НАЦІОНАЛЬНИЙ ТЕХНІЧНИЙ УНІВЕРСИТЕТ УКРАЇНИ
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

МЕХАНІКО-МАШИНОБУДІВНИЙ ІНСТИТУТ

КАФЕДРА ДИНАМІКИ І МІЦНОСТІ МАШИН ТА ОПОРУ МАТЕРІАЛІВ

«На правах рукопису»
УДК _______________

«До захисту допущено»

Завідувач кафедри

______ Сергій ПИСКУНОВ

«___»____________2021 р.

Магістерська дисертація

на здобуття ступеня магістра

за освітньо-професійною програмою «Динаміка і міцність машин»

зі спеціальності 131 «Прикладна механіка»

на тему: «Міцність композитної конструкції модуля керування відеообладнанням салону пасажирського літака»

Виконав:
студент II курсу, групи МП-01мп
Самофал Костянтин Ігорович ___________

Керівник:
к.т.н., доцент
Онищенко Євген Євгенович ___________

Рецензент:
д.т.н., проф.
Данильченко Юрій Михайлович ___________

Засвідчую, що у цій магістерській дисертації немає запозичень з праць інших авторів без відповідних посилань.
Студент

Київ – 2021 року

Національний технічний університет України

«Київський політехнічний інститут імені Ігоря Сікорського»

Механіко-машинобудівний інститут

Кафедра динаміки і міцності машин та опору матеріалів

Рівень вищої освіти – другий (магістерський)

Спеціальність – 131 «Прикладна механіка»

Освітньо-професійна програма – «Динаміка і міцність машин»

ЗАТВЕРДЖУЮ

Завідувач кафедри

________ Сергій ПИСКУНОВ

«___»_____________2021 р.

ЗАВДАННЯ

на магістерську дисертацію студенту

Самофалу Костянтину Ігоровичу

1. Тема дисертації «Міцність композитної конструкції модуля керування відеообладнанням салону пасажирського літака», науковий керівник дисертації Онищенко Євген Євгенович, к.т.н., доц. , затверджені наказом по університету від 01.11.2021 р. № 3611-с

2. Термін подання студентом дисертації: 10.12.2021 р.

3. Об’єкт дослідження: композитна конструкція модуля керування відеообладнанням салону пасажирського літака

4. Предмет дослідження: використання скінчено-елементного методу для визначення напружено-деформованого стану композитної сендвіч конструкції та отримання задовільних характеристик міцності конструкції літака.

5. Перелік завдань, які потрібно розробити:

1) Огляд особливостей використання скінчено-елементного методу для композитної конструкції літака та базових допущень.
2) Визначення методів дослідження та аналізу міцності композитної панелі, критеріїв руйнування та основних переваг і допущень визначеного методу при аналізі міцності композитної конструкції.
3) Фізичне моделювання композитної конструкції за допомогою методу скінченних елементів та програмних комплексів MSC Patran та MSC Nastran, використовуючи метод безпечного руйнування для

оптимізації та отримання задовільних експлуатаційних характеристик.

4) Аналітичні розрахунки композитних з’єднань на достатню міцність.
5) Розробка стартап–проекту.

6. Орієнтовний перелік графічного (ілюстративного) матеріалу – 6 і більше.

7. Орієнтовний перелік публікацій – 1 і більше.

8. Дата видачі завдання: 01.09.2021 р.

Календарний план

№ з/п	Назва етапів виконання магістерської дисертації	Термін виконання етапів магістерської дисертації	Примітка
1	Аналіз літератури	01.09.21 – 20.10.21	
2	Огляд та визначення методу аналізу міцності композитної конструкції	21.10.21 – 09.11.21	
3	Фізичне моделювання конструкції	10.11.21 – 17.11.21	
4	Аналітичні розрахунки з’єднань	18.11.21 – 22.11.21	
5	Стартап-проект та висновки	23.11.21 – 06.12.21	

Студент ____________ Костянтин САМОФАЛ

Науковий керівник ____________ Євген ОНИЩЕНКО

CONTENTS

АНОТАЦІЯ

Магістерська дисертація за обсягом роботи складає 76 сторінки, 42 рисунків, 34 таблиці, 1 додаток містить 12 літературних джерел.

Об'єктом роботи є Центр відеоконтролю (VCC) пасажирських літаків.

Основною метою даної дисертації є детальний аналіз центра відеоконтролю згідно вимог безпеки.

Актуальність: Інженерні композитні конструкції зі складною геометрією та навантаженнями надзвичайно важко оцінити та не мають аналітичних рішень. Справа в тому, що цю проблему можна вирішити за допомогою скінчено-елементного аналізу та програмних продуктів MSC Patran і MSC Nastran.

Конструкція центра відеоконтролю аналізується за допомогою програмного забезпечення аналізу скінчених елементів MSC (MSC Patran, MSC Nastran) та Microsoft Excel.

В результаті цієї роботи було продемонстровано, що VCC може витримувати всі передбачені перевантаження без пошкоджень, і що всі вимоги безпеки задовольняються.

ABSTRACT

The master`s degree dissertation for the amount of work is 76 pages, 42 figures, 34 tables, 1 appendix and contains 12 literary sources.

The object of the work is the Video control center (VCC) of passenger aircraft.

The main goal of this dissertation is the detailed analysis of VCC with safety requirements.

Relevance: Engineering composite structures with complicated geometry and load are extremely hard to evaluate and have no analytical solutions. The point is that this problem can be solved with finite element analysis and the software products MSC Patran and MSC Nastran.

The installation of VCC is analyzed using the finite element analysis software MSC (MSC Patran, MSC Nastran), and Microsoft Excel.

As a consequence of this work, it was demonstrated that the VCC can sustain all stipulated overloads without causing damage and that all safety requirements are satisfied.

1 INTRODUCTION

A composite material is a material that is produced from two or more constituent materials [1]. In general composite material is not a material but a construction. Commonly used composites are ferroconcrete, sandwich panels, different wood composites, etc.

In aircraft constructions, common composites are sandwich panels made from carbon tapes or fabrics, fiberglass, aluminum used for face sheets, the core can be made from aluminum, fiberglass, or aramid. In brand new aircraft like Boeing 787 models, 777X, and Airbus A350 most construction is made from carbon fibers solid sheets bonded by resin. Using composite materials gives a lot of benefits including less weight of constructions with the same strength and making the company more independent from the metallic material supplier.

Although composite materials are widely used in structural constructions for not so long (from the beginning of the XXI century), these materials were used in systems constructions from the very beginning of commercial aircraft history.

I have been working with a video cabin control (VCC) system in this work.

The PWS and VCC are cabin structures that have evolved specifically to mount Cabin System equipment. These are identified as the “Cabin Electronics Compartment” (CEC) in the ARINC 628 industry standard. In twin-aisle models, the CEC may stretch from floor to ceiling in the cabin or may be installed in the crown area above the cabin ceiling (777 models only), or maybe as large as will fit under the stairs to the upper deck (747 models only. Cabin System equipment may also be installed in traditional cabin structures not originally designed for it, including galleys and lavatories.

Figure 1.1 VCC photos

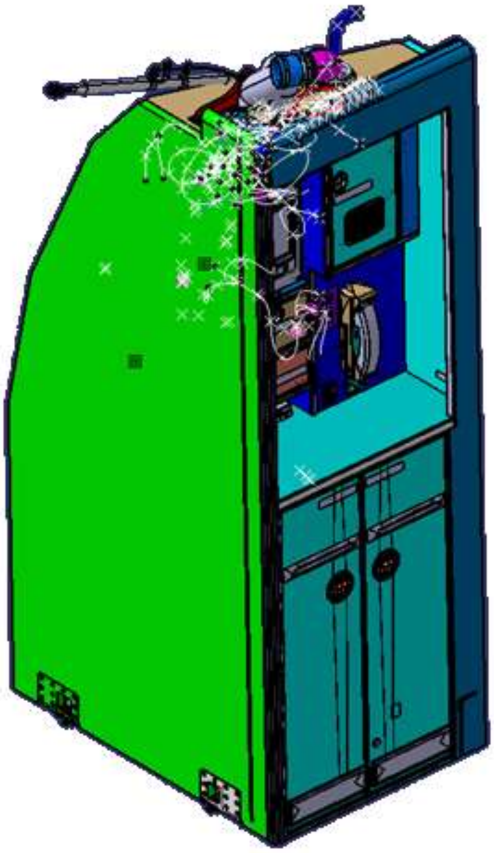


Figure 1.2 Structure definition

The main function of the system is to provide occupants with information from the crew about anything they need to know during the flight. Flight attendants use it to control the situation in the salon, regulate cabin environments, and control other electrical systems.

The frame of the VCC is made of composite panels fastened by dog-bone clips. A more complex construction review will be made in the following chapter.

Therefore, this system must be protected from environmental influences to prevent short circuits and half-bags of expensive equipment. CEC must be safe for passengers, that is, to maintain structural integrity under operational loads and not collapse in emergencies.

The subject of the work is to analyze the construction of the VCC frame, find a weak point of the construction, and give revisions on how the frame construction can be improved.

2 FINITE ELEMENT METHOD OF AEROSPACE STRUCTURE

2.1 Basic idea of finite element method

The finite element method (FEM) is a widely used method for numerically solving partial differential equations arising in engineering and mathematical modeling. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. Most of these processes are described using partial differential equations (PDEs). However, for a computer to solve these PDEs, numerical techniques have been developed over the last few decades and one of the most prominent today is the finite element method. [2]

The FEM analysis for stress helps to analyze complex, many times statically indeterminate systems that cannot be analyzed by analytical method or it is very hard and time-consuming. In the real world, all the deformable bodies are systems with infinite degrees of freedom (DOF). In FEM analysis an analyzed body divided (discretize) into the smaller elements by the mash of the different shapes and sizes and system of the PDEs substantiates with system approximate analytical equations. The divided bodies are connected in the Nodes – where the loads are calculated and transferred to the other elements. Each node can move in six DOF: three translations and three rotations.

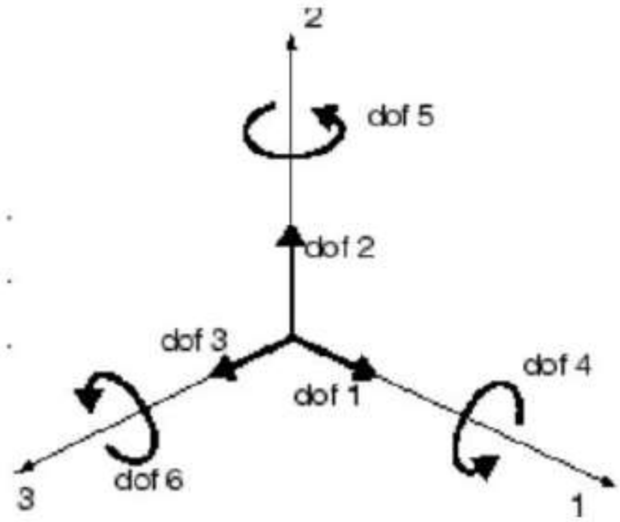


Figure 2.1. Degrees of freedom (DOF) at the node.

This method gives approximate results to the real constructions. The convergence of the method depends on the size and quality of mash, adequacy of the load applications, and boundary conditions. The weak point of the method is that a smaller mash required a better processor to solve the system of analytical equations.

2.2 Basic elements shapes

FEM divides some models into small pieces. Those are called Finite Elements (FE). Those Elements connect all characteristic points (called Nodes) that lie on their circumference. This "connection" is a set of equations called shape functions.

The elements' shapes, sizes, numbers, and configurations have to be chosen carefully so that the original body or domain is simulated as closely as possible without increasing the computational effort needed for the solution. The choice of the type of element is mostly dictated by the body's geometry and the number of independent coordinates necessary to describe the system. If the geometry, material properties, and field variable of the problem can be described in terms of a single spatial coordinate, we can use the one-dimensional or line elements shown in Fig. 2.2A. The temperature distribution in a rod (or fin), the pressure distribution in a pipe flow, and the deformation of a barunderaxial load, for example, can be determined using these elements. Although these elements have a cross-sectional area, they are generally shown schematically as a line element (Fig. 2.2B). In some cases, the cross-sectional area of the element may be nonuniform.

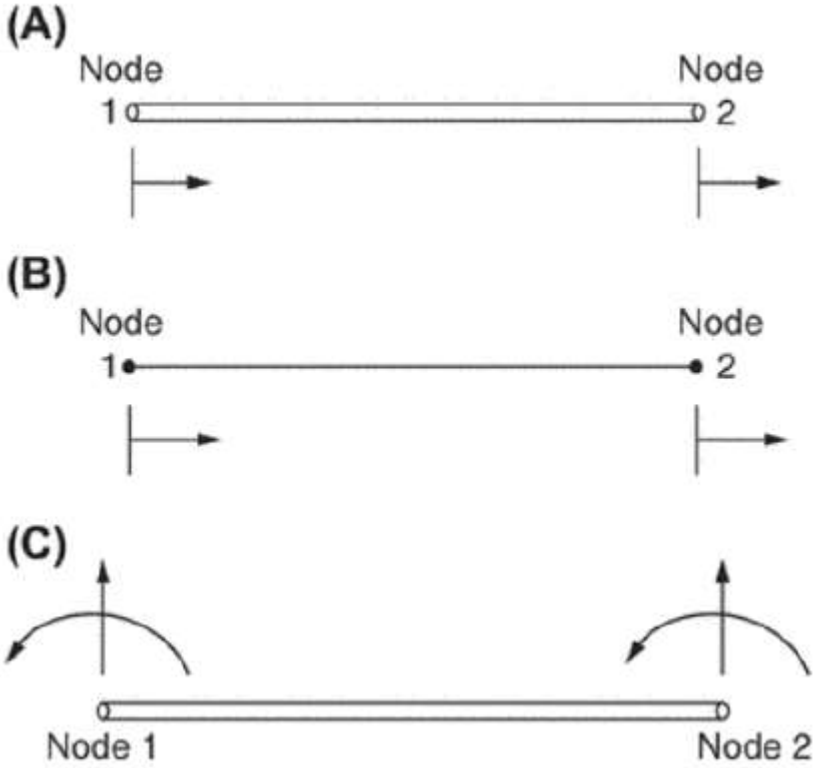


Figure 2.2 One-dimensional or line elements

One-dimensional elements are considered to contain two nodes, one at each end, for basic analysis, with the corresponding value of the field variable selected as the unknown (dof). However, for the beam analysis, the values of the transverse displacement variables and their derivative (slope) are chosen as the unknowns (dof) at each node as shown in Fig. 2.2C.

When the configuration and other details of the problem can be described in terms of two independent spatial coordinates, we can use the two-dimensional elements shown in Fig. 2.3. The basic element useful for two-dimensional analysis is the triangular element. Although a quadrilateral element (or its special forms, the rectangle, and parallelogram) can be obtained by assembling two or four triangular elements, as shown in Fig. 2.4; in some cases, the use of quadrilateral (or rectangle or parallelogram) elements proves to be advantageous. For the bending analysis of plates, multiple DOF (transverse displacement and its derivatives) are used at each node.

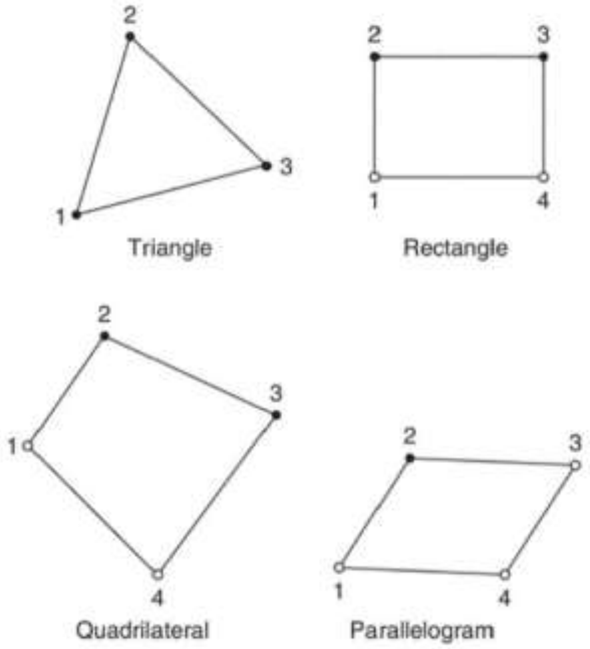


Figure 2.3. Two-dimensional elements

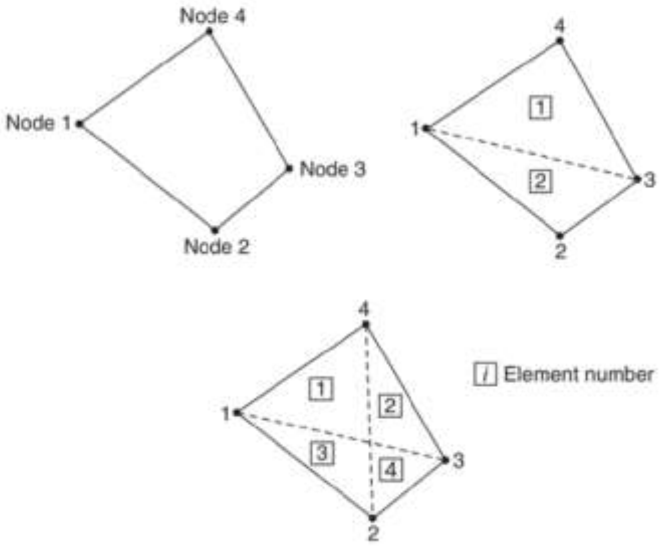


Figure 2.4. A quadrilateral element is an assemblage of two or four triangular element

If the geometry, material properties, and other parameters of the body can be described by three independent spatial coordinates, we can idealize the body by using the three-dimensional elements shown in Fig. 2.5. The basic three-dimensional element, analogous to the triangular element in the case of two-dimensional problems, is the tetrahedron element.

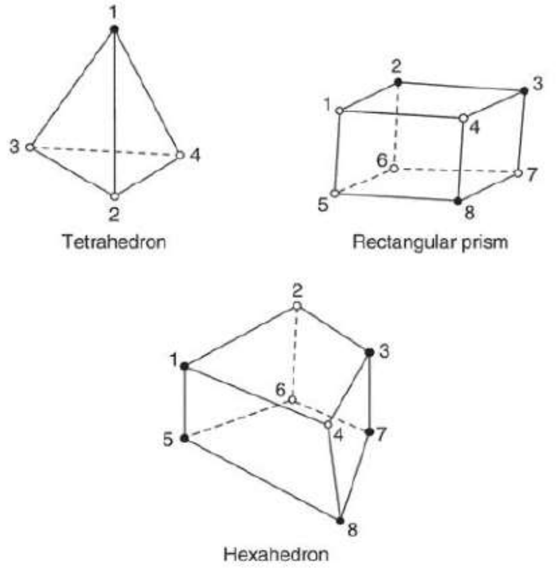


Figure 2.5. Three-dimensional elements

In some cases, the hexahedron element, which can be obtained by assembling five tetrahedrons as indicated in Fig. 2.6, can be used advantageously.

Some three-dimensional problems can be described by only one or two independent coordinates. Such problems can be idealized by using an axisymmetric or ring type of elements shown in Fig. 2.7. The problems that possess axial symmetry, such as pistons, storage tanks, valves, rocket nozzles, and reentry vehicle heat shields, fall into this category.

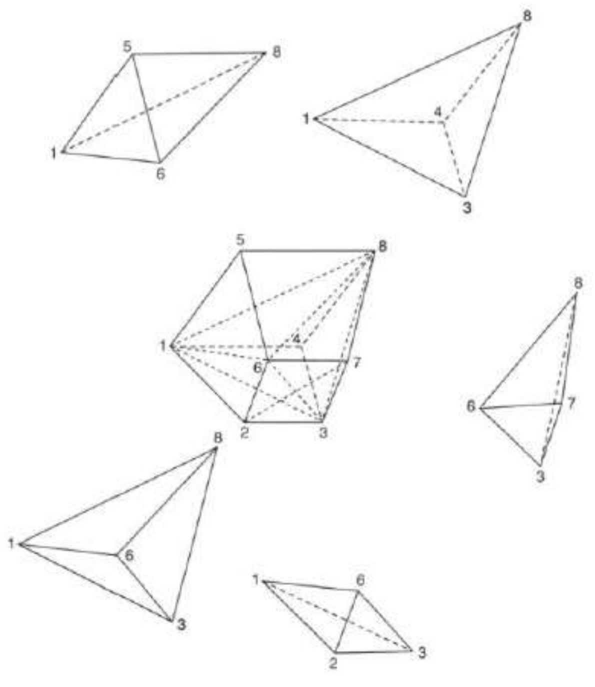


Figure 2.6 A hexahedron element as an assemblage of five tetrahedron elements.

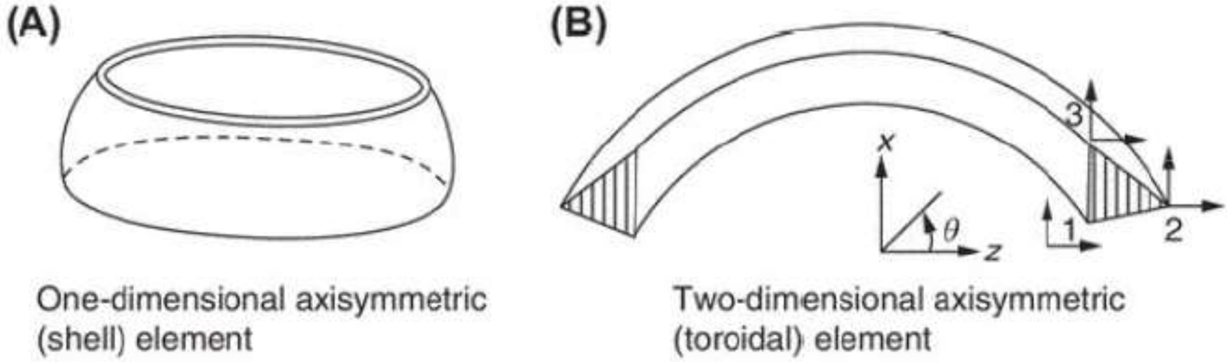


Figure 2.7. Axisymmetric elements

2.3 FEA solution

Finite element analysis (FEA) involves the solution of engineering problems using computers. Engineering structures that have complex geometry and loads, are either very difficult to analyze or have no theoretical solution. However, in FEA, a structure of this type can be easily analyzed. Commercial FEA programs, written so that a user can solve complex engineering problems without knowing the governing equations or the mathematics; the user is required only to know the geometry of the structure and its boundary conditions. FEA software provides a complete solution including deflections, stresses, reactions, etc. [3]

Engineering issues, such as determining deflections and stresses in a structure, are solved using FEA in three steps:

1. Pre-process or modeling the structure
2. Analysis
3. Post-processing.

Step1: Pre-processor modeling the structure

The structure is modeled using a CAD application that either comes with the FEA software or is offered by another software provider. The final FEA model is made up of various pieces that represent the overall structure. The elements not only depict structural segments but also imitate their mechanical behavior and properties.

