AERIAL DELIVERY DYNAMIC LOADS

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Abstract: Aerial delivery is a typical operation of military transport aircraft. It consists on the extraction of payload while the aircraft is flying with the ramp open. The pallets are moved towards the rear of the fuselage and the ramp until they leave the aircraft. The extraction may be done either by gravity or using a parachute. These pallets release creates a dynamic response in the ramp that is transmitted to the rear fuselage. In addition the aircraft may encounter atmospheric turbulence that produces loads that have to be analysed. The result is a set of scenarios that are critical for the ramp, ramp-fuselage interface and rear fuselage.

The aerial delivery dynamic loads analyses imply taking into account some parameters that are relevant for the simulations:

- Non linearities in the ramp-fuselage interfaces.
- Situations with variable “1g-steady flight” that leads to aircraft load factor > 1

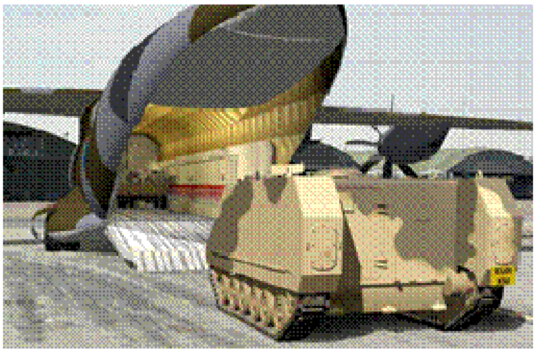
This paper presents the continuation of the works performed at Airbus DS Military Transport Aircraft Aeroelasticity and Structural Dynamics department in the last years ([1] & [2]). It will focus on the methodology to calculate aerial delivery dynamic flight loads for a heavy military transport aircraft. Two main scenarios are analysed:

- The release itself, which simulates the dynamic response of the ramp and its effect on the attachments and fuselage, which is divided in two different analyses:
  - The first analysis computes the loads in the aircraft due to the pallet release. This analysis is linear and focused on obtaining the loads in the rear fuselage.
  - The second analysis computes the loads in the ramp and ramp-fuselage interfaces (hinge, actuator and struts). This analysis is non-linear and more accurate in the ramp area.
- The aircraft response to a discrete tuned gust produced during the extraction process: with the ramp open, before, during and after the release.

Concluding remarks highlight how these results constitute a step forward in the understanding of aircraft dynamic response in this scenario. The paper will end with suggestions for further work in this topic.

1 INTRODUCTION

The missions that a military transport aircraft has to accomplish are the explanation of why these aircraft are as they are. For instance, a military transport has a high wing because it allows quick loading and unloading infantry troops, and because it provides a low floor level to carry a variety of cargo. Moreover, military aircraft usually have a T-Tail because it permits to load and unload up to the height of cargo bay. T-tail also provides a better longitudinal control at low speed and because it implies a greater height of horizontal tail-plane (thus preventing buffeting, since these aircrafts are typically turboprops). Lastly, the most recognizable feature is the ramp located in the rear fuselage, which will give clearance to payload introduction/extraction.



This need for enhancing loading and unloading performance is particularly critical in one of the most typical mission of military transport aircrafts: aerial delivery. This mission can be accomplished in different ways:

- Airland. This is the preferred method of aerial delivery because it is the most efficient and cost effective. It permits delivery of larger loads with less risk of cargo loss or damage. It can be done from a stationary aircraft or combat offload from a moving aircraft
- Airdrop. It consists of the payload release while the aircraft is still on the air. Extraction process may imply single or multiple pallets delivery depending on the mission. There are different methods of extraction:
  - Parachute extraction. Payload is pulled out the aircraft through the ramp. It is used with low-velocity loads.
  - Gravity extraction. Requires the aircraft to fly in “nose-up” configuration, making containers roll or slide out of the aircraft through ramp. This method is feasible for both low & high velocity scenarios.

This study is devoted to “Airdrop” missions and the way to calculate dynamic loads associated to their occurrence. It is established in the regulation that they must be accounted for, and the better and more accurate loads calculations are, the lighter and more efficient aircraft structures will be. These loads result critical and sizing cases for the ramp, rear fuselage and ramp-fuselage interface.

2 STATEMENT OF THE PROBLEM

One of the operations of a Military Transport Aircraft is the in-flight loads delivery. For this operation, the aircraft opens the ramp and door and then the load, usually pallets, are extracted. There are two dynamic effects associated to the fact of opening the ramp:

— Rear fuselage torsional stiffness reduction.
— Open ramp dynamic response.

Rear fuselage torsional stiffness reduction

The first effect of “opening the ramp” is the modification of the rear fuselage torsional stiffness: a closed section evolves to an open section. The section elastic axes jumps from a position close to the centre of gravity to a position above the airplane. As a consequence, the normal modes base changes. Many global modes of the rear fuselage decrease their frequency. In addition, some local modes of the rear ramp and door appear.

Next table shows the change of frequency in rear fuselage normal modes between closed and open ramp. The mode that changes the most is the HTP Roll, which reduces its frequency by a 13%

Mode No.	Mode Identification	Closed Ramp	Open Ramp	Diff
		Freq. (Hz)	Freq. (Hz)	%
7	(A) 1st VTP bending (1 NL) + 1st w ing bending (1NL)	2.13	1.97	-8%
	(A) Door torsion		2.7	
9	(A) HTP yaw + Wing chordw ise (out of phase)	2.96	2.92	-1%
12	(A) HTP Roll	3.55	3.1	-13%
26	(A) 1st Fusel later. bend (2NL) + Ramp Lateral + W bending (5NL) + HTP bend (3NL)	8.55	7.66	-10%
	(A) Door yaw + torsion		8.58	

Table 1 Frequency change in rear fuselage normal modes between closed and open ramp

Having an open section is important for gust loads in an aircraft with T-tail: the inertia of the vertical tail is high and the torque that produces the lateral gust is also higher in this open section than in a closed section.

Open ramp dynamic response

The second effect that has to be accounted for is that ramp and ramp-fuselage attachments design loads come from this operation. As a separated structure joined to the fuselage by hinge, actuators and struts, ramp local modes are expected to play a role and increase ramp response.

