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A FRAMEWORK FOR UNCONVENTIONAL LANDING GEAR CONFIGURATION MODELLING

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Abstract

In this paper a methodology is presented for the assessment of conventional and unconventional landing gear configurations. A data model is implemented with the aircraft as top-level entity. On that basis the landing gear with its components, the wing and fuselage are described in relation to each other. One focus of the framework is the structural integration of the landing gear into the wing or eventually fuselage structure for possible future aircraft configurations. Therefore, parametrical structural models of the landing gear, wing and fuselage are set up. Each of these three parts demands a preliminary sizing of the structure for the nominal load cases as the effect of landing gear integration can only be assessed afterwards. The proposed method is able to set up models for landing gears and the surrounding aircraft structure to examine the integrational aspects and the effect on the landing gear and aircraft structural mass. A first case study for a fuselage integrated landing is presented, which shows a weight reduction of ~28% compared to a conventional landing gear configuration on landing gear level. First fuselage integration possibilities are discussed as outlook for future studies.

Nomenclature

Symbol	Description	Unit
a	Acceleration	m/s²
AR	Aspect Ratio	-
CG	Center Of Gravity	-
conv	Conventional	-
EMF	Eclipse Modelling Framework	-
fuse	Fuselage	-
g	Gravity Constant	m/s²
h	Distance Ground-Fuselage	m
LG	Landing Gear	-
MLG	Main Landing Gear	-
MLW	Maximum Landing Weight	kg
MRW	Maximum Ramp Weight	kg
MTOW	Maximum Take-Off Weight	kg
N	Number Of Landing Gears	-
n	Load Factor	-
rot	Rotation	-
s	Stroke	m
sa	Shock Absorber	-
t	Tyre	-
T/O	Take-Off	-
v	Sink Speed	m/s
UML	Unified Modelling Language	-
z	Vertical Direction	-
α	Rotation Angle	deg
η	Efficiency	-
φ	Sweep Angle	deg

1 Introduction

To fulfil the ambitious goals set by the Flightpath 2050 of the European Commission [1], new aircraft configurations are required, which help to reduce fuel consumption and emissions.

Increasing the bypass ratio of aircraft turbofan engines helps to improve their efficiency [2]. Hence, the fuel consumption reduces. By this development, the nacelle diameter increases above currently applied dimensions as well. As nacelle clearance to the ground has to be ensured, future aircraft could have the engines positioned over the wing, see Fig. 1 a). This would help to solve the problem of an extensive long landing gear main strut with increased weight and storage space. Such a configuration would have new degrees of freedom in terms of landing gear layout. A body landing gear could be a possible solution.

Furthermore, a configuration with a high Aspect Ratio (AR) wing and with a lower sweep angle φ for a reduced cruise mach number could also be a possibility for the future, see Fig. 1 b). For such a wing layout, the attachment possibilities of a classical tricycle landing gear layout are restricted as the space between rear spar and false rear spar decreases.

The two described aircraft configurations are example cases for which the conventional landing gear layout changes to a greater or lesser extent. However, so far the preliminary aircraft design process does not consider the structural integration of the landing gear with its exact position and configuration. Instead, semi-empirical equations and simple relationships are used, which are based on a database of existing landing gears and aircraft for example in [3]. Moreover, the preliminary design process for landing gears is detached from the aircraft. Hence, a method is required for the preliminary design of landing gears, which has the possibility to assess different structural layouts and takes into account the interaction with the aircraft structure. The objective is to be able to assess the impact on the landing gear when changing its configuration and as well as its integration.