Complex geometry (curves, notches, holes, etc.) needs a greater number of elements to correctly describe the shape, whereas simple geometry may be represented by a finer mesh (or fewer elements). The selection of appropriate components necessitates prior FEA experience, understanding of structural behavior, available elements in the program and their properties, and so on. The nodes or common points connect the elements.

Including the geometry of the structure, the restrictions, loads, and mechanical properties of the structure are determined in the pre-processor phase. As a result, the geometric model entirely defines the whole structure during pre-processing. Mesh refers to the structure represented by nodes and elements.

Step 2: Analysis

In this stage, the geometry, constraints, mechanical characteristics, and loads are used to construct matrix equations for each element, which are then combined to generate the structure's global matrix equation. The individual equations' and structural equation's forms are always,

$$\{F\} = [K]\{u\}$$

Where

$\{F\}$ = External force matrix.

$[K]$ = Global stiffness matrix

$\{u\}$ = Displacement matrix

The equation is then solved for deflections. Using the deflection values, strain, stress, and reactions are calculated. All the results are stored and can be used to create graphic plots and charts in the post-analysis.

Step 3: Post-processing

The final phase in a finite element analysis. Step 2 results are often in the form of raw data and are difficult to comprehend. A CAD application is used in post-analysis to edit the data in order to generate the deflected shape of the structure, create stress graphs, animation, and so on. A graphical depiction of the results is quite helpful in understanding the structure's behavior.

2.4 Finite element procedure for composite structure

Finite element analysis consists of the next important steps [4]:

1. A mesh that covers the structure is generated (Fig.2.8).

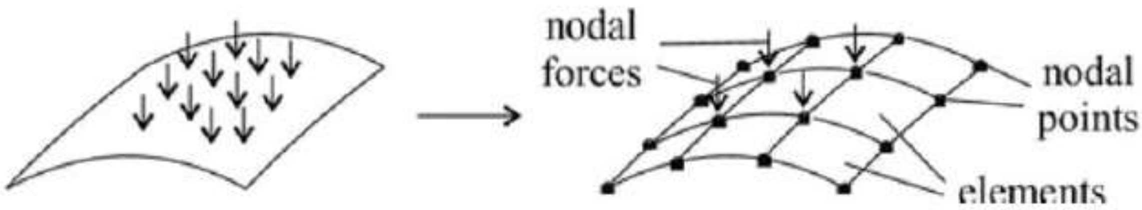


Figure 2.8. Structure and its finite element mesh

2. The stiffness matrix [k] of all elements is determined.

3. The stiffness matrix [K] of the structure is determined by assembling the element stiffness matrices.

4. The loads applied to the structure are replaced by an equivalent force system such that the forces act at the nodal points.

5. The displacements of the nodal points d are evaluated by

$$[K]d = f$$

where f is the force vector representing the equivalent applied nodal forces.

6. The vector d is subdivided into subvectors δ, each δ representing the displacements of the nodal points of a particular element.

7. The displacements at a point inside the element are calculated by

$$u = [N]\delta,$$

where the vector u represents the displacements and [N] is the matrix of the shape vectors.

8. The strains at a point inside the elements are calculated by

$$\varepsilon = [B]\delta,$$

where [B] is the strain–displacement matrix.

9. The stresses at a point inside the element are calculated by

$$\sigma = [E]\varepsilon,$$

where [E] is the stiffness matrix characterizing the material.

10. The element stiffness matrix, referred to in Step2, is defined as

$$[k]\delta = fe,$$

where fe represents the forces acting at the nodal points of the element. The element stiffness matrix is

$$[k] = \int [B]^T [E]\,[B](v)\, dV,$$

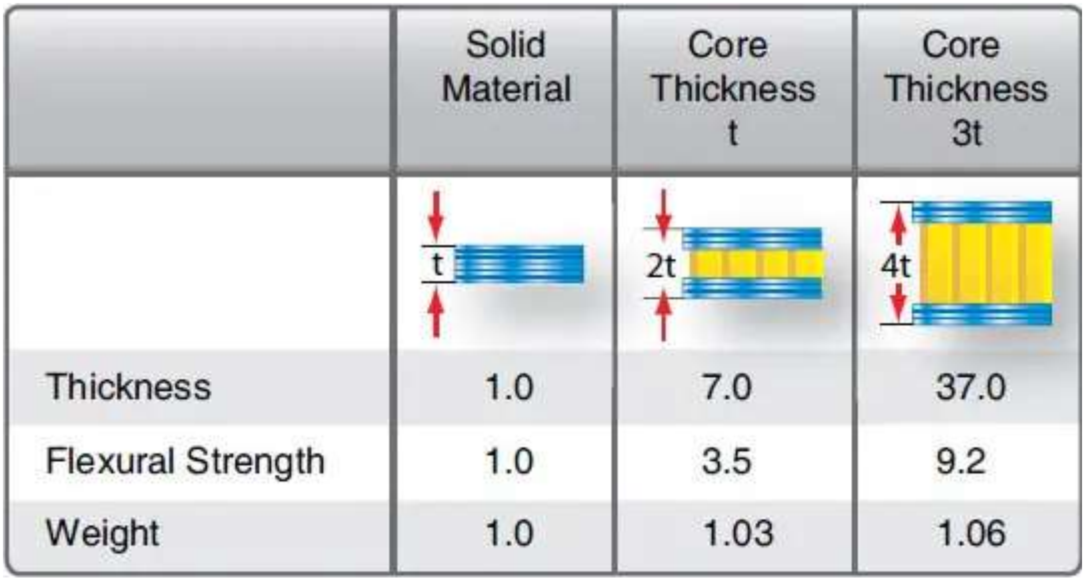
where V is the volume of the element.

The preceding steps apply to structures made of either isotropic or composite materials. The only difference between isotropic and composite structures is in the material stiffness matrix [E].

3 HONEYCOMB SANDWICH STRUCTURE DEFINITION

3.1 Sandwich Terminology

Honeycomb panels are a type of composite construction made primarily to carry bending loads. The main advantage of that structure is the high- strength-to-weight ratio, see Fig 3.1. It is obtained by dividing load carried elements by facing carried tensile-compression load and core carried shear loads in the vertical direction.



	Solid Material	Core Thickness t	Core Thickness 3t
	t	2t	4t
Thickness	1.0	7.0	37.0
Flexural Strength	1.0	3.5	9.2
Weight	1.0	1.03	1.06

Figure 3.1 - Strength and stiffness of honeycomb sandwich material compared to a solid laminate [5]

Typical sandwich bonded panel construction is shown in Fig 3.2.

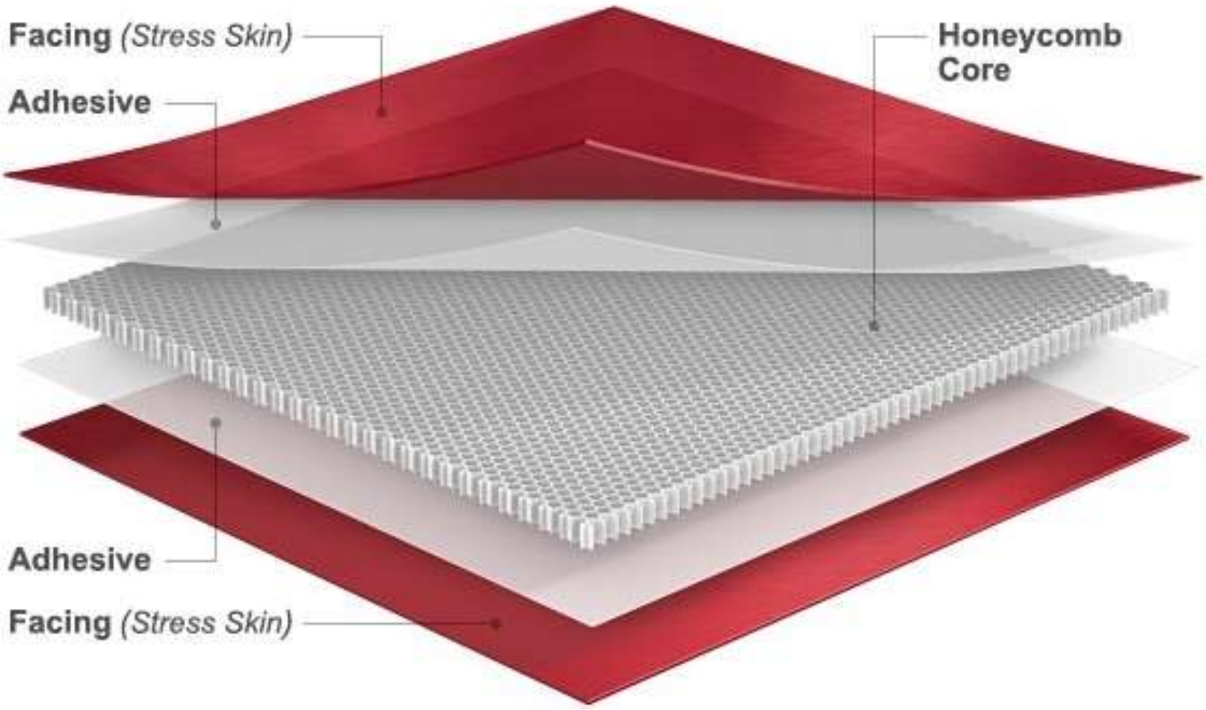


Figure 3.1 – Typical sandwich panel

Honeycomb structures are used in various types of industries like aerospace, shipbuilding, automobiles, furniture manufacturing, and civil engineering.

The facing or face sheet primarily carries tensile or compression caused by bending. Wadley used materials for facing using in the aerospace industry is:

- Aluminum – used in old model aircraft design;
- Fiberglass – used for non-structural or systems structures which strength does not affect airplane performance; also used as a cover for carbon fiber face sheet.
- Carbon fibers – used for the high-loaded primary structural elements (PSE). Carbon fibers are impregnated with resin and can be a tape or a fabric woven in different styles to obtain optimal parameters of strength for structure. Carbon fibers are oriented in different directions, typically is 0, ±45, and 90 degrees.
- Kevlar.
- Inconel – used in high-temperature areas, for example, engine exhaust.
- Titanium and steel are used for specialty applications in high-temperature constructions.

As was mentioned above core's main function is to carry vertical shear loads. The material [5]:

- Kraft paper—relatively low strength, good insulating properties, is available in large quantities, and has a low cost.
- Thermoplastics—good insulating properties, good energy absorption and/or redirection, smooth cell walls, moisture, and chemical resistance, are environmentally compatible, aesthetically pleasing, and have a relatively low cost.
- Aluminum—best strength-to-weight ratio and energy absorption, has good heat transfer properties, electromagnetic shielding properties, has smooth, thin cell walls, is machinable, and has a relatively low cost.

- Steel—good heat transfer properties, electromagnetic shielding properties, and heat resistance.
- Specialty metals (titanium)—relatively high strength to weight ratio, good heat transfer properties, chemical resistance, and heat resistance to very high temperatures.
- Aramid paper—flame resistant, fire retardant, good insulating properties, low dielectric properties, and good formability.
- Fiberglass—tailorable shear properties by a layup, low dielectric properties, good insulating properties, and good formability.
- Carbon—good dimensional stability and retention, high-temperature property retention, high stiffness, very low coefficient of thermal expansion, tailorable thermal conductivity, relatively high shear modulus, and very expensive.

The honeycomb core is available in a variety of cell sizes. Smaller sizes offer more support for sandwich face sheets. Honeycomb is also available in a variety of densities. A higher density core is more rigid and robust than a lower density core.

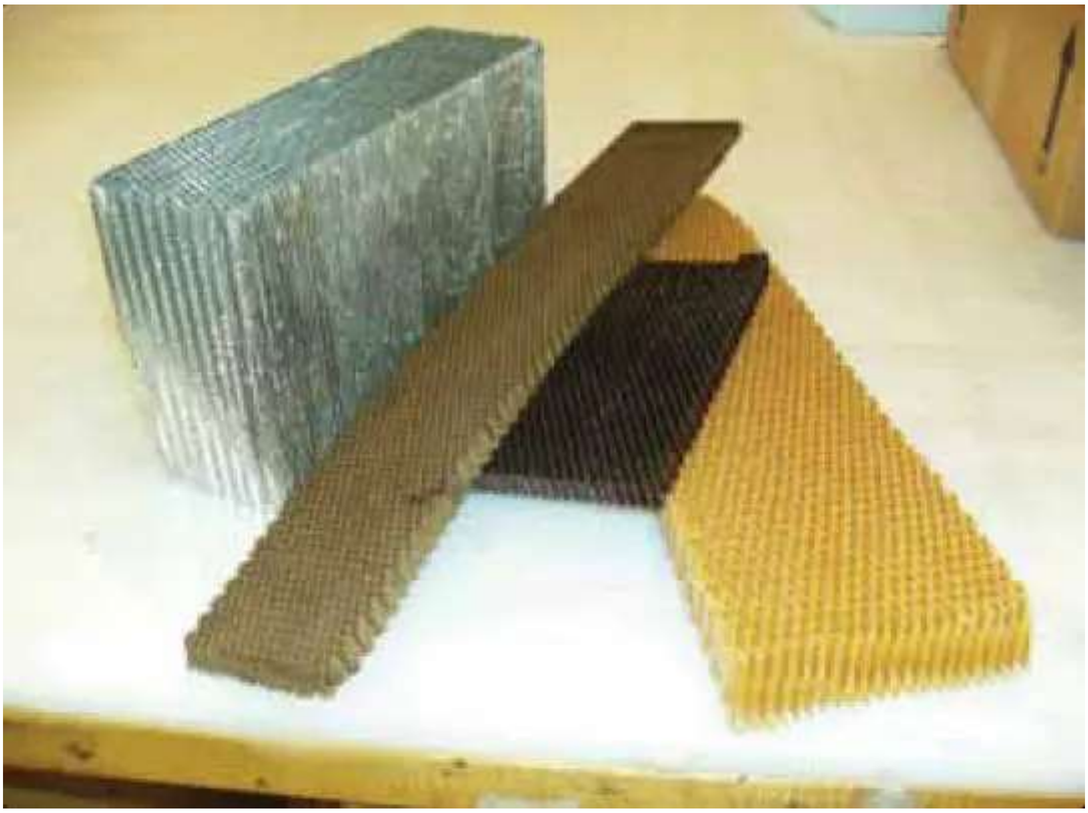


Figure 3.3 – Honeycomb typical materials

Adhesives are used to bond facing and core. Chosen for giving strength, temperature compatibility, and ability to form a fillet at the cell wall or in some other way to form a good bond with the minimal surface area of the end of some of the core materials. Adhesives also carry shear loads acting between facing plies or between facing plies and core.

3.2 Analysis details for honeycomb sandwich panels

Basic properties of composites:

- E11, E22.
- G12, ν12.

Material Allowable:

- X (Tension/compression in direction 1).
- Y (Tension/compression in direction 2).
- S (In-plane Shear).

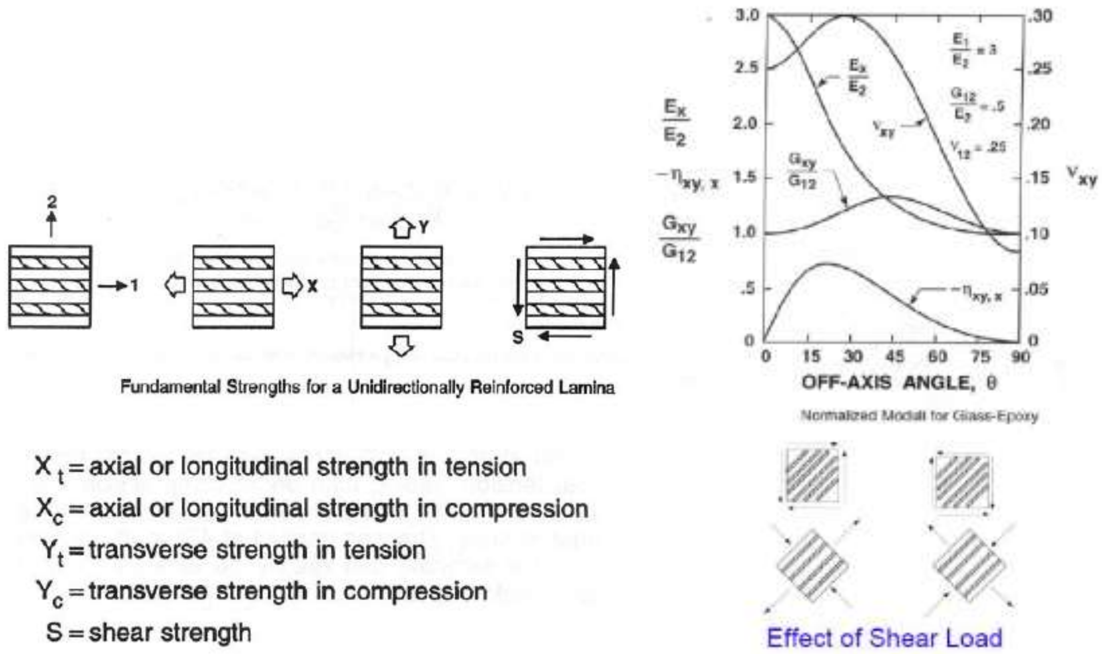


Figure 3.4 – Composite properties

The main point for the composite honeycomb sandwich panel with carbon fibers is to obtain optimal layup. If the layup will have purely chosen fiber direction, the panel behavior can be unexpected. For example, the panel loaded by tensile will twist.

3.3 Failure modes of Composite structure

Panel safety margin calculation depends on the mode of failure, see Fig 3.5. Mode of failure can be divided into three groups:

1. Strength-Based failure modes;

2. Stability Based Failure modes.

3. Other

1. Strength-Based Failure modes:

- Face sheet failure
- Transverse shear failure (core shear)
- Flexural core crushing
- Flat wise Tension or compression

2. Stability Based Failure Modes:

- Panel Buckling.
- Face Wrinkling
- Face sheet Dimpling or Intracell buckling
- Shear Crimping

Face sheet Strength Failure Details

1. Facing failure is simply characterized by cracked face sheets. This failure occurs when the face sheet strength is exceeded.

2. Transverse shear failure can manifest itself as face-to-core debonding or as a shear failure in the core itself. This failure occurs when the core or the face-to-core adhesive has insufficient shear strength.

3. Flexural core crushing is a concern when the face sheets tend to move towards each other under the influence of bending. This failure mode occurs when loads are excided core compression strength.

4. Flatwise tension or compression can be found in the ramp area where the face sheet changes direction. The flatwise, or interlaminar, stresses are induced at the ramp radii. A flatwise tension stress can cause face-to-core disbond, while a flatwise compression stress can cause core crushing.

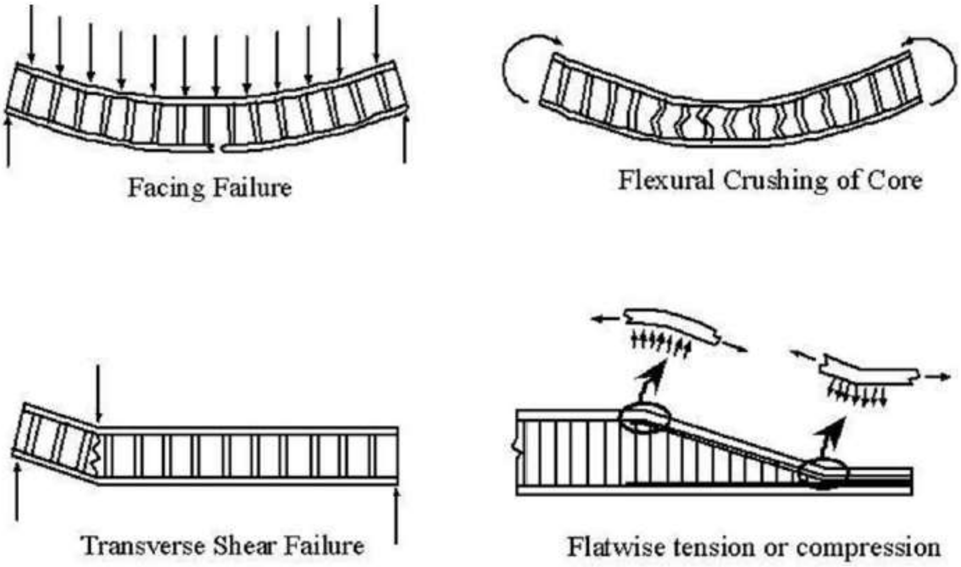


Figure 3.5. Factsheet Strength Failure

Local Instability Failure Modes, see Fig 3.6:

1. Intracell buckling or face dimpling is a local instability characterized by the buckling of a face sheet into or out of the confines of a single cell. This failure can occur when the face sheets are thin.

2. Face wrinkling is a local instability characterized by the inward or outward buckling of the face, accompanied by core crushing, core tearing, or face-to-core debonding. This failure can occur when the core has a low density.

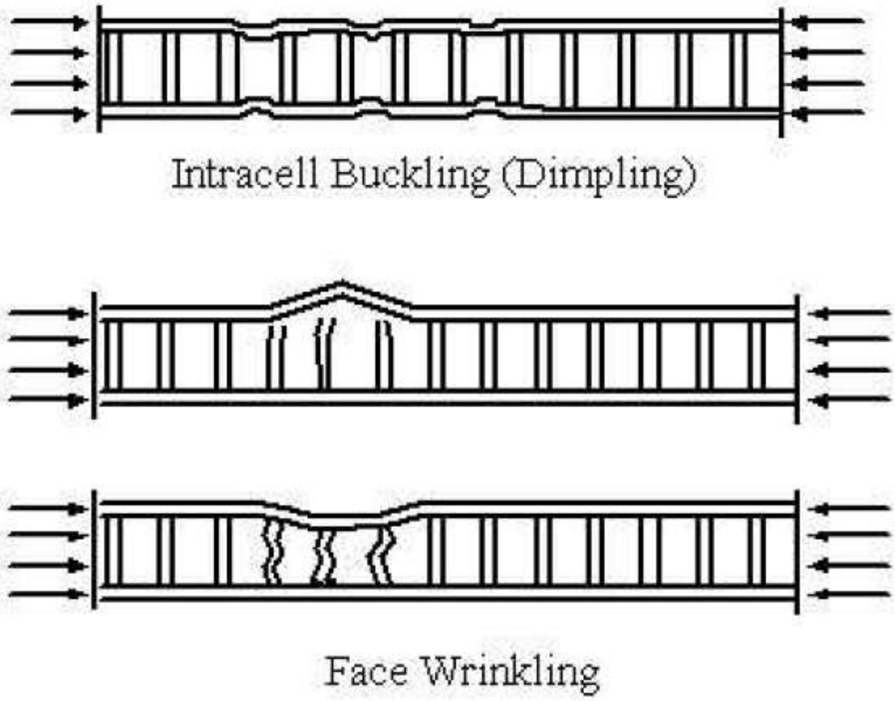


Figure 3.4. Local facing Instability

Other common failures of the composite structure are disbond, delamination, and fluid ingression.