To certificate the aircraft, the applicable regulation requirements have to be fulfilled. But in this case, there is no paragraph in the current regulation that applies to dynamic loads with the ramp open:

— CS 25 apply to civil aircrafts and these aircrafts do not have any ramp that opens during the flight
— MIL-STD and DEF STAN do not have any paragraph either for open ramp nor aerial delivery

Therefore an agreement with the authorities has to be signed for covering this aircraft operation. A typical agreement for dynamic loads should include:

1. <u>Gust loads while the aircraft is flying with the ramp open</u>

   In this configuration, the aircraft does not have payload on the ramp, and the flight speed is lower than Vc; a maximum velocity for flying with open ramp is defined. The loads due to the response to a gust of 100% of intensity defined in CS 25.341 will contribute to the design loads of the ramp and rear fuselage.

2. Gust loads during the extraction process:

   In this configuration, there is a transient movement of the payload that moves from the cargo hold to the ramp. During this process, the aircraft may encounter turbulence; therefore gust loads should be calculated. As in the Open Ramp configuration, the time that the aircraft is flying is a small portion of the aircraft life; therefore a reduction in the gust intensity is reasonable. A typical value is 50% of maximum gust intensity.

   For combining the gust excitation and the extraction process, a pseudo-1g has to be calculated. That means: the extraction process is quasi-stationary, therefore the loads in the aircraft will result in a time history of 1g loads. The gust response will be calculated by superimposing the incremental load produced by the gust to certain "1g" load level from the time history. These specific 1g is what we call pseudo-1g.

3. Release Loads:

   The extraction process is quasi-stationary, but the final release of the load is dynamic. The pallet arrives to the edge of the ramp, rotates and leaves the ramp. These movements are produced in a very short time, producing a dynamic response similar to the one produced by a step loading.

3 FLIGHT WITH OPEN RAMP + GUST LOADS

Before and after the release of the pallets, the aircraft will be flying with the ramp open. In this flight configuration, the aircraft still have to fulfil the gust requirements; therefore the loads due to the response to the gust excitation have to be computed.

During the operation with the ramp open, there are no pallets of payload on the ramp because either the release process has not started yet, or has already ended. The case in which the pallets are on the ramp has to be treated as a release event (and therefore described in §5) or a failure case.

To calculate the total load due to the gust excitation, the incremental load due to the gust response is added to the 1g steady load. The DTG incremental loads correspond with 100% of CS-25.341 gust intensity. The procedure is exactly the same as the one used for closed ramp.

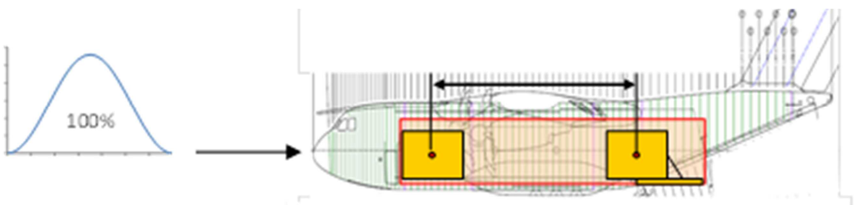


Figure 1: Gust intensity for DTG incremental load.

Moreover, another issue that modifies the gust response is the existence of a Manoeuvre Loads Alleviation (MLA) system integrated in the Flight Control System (FCS). For example, A400M has a MLA which consists in the symmetric deflection of the ailerons to reduce loads. This MLA is nonlinear. This non-linearity has been included in the gust response calculation, therefore the incremental loads has been calculated using DYNRESP©, see [5]. This non-linearity has two implications in the loads computation:

- The response of the up and down gust is different.
- It is not possible to perform the analysis based on a unitary gust intensity factorised. The real gust intensity has to be included in the response calculation instead.

The differences of this analysis with respect to the same analysis with the ramp closed are:

- The flight velocity is lower than Vc. There is a maximum speed at which the aircraft can operate with the open ramp. Indeed, operations will be performed at lower speed than this maximum.
- The lower speed that may be needed for the aerial delivery leads to the use of flaps. Therefore, there will be a maximum speed depending on the flaps configuration. All these speeds have to be analysed.
- The fuselage with the ramp open is an open section whose structural behaviour is different. The torque capability of the section will change, being very important in a T-tail aircraft.

Influence in loads:

Down bending moment and down shear force at HTP loads to gust with open ramp may be sizing cases for HTP down bending and down shear (Figure 2). This increase in downloads is produced by the increase of the steady down lift of the HTP because of the high angle of attack needed for flying at low speed and flaps deployed.

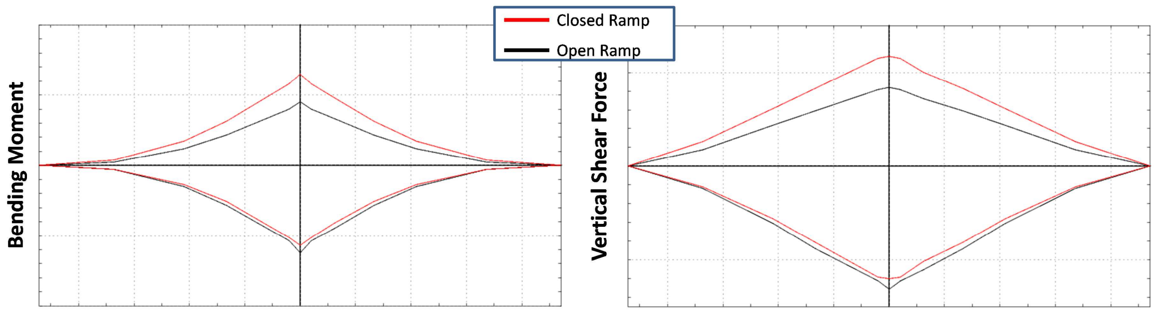


Figure 2: HTP bending moment and vertical shear force 1D comparison: open ramp vs. close ramp

With respect to the VTP, looking at the VTP root, 2D loads envelopes for open ramp are inside the closed ramp 2D envelopes (Figure 3), except for the vertical load (that integrates the load increase of the HTP). The reduction of the structural capability of the open section of the fuselage is balanced with the reduction of the incremental gust load due to the reduction of the flight speed.

