Design and Certification of an Aircraft Major Modification: Ka-Band Satcom System for Airbus A320 Family

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Abstract

With the increase of the number of aircraft in the sky in the last decades, a new business product emerged, the aircraft modifications. With the support of Jet Aviation, a company specialized in the field, this work goes through all the necessary steps to apply for a Supplemental Type Certificate (STC) to perform an installation of a ka-band satcom system, classified as a major modification, in the primary structure of an aircraft, by complying with the EASA and FAA regulations. The main steps covered are the design development, certification requirements, analyses, installation, experimental tests and required documentation. The structural provisions for this system are developed in-house and are based on an ARINC industry standard. The gains of using this standard in the design are approached. The main object of this thesis is the development of a parametric optimization study to the structural provisions in terms of weight reduction and fatigue life. To conduct that, three structural modifications in three different components of the initial design are defined and seven new designs derived from the Jet Aviation one are created. The seven hypotheses are subjected to a static analysis performed by a combination of FEM simulation and analytical methods, to verify their structural integrity. Furthermore, a fatigue analysis is conducted to the critical parts to estimate the new fatigue life of the designs. As result, is determined the optimal design between the seven in study.

Keywords: Aircraft modifications, Ka-band satcom system, Certification, Static Analysis, Fatigue Analysis

1. Introduction

With the fast growing number of aircraft flying since the introduction of jet aircraft for commercial use in the 1950s [7], new opportunities of business products emerged, including the aircraft modifications. An aircraft modification is defined by being a change/alteration or a repair. A change is the action of adding new features to the aircraft, whereas a repair is the action of re-establishing the original strength of a damage area. Furthermore, a change can be classified as major or minor, depending on if it might appreciably affect weight, balance, structural strength of the aircraft [8].

Any modification performed to an aircraft must be certified by an aviation authority. The main organizations responsible for this task are the European Aviation Safety Agency (EASA) in Europe and the Federal Aviation Authority (FAA). There are different ways to certify a change. One of the options goes through the creation of a Supplemental Type Certificate (STC). This option is more expensive compared to the other options and normally is used when there is an interest in performing the same modification several times.

The elaboration of this study was developed during my traineeship in a company named Jet Aviation, which provides me all the support to conduct it. Jet Aviation is a company of the business aviation industry sector which provides several different services, including engineering services. From these services, the one addressed in this work is the installation development of ka-band satcom system [10].

The ka-band satcom system is the state of the art in aircraft communication via satellite. This system allow to have high speed data on board in a wide area of the globe. It is composed by the systems which provide the service and the structural part which is the mechanical interface between the antenna and aircraft. The installation of a ka-band system is classified as a major change due to the fact that it will affect the structural strength of the aircraft [11].

Jet Aviation started the development of this system for the Airbus A320 family to afterwards create an STC, where are included the A319 and A320
series aircraft. The development of the structural provisions of this system is the main base for the work done in this article.

2. ARINC 791 Standard
The structural provisions of ka-band system developed by Jet Aviation have as a background the industrial standard known as ARINC 791.

The ARINC characteristic 791 is one of several standards published by SAE-ITC. This organization promote the ARINC industry activities which promote the safety, efficiency and cost effectiveness in aircraft operations [5].

This characteristic provides the full definition for the ku and ka-band satellite communication system in terms of physical installation, aircraft interfaces and electrical interfaces and functional equipment as well. The main systems which compose the ka-band system given in the standard are the Antenna Aperture (AA) which receives and transmits the radio frequency signals, the Ka-band Radio Frequency Unit (KRFU) which converts the signal from the AA, the Ka-band Aircraft Networking Data Unit (KANDU), which controls the KRFU, the MODMAN which is composed by the modem and the manager, and the Aircraft Personality Module (APM), where all the configurations for the system in each aircraft are saved.

Regarding the aircraft interface, this standard defines that the antenna must be attached to the fuselage by seven fittings fixed on its skin. The position of the seven fittings is also established by it and this provides the initial point to start the design of the internal provisions, which include the fittings as well. Furthermore, the ultimate loads for the fittings design is given by the standard.

