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CERTIFICATION OF AIRCRAFT GALLEYS BY FINITE ELEMENT METHOD AND STATIC TEST

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ABSTRACT

In this study, design and certification of G1A galley equipment have been explained and detailed information about the structural certification stages have been given. Structural analysis certification of galley equipment started with design process. After the design process was completed, the galley was modeled by using the finite element method and the numerical results were obtained. Test stages consist of measuring the applying loads during the structural tests, deformations and upper attachment loads by using the load cells. After static tests were performed, these measurements were compared with the finite element analysis results. According to the test results of this study, the structural certification of G1A galley equipment has been validated.

INTRODUCTION

Aircraft galley equipments have started to be used in aircrafts. While there are many companies that manufacture galley equipments in the world, one of Turkey's firm has successfully carried out producing, designing, and certification stages. In this project, design and production works of G1A galley equipment have been explained and detailed information about the structural certification stages have been given. Structural analysis certification of galley equipment starts with design process. Design process is carried out by building the master geometry, panel designs, aircraft attachment designs, placing the equipment and structural improvements. After completing the design process, structural analysis and structural tests are performed. Completed design of G1A galley is shown Figure 1 [Ercan H., 2006; Florio F.D.P., 2011; Karasiray N.C., 2009; Kenarlıoglu Y., 2011].

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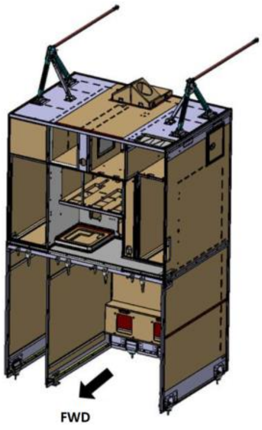

Figure 1: Structure of galley G1A

MATERIALS

One of the most common materials that are used in aircraft manufacturing are composite materials due to necessity of low weight and high strength materials. Honeycomb sandwich panels are the most common ones of composite materials that are used for galley equipment. This kind of composite structures have several material configurations. While there is structural factor such as strength, specific strength and adhesive performance that affect cell structure, surface and glue choice of honeycomb sandwich composite materials; there are also some environmental effects as fire proof, heat conduction, acoustic and humidity [Ercan H, 2006; Petras A, 1998].

Composite panels that were used in galley equipments consist of S-glass and honeycomb core materials. This material is named as Nomex. Thickness of composite panels used in galley are 10 mm and 22 mm. Core and Ply material properties of honeycomb is given in Table 1. Also, except honeycomb materials, aluminum and stainless steel were used in galleys [Onut A.E, 2016].

Table 1: Material properties of core and ply

Material Properties of PF808 Ply	
E_1 (Mpa)	18000
G_{12} (Mpa)	5000
G_{13} (Mpa)	1653
ν_{12}	0.22
Material Properties of C1-3.2-48 Core	
E_1 (Mpa)	0.20
G_{12} (Mpa)	0.16
G_{13} (Mpa)	42
G_{23} (Mpa)	25
ν_{12}	0.50
Al 6061 T651	
E (Mpa)	68250
ν	0.33
Stainless Steel	

E (Mpa)	194000
ν	0.27

FINITE ELEMENT MODEL OF GALLEY

Forces from galley to aircraft must be known during emergency load condition. Therefore, reaction forces are calculated using finite element method and reserve factors for beam of aircraft are calculated. Also, deformations and stress concentrations on galley are found using same method.

Finite element model was prepared, and mesh was done according to AM 2036 document, customize technical specification and CS- 25 requirements. For preparing finite element models, MSC Apex, Patran and Nastran softwares were used.

In this model, shell elements were used in composite panels. General mesh size for this model was 20 mm and the number of elements was 92406. Attachment and connection parts were modeled using Rbe 2, bar, rod and bush elements. Total number of these elements were 321.

Attachment Models

Attachment parts between aircraft and galley were designed according to aircraft requirements. Some of them are hardpoint, seat track and flutter point. Finite element model of these attachments was modeled using Patran according to aircraft requirements. For upper attachments, stiffness of bush elements is 15000 N/mm in each direction. For lower attachments, stiffness of bush element is 15000 N/mm in x and y direction, 5000 N/mm in z direction. Each attachment type has a special characteristic. For example, hardpoints are fixed in each direction. Flutter points are only fixed in y direction. Seat tracks are only free in z direction. Details are shown in Figure 2 and 3 [Onut A.E, 2016].

