REVISION HISTORY			
REV	DESCRIPTION OF CHANGE	DATE	APPROVED
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER HOUSTON, TEXAS

PREPARATION OF STRESS ANALYSIS REPORTS

SIZE	CAGE CODE	DWG NO	REV
A	21356	8594001	-

SCALE: NONE	AOD, CC3	SHEET: 1 OF 14

Preparation of Stress Analysis Reports

Rev –, December 2009

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12/22/2009

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1.0 Introduction

This document establishes requirements for formal stress analysis reports prepared for the NASA Johnson Space Center, Aircraft Operations Division (AOD). It places special emphasis on the importance of writing accurate, concise, and readable reports that stand alone and can serve as formal documentation for the strength of the structure. A well documented stress analysis is one that can be read and understood by anyone that is knowledgeable in the field of structures but is not familiar with the structure being analyzed.

2.0 Scope

This document is applicable to stress analysis reports prepared for the Johnson Space Center Aircraft Operations Division. This document applies to the analysis of aircraft structures, installed equipment, payloads, and ground support equipment.

3.0 Analysis

3.1 Coverage

All load carrying structures whose failure could result in damage to the aircraft or injury to personnel shall be substantiated by a stress analysis. The analysis shall cover the hardware in an as-built and as-installed configuration. Included in this analysis shall be all structures, fasteners, welds, or bonds in the primary load path.

3.2 Details

Each part shall be analyzed based on the design intent and load environment of the structure. The analyst shall ensure that all failure modes and worst case combined stresses have been examined.

The following is a list of example stress analysis categories. Note, this list is provided for reference only; it is the responsibility of the stress analyst to determine what types of analyses should be performed for a given structure

a) Bending, flexural shear and/or torsion analysis of a beam, frame, rib, shaft, or ring of various open or closed sections
b) Plate and shell analysis
c) Beam on an elastic foundation
d) Pressure vessel analysis (Note: pressure vessel analysis requires review and approval by the NASA Fracture Control Team. Contact NASA Aircraft Engineering for pressure vessel analysis requirements)
e) All types of stability analysis including general and local stability of plates, skins, webs, shells, web shear buckling or diagonal tension, local buckling or crippling of composite shapes, column stability, and beam-column stability
f) Analysis of composite, honeycomb, and reinforced materials
g) Large elastic deformations, geometrical nonlinearity, and gapping analysis

h) Nonlinear analysis beyond the elastic range of the material
i) Vibration / flutter analysis
j) Dynamic, impact, and fatigue analysis
k) Stress concentration and fracture analysis
l) Crack growth analysis
m) Machine components (spring, gear, shaft, clutch, brake, ropes, belts, chains, cables, etc.) analysis
n) Thermal structural and other analysis

For fasteners, fittings, and connections, the stress analysis may fall into any of the following categories:

a) Bolted joint, fitting, splice plate, and bolt group analysis
b) Riveted joint and connection analysis
c) Lug, pin, and bushing analysis
d) Bolt pre-load and installation torque analysis
e) Welded joint analysis
f) Bonding, adhesive, and friction analysis
g) Linear and nonlinear residual stress analysis
h) Tolerance, interference, mismatch, thermal and other structural analysis

4.0 Report Format

The stress analysis report shall contain the sections shown in Figure 1. All sections shall be clearly labeled and all report pages numbered. An explanation of the content of these sections follows.

TITLE PAGE
TABLE OF CONTENTS
LIST OF SYMBOLS AND ACRONYMS

1.0 EXECUTIVE SUMMARY
2.0 MINIMUM MARGIN OF SAFETY SUMMARY TABLE
3.0 INTRODUCTION
4.0 MATERIAL PROPERTIES & ALLOWABLES SUMMARY
5.0 COORDINATE SYSTEMS
6.0 LOADS SUMMARY
7.0 CALCULATIONS
8.0 REFERENCES
9.0 APPENDIX

Figure 1: Stress Report Outline

TITLE PAGE

The title page of the report shall include a report number and title. It shall be specific, unique, and concise. Acronyms shall not be used in the title without definition. The title page shall include a revision block for report revisions. An example title page is shown in Figure 4.

TABLE OF CONTENTS

A table of contents shall be included in the report listing each report section and applicable page number. It is acceptable to omit the table of contents for reports shorter than ten (10) pages.