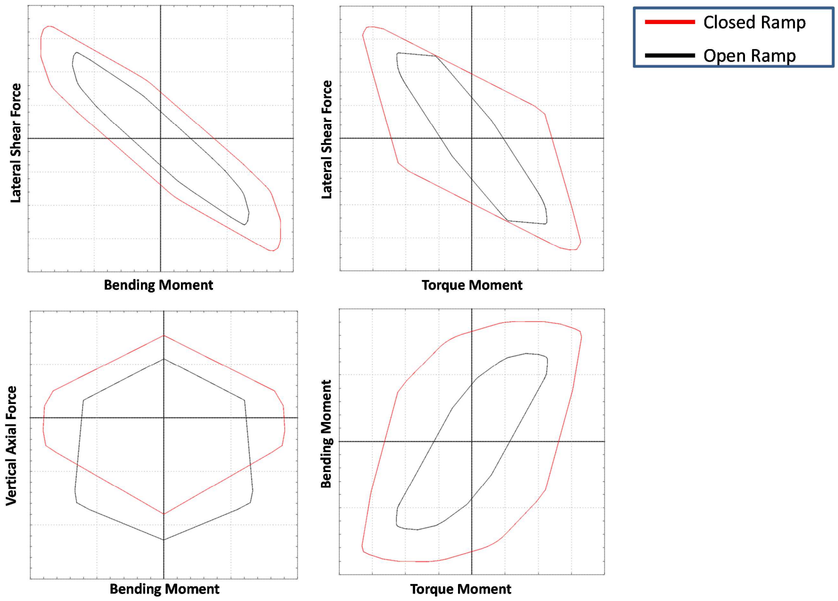


Figure 3: VTP root 2D envelopes: open ramp vs. close ramp

4 "PSEUDO-1G" CONDITION

Dynamic loads are typically obtained by using Superposition Method which combines two loads contributions: 1g load (aircraft loads in steady condition) and incremental load (due to gust or release).

The aerial delivery is intrinsically a transient process. When a platform moves inside the fuselage, the centre of gravity moves rearward as well and the effect in the aircraft is a pitch-up movement.

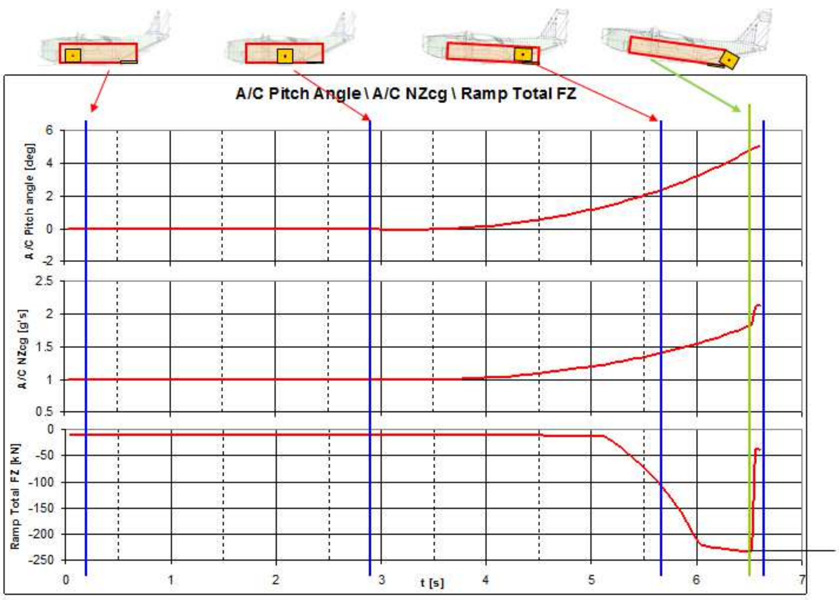


Figure 4: From top: sketch of aerial delivery; A/C pitch; Nz and ramp total Fz evolution

As a consequence there are no sets of steady 1g loads for a particular mass state and flight point but a time history of pseudo-1g loads for each combination of the cargo units extraction process. They are obtained considering the next parameters:

— No pilot command along the process. Normal FCS law.

— The origin of time is when the first cargo unit starts to move.
— All the possible combinations of flap settings, altitudes, airbrakes on/off.
— Parachute / gravity extractions.

Loads to be combined with dynamic incremental loads, [4], are then obtained by freezing at certain time instant the 1g-loads time history. This instant represents the payload position that maximizes loads at the ramp itself and/or at fuselage-ramp interfaces (struts, hinges, actuators…); then a whole set of correlated static loads corresponding to that payload position is computed for the whole aircraft representing the static load contribution to aerial delivery loads.

Extraction process may imply single or multiple pallets delivery depending on the mission. Figure 5 shows two examples of time instant selection, one for each type of delivery.

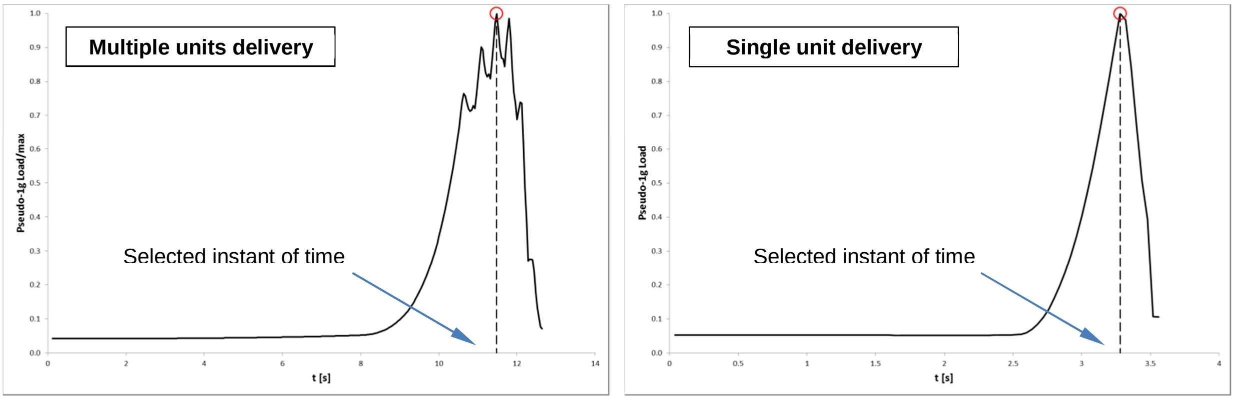


Figure 5: Example of pseudo-1g load

5 "AERIAL DELIVERY + GUST" LOADS

Aerial delivery is the operation in which a platform is moved rearward inside the fuselage and afterwards released thru the open ramp.

