# Estudo numérico e experimental do impacto lateral em componentes feitos de material composto

## English title

# Numerical and experimental study of the lateral impact on composite components


**Abstract**

Concerns with the environmental issues and fuel price increase, in the transport sector, have led airplane-producing companies to follow weight reduction and limiting $CO_2$ emissions strategies. The main strategy is employing advanced materials with high specific strength and stiffness ratios instead of heavy conventional metallic materials. Replacing the traditional metallic components with new materials, for instance, composite material, in order to produce lighter and safer vehicles, has gained wide attention. However, this substitution has arisen several engineering challenges related to the crashworthiness of new composite components. This research project aims to study the crashworthiness of composite components made of carbon fiber reinforced plastic, CFRP. The present research project deals with both finite element analysis and experimental lateral impact tests on curved and flat composite components. The project procedure has been affected by the Covid 19 outbraek , thus the timetable of project is updated here.



Keywords: Finite element Analysis, Crashworthiness, Composite material, Progressive failure analysis, Carbon fiber epoxy material, Cohesive Zone Model.


## 1. Introduction

Due to high 'strength to weight' and 'stiffness to weight' ratios rather than conventional metallic materials, the usage of advanced Fiber Reinforced Plastics (FRPs) in primary and secondary aircraft structures yields to the reduction of the amount of fuel consumption and carbon dioxide emissions [1]. Thus, during the past decades, composite materials have been increasingly considered as a promising substitution of heavy metallic parts in the aerospace industry in order to produce lighter and even safer passenger vehicles, Fig. 1 shows Boeing 787 Dreamliner that built of a significant amount of composite materials.

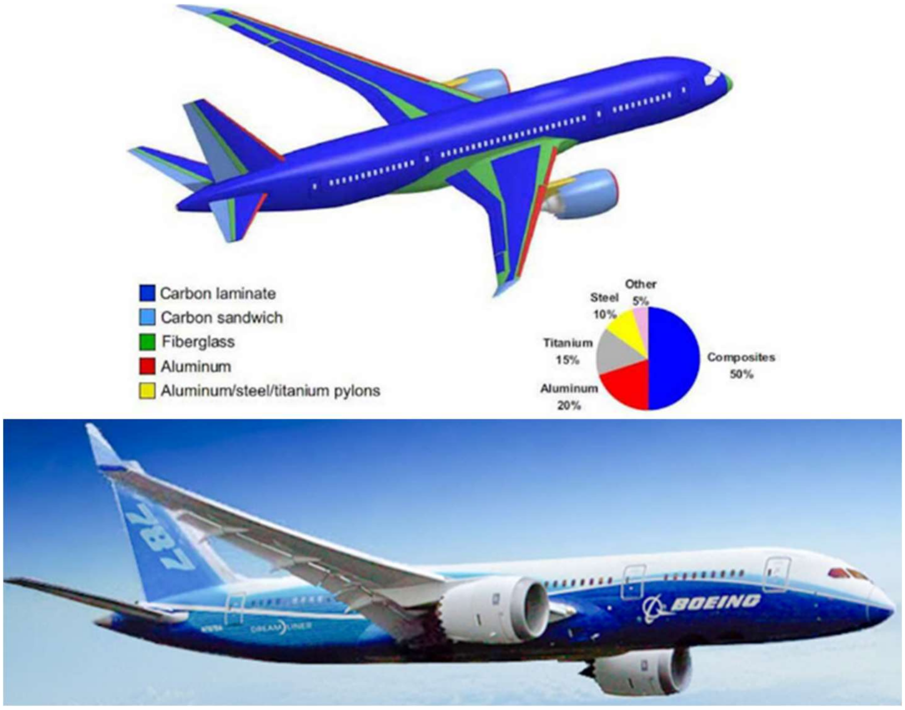


Fig. 1. Boeing 787 Dreamliner.

