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Gravel Deflector Aircraft Integration

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Abstract

A gravel deflector is a protective device installed on the aircraft to prevent debris from being thrown up by the rotating wheels.

For the integration in the C295 aircraft, it was designed to be attached it to the landing gear, as a kit. In order to support the design, a model able to compute the interface loads with the bay and the landing gear was built. This model takes into account the aerodynamics, the structural flexibility, the hydraulic system functionality and the kinematics in order to obtain realistic loads.

The model has been developed in MSC Adams software, and it has been validated against laboratory tests in order to check that the loads used for design are correct.

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1. Introduction

In this paper, it is described the challenges faced during the development of the gravel deflector loads model, under the C295 program.

The C295 is an aircraft certified[1] by Airbus that is able to operate on unpaved runways. When the aircraft is operating on unpaved runways, the landing gear wheels can lift debris (such as stones) that can damage the aircraft external surfaces. In order to avoid this, a gravel deflector was developed and installed, in order to protect the aircraft from debris hits.

The Gravel Deflector consists on a shielding element, supported by links and attached to the NLG leg by means of a supporting frame, that folds with the support of the folding system, as shown below on Figure 1.

- The shielding element is the effective part that interposes in the trajectory of the debris, absorbing the excess of its energy or preventing it to reach any impact in sensible element installed on the lower part of the aircraft fuselage that might otherwise be damaged as result of the impact.
- The links serve as support for the shielding element up to the upper and lower attachments.
- The supporting attachments support both the shielding element and the links in place, attached to the nose landing gear.
- The folding system is attached to the bay, and forces the folding of the shielding assembly into the bay during the nose landing gear retraction.

Due to the constraints of the aircraft design, it is not possible for a Gravel Deflector to provide full aircraft protection capabilities. So the design of the Gravel Deflector shall maximize the area of protection and minimize the negative effects on the non-protected areas. In the C295 Gravel Deflector case, it was designed to protect sensible elements installed on the lower part of the aircraft fuselage, but it was not ensure the protection on the propellers.

For sizing the gravel deflector, it was necessary to build a model able to compute the interface loads with the bay and the landing gear. The model shall be representative for all the aircraft flying conditions in which the gravel deflector is outside and inside of the bay: landing gear retracted phase, landing gear extended phase and landing gear transition phase (between extended and retracted position).

This model takes into account the aerodynamics, the structural flexibility, the hydraulic system functionality and the kinematics in order to obtain realistic loads. The model[2] has been developed in MSC Adams software, and it has been validated against laboratory tests in order to check that the loads used for design are correct. A description of the methodology followed is described in this paper.

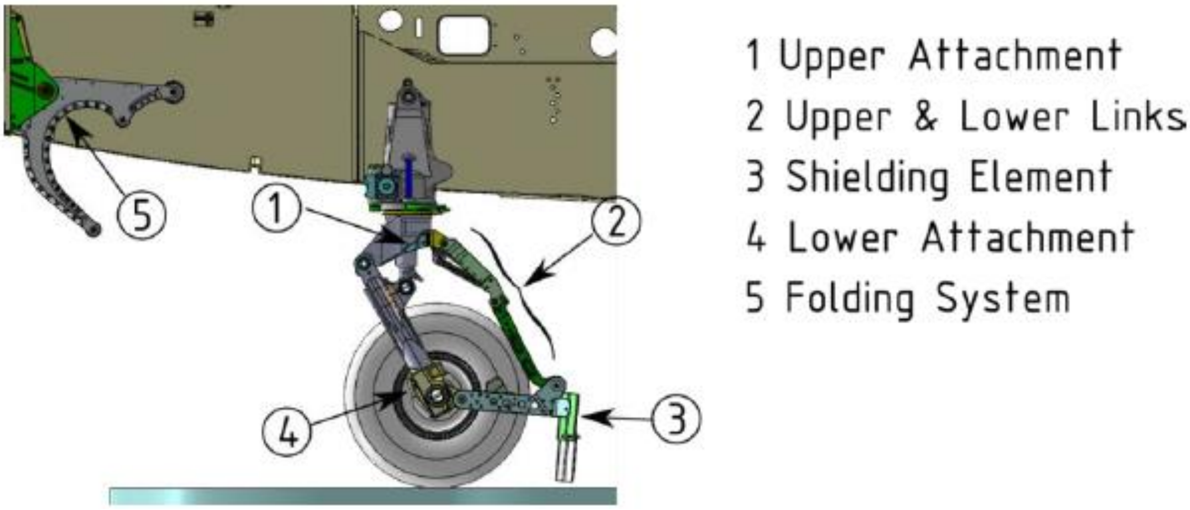

Figure 1: Gravel deflector main parts

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2. Load conditions

The gravel deflector shall withstand all the operating load conditions that occur during aircraft flight and aircraft maintenance operations.
During the aircraft flight operation, the equipment could be outside or inside of the bay: landing gear retracted phase, landing gear extended phase and landing gear transition phase (between extended and retracted position).

