The exponential evolution in the aeronautical industry in the last century opened the market for new business opportunities, such as aircraft modifications. Whether it is a repair or an alteration, these modifications must be certified, by the company that is doing them or, in case they do not have the privileges to do so, by a regulatory agency such as the European Union Aviation Safety Agency (EASA) or the Federal Aviation Administration (FAA), through the use of a Supplemental Type Certificate (STC). Two major modifications are presented: i) a Ka-band antenna, used for wireless internet access and ii) a quad camera, used for passenger entertainment. In both of them, the installation location investigation and the detailed aircraft environment definition are done, since it is considered to be one of the keys for design success. All structural provisions are produced by Jet Aviation, in-house, for both installations, although in the Ka-band antenna installation there is the additional guidance from the industry standard Aeronautical Radio Incorporated (ARINC) 791. Three quad camera design variations have been studied by using the finite element method (FEM), in order to achieve a weight and cost reduction, while maintaining the structural integrity. Finally the important documents needed, in order to apply for the STC are presented.

**Keywords:** Aircraft modifications, Ka-band antenna, Quad camera, Static analysis, Modification Certification

1. Introduction

The aviation industry is one of the most broad industries that exists, that has been growing exponentially since the 1940’s due to the increasing demand for passenger and freight services, the technological progress and the associated investment [1]. This growth created new market opportunities in the field of aircraft modifications, where companies like Jet Aviation have a large presence nowadays. This company, which operates within the General Dynamics Aerospace Group, is a global recognized leader in the business aviation industry. Their services range from completions and refurbishments to aircraft modifications.

These modifications can be divided into repairs and alterations, which can be major or minor. Both of the modifications depicted in this work (Ka-band Satellite Communication (SATCOM) system and quad camera) are major alterations, which means they "...might appreciably affect weight, balance, structural strength, performance, powerplant operation, flight characteristics, or other qualities affecting airworthiness..."[2].

In order to certify these modifications an STC needs to be created, since a product is being altered by introducing a major change to it [3]. The agency that will certify this works modifications will be EASA, since the country of origin of the aircraft, Azerbaijan, belongs to the community of countries that cooperate with EASA [4].

The design of both the Ka-band SATCOM and quad camera systems, as well as the static analysis of the latter, will be discussed in the next sections, since the two main objectives of this work were to present two different fuselage major alterations, as well as trying to improve one of the designs with the tools used in an industry environment.

2. Aircraft Telecommunication Systems and Design Standards

The aeronautical telecommunication market, which was limited to cockpit and control towers communications, has shifted focus to wireless-in-cabin communications, due to the market’s demand to make air travel more pleasant and productive for the passengers [5, 6]. The use of this type of technology is still limited however, due to the high investment needed. That is why it is usually not requested by commercial airlines and it is more of a private customer request. There are two ways of obtaining a wireless internet connection on board, which are: Air-to-Ground (ATG) and SATCOM systems.
2.1. Airplane WI-FI Connection

The ATG is a ground based communication system which uses broadband towers that transmit, route and receive data to and from the aircraft [7]. This system has some drawbacks like service disruption if passing over large bodies of water or remote terrain (since there are no towers in these locations) as well as lower internet speed (3-10 MegaBytes (MBps) per aircraft). The advantages, when compared to the SATCOM system, is the lower overall costs (equipment, maintenance, etc) and lower system latency [6].

The SATCOM system is also a communication system which contains three components: Aircraft Earth Station (AES), Ground Earth Station and the satellite. The focus will be on the AES since it is directly installed on the aircraft. This system transmits, receives and processes signals through a mounted antenna on top of the fuselage or tail [8]. Overall, the SATCOM system has a wider coverage since it does not have disruptions over the ocean and deserted land because it automatically connects to the closest satellite in orbit. Furthermore, the internet speeds have a significant improvement (as much as 70 MBps per aircraft). The disadvantages reside in the higher latency, since the signal needs to travel up to space and back, and on the higher overall costs [6, 9]. In figure 1 it is possible to observe these two ways of WI-FI connection in an aircraft.