LIST OF SYMBOLS AND ACRONYMS

All symbols and acronyms used in the report must be defined and show dimensional units if applicable. Group the symbols and acronyms separately and arrange the entries in alphabetical order in the following priority.

a) English letters
b) Greek letters
c) Subscripts
d) Superscripts

EXECUTIVE SUMMARY

The executive summary shall summarize the major results and conclusions in the report so that the reader may determine the substance of the material and decide whether to read the report from beginning to end. This section shall clearly state whether or not the structure meets the design requirements. The executive summary shall also include any recommendations based on the analysis. This section shall contain a pictorial overview of the system being analyzed along with figures or diagrams showing a summary of loading and results. This is probably the "most read" section of the report.

MINIMUM MARGIN OF SAFETY SUMMARY TABLE

This section shall include a table showing the calculated minimum margins of safety summarized in a tabular format. This table gives the reader a quick review of the results. Example tables showing the data that shall be provided is shown in Figure 2 and Figure 3. These tables may be customized to add additional relevant data but shall, at a minimum, contain the data shown. Note that each part number shall only be listed once even though there may have been several margins of safety calculated for each part. Therefore, this list is a *minimum* margin of safety summary and signifies the design critical condition.

INTRODUCTION

The introduction shall explain the purpose or objective of the report. The introduction should contain a list of the parts being analyzed and should also include any historical information that would help the reader further understand the context of the analysis. If the structure is a component of a larger assembly, this section shall indicate how the component being analyzed fits into the rest of the assembly. Other related analysis reports shall be referenced in this section to provide the reader with an overall picture of the complete analysis package. The length of the introduction should be kept as short as possible yet still convey the necessary information.

MATERIAL PROPERTIES AND ALLOWABLES SUMMARY

This section contains all the material allowables that are used in the analysis to calculate the structure margins of safety. All materials used in the analysis shall be clearly identified (alloy, heat treat, composite type, etc.) along with the applicable material properties. This is a reference section for the reader so that he can easily determine if the correct allowable was used in the analysis to obtain the margin of safety. The source of these allowables will be clearly referenced and readily obtainable by the reader. Reproduced pages of material manuals and references showing the allowables will be acceptable provided these pages also show the source.

COORDINATE SYSTEMS

The coordinate system(s) used for loads application and calculations shall be defined in this section. A diagram showing the coordinate system orientation relative to structure being analyzed and how it relates to the aircraft coordinate system shall be provided.

LOADS SUMMARY

This section shall include a summary of the critical loads applied to the component being analyzed. Component weights and centers of gravity shall also be listed. Depending on the complexity of the structure being analyzed, this section may or may not include a detailed loads analysis. If the structure is of substantial complexity as determined by the analyst, the detailed loads analysis shall be in a separate report or in the appendix. The loads shall be listed by load case in a tabular format showing load magnitude and direction based on the specified coordinate system. High-level free body diagrams showing the applied loads and reactions for the governing load conditions shall be provided in this section. More detailed free body diagrams, if applicable, specific to in-depth analyses shall be provided in the calculations section.

CALCULATIONS

This section contains the detailed analysis of the structural components. All assumptions used in the analysis shall be clearly described. In addition, all calculation units shall be clearly shown. Final results shall show maximum stresses, deflections and other pertinent data listed by load case.

Sketches, Figures, and Diagrams

The calculations section shall include sketches, figures, or diagrams to illustrate the parts being analyzed. The analysis shall be readable without reference to drawings. The following information shall be included:

a) *What* parts are being analyzed – identify all parts by part number
b) *Where* they are in the aircraft or payload
c) Where the external *loads* are
d) Where the *reactions* are. If practical, show a free body diagram in balance with applied loads and reactions
e) Show the part dimensions that are referenced in the analysis

f) Locate the sections analyzed and reference axes using a consistent coordinate system

<u>All Analyses</u>

The following information shall be included for all analyses:

a) Loads and boundary conditions shall be clearly defined. The load path as it travels from the aircraft to the structure being analyzed shall be clearly identified.
b) All sketches, figures, diagrams, and plots shall be clearly drawn and labeled.
c) All calculated margins of safety shall be clearly noted (e.g. underlined, bold, boxed, etc.)All results shall be presented using a consistent coordinate system. The coordinate system shall be clearly shown on all model and result plots.

<u>Hand Calculations</u>

The following information shall be included for hand calculations:

a) Every equation shall be referenced to its source by section/page number and the source listed in the reference section of the report. It is acceptable to omit references for very basic equations that would be common knowledge to a wide audience knowledgeable in stress analysis. See Figures 5 & 6 for example hand calculations.
b) Component loads may be obtained from a finite element model and then used in hand calculations to compute stresses. Printouts of the internal forces obtained from the finite element model shall be provided in the appendix.

