. Does test plan state that test specimen, and setup will be inspected by a representative of the FAA for conformity to the production drawings?					
	10. Does the test plan provide the name and telephone number of a company contact concerning witnessing and conformity inspections?					
	11. Does the test plan state that there will be a FAA approved test witness?					
	12. Are all load application, measuring devices and test equipment calibrations up to date? Calibration data should be included in the test plan, but if calibrations are performed just prior to test they will be listed in the results report.					
	13. Do the reaction points simulate commodity (attachments) to airplane interfaces (seat track fitting, aircraft tombstone, etc.)? And specify mounting hardware?					
	TEST ARTICLE					
	14. Is there a test article description which includes basic construction , major fitting details, joint design details, and					

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	special features?					
	15. Is the test article part number identified on the test plan?					
	16. Does the test plan provide test article drawing number with revision level? (Documentation needed for conformity reasons)					
	17. Are there any compartments with multiple shelves? a) Will each shelf be tested for the total compartment load? b) If the answer to question a) is no, will each shelf be separately tested or analyzed to loads that are consistent with the placard(s)? (monument must have weight limit placards controlling loading of monument)					
	18. Does the test plan show the method of applying loads on compartment doors that is representative of the actual load distribution for all load cases? (size and thickness of spreader panels, proper use of extrusions)					
	19. For partial or detail test, does the test specimen's structure simulate actual monument structure? If no, explain:					
	20. Are overall monument weight and C.G. identified? If yes, do they agree with calculated weight and C.G. as defined in the interface loads document?					
	21. Are content weights and C.G.s identified?					
	METHOD					
	22. Identify load application method. Is it applied correctly? a) Whiffle tree b) Weights c) Centrifuge Does it use the equation RPM = $60/2\pi$ * (load factor * g/r) ½? Where g = 32.2 ft/s² and r = radius in ft. d) Combination of a) and b)					
	23. Has this load application method been used before? May be helpful to describe successful use on previous projects in the test plan.					
	24. Has the interface loads report been approved?					
	25. Are the correct factors included? a) Monument equipment restraints (1.33 for UK-CAA) b) Attendant seat attachments (1.33) c) Wear and tear per FAR 25.561 d) variability factors, including their derivation					
	26. Have all load factors, including combined loads, been addressed in the test plan?					
	27. Are all loads identified? a) Content loads b) Structure loads c) Customer attached items (e.g. magazine racks, video monitors & etc.) d) Adjacent units which will load share e) Assist / abuse loads					
	28. Do the summation of these loads meet or exceed the overall weight multiplied by the load factors? (Note: Include structure weight, if applicable)					
	29. Are primary and secondary restraints tested individually for maximum load?					
	30. If the answer to # 30. is no, what is the proposed method? (Detail test or analysis)					
	31. Does the proposed substantiation method simulate all internal masses correctly? (Loose contents, shelf					

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	mounted, wall mounted, and etc.) Are test jigs described in detail?					
	32. For galleys / stowages with "double deep" compartments, does the compartment have an intermediate restraint for the rear mass when the front mass is removed? Will this restraint be checked for carrying flight loads? Does the test plan take this into account?					
	33. For "Down" load case only, are cart loads / floor loads included with galleys / stowages that have integral floors?					
	34. Are the test load application points for all load cases identified by dimensions with tolerances?					
	35. Are there attendant seats attached to this monument? Static Load Requirement a) Does the test setup simulate actual attendant seat interfaces and stiffness? Note: Single seats are most common. Double seats, "swing out" seats, and "high" comfort seats are rare. The test plan should consider if the test fixture is representative for use with the monument test article. b) Are the loads applied through a body block or equivalent C.G. per NAS 809? If no, is method acceptable? c) Is the 1.33 fitting factor applied to seat and monument attachment interface loads per FAR 25.785? Dynamic Load Requirement d) For FAR 25.562 seats, has the method of substantiation been established?					
	36. Are deflection measurement locations identified?					
	37. Does the test plan state the Pass / Fail criteria?					
	RECORDS					
	38. Does the test plan state photographs or electronic format images will be included in the report? (Note: Photos must be taken during maximum load [3 seconds]).					
	39. Is the test article to be refurbished for production use? If yes, is post-test inspection test identified? Does the test plan state that a refurbishment report will be included in the test report?					
	40. As part of determining a successful test, the test article should be inspected after every test for cracks, etc. (whether it is to be refurbished or not). Does the test plan state that the article will be inspected by QA, or equivalent, after every test?					

APPENDIX C. CHECKLIST – FINITE ELEMENT ANALYSIS

CHECKLIST – FINITE ELEMENT ANALYSIS

Author: ________________________________ Report No.: ______________________ Revision: __________

Make: ________________________ Model: _________________ Effectivity: _________________________

Monument Part Nos.: ____

Reviewed by: _________________________________ Review Date: __________ Project No.: _______________

NOTE: This checklist provides guidance only. Acceptable practices are contained in the APD document, and the requirements in the applicable FAR's.
E = Essential for Finite Element Analysis Report I = Informational

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	1. Does the orientation of the loads match the installation in the aircraft? Are the gust loads consistent with the flight station?					
	2. Does the coordinate system make sense?					
	3. Are the boundary conditions realistic?					
	4. Are the boundary conditions at least conservative?					
	5. Do the loads and reactions balance?					
	6. Do the moments balance?					
	7. Are "decorative features" left out that are structurally significant?					
	8. Are there any local features that could be an "Achilles heel" that the overall model might miss? (i.e. a reinforced corner of a panel for building up an attachment to the airframe.).					
	9. Are features ignored because they are considered trivial but really aren't? (i.e. non-structural shims or spacers)					
	10. Is the estimated weight >= the actual weight?					
	11. Is the center of gravity (CG) reasonable?					
	12. Does the weight given for the fixed equipment items match the weights on their respective data sheets?					
	13. Did the analyst include a rough analysis/estimate that tends to support the FEA data?					
	14. Does the analysis have test data from similar items that show a reasonable correlation?					
	15. Is there historical data that can be compared to this data?					
	16. Do the deformations look like they may be large for a linear model?					
	17. Is deformation data included?					
	18. Can the deformation be estimated based on the existing data?					
	19. If a margin of safety (MS) is tight (after adding appropriate factors), is it passing because the output data is being expressed to a greater accuracy than the input data? (i.e. - if your input data is known to 3 figures, you can't express your output to 5 figures)					

APPENDIX D. CHECKLIST – INTERFACE LOADS

CHECKLIST – INTERFACE LOADS

4.