2.2. ARINC 791 Standard

This standard sets the desired characteristics of the Ka/Ku-band SATCOM system intended to be installed on the B777-200LR. This system is composed by the Outside Antenna Equipment (OAE), the Ka/Ku Band Radio Frequency Unit (KRFU), Ka/Ku Band Aircraft Network Data Unit (KANDU), Modem and Manager (MODMAN) and Aircraft Personality Module (APM) [8].

The most important components of the OAE are the antenna aperture, which is a high gain radiating structure that receives and transmits the Ka/Ku-band radio signals; the radome, which is used to protect the OAE from environmental agents; the adapter plate, which provides the mechanical interface between the antenna subsystems and the aircraft through seven fittings (produced in Jet Aviation) and the skirt which provides an interface between the radome and the aircraft fuselage. The ARINC 791 standard was used due to its several interchangeability advantages and guidance on the initial design concepts [8].

2.3. Fuselage Cut-Outs

When a fuselage cut-out is made it should be reinforced with a doubler, which is a sheet metal part, in order to carry the load that would have been carried in the cut-out panel. It will also help to redistribute the load [14]. Furthermore, these cut-outs are usually done with a round shape since it leads to lower stress concentrations (localized high stress that occur at a geometric discontinuity) [15]. It is also important to note that the reason why open holes are more critical to the structure is because the stress concentrations on them are higher, than when compared to a hole with a rivet, since the rivet will create a compression field and reduce the stress concentrations on the hole [16]. This is why special attention needs to be given to skin cut-outs used for cable passing or other similar functions.

The design of a new structural modification includes, inevitably, the use of rivets and its distribution. In order to have a safe design there are certain rules that should be followed, such as the inter-rivet pitch, edge margin and radius clearance. The inter-rivet pitch should be between 4D-6D (D is the diameter of the rivet) in order to avoid the high stress concentrations from consecutive rivets and the inter rivet buckling, which is more likely to happen if the rivets are farther away [17]. The edge margin is set to 2D+1mm according to static and fatigue requirements and in order to take into consideration the oversize of the rivets, when a repair is being made [17]. Finally the radius clearance, which is the distance that a rivet should have from...
a specific radial component, is set to D+1mm since the head of a rivet has a dimension of approximately between 1.25D-1.66D, so by granting this clearance the clash to the radial component is avoided.

3. KA-Band Antenna Structural System Design

The Ka-band antenna installation is a major modification that requires a thorough investigation of the B777-200LR primary structure and engineering knowledge in order to be able to design the adequate structural attachment of the SATCOM system.

3.1. Antenna Installation Position

In order to position the antenna on the aircraft there are several aspects that need to be taken into consideration such as:

- Aerodynamic Considerations

  In general an aircraft can be divided into two sections, when it comes to the aerodynamic domain. The first section is called the critical aerodynamic area and goes from the nose of the aircraft until the middle of the wings. This area is more sensitive to flow perturbations since they can change the flow conditions reaching the wings. The second section is the non critical aerodynamic area and includes the region from the middle of the wings until the end of the fuselage [18]. It is then concluded that the most suitable location to install the antenna is the non critical aerodynamic area. Additionally, it should be installed in the vertical plane of symmetry of the aircraft, to avoid anti-symmetric flow perturbations.

- Fuselage Bending Moment

  The bending moment increases along the fuselage having its maximum at the wingbox and then decreasing until the tail. It is therefore structurally preferable not to perform modifications on the central fuselage since it would decrease the lifespan of the installation and reduce the inspection intervals of the antenna, due to the higher bending loads.

