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STUDY ON NEW CONCEPT OF AIRCRAFT FRAME - PAX CROSSBEAM CONNECTION

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Abstract: *The paper is presenting a study on a new concept of an aircraft frame to passenger floor crossbeam connection. The current standard in the industry consists in a fastened joint (large bolt field) between the aircraft frame's web and the web of the crossbeam profile. This extremely rigid connection also transfers, on top of the axial loads, bending moments between the parts, which leads to high stresses and strains in the area. In order to mitigate these high local loads, the parts require increased stiffness, leading to increased weight. The new proposed concept consists of an articulated connection that transfers only axial loads, while the bending moments are not transferred any more. A Finite Element Analysis (FEA) is carried out for both standard and new concept, on isotropic materials (metallic) components. Results (deformations, stress and strains) are compared in order to determine the new concept behavior.*

Keywords: *new concept, frame-crossbeam connection, composite materials, stress, strain*

1. INTRODUCTION

The main two goals in the aviation industry are to increase the safety of flight (which is already at a high level) and to reduce the costs. Both of these goals are followed from the beginning of the design phase and into the operational phase, until the end of the aircraft life cycle.

In general, most components are already optimized in terms of weight to cost ratio, while reducing the weight is one of the main driving factors accounted in the final cost. Nevertheless, there are highly stressed areas and components that need additional material to sustain the loads from the worst possible case.

This leads to additional weight that increase the manufacturing and operational costs and reduce the maximum passenger and cargo capacity.

One of these highly loaded areas is the connection between the passenger (noted as Pax) Crossbeam and the Frame, as marked in Fig. 1.

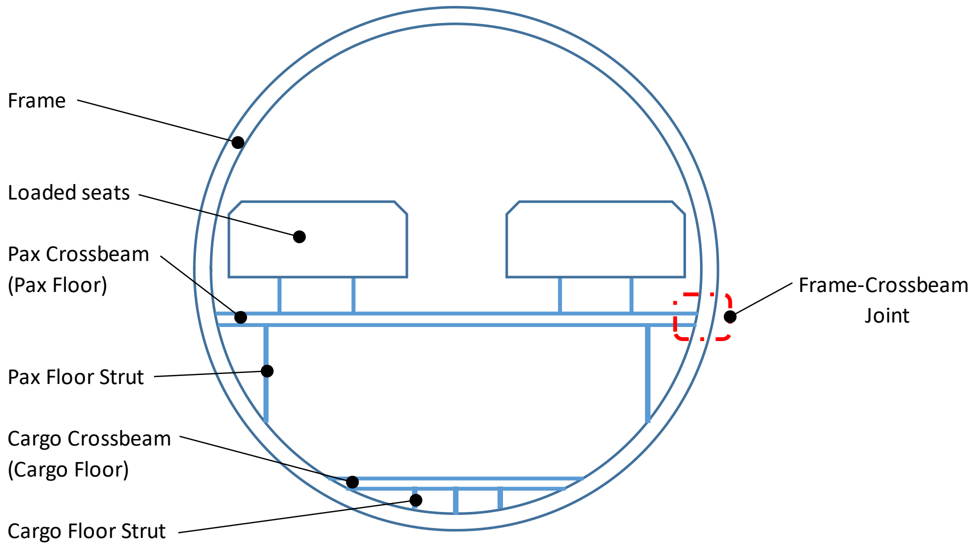

Figure 1: Typical passenger aircraft section (single aisle)

The current standard in the industry consists in a fastened joint (large bolt field) between the aircraft frame's web and the web of the crossbeam profile [1], as presented in Fig. 2. This extremely rigid connection, on top of the axial loads, also transfers the bending moments between the parts, which leads to high stresses and strains in the area. In order to mitigate these high local loads, the parts require increased stiffness, leading to increased weight.

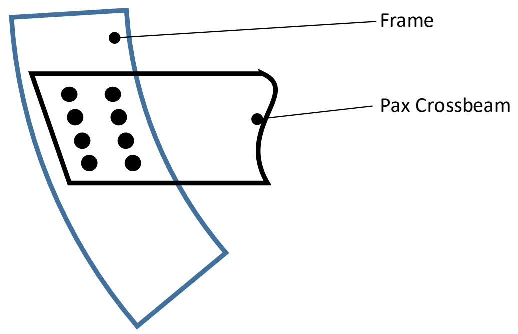

Figure 2: Typical passenger aircraft Frame to Pax. Crossbeam Bolted Joint

In this paper is proposed a new concept of an aircraft frame to passenger floor crossbeam connection. The new proposed concept consists of an articulated connection that transfers only axial loads, while the bending moments are not transferred any more. A Finite Element Analysis (FEA) is carried out for both standard and new concept, on isotropic materials (metallic) components. Results (deformations, stress and strains) are compared in order to determine the new concept behavior.