Author: ______________________ Report No.: ______________________ Revision: ______________

Make: ______________________ Model: ______________________ Effectivity: ______________________

Monument Part Nos.: ____

Reviewed by: ______________________ Review Date: ______________ Project No.: ______________

NOTE: This checklist provides guidance only. Acceptable practices are contained in the APD document, and the requirements in the applicable FAR's.

R = Recommended on Interface Load Report I = Informational

R/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
I	1. Is there a brief description of the monument?					
I	2. Are views of the monument location/s included with respect to the airplane, and with respect to adjacent items?					
R	3. Are views of the monument showing every attachment point location (STA, BL and WL) included?					
R	4. Is a sketch showing fixed equipment layout included?					
R	5. Are all applicable monuments covered?					
R	6. Are the correct attachment locations (per project documents) used?					
R	7. Check weights used (per project documents)					
	a. Are all equipment and consumables accounted for?					
	b. Verify that weights and C.G. (for structure, equiipment, totals, attendant, etc.) are correct.					
	c. Total weight per project documents?					
R	8. Is F.E.M. used? For F.E.M. Analysis, are the following included:					
	a. Node and element plots?					
	b. Element property definition and locations?					
	c. Applied load and boundary conditions and location modeled per appropriate data?					
	d. Floor and other attachments stiffness modeled per appropriate data?					
R	9. Are loads acting on the airplane structure?					
R	10. Is the sign convention correct per the selected axis system?					
R	11. Are the correct Design/Flight load factors used?					
R	12. Is there a decompression load case for the monument? Is the decompression in the right direction?					
R	13. Do the loads balance (force and moment)? Check load summation vs. total weight?					
R	14. Do the loads reflect the type of fitting used (i.e. casting, etc.)?					
R	15. Verify the attach points and fitting capabilities are correct?					
R	16. Does the report include deflection analysis? If so, are predicted stresses/loads in the elastic range of the materials used?					

R/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	17. Are the signatures of the preparer and the checker included?					
	18. Are the part, drawing, and project numbers correct?					
	19. Compare to previously calculated loads to determine if loads appear acceptable. Do the loads make sense?					
	20. Has all the attachment hardware been checked for interface loads?					
	21. Are loads from adjacent monuments, equipment, and/or seats being considered?					
	22. Does the report format include the following: cover page, list of effective pages, list of revisions, references, drawings with revision level & date, and table of contents?					

APPENDIX E. CHECKLIST – STRESS ANALYSIS

CHECKLIST – STRESS ANALYSIS

Author: ______________________________ Report No.: ____________________ Revision: __________

Make: ______________________ Model: ________________ Effectivity: ________________________

Monument Part Nos.: ____

Reviewed by: ______________________________ Review Date: __________ Project No.: ______________

NOTE: This checklist provides guidance only. Acceptable practices are contained in the APD document, and the requirements in the applicable FAR's.
E = Essential for Stress Analysis Report I = Informational

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
E	1. Has the Certification Proposal been approved by the responsible regulatory agency?					
	2. Does this report cover all the monuments listed in the header of this checklist?					
	3. If this report doesn't cover all the monuments listed, what other reports apply?					
	4. Have the necessary drawings been submitted in support of the analysis?					
	5. Are the Interface loads approved? [Report No.:]					
	6. Are interface loads shown in the Stress Report equal to, or greater than the loads in the Loads Report?					
	7. Have the monument weights been verified?					
	8. Table listing minimum margins of safety including the mode of failure (i.e. bending, shear, torsion, crippling, as well as the critical load condition).					
	9. Are the correct flight load factors listed for each location?					
	10. Are the compartment weights listed on the drawing the same as those used in the analysis?					
	11. Does the report format include the following: cover page, list of active pages, list of revisions, references, drawings with revision level & date, and table of contents?					
	12. Description of the monument location in the airplane.					
	13. Panel construction, i.e. face sheet and core material.					
	14. Joint construction, including panel joints and monument split joints. The monument structure is adequately described (e.g. types of fasteners and use of bonding)					
	15. Description of primary and secondary restraints (if applicable).					
	16. Location and type of floor fittings.					
	17. Description of floor fitting to panel joints					
	18. Description of outboard and overhead tie assemblies, including location of attach points					
	19. Are design allowables being utilized?					
	20. Are the design allowables approved by the responsible regulatory agency?					
	21. If the design allowables are not approved, are they taken from MIL-HDBK-5, MIL-HDBK-17 or MIL-HDBK-23?					
	22. If the allowables used do not satisfy #20 or 21, then what is the plan for allowables?					
	23. Are allowables approved by the responsible regulatory agency for purchased hardware? Note: Manufacturers					