As stated in §2, neither civil nor military applicable regulations mention the requirements for gust and turbulence with ramp open, which is an specific military operation. In the case of A400M the agreed requirements with the Airworthiness Authorities [4] are as follows:

The airplane shall encounter discrete tuned gusts of:

— the specified intensities at VC in CS 25.341, before and after the cargo extraction process and
— intensities of 50% of those specified at VC in CS 25.341, during the cargo extraction process

Figure 6 illustrates the two scenarios foreseen, considering any position of the platform through the fuselage and any position on the ramp. While the platform is still inside the fuselage cargo hold area, the DTG incremental loads correspond with 100% of CS-25.341 gust intensity (analysis described in §3). When the platform is already on the rear ramp DTG loads are computed using 50% of CS-25.341 gust intensity.

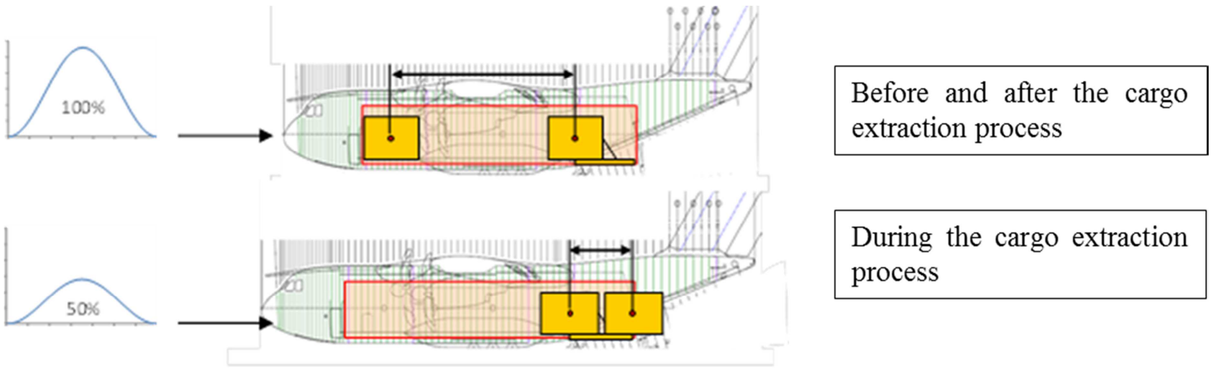


Figure 6: DTG analysis should cover any position of the platform during aerial delivery

As general procedure for dynamic loads analysis, the total load is a combination of the 1g steady load plus the incremental load that results from the dynamic response to the excitation. In the aerial delivery + gust analysis, the pseudo-1g (already described in §4) is used instead of 1g steady load.

A reduced set of pseudo-1g time steps is selected attending to the target of the analysis. Aerial Delivery + gust loads are important for rear fuselage, ramp and ramp to fuselage interfaces (hinge, actuator and strut), therefore, these stations (interesting quantities) should be monitored and use as criteria for selecting the set of time histories.

The procedure used for selecting the cases to be run and calculate the loads envelope is shown in Figure 7.

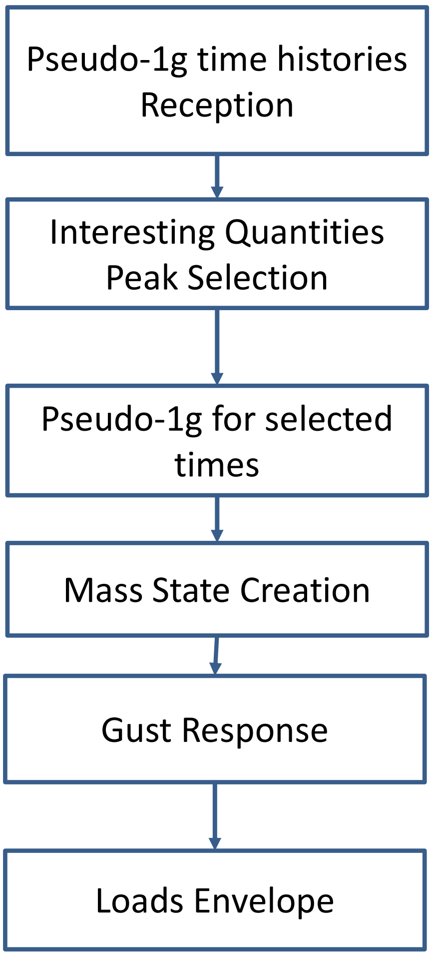


Figure 7: Aerial Delivery + gust loads calculation procedure

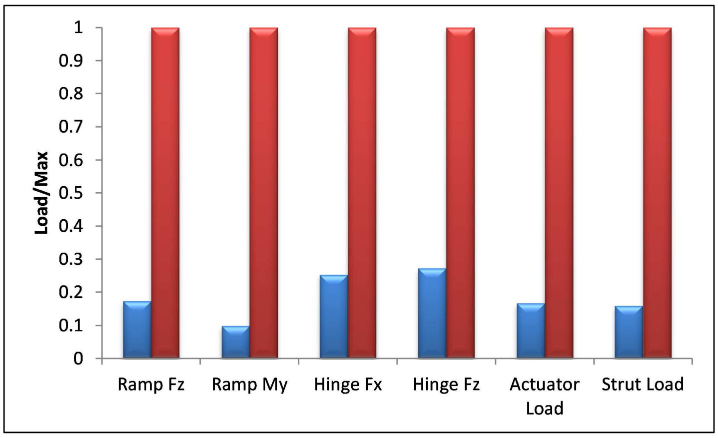
This procedure description is as follows:

1. For different flight points and payload types, a set of pseudo-1g time histories is computed. Rear fuselage, ramp, hinge, actuators and struts forces and moments are requested.
2. The maximum positive and negative peak of each monitored magnitude is calculated. This defines the time of occurrence and the magnitude of the pseudo-1g that will be added to its corresponding incremental load. The case is identified by the source time history: load position, altitude, aircraft speed, aircraft attitude, instant time.
3. The full set of aircraft correlated loads corresponding to this pseudo-1g is calculated for each of the load cases selected.
4. The specific mass state for each of the load cases is created. As the pallets are moving along the fuselage, the specific x-position is needed in order to create the CONM2 entries.