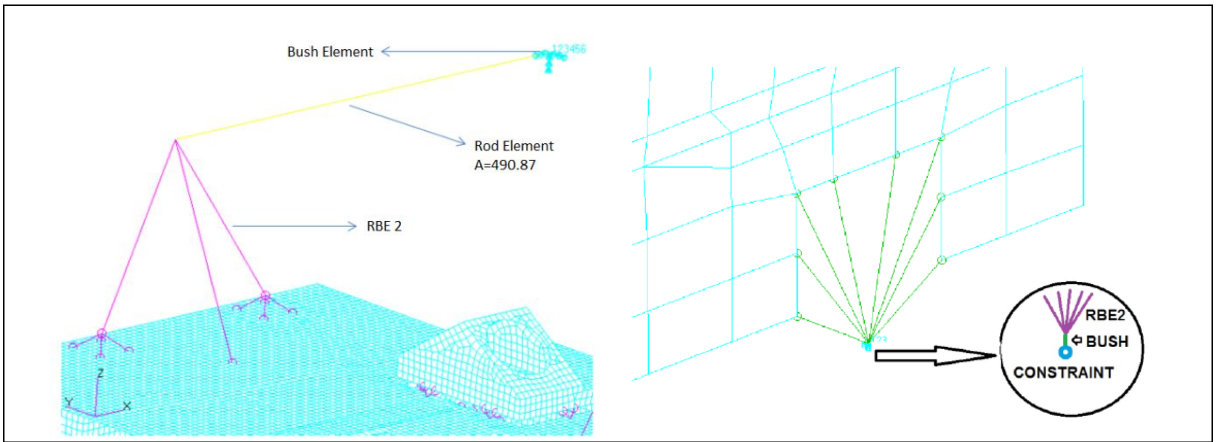

Figure 3: Lower and upper attachment models

Load Application Methods

According to airlines companies, configuration of galley is determined, and design of configuration was completed according to this request.

In this study, 9 G forward case was performed. Necessary loads were calculated according to insert configuration (oven, water boiler, F/S card, etc.) and center of gravity of inserts. Configurations are shown in Table 2. These loads were identified by using nodal force and point weight in Patran software. Inserts have mechanical connections connected to galley using RBE 3 elements as shown in Figure 4. Point forces were modeled as nodal forces [Onut A.E, 2016].

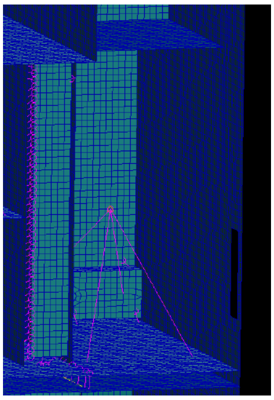

Figure 4*:* Point mass model

Table 2*:* Load application methods

Configuration	Load application	Method
Standard Units	Force	Nodal
Stowage Compartmens	Force	Nodal / RBE 3
Oven Compartments	Point Weight	RBE 3
Water Boiler	Point Weight	RBE 3
Coffee Maker	Point Weight	RBE 3
Hot cup	Point Weight	RBE 3
F/S Compartment	Force	Nodal
Structural Weight	Density	Gravity

Boundary Conditions

Loads and materials were defined in finite element model, boundary conditions were defined on attachment locations. Boundary conditions on lower attachment are fixed in translation x, y and z direction, while boundary limits on upper attachment are fixed in all translation and rotational directions. All boundary conditions in G1A galley are shown in Figure 4 [Onut A.E, 2016].

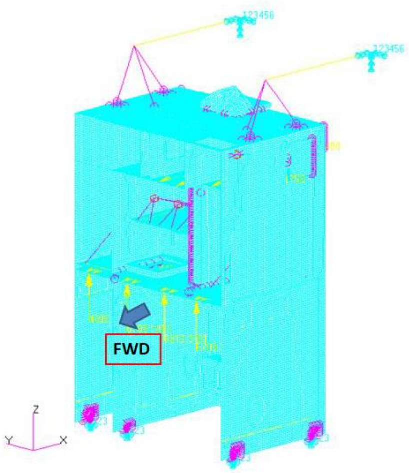

Figure 4*:* Boundary conditions on G1A galley

Model Check

Because of model geometry, some element geometries have not been in element quality limits in Nastran software. They are named as fail elements. Although fail elements are not in the quality limits, solution of whole geometry is continued. But they have effect on load distribution. Because of this effect, fail elements are removed [Schaeffer H.G, 2001].

For quad elements, geometric parameters (like aspect ratio, skew, taper and warping) must be in quality limits in Nastran software. For tria elements, two of geometric parameters (aspect ratio and skew) must be in quality limits. Nastran limits for element fail are shown in Table 3 [Schaeffer H.G, 2001].