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	catalog strength ratings are not acceptable.					
	24. What items are not approved, and how are these items to be approved?					
	25. Have the manufacturing methods and processes been approved by the responsible regulatory agency?					
	26. For foreign manufacturers, has the foreign regulatory been determined?					
	a. If yes, which one? [ ]					
	b. List of structural materials.					
	c. Comparison of materials and allowables with U.S. standards.					
	d. Written approval by foreign regulatory agency of allowables.					
	27. General – for each part analyzed, the following have been provided:					
	a. Part number					
	b. Sketch with dimensions and part number					
	c. Critical load condition					
	d. Assumptions					
	e. Balanced free body diagram, including all necessary dimensions					
	f. References called out for allowables and material properties					
	28. Is F.E.M. data used?					
	a. Is F.E.M. properly documented?					
	b. Was F.E.M. used to calculate interface loads?					
	c. Was the use of F.E.M. for interface loads approved?					
	d. Are stress levels reported from F.E.M. for panels away from constraints?					
	e. If yes, is modeling appropriate to produce reliable stresses?					
	f. Other F.E.M. generated stress levels are not acceptable for stress analysis?					
	g. Are balanced-free bodies shown for components analyzed, using internal loads from F.E.M.?					
	29. Attendant Seat					
	a. Correct attendant seat and attendant weight is used					
	b. Is the attendant seat used for Take-Off and Landing______ In Flight Only_____?					
	c. Is a 1.33 fitting factor used in the attachment design?					
	d. The panel supporting the seat has been analyzed with all appropriate applied loads for bending shear, attachments to other?					
	e. Does the 16G requirement apply?					
	30. Floor fittings (Interface fitting on the monument side, Interface fitting on the aircraft side and the bolt to the aircraft floor)					
	a. Have all floor fittings been checked by analysis, testing or comparison?					
	b. Has a 1.33 fitting factor_____ or a 1.15 fitting factor_____ been applied?					
	c. Are floor attachment interface loads applied at the proper structural interface point and are the corresponding moments accounted for?					
	d. Do the assumptions regarding distribution to adjacent structure accurately reflect the actual relative stiffness?					
	e. Does the analysis of the module fitting include moments due to offsets between applied loads at the					

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	fitting and reactions in the panel?					
	f. Does the analysis for the critical out-of-plane loads include the transfer of the out-of-plane load into the panel and/or adjacent structure?					
	g. If the loads are transferred to edge extrusions, does the edge extrusion analysis include:					
	1. Axial strength of the extrusion (crippling of flanges – if applicable)?					
	2. Load transfer from the extrusion to the panel?					
	Note: Edge extrusions are only effective for in-plane axial loads and some limited out-of-plane loads.					
	h. Does the fitting analysis include:					
	1. Critical section(s) of the “Bridge Piece” for combined (principal) stresses due to bending and shear (including torsion) about two axes?					
	2. Validation of end fixity assumption?					
	3. Fasteners and flange bending at the attachment to the panel?					
	4. Fasteners and flange bending at the joint between the two halves of the fitting?					
	5. Margin of safety of a bond-only joint between the fitting and the panel? Validation of bond joint strength?					
	6. Transfer of load from an imbedded metal filler to the honeycomb?					
	31. Overhead ties, inter-monument ties and side ties					
	a. Have all overhead ties assemblies been checked? (Bolt/pin at the end of the tie rod on the aircraft side, tie rod, bolt/pin at the end of the tie rod on the monument side, and the upper attach bracket on the monument side)					
	b. Has an appropriate fitting factor been used from the monument/airplane interface to the supporting-structure?					
	c. Does the analysis of the monument overhead structure take into account the following:					
	1. Critical bending section					
	2. Axial strength (maximum section area)					
	3. End strength					
	4. Column stability (with eccentricity)					
	5. An allowance for misalignment?					
	d. At the fitting-to-monument overhead panel joint, does the load and moment distribution to the fasteners accurately reflect the support structure stiffness?					
	e. Does the analysis include the load path into adjacent vertical panels?					
	32. Panels					
	a. Drawings or sketches that identify structural panels, i.e. sidewalls, ceiling, counters, etc., are provided.					
	b. Sketches should ensure load paths are included.					
	c. Have critical panels been checked for each module system?					
	1. Forward panels on aft-facing and side-facing modules for out-of-plane bending and core shear.					
	2. Ceiling work deck and side panels for in-plane shear moments (especially around panel					

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	cutouts)					
	d. If the bending section includes fiberglass and aluminum sheets, do the section property and bending stress calculations account for the differences in modulus of elasticity ("E")?					
	e. If the module has a floor, has the floor been checked (i.e. is the monument floor capable of transferring cart loads to the floor fittings)?					
	f. Have individual shelves within compartments been included in the analysis?					
	g. If compartment doors have been included in the analysis, is the loading on the doors representative of the actual load distribution?					
	h. What failure theory was used to take into account interaction between the normal and shearing stresses (i.e. Tsai-Hill or other)?					
	33. Joints					
	a. What bonding factor is applied for 100% load transfer through bond?					
	b. Does the joint analysis include allowables for combined fasteners and bonding? If yes, are there FAA approved joint allowables for the configuration? If not, then the analysis should use only the lower of the two allowable values.					
	c. For split joints, is there a description of fastener type and load transfer along with the analysis?					
	d. Does the split joint include the 1.15 fitting factor? (not required if joint is continuous or if joint qualifies as a fastener pattern. To qualify as a fastener pattern, the joint must have the structural capability to redistribute and transfer the loads and moments after the critical (highest load) fastener has failed. If the joint does not have this capability, then it must be regarded as a fitting, and the appropriate fitting factor must be applied.)					
	34. Fixed equipment restraints					
	a. Is there a drawing showing the location of all fixed equipment?					
	b. Are fixed equipment restraints adequately defined (type of restraint and its capability)?					
	c. Do all fixed equipment items not structurally attached to the module have primary and secondary restraints (if applicable)?					
	d. Is each restraint capable of bearing the entire load (Note: Including 2 half-size carts in a compartment)?					
	e. For CAA, is a 1.33 fitting factor used?					
	f. Do all doors have dual restraints? If not, are latches positive?					
	g. Are doors designed to restrain maximum compartment weight?					
	1. Does check include door panel bending? (single door restraint engaged may be critical)					
	2. Does the check cover hinge, and latch attachments to the door and frame?					
	3. If critical, does door deflection address the latch engagement to ensure that the door remains latched and hold the contents?					
	h. Method of latch/door substantiation. Analysis_____ Test_____ Similarity_____					
	i. For ovens, is the rear, attach point part of the electrical connection?					
	j. Is the connection a structural connection? If so, has it been analyzed?					
	Note: Non-structural electrical connection is not acceptable for use as a load path.					
	k. Have the chiller attachments been analyzed?					