However, in-service damages due to impacts of objects, small debris, falling tools, birds, can be considered as the main disadvantage of composite materials, Fig.2 shows damages on airplane structure due to bird strike. In the worst-case these damages, like delamination, matrix cracks, and fiber breakage (as presented in Fig. 3), are invisible although degraded the material properties dramatically. Thus, Low-Velocity Impact (LVI) on structural composite panels has been investigated extensively [2–7] and remains challenging among researchers around the world.

Fig.2. Damages induced by a bird strike.

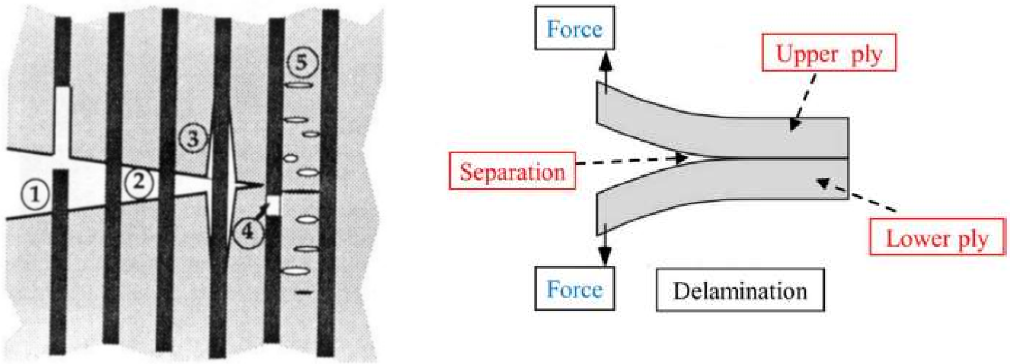


Fig. 3. Damages intra-laminar and inter-laminar (delamination) in laminated composite [8].

A significant number of experimental studies about the impact behavior of composite laminates are available in the literature [2–7]. Several groups around the world have investigated low and high-velocity impact events by using the falling weight [9] and high-pressure gas-gun projectile launcher [5,10]. Most of these studies used the round-shape impactors (sphere) to impact the composite panels, as presented in Fig. 4. However, in the more realistic scenarios the impactors, tools, and debris, may have arbitrary shapes (even having sharp edges).