- Aircraft External and Internal Equipment

  The original aircraft already has different equipment in place (antennas, lights, etc) when it is produced in order to allow its correct functioning. In order to avoid electromagnetic, structural and aerodynamic interferences it is important to have a look at the B777-200LR layout and analyze the available installation options. The same happens with the internal aircraft structure, which should be checked in order to see if the installation would be in clash with an already existing internal component.

- Illumination Obstruction

  The final aspect to take into consideration is the obstruction of the beacon light, which has an allowable limit according to EASA’s Certification Specifications (CS) 25 Amendment 22 Section 25.1401. By doing a mathematical analysis it was concluded that the antenna was fully contained inside the allowable obstruction zone thus being in agreement with the limit set by CS 25.

  By taking all the previous items into consideration it was concluded that the installation would be placed between frame Station (STA) 1455 and STA 1546.5 since it fulfills all the necessary requirements. The term STA refers to frame stations, which are numbered in order to allow a faster identification.

3.2. Aircraft’s Environment Modelling

In order to have a precise design it is important to use several environment modeling techniques, thus assuring that the aircraft’s primary environment is reproduced with the utmost reliability. One of these tools is the Three Dimensional (3D) scanning, which replicates the installation area by scanning it physically through the use of a hand scan. Furthermore it is also useful to use certain drawings supplied by Boeing, such as the frame and skin drawings. To complement this the Structural Repair Manual (SRM) should be used, since it contains relevant information regarding the fuselage’s radius, typical pre-approved repairs, among others.

With these three tools it was possible to build a CATIA [19] model that included the most important primary structure components of the aircraft such as:

- Skin

  The aircraft’s skin covers all fuselage and carries cabin pressure (tension) and shear loads. It is made of several panels which are optimized in terms of weight by being machined with different thicknesses. This means that there needs to be special attention when installing the provisions, since they should be installed onto a single skin thickness. Additionally the skin curvature is given in the SRM as being 122 inches.

- Stringers

  The stringers are made to carry the longitudinal tension and compression loads. In the B777-200LR they have a Z cross-section, although their dimensions cannot be perfectly determined due to the inaccessibility to the stringer’s shape drawing. Nonetheless the important factor in this design was the stringer holes position since it will influence the doubler shapes.

- Frames
The frames help to maintain the fuselage’s cross section shape and redistribute loads in the skin. They are also optimized in terms of weight, reason why they are machined with pockets of different thicknesses. It is also important to take these thickness changes into consideration when attaching a component onto the frames.

- Shear Ties and Stabilizers

The shear ties make the connection between the skin and the frames whereas the stabilizers connect the stringers and the frames, both with the objective of helping to distribute the loads between components.

### 3.3. Installation Breakdown

The complete antenna’s methodology is presented in figure 2 and shows all the components used in the installation.

![Figure 2: Exploded view of the Ka-band antenna installation [20].](image)

The installation was divided into two parts: external and internal. The external part is composed of seven fittings, doublers and gussets (they are inside the aircraft but are projected at the same time as the other external components) and two feedthroughs. The internal part is composed of several intercostals, T-brackets and shims.

#### 3.4. External Structural Installation

The fittings are an assembly of a machined part and a bearing which connects to the adapter plate. The ARINC 791 provides the coordinates for the attachment points of the fittings which was the start of the design. The adapter plate allows some flexibility in the X attachment coordinates (aircraft’s flight direction) due to the frame spacing, which varies from aircraft to aircraft. From the coordinates it was possible to design the fittings, by extruding them until the skin was reached and by using some of the ARINC 791 manual’s additional guidance.

The gussets are machined parts that are used in order to transfer the loads from the fittings to the intercostals. The positions of the fitting’s fasteners will influence the design of the gussets, hence why they are designed at this phase. Fitting seven (figure 3) had a different gusset concept, since only one intercostal was used at this location.

The doublers are thin sheet metal parts that are used to strengthen the skin due to the drilling of the fitting’s attachment holes, and in order to redistribute the shear loads that would be concentrated on the fitting’s fasteners. The skin has a thickness of 0.09 inches (at the panels where the fittings are) so, according to the SRM, the doubler would need to be 0.1 inches thick which is what was chosen.