<u>Computer Analyses</u>

The following information shall be included for computer analyses:

a) For Finite Element Analyses (FEA), this section shall include a description of the mesh strategy, boundary conditions, load application, and convergence criteria.
b) Where FEA results are used to compute margins of safety, a stress plot shall be provided with the maximum stress location and value noted on the figure.
c) FEA results shall be cross-checked via handbook calculations to verify FEA results are reasonable. Component testing to verify FEA results is also highly desirable. The cross-check process shall be clearly described in the report. The following provides a recommended checklist for items to be reviewed:
    a. Reactions (vs. hand calculated free body diagram values)
    b. Results (vs. hand calculated stresses and deflections)

All repetitious and simple calculations should be omitted. One sample calculation shall be shown and the remaining results summarized by tabular or graphical form (such calculations should be stated as typical).

A complete file of unsubmitted "back-up" or "notebook" analyses shall be maintained by the responsible stress analysis personnel within the originating organization. These unsubmitted supporting analyses shall be saved until the hardware has completed its design life.

REFERENCES

A list of all references cited in the report shall be included in order to document the source of information used in the analysis. All documents referenced shall be readily obtainable by the reader so that they can be studied if additional information is required. It can be assumed that the NASA has access to all government specifications, published technical articles, and published books. However, it should not be assumed that NASA has access to Contractors' internal letters, reports, or stress manuals since these items are usually Contractors' proprietary information. When items of this type are referenced in the stress analysis, the pertinent data shall be included in the stress report. If this data cannot be inserted at the place in the report where it is needed (due to bulk) then it shall be made an appendix to the report. A simple curve taken from a Contractors' stress manual to show where a particular factor came from is not sufficient documentation to validate the factor unless there is sufficient information written directly on the curve to show how it was generated; i.e., boundary conditions, assumptions, etc.

APPENDIX

Examples of items that may be included in the appendix:

- Drawings and technical information
- Technical correspondence
- Finite element analysis model plots & results
- Stress manual references
- Multiple calculation results
- Computer file table

5.0 Checking

The stress analysis report shall be checked by an approved representative from the originating organization independent of the report author. Verification of the following shall be completed:

a) Numerical calculations (equations, unit conversions, etc.)
b) Method of analysis (analysis techniques, assumptions, etc.)
c) Material properties (tensile strength, yield strength, modulus of elasticity, etc.)
d) Completeness of coverage (all failure modes and load conditions investigated)
e) Finite Element Analysis (analysis strategy, geometry, mesh, mass, boundary conditions, load selection, load application, reactions, & results)
f) Legibility and readability of analysis

6.0 Report Signatures

The report title page or signature page shall include, at a minimum, the signatures below. Note that the required signatures are different for reports generated internal to NASA Aircraft Operations Division and for reports generated by organizations external to NASA Aircraft Operations Division.

Required Signatures for NASA Aircraft Operations Generated Reports

a) Author / Engineer (person who prepared report)
b) Stress (person who checked stress analysis)
c) Authorization (person authorized to approve report release into NASA configuration control system)

Required Signatures for Reports Generated by Organizations External to NASA Aircraft Operations

a) Author / Engineer (person who prepared report from originating organization)
b) Checker /Stress (person who checked stress analysis from originating organization)
c) Approver (person authorized by originating organization to approve report release)
d) AOD Stress (NASA Aircraft Operations Division person who reviewed stress analysis)
e) AOD Authorization (NASA Aircraft Operations Division person authorized to release report into NASA configuration control system)

For reports generated by organizations external to NASA, the originating organization shall submit the report with the Author, Checker, and Approver boxes signed. NASA shall then review the report and sign the NASA Stress and NASA Authorization boxes for release into NASA's configuration control system.

7.0 References

The following references were used in the preparation of this document:

1. *Instructions for the Preparation of Stress Analysis Reports*, JSC-19652A, NASA Johnson Space Center, 1987
2. *Criteria For Preloaded Bolts*, NSTS 08307, NASA Johnson Space Center
3. E.F. Bruhn, *Analysis and Design of Flight Vehicle Structures,* 1973
4. Thomas P. Sarafin, *Spacecraft Structures and Mechanisms, From Concept to Launch*, 2003

Figure 2: Minimum Margin of Safety Summary Table

Description			Analysis		Minimum Margin of Safety		Reference	
Part Number	**Name**	**Material**	**Failure Theory**	**Applied Load (Load Case)**	**Yld.** [1]	**Ult.** [2]	**FEA Filenames**	**Report Page #(s)**
MSCZZD001-001	Widget	Ti 6AL-4V	Von-Mises	Fx=125 lbs, Tx=6000 in-lbs (Load Case 1)	+.05	+.01	widget.db widget.rst	10 - 12