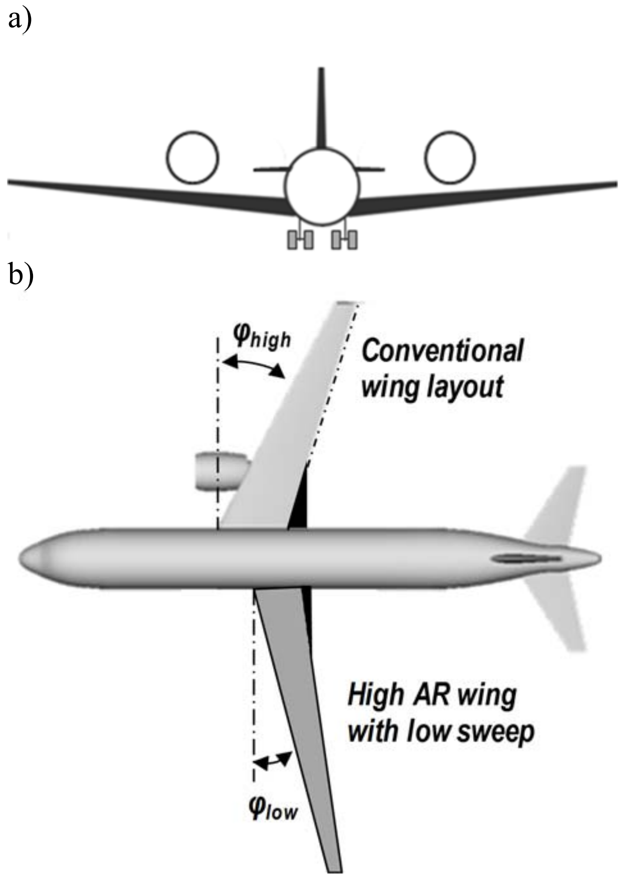

Fig. 1: Possible future aircraft configurations: a) Body landing gear with over wing engines; b) High aspect ratio wing layout compared to conventional wing planform

2 Landing gear design framework

2.1 Introduction to the design process

The developed landing gear design method aims at the assessment of different structural layouts of a landing gear for a given aircraft configuration. The objectives of the method can be summarized as follows:

- Weight estimation of the structural components of a landing gear
- Examine different landing gear configurations to identify the most promising solution
- Investigate integration possibilities by looking at the aircraft structure

The first two above introduced objectives align with the preliminary landing gear design activities presented by Currey [4]. However, the last objective introduces the aircraft structure to these proposed design activities, see Fig. 2.

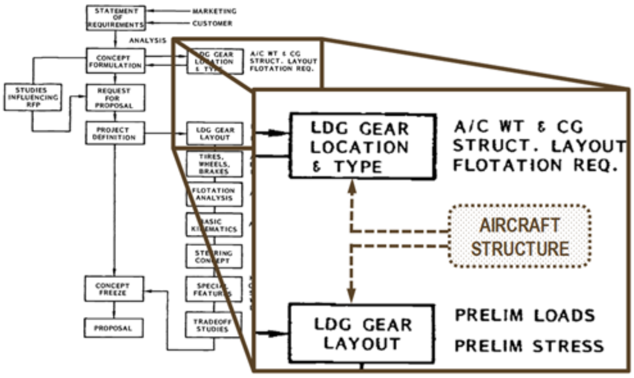

Fig. 2: Landing gear design activities [4] with included aircraft structure

2.2 Landing gear design process

An overview of the established landing gear design process is given in Fig. 3. In a first step the landing gear layout is defined including the number of wheels and, depending on the type of landing gear, for example nose or main landing gear, the share of the applied load. In the next step the shock absorber is sized and its diameter is dimensioned, which, depending on the landing gear configuration, defines one of the main structural parts. After this step, the structural optimization loop sizes the components of the landing gear for minimal weight according to specified load cases and yield strength of the used materials including a safety factor of 1.5.

2.3.1 Shock absorber sizing

The structural key part of the landing gear is the shock absorber. A conventional oleo-pneumatic shock absorber is filled with oil and gas (nitrogen) [4]. The gas serves as a spring. The landing shock presses the oil through an orifice and the nitrogen is compressed. Hence, the impact energy of the landing is absorbed. The efficiency of a shock absorber describes how much energy can be absorbed by pressing the oil through the orifice and compressing the gas spring. Oleo-pneumatic shock absorbers can reach an efficiency of up to 80% [4]. The efficiency is important for the calculation of the stroke of the shock absorber. By assuming that the produced lift equals the weight of the aircraft,