2. INITIAL ASSUMPTIONS AND MATHEMATICAL MODEL

As described above, this paper is trying to assess the loads transferred from the passenger floor crossbeam into the frame. An initial mathematical approach is done to compare the transferred loads in both cases: the current case with the crossbeam bolted onto the frame and the proposed case with an articulated connection.

For the classical connection, the crossbeam is considered clamped at one side (frame side) and supported at the other side. Vertical and horizontal loads are applied in the middle of the beam.

For the articulated connection, the crossbeam is considered articulated at the frame side and supported at the other side. Same loads are applied as for the classical connection model.

In order to calculate the reactions from both models in Fig. 3, the classical equilibrium equations are used [2]. Additionally, for the classical joint model, since the equation system is undetermined, the Castigliano's Theorem [3] is used. All equations are presented in (1). Results (reactions in points A and B) are presented in (2).

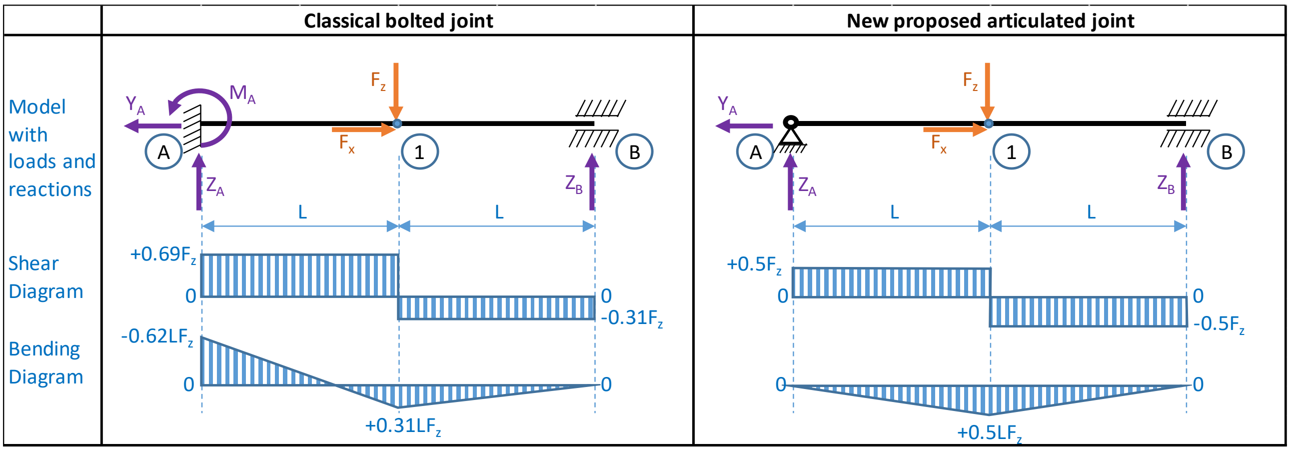

Figure 3: Simplified mathematical model and loading diagrams

	Classic bolted joint	**New proposed articulated joint**	
Static equilibrium equations $\sum F_y = 0$ $\sum F_z = 0$ $\sum M_x = 0$	$X_A = F_y$ $Z_A + Z_B = F_z$ $M_A - F_z \cdot L + Z_B \cdot 2L = 0$	$X_A = F_y$ $Z_A + Z_B = F_z$ $F_z \cdot L - Z_B \cdot 2L = 0$	(1)
Castigliano's Theorem	for vertical displacement of point B ($v_B = 0$)		
$\sum \frac{M(y)}{E \cdot I} \cdot \frac{\partial M(y)}{\partial Z_B} = 0$	$\int_0^L \frac{Z_B \cdot y}{E \cdot I} \cdot y\, dy + \int_0^L \frac{Z_B \cdot (L+y) - F_y \cdot y}{E \cdot I} \cdot (L+y) dy = 0$	-	

Classic bolted joint	**New proposed articulated joint**	
$X_A = F_y$; $M_A = 0.62\, L \cdot F_z$ $Z_A = 0.69\, F_z$; $Z_B = 0.31\, F_z$	$X_A = F_y$; $M_A = 0$ $Z_A = 0.5\, F_z$; $Z_B = 0.5\, F_z$	(2)

3. FINITE ELEMENT MODEL

In order to assess and evaluate the new proposed articulated joint, a FE Model is created. The model is a loads model (GFEM – Global FEM) with coarse elements. Pre and post-processing are carried out in MSC Patran 2019, while the processing is done with MSC Nastran 2019, using solution 101 (linear static).