With the employment of the ARINC standard 791 in the development of the structural provisions of the ka-band system there is a huge earned value. Firstly, the standard is valid for all types of aircraft and independent of the manufacturer [5], this means that, the developed solution can be adapted to any airframe in a short time. Secondly, the equipments required for the installation are not exclusive, different manufacturers equipments can be fitted in the standardized provisions [5], which signify the end of the dependency on only one supplier. And thirdly, the fully definition of the mechanical interface between antenna and aircraft provide a way to start designing not from the scratch.

3. Ka-band System Structural Base Design
3.1. Design Constraints
Before detail design stage starts, it is necessary to be aware of all the conditions which will constrain the design.

First of all, the certification requirements. Every aircraft has a certification basis linked to itself, which shows that aircraft complies with a specific amendment of the certification specifications (CS). For the modification in study, Jet Aviation elected to comply with CS25 amendement 22, which is the certification basis of the target Airbus A319. The certification paragraphs which must be shown compliance by the structural provisions are presented in table 1. The description of each paragraph is found in [2].

<table>
<thead>
<tr>
<th>Title</th>
<th>Paragraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads</td>
<td>25.301</td>
</tr>
<tr>
<td>Factor of Safety</td>
<td>25.303</td>
</tr>
<tr>
<td>Strength and Deformation</td>
<td>25.305</td>
</tr>
<tr>
<td>Proof of Structure</td>
<td>25.307</td>
</tr>
<tr>
<td>Flight Loads - General</td>
<td>25.321</td>
</tr>
<tr>
<td>Pressurized</td>
<td>25.365</td>
</tr>
<tr>
<td>Compartment Loads</td>
<td>25.561</td>
</tr>
<tr>
<td>Emergency Landing Conditions - General</td>
<td>25.613</td>
</tr>
<tr>
<td>Material Strength Properties and Design Values</td>
<td>25.625</td>
</tr>
<tr>
<td>Fitting Factors</td>
<td>25.625</td>
</tr>
</tbody>
</table>

Table 1: Certification paragraphs applicable to the structural modification [3].

Secondly, the location where antenna will be installed is analysed. The optimal position is found on top of the fuselage in the upper crown area aligned with the vertical plane of aircraft’s symmetry, due to the reduction of anti-symmetrical flow perturbation. In terms of the longitudinal location, several factors play an important role. These are the critical aerodynamic sections, the existing external equipment, the inside aircraft’s environment and the non obstruction light condition. Regarding the first factor, the area between the nose and end of the wings is considered aerodynamically critical due to any flow perturbation in the region can have a considerable impact on the conditions of the airflow incoming on the wings. Thus, the installation location chosen for the current aircraft was on the rear part of the fuselage, after the wings.

3.2. External Supplied Components
Some structural components are not designed by Jet Aviation, these are bought from suppliers. The radome, adapter plate and fairing are the three parts which are bought externally. The radome is the component which covers the outside antenna equipment and protect it from the external agents, such as, dirt, hail stones, water, de-icing fluid and birds [5]. The adapter plate is the antenna base and also the mechanical interface between the radome, fairing and the Jet Aviation’s designed structure. These two components fit in all aircraft types. Lastly, the fairing is the part which is specific for
each aircraft type and its main function is to provide the drainage required to avoid trap water and avoid corrosion [5]. Figure 1 presents an exploded view of these three components plus the AA and KRFU.

Figure 1: Exploded view of external equipment and outside antenna equipment [1].

3.3. Jet Aviation’s Structural Provisions Design
To start the detail design of the structural provisions, firstly, the environment of the A319 was built with the main structural components of the airframe, such as, frames, stringers, skin and shear clips. Concluding the environment, the provisions were designed on top of that. The developed solution is made of seven external fittings which secure an adapter plate that supports the antenna mounting plate and radome. Each fitting is attached to the aircraft external fuselage surface through a doubler. A mounting gusset is installed inside the fuselage along with each external fitting, supported by internal intercostals within the fuselage supported by the fuselage frames. Different type of fasteners perform the connection between this components. Figure 2 illustrates the final solution of the A319, reusable also for the A320.

