

Sealant Joints in Aircraft Integral Fuel Tanks

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ABSTRACT: Leaks arising from aircraft fuel tanks have constantly represented a problem for aircraft manufacturers, operators and maintenance crews. The integral fuel tanks within aircraft structures are in general located within the wings and they rely on sealant materials to prevent leakage through joints and fasteners. However, aircraft integral fuel tanks are designed from a structural point of view first and as a fuel tank second. There are numerous potential leak paths for the fuel on these complex wing structures. The overall aim of the current research was to reduce the fuel leaks in the aircraft fuel tanks at the delivery. Following this approach a company background analysis was performed in order to find out the regions in the fuel tanks susceptible of fuel leaks. A Finite Element Analysis (FEA) of a critical structural member was done to investigate the structural behavior and propose structural improvements. A workcard with instructions to perform a Nondestructive Inspection (NDI) in the identified structural member was developed. A research and test of new sealants products was accomplished. The main goal was to initiate a research and test of potential sealants products in order to conduct a future proposal to the Lockheed Martin. A maintenance instructions manual was developed in respect to the procedure to inspect, clean and seal the fuel tanks. It was introduced simplified maintenance instructions to all the technicians in order to make possible an accurate sealing of the fuel tanks.

Keywords: Aircraft, External Fuel Tank, Pylon Fitting, Structural Analysis, Sealants, Maintenance Instructions.

1. Introduction

Aircraft fuel tanks correspond to a constant source of problems for aircraft designers and users. The integrity of sealed joints in the integral fuel tanks of military and civil aircraft has important cost, operational, safety and environmental implications. Integral fuel tanks within aircraft structures are typically located within the wings. Usually, aircraft integral fuel tanks are designed from a structural point of

view first and as a fuel tank second. The skin of the wing is attached to the inner structure of the wing and the joints connecting the internal structure and the skin has to be sealed to avoid leakage of fuel. The structures on an aircraft as the C-130 are designed and manufactured with the use of machined parts that, if sealed correctly, perform both as a load bearing structural element and as an integral fuel tank. Unfortunately, inside the wings of an aircraft there are innumerable potential leak pathways for the fuel ranging from those stuck

between inter-faying surfaces, those from skin joints, those from the fasteners themselves, those from conduits (housing electric cables) and those from pipes and hoses (for fuel, hydraulic and de-icing fluids). It can also be added the special effects of flight stress fatigue, temperature, contaminants (water, deicer fluid and microbiological attack), the fuel itself and application failures on original assembly and at following repairs. It can therefore be appreciated that the potential for leaks is vast.

The operational life of an aircraft can be more than 30 years with no considerable operational leaks, but after a certainly period it starts to emerges several problems that increases the cost of maintenance and the current aircraft is no longer viable to operate.

In a single typical wing of a military aircraft it is likely that there is about 660 lbs of sealant substance. This is applied and has to stick to prepared, coated and anodized aluminum in current aircraft. As a result a sealed joint system comprises the sealant, basic coverage coating(s) and the parent skin material (figure 1) [1], [2].

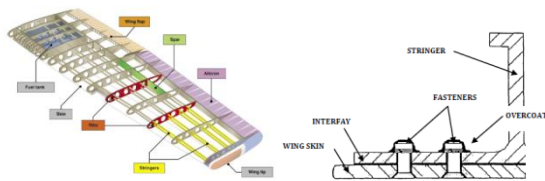


Figure 1 – Internal wing components and cross section through the wing skin [1] [3].

The investigation for new sealants has to be an active project in the current aerospace industry.

The overall aim of the current research was to reduce the fuel leaks in the aircraft fuel tanks at the delivery. A research and test for

new sealants products were performed and the maintenance instructions manual developed, evaluated and updated in respect to the procedure to inspect, clean and seal the fuel tanks. Following this approach a finite element analysis (FEA) of a critical structural member was done to investigate the structural behavior.

2. Pylon Fitting Analysis

2.1. Aerodynamic Analysis

In this section, the contributions of the aerodynamic forces are evaluated. Since the external tank is a component with significant dimensions there is a significant contribution of this to the aerodynamics forces acting on the Pylon Fitting.