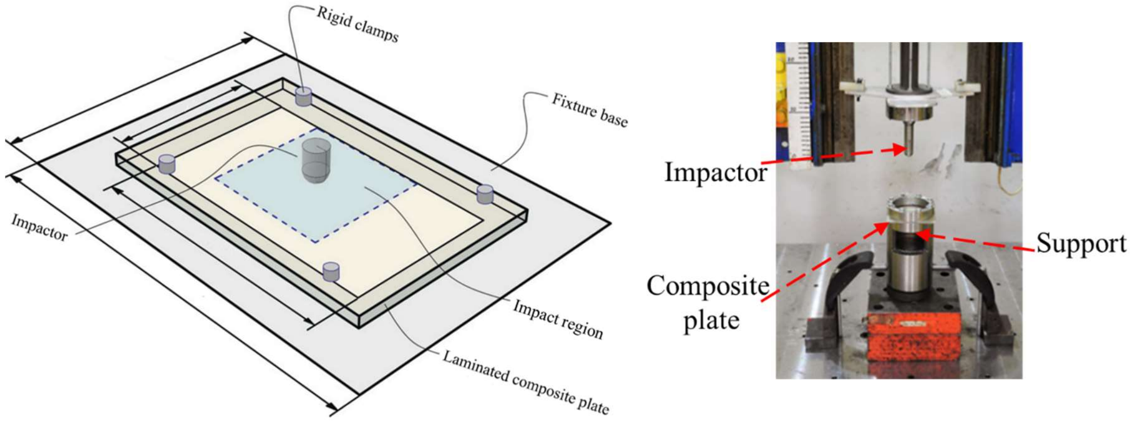


Fig. 4. Schematic of lateral impact test on a laminated plate with round-shaped impactors
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There are several parameters affecting the damaging behavior of composite components, e.g. fiber type, fiber orientation, geometry of component, loading conditions and many others. Thus, testing of composite components required several physical specimens and this makes the development of a new product to be costly. For instance, it is reported that design time and structural testing are expensive, for instance, roughly $40 million for a new airplane [11]. Therefore, at each step of the development process of new composite structural components, a combination of testing and analysis techniques, virtual models, is usually required [12]. Due to the complex damaging behavior of composite materials under dynamic loading, the proposed analytical models [13] have received limited attention yet. Therefore, there is an obvious interest in developing validating and reliable finite element models in order to decrease the cost of the new composite product through a decreasing number of required physical test specimens under dynamic impact events [5,9,10].

The available FE models in the literature, share several similarities, however, the main differences can be related to the modeling techniques of intra-laminar (composite plies) and inter-laminar (delamination) of laminated composites. In the simplest FE models, delamination between laminae (composite layers) is neglected and laminated composite is considered as only one single-equivalent layer [14], thus, this model may overestimate the laminate response. Layer-wise models that are more complicated may produce results that are more reliable since the adjacent composite plies are bonded together with using cohesive interface modeling . The composite layers (laminae) themselves can be modeled with different finite elements such as thin shell element [15], thick shell element [9] and solid element [16]. In a few advanced publications [9,15–17] authors proposed a modified constitutive model for composite layers through providing commercial FE packages by user-subroutine material models (e.g., VUMAT in Abaqus).

## 2. General and specific objectives of the present proposal

### 2.1 General objective

This research project aims to study numerically and experimentally the lateral high- and low-speed impact on laminated composite structures with flat and curved geometries.

### 2.2 Specific objectives

- In-plane material characterization of composite material,
  - Static tests (Universal testing machine)
  - High strain rate tests (using Split-Hopkinson pressure bar).
- Lateral impact tests on curved and flat CFRP components.
  - In the present research besides round-shape impactors, cube impactors will be used to study the effect of impact on composite specimens with sharp edges of the cube, specimens and impactors are presented in Fig. 5.
- Developing finite element modes for lateral impact on composite parts
  - Developing a user-subroutine material model (VUMAT) based on Continuum Damage Mechanics (CDM).
  - Comparative study between 2D FE models based on shell element and three-dimensional FE model based on the solid element.

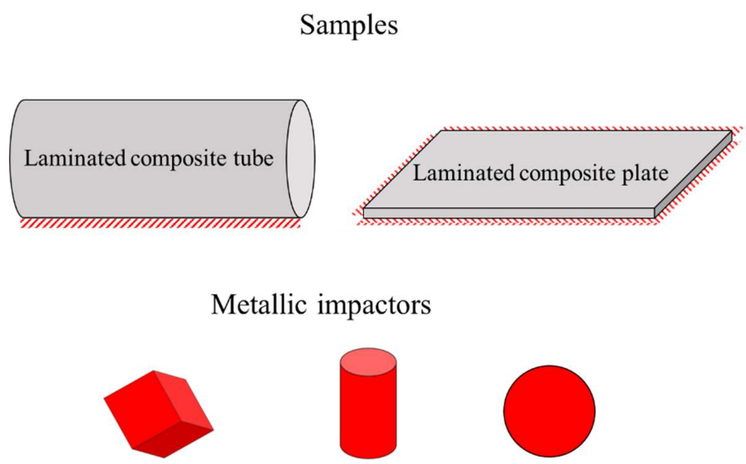


Fig. 5. Composite specimens and different impactors.

## 3. Proposed methodology

### 3.1 Experimental tests

GMSIE Group at the University of São Paulo has a series of equipment in the area of structural impact and material characterization as follows.