Figure 2: Jet Aviation structural provisions 3D model installed in the upper lobe fuselage with identification numbering of each fitting.

To sum up, the structural components which compose the design are presented in the following list.

- External fittings
- Mounting gussets
- Doublers
- Intercostals

All these parts are made of aluminium alloys with different properties and some of them are machined and others are sheet metal bended. In order to perform the sizing of these parts several failure modes were identified to be analysed and checked for structural integrity.

4. Parametric Optimization
The parametric optimization began with the creation of seven candidates for the optimal design. Followed by the selection of the critical load case between thirteen initial load cases. Finally, the methodologies used for the analyses are introduced.

4.1. Hypotheses
To create seven new designs, three modifications in three different components were elaborated in order to combine them and obtain the seven different combinations for the new designs. The fittings, doublers and intercostals were the components which were found more interesting to modify. These modifications are explained in the follow paragraphs.

- Fittings (F) - In order to reduce weight, the overall thickness of the fittings was reduced from 0.346 to 0.189 inches, except the area around the lug which remain 0.346 inches. Furthermore, the thickness of the fittings’ base was decreased to 0.197 inches. Figure 3 illustrates the modifications done in the fittings.

Figure 3: Illustration of fittings modification - fitting one.

- Doublers (D) - The usual process for doubler design is driven the structural repair manual of the aircraft which states that the doubler thickness must be one gage (0.008 inches) thicker than the skin panel in touch. Here, will be studied the case where the doubler’s thickness will be the same of the skin panel. Thus, the modified doubler will be 0.063 inches thick and not the initial value of 0.071 inches.
• Intercostals (I) - In Jet Aviation design for the A320 family, the intercostals were sized with a thickness of 0.1 inches, whereas for the Boeing 737 family aircraft, these have only 0.08 inches. These two families of aircraft are in a similar weight category, so the intercostals modification proposed in this study is the reduction of their thickness to the 0.08 inches.

Therefore on table 2, the seven hypothesis are defined by the following combinations of modifications.

<table>
<thead>
<tr>
<th>Design Hypothesis</th>
<th>Bending &amp; Shear</th>
<th>Cabin Pressure</th>
<th>Radome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inertia</td>
<td>1.0g Down</td>
<td>3 Psi Radome</td>
</tr>
<tr>
<td>2</td>
<td>Fuselage</td>
<td>1.0g Down</td>
<td>Over Pressure</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td></td>
<td>+ CFD Cruise</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td></td>
<td>Load Case</td>
</tr>
<tr>
<td>5</td>
<td>I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>F+D</td>
<td>DP = 8.99 psi</td>
<td>Load Case</td>
</tr>
<tr>
<td>7</td>
<td>F+D+I</td>
<td>Operating</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Definition of the seven hypotheses for the study.

4.2. Load Case
In order to perform the static and fatigue analyses, the load cases for each analysis must be defined. There are thirteen load cases which were used in the substantiation of the initial design. This set of load cases are composed by gust, fatigue or crash load cases, or rapid decompression of the radome and fuselage burst pressure. All situations which can happen during a flight and thus, the ka-band designed provisions must withstand them. These load cases are a combination of the inertia of the designed structural provisions plus the equipments, the bending and shearing of the fuselage barrel in the target section, and the aerodynamic and pressurization loads. The cabin operating pressure, and static flight loads envelope are extracted from [6].

For the static analysis the load case selected for the study was the radome rapid decompression load, which can be assumed as a good approximation of the most critical load case. For the fatigue analysis, the fatigue load was used. Table 3 presents the composition of each load case.

4.3. Methodologies
Regarding the static analysis, this was performed in two steps. Firstly, the reaction loads on the fittings’ lug were extracted from the results given by the FEM model developed in FEMAP for all the hypotheses. Secondly, with the extracted loads, analytical methods were employed to determine the safety margins for all the parts of the design. For this study, the consider failures loads used for the safety margin calculations are only presented for the modified parts.