E/I	CONTENTS	Ref. Para#	Yes	No	Page	Section
	35. Cart Loading					
	a. Are module cart weights correct per interface loads?					
	b. Is a free-body diagram of the cart loading on the module shown correctly (e.g. cart kick loads in the 9.0 G forward load case)?					
	c. Are the cart loads accounted for in strength calculations of the counter, wall panels, and module floors?					
	1. Cart kick loads for the 9,0 G forward load case?					
	2. Loading on wall panels for aft/side-facing modules?					
	3. Quarter-turn load and moment into the panel?					
	d. For mushroom fittings, is the module substantiated for failure of one mushroom at the most critical location? (kick loads)					
	e. If work deck quarter-turns must act as a cart door secondary restraint, are they substantiated for the secondary restraint condition?					
	f. Are lower quarter-turn restraints provided for half carts? If not, is there an equivalent lower restraint provided for the half carts?					
	36. Additional equipment and abuse loads. Have the following items been substantiated (including abuse loads where appropriate)?					
	a. Baby bassinet attachment					
	b. Curtain supports					
	c. Sliding drawers (closed and open for flight loads)					
	d. Folding and pullout tables					
	e. Flight attendant assist handles and steps					
	f. Stub walls					
	g. Other _______________________					
	37. Castings					
	a. Are casting factors as defined in FAR 25, Paragraph 25.621, used correctly?					
	b. If casting is a fitting, has correct fitting factor been used? NOTE: The higher of fitting factor or casting factor has to be applied, but not both.					
	38. Deflections					
	a. Has the maximum deflection been addressed?					
	b. Has plot of maximum deflection been included?					

APPENDIX F. MATERIAL STRENGTH PROPERTIES AND DESIGN VALUES

1. Introduction

This Appendix identifies the regulations concerning material properties & design values, and explains the engineering, manufacturing, quality assurance, and procurement requirements to ensure material strength and performance.

2. Applicable Regulations

14 CFR, Part 25, Subpart D, Design & Construction

- Section 25.601 – General

The airplane may not have design features or details that experience has shown to be hazardous or unreliable. The suitability of each questionable design detail and part must be established by tests.

- Section 25.603 – Materials

The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must--

(a) Be established on the basis of experience or tests;

(b) Conform to approved specifications (such as industry or military specifications, or Technical Standard Orders) that ensure their having the strength and other properties assumed in the design data; and

(c) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.

- Section 25.605 - Fabrication Methods

(a) The methods of fabrication used must produce a consistently sound structure. If a fabrication process (such as gluing, spot welding, or heat treating) requires close control to reach this objective, the process must be performed under an approved process specification.

(b) Each new aircraft, fabrication method must be substantiated by a test program.

- Section 25.613 - Material Strength Properties and Design Values

(a) Material strength properties must be based on enough tests of material meeting approved specifications to establish design values on a statistical basis.

(b) Design values must be chosen to minimize the probability of structural failures due to material variability. Compliance with paragraph (b), must be shown by selecting design values that assure material strength except as provided in paragraph (e) of this section with the following probability:

(1) Where applied loads are eventually distributed through a single member within an assembly, the failure of which would result in loss of structural integrity of the component, 99 percent probability with 95 percent confidence.

(2) For redundant structure, in which the failure of individual elements would result in applied loads being safely distributed to other load carrying members, 90 percent probability with 95 percent confidence.

(c) The effects of temperature on allowable stresses used for design in an essential component or structure must be considered where thermal effects are significant under normal operating conditions.

(d) The strength, detail design, and fabrication of the structure must minimize the probability of disastrous fatigue failure, particularly at points of stress concentration.

(e) Greater design values may be used if a "premium selection" of the material is made in which a specimen of each individual item is tested before use to determine that the actual strength properties of that particular item will equal or exceed those used in design.

3. Material Strength Properties

Material strength properties are often based upon a material properties test program that is performed by the applicant (OEM and/or supplier), and approved by the FAA. The data is often considered proprietary. To the extent possible, the data set should be based on a consensus organization document such as MIL-HDBK-5 (MMPDS-01), MIL-HDBK-17. etc.

4. Design Values

Design values are applied to a design detail, feature or component that is considered as a unique item. Design values include the characterization of the physical and strength values on a statistical basis such that they may be used to predict a reliable, repeatable level of performance.

5. Engineering Definition

The following information should be included in the design data to ensure strength and performance:

(1) Physical characteristics (drawing detail, unique drawing, specification)

(2) Material properties (material specifications, process specifications, drawing notes)

(3) Fabrication methods (fabrication specifications, manufacturing specifications, drawing notes)

(4) Installation Instructions (manufacturing specifications, installation specifications, drawing notes)

6. Manufacturing Considerations

(1) Is process specific training necessary? Are the process skills within the limitations of a person normally skilled in the trade?

(2) Should operators be certified? Demonstration of maintained skill level is needed.

(3) Are product/process specific inspections or tests required?

7. Basis of Properties

(1) Strength Properties (generally are related to a probability of failure and confidence level)

a. A-Basis Design Values (99% Probability/95% Confidence)

b. B-Basis Design Values (90% Probability/95% confidence)

c. Other (any combination that demonstrate compliance with 25.601, 25.603 and 25.605)

(2) Physical Properties (generally presented as typical or average values)

(3) If the proper functioning of the design feature or detail depends upon having some maximum, minimum or tightly controlled property, then "average" may not be acceptable.

8. Testing - Sample Size

Example Baseline = B-Basis design allowable
Normal Distribution $B = X_{bar} - k_B\ s$
Where $k_B = f$ (n, confidence)
(Ref: MIL-HDBK-5, Chapter 9)

a. In the limit, for normal distribution

B-Basis Design Allowable, k = 1.28

A-Basis Design Allowable, k = 2.33

b. An approximation of the best that can be obtained:

$A = X_{bar} - 2.33\ s$

$B = X_{bar} - 1.28\ s$

c. For B-Basis baseline, normal distribution:

1. A sample size of much less than 10 is generally not regarded as being fully capable of capturing variables
2. A sample size of more than 17 does not generally give much improvement

NOTE: In the absence of mitigating data, the FAA considers 12 samples acceptable.