- 50 kJ impact hammer tower,
- Low-energy impact tower
- Split-Hopkinson pressure bar
- Gas-gun and pressurized vessels
- The universal testing machine at low loading speeds,
- Tensile, compression, and torsion testing machine at medium loading speeds,
- Tensile and compression test machine at high deformation rates,
- High-speed cameras with a maximum of 700 kfp and required illumination equipment,
- Various types of data acquisition boards at high acquisition rates,
- High-resolution laser velocimeter,
- Various sensors.

The impact tests on the specimens will be done by modifying 50 kJ impact drop hammer equipped by gas-gun and pipelines. Laser velocimeter and High-speed cameras will be installed in the setup in order to measure and calculate crushing force on the specimens. The material characterization tests (tensile, compression and shear) will be carried out at the

GMSIE laboratory if required. A low-energy impact tower at the GMSIE laboratory will be used in order to perform LVI (Low-Velocity impact). Fig. 6 shows the schematic presentation of the high-velocity impact test setup. The gasgun setup is now ready to be used for experimental tests.

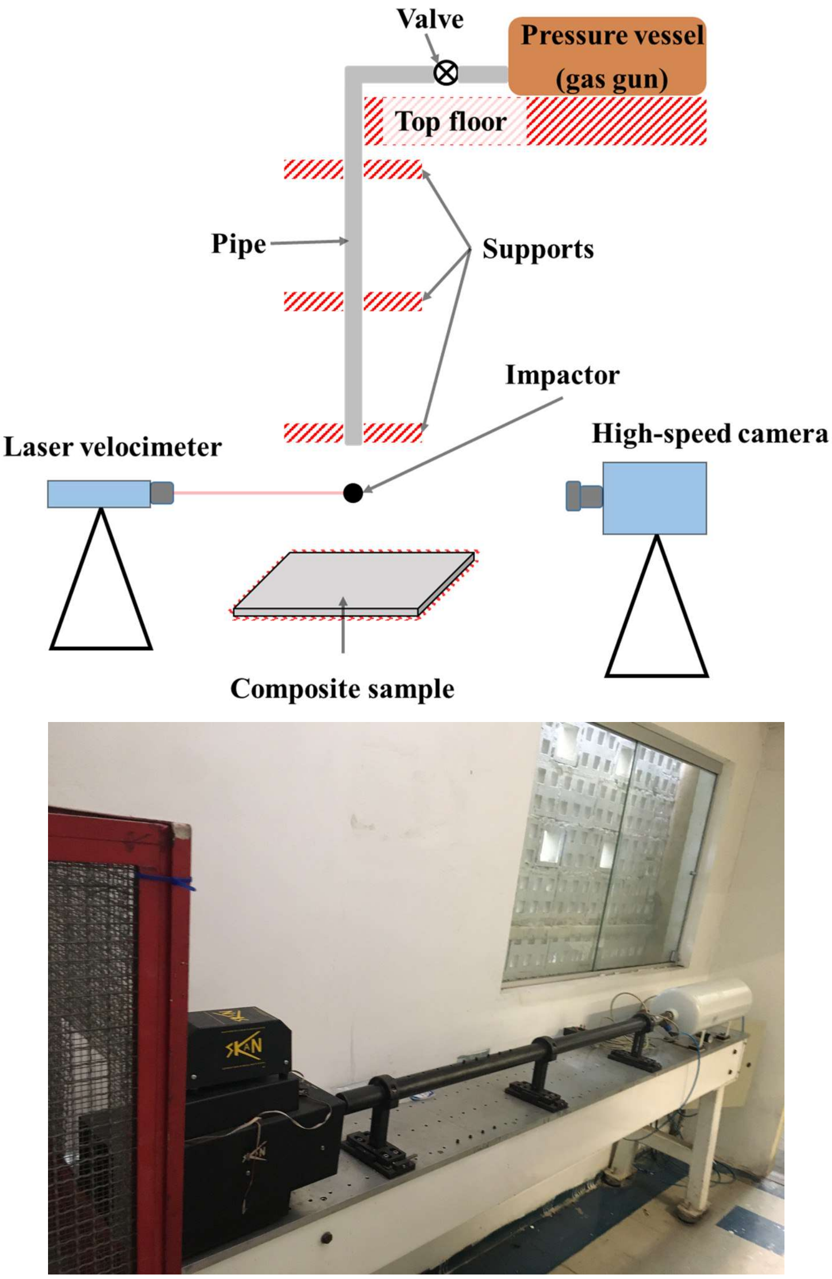


Fig. 6. Schematic and real presentations of lateral impact on composite specimens.