Therefore, the failure modes consider in the analysis for the fittings, doublers and intercostals were the following:

- Lug analysis
- Fitting strength
- Base bearing
- Von mises stress

- Bearing
- Outer/inner flanges stress
- Web shear stress
- Von mises stress

The global methodology used to determine the safety margin for each of the failure modes was similar for all. Equation 1 was the core equation used in all the calculations of the safety margin.

\[
MS = \frac{F}{FF \times f} - 1
\]

\(MS\) is the safety margin, \(FF\) the fitting factor imposed by the certification paragraph 25.625, \(F\) is the allowable stress of the material for a specific direction (L or LT) under the ultimate or yield condition and \(f\) is the maximum stress found in each analytical analysis. For the different failure modes, the computation of this value is performed by different sub-methodologies which are presented in detail in the complete document.
Regarding the fatigue analysis, this is based on the material Wohler curves, also known as stress-life curves (S-N), which relates the maximum stress with the fatigue life, in cycles. For this analysis is assumed that one cycle is equivalent to one flight by considering a constant amplitude Ground-Air-Ground (GAG) loading cycle [9]. The goal of this analysis is justify that the fatigue life is not a limiting factor for the threshold inspection. Due to the highest load condition, the doublers are the critical components which must be subjected to the study. Figure 4 illustrates the S-N curves for the doublers material - Aluminium alloy 2024-T3. In addition, also the fatigue life of the modified fittings is studied in order to compare with fatigue life of the initial fittings.

![S-N curves for aluminium alloy 2024-T3 from [4].](image)

Therefore, to extract the fatigue life from the correlations of the graphic in figure 4, firstly is necessary to compute the stress concentration factor which is estimated by the theory of severity factor (SF) times a discrepancy factor of 1.2 for the doublers. For the fittings case, this factor is computed by the quotient between the maximum principal and nominal stress extracted from the FEM analysis. Secondly, the local stress concentration factor and net section stress are computed to finally determine the equivalent stress which is the required parameter in the correlation to obtain the fatigue life. For the fittings the equivalent stress is simply the maximum principal stress extracted from the FEM analysis. Equation 2 presents the correlation to obtain the fatigue life of the doublers.

$$\log(N_f) = 8.3 - 3.3\log(S_{eq} - 8.5)$$ (2)

Finally, to obtain the required value is necessary to divide the $N_f$ by a scatter factor of 5 used by the OEMs. This value is the fatigue life number cycles used to compare with the initial values. The detail description of the methodology is presented on the complete document.

5. Results

Several results were obtained from this study. Firstly, it is presented the obtained results in terms of weight of the several hypotheses. Secondly, the results of the static analyses are shown. Thirdly, the fatigue life cycles of the modified components are presented as part of the fatigue analysis results. Finally, a combination of all the results are performed to find out the optimal hypotheses.

5.1. Weight

Regarding the weight results, with the modification performed in the fittings, doublers and intercostals to define the seven design hypotheses as a combination of these three changes, the weight reduction flow with all the hypotheses are presented in table 4 and figure 5.

![Percentage of weight reduction of initial Jet Aviation provisions.](image)

**Table 4: Values of weight reduction percentage for the seven hypothesis.**

<table>
<thead>
<tr>
<th>Hypothesis ID</th>
<th>Weight Reduction [%]</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1.26</td>
<td>1.00</td>
<td>8.16</td>
<td>2.26</td>
<td>9.42</td>
<td>9.15</td>
<td>10.42</td>
</tr>
</tbody>
</table>

The results presented in table 4 shows that hypothesis number seven, which includes the three modified components, presents the highest weight reduction, a reduction of 10.4% of the total weight of the initial design. In addition, it also shows that the modified component with the larger impact on the weight reduction is the intercostals, due to the large number of times that this component is used and also, to its considerable initial weight compared to the other two modified parts. Following the same logic, accounting only for two modified components, the hypothesis with the greater result is the hypothesis number five, which combines the modified intercostals with the modified fittings, which are the
second component with more impact on the weight reduction.

To sum up, the hypothesis number seven is the lightest design from all the hypotheses. The static analysis results will confirm if the structural configuration of this hypothesis maintains the structural integrity by continuing to have positive safety margins in all the design components.