Over the landing gear retracted phase, the gravel shall be able to withstand the inertia loads that come from the flight phase.

All along the landing gear extended phase, the gravel shall be able to withstand the loads coming from: landing approach, landing run, ground handling, taxi and take off run.

Midst the landing gear extension-retraction phase, two conditions shall be analysed: the flight condition and the ground condition. The difference between these two conditions is the application of the aerodynamic loads. In the case of the ground condition no aerodynamic loads are applied. The ground condition is related to the aircraft maintenance operations.

During the aircraft ground operation the gravel is subjected to external forces coming from material projected from the tyre to the shield: water and debris (slush or gravel).

In order to cover all the above conditions, it has been defined load cases for structural design:

a) Inertia loads.
b) External load
c) Ground loads
d) Extension-retraction loads
e) Lateral loads

2.1 Inertia loads

Two conditions are analysed: the flight phase inertia load case and the rebound landing load case.

For the flight phase inertia load case, it is analysed the combinations of maximum and minimum acceleration in each of the aircraft axis. In order to simulate these conditions, all the masses of both the NLG and the Gravel Deflector assemblies have been excited under the same conditions with the NLG in the retracted position, assuming that the kinematic of the NLG is fixed.

For the rebound landing case, the rule[1] is requesting that the unsprung mass of the landing gear has to withstand 20g. This case is applicable for gravel deflector elements that stop the movement suddenly because the shock absorber piston reaches their abutments. In this case, the landing gear is at their extended position. Typically this case occurs after a rebound landing or after take-off run. Also it has been applied a 20g load case to the folding system when main part suddenly stop against their attachment.

2.2 External loads

External loads are defined to cover the aircraft operation on flight and on ground. In this case, the landing gear is at the extended position. The external load cases are due to the aerodynamic forces applied on the shield and from material projected from the tyre to the shield.

The gravel deflector shall withstand the loads coming from the aerodynamics with the aircraft flying at the maximum gear extended speed. These loads shall be validated by flight tests. The shock absorber is at the extended position

The equipment shall withstand the loads originated by solid elements projected from the tyre. These solid elements has a determined mass and hardness that has been agreed with the aircraft buyer since it is not possible to cover any size and hardness without affecting the already landing gear and aircraft design. The impact energy has to be associated to the maximum aircraft ground speed. For the shielding element a reduction on the aircraft ground speed is allowed in

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order to penalise the equipment weight since this element can be replaced in case of damage. This case is computed with the shock absorber and tyre at their 1g static compression.

The gravel deflector components shall withstand the loads generated by the water sprayed by the tyres when the aircraft traverses a specified water layer thickness at maximum aircraft ground speed. In the case of the C295 the water layer thickness is 1/2 inches. This case is computed with the shock absorber and tyre at their 1g static compression.

2.3 Ground loads

The gravel deflector is connected to the aircraft through the nose landing gear and moves jointly with the shock absorbers. Although the inertia loads coming from the shock absorber movement are small, it shall be taken into account in the design. It has to be noted that in the external load cases the shock absorber is stroke is fixed and there is no movement of the gravel deflector parts. For the analysis it has been selected the cases that has the greater inertial loads: landing impact critical case and rolling on ground critical case.