The design of the rivet patterns was also done at this stage, by following the design rules already presented. Finally, all the doublers were made with lobes at the stringer areas, in order to allow adjustment margin due to the uncertainty on the stringer rivets positions.

The feedthroughs were positioned by using the guidelines from the ARINC 791 manual. These parts are similar to a doubler, the only difference is that they have a larger central hole to allow cable passing and a cable seal in the interior of the aircraft in order to secure the cables.

#### 3.5. Internal Structural Installation

In order to transfer the loads from the antenna’s structure to the frames, an internal installation part was done which consisted of connecting the intercostals to the gussets and frames. The connection to the gussets was made by using eight fasteners (four on each intercostal), and the connection to the frames was made by using two T-brackets per intercostal. Since the frames do not have a constant thickness then it is necessary to use shims (small machined parts) that make the connection between the frames and T-brackets thus compensating the different frame thicknesses.

Furthermore, fitting seven only attaches to one intercostal (this was a new approach when compared to some past company projects) since it is only loaded in the Z axis, which is not the most critical loading direction for an intercostal (that is Y). This concept can be tested as well on fitting’s two and six since the loading conditions are similar, though a detailed analysis would be required. This design came with the advantage of weight saving which was 2 %, reason to why it seems interesting to, in the future, try and reduce more intercostals.

The final external and internal installation design, with the proper aircraft environment can be seen in figure 3. After the design was made, the part drawings (doubler’s, gusset’s,...) and installa-
tion drawings were completed. At the end several documents needed to be prepared, in order to certify the installation.

Figure 3: Ka-band SATCOM system structural installation with the fitting’s numbers shown.

4. Quad Camera Structural Installation and Static Analysis

The quad camera technology can be used for a variety of applications such as ground maneuvering during taxi, in-flight entertainment and external security. Moreover, this system provides a 360° field of view by splitting the fields in four views: Forward, Aft, Left and Right. It is usually installed on the lower fuselage of the aircraft, in order to fulfill the applications depicted above. The structural installation and the static analysis were done, as a way of better understanding important engineering concepts such as the margins of safety of a component.

4.1. Structural Installation

The first step was to determine the camera’s position, for which the horizontal and vertical fields of view were considered. The location with the least amount of view obstruction was found to be forward to the wings, since both on the center of the fuselage and closer to the tail, there would be the problem of obstruction due to the wings and engines. Furthermore on the central fuselage the bending moments are higher, which would worsen the static analysis results. With this in consideration, the camera was installed between STA 718 and STA 739 at the X symmetry axis of the aircraft (Y = 0).

The environment design and installation were done afterwards. It was seen that in this region of the aircraft the skin had a thickness of 0.1 inches, with no pockets, which provides more space for additional fastener installation. The stringers were also modeled in order to check the position of its rivets, which will be important for the doubler design.

The installation design process started by analyzing the camera itself and its interface requirements. It has four holes that serve as attachments to the skin and a central connector. In order to perform the wire connection to the antenna, a fuselage penetration is required and thus a local reinforcement as well. Since the camera attachment holes are very close to one each other (closer than the general rule of minimum pitch of 4D), then this would result in a high stress concentration on that area which would reduce drastically the number of cycles for crack propagation. For this reason an adapter plate was also created, with six fasteners that serve as attachments to the skin. Finally the rivet pattern was developed, having a circular shape around the cut-out and a more rectangular shape near the doubler’s borders. The adapter plate’s screws were attached to nutplates which were used to keep them in place. Four extra sheet metal plates were used to install the nutplates on, thus preventing drilling the aircraft’s skin with the non structural holes of the nutplates, that would be very close to each other.

Just like in the Ka-band system, the part and installation drawings were done in order to help in the certification process and to ease the installation of the camera. The design of the camera is presented in figure 4, as done in CATIA V5.