9. Sample Composition

(1) Sample sets should include different material lots (3 minimum).

(2) For operator-dependent processes, the sample sets should include the range of operator skills.

(3) For equipment dependent processes, the sample sets should include range of settings or adjustments, or worst combinations.

10. Data Sets

Data points may be discarded if:

(1) There are physical characteristics or evidence that demonstrate that the test article was not representative of the sample set.

(2) There are changes to the material, process or fabrication specifications that mitigate the undesirable characteristic.

(3) A data point is NOT discarded simply because it is an extreme value that unfavorably alters the statistical results. Any discarded point should be included in the test results and a valid explanation provided for not taking it into consideration.

11. Interpretation of Results

If the design allowable values are not acceptable (for example, negative), and the material property values are assumed to be acceptable, then the process and/or fabrication controls are not adequate. The solution is not found in "statistical magic."

12. S-Basis Material Strength Properties

(1) S-Basis: The minimum value specified by the governing specification (statistical assurance associated with this value is unknown)

(2) S-Basis design value is not necessarily guaranteed by the specification (properties are as agreed upon between the purchaser and supplier.

13. How Design Values are Guaranteed?

(1) Define process, quality control, and testing requirements necessary to ensure achieving minimums and set certification documentation.

(2) Define the design values as an engineering requirement.

(3) The drawing notes establish the requirements directly, and enforce compliance with specification paragraphs that ensure design properties, quality control and certification requirements.

14. Requirements Not Necessarily Visible to Engineering

(1) Procurement System (flow engineering requirements to supplier)

(2) Quality Control System (specification & engineering compliance)

a. 100% Supplier Certification

b. Supplier Certification Plus In-House QC (including receiving inspection/tests)

c. 100% In-House QC Testing

NOTE: For additional information, see MIL-HDBK-5 (recent edition), Chapter 9, and/or appropriate statistics text book.

APPENDIX G. SAMPLE DETAIL STRESS ANALYSIS

(NOTE: The intent of this section is to provide examples of detail stress analysis. It is not intended to be a regulatory guidance for the FARs)

1. Detail Stress Analysis

(1) Panels, countertops, and shelves as applicable.

(2) A detail stress analysis shall be provided which includes the requirements outlined in Chapter 3, Section 6.

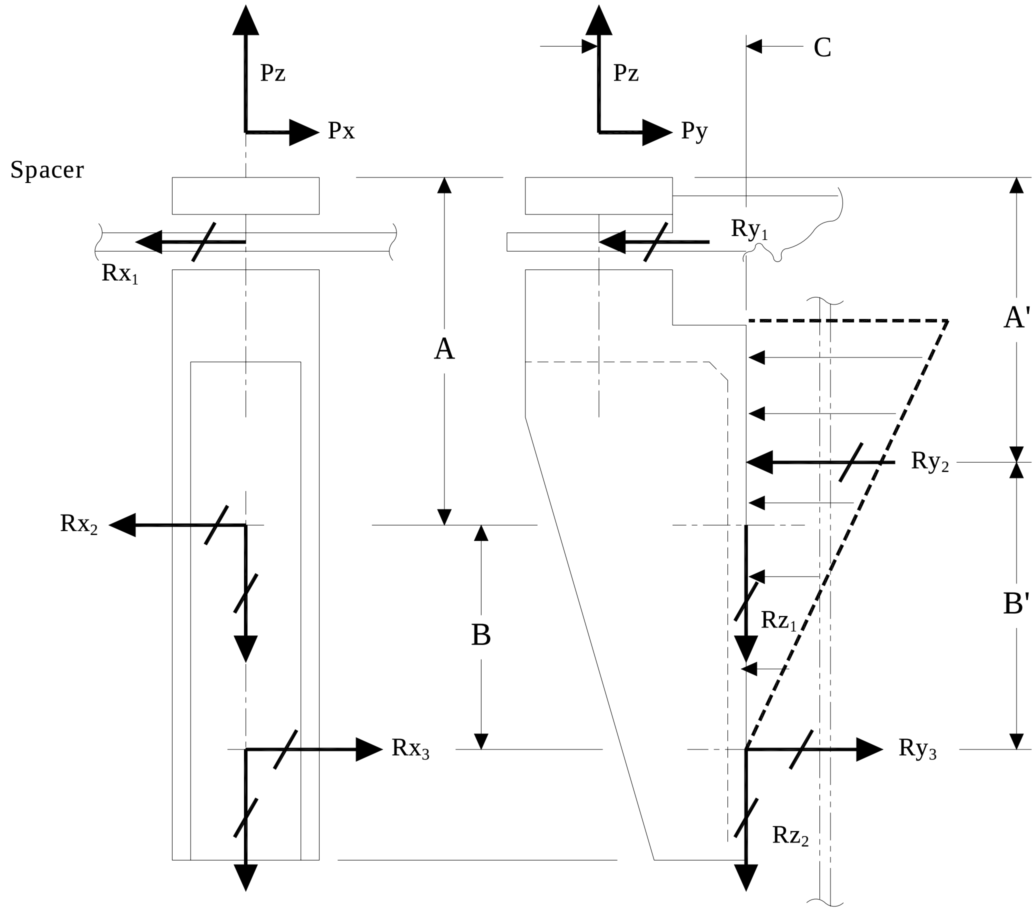
(3) A table showing deflection analysis results shall be provided.

(4) A three dimensional view of each galley or interior furnishing shall be provided showing part number callouts for major structural panel assemblies, attachment fittings, etc.

(5) A simple free body diagram is required for each structural detail analyzed. All applied loads and reactions must be shown in equilibrium for each critical load case. Refer to the figures on the following pages for examples of detail analysis methods including: “Bracket Reactions,” “Calculating Moments in Brackets,” “Compound Clips,” and “Simple vs. Multi-span.”