   The gust response is calculated. The total loads are calculated adding the pseudo-1g (acting as steady 1g) to the incremental load. The non-linear Flight Control System (FCS) is used with the Manoeuvre Loads Alleviation (MLA) system described in §3.

5. 1D and 2D envelopes are calculated and compared with the Aircraft Design Loads.

Figure 8 assesses the relevance of “Aerial Delivery + Gust” for ramp loads respect to “Open Ramp + Gust” ones. In spite of only applying 50% of gust intensity, ramp AD loads are far higher for OR ones.



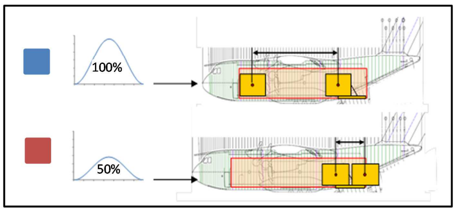


Figure 8: “Open Ramp + Gust” vs “Aerial Delivery + Gust” ramp loads comparison

6 RELEASE LOADS

6.1 Release Loads Procedure Description

The final phase of the aerial delivery is the platform release. During this last phase, the total release loads is the sum of two parts:

- <u>Pseudo 1g loads</u>: the loads when the platform is in the ramp edge and the aircraft behaviour corresponds to the platform movement up to that point.
- <u>The incremental dynamic part</u>: when the platform rotates over the ramp edge and immediately abandons the ramp creating a transient excitation. During the subsequent non-linear response, the non-linearity of some components should be taken into account (e.g. strut, which only work under traction, but not under compression).

When the platform is on the ramp, the ramp frames support the weight of the platform until the platform centre of gravity reaches the ramp edge. Figure 9 shows the triangular distributed load on frames. This weight is not at 1g level flight but is computed at the local load factor on the ramp corresponding to the aerial delivery manoeuvre at that time.

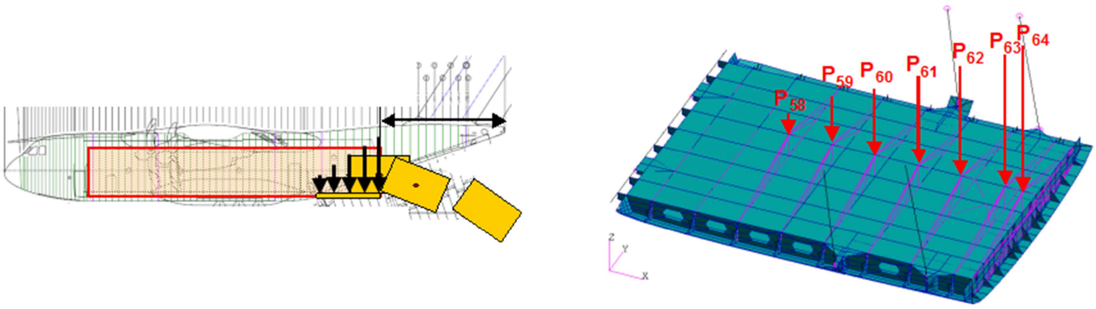


Figure 9: Sketch of aerial delivery.

The quasi-steady ramp Fz time history is used twofold, to fix the magnitude of the applied load at the critical instant of time, and to select the instant of time for the pseudo-1g loads.

Figure 10 shows the instant of time when the platform rotates producing the maximum load on the ramp (ti) and when the platform leaves the ramp (tf).

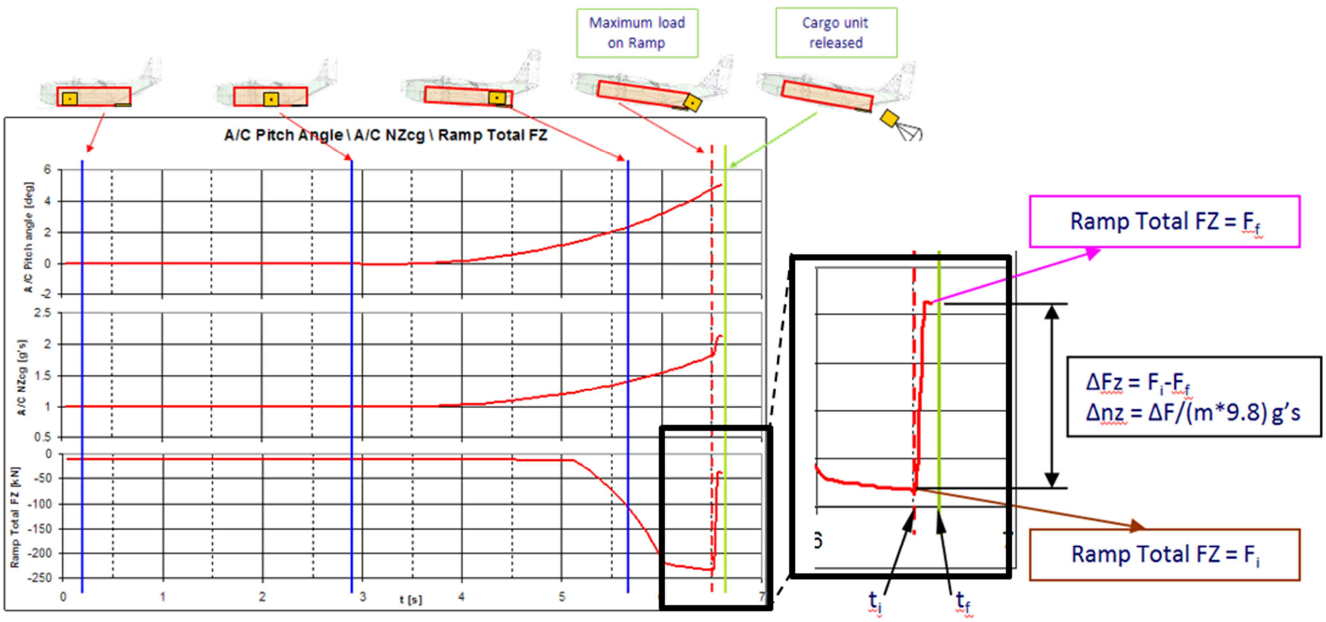


Figure 10: From top: sketch of aerial delivery; A/C pitch; A/C Nz and total ramp Fz evolution.