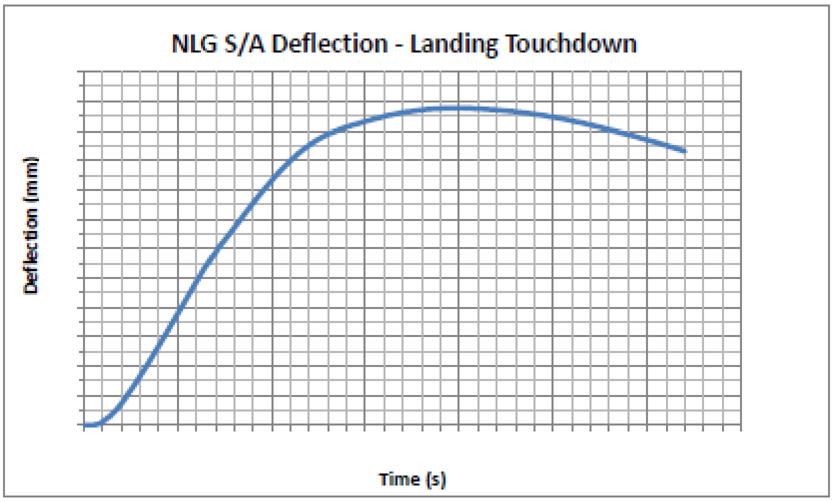

Figure 2: Landing impact critical case

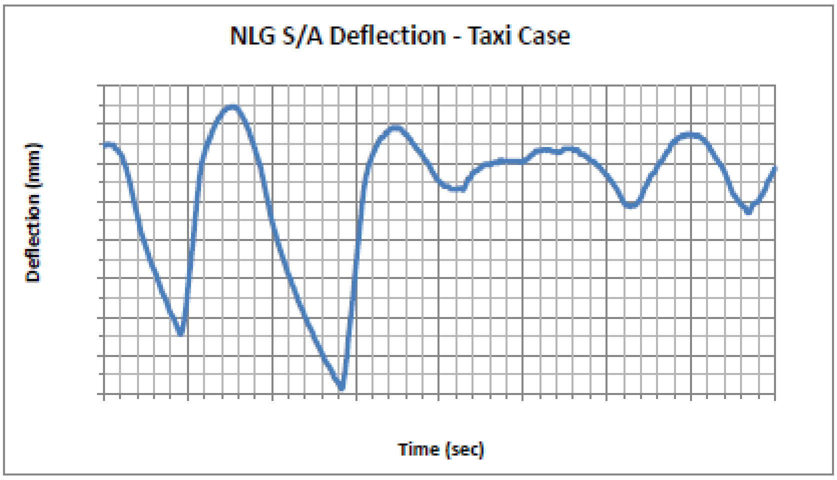

Figure 3: Rolling on ground critical case

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2.4 Extension / retraction loads

The extension / retraction loads are computed according to two scenarios: maintenance operation on ground and aircraft flight operation. For the maintenance operation on ground, the aerodynamic forces are not taken into account. For the aircraft flight operation the loads are computed at the maximum gear operating speed.

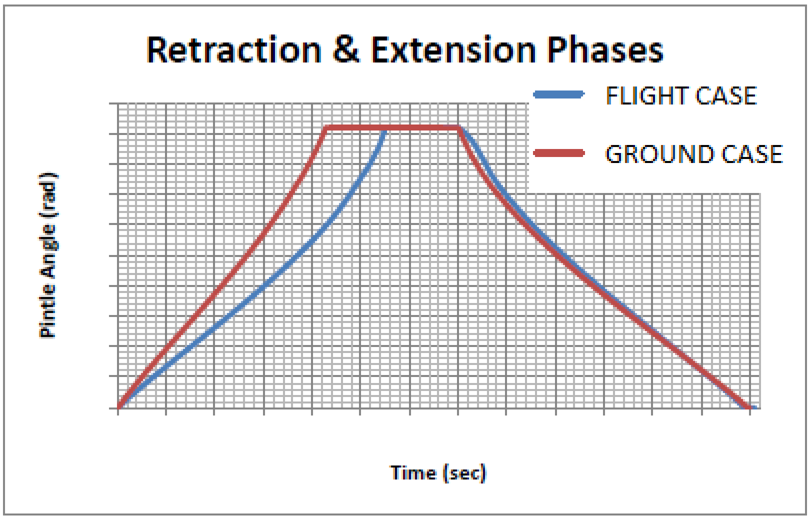

Figure 4: NLG angle extension-retraction timehistory

2.5 Lateral loads

Friction side loads are generated in the rollers of the folding brace when the contacting points on the landing gear suffer lateral displacements. The maximum friction force corresponds to the start of slipping and it is proportional to the contact normal load.

Friction forces during impacts shall not be considered for sizing due to the short duration time of application. For this reason we assume that folding system upper roller doesn't have friction forces, as the contact times are below 0.1 sec.

For the rest of folding system rollers, the contact load to be considered is the static load in the folded configuration as this covers all other load oscillations.

The friction coefficient depends on the material used on the roller and on the contacting structure.

Two types of materials are considered for the rollers: Nylon and Rubber.

During the flight phase, the landing gear has very little movement so the friction loads will be much lower than the maximum friction loads

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3. Modelling

The method to compute the loads to be used depends on the load case.

3.1 Inertia loads model

In this case, it has been used an ADAMS[2] to compute the loads over each of the gravel deflector component, the landing gear uplock and the landing gear interfaces.

In the following figure can be seen the landing gear at the retracted position. At this position has been excited the model with the inertia load factors.

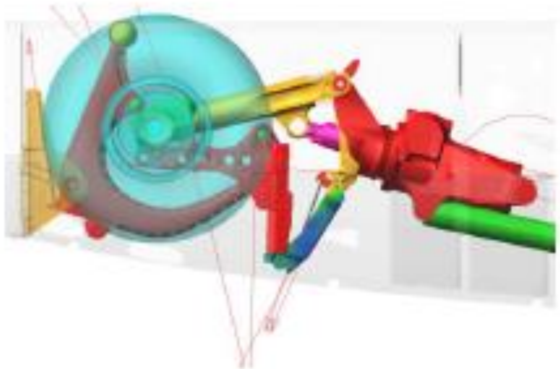

Figure 5: NLG Retracted Position for computation of flight inertia load cases

For the rebound landing case, the landing gear is at the extended position. At this position it has been applied the 20g load cases.