Therefore, a five frame bays zone (5 times the length between 2 consecutive frames) from a constant single aisle aircraft section is used. The boundary conditions from the first frame are not affecting the results extracted from the middle of the model (at the third frame).

The model is created once for the classic frame-crossbeam joint, and once for the new hinged joint. The loads and the corresponding 9 load cases are defined in such a way that the results cover a wide range of different interactions.

3.1. FE Model Description

In Fig. 4 is presented the 5 frame bays length aircraft constant cylindrical section. The model contains all the main parts of a classical passenger aircraft section: skin with longitudinal reinforcements (stringers) and radial reinforcements (frames), the passenger floor with the longitudinal rails, transversal crossbeams and the floor panels, the Z-struts that supporting the passenger floor, and the cargo floor with similar components as the main floor.

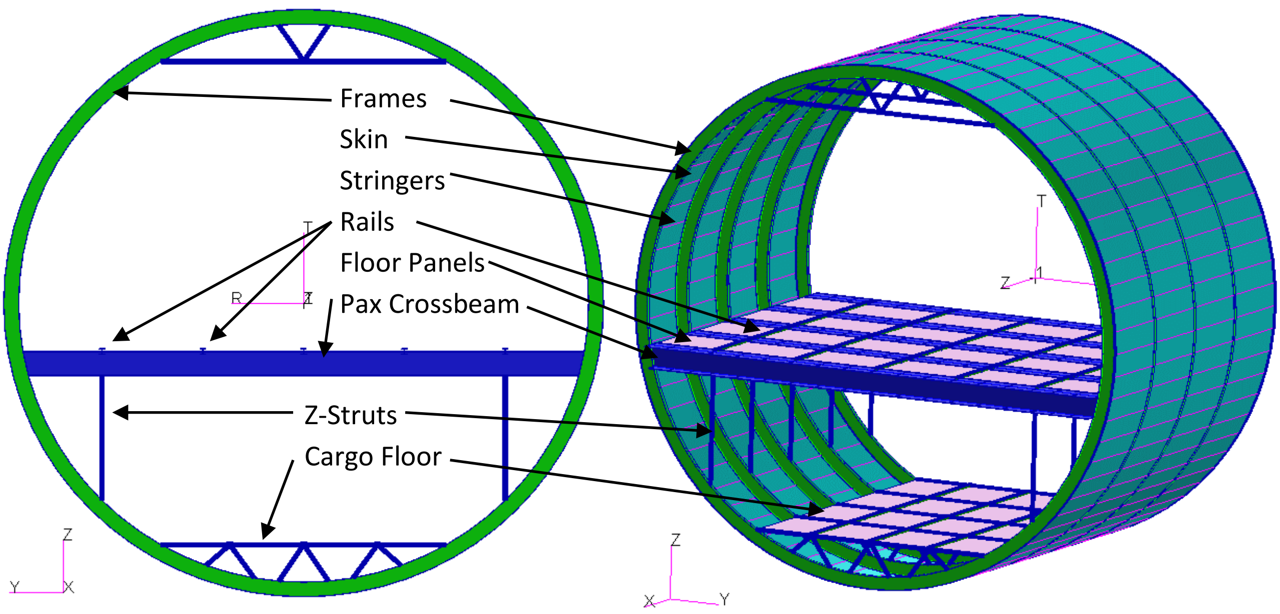

Figure 4: FE Model of the single aisle aircraft (5 frame bays length)

The model is meshed with:

- 1D beam elements for: stringers, frames free and attached flanges, all rails and struts, crossbeams upper and lower flanges,
- 2D shell elements for: skin, floor panels, frame web, crossbeam web.

All parts are considered to be metallic (aluminum alloys) with different thicknesses. For the scope of this model, which is to compare results between two concepts, the materials and properties are of secondary interest.

The boundary conditions consists of fixing all degrees of freedom for all the nodes on the first frame through an MPC (Multi Point Constraint) RBE2 (Rigid Body Element).