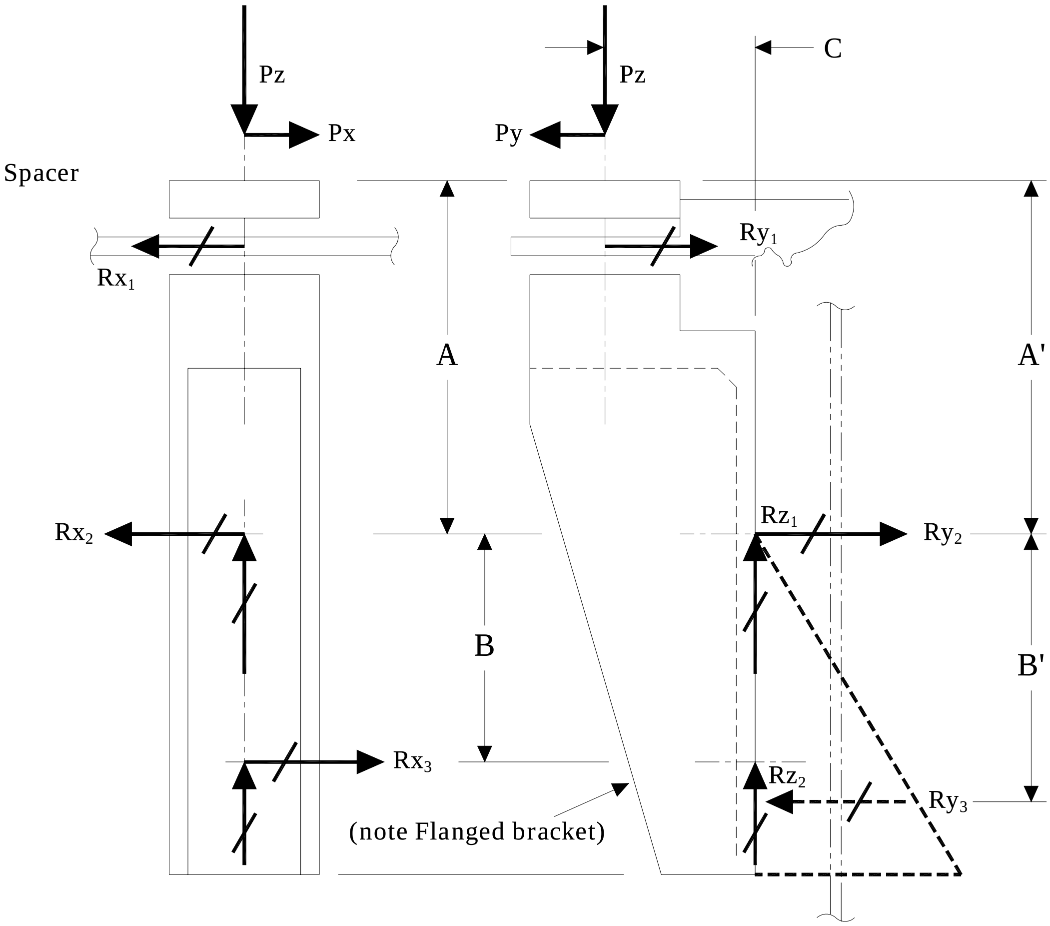
(6) When finite element modeling is used to support detail stress analysis, refer to Chapter 3, Section 10 for guidelines.

BRACKET REACTIONS (A). Attachment to flange of seat track, and web of seat track beam.



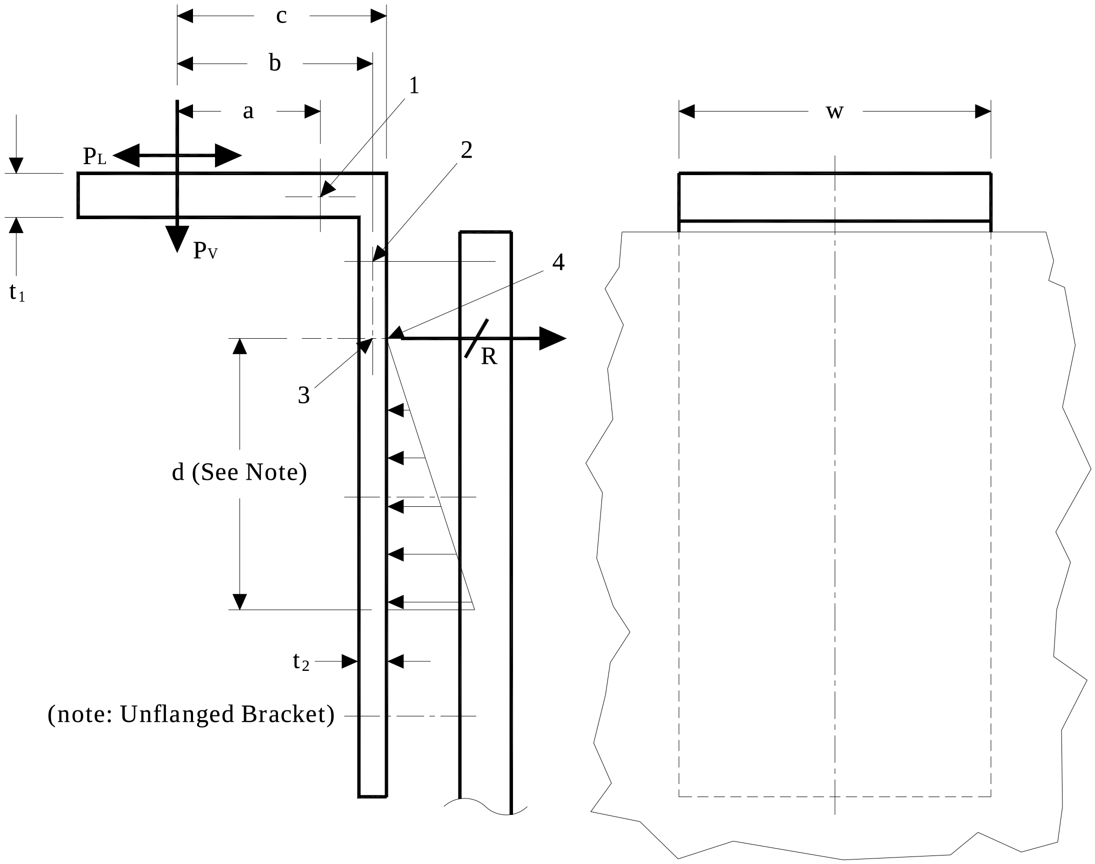
1. Px may be reacted by Rx_1 if the hole in the flange is considered a tight fit, or by Rx_2 and Rx_3 (Including couple load*) if the hole in the flange is considered large. Or by a combination, although the solution for this is difficult. Better to check the two conditions independently. *Couple load = Px * A/B
2. Py is reacted by Ry_1 since it is the stiffest load path.
3. Pz is reacted by Rz_1, Rz_2 (which may be considered equal), and by the couple load comprised of Ry_2 and Ry_3 (= Pz * C./B').