Figure 4: Quad camera structural installation.

4.2. Finite Element Method Model Definition

An important aspect when doing an installation is checking if it fulfills all stress requirements by performing different analyses such as the static analysis and the Damage Tolerance Analysis (DTA). The program FEMAP [21] was used in order to conduct the static analysis, which consists in calculating the margins of safety of the components that are being installed or already in place, like the aircraft’s skin, in order to check if they are statically adequate [22], which is verified if the margin of safety is bigger than zero.

In order to to build the FEM model the materials, geometries, properties, meshes, loads and boundary conditions were all defined and will be presented
next.

- Geometry

The skin was represented without any curvature since it would not influence the results that much, due to the fact that the fuselage radius is very large and the installation is located at \( Y = 0 \). The doubler was also modeled as a non curved plate and the stringers as two straight lines below the skin. Finally the rivet pattern and cut-out were designed, with an extra circle around them in order to assure a good quality mesh at those locations, where the results should be as accurate as possible. The camera and the adapter plate, as well as their screws were not modeled due to the low camera weight (1kg), from which it was concluded that the inertial load cases would not have much influence on the static analysis.

- Materials

The doubler is made of Aluminum (AL) alloy 2024 T3, the skin of AL alloy 2523 T3 and the stringer of AL alloy 7150 T77511. Their Young’s modulus, Poisson ratio and density were taken from the Metallic Materials Properties Development and Standardization (MMPDS) [23].

- Properties and Mesh

The skin and doubler were modeled with plate elements, both squares and triangles, being defined by their thickness \( t_{\text{skin}} = 0.1 \text{ in} \) and \( t_{\text{doubler}} = 0.11 \text{ in} \). The stringer was modeled as a rod element, having thus a section area \( A_{\text{stringer}} = 0.1801 \text{ in}^2 \). The rivets were modeled with spring elements which simulate the shear and tensile stiffness and rigid elements which simulate the rivet on the skin and doubler. With these properties it was possible to mesh the model, taking into consideration that a convergence analysis was done beforehand in order to select the most appropriate mesh size.

- Loads

In order to run the model it is necessary to apply loads to it. Four load cases were considered, which take into account the fuselage loads, which are a combination of the cabin pressure loads and the fuselage bending, as well as the ultimate load factors that affect the aircraft. The aerodynamic loads are not being considered because they are very small when compared to the rest of the considered loads, due to the size of the camera.

For the fuselage loads, a detailed investigation of the aircraft was needed, in order to determine factors such as its fuselage weight, fuselage area, among others. In regards to the load factors, the positive and negative limit maneuvering load factors where compared with the positive and negative limit gust load factors, as to determine which one was the most conditioning for the flight envelope. With this it was determined that the ultimate load factors down and up were 5.1g and 1.5g respectively. The emergency landing load factors were also taken, since there is a load case that depends of this parameter, from CS25.561 as being 6g down and 3g up.

With all this information it was possible to determine the total circumferential and longitudinal stresses of the four load cases, whose descriptions will be presented next. The first load case (LC101) is the combination of the longitudinal and circumferential pressure loads only (ultimate) multiplied by 1.33. The second load case (LC102A) is the combination of the longitudinal load due to the flight envelope up and the ultimate pressure. In the bottom part of the fuselage the internal pressure and up flight loads create tension, which means that both loads are added in order to calculate the total longitudinal load. The third load case (LC102B) is the combination of the longitudinal load due to the flight envelope down and the ultimate pressure. Since now the flight loads are in the down direction then a compression will be created in the bottom part of the fuselage. By this reason, the bending contribution is subtracted. The fourth and last load case (LC103) represents the longitudinal load due to the emergency landing (ultimate) [24]. Finally these stresses are converted into loads and applied on the skin and stringers.