Example Choices:

- Von-Mises
- Maximum Normal Stress
- Buckling
- Fatigue
- Tsai-Wu
- Other (describe)

[1] $$M.S._{yield} = \frac{\sigma_{yield\,strength}}{\sigma_{limit}} - 1$$

[2] $$M.S._{ultimate} = \frac{\sigma_{ultimate\,strength}}{\sigma_{limit} \times F.S.} - 1$$

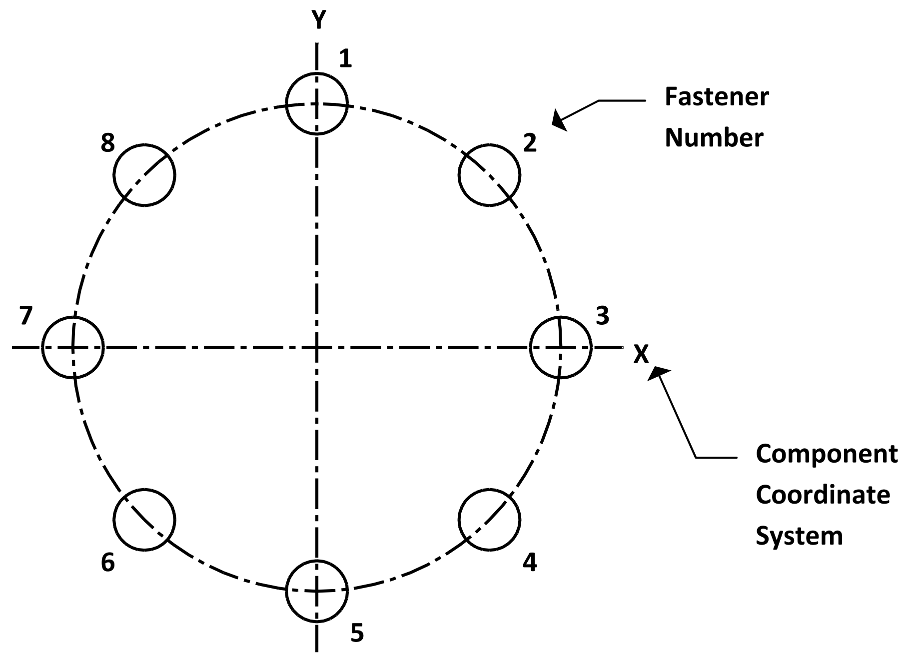
σ_{limit} : the stress limit is calculated based on the flight vehicle limit loads. Limit loads are the maximum loads anticipated on the flight vehicle during its lifetime of service.

$F.S.$: the Factor of Safety varies based on the type of aircraft, installed location, material, and other conditions. Please contact NASA Aircraft Engineering for the applicable factor of safety to use in your application.

Figure 3: Fastener Minimum Margin of Safety Summary Table

Fastener					Analysis	Fastener Forces		Minimum Margin of Safety			Reference	
#	Fastener Location	Fastener Part Number	Description	Material	Applied Load	Max Tensile (lbs)	Max. Comb. Shear (lbs)	Tension	Shear	Interaction[1]	FEA Filenames	Report Page#(s)
1	XXXXXXX-001 Rear Flange	NAS6707-10	7/16-20 UNF X 1.3L	A286	Fx=125 lbs, Tx=6000 in-lbs (Load Case 1)	868	1830	+.36	+.79	+.16	widget.db widget.rst	10-12

[1] See NSTS 08307, *Criteria For Preloaded Bolts* and *Analysis & Design of Flight Vehicle Structures*, Chapter D1.8, by Bruhn for example interaction calculations.



Example Fastener Pattern

REVISION HISTORY			
REV	DESCRIPTION OF CHANGE	DATE	APPROVED

Figure 4: Example Title Page

Format may be different based on originating organization standards
but title page shall contain required information outlined in Section 4.0

SIGNATURES		DATE
ENG	(AUTHOR)	
CH	(CHECKER)	
APP	(APPROVER)	
STRESS	(NASA)	
AUTH	(NASA)	

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER HOUSTON, TEXAS

TITLE

SIZE	CAGE CODE	REPORT NO	REV
A	XXXXX	XXXXXX	-

SCALE: NONE	ORG	SHEET: X OF X

Figure 5: Example Hand Calculation – Locker

PREPARED BY F. DOWARD	ANYWHERE AIRCRAFT COMPANY A DIVISION OF WATFOR CORE	PAGE NO. 2.39 OF ____
CHECKED BY R. HENRY		REPORT NO. SCE-14971
DATE 11/8/81	TITLE MODULE SECONDARY STRUCTURE	MODEL NO.
		DWG NO. V802-660621