Table 3*:* Nastran element fail limits

Qulity parameters	**Nastran limits**
Aspect Ratio	5
Max. Warping Factor	0.05
Max. Taper Ratio	0.5
Min. Quad Skew	30
Max. Quad Angle	30
Min. Quad Angle	150
Max Tri Angle	160
Aspect Ratio	5

Material orientation must be checked in finite element model when composite materials are defined. After material orientation was checked in Patran software, composite materials were defined correctly [Schaeffer H.G, 2001].

Another check procedure is load-balance. Applied force came with 9 G forward case must be same with reaction forces calculated from attachments. After reaction forces were calculated using finite element method, sum of reaction forces was 66601 N. It is same with applied force [Schaeffer H.G, 2001].

Results

Reaction forces were calculated from attachments by using finite element method. According to aircraft requirement, allowable force was defined for each aircraft beam for each translational direction. Generally, reserve factors for hardpoint attachment is calculated as below Equation 1 and 2 [Onut A.E, 2016].

$$RF_x = \frac{F_x}{F_{xmax}} \quad RF_y = \frac{F_y}{F_{ymax}} \quad RF_z = \frac{F_z}{F_{zmax}} \tag{1}$$

$$RF_{xy} = \frac{1}{\sqrt{\frac{1}{RF_x^2} + \frac{1}{RF_y^2}}} \tag{2}$$

For flutter point attachment types, they are only fixed in translational y direction. Therefore, reserve factor was only calculated for translational y direction.
For Upper Attachments, all reserve factors were calculated. Additional reserve factor must be calculated and this one is shown in Equation 3.

$$RF_{xyz} = \frac{1}{\sqrt{\frac{1}{RF_x^2} + \frac{1}{RF_y^2} + + \frac{1}{RF_z^2}}} \quad (3)$$

In G1A Galley, reaction forces for each attachment was calculated and listed in Table 4. According to this result, Reserve factors were calculated and listed in Table 5 [Onut A.E, 2016].

Table 4*:* Reaction force results

Attachment no	F_x (N)	F_y (N)	F_z (N)
1	-8522	-428	-6692
2	-11178	2192	11401
3	-6678	635	7669
4	494	-1502	7564
5	-11782	-1279	10204
6	-8436	446	-5219
7	0	-64	0
20	-9302	0	0
21	-11197	0	0
Sum	66601	0	24927

Table 5*:* Reserve factor results

Attachment no	RF_x (N)	RF_y (N)	RF_z (N)	RF_{xy} (N)	RF_{xyz} (N)
1	1.40	28.03	2.80	1.39	-
2	1.07	5.47	1.64	1.05	-
3	1.79	18.89	2.45	1.78	-
4	24.28	7.98	2.48	7.58	-
5	1.01	9.38	1.84	1.00	-
6	1.42	26.90	3.60	1.41	-
7	-	79.95	-	-	-
20	2.90	-	-	-	1.70
21	2.41	-	-	-	1.55
Sum	66601	0	24927		

According to finite element results, some locations on galley were determined as critical locations for deformation. Therefore, deformation values on these critical locations were taken from Nastran software and listed in Table 6. Also, Deformation results on Galley G1A are shown in Figure 5 [Onut A.E, 2016].

Table 6*:* Deformation results

Direction	Location A (mm)	Location B (mm)	Location C (mm)	Location D (mm)
X	-3.35	-4.45	-11.52	-11.04
Y	1.12	0.49	0.32	-3.00