- Constraints

The applied constraints were used in order to try and better approximate this model to reality, being then applied in the four corners of the skin and edges of the stringers.

4.3. Static Analysis

In general, the margin of safety for the skin, doubler and other components in tension or compression is [24]:

\[
MS = \frac{\sigma_{Tu}}{\sigma_{V M_{\text{max}}}} - 1, \tag{1}
\]

where \( \sigma_{Tu} \) is the ultimate tensile stress and \( \sigma_{V M_{\text{max}}} \) is the maximum Von Mises stress on the surface. The Von Mises stress is being used to determine the margin of safety because this parameter takes into account different stress components such as \( \sigma_X, \sigma_Y \) and \( \tau_{XY} \) [25], thus predicting the stress on the model in a more accurate way.

Furthermore, in order to obtain the fasteners margins of safety, equation 2 was used, where the maximum shear force applied to a specific fastener type was taken from FEMAP and replaced in it [24].
\[ MS = \frac{\sigma_{Su} \times A_f}{S_{max} \times 1.5} - 1, \quad (2) \]

where \( \sigma_{Su} \) is the ultimate shear stress of the fasteners material, \( A_f \) is the fastener’s cross section area and \( S_{max} \) is the maximum shear force applied to the fastener. The factor 1.5 is included as a safety factor.

Finally another type of analysis that is usually done is the bearing’s margin of safety calculation. The bearing forces exist due to the presence of a rivet in its hole which can cause deformation if the ultimate bearing load is surpassed. In order to calculate this margin of safety, the formula from equation 3 applies [24]:

\[ MS = \frac{t_{plate} \times D \times F_{bu}}{S_{max} \times 1.5} - 1, \quad (3) \]

where \( t_{plate} \) is the thickness of the plate in which the fastener is going through, \( D \) is the fastener’s diameter and \( F_{bu} \) is the bearing’s ultimate load.

By running the model the stress distributions were obtained, for the doubler and skin as well as the shear load distribution on the fasteners. In figure 5 and 6 the skin Von Mises stress distribution and the fasteners shear loads are presented.

![Figure 5: Von Mises stress (psi) distribution on the Skin.](image)

The value of the maximum Von Mises stress, in figure 5, was expected to happen at the cut-out and in reality it does, however, in the model, the stresses around the rivets are unrealistic due to the rigid elements, which explains the obtained results. This is not a problem and only means the model is more conservative. By using the values obtained from FEMAP, the margins of safety were calculated starting with the values presented in table 1.

### Table 1: Skin, doubler and rivets margins of safety.

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Skin MS</th>
<th>Doubler MS</th>
<th>NAS 1997D8 MS</th>
<th>BACR15F7K8 MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC101</td>
<td>0.636</td>
<td>1.319</td>
<td>0.35</td>
<td>3.161</td>
</tr>
<tr>
<td>LC102A</td>
<td>1.217</td>
<td>2.396</td>
<td>0.758</td>
<td>3.591</td>
</tr>
<tr>
<td>LC102B</td>
<td>0.714</td>
<td>1.349</td>
<td>0.231</td>
<td>2.413</td>
</tr>
<tr>
<td>LC103</td>
<td>0.861</td>
<td>1.726</td>
<td>0.535</td>
<td>2.462</td>
</tr>
</tbody>
</table>

The margins of safety around the larger cut-out, on both the skin and doubler were also checked, in order to allow the comparison between the different load cases, to see which one lead to the most critical results. These MS values may or may not be the same as the skin and doubler’s MS from table 1, due to the already mentioned unrealistic stresses due to the rigid elements. These values are presented in table 2.

### Table 2: Skin and doubler margins of safety at the cut-out.

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Skin MS at the cut-out</th>
<th>Doubler MS at the cut-out</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC101</td>
<td>0.798</td>
<td>1.319</td>
</tr>
<tr>
<td>LC102A</td>
<td>1.595</td>
<td>2.396</td>
</tr>
<tr>
<td>LC102B</td>
<td>0.890</td>
<td>1.349</td>
</tr>
<tr>
<td>LC103</td>
<td>1.089</td>
<td>1.726</td>
</tr>
</tbody>
</table>

The bearing’s MS were also calculated and are presented in table 3.