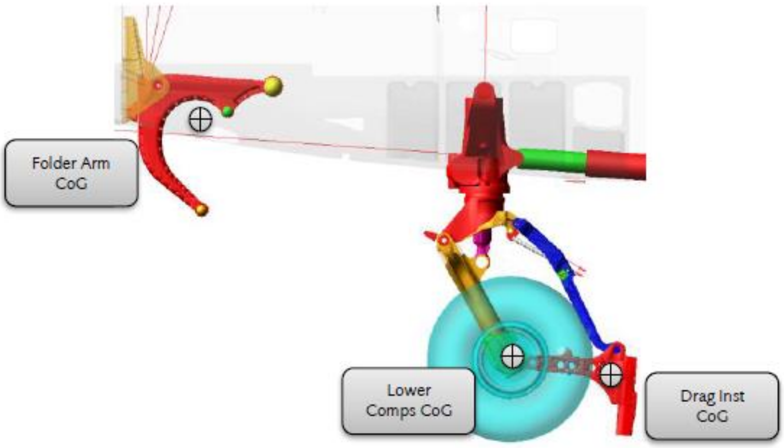

Figure 6: NLG Extended Position for computation 20g load cases

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3.2 External loads model

To compute the external loads, it has been used the landing gear ADAMS model at the extended position. The external forces (aerodynamic, debris or water) are reduced to one point of application in order to have an easy implementation.

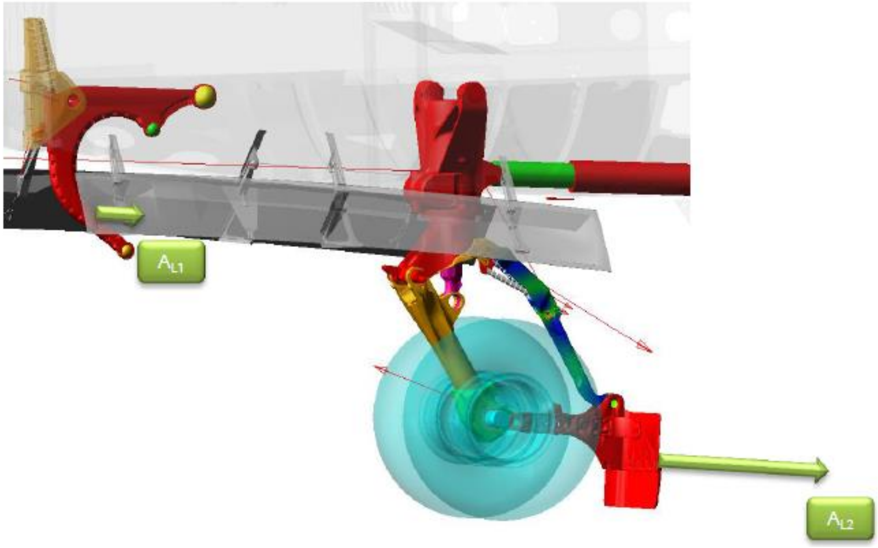

Figure 7: NLG Extended Position for computation of aerodynamic loads as an example.

In the case of the aerodynamic loads, it was necessary to build a CFD model in order to compute the air pressures on the shielding element since there the FLIR and the wheels disturbing the air stream upstream. A simple flat plate model based on ESDU[4] is used to estimate the normal force of the gravel deflector plate.

For the computation of the normal force the following equation has been used:

$$F_N = q_\infty \cdot S_{gra} \cdot \left[C_N \cdot \left(\frac{q_{eff}}{q_\infty}\right)_{bay} \cdot \left(\frac{q_{eff}}{q_\infty}\right)_{gear} \right] \cdot FF \qquad \textbf{(1)}$$

Where

q_∞ is the dynamic pressure of the non-disturbed stream upstream.
S_{gra} is the gravel deflector area
C_N is the normal force coefficient computed through the ESDU[4]
$\left(\frac{q_{eff}}{q_\infty}\right)_{bay}$ is the effective dynamic pressure ratio estimated with CFD for an open bay without landing gear
$\left(\frac{q_{eff}}{q_\infty}\right)_{gear}$ is the effective dynamic pressure ratio estimated with CFD for the landing gear
FF is the normal force coefficient ratio between the CFD computation and $C_N \cdot \left(\frac{q_{eff}}{q_\infty}\right)_{bay} \cdot \left(\frac{q_{eff}}{q_\infty}\right)_{gear}$

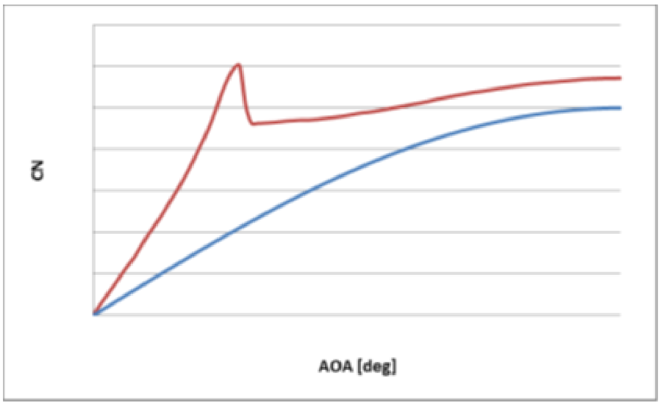

Figure 8: Graveller Normal Force Coefficient.