BRACKET REACTIONS (B). Attachment to flange of seat track and web of seat track beam. Note direction of Py and Pz loads.



4. Px may be reacted by Rx_1 if the hole in the flange is considered a tight fit, or by Rx_2 and Rx_3 (Including couple load*) if the hole in the flange is considered large. Or by a combination, although the solution for this is difficult. Better to check the two conditions independently. *Couple load = Px * A/B
5. Py is reacted by Ry_1 since it is the stiffest load path.
6. Pz is reacted by Rz_1, Rz_2 (which may be considered equal), and by the couple load comprised of Ry_2 and Ry_3 (= Pz * C./B').

CALCULATING MOMENTS IN BRACKETS

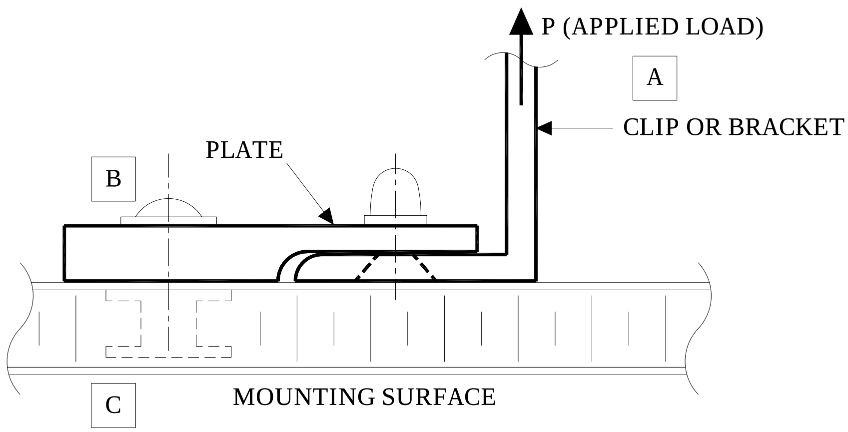


The above bracket should be analyzed for loads at point 1 if $t_1 < t_2$, at point 2 if $t_1 \geq t_2$, and at point 3 if there is a lateral load P_L. The bending moment due to P_V acting on the vertical flange is (P_V x b). It is conservative to use (P_V x c), which is used to calculate the reactions due to P_V. It is also recommended that the allowable stress be based on Fcy.

Note: Dimension "d" may be taken to the lower end of the vertical flange if the bracket is very rigid compared to the supporting member, such as a flanged bracket in the preceding example. If the racket is thin compared to the supporting structure, or if the vertical flange is very long, the distribution will not be linear, and a conservative assumption of an "effective" area for the compressive reaction may have to be assumed. Values ranging from 10t to 20t may be acceptable, depending on the relative thicknesses.

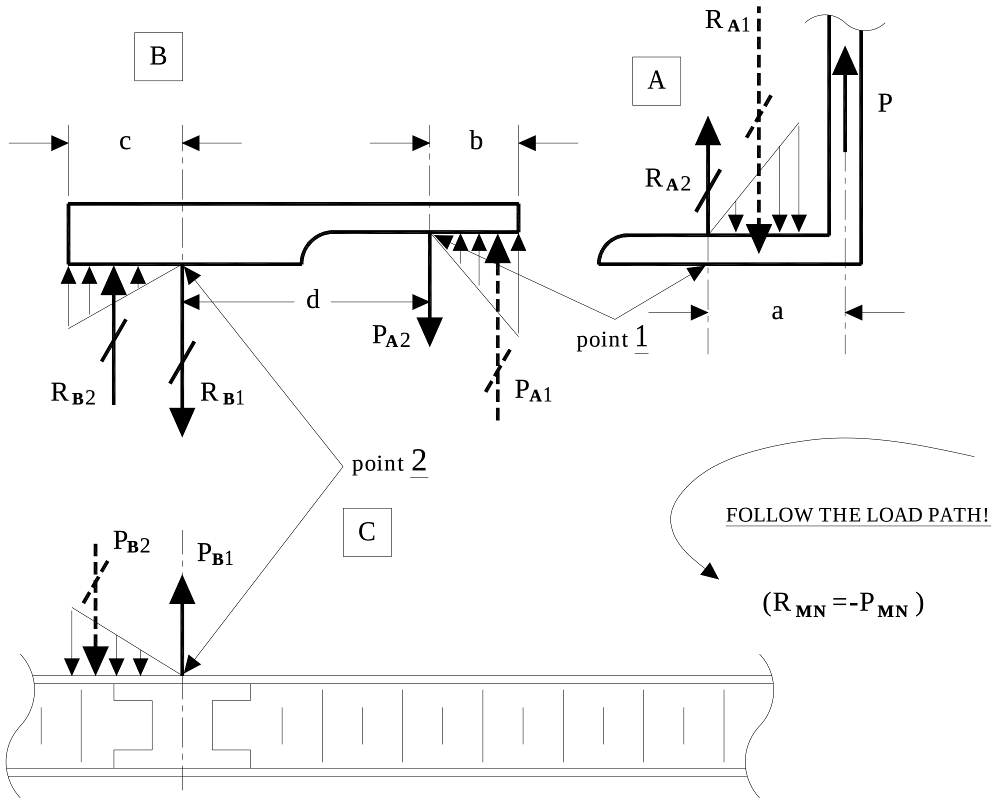
COMPOUND CLIP

We have stress memos regarding analysis of plain or gusseted clips. This note addresses the details regarding the analysis of what can be termed as a compound clip, rated by the sketch below.