Drag forces are defined as those loads encountered during flight at maximum design airspeed due to the shape and size of externally-mounted equipment. To estimate the drag coefficient from the fuel tank installation geometry and using the basic formulas following was assessing the drag, where (ρ) is the air density, (V) is the free air stream speed, (S) the front effective surface of the fuel tank or Pylon, and (C_D) the drag coefficients [4].

$$Drag_{ExternalTank} = 0.5\rho V^2 S_{tank} C_{D_{Tank}} \quad (1)$$

$$Drag_{Pylon} = 0.5\rho V^2 S_{Pylon} C_{D_{Pylon}} \quad (2)$$

$$Drag_{Installation} = Drag_{ExternalTank} + Drag_{Pylon} \quad (3)$$

The table 1 presents the drag components determined previously.

Components	
$Drag_{ExternalTank}$ (lbf)	2674.63
$Drag_{Pylon}$ (lbf)	526.15
$Drag_{Installation}$ (lbf)	3200.8

Table 1 – Drag components

2.2. Structural Analysis

The purpose of this section is to evaluate the behavior of the Pylon Fitting component under ultimate loads that the aircraft is subject in three different flight conditions. The Fitting structure layout is presented and a detailed finite element model of the Fitting has been built and analyzed to verify the design of the structure and the critical regions.

All the loads acting on the structure are supposed to be only from the external fuel tank installation. This part of the structure has had in-service several fuel leak problems. The structure member is shown in figure 2.



Figure 2 – Pylon Fitting (Front web)

The simplification adopted consists of assessing the reactions R_1 and R_2 in the front and rear Fitting, respectively. The forces applied are the drag and the gravitational of the two components. Figure 3 presents a scheme of the free-body diagram. The variable (R_1) is the vertical reaction created at

the front Fitting, (R_2) is the vertical reaction created at the rear Fitting. (D_1 , D_2) and (W) are the drag force components and the gravitational force, respectively. The (R_{D1} and R_{D2}) are the reactions created due to the drag force components. The (M_D) is the moment created by the drag force, applied in the rear Fitting. The distance (d_1) is the horizontal distance between the component R_1 and the center of mass, (d_2) is the horizontal distance between the component R_2 and the center of mass, and (H) is the vertical distance between the components R_1 and R_2 to the center of mass.

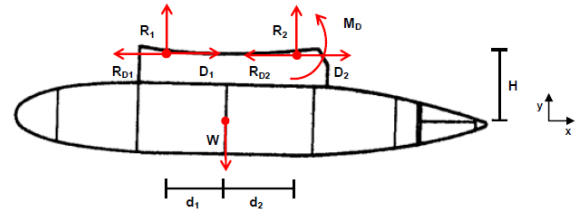


Figure 3 – External tank installation simplification (Free-body diagram)

The reactions created by the two components to the Fittings are obtained through forces and moment equilibrium. The equation signs are taken based on figure 3 scheme.

$$D_1 = D_2 = \frac{Drag_{Installation}}{2} \quad (4)$$

$$M_D = Drag_{Installation} H \quad (5)$$

$$\sum F_i = 0 \Leftrightarrow R_2 = W - R_1 \quad (6)$$

$$\sum M_i = 0 \Leftrightarrow R_1 = \frac{Wd_2 + M_D}{d_1 + d_2} \quad (7)$$

The values for the reactions determined previously are shown in the table 2

Components	
R1 (lbf)	7551.93
R2 (lbf)	4171.42

Table 2 – Distances components and reactions

In this analysis, three different flight conditions were considered. The purpose is to evaluate the behavior of the Pylon Fitting component under ultimate loads [1].

1. Airspeed – 320 knot at 20000ft conditions;
2. Level Flight – 1g down;
3. In Flight Gust Loads – 8.25g down;
4. Banked turn with $\theta=60$ degrees and 3g down.

Finite Element Analysis

The analysis of a complex member such as the Pylon Fitting requires a finite element model on which the constraints, loads and elements characteristics will be applied in order to obtain a solution. The software used in the analysis was the ANSYS® APDL interface [5], [6].