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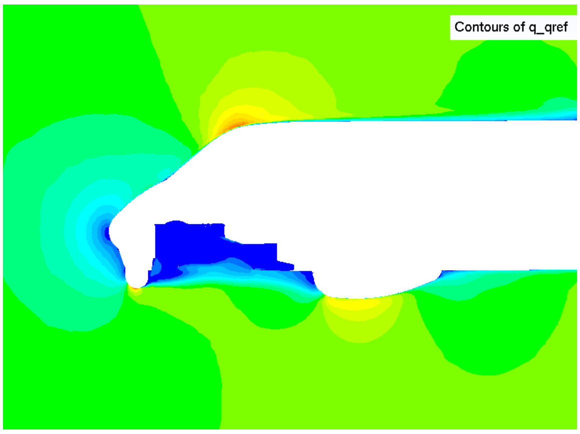

Figure 9: Effective dynamic pressure ratio is estimated with CFD.

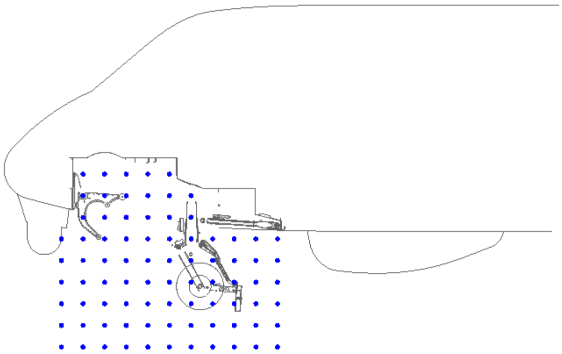
Figure 10: Landing gear bay control points.

In the case of the water spray loads, the loads has been computed using the method described in ref 3.

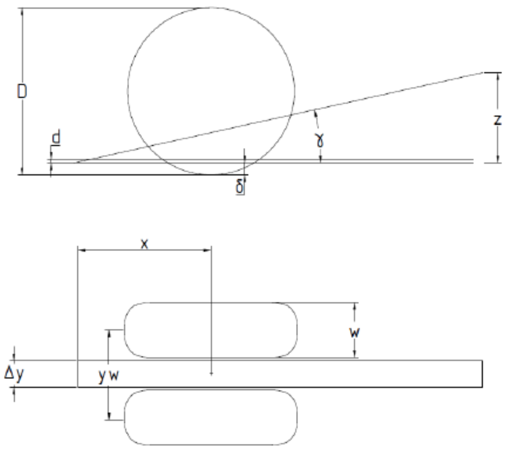

Figure 11: Spray Plume and Tyre Geometry according to ref. 3.

3.3 Ground loads model

For the ground load model, it has been used the landing gear ADAMS model at the extended position. In this model, it has been excited the shock absorber strokes according to the one defined in the corresponding load condition.

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3.4 Extension / Retraction loads model

For the extension-retractions, it has been used the landing gear ADAMS model at the extended position. In this model, it is included the hydraulic behaviour of the extension-retraction actuator in order to simulate with an accurate the extension-retraction times with and without the gravel deflector installation. Also it is included the aerodynamic model used for computation of the external loads. In case of ground simulation for maintenance operations the aerodynamic model is deactivated.

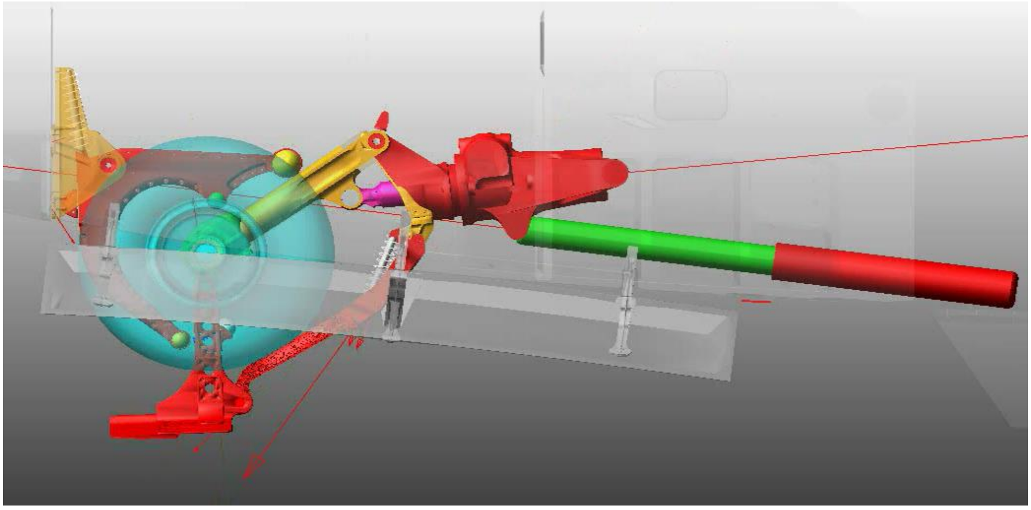

Figure 12: NLG extension-retraction model at an intermediate position.