COMPOUND CLIP

The resulting free body diagrams should look as follows:



Starting at *A*, taking moments about point 1, we solve for R_{A1}

$$R_{A1} = (P * a) \,/\, (\tfrac{2}{3} * b)$$

$$R_{A2} = R_{A1} - P$$

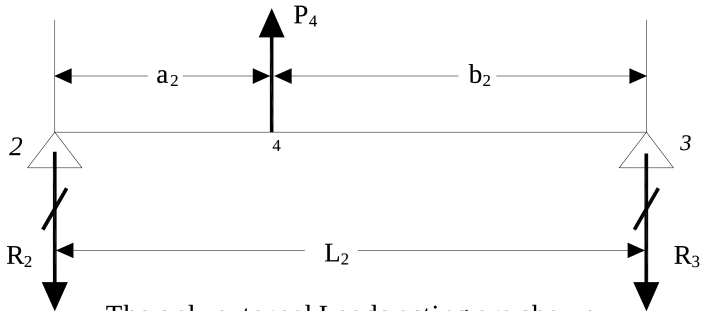
Similarly, going to *B* and taking moments about point 2,

$$R_{B2} = [\, P_{A1} * (d + \tfrac{2}{3} * b) - P_{A2} * d \,] \,/\, [\, \tfrac{2}{3} * c \,]$$

$$R_{B1} = P_{A1} + R_{B2} - P_{A2}$$

SIMPLE BEAM vs. MULTI-SPAN BEAM

Case I.



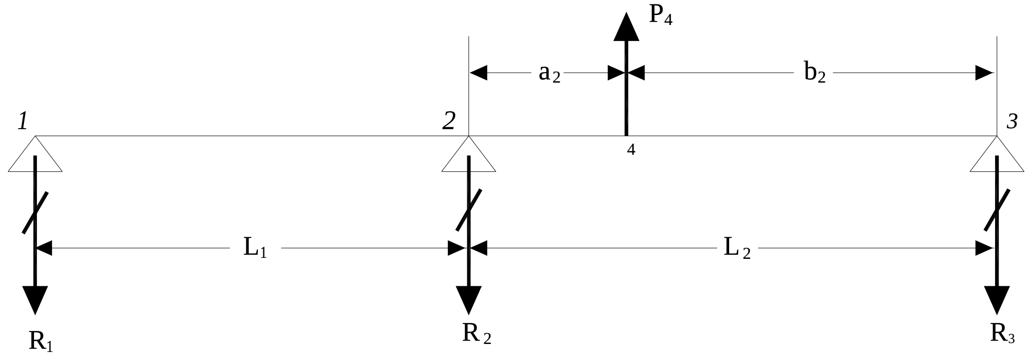
The only external Loads acting are shown

$R_2 = P_4\ (b_2\ /\ L_2)$

$R_3 = P_4 - R_2$

$M_4 = R_3 * b_2$

Case II.



$M_1 = M_3 = 0$

$2M_2(L_1/I_1 + L_2/I_2) = (P_4\, b_2/I_2 L_2)\ (L_2^{\ 2} - b_2^{\ 2})$

if $I_1 = I_2$ & $E_1 = E_2$ (constant): $M_2 = [P_4\, b_2\, (L_2^{\ 2} - b_2^{\ 2})]\ /\ [2(L_1 + L_2)L_2]$

from $\Sigma M2 = 0$, $S_{+1} = M_2\ /L_1$ & $R_1 = -S_{+1}$

$\Sigma V_1 = 0 = S_{+1} - S_{-2};\ \ S_{-2} = S_{+1}$

$\Sigma M_3 = 0 = M_{+2} + S_{+2}L_2 + P_4\ b_2$ so that $S_{+2} = -(M_{+2} + P_4 b_2)\ /\ L_2$

$R_2 = S_{-2} - S_{+2}$

$\Sigma V_2 = 0 = S_{+2} + P_4 - S_{-3};\ S_{-3} = S_{+2} + P_4$ & $R_3 = S_{-3}$

$M_4 = -R_3\ b_2$

SAMPLE APPLICATION FOR THE ABOVE CASES:

$L_1 = 20$ in
$L_2 = 30$ in
$b_2 = 20$ in
$P_2 + 1000$ lb

FOR CASE I.

$R_2 = 1000 * 20 / 30 = \underline{666.67 \text{ lb}}$

$R_3 = 1000 - 666.67 = \underline{333.33 \text{ lb}}$

Moment at point 4 = 333.33 * 20 = <u>6,666.67</u> in-lb (highest)

FOR CASE II

Using the equations noted above,

$$M_2 = \frac{(1000)(20)(30^2 - 20^2)}{2(20 + 30)(30)} = \underline{3{,}333.33 \text{ in-lb}}$$ ← compared to 0.0 for Case I

$R_1 = \underline{-166.67 \text{ lb}}$

$S_{-2} = 166.67$

$S_{+2} = -(3333.33 + 1000 * 20) / 30 = -777.78$

$R_2 = 166.67 + 777.78 = \underline{944.44 \text{ lb}}$ ← compared to 666.67 for Case I

$S_{-3} = -777.78 + 1000 = 222.22$ lb

$R_3 = \underline{222.22 \text{ lb}}$

$M_4 = -222.22 * 20 = \underline{-4{,}444.44 \text{ in-lb}}$

NOTE:

The above examples considered constant moment of inertia and material properties. If the beam has variable section properties, such as in the sketch below, the solution is more complex, and would require calculating the reactions and resulting moment distributions taking into account the variables.