The magnitude of the applied load ΔFz is obtained by difference between the force at the ramp in t_f and t_i.

The working methodology is based in the simulation of the load that is going to be released as a force that "moves" along the ramp and suddenly disappears when the platforms leaves the ramp. The procedure follows the diagram in Figure 11.

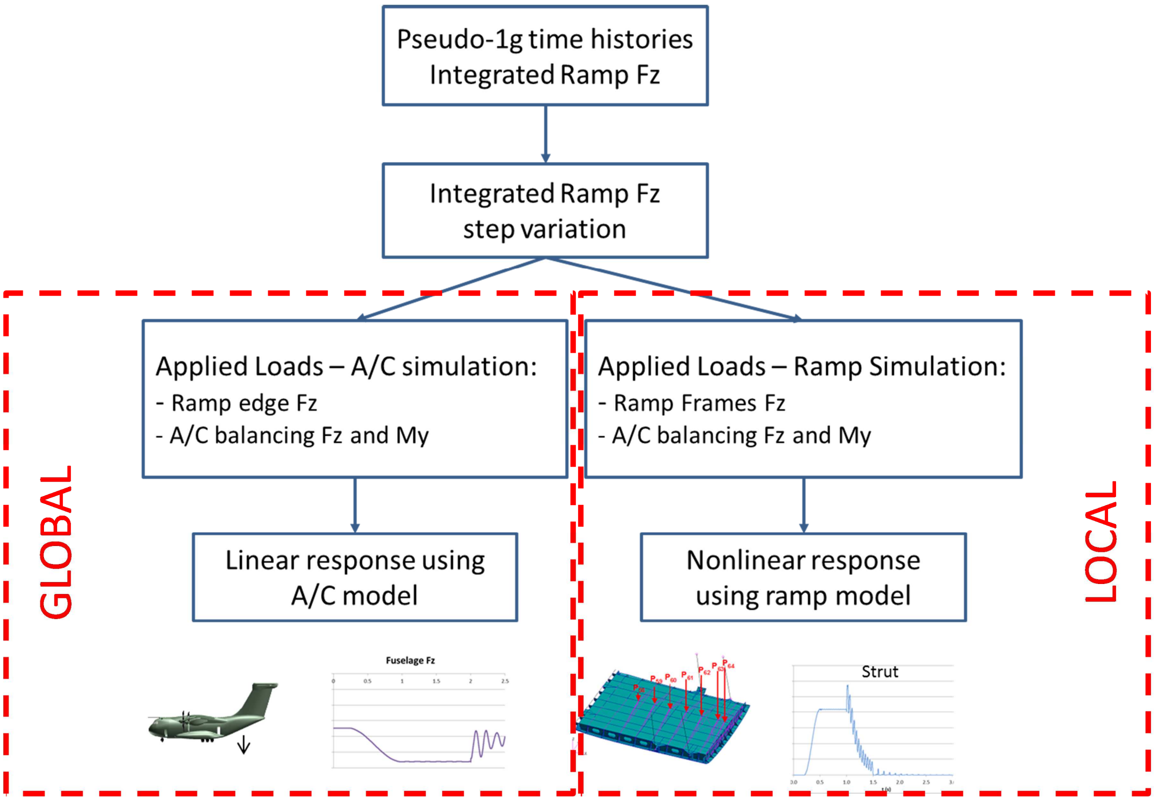


Figure 11: Release loads computation process

This procedure is as follows:

1. The vertical force at the ramp (F_z) is the criterion to select the most critical release loads.
2. From the different unit loads release F_z time histories, those which produce the maximum variation in F_z at the platform rotation moment are selected. As shown in Figure 10 above, this variation is obtained by difference between the maximum F_z and its value when the load unit has left the ramp. (Figure 12)

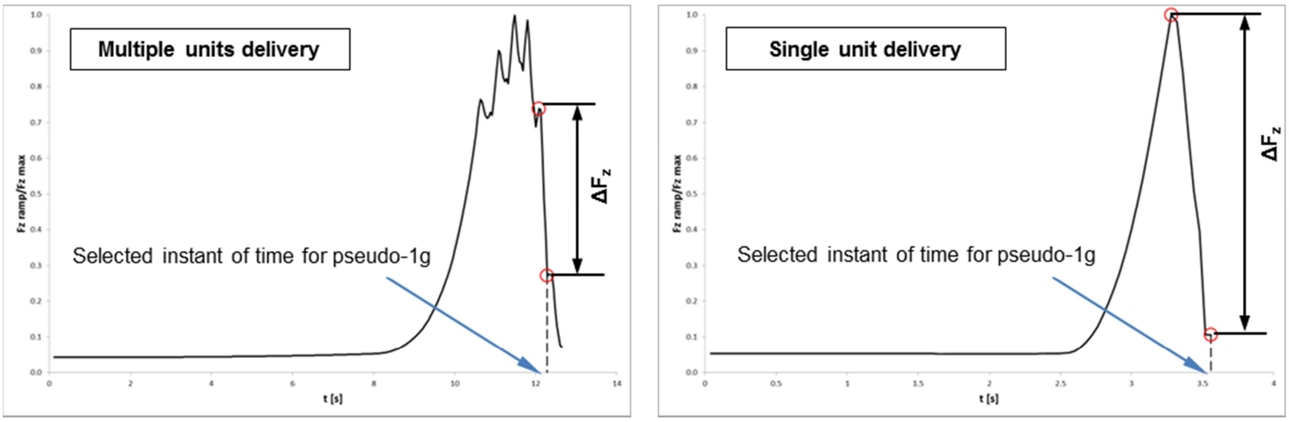


Figure 12: Selection of delta Total Ramp Fz

3. The aircraft global loads are not affected by local non-linear effects and a linear approach can be used to obtain rear fuselage and ramp loads due to release (§6.2). Instead, the strut is strongly non-linear (works only under traction, but not under compression) and this affects to actuator compression loads (§6.3).

6.2 Linear Release Analysis

For the linear release analysis, a vertical transient load applied in the ramp edge simulates the effect of the platform over ramp, when the platform mass reaches the ramp edge and it rotates and slides around this point. The full A/C condensed dynamic model is used for this purpose.