### 3.2. Finite element simulation

The FE simulation will be done at the GMSIE laboratory, which has a powerful cluster system and finite element commercial software like Abaqus.

This FE model will consider intra-layer and inter-layers behavior. The finite element model of impact on composite laminated components, for this research plan, is based on PFA, Progressive Failure Analysis, available in Abaqus software. The models consist of multi-shell (or solid) layers element that considers both in-plane, fiber failure under tension/compression and matrix failure under tension/compression, and out-of-plane, delamination, failure modes. The model uses Hashin's criteria to model in-plane failure and behavior of composite layers, while the Cohesive Zone Model, CZM is implemented to mode interface behavior and delamination process to perform the 2D simulation. A user-subroutine material model will be developed to consider 3D solid models and apply improved material constitutive models available in the literature.

The out-of-plane (delamination) behavior of laminated composite will be modeled by using a 'surface-based' cohesive zone model and element-based cohesive model with the traction-separation law (see Fig. 7). The only difference between 'element-based' and 'surface-based' CZM is that in the 'surface-based' model there is no need of element between two adjacent layers (the interface thickness is negligible).

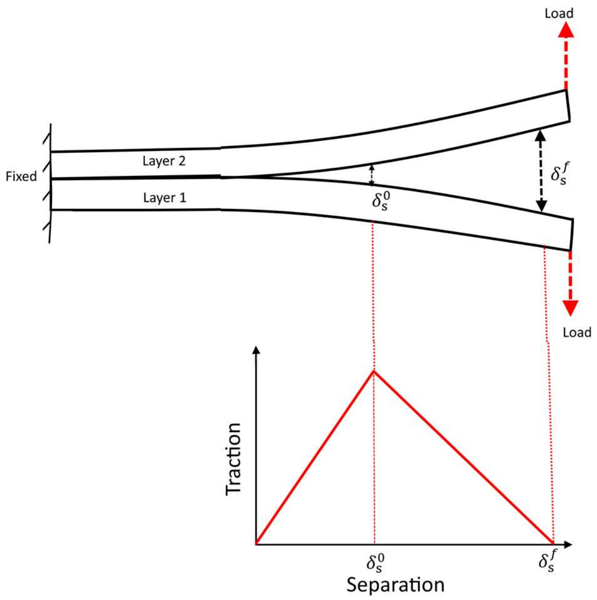


Fig. 7. Bilinear traction-separation law for cohesive zone model.

Preliminary FE model of lateral impact on the plate is presented in Fig. 8.

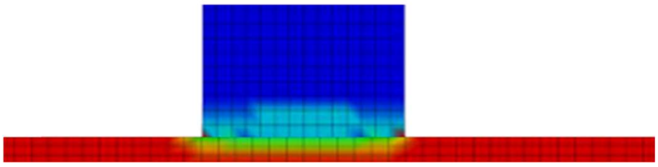

Fig.8. Lateral impact on plate with cubical impactor.

### 3.3 Activities plan and timetable

The research duration is divided into three periods of four two (strats from 01/01/2021), Q1, Q2, and Q3, as listed in the following timetable.

Table 1. The timetable of the activities.

| Activity | Q1 | Q2 | Q3 |
|---|---|---|---|
| Literature review on composite crashworthiness | Finished | | |
| Developing an FE model for impact on the composite structure | Under development | | |
| Experimental test design and conduction | Set-up is ready | | |
| Publishing the results in the international journals | | | |

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