Z	3.69	5.05	-0.28	0.98

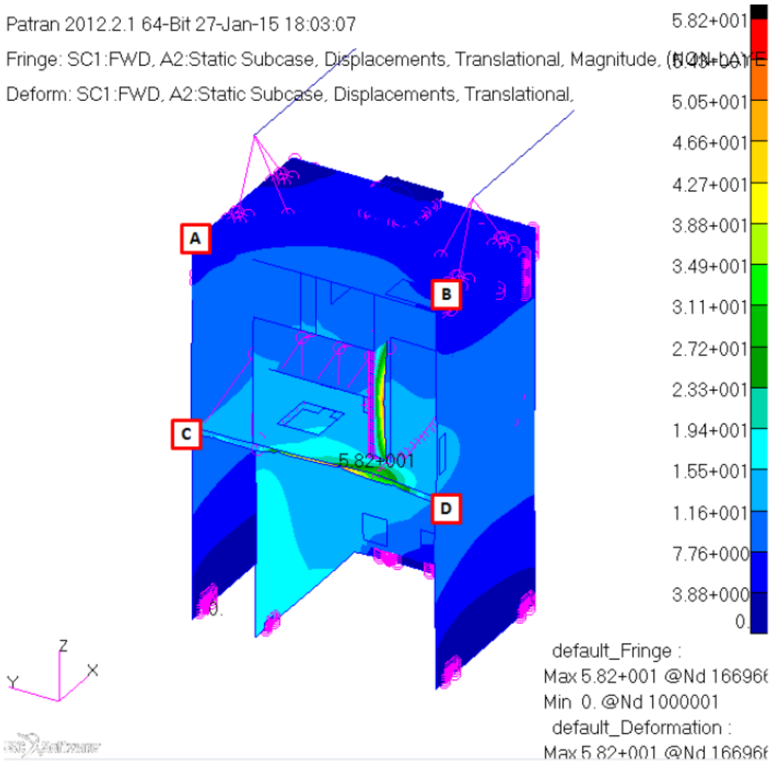

Figure 5: Deformation results of G1A galley

STATIC TEST OF GALLEY

Test Parts

After structural analysis of G1A galley equipment was completed, static tests for certification were performed. According to CS 25.561, load cases were determined and are shown in Table 7 [Onut A.E, 2016].

Table 7: Load cases

Load Factor	Direction
9.0G	Forward
1.5G	Aft
3.0G	Side
7.3G	Down
4.2G	Up

In this study, 9 G Forward case was performed, and galley was validated with this load case. Load was performed by using 150 kN hydraulic piston. Deformations at critical locations that were determined using finite element method were measured by using transducers [Onut A.E, 2016].

Test fixture consists of 3 parts. They are u-fixture, whiffle-tree fixture and main fixture. Hydraulic systems are fixed to u fixture. Whiffle tree connections are used in whiffle-tree fixture area. Also, Galleys are attached to main fixture. Test systems are shown in Figure 6.

Figure 6*:* Test rig

Spring plates are used between main fixture and galley. Galleys are fixed to main fixture by using spring plates. Spring plates used in static test have same stiffness value with aircraft beam. In this project, stiffness values of spring plates used in lower attachment are 15000 N/mm for translational x and y direction, 5000 N/mm for translational z direction. Stiffness value of spring plate used in upper attachment are 15000 N/mm for each translational direction [Onut A.E, 2016].

Dummy parts are simulated to inserts (coffee maker, oven, F/S cart, standard units and water boilers) during static tests. Therefore, these dummies have same attachment parts with original one.

Whiffle trees are used to distribute load to inserts correctly. Basically, they are steel parts and consist of rectangular beam. According to tension load, strength of beam was calculated and designed.

In static tests, load was performed using 150 kN hydraulic system and load cells were used to measure applied load. Capacity of these load cells used in static test is 200 kN and calibration factor is +-0.5%. In the same time, transducers are used to measure deformation at critical locations on galley. Capacity of these transducers is 200 cm.

9 G Load was applied from center of gravity of inserts determined location with whiffle tree and hydraulic piston. While test is performed, some latches of doors must be closed. Critical latches were determined and closed. Therefore, emergency load case was simulated with worst case scenario [Onut A.E, 2016].

Load Application

Deformations were measured from critical locations determined using finite element method. Therefore, deformation results measured from critical locations during static test were compared with results taken from finite element method. Deformations were measured two times. One of them was full load, another one was after static test was performed. Therefore, permanent deflection was measured. This method is one of validation methods [Onut A.E, 2016].

Another validation method is load measurement from upper attachment. While test is performed, loads must be measured from upper attachment using load cells. Therefore, upper attachment forces calculated with FEM were compared with static test results. Galley was validated with this method. Load measurement method is shown in Figure 7 [Onut A.E, 2016].

Figure 7: Load measurement method

Requirement load was calculated as 77041 N for 9 G load case. Some factors were used in this calculation and they are shown in Table 8. This load was performing in 40 seconds. According to EASA regulations, equipment is hold on 3 seconds at full load. For stay in safe side, this time was applied as 5 seconds. After full load was applied, force came back to zero and it's time was 5 seconds. Load application graph is shown in Figure 8 [Onut A.E, 2016].