### Table 3: Skin and doubler bearing’s MS for both rivet types.

<table>
<thead>
<tr>
<th>Skin Bearing MS</th>
<th>Doubler Bearing MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAS</td>
<td>BACR</td>
</tr>
<tr>
<td>LC101</td>
<td>3.434</td>
</tr>
<tr>
<td>LC102A</td>
<td>4.775</td>
</tr>
<tr>
<td>LC102B</td>
<td>3.043</td>
</tr>
<tr>
<td>LC103</td>
<td>4.040</td>
</tr>
</tbody>
</table>

By looking at the results it is clear that LC101 was the most critical load case for the skin and doubler, while LC102B was the most critical load case for the rivets. The bearing’s MS are very high, which is why they are usually not calculated due to the already existing knowledge of its guaranteed...
safety. To conclude, this installation which is going to be mentioned as configuration 1, passed on the static analysis.

5. Design Improvements

After doing the quad camera design, an improvement strategy with the objective of achieving a lighter, cheaper and equally secure design was made. The design concepts were varied and the static results, weight and installation cost were analyzed.

5.1. Configuration 2

The first noticeable aspect when designing the quad camera installation is the large and thick doubler, which has a high impact in terms of weight of the installation. Therefore, this design improvement investigation started by trying to reduce the doubler. This was also motivated by the fact that the stringer rivets were being used, in the doubler, which should be avoided because when a rivet is removed there is a high probability of needing an oversize rivet at the installation, in order to use that same hole. A larger fastener may concentrate more loads and thus lead to a crack initiation and propagation earlier than expected. To sum up, the doubler of configuration 2 is sitting between both stringers, being then much smaller than the doubler from configuration 1.

The weight reduction aspect was achieved, having reduced it by 19.1%. The overall cost was also reduced since less holes need to be drilled on the skin, which means less installation time required. If the installation takes less two hours then the company would save around 388 euros. The static analysis response will be presented in the final comparison among all the design configuration proposals, however the skin was now more loaded, which is what motivated the next configuration. This is a good example of design to weight and design to cost, which is crucial in the aerospace industry.

5.2. Configuration 3

A different approach was followed in order to try and reduce the stresses on the skin of configuration 2, by using internal L-brackets and stringer attachments which connected the doubler to the stringer, thus trying to lower the stresses on the skin. Unlike configuration 2, the weight of the installation has now increased, when compared to configuration 1, by 3.49%. The overall cost is assumed to be the same as in the first configuration.

The results of the static analysis are not very satisfactory, even though the worst case scenario for the skin has now a higher MS, when compared to configuration 2, which means that this strategy achieved its purposes to some extent.

5.3. Configuration 4

Another design variation strategy was followed which resided in changing the doubler’s thickness and not its length. Instead of using the SRM rule of thicknesses, which resulted in a doubler with a thickness of 0.11 inches, the rule from [22] was followed which states that:

\[ 1 \leq \text{Stiffness Ratio} = \frac{(E \times t)_{\text{doubler}}}{(E \times t)_{\text{skin}}} \leq 1.5, \quad (4) \]

where \( (E \times t)_{\text{doubler}} \) represents the Young’s modulus and thickness of the doubler, and \( (E \times t)_{\text{skin}} \) represents the Young’s modulus and thickness of the skin. The structural installation is adequate if the stiffness ratio is between 1 and 1.5, being considered too stiff when the value is greater than 1.5 and not stiff enough when it is less than 1.0. From this, and by taking a look at the existing sheet metal thicknesses, it was concluded that the minimum doubler thickness that could be used was 0.1 inches which means a 10% installation weight reduction, from configuration 1. The overall cost was maintained, and the stresses on the skin and doubler got increased.