5.2. Static

Before performing the analysis, the reactions loads in the fittings in the three directions were extracted from the FEM analysis. Figure 6 presents the values obtained for the Z direction, which gives a good representation of what happens in the other two directions.

Figure 6: Fittings reactions in Z direction.

These results show that for all the configurations the reactions in the fittings are almost similar. Comparing the reactions from the seven hypothesis against the reactions of the initial design, it shows that the reactions suffer short alterations, at units scale, as it is possible to confirm with the nearly horizontal lines in the graphics of figure 6. These results show that the geometry modifications performed in the selected parts had an insignificant impact on the global structural systems rigidity, what explains the short changes in the reactions.

From the second step, the safety margins were calculated for the specific failure modes for the fittings, doublers and intercostals. Below are presented only the obtained critical results for each of the three components.

- **Fittings**

Table 5: Safety margins results of fitting 3.

<table>
<thead>
<tr>
<th>Hypothesis ID</th>
<th>Initial Design</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing</td>
<td></td>
<td>2.69</td>
<td>2.68</td>
<td>2.42</td>
<td>2.67</td>
<td>2.42</td>
<td>2.42</td>
<td>2.42</td>
</tr>
<tr>
<td>Von Mises Stress</td>
<td></td>
<td>0.04</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td>0.05</td>
<td>0.01</td>
</tr>
</tbody>
</table>

- **Doublers**

Regarding the doublers, the analyses performed showed that the doubler three is the most critical. Table 6 presents the safety margins results for that doubler.

Table 6: Safety margins results of critical doubler - Doubler 3.

<table>
<thead>
<tr>
<th>Hypothesis ID</th>
<th>Initial Design</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing</td>
<td></td>
<td>2.69</td>
<td>2.68</td>
<td>2.42</td>
<td>2.67</td>
<td>2.42</td>
<td>2.42</td>
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</tr>
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<td></td>
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<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td>0.05</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Observing the results of table 6, the doubler three is the component with the lowest safety margin, with a value of 0.02 for the hypothesis seven. In spite of being very close to the ultimate allowable load, it is still under it, so it remains in the safe zone. Furthermore, it is known that the load case applied is conservative, so it is concluded that the doubler has sufficient strength.
Observing the results in figure 7, firstly, it shows the intercostals in fitting seven presented the lowest safety margins, however the analytical method used does not account for the cut-out in intercostals of fitting 3 and 4. Thus, the critical intercostals are in fitting 3 and 4, which are shown by the FEM results. Secondly, it shows that all the intercostals are able to withstand the applied loads on all the hypotheses. And lastly, it is possible to confirm the safety margin reduction in some of the failures modes in the successive hypotheses.

5.3. Fatigue

Regarding the fatigue analysis, the follow results were obtained for the critical fitting and doubler.

- **Fittings**

Table 8: Fatigue lifes number of cycles of fitting 3 for the initial design and seven hypotheses.

<table>
<thead>
<tr>
<th>Hypothesis ID</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cycles</td>
<td>1070985</td>
<td>71998</td>
<td>680111</td>
<td>676339</td>
<td>71792</td>
<td>71597</td>
<td>680111</td>
<td>79611</td>
</tr>
</tbody>
</table>

Observing the results in figure 8, firstly, it shows that the fitting modification decreases the number of cycles in 93% due to the increase of the maximum principal stress in the base of the fitting. On the other hand, the number of cycles for the modified fitting is still acceptable, because is below to the limit of 24000 flight cycles imposed as threshold by Airbus for the aircraft models A319 and A320. This value is obtained by equation $N_{th} = 0.5 DSG$ provided in the Airbus structure training manual, where DSG is the Design Service Goal and is equal to 48000 flight cycles for the mentioned aircraft. These information is given in the Airbus fatigue stress manual.

- **Doublers**

Table 9: Number of cycles of fatigue life for doubler 2 for the initial design and seven hypothesis.