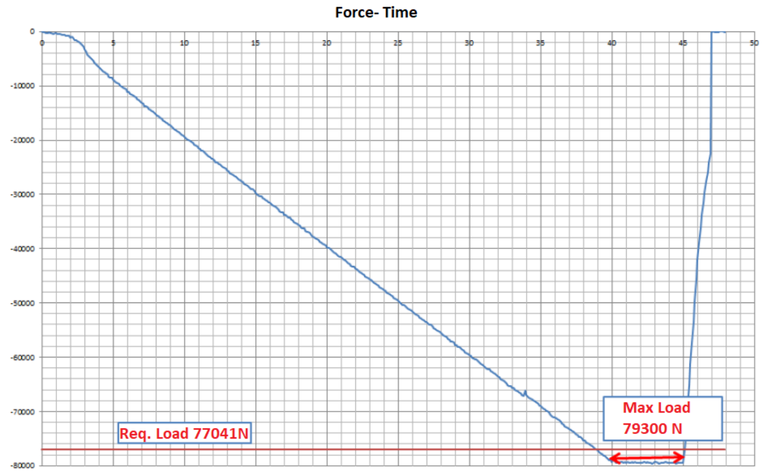

Figure 8: Full load – time graph

Table 8: Test load and factors

Load Case	Weight [Kg]	Load Factor	Material Variation Factor	Total Factor	Req. Load [N]	Applied Load [N]
Fwd	754.4	9.0	1.15	10.41	77041	79300

Pass- Fail criteria

According to EASA requirements, pass- fail criteria are determined. These criteria are shown below;

- Galley must be hold on 3 seconds at full load.
- Load distribution must not be changed at attachment location, if failure is emerged in galley.
- Loads calculated using finite element method are compared with static test results and difference between static test results and finite element results must be in acceptable.
- Configuration equipment is not failed.
- Doors of configuration must not be opened.

Results

After static tests were completed, loads were measured from upper attachments with load cells. Load data is shown in Figure 9 [Onut A.E, 2016].

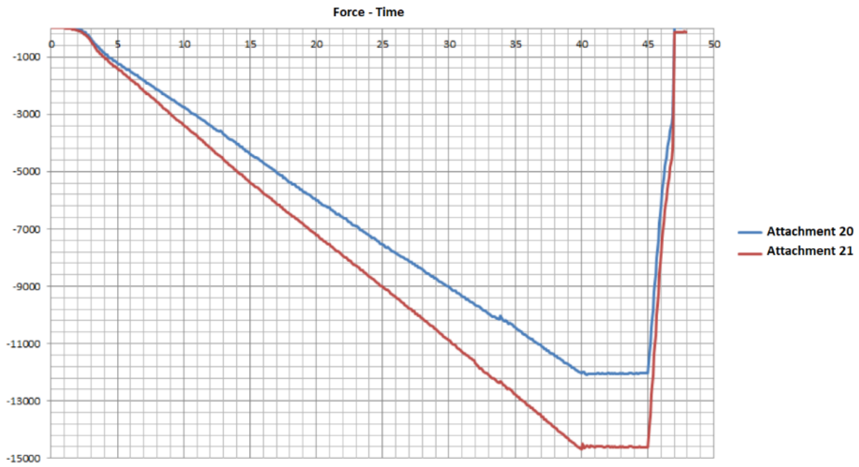

Figure 9: Force- time graph on upper attachment

Maximum load in static test was interpolated to maximum load of finite element method. Therefore, measured loads from upper attachment were interpolated too. These values were compared with results of finite element method and difference between FEM and test was calculated. Loads were shown in Table 9 [Onut A.E, 2016].

Table 9: Upper attachment loads

	Attachment 20	**Attachment 21**	**Total Load**
FEM Load	-9302 N	-11197 N	66601 N
Test Load	-10065 N	-12224 N	66601 N
Difference	%9	%9	

Deformations at critical points that are shown in Figure 5 were measured with transducers. These deformation values were taken at maximum load of static test. They must be interpolated to compare with results of FEM. Deformation results are shown in Table 10 [Onut A.E, 2016].

Table 10: Deformation results

	A	**B**	**C**	**D**
Max deformation at 79580 N (mm)	5.5	6.5	11.7	12.1
Permanent deformation (mm)	1.0	0.7	4.0	3.1
Deformation at 66601 N (mm)	3.8	4.9	6.4	7.5

G1A galley at maximum load is shown in Figure 10.

Figure 10*:* G1A galley at maximum load

CONCLUSION

Deformation and load values were compared with the finite element analysis results.

At the end of the structural test results, it is approved that structural test certification process was successful in terms of there is not any unfavorable situation about galley structure and test graphics by European union aviation safety agency witness.

After the successful structural tests and analysis studies, the model of finite element must be validated. That is why, the loads that were measured from upper attachments and forces that were calculated in upper attachments using Nastran were compared and the acceptable similarity between them was approved by EASA witness.

Another comparison situation between structural test and finite element model is deformation results. Differences between FEM and test occurred due to dummy structures and distribution of structure weight.

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