5.4. Configurations Comparison

In order to compare the results, the lowest values of the margins of safety, for each comparison parameter were taken for all four configurations, since they represent the critical cases. The results were presented by using a spider chart (figure 7), which represents the results from configuration 2, 3 and 4 in regards to 1. An additional line was made in red, that represents MS = 0 which is the limit case.

![Figure 7: Comparison between configurations 1, 2, 3 and 4.](image)

The first thing that is clear when analyzing figure 7 it that configuration 3 is never the best one in terms of static analysis. This combined with the increase in weight make it a non-viable option for this
type of installation. Additionally, configuration 4 has a very similar profile of margins of safety to configuration 1, and a weight reduction of 10%, while configuration 2 has a noticeable reduced margin of safety on the skin (although it is still far from the red boundary), but other advantages which should not be undermined such as the 19.1% weight and cost reductions.

Based on the margins of safety and by taking into consideration the weight and cost saving, then it is concluded that the design of configuration 2 would be very interesting to pursue, which means, doing the fatigue and DTA analysis and then comparing it with configuration 1. If those extra analyses led to similar results when compared to configuration 1, then it would be beneficial for the company to choose the improved design. In case the results do not prove that configuration 2 is better, then the fatigue and DTA of configuration 4 should be done, since it also shows promising static stress results.

6. Certification and Compliance Documents
A modification project is not over once the design and stress analyses are finished. There are several documents that need to be prepared in order to apply for the STC and successfully certify the modifications.

This documentation is often divided into two categories which are the certification documents and the compliance documents. The purpose of the latter is to prove compliance to the different certification chapters while the certification documents summarize all the certification aspects of the modification, and guarantee that all certification chapters impacted by the modification are addressed.

A list of these documents and their descriptions is presented in [26].

Once all the documents are released, then the STC application can go forward to the competent authority, which in this project, as already stated, was EASA, which will approve the modification if all requirements are fulfilled.

7. Conclusions
The primary objective of this work was to present aircraft modifications as done in Jet Aviation, while showing two different installations: a Ka-band antenna and a quad camera. Even though they are different systems it was possible to see that their design goes through similar processes such as choosing the installation location and defining the aircraft’s environment on that area.

Furthermore, the industry standards such as the ARINC 791 are used in order to ease the design of the structural modification, through the use of already existing instructions. The design guidelines, such as the inter-rivet pitch, also have a scientific background which means that by following them, the analysis and calculation effort is considerably reduced, which benefits the project’s budget. As seen, the Ka-band design was successful, having been in accordance with the stress department as well. The stress analyses still need to be approved and the documentation prepared, in order to fully finish the project.

Regarding the quad camera, the design was also approved and the static analysis results were satisfactory. This modification brought the second biggest objective of this work which was doing an improvement to the released design, that resulted in a weight and cost reduction without compromising the structural integrity of the structure. In order to test this, three new configurations were created, which introduced variations to the released design such as reducing the doubler’s size, thickness or adding more parts to the installation.

In terms of results it was seen that configuration 3 did not achieve what was supposed to, being then configuration 2 and 4 more promising. In regards to the original design, configuration 2 achieved a 19.1% weight reduction and a cost reduction of about 388 euros, and configuration 4 a 10% weight reduction. The fatigue and DTA analysis still need to be done in order to determine the inspection intervals of the installation and therefore conclude the best installation option.

At last it was seen that the documentation part is very important since it will help certify the modification.

To conclude, several future work opportunities were analyzed. The first aspect is regarding the Ka-band antenna, since fitting’s 2 and 6 can probably also have one intercostal, since they are loaded in the same direction as fitting 7. One other interesting continuation to the work would be to finish the analysis of configuration 2 and 4 of the quad camera, by doing the fatigue and DTA, thus determining if either one of them is better than the original configuration or not.

References