Applied force at ramp edge used for the analyses is shown in 13. The applied load during (a) and (b) interval times are considered quasi-steady process.

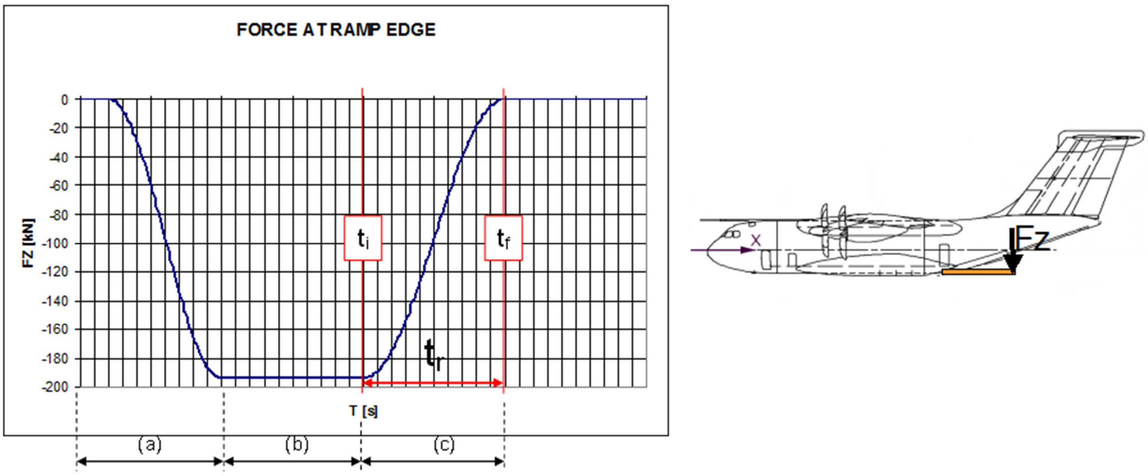


Figure 13: Force applied at ramp edge for release analysis and application point

Where:
(a): (1-cos) smooth shape to introduce the quasi-steady loads corresponding to the initial conditions.
(b): Initial conditions.
(c): Release event. (1-cos) assumed shape.
t_i: Time instant when the centre of gravity of the platform reaches the ramp edge.
t_f: Time instant when the platform leaves the ramp.
t_r: Platform rotation and sliding time.

During the release process, this load is balanced with a force and a moment in the wing-fuselage joint in order to ensure the equilibrium of forces in the aircraft. Balance force is smoothly applied and smoothly removed in a tr = 1sec.

Platform release time sensitivities: Five release time intervals, from 0.0001s to 1s were considered. The analysis time step is varied coherently. The selected time intervals for the release analysis is 0.001s, which does not improve the results with respect to 0.0001s.

From MSC-NASTRAN SOL 112 analysis, linear modal transient response, fuselage, ramp and ramp and hinge total loads are obtained. Actuator linear loads are also obtained for comparison with the isolated ramp actuator non-linear loads.

6.3 Non-linear Release Analysis

For the non-linear release analysis, the vertical transient load is applied in the ramp frames, and for this purpose a detailed model of the clamped ramp with actuators and struts is used.

In the detailed ramp Finite Element model, same as in the A/C, the actuator and strut are modelled as NASTRAN CROD elements with constant stiffness. For the non-linear release analysis the strut non-linearity is modelled by substituting the strut element (CROD) by an equivalent non-linear force in two steps (see Figure 14 and Figure 15).

In a first step the strut element is replaced by equivalent linear forces for the process checking:

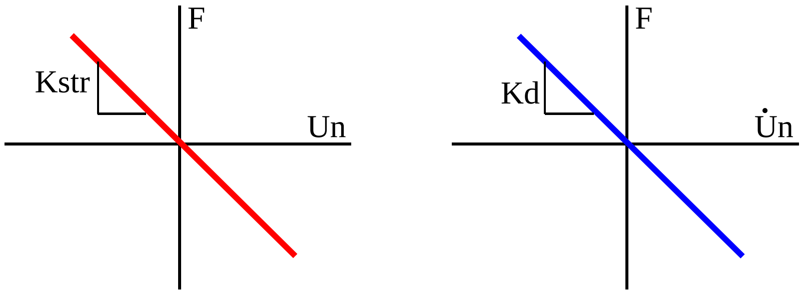


Figure 14: Equivalent linear forces for strut

In the second step the non-linear forces replace the struts: traction force is the same as the linear one and compression force is set to zero.

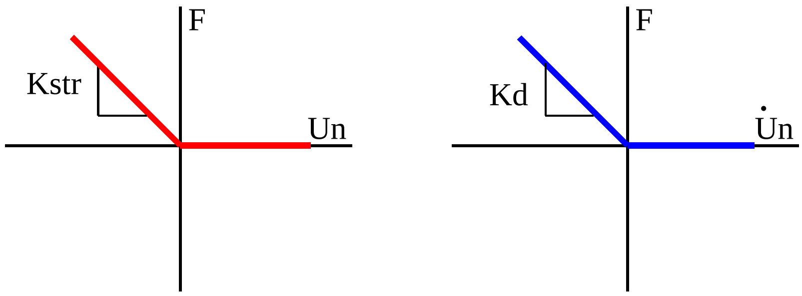


Figure 15: Equivalent non-linear forces for strut

When the platform moves rearward, once its centre of gravity lies outside the ramp, there is a rotation of the platform that separates it from the ramp except in the last frame. Therefore there is a sudden increase of the load at the last frame while the load vanishes at the rest of ramp frames. This phenomenon is depicted in Figure 16 (time histories of the transient loads in all frames) including a zoom of the central period with the rotation of the platform that corresponds with the most dynamic part of this event.