Additionally, 9 load cases are defined, based on the special load cases used in the aerospace industry (double internal pressure, emergency landing with up / down / sideways accelerations [4]) and some load cases with load combinations.

3.2. FE Model Results

Each of the two models (classic joint and hinge at the frame – crossbeam connection) was analyzed at all 9 defined load cases. Figure 5 presents in parallel some of the results (deformation, stress etc.), while in Figures 6 and 7 are presented as graphs the compared results for the Frame's Outer Flange (flange attached to skin) and for the Frame's Inner Flange respectively.

	Classical bolted joint	New articulated concept
Displacement (LC2 shown)		
Von Mises Stress (LC3 shown)		
Bar forces (LC1 shown)		

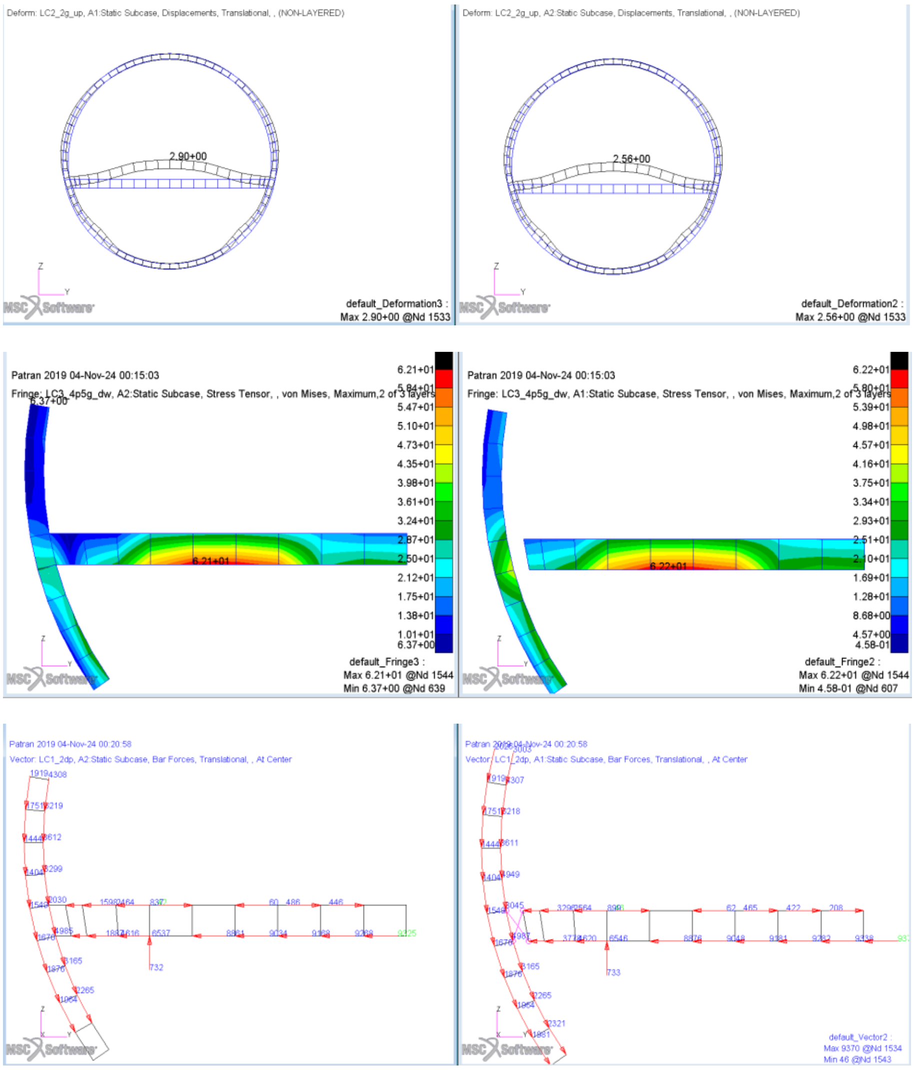

Figure 5: FE Results – comparison between the two analyzed concepts

As seen in the examples presented in Figure 5, on the frame side are relevant differences between the two analyzed concepts.