<table>
<thead>
<tr>
<th>Hypothesis ID</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cycles</td>
<td>17024</td>
<td>167245</td>
<td>159107</td>
<td>160490</td>
<td>158597</td>
<td>151281</td>
<td>145079</td>
<td>145603</td>
</tr>
</tbody>
</table>

The results shows a reduction in the number of cycles for all the hypothesis, having the maximum reduction in the hypothesis where the doubler with reduced thickness is employed. In addition, it also shows the impact of changing the intercostals and the fittings in terms of doublers fatigue life, with a reduction of 10% and 6% in the number of cycles, respectively. In spite of that reduction, all the hypotheses have the number of cycles above the threshold imposed again by Airbus of 24000 flight cycles.

Cross checking the obtained results for the fittings and doublers, it shows that with the fitting modification, this component became the critical one in terms of fatigue life, due to the huge reduction of the number of cycles. Therefore, the fatigue life of hypotheses 1, 4, 5 and 7 is driven by the fittings and not the doublers as in the initial design. The other hypotheses continue to be driven by the doubler and does not introduce a huge reduction in the number of cycles. Figure ?? summarize the critical values of the number of cycles for all hypotheses.

5.4. Optimal Hypothesis

Once all the results are presented, it is time to decide which is the optimum hypothesis to go for. This decision is a compromise between several requirements, such as, the certification, the business and the company internal requirements. The business ones are traduced by the customer requirements, where there will be two possible scenarios. Or the customer is an airliner or a private one. In case of an airliner as a customer, it is known that the goal of an airline is to make profits in their flights, so less weight introduced in the aircraft means less fuel consumption, which reflects in less operational cost, so for an airliner the main requirement is the weight reduction. On the other hand, for a private customer which is not worried about weight but is concerned about extra costs, the inspections interval are the main requirement, the design provided must guarantee that the customer will not have extra costs in terms of maintenance due to shorts intervals of inspection and the aircraft must be on ground only because of the antenna. Regarding the internal requirements, these will influence the developed design. Examples of these requirements are the capacity of company to produce a certain design and also if the company has the knowledge required for the development of that.

To support the decision normally a graphic named pareto front is produced, where for two variables are plot the several hypotheses to be easy to cross check the results and confirm which is optimum decision according to the weight given for each
variable. Figure 7 presents the graphic with the critical fatigue life number of cycles which drives each hypotheses versus the weight reduction.

![Figure 7: Pareto Front - Critical fatigue life’s number of cycles VS Weight reduction.](image)

Observing the graphic above, it is possible to see that there are two groups of sets of hypothesis, one close to the 1% weight reduction and another close to the 9%. The first group is composed by hypotheses 1 (F), 2 (D) and 4 (F+D). Furthermore, hypothesis 1 and 4 in this group has a reduction in the fatigue life comparable to other hypothesis with higher weight reduction percentage. Thus, these hypotheses are far to be the preferable ones. The second group is composed by hypotheses 3 (I), 5 (F+I), 6 (D+I) and 7 (F+D+I). From these hypotheses, the number seven is the one which improves more in terms of weight reduction, however has a reduction impact of 59.8% on the number of cycles. The optimum option can be hypotheses 6 which has 9.2% of weight reduction and the impact in the reduction of number of cycles is lower than the hypothesis seven, 18.8% for this hypothesis.

Regarding the last requirement, the certification, all these hypotheses of design are not certifiable yet because it is necessary to prove that the hypothesis can withstand all the other mentioned load cases and for this study it was only considered one of the load cases which is a good representation of the critical load cases but is not enough. In addiction, a damage tolerance analysis must be performed in order to find the inspection intervals, performing only a fatigue analysis is not enough again for certification. In spite of that, this initial study gives good indications on which improvements can be done in the initial design in order to achieve higher quality values.

6. Design Initial Release

Reaching to the final stage, once the structural analyses are completed, the solution design is converted into 2D drawings. There are the installation drawing and drawings for each component of the design. When all these are completed and released by the engineering, this moment is known as the Initial Release. The next step is the installation when the parts have been already manufactured by the production department. During the installation, the engineers work closely with the technicians in order to give support to some deviations which can happen, so that the installation does not stop. In the meanwhile, the engineering work also continues in the office by producing and finalizing the certification documents which prove that all the requirements are complied and also will allow the aircraft to perform a flight test to be conducted some experimental tests.