Disbond and delamination caused by adhesives fail. It may be caused due to strength insufficient or due to environmental influences. Fluid ingression can occur due to panel edge covers cracking. It can significantly affect panel strength aseptically if the core is made from paper. Fluid can freeze or heat and it can damage honeycomb panels.

3.4 Failure Criteria for face sheet failure Mode

Several failure criteria have been developed based on the strength of each lamina in a laminate. When applied to laminates these criteria predict the failure based on the first ply failure and a progressive ply-by-ply failure analysis needs to be performed to predict the laminate failure more accurately.

Lamina based Failure theories:

- Maximum Stress Criteria
- Maximum Strain Criteria
- Tsai-Hill Criterion
- Hoffman's Criterion
- Tsai-Wu Criterion
- Strain Invariant Failure Theory (SIFT)
- And other numerous theories.

However, Tsai-Hill, Tsai-Wu, Hoffman, and other similar failure criteria are not recommended for analyzing the face sheet strength, because all these criteria are based on lamina strength whereas our allowable are based on laminate strength. (Lamina strength does not account for lamina interaction within laminate in failure criteria).

Proposed Method for Calculating Strength MS:

Use the following criteria for calculating the Margin of Safety:

Case 1. When both S11 and S22 are tension and S11 >S22 no shear:

$$MS = \frac{X_T}{S_{11}} - 1$$

Case 2. One tension and one compression (i.e. S11 > and S22 <0) no shear:

$$MS = \frac{1}{\frac{S_{11}}{X_T} + \frac{|S_{22}|}{X_c}} - 1$$

Case 3. Tension or compression with the shear:

$$MS = \frac{1}{\sqrt{\left(\frac{S_{11}}{X_T}\right)^2 + \left(\frac{S_{12}}{X_S}\right)^2}} - 1$$

Where: S11, S22, S12 are stresses in fiber direction and XT, Xc and Xs are design values in Tension, Compression and Shear respectively.

Above failure criteria are applicable for woven fabric assuming strength and stiffness properties in “1” and “2” directions are equal (or nearly equal).

3.5 Analysis Assumptions and Benefits

Assumptions:

1. The failure criteria for the face sheet and core are not identical.

2. PCL has been developed only for honeycomb sandwich panels with composite properties defined as exactly a 3-layer laminate whereby:

-Layer 1 is an equivalent face sheet representing one or more plies

-Layer 2 is the core

-Layer 3 is an equivalent face sheet representing one or more plies

If composite elements are not defined with this exact 3-layer laminate format this PCL will generate incorrect results.

Margins of Safety calculated at 5 or higher will be displayed as exactly 5 in the results.

Benefits:

1. Implementation of SMA failure criteria’s for “Honeycomb Sandwich Panels” in MSc Patran

2. Reduction in analysis time and manual errors

3. Visual plot for Margin of Safety (All fringe plot options can be used during post-processing)

4. Detailed analysis and plots for sandwich panels (like layer by layer results, failure index values and plots, critical layer plot etc).

3.6 The method of calculation margin of safety for Honeycomb Sandwich Panels

The method of calculation margin of safety for Honeycomb Sandwich Panels using SMA failure criteria used for calculation of MS is as follows:

For Face sheet:

When S11 and S22 are both positive (tension) or negative (compression):

For both tension:

- Critical component - layer ID-1

$$MS = \frac{1}{\sqrt{\left(\frac{S_{11}}{X_{1T}}\right)^2 + \left(\frac{S_{22}}{X_{2T}}\right)^2 + \left(\frac{S_{12}}{X_S}\right)^2}} - 1$$

where S – action stress; X –allowable stress in the different directions;

For both compression:

- Critical component - layer ID-2

$$MS = \frac{1}{\sqrt{\left(\frac{S_{11}}{X_{1C}}\right)^2 + \left(\frac{S_{22}}{X_{2C}}\right)^2 + \left(\frac{S_{12}}{X_S}\right)^2}} - 1$$

S11 and S22 has different sign and S12=0:

For S11 tension and S22 compression:

- Critical component - layer ID-3

$$MS = \frac{1}{\frac{S_{11}}{X_{1T}} + \frac{|S_{22}|}{X_{2c}}} - 1$$

For S11 compression and S22 tension:

- Critical component ID-3

$$MS = \frac{1}{\frac{|S_{11}|}{X_c} + \frac{S_{22}}{X_T}} - 1$$

S11 and S22 has different sign but S12 $\neq$ 0:

a) S11 tension and S22 compression:

- Critical component ID-4

$$MS = min\left[\frac{1}{\sqrt{\left(\frac{S_{11}}{X_{1T}}\right)^2 + \left(\frac{S_{12}}{X_S}\right)^2}} - 1; \frac{1}{\sqrt{\left(\frac{S_{22}}{X_{2C}}\right)^2 + \left(\frac{S_{12}}{X_S}\right)^2}} - 1; \frac{1}{\frac{S_{11}}{X_{1T}} + \frac{|S_{22}|}{X_{2c}}} - 1\right]$$

b) S11 compression and S22 tension:

- Critical component ID-4

$$MS = min\left[\frac{1}{\sqrt{\left(\frac{S_{11}}{X_{1C}}\right)^2 + \left(\frac{S_{12}}{X_S}\right)^2}} - 1; \frac{1}{\sqrt{\left(\frac{S_{22}}{X_{2T}}\right)^2 + \left(\frac{S_{12}}{X_S}\right)^2}} - 1; \frac{1}{\frac{S_{11}}{X_{1C}} + \frac{|S_{22}|}{X_{2T}}} - 1\right]$$

For CORE:

- Critical component ID-5

$$MS = min\left[\ \frac{X_{13}}{S_{13}} - 1;\ \frac{X_{23}}{S_{23}} - 1\right]$$

4. VIDEO CONTROL CENTER LOCATION AND STRUCTURE

The video control center is installed in the forward section of the airplane and attached to the floor sit tracks and to the ceiling beam by the tie-rod.

The total weight of the Video Control Centre (VCC) component is 361,08 lb.

The module for equipment is made from honeycomb sandwich panels with fiberglass (forward, AFT, back, and front panels) and aluminum (ceiling and floor panel) facing, and aramid core. The Video Control Centre is shown in Figure 4.1.

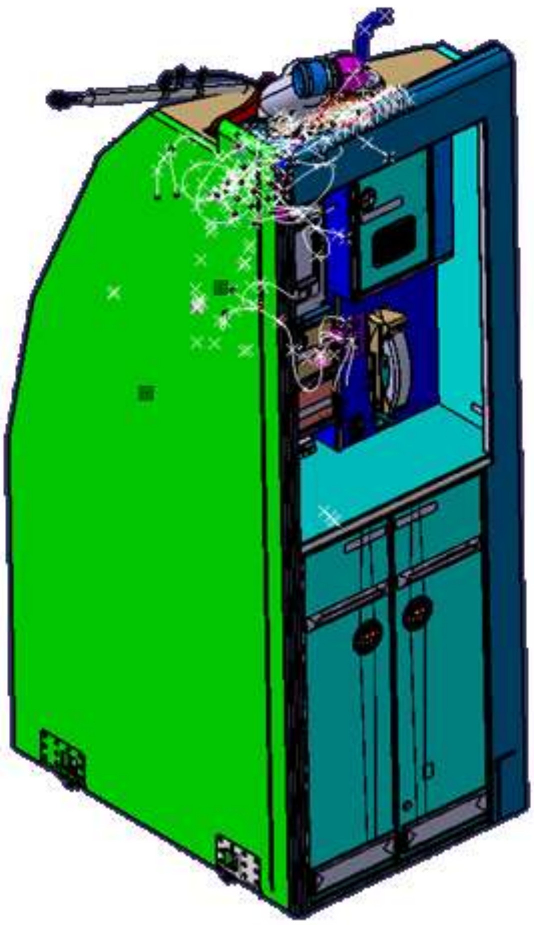


Figure 4.1 VCC structure

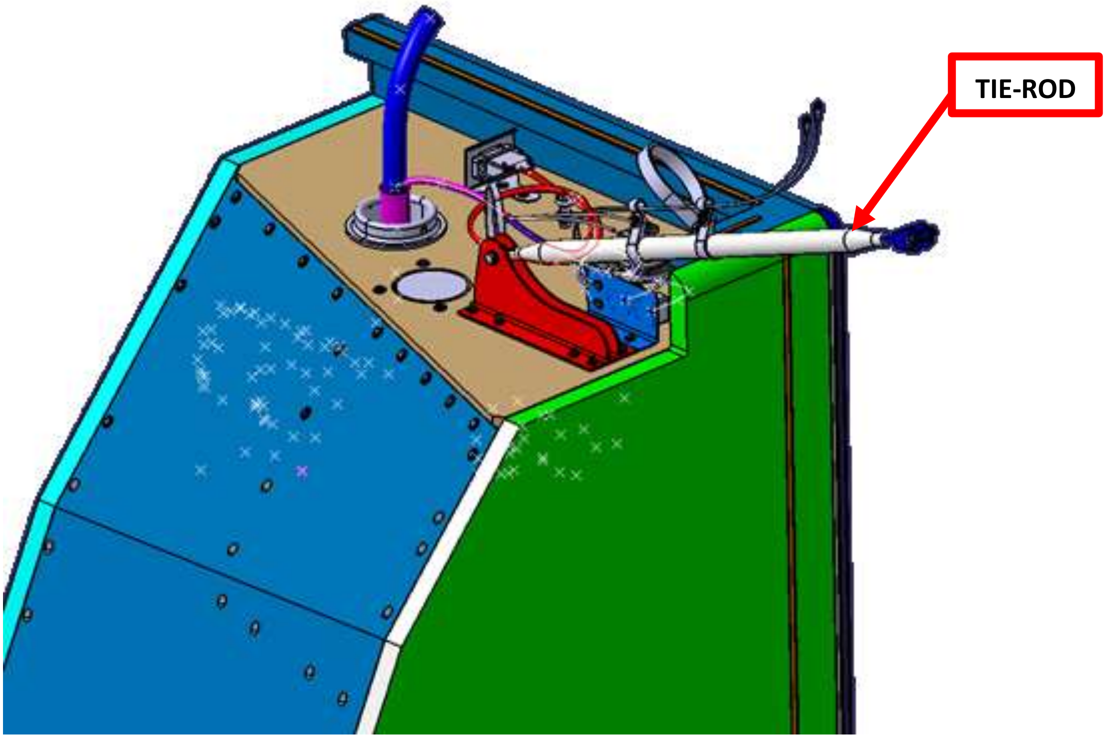


Figure 4.2 VCC ceiling connection tie-rod

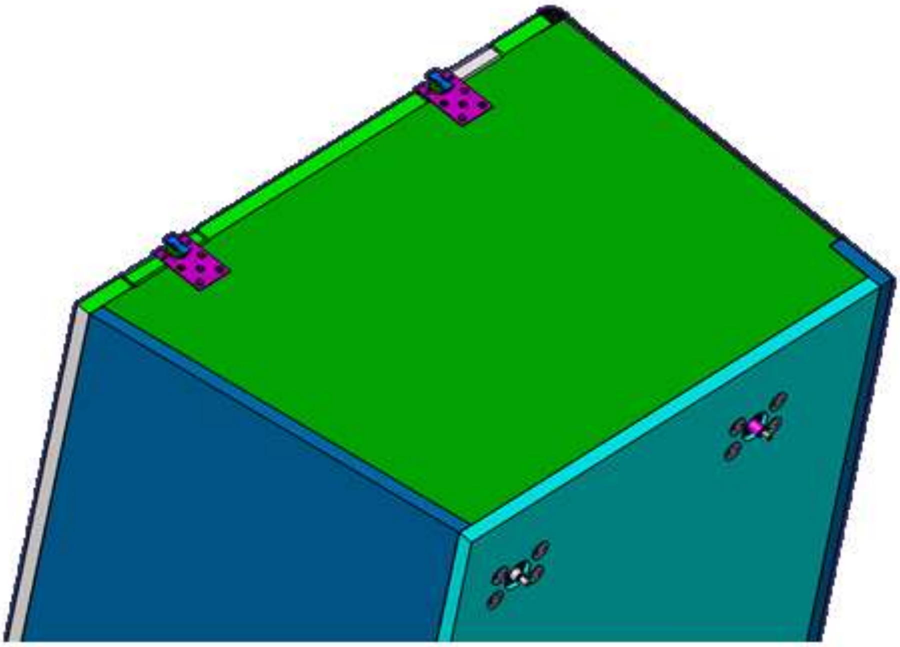


Figure 4.3 VCC floor connection

5. JOINT DEFINITION

The VCC Panels are joined by Bolts, Dog bones, and inserts.

5.1 Dog-Bones joints

Dog-Bones are scalloped single or double shear-tie fittings made in the shape of a bone. The Dog-Bone is presented in Figure 5.3.

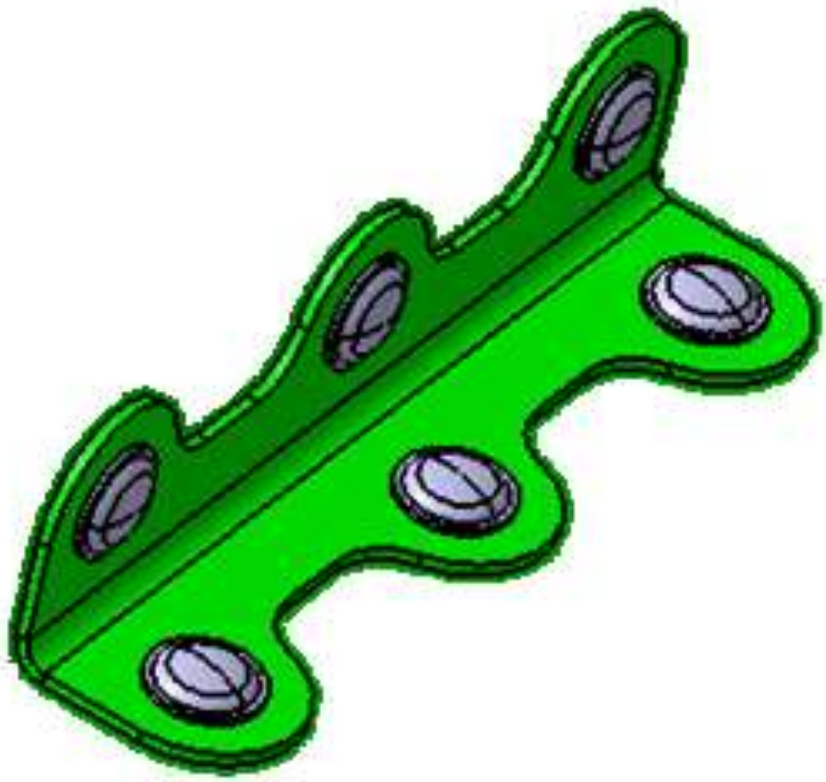
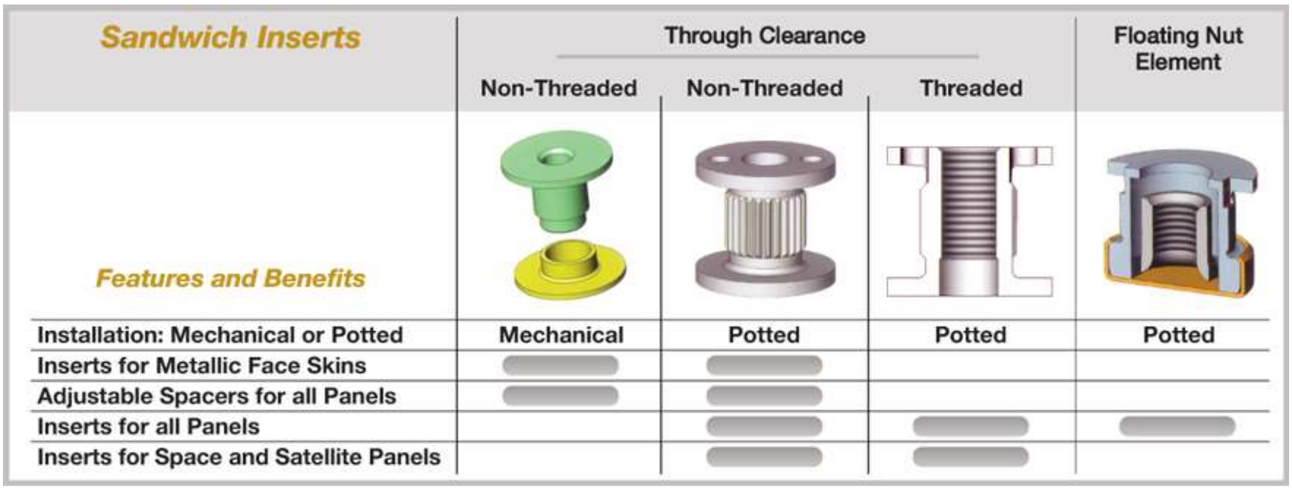


Figure 5.1 Dog-Bones joints

5.2 Bolts and Inserts

The inserts were designed for sandwich panels since manufacturers need more efficient and suitable joints for composite structures. There are different forms and materials for this type of fastener materials. The most common material is 2024 aluminum alloy.



Sandwich Inserts	Through Clearance			Floating Nut Element
	Non-Threaded	Non-Threaded	Threaded	
Features and Benefits				
Installation: Mechanical or Potted	Mechanical	Potted	Potted	Potted
Inserts for Metallic Face Skins	●	●		
Adjustable Spacers for all Panels	●	●		
Inserts for all Panels		●	●	●
Inserts for Space and Satellite Panels		●	●	

Figure 5.2 Sandwich inserts types.

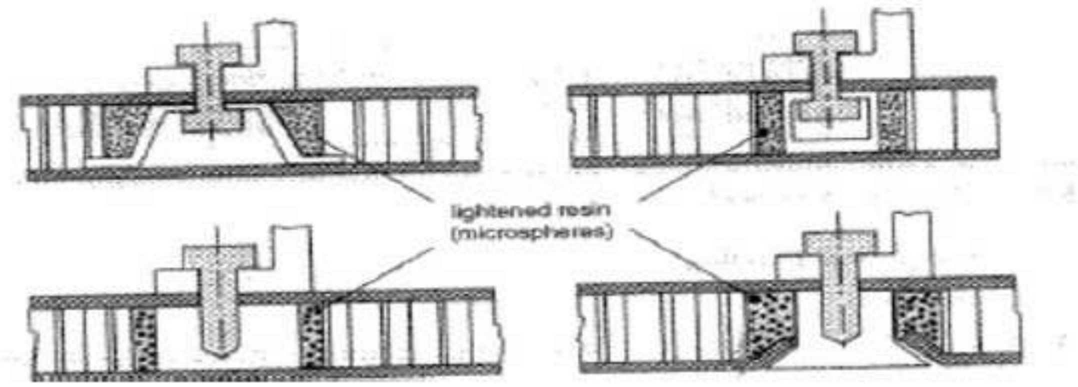


Figure 5.3 Inserts installation

6 PROPERTIES AND DESIGN VALUES

The material properties are given for the panel's coordination system, where materials are used and are sensitive to the global coordinate system.

The majority of composite analyses are based on stresses in the direction of the material direction. No reliable analysis can be performed if the material orientation is unknown, i.e., θ is uncertain.

The material properties and design values for the analyzed panels of VCC are listed in Table 6.1.

Table 6.1 – VCC Panel Assembly description

Panels	Thickness, inch	Core type	Facesheet<1>
PANEL-AL SKIN,FLR	0.50	Aramid Paper	B(1/1)
PANEL-AFT	1.00	Aramid Paper	A(2/2)
PANEL-OUTBD	1.00	Aramid Paper	A(2/2)
PANEL-FWD	1.00	Aramid Paper	A(2/2)
PANEL-CLOSEOUT	0.55	Aramid Paper	A(2/2)
PANEL-HEADER/AISLE	1.00	Aramid Paper	A(2/2)
PANEL-WORK SURFACE	1.00	Aramid Paper	A(2/2)
PANEL-SHELF 1	0.55	Aramid Paper	A(2/2)
PANEL-DIVIDER	0.55	Aramid Paper	A(2/2)
PANEL-SHELF 2	0.55	Aramid Paper	A(2/2)

Panels	Thickness, inch	Core type	Facesheet<1>
PANEL-EDGE/HEADER	0.55	Aramid Paper	A(2/2)
PANEL-SHELF 3	0.55	Aramid Paper	A(2/2)
PANEL-SWITCH	0.55	Aramid Paper	A(2/2)
PANEL-SHELF 4	0.55	Aramid Paper	A(2/2)
PANEL-SHELF 5	0.55	Aramid Paper	A(2/2)
PANEL-SHELF 6	0.55	Aramid Paper	A(2/2)
PANEL-AL SKIN CEILING	1.00	Aramid Paper	B(1/1)
PANEL-PLENUM	0.55	Aramid Paper	A(2/2)
PANEL-AL SKIN,PHONE	0.50	Aramid Paper	B(1/1)
PANEL-MAINT DOOR 1	0.55	Aramid Paper	A(2/2)
PANEL-PRINTER DOOR	0.55	Aramid Paper	A(2/2)
PANEL-MAINT DOOR	0.55	Aramid Paper	A(2/2)
PANEL-RIGHT DOOR	1.00	Aramid Paper	A(2/2)
PANEL-LEFT DOOR	1.00	Aramid Paper	A(2/2)

Notes: <1> The number of plies is indicated in parenthesis.