The ADPL interface allows the user to create a 3D model of the structure. However, the ADPL modeler is not so handy when it comes to complex parts. So, a CAD model was created with external software (such as SolidWorks®) and then exported in the *IGES* format, to ANSYS APDL. The fasteners were modeled considering some simplifications and applied to the member structure. Following the boundary conditions were applied to the structural model and chosen accurately in order to obtain the best simulation of the real behavior of the structure.

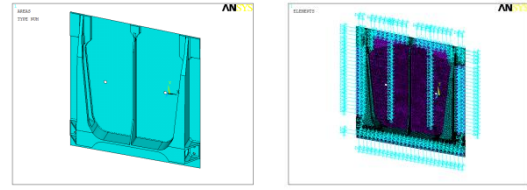


Figure 4 – Fitting model created and assembled in ANSYS®

FEA Results

Once the geometrical values, boundaries conditions and load distribution have been introduced in the FE Model the static analysis was performed. There were determined several safety margins related with the various elements which allowed to define the static behavior of the structure.

The safety margins were determined using the next equation [7]:

$$MS = \frac{\sigma_{ultimate}}{\sigma_{applied}} - 1 \quad (8)$$

In order to reach the safety margins an Excel file was developed to implement all the calculus related with the static analysis. For each element it was created a similar worksheet to evaluate the behavior under each condition. These results are fundamental to assess the maximum forces and stresses and compare with the ultimate for each element. The fastener shear-off and bearing failure were also evaluated.

Analysis Results

Considering the results from the previous analyses evaluated in the Excel file, the critical case was the in flight gust loads. Taking in attention this case, several critical regions were identified.

1. Fasteners (Hi-Lock, Solid Rivets, Shear Bolts)

The fasteners elements were evaluated in the Excel file considering the results provided by the FEA. For each element the shear force component was determined and compared with the ultimate. For the tensile force and the bearing failure the procedure was the same and the results compared with the material data.

The results indicate that the fasteners elements loaded the most are the shear bolts (Pocket) followed by the Hi-Locks in the Lower Flange.

The evaluation performed in the Excel concludes that the fasteners are in the safe zone but some MS are close to 0.5 for several elements (Pocket Shear Bolts and Lower Flange fasteners).

For some Lower Flange fasteners the MS for bearing failure presents to be in a relatively low value which correspond to a possible bearing failure on structural member (Fitting) at these fastener locations.

2. Fitting Member

Following the principal stresses are presented as well as the identified regions.

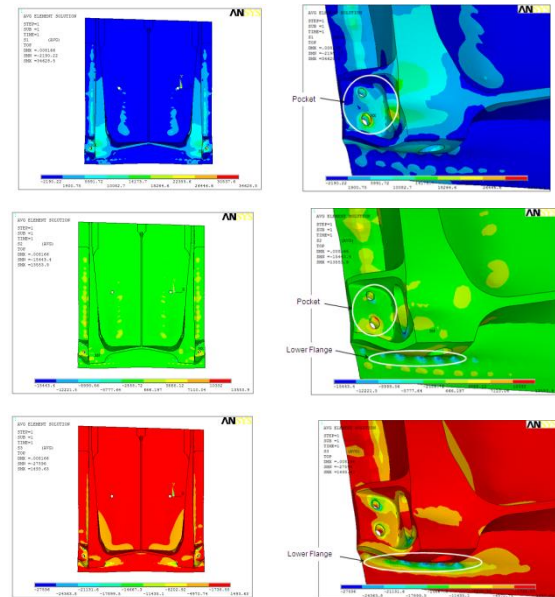


Figure 5 – Standard configuration – S1, S2 and S3

In the figure 5 are assigned the regions where the maximum stresses were identified. The region of the Pocket and the first line of fasteners in the Lower Flange are the critical zones. In accordance with aircraft structures design these results were expected once these elements are the first to be loaded and consequently the ones supporting more loads. Fuel leaks result mainly from net tension (cracking) or bearing in the elements [8].