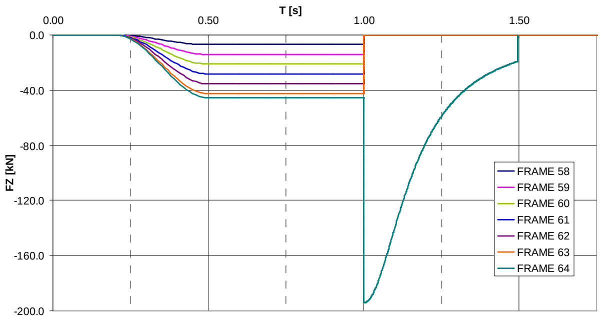


Figure 16: Loads applied in the ramp frames

From MSC-NASTRAN SOL 129 analysis, non-linear transient response, actuator and strut loads are obtained. Comparison between actuator and strut maximum loads in traction obtained with the aircraft model and linear approach and the ones obtained with the ramp isolated model and non-linear approach show good agreement.

6.4 Comparison between linear and non-linear response

The non-linear release methodology has been checked in several steps. With the detailed ramp Finite Element model clamped at the hinge fittings and at the actuator and strut fuselage ends, the process has been as follows:

- Transient linear response using a linear solution (SOL112).
- Transient linear response using a non-linear solution (SOL129). The strut is modelled with the original linear CROD element.
- Transient linear response using a non-linear solution (SOL129) and a linear force replacing the original linear CROD strut element.
- Transient non-linear response using a non-linear solution (SOL129) and a non-linear force replacing the original linear CROD strut element.

The first three steps provide equal results, thus guaranteeing the procedure robustness. The actuator and strut non-linear loads, as expected, are similar to the linear loads while in traction and only different while the actuators are in compression.

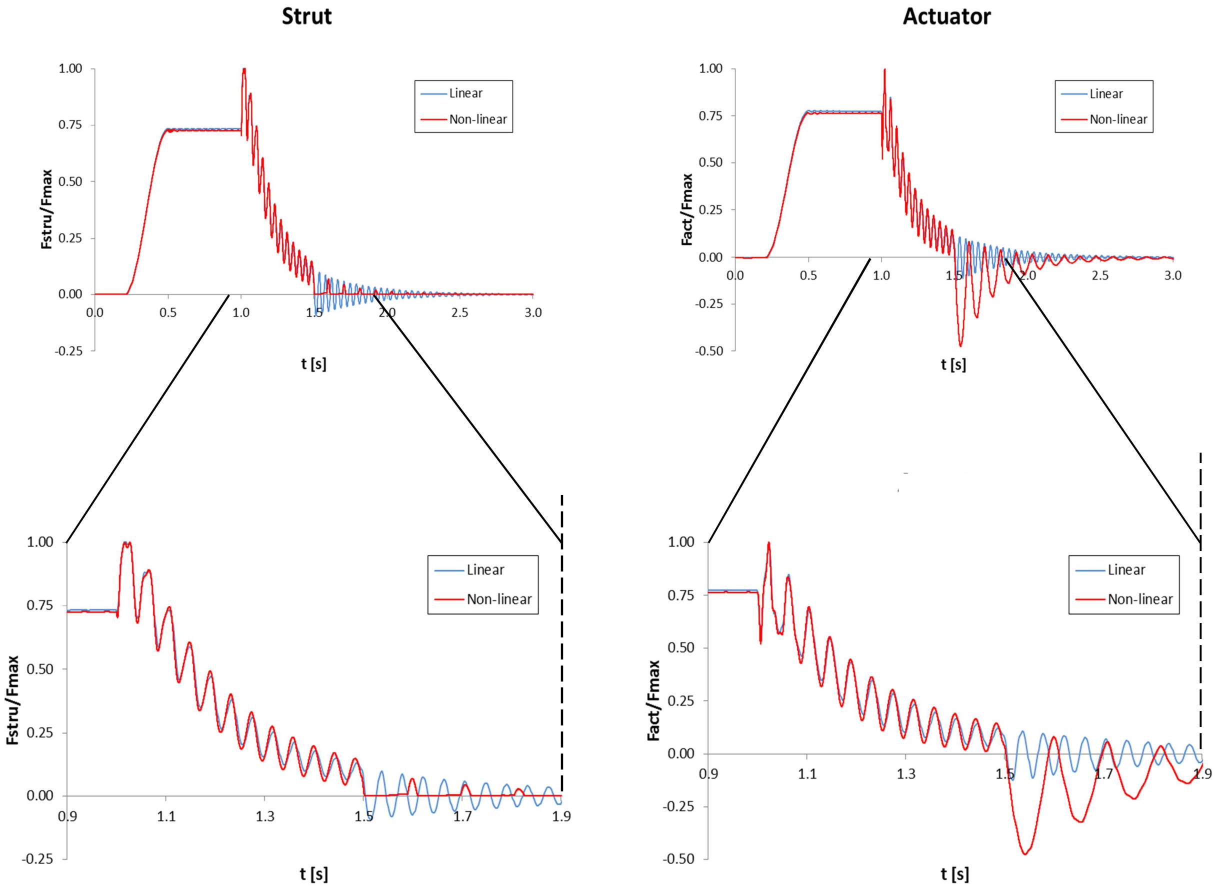


Figure 17: Comparison between linear and nonlinear analysis

7 FLIGHT TEST INSTRUMENTATION

A flight testing campaign is scheduled after this paper writing. This means that unfortunately its results will not be available for being presented at this time.

Flight testing involves the aerial delivery of cargo from the rear of the aircraft, where the cargo traverses over the cargo ramp floor. For this aerial delivery to occur the cargo ramp must be fully open and the cargo door must be in its up-latched position.

The primary objective of these tests is to check the load assumptions associated with an aerial delivery event. In addition, the cargo extraction speed and its effect on the local aircraft g-level are to be investigated, where the time required for a payload to traverse the cargo ramp is of specific interest.

For load measurement, strains from the gauges will be used. From these strains it is anticipated that the aerial delivery loads can be deduced using the associated strain/load calibration information, where such calibration has been performed prior to flight test. The main areas of interest for load measurement are the interfaces between the cargo ramp and the rear fuselage to which the cargo ramp is attached and supported:

- Ramp hinges, struts and actuators
- Payload mass, CG and speed along the ramp and its effect of on the local aircraft g-level.

Flight testing will include gravity drops and parachute extraction.

8 CONCLUSIONS AND FUTURE WORK

Next steps will be focused on the dynamic loads model validation, mainly based on simulation results comparison with flight test data. Dedicated analyses to reproduce flight conditions, payload distribution and release conditions of flight test will be carried out and compared with flight test results, in the same way as it was done in [1].

9 REFERENCES

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