Facesheet A: 0.0083in thick;

Facesheet B: 7075-T6 Bare sheet, 0.032 in thick;

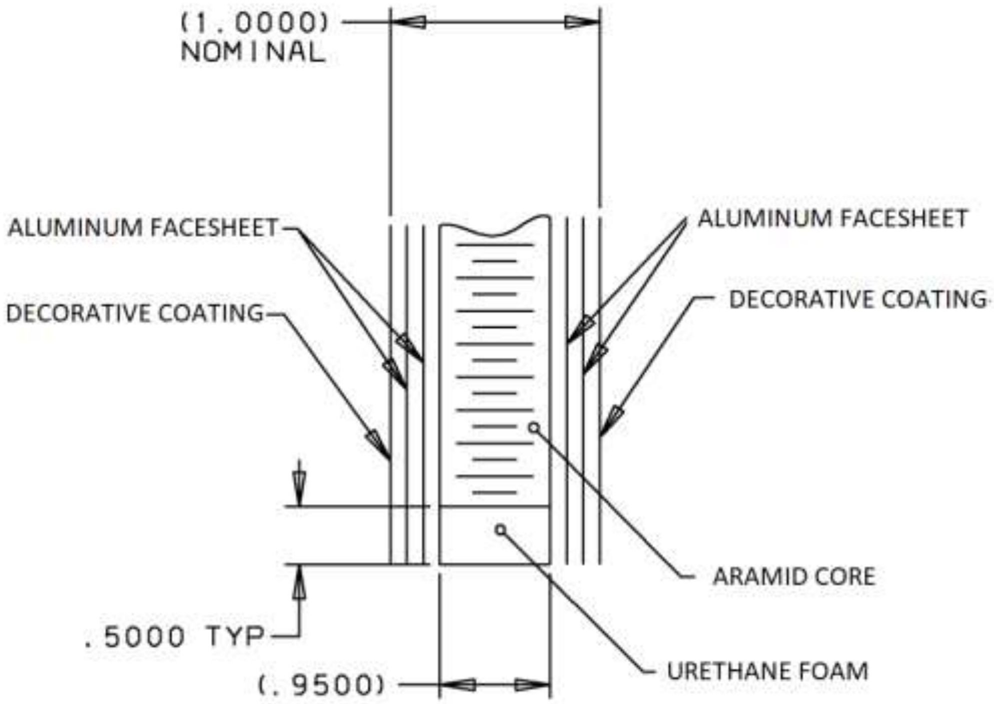


Figure 6.1. Panel Build-Up, Fiberglass Facesheets

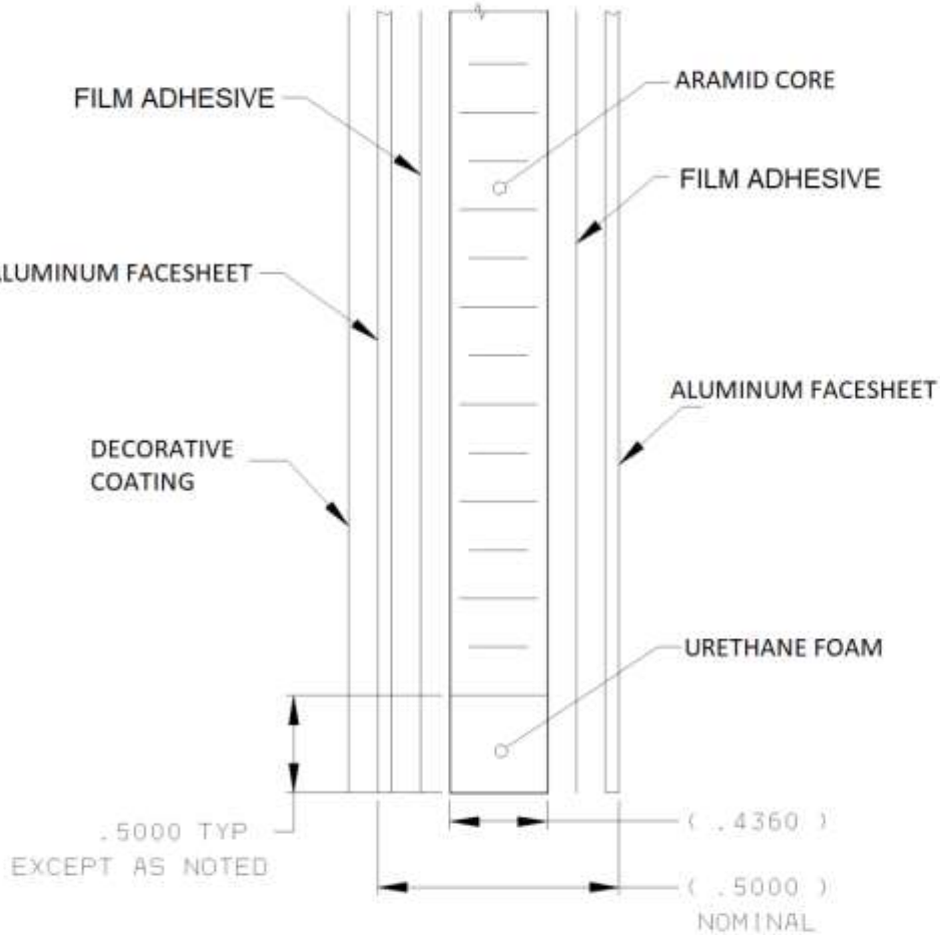


Figure 6.2. Panel Build-Up, Aluminum Facesheets

Table 6.2 – Sandwich Panel Material Properties

	Identification	Tens./Comp. Modulus (psi)		Shear Modulus (psi)			Poisson Ration
		E11	E22	G12	G23	G13	
Face sheet	A (MODIFIED PHENOLIC PREIMPREGNATED GLASS FABRIC FOR INTERIOR SANDWICH PANEL AND LAMINATES)	3146500	314650	680000	1391000	1391000	0.13
Core	NONMETALLIC HONEYCOMB CORE), 0.436 in thk.	100.	100.	100.	10302.	22763.	0.13
	NONMETALLIC HONEYCOMB CORE), 0.436 in thk. 3.0 Density	100.	100.	100.	3737	7107	0.13
	(NONMETALLIC HONEYCOMB CORE), 0.47 in thk.	100.	100.	100.	3700	6969	0.13
	(NONMETALLIC HONEYCOMB CORE), 0.5 in thk	100	100	100	3700	6900	0.13
	(NONMETALLIC HONEYCOMB CORE), 0.93 in thk	100	100	100	10200.	20330	0.13
	(NONMETALLIC HONEYCOMB CORE), 0.95 in thk	100	100	100	3700	6417	0.13

NOTE: Value 100 means real value is too small comparing to other properties;

Table 6.3 – Sandwich Panel Design Values

Type	Face Sheet (# of plies) / Core	Facesheet Tension / Compression Failure (ksi)	Facesheet In-Plane Shear (ksi)	Core Shear, L (psi)	Core Shear, W (psi)
0.55 IN THICKNESS	A (2) (MODIFIED PHENOLIC IMPREGNATED GLASS FABRIC)/ ARAMID HONEYCOMB CORE	35/14	7,432	167	86
1.0 IN THICKNESS	A (2) (MODIFIED PHENOLIC IMPREGNATED GLASS FABRIC)/ ARAMID HONEYCOMB CORE	35/26	7,432	138	75
0.5 IN THICKNESS	B (1) (MODIFIED PHENOLIC IMPREGNATED GLASS FABRIC)/ ARAMID HONEYCOMB CORE	50/50	27,500	433	226

Insert design values are tabulated below.

Table 6.4 – Insert Shear and Tension Design Values

<table>
<tr><th>Insert P/N</th><th>Core thickness, in</th><th>Core Material</th><th>Facesheet</th><th>Number of plies</th><th>ED</th><th>Shear design value, lbs</th><th>Tension design value, lbs</th></tr>
<tr><td rowspan="8">3A3</td><td rowspan="2">0.436</td><td rowspan="2">Nomex</td><td rowspan="4">Al Alloy Sheet 0.032 in thk 7075-T6</td><td rowspan="2">1</td><td>0.5</td><td>1193</td><td>516</td></tr>
<tr><td>1.5</td><td>1930</td><td>516</td></tr>
<tr><td rowspan="2">0.93</td><td>Nome</td><td>1</td><td>1.5</td><td>1785</td><td>560</td></tr>
<tr><td>Nomex/FOAM</td><td>1</td><td>0.5</td><td>1200</td><td>560</td></tr>
<tr><td rowspan="3">0.5</td><td>Nomex/FOAM</td><td rowspan="4">Fiberglass</td><td rowspan="4">2</td><td>0.5</td><td>310</td><td>118</td></tr>
<tr><td rowspan="2">Nomex</td><td>1.5</td><td>375</td><td>172</td></tr>
<tr><td>0.5</td><td>200</td><td>172</td></tr>
<tr><td>0.95</td><td>Nomex</td><td>1.5</td><td>375</td><td>238</td></tr>
</table>

Insert P/N	**Core thickness, in**	**Core Material**	**Facesheet**	**Number of plies**	**ED**	**Shear design value, lbs**	**Tension design value, lbs**
					0.5	200	238
		Nomex/Foam			0.5	310	216
		FOAM			0.5	325	266
K550	0.5	Nomex	Fiberglass	2	1.5	360	112
					0.5	217	112
		FOAM			0.5	335	393
		Nomex/FOAM			0.5	245	185
12AD*	0.5	FOAM	Fiberglass	2	0.5	250	260
500	0.5	Nomex/FOAM	Fiberglass	2	0.5	310	118
		Nomex			0.5	217	112
					1.5	360	112
34A3	0.5	Nomex	Fiberglass	2	0.5	217	112
					1.5	360	112
	0.95				0.5	245	318
					1.5	400	318
		FOAM			0.5	385	449
550	0.5	Nomex/FOAM	Fiberglass	2	0.5	245	185
		Nomex		2	1.5	400	185
C4C	0.95	FOAM	Fiberglass	2	0.5	760	760

Additionally, the capability of the inserts installed with the dog bones depends on the dogbanes. Every dog bone has a different factor for tension and shear.

Metal material allowable for Aluminum 7075-T6 Bare Sheet are provided below:

Allowable material tensile ultimate strength: Ftu = 80 [ksi]

Allowable material tensile yield strength: Fty = 71 [ksi]

Allowable material compression yield strength: Fcy = 75 [ksi]

Allowable material shear ultimate strength: Fsu =42 [ksi]

Allowable material bearing ultimate strength: Fbru = 144 [ksi, e/d = 2]

Allowable material bearing yield strength: Fbry =112 [ksi, e/d =2]

Elastic modulus for tension: E =10.3E6 [psi]

Elastic modulus for compression: Ec = 10.5E6 [psi]

Shear modulus: G = 3.9E6 [psi]

Poisson Ration: M = 0.33.

7 DESIGN LOADS

The loads presented below are the interface loads for VCC, see Figure 7.1. Fitting 1 is VSF type fitting. Fitting 2 and Tie rod 5 do not take side loads. Fittings 3 and 4 do not take forward loads.

These interface loads were extracted from the FE model. The gross weight equals 361.08 lb. The mass includes the weight of the panel, equipment, doge bones, fasteners, and compartment.

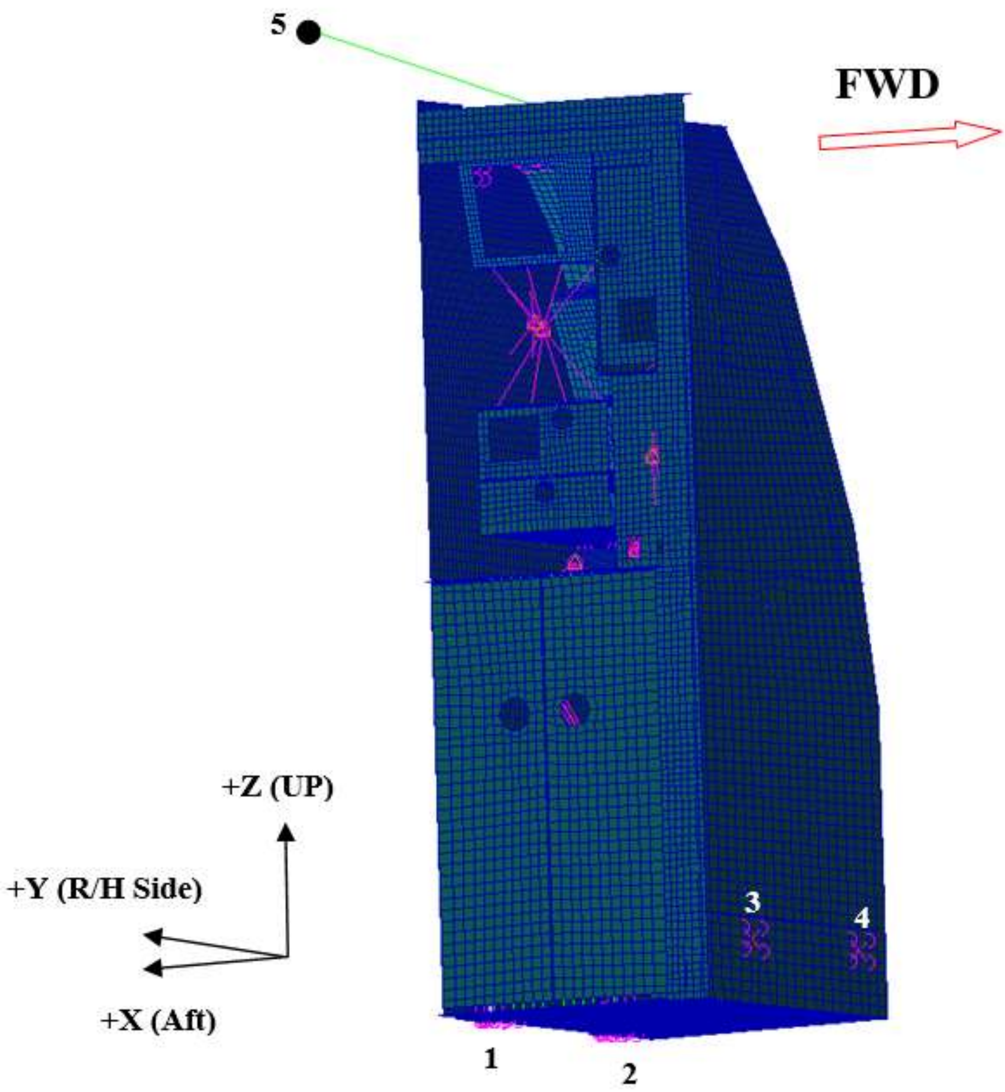


Figure 7.1 - VCC FEM

Design loads for VCC installation are obtained from the references to support FAA/Boeing requirements.

The table below publishes the most critical Flight and Ground load cases in the airplane global coordinate system.

Sign Convention: +X = Aft, +Y = Right, +Z = Up.

Table 7.1 Ultimate Design Load Cases

Point	Load lbs	Ultimate Design Load Cases					
		9g Fwd	6g Down	3g Up	3g Right	3g Left	7.0g Down +0.5g FWD
1	Px	-784.08	-28.81	14.41	-175.93	175.93	-77.17
	Py	140.45	-5.37	2.69	385.20	-385.20	1.54
	Pz	-675.21	-679.15	339.58	-572.17	572.17	-829.85
2	Px	-1100.22	4.31	-2.16	246.10	-246.10	-56.10
	Py	0.00	0.00	0.00	0.00	0.00	0.00
	Pz	490.13	-395.26	197.63	376.65	-376.65	-433.91
3	Px	0.00	0.00	0.00	0.00	0.00	0.00
	Py	-87.66	7.11	-3.56	358.23	-358.23	3.43
	Pz	1143.47	-757.56	378.78	-786.32	786.32	-820.29
4	Px	0.00	0.00	0.00	0.00	0.00	0.00
	Py	-52.80	-1.75	0.88	339.87	-339.87	-4.98
	Pz	-461.24	-343.54	171.77	1007.37	-1007.37	-426.42
5	Px	-1365.59	24.49	-12.25	-70.17	70.17	-47.29
	Py	0.00	0.00	0.00	0.00	0.00	0.00
	Pz	-497.15	8.92	-4.46	-25.55	25.55	-17.21
Total	Px	-3249.90	0.00	0.00	0.00	0.00	-180.54
	Py	0.00	0.00	0.00	1083.3	-1083.30	0.00
	Pz	0.00	-2166.60	1083.30	0.00	0.00	-2527.69

Additionally, Abuse and Handling loads could be applied to VCC door panels - the case does not consider in the current analysis.

8. FINITE ELEMENT ANALYSIS

Analysis Criteria for aircraft structure:

• Must be able to withstand specific impact damage requirements and still be capable of sustaining ultimate load.

• Honeycomb panels, spars, and ribs must be stable to ultimate load.

• Aerodynamic smoothness: deflection at 1G cruise conditions must meet aero groups requirements.

The stress analysis of the Video Control Centre (VCC) installation has been performed. MSC Patran 2018.1 code was used in the FE model development, pre-and post-processing. The MSC Nastran 2018.1 was used for the FE solver.

The finite element analysis of the VCC has been developed per the guides set forth in the Boeing Nastran/Patran Standards as posted on IRC website.

Hand analysis has been evaluated as required per standard methods and procedures.

FEM model name: VCC_Final.db, saved in current the stress report. The general methods used in the FEA model are listed below:

1. The electrical equipment is represented either by lumped mass elements modeled at the CG of a certain structure (RBE3 elements are used to attach mass points to the structure).
2. For the sandwich panels, mass is represented by a non-structural mass property.
3. The inserts are modeled as RBE2 elements.
4. The gap elements are used. These elements are modeled with the gaps that closed in certain load levels and provide additional support.
5. Because of using gap elements, the non-linear analysis (106) is performed.
6. The panels material is defined as a composite material with three layers: the first and third layers is aluminum or fiberglass sheets, the second layer is a core.

RBE2

Rigid body with independent DOF at one GRID, and dependent DOF at an arbitrary number of GRIDs.

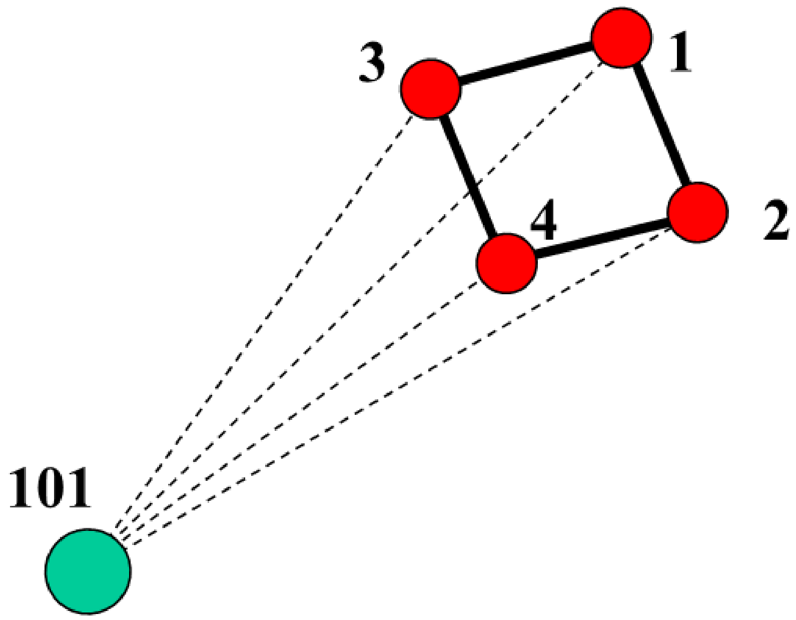


Figure 8.1 – RBE2 elements

No deformation of element(s) between these GRIDs

Example in the model:

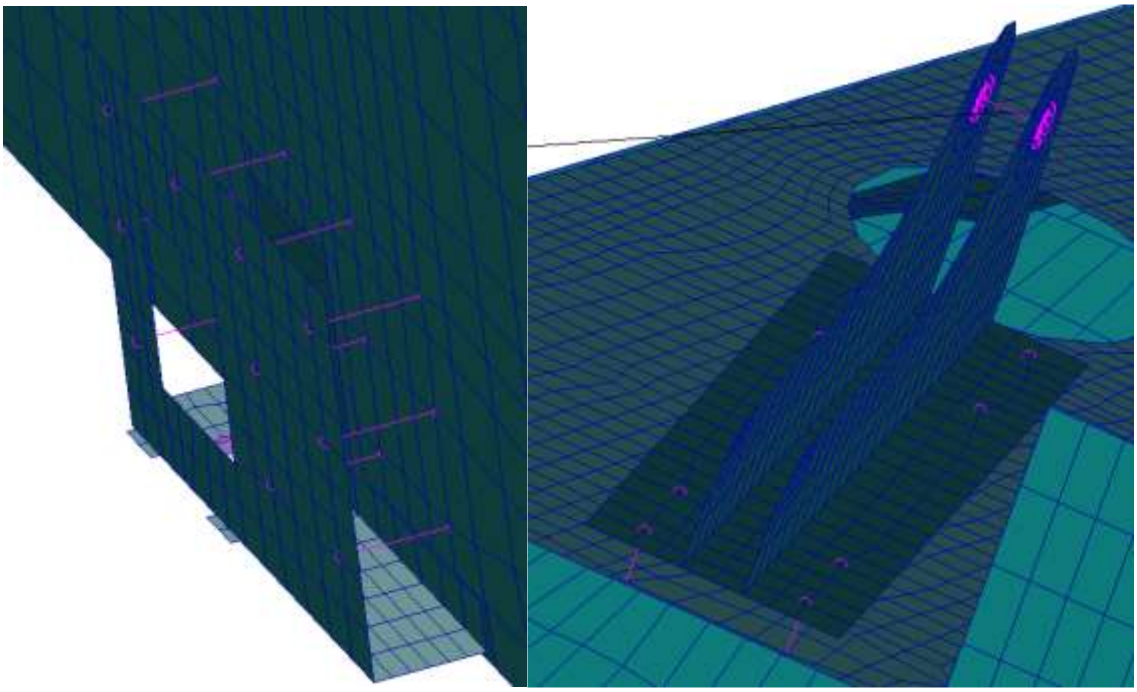


Figure 8.2 – RBE2 elements in FEM model

RBE3 Elements

Motion at a dependent GRID is the weighted average of the motion(s) at a set of master (independent) GRIDs

- By default, the reference grid DOF will be the dependent DOF
- Number of dependent DOF is equal to the number of DOF on the REFC field
- Dependent DOF can not be SPC'd, OMITted, SUPORTed, or be dependent on other RBE/MPC elements

Example in the model:

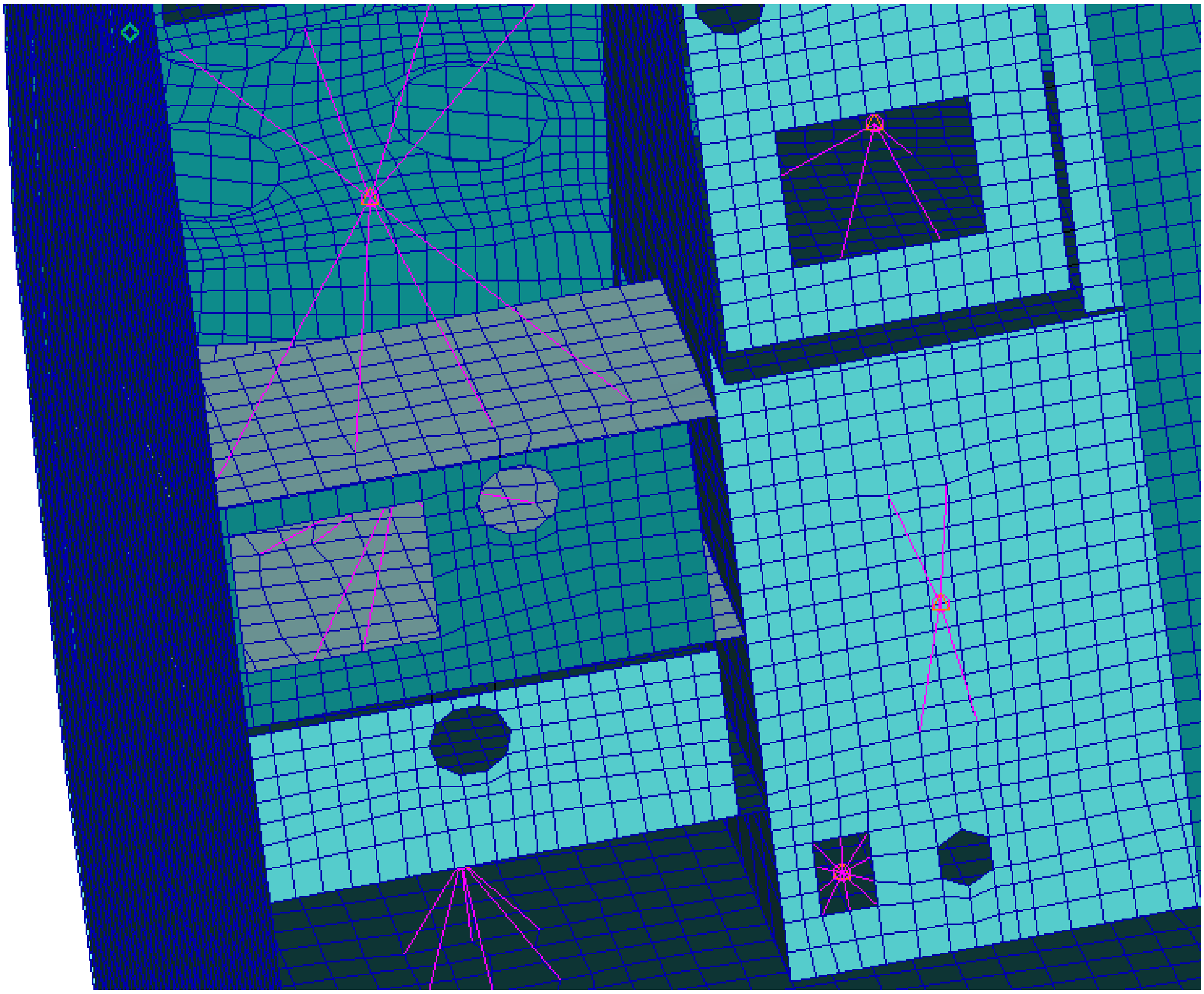


Figure 8.3 – RBE3 elements in FEM model

FEM Modeling composite materials

It is acceptable to model two fiberglass sheets as one with the doubled thickness due to fiberglass properties not depends on directions.

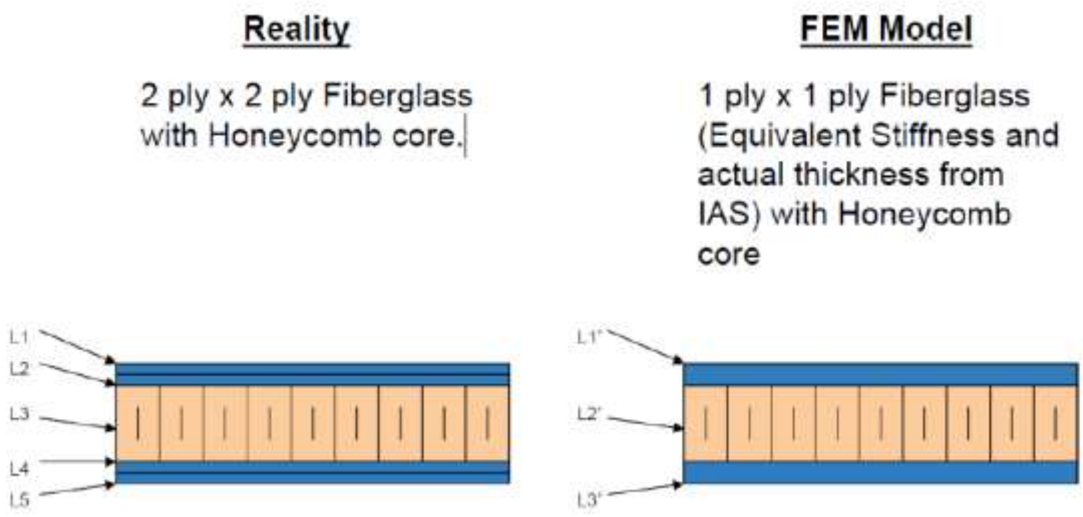
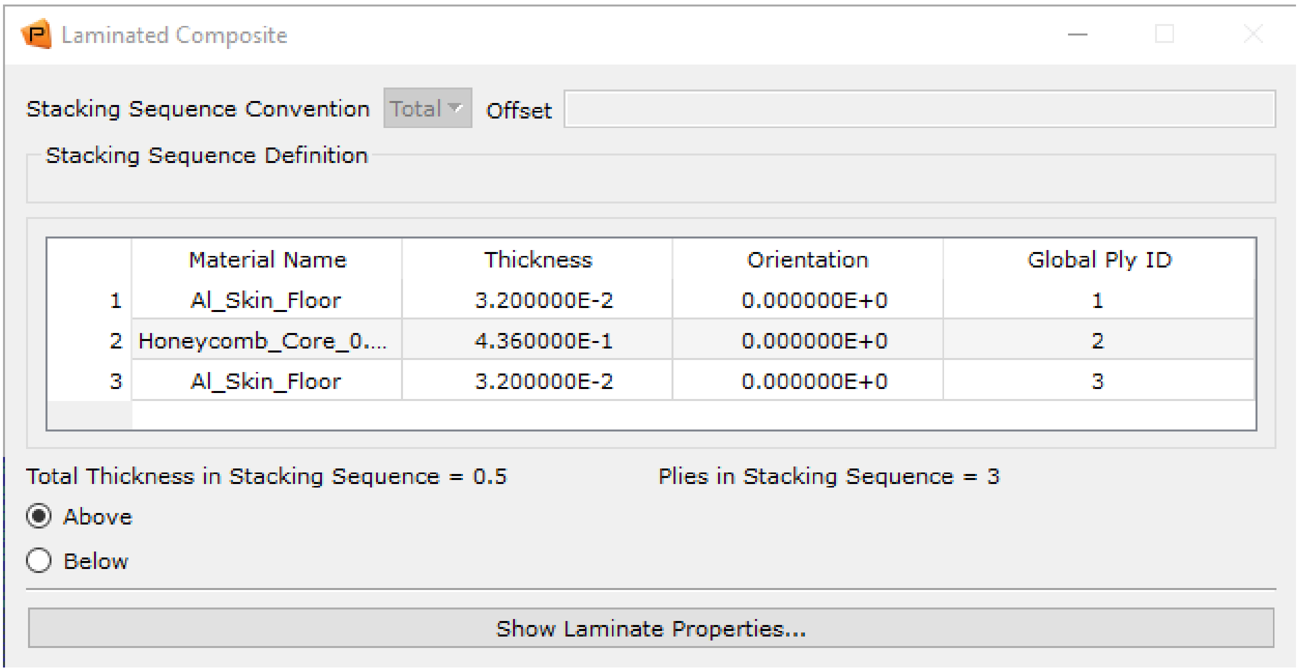


Figure 8.4 – FEM modeling of the composite panel


Laminated Composite

Stacking Sequence Convention Total Offset

Stacking Sequence Definition

	Material Name	Thickness	Orientation	Global Ply ID
1	Al_Skin_Floor	3.200000E-2	0.000000E+0	1
2	Honeycomb_Core_0....	4.360000E-1	0.000000E+0	2
3	Al_Skin_Floor	3.200000E-2	0.000000E+0	3

Total Thickness in Stacking Sequence = 0.5 Plies in Stacking Sequence = 3

Above

Below

Show Laminate Properties...

Figure 8.5 – Example of the panel material with aluminum facesheet

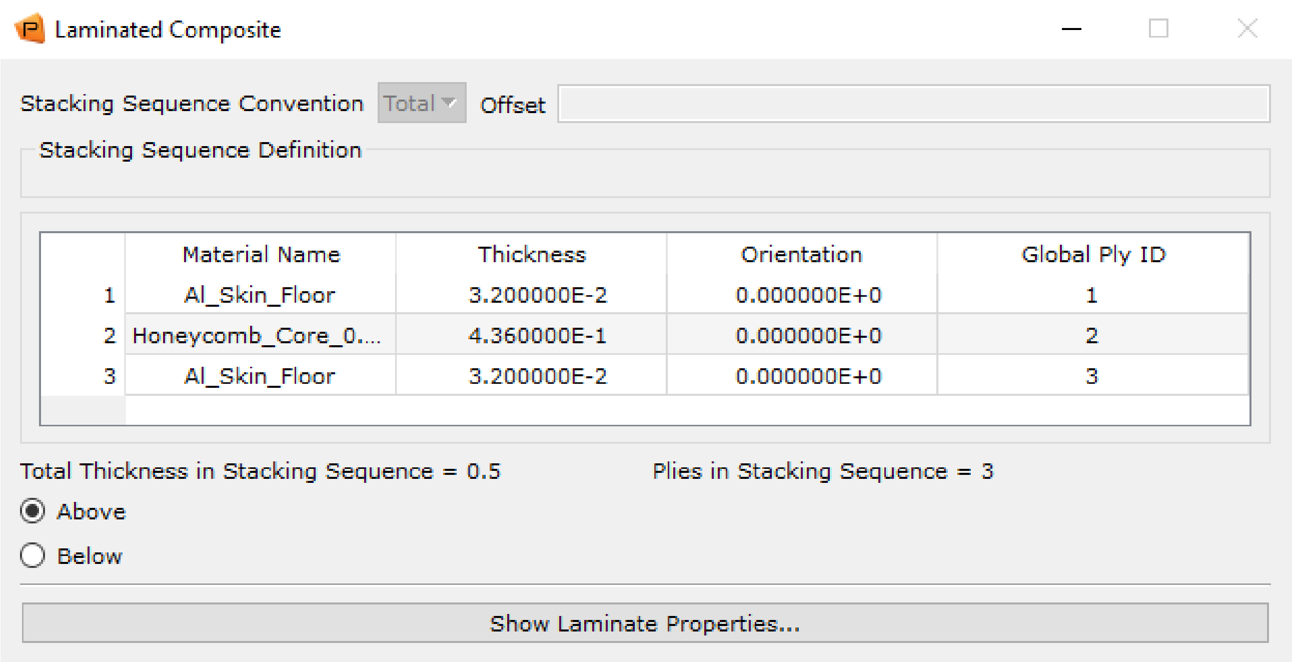


Figure 8.6 – Example of the panel material with fiberglass facesheet

8.1 Interface points, loads, and boundary conditions

The VCC was installed in the forward section of the airplane and attached to the floor structure (sit tracks) by fittings and to the ceiling beam by tie-rod. Additionally, it can rely on a compartment during a 9.0G overload load case when the gap between the AFT panel and gap is closed. This is taken into by applying step loads to the structure.

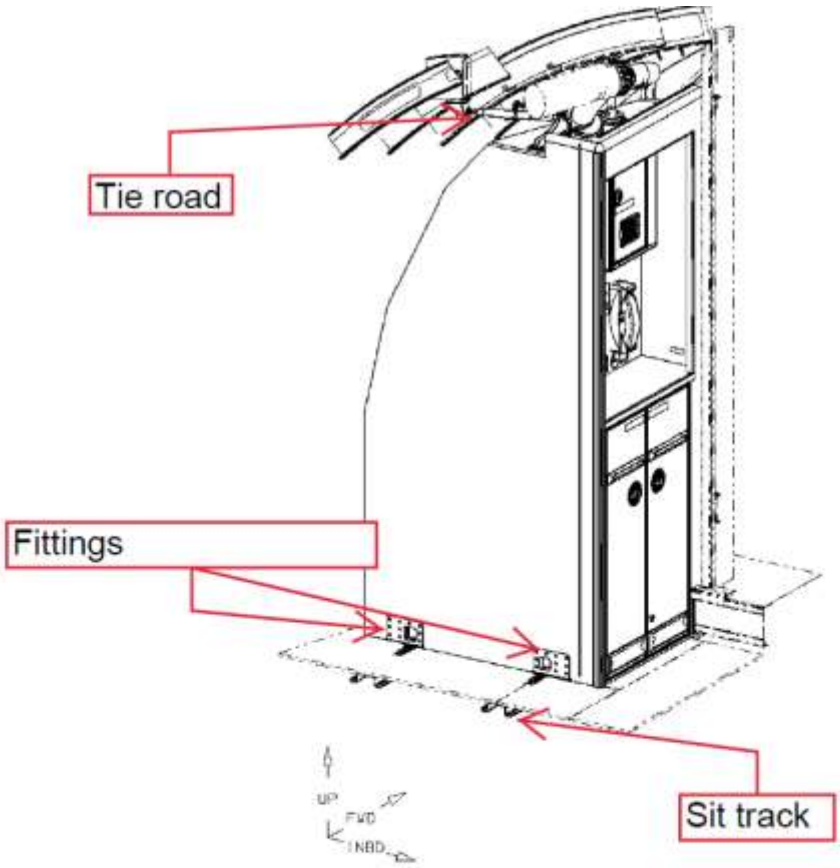


Figure 8.7 – Connections of the VCC

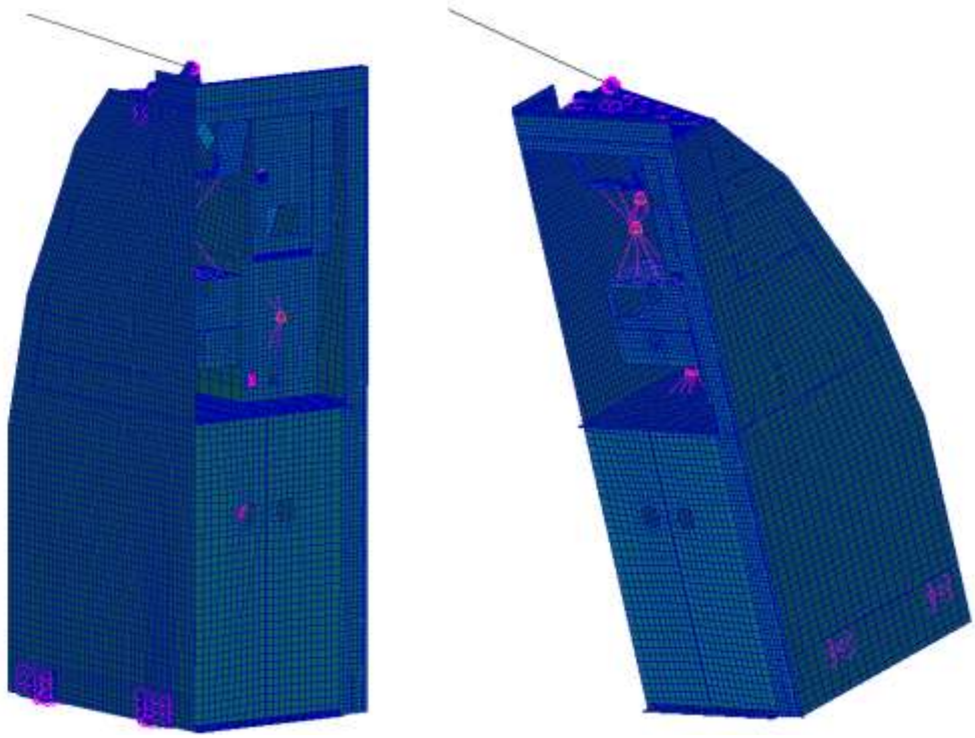


Figure 8.8 – VCC FEM model

Boundary conditions:

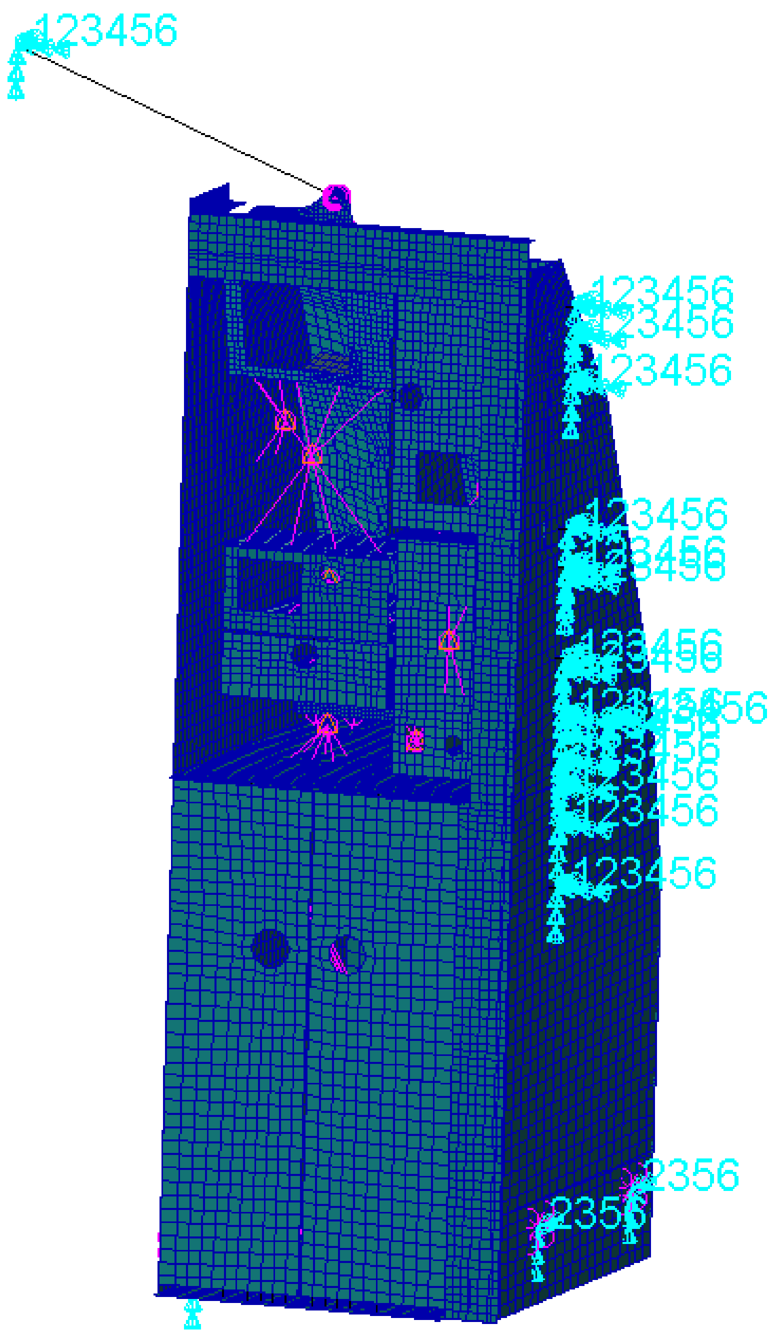


Figure 8.9 – VCC FEM model boundary

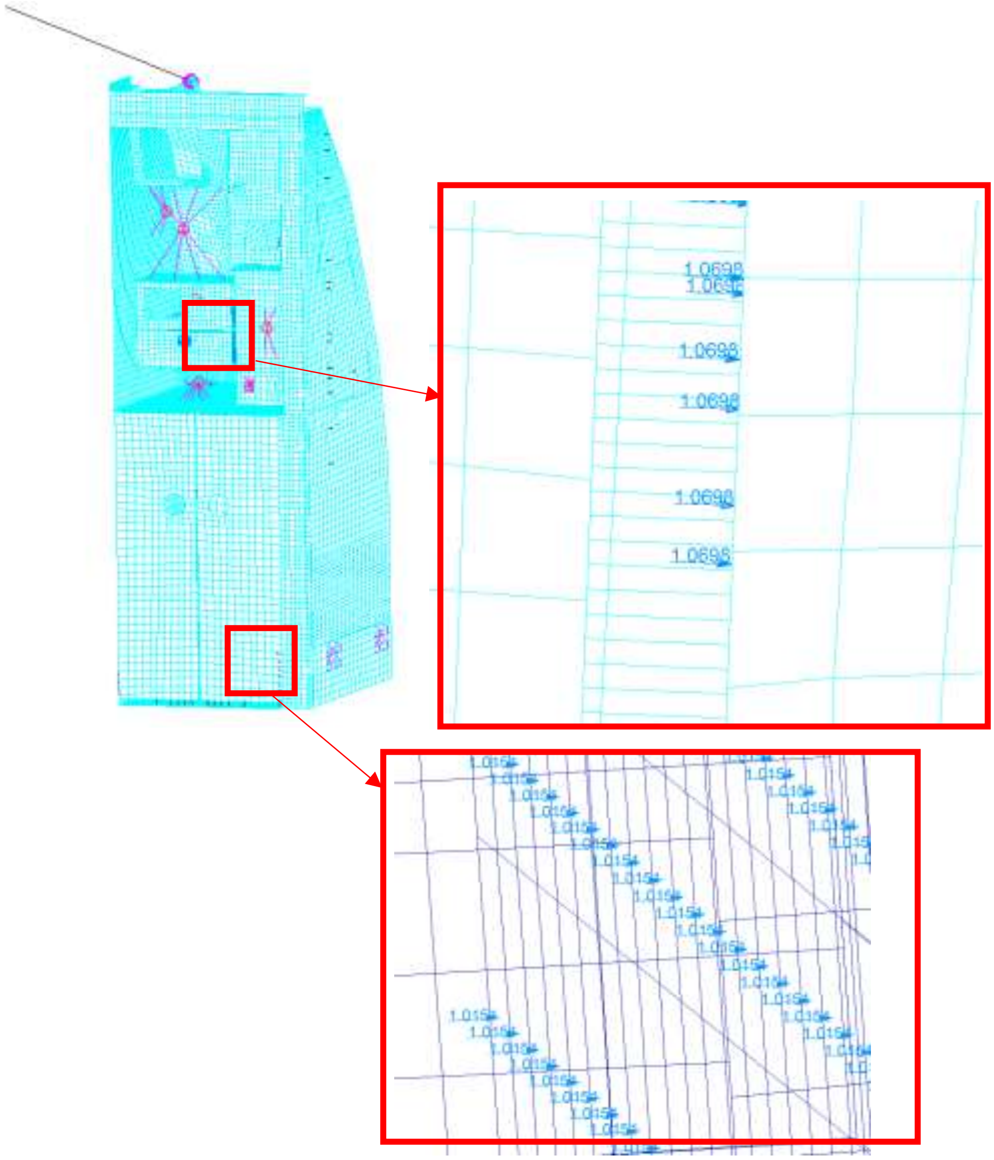


Figure 8.9 – 1G FWD closet and stowage loads

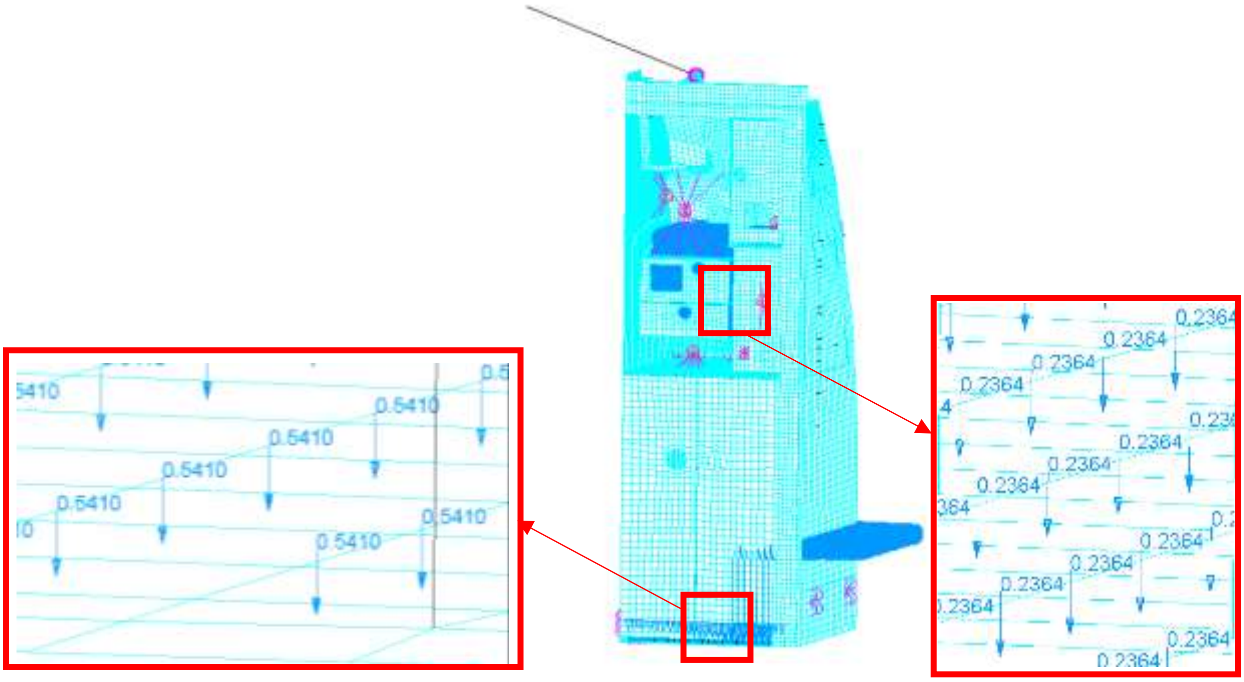


Figure 8.10 – 1G Down closet and storage loads

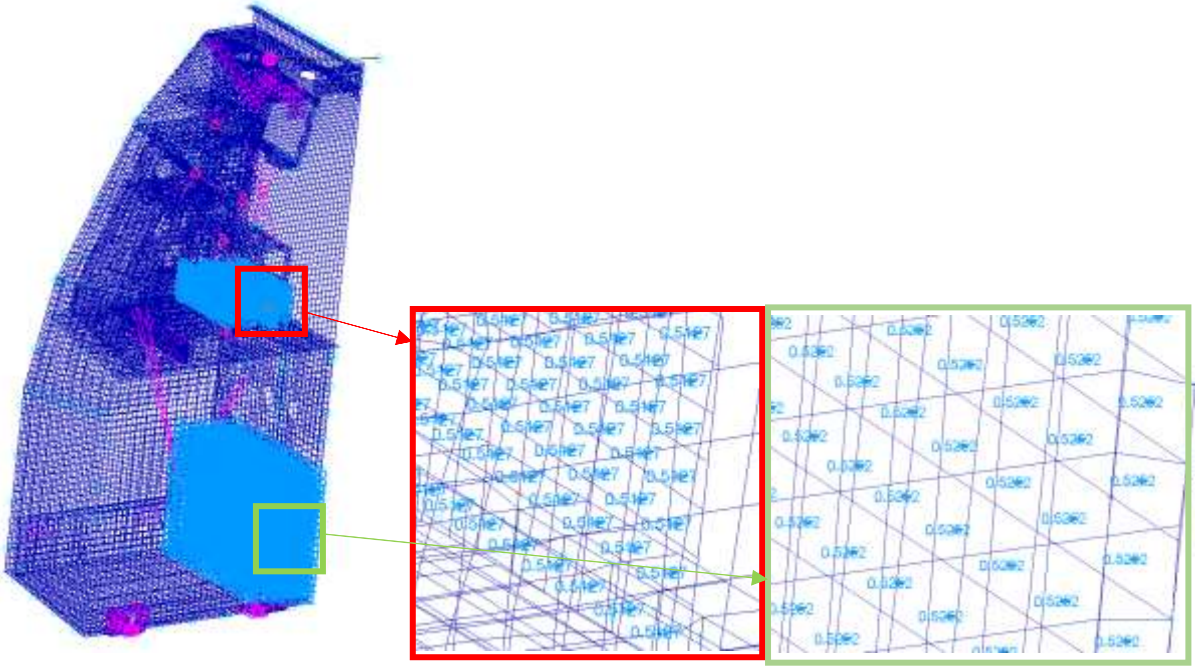


Figure 8.11 – 1G Right closet and storage loads

Panel interface loads

The interfaces loads for each panel are shown in the tables below:

Table 8.1 - Floor panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-211	62	14	-1	0	10	13	-1	5	-13	3	12
DB2	-261	47	13	-4	3	39	16	-2	-2	-20	6	46
DB3	-263	46	2	-7	3	44	20	-3	-1	-22	7	51
DB4	-241	15	-29	-4	-1	2	29	-3	4	-18	-1	0
DB5	-25	6	1	-2	14	29	1	-63	-10	-3	17	33
DB6	-78	-121	6	-1	-1	61	2	0	-1	-5	-8	71
DB7	-68	-173	-3	-1	19	58	3	-29	4	-5	13	68
DB8	-208	-35	10	-12	-44	77	-10	-125	6	-25	-53	90
DB9	-12	78	-11	5	40	65	-2	53	-3	6	51	75
DB10	-9	58	-2	3	12	44	-1	55	-2	3	17	51
DB11	-4	39	-22	4	-11	57	-1	60	2	5	-10	65
DB12	-74	-11	15	-2	-6	-2	1	3	3	-6	-8	-2
DB13	-90	27	22	-4	-1	19	-1	8	-3	-10	1	23
DB14	-47	-9	-17	9	-16	85	5	-23	-1	8	-19	98
1	236	-31	0	22	26	0	-38	6	0	38	28	0
2	245	15	0	-25	-7	0	-74	-13	0	-16	-7	0
3	245	41	0	28	26	0	-35	26	0	46	32	0
4	232	-38	0	-21	-4	0	-77	36	0	-12	-7	0
5	124	3	0	-6	-2	0	-23	5	0	0	-2	0
6	167	-37	0	-3	12	0	-4	-7	0	6	12	0
7	160	12	0	16	-3	0	86	19	0	27	-3	0
8	180	17	0	-8	-19	0	-16	-92	0	1	-21	0
9	146	-13	0	20	-36	0	95	-86	0	32	-42	0

10	72	0	0	-7	-6	0	13	-17	0	-4	-7	0

X-Y is Shear Plane Z is Tension Direction

Table 8.2 - Phone panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	8	1	14	-43	-1	28	-16	-6	10	-50	-1	34
DB2	18	0	8	4	-1	-17	-5	-2	-5	6	-1	-19
DB3	-28	-1	-39	0	0	-16	2	-4	-13	-1	0	-21
DB4	-13	-1	-32	1	1	-22	1	-5	-19	0	1	-27
DB5	83	1	49	38	1	71	18	-6	27	48	1	86
1	-8	-14	0	0	2	-4	0	3	0	0	2	-5
2	-8	14	0	0	2	-4	0	3	0	0	3	-5
3	-5	-14	0	0	-2	-4	0	2	0	0	-3	-5
4	-5	14	0	0	-2	-4	0	2	0	0	-2	-5

X-Z is Shear Plane Y is Tension Direction

Table 8.3 - Shelf Panel 1

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-75	-40	-5	5	-1	16	-2	-8	0	2	-3	18
DB2	-57	-55	-11	5	3	11	-3	-6	-1	3	1	12
DB3	9	-37	-14	8	-1	10	3	-5	0	10	-4	11
DB4	-20	50	22	-2	-2	11	1	-1	1	-3	0	14
DB5	-35	82	8	-4	1	19	-3	-5	0	-6	6	22
1	43	-19	22	-11	4	-2	1	0	1	-11	4	-1
2	60	5	9	-11	-3	6	1	0	0	-9	-3	8
3	61	-6	-7	2	-3	9	1	0	0	6	-4	10
4	49	20	-23	7	2	3	1	0	-1	11	3	2
5	0	0	0	1	0	-2	0	2	0	2	0	-4
6	0	0	0	2	0	0	0	1	0	4	0	-1
7	0	0	0	1	0	-2	0	2	0	2	0	-4
8	0	0	0	2	0	0	0	1	0	4	0	-1
9	-1	0	0	-2	0	0	0	1	0	-4	0	0
10	-1	0	0	-2	0	-2	0	2	0	-4	0	-4
11	-1	0	0	-2	0	0	0	1	0	-4	0	0
12	-1	0	0	-2	0	-2	0	2	0	-4	0	-4
13	0	0	1	2	0	2	0	2	0	2	0	3
14	0	0	0	0	0	3	0	2	0	-1	0	3

X-Y is Shear Plane Z is Tension Direction

Table 8.4 - Shelf Panel 2

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	1	65	20	0	3	35	-2	-6	5	0	7	42
DB2	5	50	9	4	6	10	2	-17	-5	5	10	12
DB3	119	-53	-2	7	-7	2	5	-15	-2	15	-11	2
DB4	22	-35	-9	-2	-7	15	0	-16	-5	-2	-10	17
DB5	0	-28	-18	-9	4	37	-5	-9	7	-10	3	42
1	-14	-1	-20	0	0	-7	0	5	5	-1	0	-10
2	-14	-1	-12	0	0	-8	0	5	5	-1	0	-10
3	-14	1	12	0	0	-9	0	5	5	-1	0	-10
4	-14	1	20	0	0	-10	0	5	5	-1	0	-10
5	-16	-1	-20	0	0	-10	0	5	-5	-1	0	-12
6	-16	-1	-12	0	0	-10	0	5	-5	-1	0	-13
7	-16	1	12	0	0	-12	0	5	-5	-1	0	-13
8	-16	1	20	0	0	-12	0	5	-5	-1	0	-13
9	1	0	-3	2	0	-5	1	0	-1	5	0	-11
10	1	0	-3	2	0	-5	1	0	-1	5	0	-11
11	0	0	1	2	0	0	1	0	0	4	0	1
12	0	0	1	2	0	0	1	0	0	4	0	1
13	1	0	-1	0	0	0	-1	0	0	-1	0	0
14	1	0	-1	0	0	0	-1	0	0	-1	0	0
15	1	0	1	-2	0	-4	-1	0	-1	-5	0	-9
16	1	0	1	-2	0	-4	-1	0	-1	-5	0	-9
17	0	0	0	0	0	0	0	4	0	0	0	0
18	0	0	0	0	0	0	0	4	0	0	0	0
19	0	0	0	0	0	0	0	4	0	0	0	0
20	0	0	0	0	0	0	0	4	0	0	0	0

X-Y is Shear Plane Z is Tension Direction

Table 8.5 - Shelf Panel 3

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-7	-1	-70	0	3	35	-2	-6	5	0	7	42
DB2	-34	2	-23	4	6	10	2	-17	-5	5	10	12
DB3	-40	0	-101	7	-7	2	5	-15	-2	15	-11	2
DB4	143	-4	226	-2	-7	15	0	-16	-5	-2	-10	17
DB5	-33	2	-20	-9	4	37	-5	-9	7	-10	3	42
DB6	-10	0	-12	0	0	-7	0	5	5	-1	0	-10
1	-2	0	0	0	0	-8	0	5	5	-1	0	-10
2	0	0	0	0	0	-9	0	5	5	-1	0	-10
3	4	0	0	0	0	-10	0	5	5	-1	0	-10
4	-2	0	0	0	0	-10	0	5	-5	-1	0	-12
5	0	0	0	0	0	-10	0	5	-5	-1	0	-13
6	-15	0	0	0	0	-12	0	5	-5	-1	0	-13
7	-21	0	0	0	0	-12	0	5	-5	-1	0	-13
8	23	0	0	2	0	-5	1	0	-1	5	0	-11

X-Z is Shear Plane Y is Tension Direction

Table 8.6 - Shelf Panel 4

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-10	0	0	-12	0	19	-2	-5	0	-15	0	22
DB2	45	10	1	-1	4	16	-5	-3	0	1	5	19
1	-13	-2	1	-1	1	-10	0	5	0	-1	1	-11
2	-13	-1	0	-1	1	-9	0	5	0	-1	1	-11
3	-13	1	0	-1	1	-9	0	4	0	-1	1	-11
4	-13	2	-1	-1	1	-9	0	3	0	-1	1	-10
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
DB1	-1	-1	0	3	-3	8	0	-5	0	4	-4	9
DB1	11	-6	0	3	-3	-4	2	-4	0	4	-4	-4
DB2	11	1	-2	0	1	6	0	-2	0	1	1	7
DB2	6	-4	1	9	0	-3	5	-2	0	11	-1	-3

X-Y is Shear Plane Z is Tension Direction

Table 8.7 - Shelf Panel 5

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	24	-5	0	0	-1	8	-3	-9	0	1	-2	9
DB2	-24	6	0	2	-2	12	7	-12	0	2	-2	14
DB3	-23	1	2	-1	0	-6	-1	1	0	-3	0	-7
DB4	-5	0	-38	-1	0	-3	3	0	2	-1	0	-6
DB5	-2	2	37	3	0	-6	-1	1	1	3	0	-5
DB6	-38	-1	0	4	0	-9	3	1	-2	3	0	-10
1	-15	2	-1	1	-1	-9	0	4	0	0	-1	-10
2	-15	1	0	1	-1	-9	0	5	0	0	-1	-11
3	-15	-1	0	1	-1	-9	0	5	0	0	-1	-11
4	-15	-2	1	1	-1	-10	0	6	0	0	-1	-11

X-Y is Shear Plane Z is Tension Direction

Table 8.8 - Shelf Panel 6

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	41	-3	-1	-1	0	8	0	-3	-6	2	0	9
DB2	-20	3	1	1	0	6	0	-4	6	0	0	7
1	-3	0	5	0	0	-1	0	1	-1	0	0	-1
2	-3	0	-5	0	0	-2	0	1	-1	0	0	-2
3	-4	0	5	0	0	-3	0	1	1	0	0	-3
4	-4	0	-5	0	0	-3	0	1	1	0	0	-4

X-Y is Shear Plane Z is Tension Direction

Table 8.9 - Shelf Panel 7

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-1	-1	-2	8	-2	0	7	-3	0	9	-2	0
DB2	47	8	-2	-12	-2	6	-12	-3	0	-11	-2	7
DB3	-31	-7	4	4	4	4	5	1	0	3	4	5

X-Y is Shear Plane Z is Tension Direction

Table 8.10 - Ceiling panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-143	4	-226	21	2	-10	2	2	-13	16	2	-24
DB2	4	103	36	-3	-7	4	-2	-2	3	-3	-3	7
DB3	23	-4	35	-4	-39	10	-1	-29	1	-4	-46	13
DB4	-22	-2	22	-1	-2	5	4	1	3	-2	-2	7
DB5	-46	0	1	3	0	0	-6	1	-1	0	0	0
DB6	-67	1	-12	2	-10	4	1	-5	-1	-1	-12	4
DB7	26	-2	-34	-3	0	4	2	2	-1	-2	0	3
DB8	-7	-10	-72	-1	0	3	-2	1	-3	-1	0	0
1	-17	64	32	-7	-1	-1	-8	4	1	-10	2	1
2	-63	43	5	-5	8	3	-11	5	0	-9	11	4
3	-120	1	-42	0	15	5	-11	5	-2	-6	18	4
4	-186	-22	-93	7	20	7	-12	5	-4	-3	22	3
5	-32	-7	-154	3	10	6	-1	3	-7	2	11	-1
6	-101	-44	-155	1	7	5	-5	-1	-7	-5	5	-3
7	-72	-58	-107	1	5	2	-3	-2	-5	-3	3	-3
8	-72	-44	-48	-1	2	0	-2	-2	-2	-5	0	-2
9	-42	-16	-13	-4	-7	-3	-2	-3	-1	-7	-10	-4
10	-38	-45	14	2	2	0	-1	-2	1	0	0	1
11	-8	-57	1	1	3	0	0	-2	0	1	1	0
12	22	-33	1	1	3	0	2	-1	0	3	2	0
13	136	68	359	-4	2	-6	7	4	18	3	6	13
14	66	53	174	-1	1	-2	3	3	9	2	4	8
15	296	-78	362	-6	5	-6	15	-3	18	9	1	13
16	139	-64	168	-1	3	-2	8	-3	8	7	0	7
17	72	22	-88	5	-3	3	8	0	-5	10	-3	-1
18	139	24	-79	-6	0	3	4	2	-4	0	2	-1
19	48	43	-45	7	-12	3	8	-6	-3	11	-12	1
20	132	61	-46	-7	-5	4	3	-1	-2	0	-2	2

X-Y is Shear Plane Z is Tension Direction

Table 8.11 - Plenum panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	16	0	0	1	1	-1	2	1	0	2	1	-2
DB2	-20	-2	0	-1	1	-1	-3	1	0	-3	1	-1
DB3	-47	-2	57	6	2	-23	-1	2	-2	4	2	-24
DB4	25	-10	-5	5	0	-33	1	2	-1	7	-1	-39
DB5	21	-9	-6	4	0	-35	4	2	-5	5	0	-41
DB6	-65	-1	-79	-5	2	-21	-18	2	-8	-10	2	-28
DB7	-4	3	22	-5	2	-35	-7	3	13	-6	2	-40
DB8	-10	-1	104	-3	4	-41	0	1	30	-5	5	-42
DB9	-57	-1	-54	4	1	-2	8	1	2	2	1	-5
DB10	-14	1	-11	3	-1	8	7	1	3	3	-1	9
DB11	10	3	4	-4	0	8	4	1	3	-4	0	9
DB12	43	-1	61	-5	3	-5	0	0	7	-4	3	-2
DB13	29	6	-5	1	-2	61	0	4	-21	3	-2	71
DB14	5	-7	-85	-3	3	78	-3	1	-10	-3	3	87

For DB1-DB2: X-Y is Shear Plane Z is Tension Direction

For DB3-DB14: X-Z is Shear Plane Y is Tension Direction

Table 8.12 - FWD panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	25	-6	-1	2	-14	-29	-1	63	10	3	-17	-33
DB2	78	121	-6	1	1	-61	-2	0	1	5	8	-71
DB3	68	173	3	1	-19	-58	-3	29	-4	5	-13	-68
DB4	208	35	-10	12	44	-77	10	125	-6	25	53	-90
DB5	-171	-17	-46	-7	-2	-23	-8	-3	-36	-17	-3	-29
DB6	1	5	-57	2	1	-10	1	-1	-1	2	1	-15
DB7	10	-3	36	0	1	12	0	1	13	1	1	16
DB8	-23	4	-35	4	39	-10	1	29	-1	4	46	-13
DB9	167	-310	10	-1	-10	-13	-3	26	-1	8	-29	-15
DB10	187	-247	-10	-4	-16	-40	-5	26	-15	6	-32	-47
DB11	-18	-19	-233	-1	-1	-32	0	5	90	-2	-3	-51
DB12	84	-17	-254	-2	0	-29	-1	0	43	2	-1	-48
DB13	81	-17	-263	-2	0	-19	-1	0	-1	3	-1	-37
DB14	49	23	-294	0	2	-9	0	4	-37	2	3	-27
DB15	15	20	144	1	-6	-21	-1	12	46	2	-6	-17
DB16	14	162	281	2	-3	-9	2	22	35	3	5	5
DB17	-6	-389	9	-1	-4	-6	0	18	5	-1	-26	-6
DB18	48	-165	8	-2	14	-19	-3	19	-6	1	7	-22
DB19	-10	47	92	-2	-13	-39	0	14	26	-3	-13	-40
DB20	-3	14	18	-4	-13	-33	-6	10	9	-5	-14	-37
DB21	51	81	210	-1	0	-8	1	9	15	1	5	3
DB22	-103	-15	-7	16	9	-12	16	15	4	14	10	-15
DB23	-23	-22	-10	4	9	-15	3	19	-4	4	9	-18
DB24	69	14	132	-5	3	-6	0	1	-2	-2	4	1
DB25	-62	-21	-78	-4	-6	-20	-17	2	-10	-9	-8	-28
DB26	45	194	237	-3	-8	-22	0	25	18	0	5	-12
DB27	-47	-8	2	12	2	-6	12	3	0	11	2	-7
DB28	1	1	2	-8	2	0	-7	3	0	-9	2	0
DB29	7	1	70	-2	0	-28	-2	1	-4	-2	0	-29
DB30	-41	3	1	1	0	-8	0	3	6	-2	0	-9
DB31	9	152	192	1	-13	-20	2	10	9	1	-7	-13
DB32	34	-2	23	-8	-1	3	0	0	3	-7	-1	5
DB33	40	0	101	0	0	-16	1	1	-1	2	0	-13
DB34	13	-2	118	0	1	5	0	1	13	1	1	12
DB35	13	2	102	0	0	3	0	1	14	0	0	9
DB36	4	1	69	-1	0	3	0	0	15	0	0	7
DB37	-17	3	29	0	0	-4	0	-3	10	-1	0	-3
DB38	41	2	-71	1	1	-15	3	12	-2	3	1	-21
DB39	82	4	-67	-1	1	-24	4	23	-10	3	1	-32
DB40	92	4	-73	-5	0	-30	3	26	-21	-1	0	-39
DB41	-85	-34	-14	3	7	-16	-1	4	0	-1	6	-19
DB42	-41	17	-23	3	0	-19	1	-6	0	1	1	-24
1	0	-18	105	0	7	94	0	-96	-318	0	8	116
2	0	-15	70	0	-3	99	0	-93	-312	0	-4	119
3	0	38	115	0	-3	69	0	-61	-186	0	-1	87
4	0	42	83	0	-2	71	0	-95	-211	0	0	87
5	0	53	-370	0	15	216	0	-72	225	0	20	232
6	0	98	-322	0	-10	227	0	-95	249	0	-6	247
7	0	-21	-268	0	-9	165	0	-107	168	0	-11	178
8	0	-25	-199	0	0	163	0	-90	162	0	-2	179