Fitting Upgrades

Once the critical regions were identified several Fitting upgrades were evaluated. The procedure adopted considers a redesign of the Fitting avoiding modifying the shape which is essential to the assembly on the wing. As a result an effective solution is through the increase of the thickness in the identified regions increasing the net area and thus reducing the stress concentration.

The improvements considered were the increase of the thickness in the Lower Flange

from 0.2in to 0.3in and in the Pocket base by 0.1in.

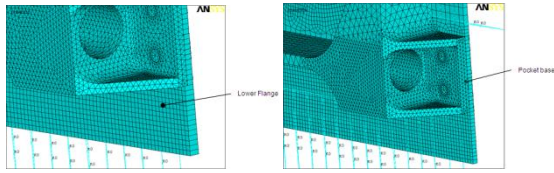


Figure 6 – Lower Flange and Pocket base thickness increase

1. **Lower Flange** – This upgrade consists in the increase of the thickness in the Lower Flange. It was observed that the improvement in the Lower Flange reduced significantly the maximum stresses in the structure but increases the loads transfer by the lower fasteners. This increase is suitable once the load values carried by these fasteners are in the safety zone.
2. **Pocket** – This upgrade consists in the increase of the thickness in the Pocket base. The modification in the Pocket did not carry significant improvement. Although the maximum principal stresses decreases the stress concentration increases in the Pocket. The Lower Flange fasteners are slightly relieved as observed but the increase of stress in Pocket is not intended.
3. **Lower Surface** – Considering the results obtained with the improvement in the Lower Flange, the same procedure was applied to the Lower, Side and Top Flanges as well as the Interior surface.

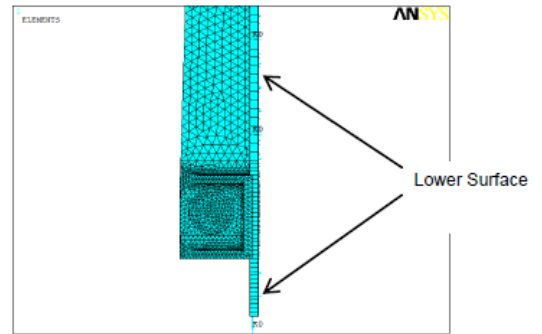


Figure 7 – Lower surface thickness increase

This modification introduced reinforcement in such regions resulting in a load transfer from the Pocket and Lower Flange section to the Fitting Side Flanges, Interior and Top. Consequently the Pocket and Lower Flange sections were relieved and the stress concentration decrease in the critical regions.

The previous improvements performed in the Fitting member were evaluated in respect to the weight increase. The table 3 presents the detailed weight increase in percentage (%) considering the standard configuration.

Configuration	Total Weight (Lbs)	Weight increase (%)
Standard	24.32221	0
Lower Flange	24.90145	2.381506
Pocket base	24.39706	0.307706
Lower Surface	28.56482	17.44334

Table 3 – Weight increase (%) of the configurations considered

The Lower Surface upgrade increases the Fitting weight by approximately 4.2 lbs. Considering the aircraft empty weight this increase is about 0.005 % (negligible).

2.3. WorkCard

A workcard with instructions to perform a Nondestructive Inspection (NDI) on the forward and aft Pylon attach Fittings was developed. These inspection procedures are in the SMP 583 [9] and the purpose was to develop and update these procedures in order to inspect the identified zones. These instructions were based on the results from the FEA carried previously.

The procedure to inspect is accessible on the card SMP 583 [9]. The figure 8 presents the front Fitting with the scan areas indicated. It includes the Bottom Cap Hi-Locks (Countersunk fasteners) and the Pocket holes (Shear Bolt holes).