3.5 Lateral loads model

The lateral loads are computed during the extension-retraction simulations. So same model as for extension-retraction loads computation is used.

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4. Loads results

The C295 gravel deflector is installed as an optional kit. For this reason, it is necessary to check if the loads coming from the gravel deflector size the bay or the landing gear.

In the case of the landing gear, the deflector gravel loads are not expected to size any part of the gear as the ground loads are much higher.

Since the bay bracket is located in an area that is not prepared to support loads inputs, it may be necessary to reinforce it.

To verify that the loads introduced by the gravel do not size the landing gear or the bay, the stress team defines some points in both structure in which the loads are calculated.

In addition, to sizing the components of the gravel deflector, the stress team defines points where it is necessary to apply the loads. These points are usually the joints of the parts and the contact zones.

For static load cases, the loads are given at the points defined by the stress team, which are defined as monitoring points.

For dynamic load cases, it is necessary to obtain the time instants in which the load can be sizing for the parts. For this reason, monitoring criteria are defined to identify these cases. The monitoring criteria depend on the joints and the parts to be monitored. An often value monitored is the Fmax or Tmax in a joint:

$$Fmax = \sqrt{Fx^2 + Fy^2 + Fz^2} \quad \textbf{(2)}$$

$$Tmax = \sqrt{Tx^2 + Ty^2 + Tz^2} \quad \textbf{(3)}$$

Where

Fx, Fy and Fz are the component of the force values applied at the joint.
Tx, Ty and Tz are the component of the torque values applied at the joint.

In the case of the extension / retraction loads the simulation is done in the XZ plane, so there is no values of Fy, Tx and Tz. In this case, it is only monitored:

$$Fmax = \sqrt{Fx^2 + Fz^2} \quad \textbf{(4)}$$

$$Tmax=Ty \quad \textbf{(5)}$$

The loads results are given for the eleven monitored points.

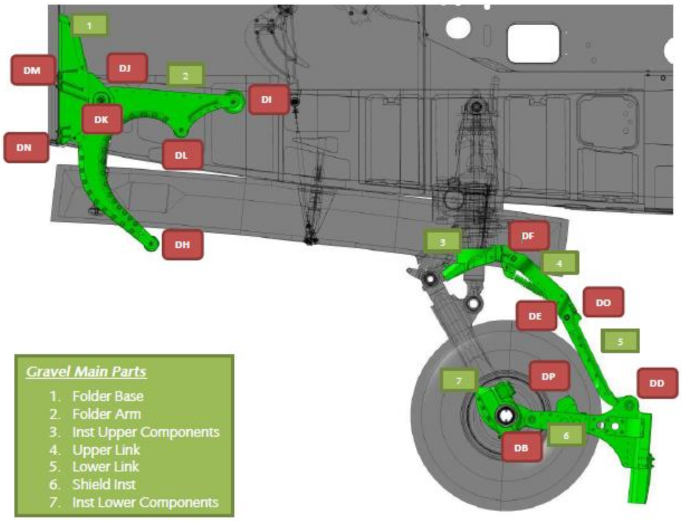

Figure 13: Load monitoring points.

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5. Flight test instrumentation requirements

The validation of the model is necessary to corroborate all the assumptions that have been made during the building of it. Before carrying out the validation tests, the gravel deflector, the landing gear and the bay are instrumented. The main objective of the instrumentation is to validate the maximum load values that have been used for the design of the parts.

Since the bay is sized for the impact loads between components 6 and 2, it is necessary to put strain gauges in parts 1 and 2 to obtain the loads during the test.

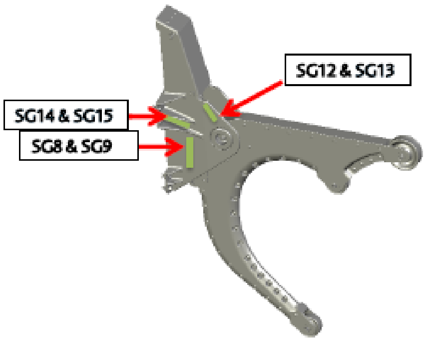

Figure 14: Location of strain gauges in parts 1 and 2

It is also necessary to monitor the loads coming from the extension of the gravel deflector because they are sizing for the parts 3, 4, 5, 6 and 7. For this purpose, strain gauges have been installed in component 5. In addition, the accelerations in the gravel will be monitored to determine the magnitude of the impacts between the parts.