REF. — REV A FL 12/7/81

2.2 ENDPLATE – INBOARD, LWR LOCKER

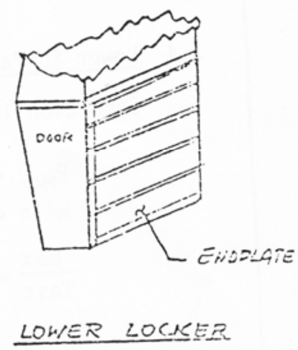


Fig 0.6.4 — CRASH COND. (COND 14) IS CRITICAL.

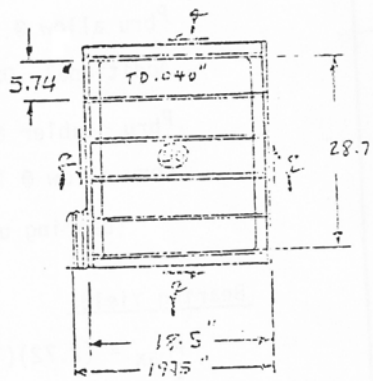
$N_X = -18.8g$, $N_Y = -6.84g$

MAX SHEAR ON ENDPLATE:

$q = -7.16$ #/IN (COND 3 NASTRAN OUTPUT REF 7)

ASSUME THIS SHEAR OCCURS AT COND. 14 SO THAT COMBINED LOADING ANALYSIS IS JUSTIFIED.

FOR A RECTANGULAR PLATE 28.7" x 19.75" LOADED WITH "W".



REF 5 Pg 271 CASE 14 —

$W = (88.5)(6.84) = 605$#

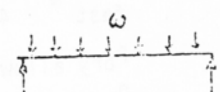
$\omega = \frac{605}{(19.75)(28.7)} = 1.07$ #/IN²

RIB STRESS

$M_{RIB} = \frac{1}{8}(1.07)(5.74)(18.5)^2$

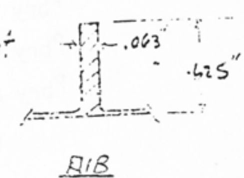
$M_{RIB} = 263$ IN-#

$f_b = \frac{Mc}{I} = \frac{(263)(.625)}{(2)(.0013)}$



$f_b = 63220$ PSI

Pg 2.2! A — $F_{bu} = 82000$ PSI



(RIB BENDING)

A — $M.S. = \frac{82000}{63220} - 1 = +.29$ (ULT) (LOAD COND 14)

Figure 6: Example Hand Calculation – Flap

PREPARED BY A. Collins	ANYWHERE AIRCRAFT COMPANY A DIVISION OF WATFOR CORP	PAGE NO. 3.37
CHECKED BY F. Harris		REPORT NO. MRH-75
DATE 3/23/79	TITLE BODY FLAP	MODEL NO.
		DWG NO. BF074-145780

3.4 Lower Surface Leading Edge Panel (cont)

Condition 101031 critical for load transfer (ref. 15a)

$P_{max} = (2.72)(1.4)(1.11) = 4.23^k$

with 4 fasteners:

$\frac{P_{max}}{fast} = \frac{4.23}{4} = 1.06^k$

P_{bru} allow @ R.T. = 1.34^k
P_{bru} allow @ 350° = $.94^k$
P_{bru} allow @ 150° = 1.23^k
} Ref page 3.26

Additional .025 inch doubler exists and is assumed to be 50% effective

P_{bru} doubler @ 150° = $(109)(.156)(.025)(.5) = .21^k$

P_{bru} allow @ 150° = $1.23 + .21 = 1.44^k$

(bearing ultimate) M.S. = $\frac{1.44}{1.06} - 1.0 = \underline{+.36}$ (load cond 101031)

Bearing Yield

$P_{max} = (2.72)(1.11) = 3.02^k$

$\frac{P_{max}}{fast} = \frac{3.02}{4} = .755^k$

P_{bry} allow @ R.T. = $.88^k$
P_{bry} allow @ 150° = $.83^k$
P_{bry} allow @ 350° = $.69^k$
} Ref page 3.27

P_{bry} doubler = $(86)(.156)(.025)(.5) = .17^k$

P_{bry} allow @ 150° = $.83 + .17 = 1.00^k$

(bearing yield) M.S. = $\frac{1.00}{.755} - 1.0 = \underline{+.32}$ (load cond 101031)