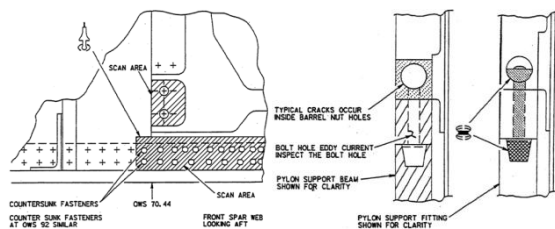


Figure 8 – Forward Pylon attach Fitting and Pylon attach bolts and nuts (Scan Areas) [Adapted 9]

3. Sealants and Sealant Testing

One definition of sealant is "a material that isolates one environment from another"[10]. For a sealant to be effective in performing its function it must have some essential characteristics: flexibility and fatigue resistance; physical strength, chemical and environmental resistance, and high adhesion to all surfaces to which the sealant is applied. Of these characteristics, adhesion is the most important as a material will lose its ability to

"seal" the moment that adhesion is lost. There is no such thing as the "perfect sealant" since no sealant can possess all of the desirable properties for all applications.

It is produced in the following classifications [11]:

1. **Type I** – Sealing material suitable for brush or dip application
2. **Type II** – Sealing material suitable for application by extrusion gun or spatula
3. **Type III** – Sealing material suitable for spray gun application
4. **Type IV**– Sealing material suitable for faying surface application gun or spatula

Sealant joints used in aircraft integral fuel tanks:

- **Interfay Sealing**
- **Joint Edge Sealing**
- **Overcoat**
- **Wet assembly**

The principal application areas are shown in a typical skin butt-strap joint in figure 9 [12], [13].

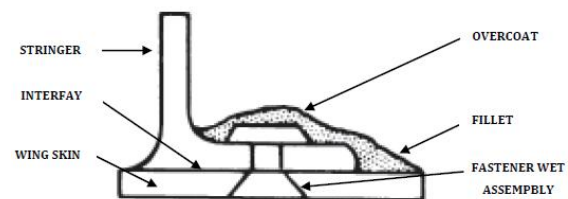


Figure 9 – Sealant application used in aircraft integral fuel tanks [adapted 13]

Sealants Tests and Results

In order to acquire results from the sealants used in aircraft fuel tank maintenance, 4 different sealants (types II) were evaluated.

From these sealants 2 are currently employed in fuel tanks sealing at OGMA (1 and 3) and the other 2 are potential products to apply (2 and 4).

The products tested were:

Specification - AMS-S-88002

1. PR 1440 B2
2. AC 236 B2

Specification - MIL-PRF-81733

3. PS 870 B2
4. MC 780 B2

The products currently used at OGMA in C-130 (1 and 3) were tested to validate their standard properties from the manufacturer and to compare with the results from the products not employed at present (2 and 4).

The tests are presented next [3]:

1. Application properties test (Appearance and Color)



Figure 10 – Preparation of sealing compound

2. Viscosity of base compound test

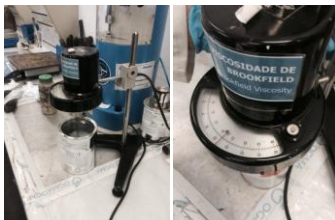


Figure 11 – Viscosity of base compound test

3. Flow test

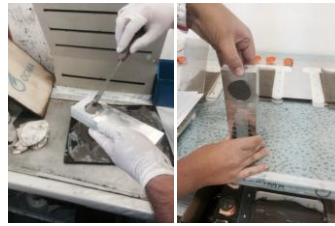


Figure 12 – Flow test fixture and procedure

4. Tack-free time test



Figure 13 – Sealing compound under test

5. Standard curing and 14-day hardness test (Complete cure)



Figure 14 – Type A Durometer

6. Shear strength test

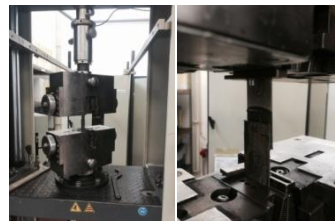


Figure 15 – Shear strength test machine

7. Peel strength test

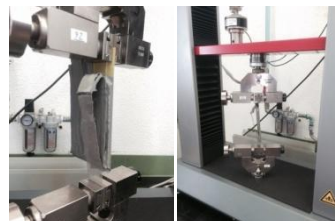


Figure 16 – Peel strength Test

A correct sealant application has direct influence on the sealant adhesion and long term performance. For this reason it is very

important to ensure that maintenance instructions are accomplished during maintenance process. The correct products and procedures to deal with fuel tank sealing repair and application reduce significantly the possibility of fuel leak in future. In the next chapter it is presented a brief resume of the general fuel tanks sealing instructions.