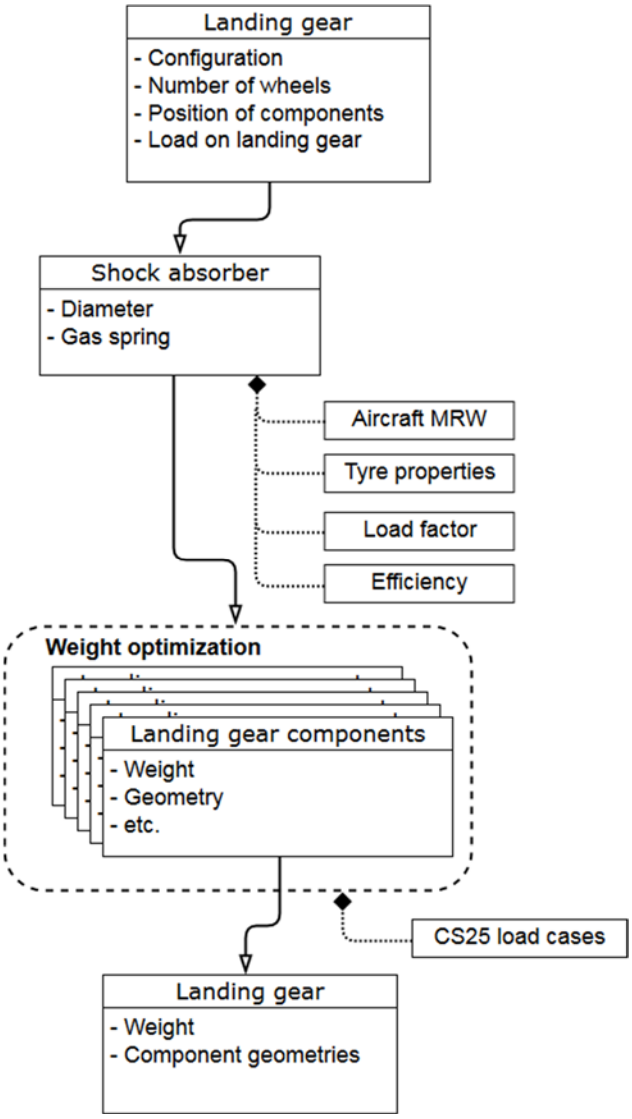

Fig. 3: Landing gear design process

the landing gear stroke can be calculated with the following equation [4].

$$s_{sa} = \frac{v^2}{2gn} - \frac{s_t \eta_t}{\eta_{sa}} \qquad (1)$$

where, s_{sa} is the stroke of the shock absorber, v is the sink speed, g is the acceleration due to gravity, s_t is the deflection of tyre, η_{sa} is the efficiency of the shock absorber, η_t is the efficiency of the tyre and n is the load factor. For the assumption of lift equals weight, the stroke is independent of the aircraft weight.

To design the shock absorber an optimization algorithm is developed, which minimizes the internal volume of the gas spring and hence, the volume of the shock absorber. The assumption is

that a minimum volume of the shock absorber leads to less weight as well. The optimization process in displayed in Fig. 4.
Tab. 1 shows the used values for the tyre properties and the load factor.

Tab. 1: Used parameters for stroke calculation [4]

Parameter	Value	Unit
Tyre efficiency	0.47	-
Tyre deflection	0.1	m
Load factor	1.5	-

Depending on the landing gear arrangement the load on each landing gear is calculated. For example, large transport aircraft commonly have a tricycle landing gear arrangement with one nose landing gear and two main landing gears [5]. For this arrangement, the range of the applied load on the nose landing gear should be 8% with the center of gravity aft and maximal 15% with the center of gravity forward [4]. This leads to a maximum load on the main landing gears of $\mu_{MLG} = 0.92$ for the aft center of gravity position. The maximum vertical deceleration of the aircraft, a_z, during landing can be calculated by assuming that the sink speed of the aircraft has to be zero after compressing the shock absorber and deflecting the tyre.

$$a_z = \frac{v^2}{2(s_{sa} + s_t)} \tag{2}$$

From this the maximum vertical force can be calculated.

$$F_z = \mu_{MLG}\, N_{MLG} a_z MLW \tag{3}$$

Where, F_z is the vertical force, N_{MLG} is the number of main landing gears. F_z is now applied on the landing gear structure in the structural optimization. It is the main force applied in the selected load cases and serves as base to calculate the other forces, for example side loads.