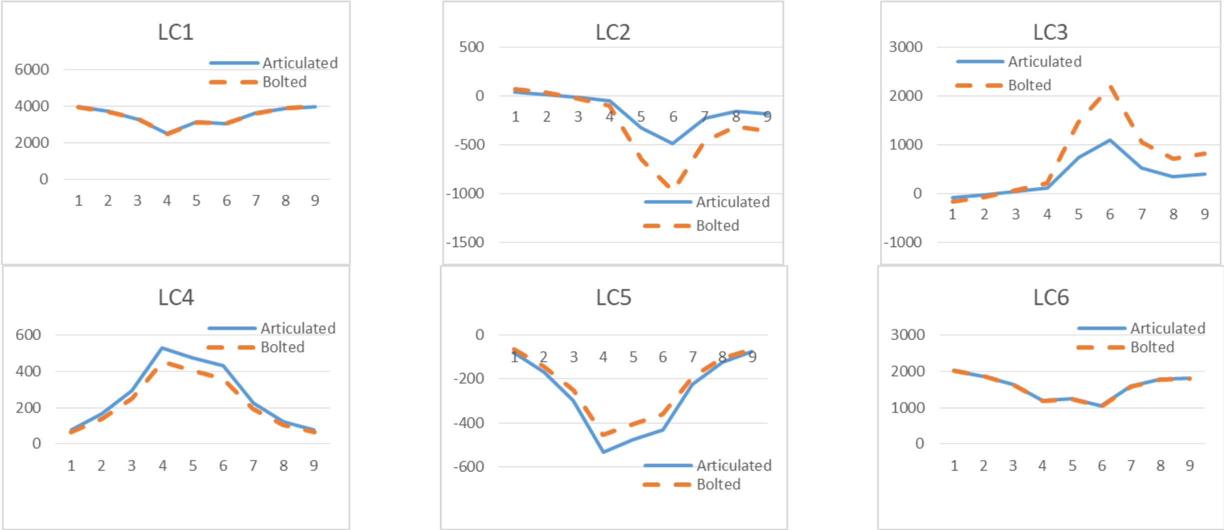

Figure 5: FE Results – Axial load in the beam elements modelling the Frame's Outer Flange

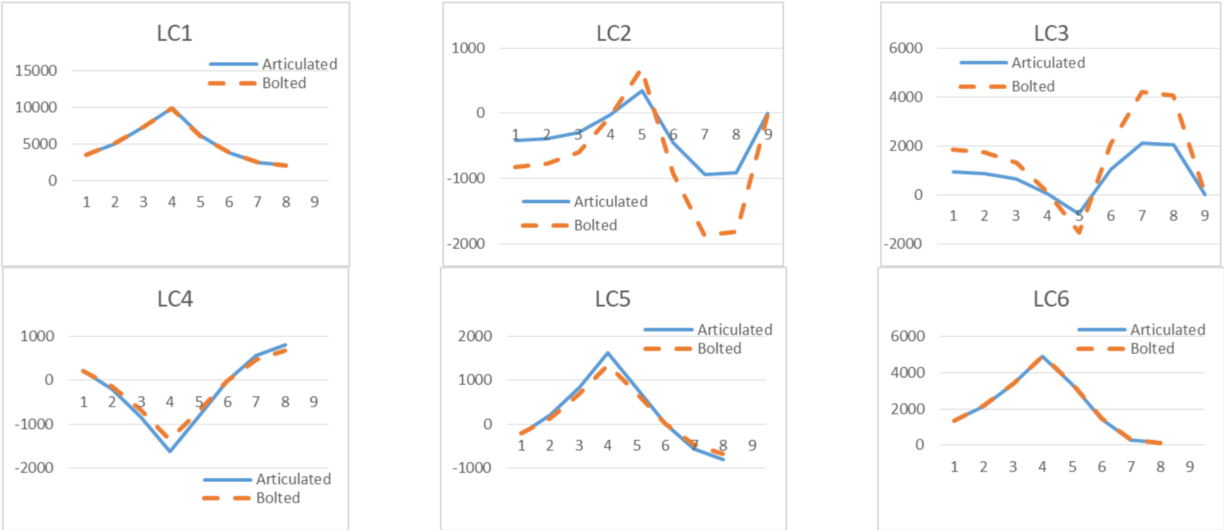

Figure 5: FE Results – Axial load in the beam elements modelling the Frame's Inner Flange

4. CONCLUSIONS

As can be observed in the compared results between the classical bolted joint and the new hinged concept, the way how the frame is connected to the crossbeam affects the load path and the load transfer. With the new concept, the loading of the frame's flanges (outer and inner) is reduced even with 50% in the area of the connection for some load cases, while at the pressurized load cases, the differences are small. At higher distances from the connection, the load differences are also small.

These results prove that the new concept could reduce the loading of the parts in some configurations. Additional work should follow to improve the modeling.

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