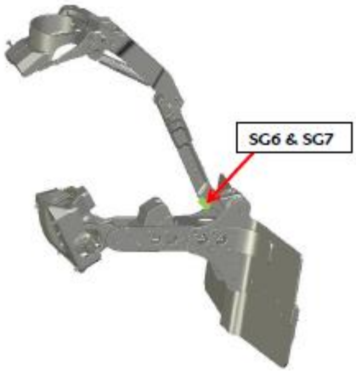

Figure 15: Location of strain gauges in part 3

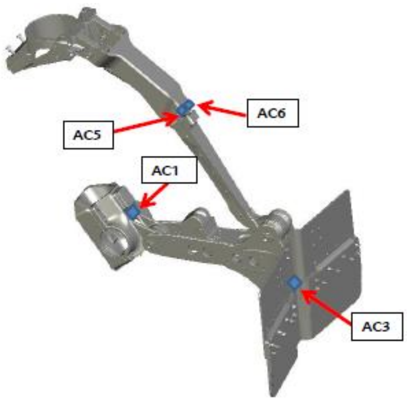

Figure 16: Location of accelerometers in parts 4, 6, and 7.

In order to know at any time the position the gravel deflector parts during the test, potentiometers are installed that measure the angles of rotation of both the folder arm and the shield.

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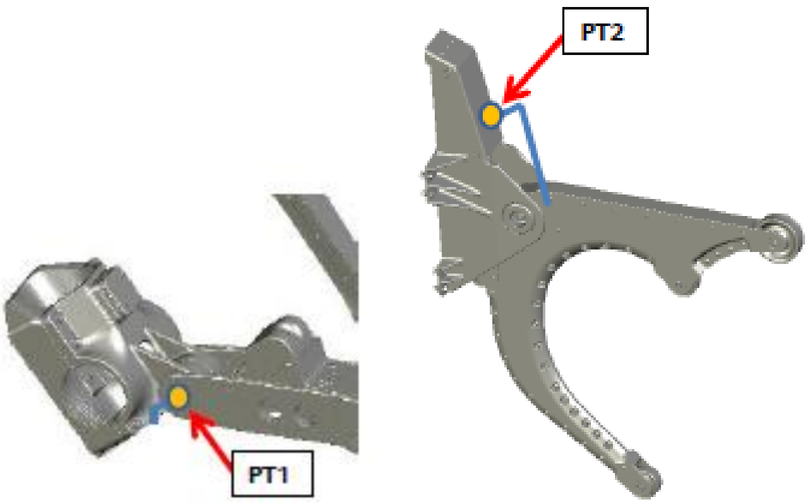

Figure 17: Potentiometers to measure the angles in the shield and the folder arm.

Bridge gauges are also installed on reinforcements located in the train bay. In this way it will be possible to monitor the loads in the bay.

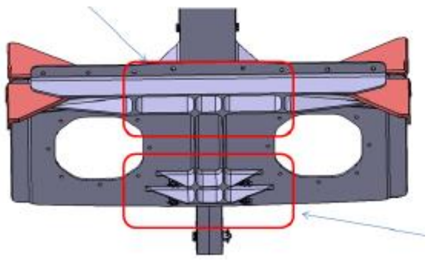
Figure 18: Bridge gauges installation on frame.

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6. Model validation

Since all the load cases come from the ADAMS model, the validation focuses on validating this model. The Euler-Lagrange equations are used by the ADAMS/Solver[2] to generate the equations of motion:

$$\frac{d}{dt}\left[\left(\frac{\partial L}{\partial \dot{q}}\right)^T\right] - \left(\frac{\partial L}{\partial q}\right) + \Phi^{\mathrm{T}}\lambda = \mathrm{Q} \quad \textbf{(6)}$$

q is the column matrix of n generalized coordinates of the rigid bodies which describe the configuration of the system at any given instant in time. L defines the Lagrangian, which is the difference between the kinetic energy (T) of the mechanical system and the potential energy (Venergy). The first term represents the inertial forces; the second term represents the potential forces; the third term represents the constraint (i.e., joints and motions) forces, and Q represents the externally applied forces.

To validate the model, controlled extension-retraction tests are carried out with the plane on jacks. In order not to damage the aircraft, the speed of retracting and extending the landing gear is controlled by regulating the supply pressure of the hydraulic system. Since the loads are conservatively predicted by the model, it

Since the loads are conservatively predicted by the model, the tests could be carried out with the nominal operating pressure of the hydraulic system.

Below can be seen a comparison of the test and model results.