4. Maintenance Instructions

Correct and simplified maintenance instructions must be available to all the technicians in order to make possible an accurate and efficient sealing of the fuel tanks. It is also important that they are aware of the principal causes of leaks and how they can be reduced. In this chapter it is presented a brief resume of the general fuel tanks sealing instructions addressed [9], [11], [13].

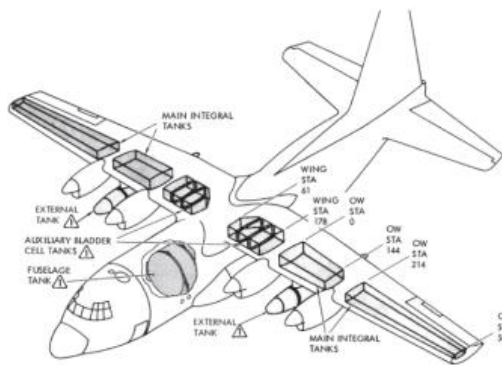


Figure 17 – Fuel tank locations [13]

Inspecting, Cleaning, and Sterilizing Fuel Tanks

1. Defueling
2. Purging and ventilation
3. Tank Entry
4. Cleaning Fuel Tanks
5. Decontamination

Sealing Process

1. Sealing during assembly
2. Injection sealing
3. Fillet sealing

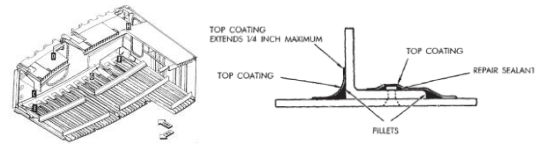


Figure 18 – Sealing during assembly and fillet sealing illustration [13]

4. Fastener sealing
5. Brush sealing
6. Sealing repairs

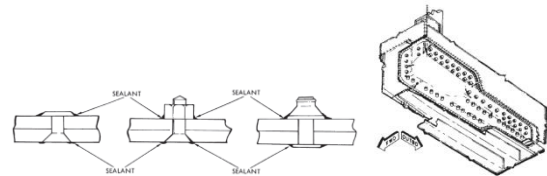


Figure 19 – Fastener sealing and brush sealing illustration [13]

Corrosion Protection

1. Sealing for corrosion protection
2. Inspection for corrosion under sealant

5. Conclusions

The overall aim of the current research was to reduce the fuel leaks in the aircraft fuel tanks at the delivery. Following this approach a FEA of a critical structural member was performed in order to investigate the structural behavior under critical loads. This analysis allowed to decide the upgrades and the location of structural reinforcement applied and verified through FEA.

A workcard with instructions to carry out a Nondestructive Inspection on the forward and aft Pylon attach Fittings was considered. The purpose was to evaluate and update these procedures in order to inspect the identified zones. These instructions were based on the results from the FEA carried previously. These instructions are also valid for others fuel tank areas.

A research and test of new sealants products were performed. The main goal was to initiate a research and test of potential sealants products in order to make a future recommendation to Lockheed Martin. It was concluded that the results obtained were directly associated with the poor surface preparation (absence of promoter) before the sealant application and these results are important to advertise the maintenance technicians for the importance of the correct surface preparation. A correct sealant application has direct influence on the sealant adhesion and long term performance.

The maintenance instructions manual was developed, evaluated and updated in respect to the procedure to inspect, clean and seal the fuel tanks. It was introduced correct and simplified maintenance instructions to all the technicians in order to make possible an accurate sealing of the fuel tanks.

The direct result of the developed work is expected to reduce the maintenance hours and avoid delays in the aircraft delivering, contributing to optimize the costs of the company.

Future developments should be concerned with the introduction of dynamic and environmental parameters representative of actual flight conditions. Almost all tests performed are of a static nature, it is

acknowledged that movement (high stressed areas) and poor surface preparation lead to leaks. Thus the missing component of testing is movement coupled with the other key variables.

6. References

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