2.3.2 Structural optimization

Fig. 5 shows an example of a simplified main landing gear model how it is set up in the structural optimzation. The structural model consists of the main structural components. These are modeled as beam elements. The tyres are replaced by infinite stiff beam elements. At their end, the load of the different load cases is applied according to the calculated load of the shock absorber design. The result is a simplified landing gear model. The main fitting and sliding tube are modelled as tubes. However, in Fig. 5 they are displayed with a rectangular cross section. Both together form the shock absorber of the landing gear. The open source software calculix [6] is used for the structural simulation.

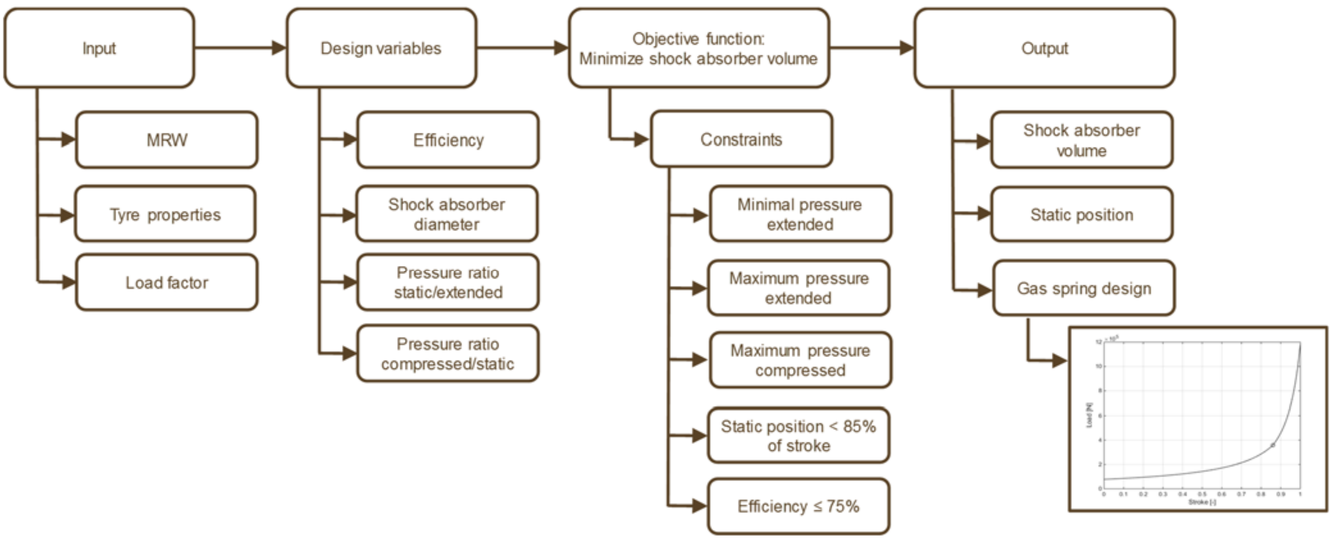

Fig. 4: Design process for shock absorber

Once a landing gear layout is established the dimensions of the different components can be sized by optimising the cross section of each component to withstand the applied loads. These loads are defined using load cases of the Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes (CS 25) [7]. The applied load cases are:

- Level landing
- Tail down condition
- Side load condition
- Braked roll condition

These load cases are applied at a sink speed of $v = 3.048$m/s and the Maximum Landing Weight (MLW) of the corresponding aircraft. Additionally, a spring back load case is defined.