To solve deviations there are three solutions. Performing a drawing revision, prepare a deviation sheet or perform a concession are the three actual solutions. The first is normally used when the drawing will be reused more times. The second is the fastest to perform, however, the process each time that the respective drawing is used must be repeated. The last happens when there is a deviation but this is not reported to engineering during the installation process and a document is prepared by the technicians department to be approved after by engineering before the aircraft leaves the company. In order to reduce the number of deviations is provide a flexible design, where the drawing is done in a way which can absorb the deviations of the aircraft.

In terms of certification, one option to show compliance with a specific requirement is with experimental results. This method is used by Jet Aviation to show compliance with the vibration and buffeting requirement for the ka-band system where a flight test is performed. In this test are installed sensors to measure the acceleration in all the directions in the frames where is installed the new system. For the A319 aircraft, object of this work, the test was also performed and the results show that no particular frequency is subject to peaks of vibration energy indicating resonance or flutter for the range of frequencies of interest, below the 100Hz. Thus, the installation complies with the vibration and buffeting requirements for certification.

The last stage, before apply for the STC is to prepare and conclude all the required documents which will prove that all the certification requirements are being fulfilled. Therefore, the required documents are presented in the following list.

- **CAF** - Classification Assessment & Application Form
- **MDL** - Master Data List
- **CCS** - Certification Compliance Sheet
- **DLM** - Drawing List Mechanical
- **DLE** - Drawing List Electrical
7. Conclusions
Several achievements have been fulfilled in this work, starting with the demonstration of the benefits for the industry by using a standard as the ARINC 791 for the ka-band antenna, which is the base of the design developed by Jet Aviation.

Secondly, the illustration of all the steps to certify a major modification as the installation of the ka-band system was accomplished, by going through the selection of the antenna location, the certification requirements, the mechanical design development, the installation and respective deviations, the flight test and the documentation required for the Supplemental Type Certificate (STC) application.

Thirdly, the major achievement in this work was the results obtained from the static and fatigue analysis for the seven hypotheses in the parametric optimization. The results proved that all designs are strong enough to withstand the selected critical load case, rapid decompression of the radome. All the structural components presented a safety margin higher than zero. In terms of fatigue, the alterations introduced in the fittings, doubler and intercostals led to a reduction on the fatigue life for all the hypothesis, although without any negative impact on the Airbus threshold. As final result, hypothesis number six - design with modified doublers and intercostals - was considered the optimal due to the high percentage of weight reduction and low reduction on the fatigue life number of cycles. To sum up, this initial parametric optimization was useful to find an optimal design which can be an option in the future. However, further analysis must be conducted to verify the structural integrity for other load cases and to determinate the threshold and intervals of inspection in order to certify a design.

Lastly, the important role played by the experimental flight test in the certification of the initial design of Jet Aviation was shown. The obtained results during the flight test covering the vibration and buffeting requirement proved that any peaks of vibration energy indicating resonance or flutter occurs within the required range of frequencies. With these results plus the numerical ones was achieved a certified solution, where an EASA Supplemental Type Certificate was issued with the number 10071445, named as "KA Band Satcom System" applicable for the Airbus A319 and A320 series aircrafts on the rear fuselage.

As a future work, there are two identified opportunities:
The first one is to continue the scope of the present work, where the static analyses for the remaining loads cases could be performed in order to prove that all the seven hypotheses are strong enough under all the load cases. In addiction, the damage tolerance analysis could also be conducted in order to find the intervals of inspections required for certification. With these two topics covered, the results could show if all the hypothesis are certifiable designs or not.

The second option is to take the initial design developed at Jet Aviation and update it for the new standard ARINC 792, where there were 7 fittings interfacing the antenna and the aircraft airframe, there would be only six fittings, the most backward, the number seven would be removed. An initial study could be performed to verify if the updated design is still feasible in terms of stress and certifiability. In case of a negative result, what changes could be performed in the design in order to make it feasible.

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References

[1] Property of jet aviation.


[8] Federal Aviation Administration, Department of Transportation. Title 14 of the Code of Federal Regulations Aeronautics and Space, Chapter 1.