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
9	-61	0	112	0	0	-44	181	23	0	-3	0	-45
10	-61	0	112	0	0	-44	-181	23	0	-3	0	-45
11	-74	0	112	0	0	-44	181	23	0	-4	0	-45
12	-74	0	112	0	0	-44	-181	23	0	-4	0	-45

Z-Y is Shear Plane X is Tension Direction

Table 8.13 - Closeout panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	85	34	14	-3	-7	16	1	-4	0	1	-6	19
DB2	41	-17	23	-3	0	19	-1	6	0	-1	-1	24
DB3	74	11	-15	2	6	2	-1	-3	-3	6	8	2
DB4	90	-27	-22	4	1	-19	1	-8	3	10	-1	-23

For DB1-DB2: X-Y is Shear Plane Z is Tension Direction

For DB3-DB4: X-Z is Shear Plane Y is Tension Direction

Table 8.14 - Shelf panel 8

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-18	-11	-1	-2	6	6	2	-2	0	-3	7	7
DB2	-3	-25	-6	-8	10	14	-5	-2	-4	-10	10	16
DB3	103	15	7	-16	-9	12	-16	-15	-4	-14	-10	15
DB4	23	22	10	-4	-9	15	-3	-19	4	-4	-9	18
DB5	-18	0	-8	-4	1	17	5	2	5	-6	1	19
DB6	-8	-1	-14	43	1	-28	16	6	-10	50	1	-34
DB7	10	0	12	-8	0	24	1	1	9	-8	0	29
1	-18	0	30	0	0	-9	1	6	-5	-1	0	-9
2	-18	0	31	0	0	-9	-1	6	5	-1	0	-8
3	-18	0	-31	0	0	-16	1	6	-5	-1	0	-20
4	-18	0	-30	0	0	-15	-1	6	5	-1	0	-19

X-Y is Shear Plane Z is Tension Direction

Table 8.15 - Divider panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	0	31	42	-3	-35	31	1	-14	6	-3	-39	39
DB2	8	70	19	0	-2	-6	1	-4	-8	1	2	-6
DB3	4	-45	-74	-2	38	69	-2	-3	-10	-2	41	76
DB4	30	-5	-6	0	25	57	1	-5	-20	2	29	66
DB5	20	-50	-21	2	3	-11	-1	2	-1	3	0	-14
DB6	35	-80	-8	4	-1	-19	3	5	0	6	-6	-22
DB7	-5	-49	-9	-3	-5	-10	-2	17	5	-4	-8	-12
DB8	3	-62	-20	0	-3	-35	2	6	-5	1	-7	-42
DB9	-6	4	-1	-9	0	3	-5	2	0	-11	1	3
DB10	12	1	33	-1	-1	21	-1	5	18	-1	-1	27
DB11	36	2	45	-1	0	16	-3	4	12	0	0	21
DB12	-21	5	0	1	1	-8	3	9	0	0	2	-9
DB13	-1	10	34	3	-1	-6	-1	1	1	3	-1	-5

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB14	-37	-1	0	4	-2	-8	3	0	-2	3	-2	-10
DB15	14	65	-24	0	2	-2	0	-26	-2	1	7	-3
DB16	4	73	-34	0	6	-17	0	-30	1	0	11	-22
DB17	-3	25	7	11	-10	-14	7	2	4	13	-11	-16
DB18	28	16	0	2	-7	-6	-4	1	0	4	-7	-6
DB19	18	-3	-1	-1	0	-6	0	4	-6	0	0	-7
DB20	29	7	-4	-4	-4	-4	-5	-1	0	-3	-4	-5
DB21	32	-2	20	-4	-1	14	-1	0	6	-3	-1	17
DB9	-11	-1	2	0	-1	-6	0	2	0	-1	-1	-7
DB9	-45	-10	-1	1	-4	-16	5	3	0	-1	-5	-19

Y-Z is Shear Plane X is Tension Direction

Table 8.16 - Work surface panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	42	4	62	-4	3	-5	0	1	6	-3	3	-3
DB2	11	1	4	-4	2	7	4	1	3	-4	3	9
DB3	-13	1	-12	3	0	8	7	0	3	3	0	9
DB4	-56	-1	-55	4	-1	-2	8	0	2	2	-1	-5
DB5	-83	-1	-49	-38	-1	-71	-18	6	-27	-48	-1	-86
DB6	-4	-77	33	0	-6	17	0	31	-1	0	-11	21
DB7	-14	-70	24	0	-2	2	0	27	2	-1	-6	3
DB8	-175	-157	3	0	-3	15	6	-46	1	-9	-12	17
DB9	-4	-218	-16	-1	-2	6	-4	-14	0	-1	-15	6
DB10	6	389	-9	1	4	6	0	-18	-5	1	26	6
DB11	-48	165	-8	2	-14	19	3	-19	6	-1	-7	22
DB12	-66	-107	4	-3	-5	13	9	-13	0	-7	-12	16
DB13	-64	-193	-14	-2	-4	16	-1	-12	-2	-6	-16	17
DB14	-167	310	-10	1	10	13	3	-26	1	-8	29	15
DB15	-187	247	10	4	16	40	5	-26	15	-6	32	47
DB16	464	-95	1	10	1	2	-10	2	-4	37	-4	2
DB17	441	-93	12	5	2	2	-5	6	-2	30	-3	4
DB18	337	-104	13	0	0	1	-3	8	-3	18	-5	1
DB19	-68	2	10	11	1	14	0	-2	4	9	1	17
1	-63	-24	-32	-4	-1	-5	-2	0	0	-8	-2	-7
2	-70	9	-12	1	2	-2	-1	0	0	-3	2	-3
3	-51	0	13	8	2	-3	-1	0	0	6	2	-3
4	-30	14	30	8	-3	-6	0	0	0	7	-3	-6
5	-2	3	-8	0	0	0	0	1	-2	0	0	0
6	-2	0	0	0	0	0	0	1	-2	0	0	0
7	-2	-3	8	0	0	0	0	1	-2	0	0	1
8	-7	3	-8	0	0	-6	0	1	2	0	0	-8
9	-7	0	0	0	0	-6	0	1	2	0	0	-7
10	-7	-3	8	0	0	-6	0	1	2	0	0	-7
11	-3	2	0	0	0	0	0	13	0	-1	0	0
12	-3	2	0	0	0	0	0	13	0	-1	0	0
13	-2	-4	0	0	0	0	0	11	0	0	-1	0
14	-2	-4	0	0	0	0	0	11	0	0	-1	0

X-Y is Shear Plane Z is Tension Direction

Table 8.17 - Aisle Panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB2	212	19	47	7	2	23	8	3	36	20	3	29
DB3	-88	-3	85	5	0	30	-3	-26	21	1	0	39
DB4	-92	-3	98	1	-1	24	-4	-23	10	-4	-1	34
DB5	-60	1	136	-1	-1	15	-3	-12	2	-4	-1	25
DB6	-15	-10	147	-2	-1	10	-1	1	1	-3	-2	20
DB7	35	5	-17	-11	-1	-14	0	2	-4	-10	0	-17
DB8	22	-13	-21	0	0	4	0	3	-10	1	0	3
DB9	-13	-5	-139	1	0	-3	0	0	-15	0	0	-11
DB10	-27	-2	-202	0	0	-3	0	-1	-14	-1	0	-15
DB11	-37	7	-209	0	-1	-5	0	-1	-13	-2	0	-17
DB12	-31	8	6	0	-1	-12	0	-1	-13	-2	-1	-14
DB13	86	-4	-23	1	2	-5	-4	-1	-3	6	2	-8
DB14	24	7	25	3	0	-4	-2	-2	1	5	0	-3
DB15	-14	19	73	1	0	-3	2	-1	3	0	1	0
DB16	2	12	14	-3	0	0	6	-1	1	-3	0	1
DB17	-7	3	-1	1	0	7	1	-1	-3	1	0	8
DB18	56	-33	-8	4	1	-1	-1	1	0	7	-1	-1
DB19	54	-11	9	-3	0	0	0	1	0	0	-1	0
DB20	-34	3	-2	-4	0	-2	1	0	0	-6	1	-2
DB21	34	-3	2	4	0	2	-1	0	0	6	-1	2
DB22	-54	11	-9	3	0	0	0	-1	0	0	1	0
DB23	-56	33	8	-4	-1	1	1	-1	0	-7	1	1
DB24	82	-41	-1	-3	1	1	0	0	0	1	-1	2
1	-108	-9	72	5	0	1	-1	-11	2	0	0	5
2	-47	2	82	4	0	1	-1	-3	3	2	0	6
3	33	5	47	0	0	-1	0	2	0	2	0	2
4	48	5	15	-1	0	-2	1	6	-2	1	0	-2
5	41	4	-9	-1	0	-4	1	6	-3	1	0	-5
6	29	3	-11	-1	0	-3	1	6	-1	0	0	-4
7	27	2	-10	-1	0	-2	1	5	-2	0	0	-3
8	32	2	-24	-1	0	-3	0	7	-4	1	0	-5
9	32	2	-40	-2	0	-5	-1	12	-2	-1	0	-8
10	15	2	-61	-2	0	-4	-1	12	2	-2	0	-8
11	-55	-8	-59	-2	0	-4	-2	6	5	-5	-1	-8
12	-46	-7	-13	1	0	-2	0	0	2	-2	-1	-3
13	-25	-4	-7	2	0	-1	2	-7	1	1	0	-1

X-Z is Shear Plane Y is Tension Direction

Table 8.18 - AFT panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-3	14	185	-2	0	-21	0	-1	-9	-2	1	-14
DB2	9	-1	175	1	-1	-19	0	1	-11	2	-1	-12
DB3	13	0	173	1	0	-12	0	2	-18	2	0	-4
DB4	16	-2	177	1	0	-4	0	2	-23	2	0	5
DB5	11	-35	192	0	-1	2	-1	6	-23	1	-3	13
DB6	6	48	138	0	0	-7	1	-12	-39	0	3	0
DB7	19	-14	-3	3	-8	-34	4	0	-6	5	-11	-40
DB8	20	-16	4	4	-16	-29	2	1	-1	6	-19	-34
DB9	-49	35	47	6	-10	-21	0	0	-3	4	-10	-22
DB10	24	-163	-231	1	-1	-8	0	-8	-15	2	-10	-22
DB11	39	-116	-208	0	0	-6	1	-7	-17	2	-7	-18
DB12	49	-71	-193	-1	3	-3	2	-2	-20	1	0	-15
DB13	14	-56	-42	1	-6	-16	1	-2	-5	2	-11	-21
DB14	-9	-37	-41	1	-11	-13	0	-4	-4	1	-15	-18
DB15	-3	-102	-36	3	7	-4	2	2	-3	4	3	-7
DB16	-36	15	2	3	-1	-1	0	0	0	2	-1	-2
DB17	4	-2	32	-1	0	-7	-1	1	3	-1	0	-6
DB18	47	9	17	-9	16	-85	-5	23	1	-7	19	-98
DB19	-23	1	2	-1	-1	-6	-1	0	0	-3	-1	-7
DB20	-7	-10	-37	-2	-1	-3	3	1	2	-3	-1	-6
DB21	20	-6	0	-3	2	-12	-7	12	0	-2	2	-14
DB22	66	-1	12	-3	10	-4	-1	4	1	0	11	-4
DB23	64	109	-5	2	5	-13	-9	12	0	6	12	-16
DB24	64	195	14	2	4	-16	1	12	2	6	15	-17
DB25	12	-78	11	-5	-40	-65	2	-53	3	-6	-51	-75
DB26	45	194	2	-3	-12	-44	1	-55	2	-3	-17	-51
DB27	4	-39	22	-4	11	-57	1	-60	-2	-5	10	-65
DB28	175	159	-3	0	3	-14	-6	45	-1	10	12	-17
DB29	4	220	15	1	2	-6	4	13	0	1	15	-6
DB30	-9	37	14	-8	1	-10	-3	5	0	-9	4	-11
DB31	57	55	11	-5	-3	-11	3	6	1	-3	-1	-12
DB32	74	40	5	-5	0	-16	2	8	0	-2	3	-18
DB33	-7	27	18	6	-6	-37	4	8	-7	7	-5	-42
DB34	-22	33	9	3	6	-15	1	16	5	2	9	-17
DB35	-116	52	2	-6	7	-2	-5	15	2	-14	11	-2
DB36	10	0	0	12	0	-19	0	5	0	15	0	-22
DB36	1	1	0	-3	3	-8	0	5	0	-4	4	-9
DB36	-11	6	0	-3	3	4	-2	4	0	-4	4	4
1	9	-58	-74	1	8	2	0	3	-2	2	6	-1
2	17	-45	-37	1	8	-4	0	2	-4	2	7	-7
3	26	-15	-116	1	2	2	0	1	-2	2	1	-5
4	24	-8	-65	2	1	-5	0	0	-4	3	1	-10
5	-61	0	-112	0	0	-46	181	23	0	-3	0	-60
6	-74	0	-112	0	0	-46	-181	23	0	-4	0	-60
7	-61	0	-112	0	0	-46	181	23	0	-3	0	-60
8	-74	0	-112	0	0	-46	-181	23	0	-4	0	-60
9	-4	-22	14	0	6	-5	1	1	2	-1	6	-5
10	0	-12	22	0	4	-8	0	-2	3	0	4	-8
11	0	-22	51	0	5	-26	0	-5	18	0	4	-28
12	0	-21	24	0	5	-26	0	-4	26	0	5	-30
13	-1	-10	17	0	-2	-24	0	5	27	0	-3	-28
14	-1	-20	36	0	14	-46	0	-9	52	0	15	-51
15	1	11	10	-1	-1	-26	1	8	30	-1	0	-30
16	-26	41	19	22	-21	-23	-21	35	30	24	-22	-26
17	-22	-8	-3	18	1	-7	-17	1	9	20	1	-8

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
18	0	-3	0	0	1	-7	0	-1	8	0	1	-8
19	46	81	-58	50	57	-50	44	96	-51	61	71	-62
20	-5	14	-53	-5	1	-49	-4	19	-50	-6	2	-60
21	0	-14	-105	0	-31	-96	0	-13	-102	0	-37	-118
22	0	-7	-56	1	-19	-50	1	-10	-53	1	-23	-62
23	-1	-5	-10	-1	-11	-5	-1	-7	-8	-1	-13	-7
24	-1	-27	-9	0	-22	-24	0	-18	-3	0	-28	-29
25	-1	-17	-7	-1	-3	-19	-1	1	-1	-1	-4	-23
26	-3	-5	-6	-1	5	-15	-2	19	-1	-2	5	-18
27	10	-1	-17	12	-2	-13	10	3	-11	15	-3	-16
28	2	-3	-27	2	-4	-23	1	-2	-20	2	-4	-29
29	-2	42	7	0	2	-8	-2	20	4	0	5	-9
30	0	25	2	0	-3	-14	0	4	1	0	-2	-16
31	-1	0	-9	0	-20	-28	0	-16	-1	0	-23	-33
32	1	-3	-7	1	-10	-10	1	-5	-6	1	-12	-12
33	-1	-12	-62	-1	-20	-58	-1	-9	-55	-1	-24	-71
34	0	-24	-119	0	-31	-102	0	-10	-108	0	-38	-126
35	4	5	-63	5	3	-52	4	24	-56	6	4	-65
36	-55	77	-57	-53	57	-49	-45	105	-53	-65	71	-60
37	-15	7	-4	-14	-2	-10	-12	5	-6	-17	-2	-12
38	-1	1	-16	-2	-3	-22	-1	0	-17	-2	-3	-27
39	20	70	39	-22	-21	-21	24	35	26	-25	-21	-22
40	-1	30	35	1	-5	-18	-1	10	24	1	-4	-19
42	-1	9	64	0	11	-47	0	-6	57	0	14	-51
42	0	2	27	0	9	-24	0	-5	26	0	11	-27
43	0	-2	21	0	7	-28	0	-2	26	0	8	-32
44	1	-10	7	0	7	-31	0	-2	18	0	8	-35
45	-1	-15	2	0	5	-9	0	0	3	0	5	-10
46	-5	-23	3	1	8	-6	0	1	1	0	8	-7
47	15	-2	12	-18	2	-6	18	0	6	-20	3	-7
48	0	-2	12	0	2	-7	0	0	6	0	2	-7
49	-12	0	0	-4	0	-8	3	4	0	-5	0	-9
50	-10	0	0	-4	0	-7	-3	4	0	-5	0	-8
51	-12	0	0	4	0	-8	3	4	0	4	0	-9
52	-10	0	0	4	0	-7	-3	4	0	4	0	-8
53	-37	4	-39	-4	-1	4	-1	-13	-2	-6	-1	3
54	-12	0	-27	-2	0	5	1	-7	-3	-3	0	4
55	9	-4	-17	0	0	4	1	-1	-3	0	0	4
56	13	-3	-2	0	0	1	0	5	-1	1	0	1
57	12	-2	7	0	0	-2	0	7	-1	1	0	-2
58	9	-1	7	1	1	-3	0	9	-2	1	1	-3
59	5	0	8	1	0	-5	0	8	-2	1	0	-5
60	4	0	6	1	0	-4	-1	7	-2	1	0	-5
61	5	0	9	1	0	-8	-1	13	-2	2	0	-9
62	5	-1	12	2	0	-12	-2	16	1	3	0	-14
63	-4	-1	15	4	-2	-9	-1	9	7	4	-2	-10
64	-16	3	13	1	0	2	1	-3	7	0	0	3
65	-25	6	9	-4	1	2	2	-11	2	-5	2	2

Y-Z is Shear Plane X is Tension Direction

Table 8.19 - Outboard panel

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB1	-11	35	-192	0	1	-2	0	-6	23	-1	3	-13

Fastener	9G FWD			6.0G Down			3G Right			7.0G Down+0.5G FWD		
	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ	FX	FY	FZ
DB2	-16	2	-177	-1	0	4	0	-2	23	-2	0	-5
DB3	-13	0	-173	-1	0	12	0	-2	18	-2	0	4
DB4	-9	1	-174	-1	1	19	0	-1	11	-2	1	12
DB5	3	-14	-185	2	0	21	0	1	9	2	-1	14
DB6	211	-62	-14	1	0	-10	-13	1	-5	13	-3	-12
DB7	261	-47	-13	4	-3	-39	-16	2	2	20	-6	-46
DB8	263	-46	-2	7	-3	-44	-20	3	1	22	-7	-51
DB9	241	-15	29	4	1	-2	-29	3	-4	18	1	0
DB10	18	19	233	1	1	32	0	-5	-90	2	3	51
DB11	-84	17	254	2	0	29	1	0	-43	-2	1	48
DB12	-81	17	263	2	0	19	1	0	1	-3	1	37
DB13	-49	-23	294	0	-2	9	0	-4	37	-2	-3	27
DB14	17	-9	145	1	-1	-22	-1	1	47	2	-2	-17
DB15	-473	-9	20	-9	-3	-2	10	-1	3	-37	-4	-2
DB16	-451	-4	9	-5	-2	-3	6	-5	1	-31	-3	-3
DB17	-352	29	11	0	0	-1	5	-8	1	-19	2	0
DB18	-2	-18	-145	1	-1	6	-1	3	40	1	-2	-1
DB19	-34	37	279	0	-3	8	0	0	17	-2	-1	25
DB20	-40	3	237	1	-2	5	0	-2	18	-1	-2	19
DB21	-42	-33	205	3	-4	1	0	-7	19	1	-6	13
DB22	8	24	324	2	2	-10	1	4	41	2	3	6
DB23	54	-6	224	-2	3	-7	0	2	17	1	3	4
DB24	78	-26	124	-6	4	-4	-1	2	-1	-3	3	2
DB25	-20	-2	2	-1	1	-1	-3	1	1	-3	1	-1
DB26	16	0	-2	1	1	-1	2	1	0	2	1	-2
DB27	-17	9	68	0	-6	16	-1	-2	5	0	-7	22
DB28	9	2	55	-1	-1	17	0	0	5	0	-1	23
DB29	-1	4	-54	-10	47	1	-5	15	5	-12	55	-2
DB30	2	-40	-63	0	-3	6	0	-3	9	1	-5	4
DB31	57	45	344	-5	7	-21	-2	6	30	-3	11	-6
DB32	12	-13	245	0	4	-24	2	2	14	0	4	-15
1	44	3	-2	6	4	4	2	1	2	9	4	4
2	63	4	58	7	-1	-2	4	0	2	11	-1	0
3	92	10	116	3	-4	-7	5	-1	4	9	-4	-2
4	137	29	178	-3	-8	-12	7	-1	6	5	-8	-5
5	206	21	174	-7	-11	-17	10	-3	4	3	-12	-11
6	199	9	101	-1	-12	-21	14	-4	-2	9	-14	-19
7	158	2	21	-2	-7	-13	13	-2	-3	7	-8	-14
8	119	-5	-29	-3	-2	-5	11	-1	-2	3	-3	-7
9	59	-10	-53	-2	3	3	6	1	0	1	3	1

Y-Z is Shear Plane X is Tension Direction

9 ANALYSIS RESULTS

For the VCC module structure the requirement for maximum translation is 1.0 inches.