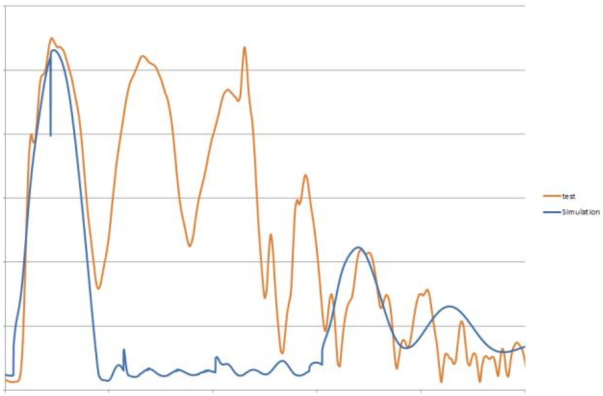

Figure 19: Peak load on the point DJ. Sizing bay case.

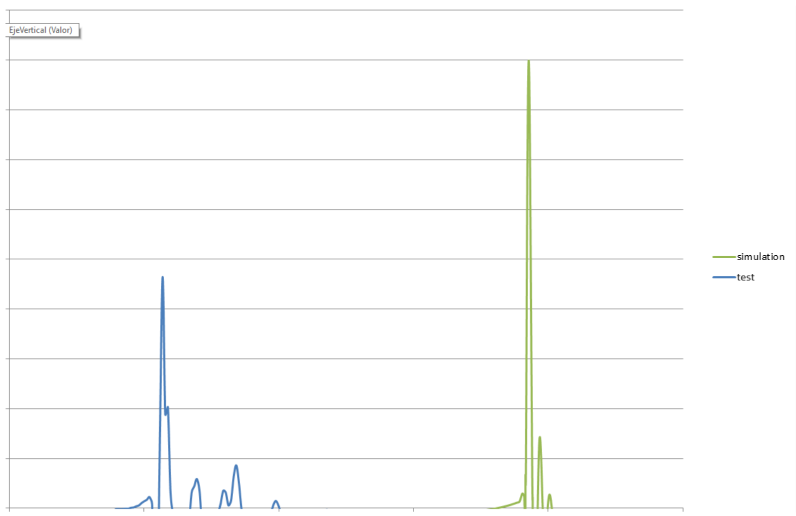

Figure 20: Peak deformation on the SG6. Sizing for gravel deflector components.

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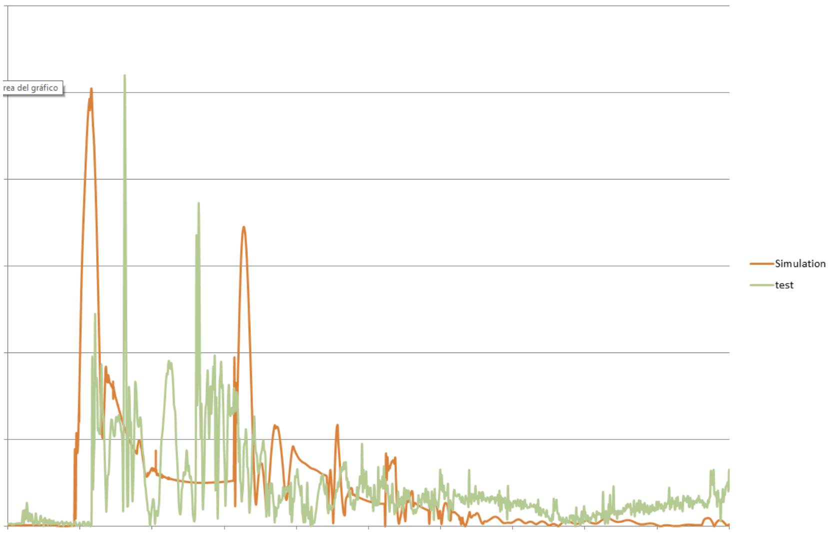

Figure 21: Acceleration peak on the AC5. Sizing for gravel deflector components.

7. Conclusion

This paper presents the integration process of a gravel deflector in the C295 aircraft from the point of view of loads. In first place, the conditions in which it will operate together with the aircraft are defined. Once the load conditions are defined, the parameters that lead to have maximum load in each of the load condition are identified. Then, taking into account the specific gravel deflector design, the monitoring points at which the design loads are going to be calculated are defined. A representative model of the loading conditions is built in order to simulate the dynamic characteristics of the gravel deflector. With this model the design loads of the equipment together with their interfaces will be calculated. Finally, the design loads were validated with representative tests of the worst load conditions. In this way, it was validated that the components of the gravel deflector and its aircraft interfaces will resist the loads that occur during the aircraft operation

References

References must be numbered in the text in the following style [3] and listed at the end of the paper in the following way.

[1] Federal Aviation Regulation TRANSPORT CATEGORY AIRPLANES (FAR part 25)
[2] Dan Negrut, Andrew Dyer “ADAMS/Solver Primer” Ann Arbor August, 2004
[3] ESDU83042 Estimation of Spray Patterns Generated From The Sides Of Aircraft Tyres Running In Water Or Slush.
[4] ESDU 70015 “Fluid forces and moments on flat plates”