Deformation results:

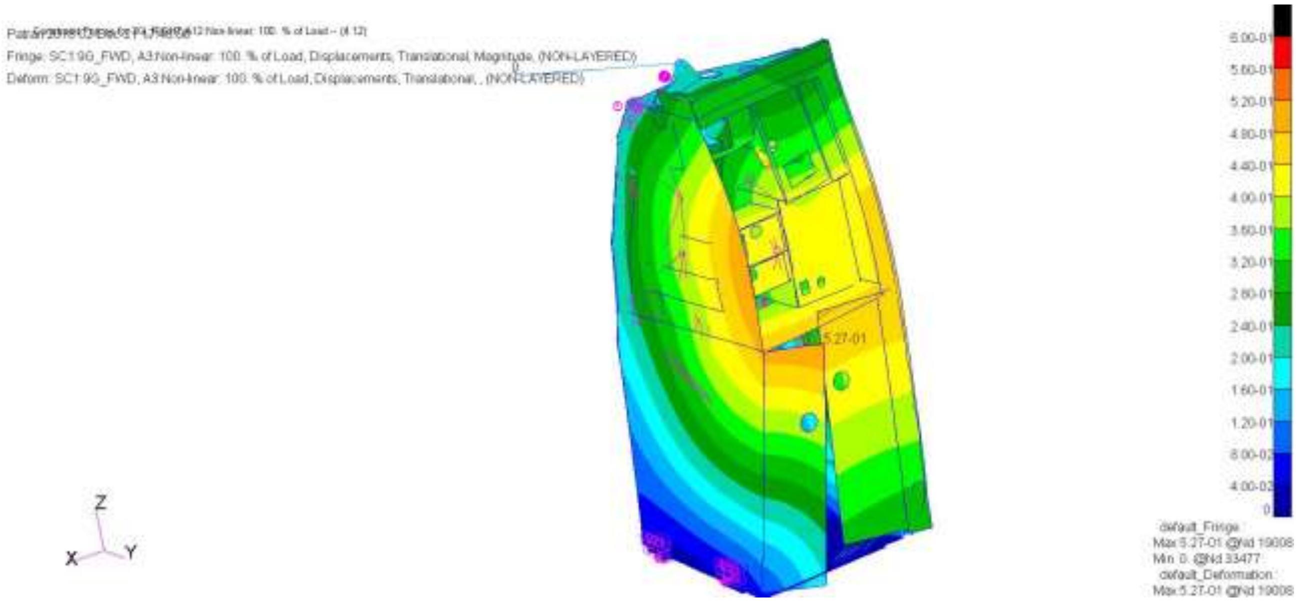


Figure 9.1 Total translation 9.0 G FWD LC

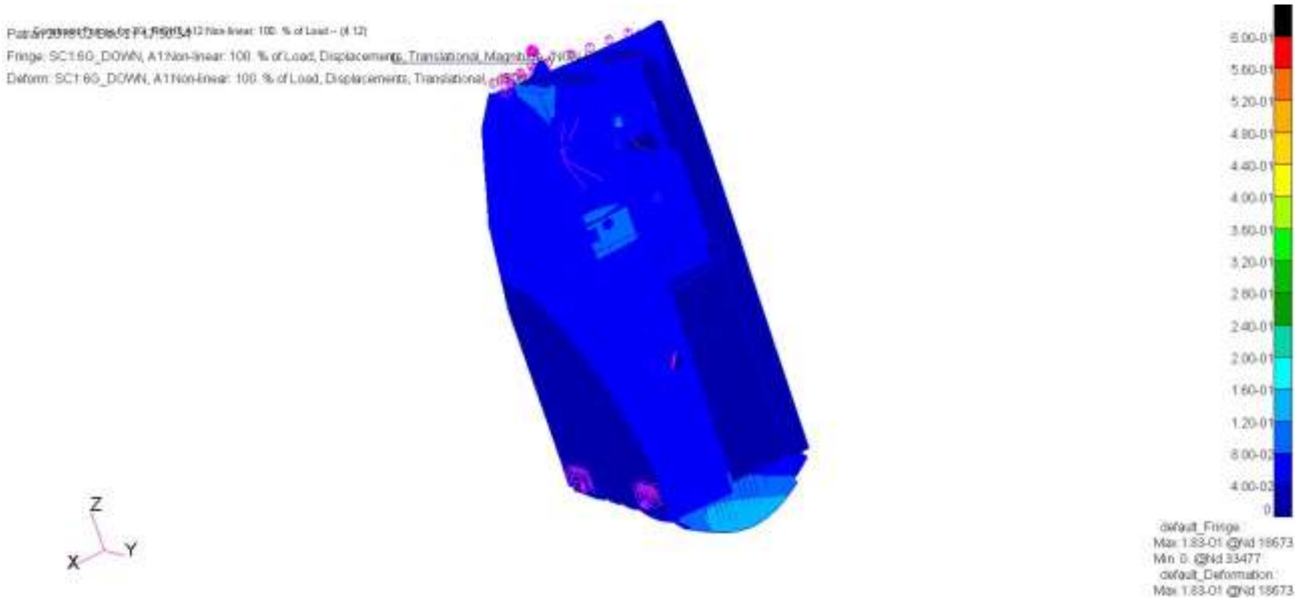


Figure 9.2 Total translation 6.0 G DOWN LC

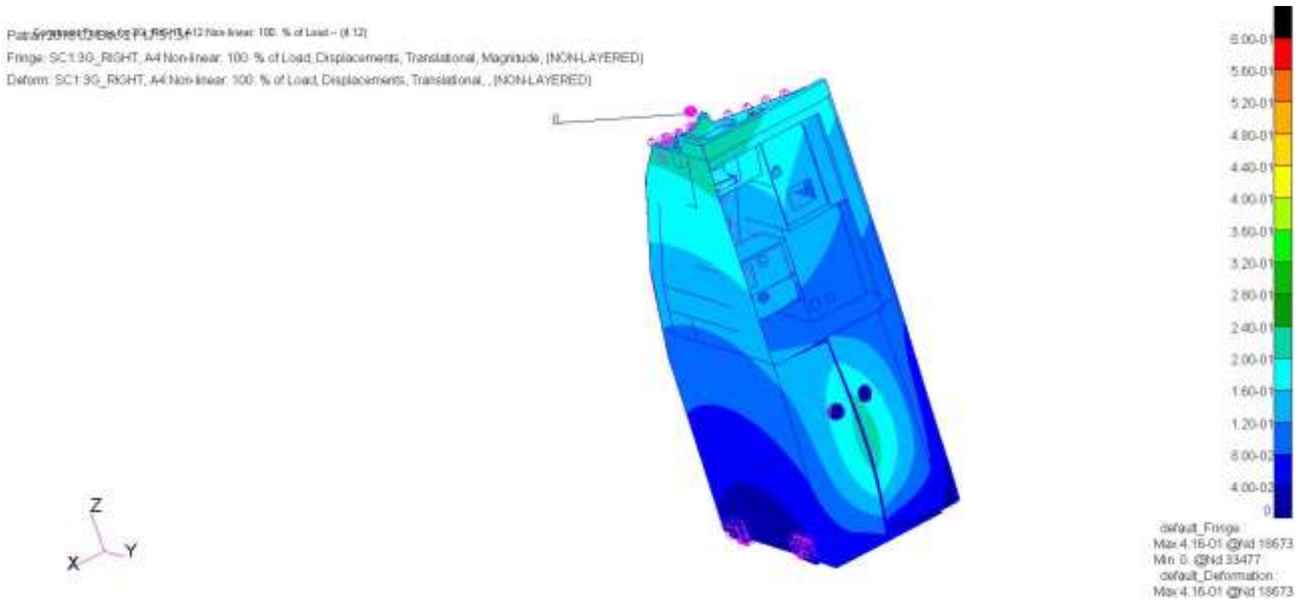


Figure 9.3 Total translation 3.0 G Right LC

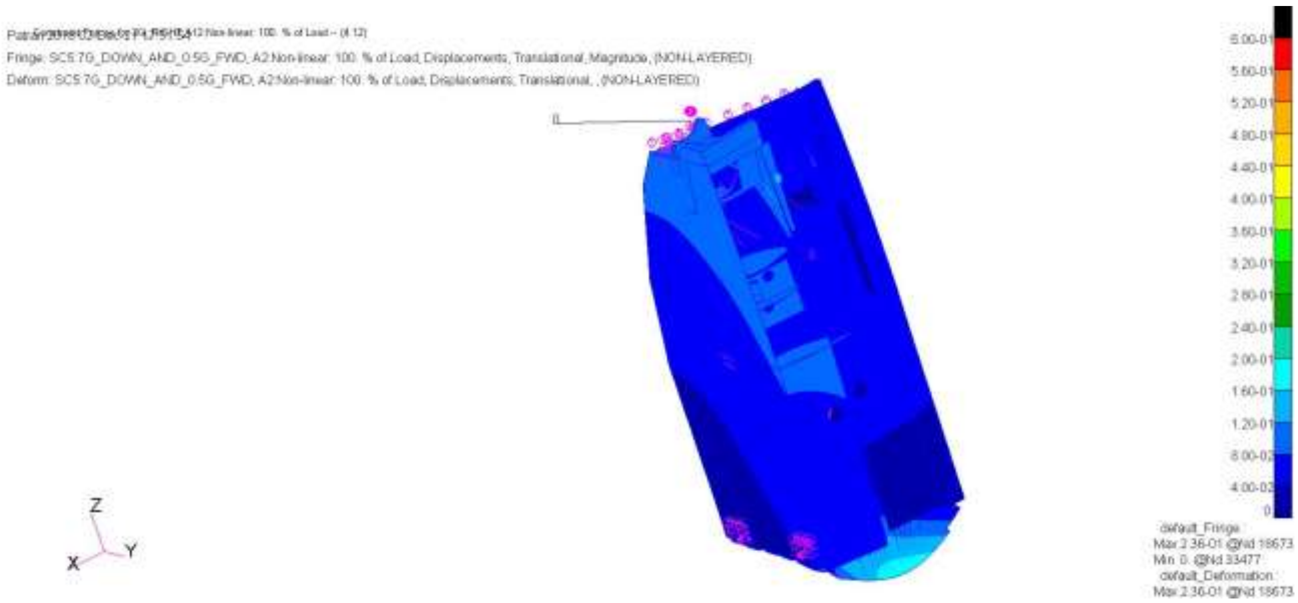


Figure 9.4 Figure Total translation 7.0 G Down+0.5 G FWD LC:

The maximum translation obtained from FEA analysis is 0.527 inches for 9.0G FWD Load case. Therefore, the requirement for the maximum translation requirement for the panel is met.

Example of element stress report:

As was noted in paragraph 8, the model of the composite panel consists of three layers. To calculate margins of safety for each panel and fasteners, results of stress tensor components (X, Y, Z, XY, XZ, and YZ) and loads of connecting nodes must be obtained.

Use PATRAN results report to obtain this data for each analyzed panel separately.

An example of the report for one element for 6.0 G Down LC is shown in Figure below:

```
-Source Id---Loadcase Name---------Subcase Name---------Layer Name----
      1     SC1:6G_DOWN           A1:Non-linear: 100. % of Load  Layer 1
              Global Variable: Percent of Load      =         100.
      2     SC1:6G_DOWN           A1:Non-linear: 100. % of Load  Layer 2
      3     SC1:6G_DOWN           A1:Non-linear: 100. % of Load  Layer 3


-Source ID--Entity ID--El. Pos. ID--X Component---Y Component---Z Component---XY Component--YZ Component--ZX Component-
       1    13807          0       -240.849564    123.222969      0.000000     53.040661     0.487861     -1.259035
       2    13807          0          0.000134     -0.000789      0.000000     -0.000280     0.487861     -1.259035
       3    13807          0        191.217743   -114.787857      0.000000    -49.235168    -0.000000      0.000000
```

Figure 9.5 Example of stress report

9.1 Panel margins of safety summary

Using Failure Criteria described in Paragraph 3.6 the following critical margins were obtained for each panel:

Table 9.1 Margin of Safety summary

Panels	Minimum MS	Frailer Mod	Critical LC
PANEL-AL SKIN,FLOOR	+1.79	Core Shear	7.0G Down + 0.5G Aft
PANEL-AFT	+0.08	Face sheet failure	9G Fwd
PANEL-OUTBD	+0.40	Face sheet failure	9G Fwd
PANEL-FWD	+0.29	Core Shear	9G Fwd
PANEL-CLOSEOUT	+0.67	Core Shear	9G Fwd
PANEL-HEADER/AISLE	+0.79	Face sheet failure	9G Fwd
PANEL-WORK SURFACE	+0.15	Core Shear	9G Fwd

Panels	Minimum MS	Frailer Mod	Critical LC
PANEL-SHELF 1	+1.83	Face sheet failure	9G Fwd
PANEL-DIVIDER	+1.46	Core Shear	9G Fwd
PANEL-SHELF 2	+1.77	Core Shear	7.0G Down + 0.5G Aft
PANEL-SHELF 3	+1.40	Face sheet failure	9G Fwd
PANEL-SHELF 4	+6.0	Core Shear	7.0G Down + 0.5G Aft
PANEL-SHELF 5	+0.54	Face sheet failure	9G Fwd
PANEL-SHELF 6	+4.96	Face sheet failure	3G Right
PANEL-AL SKIN CEILING	+0.04	Core Shear	9G Fwd
PANEL-PLENUM	+1.86	Face sheet failure	9G Fwd
PANEL-AL SKIN,PHONE	+High	-	-
PANEL-SHELF 7	+5.85	Face sheet failure	9G Fwd

Panels	Minimum MS	Frailer Mod	Critical LC
PANEL-SHELF 8	+1.63	Face sheet failure	9G Fwd

NOTE: +High means MS>+7.0

Additional shear analysis was performed for panels that have bent cutouts (Outboard panel, closeout). All shear check shows MS=+High. See appendix.

9.2 Inserts margins of safety

The analysis for inserts was performed for the combination of tension and shear loads.

MS calculated using the following equation [10]:

$$MS = \frac{1}{R_s + R_t} - 1$$

Where:

$$R_s = \frac{V_{applied}}{V_{Max}}$$

$V_{applied}$ - applied shear load, see paragraph 7.2

V_{Max} - allowable shear load for fastener, see paragraph 6

$$R_t = \frac{P_{applied}}{P_{Max}}$$

$P_{applied}$ - applied tension load, see paragraph 7.2

P_{Max} - allowable tension load for fastener, see paragraph 6

The most critical case for the entire VCC structure is:

The most critical fastens for each panel is shown in Table 9.2.

Table 9.2 Joints margins of safety summary

Panels	Minimum MS	Insert P/N	Critical LC
PANEL-AL SKIN, FLOOR	+3.08	3A3	7.0G Down + 0.5G Aft
PANEL-AFT	+0.22	3A3	3G Right

Panels	Minimum MS	Insert P/N	Critical LC
PANEL-OUTBD	+0.17	34A3	9G FWD
PANEL-FWD	+0.11	3A3	9G FWD
PANEL-CLOSEOUT	+0.35	K550	9G FWD
PANEL-HEADER/AISLE	+1.18	3A3	9G FWD
PANEL-WORK SURFACE	+0.18	34A3	7.0G Down + 0.5G Aft
PANEL-SHELF 1	+1.83	K550	9G FWD
PANEL-DIVIDER	+0.32	K550	9G FWD
PANEL-SHELF 2	+1.18	3A3	7.0G Down + 0.5G Aft
PANEL-SHELF 3	+0.74	3A3	9G FWD
PANEL-SHELF 4	+0.85	3A3	7.0G Down + 0.5G Aft
PANEL-SHELF 5	+3.10	K550	9G FWD
PANEL-SHELF 6	+11.42	3A3	9G FWD
PANEL-AL SKIN CEILING	+0.22	3A3	9G FWD
PANEL-PLENUM	+3.19	550	9G FWD
PANEL-AL SKIN, PHONE	+6.86	3A3	7.0G Down + 0.5G Aft

Panels	Minimum MS	Insert P/N	Critical LC
PANEL-SHELF 7	+8.68	3A3	9G FWD
PANEL-SHELF 8	+0.59	K550	7.0G Down + 0.5G Aft

10 STARTUP PROJECT DEVELOPMENT

10.1 Description of the project idea

The section investigates the marketing study of a startup initiative, identifying prospects and the viability of its market launch.

Table 10.1 Description of the startup project

Project content	Areas of application	Benefits for users
Structural and finite element analysis of the composite courses.	Mechanical engineering, Education	1) Gain knowledge about structural analysis of the composite structure 2) Have the ability to perform the analysis

The proposed course allows customers to gain knowledge and obtain the ability to perform structural analysis of the composite panel using the Finite element method and in a short time have the ability to have a profit from the work. Additionally, mobile and desktop applications may be launched in the market.

10.2. Technology audit

The project's concept may be realized through field tests and statistical analysis. Table 10.2 compares the possible technical and economic advantages of this proposition to opponent No. 1. (www.solidprofessor.com as SP)

Table 10.2 Determination of strong, weak, and neutral characteristics of the project idea

№	Technical and economic characteristics of the idea	W	N	S
1	Expenses	SP	-	My Proj
2	Experience	My Proj	-	SP
3	Accessibility to the domestic consumer	-	My Proj	-

Table 10.3 Technological feasibility of the project idea

№	The idea of the project	The technology of its implementation	The presence of technology	Technology availability
1	Launch course in desktop and mobile for structural analysis of the composite structures	Good UI/UX design	yes	yes
		Access in all devices with or without the internet connection		
The selected technology can be implemented.				

According to market indications, we can assume that this project will be lucrative.

10.3. Analysis of market opportunities for launching a startup project

Determining market opportunities that may be utilized in project market implementation and market risks that may hamper project market implementation is challenging, given that diverse approaches to accomplishing the work are an aspect of the industry's long-term scientific growth. That is, evaluating the prospective market for a startup initiative is only conceivable in the long term, not based on obvious numerical market features. Let's look at the market potential for our project's execution. To begin, we will do a demand study, which will include demand availability, volume, and market development dynamics Table 10.4.

Table 10.4 Preliminary description of a potential startup project market

№	Market state indicators	Characteristics
1	Number of main players, units	4
2	Total sales, USD/ unit	15
3	Market dynamics	increase
4	Sign-in restrictions	Absent
5	Specific requirements for standardization and certification	available
6	The average rate of return in the industry,%	100%

According to the indicators of the state of the market, we can conclude that this project is profitable.

10.4 Identification of potential customer groups

Primary and secondary consumers are the two main categories of potential customers. The major category is the domestic students and engineers with working experience. We will identify possible client groups in the future, as shown in Table 10.5.

Table 10.5 Characteristics of potential clients of a startup project

№	The need that shapes the market	Target audience	Differences in the behavior of different potential target customers	Consumer requirements for the product
1	High-quality education courses for engineers	Domestic students of mechanical engineering and engineers	Finances	Simple access and practical orientation

Given the competitive climate, there is a chance to work in this industry. To be market competitive, a project must-have features such as computation speed and software availability.

Determine and justify the list of competitiveness criteria based on the competition study and take into account the peculiarities of the project's idea, customer needs for the table, and marketing environment variables. Table 10.6 formalizes the analysis.

Table 10.6 Rationale for competitiveness factors

№	Competitiveness factor	Rationale (citing factors that make the comparison of competing projects meaningful)
1	Less price	Using the subscription model
2	Better explanation	Hire more experienced teachers
3	Easy access	Design application

Table 10.7 will examine the strengths and weaknesses of my startup project based on the specified competitiveness variables.

The compilation of SWOT analysis (Strength and Weak matrices, Troubles and Opportunities on the basis of chosen market threats and opportunities, and strengths and weaknesses) is the last step of the market study of project implementation opportunities Table 10.7

Table 10.7 Comparative analysis of strengths and weaknesses "Design of metal-composite compound structure by means of manual calculations”

№	Competitiveness factor	Points 1-20	Competitive rating of products compared to the project "Design of metal-composite compound structure by means of manual calculations "						
			-3	-2	-1	0	1	2	3
1	Less price	20						•	
2	Better explanation	20			•				
3	Easy access	15					•		

The list of market risks and opportunities is prepared based on an examination of threat elements and marketing environment aspects. Market dangers and opportunities are the outcomes of events that have not yet been manifested in the market but are anticipated to occur.

Based on the SWOT analysis, market behavior choices for introducing a startup project to market are produced, as well as an approximate best date for market implementation in light of prospective rivals' projects that may be launched. The alternatives suggested are evaluated in terms of timing and the possibility of getting funding Table 10.8.

Table 10.8 Alternatives to market introduction of a startup project

№	An alternative to market behavior	The probability of receiving resources	Terms of implementation
1	Public review, review of existing studies, state approval	high	2 months
2	Publication, validation of the present experiment, state approval	high	8 month

We will select the first option from the list above since collecting resources is easier and more likely, and the implementation time is shorter.

11. CONCLUSION

Video control center (VCC) Installation is structurally acceptable for stress and translation. The results of the analysis demonstrate all Margins of Safety are positive, indicating that the safety requirements are satisfied.

Therefore, the VCC structure meets the strength requirements while accounting for large overloads that may occur during an emergency landing.

The solution to this problem allowed us to establish an important practical conclusion: the suggested VCC structure may be fitted in an airplane by connecting it to the ceiling beams and floor structure of the aircraft. The generated finite element model may be used to calculate the strength of other structures of a similar design.

APPENDIX

REFERENCES

1. https://discovercomposites.com/what-are-composites
2. https://www.comsol.com/multiphysics/finite-element-method
3. ME 273 Lecture Notes © by R. B. Agarwal
4. Finite Element Procedures. Second Edition - Klaus-Jürgen Bathe -
5. https://www.flight-mechanic.com/sandwich-structures/
6. Baumeister, et al.: Mark's Standard Handbook for mechanical Engineers. 8th ed., McGraw-Hill, 1978.
7. User's Guide "MSC Nastran 2018.2 Documentation"
8. Учебное пособие "MSC.PATRAN в инженерных задачах", Яхно Б.О., Гладский М.Н. 3. Lecture Notes by R. B. Agarwal
9. Michael C.Y. Niu. Composite Airframe structures practical design information and data, 1992.
10. Michael C.Y. Niu. Atrframe stress analysis and syzing, 2nd ed, jan., 1999
11. Airworthiness Standards FAA CFR Part 25.
12. Бланк, С. Стартап. Настольная книга основателя / С. Бланк, Б. Дорф ; пер. с англ. Т. Гутман, И. Окунькова, Е. Бакушева. – 2-е изд. – Москва : Альпина Паблишер, 2014