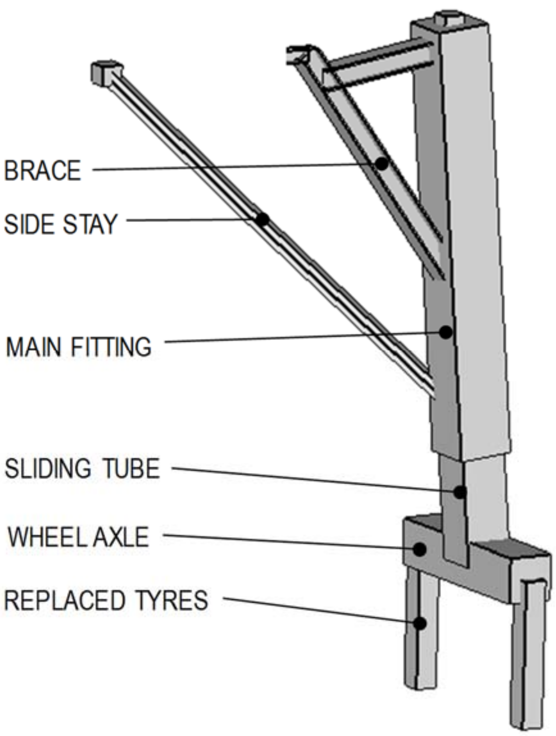

Fig. 5: Simplified landing gear model for structural simulation

2.3 Fuselage design

For the fuselage a parametric model is developed. All main structural parts of the fuselage are defined, such as skin, frames, stringers, cabin floor with supports and bulkheads.
A sizing strategy dimensions the structural components according to specified load cases. The used load cases include in particular cabin pressure and 2.5g maneuver loads. For the integration of a fuselage integrated body landing gear, the center part of the fuselage is modelled with a generic wing box. Fig. 6 shows an example of a fuselage model.

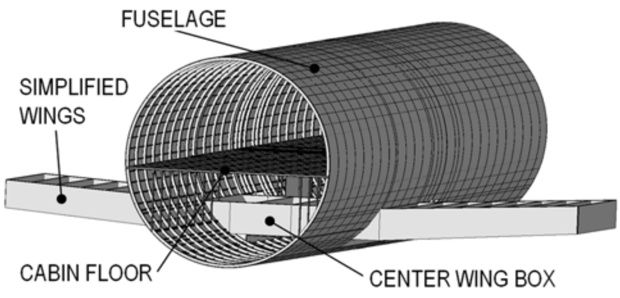

Fig. 6: Example fuselage model

2.4 Wing design

A parametric wing model is under development as well. The wing structural model consists mainly of the wing box. The wing box is sized according to the 2.5g maneuver load case. An elliptical lift distribution is applied on the wing box, which equals the Maximum Take-Off Weight (MTOW) multiplied by the load factor of the considered load case. The lift distribution is assumed to have an elliptical shape even for the 2.5g load case to keep the model simple. Furthermore, the purpose of the wing model is to see the impact of different landing gear integration possibilities. By using the simplified elliptical lift distribution, the impact of the landing gear loads should be easier to identify, which leads to a more conservative approach if the landing gear loads do not have an impact on the sizing of the wing structure.
The applied wing sizing process is comparable as described in [8]. The structural model itself is designed with shell elements representing the different components, such as spars, skin, ribs and stringers. A simplified pylon, to introduce thrust loads and engine weight, is also part of the wing model. Important for the assessment of the landing gear integration is the implemented parametric false rear spar. This makes it possible to assess different integration possibilities of the landing gear and hence, different landing gear layouts.

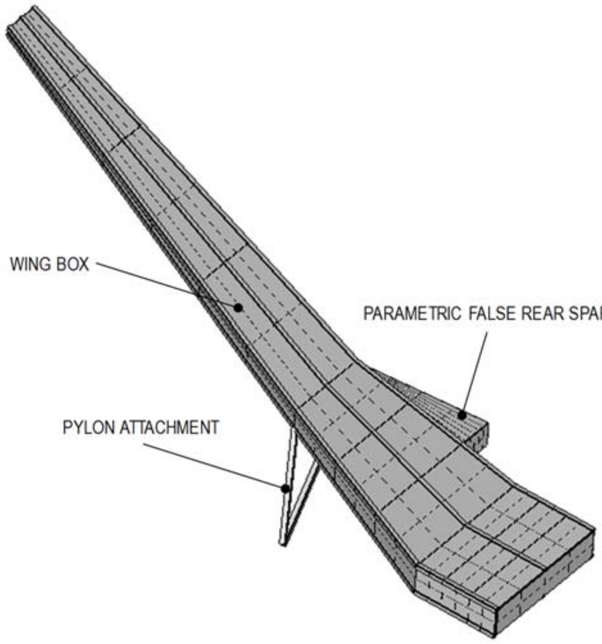

Fig. 7: Parametric wing model

2.5 The framework

The framework for the evaluation of different landing gear configurations is designed via an object-oriented approach using the Eclipse Modelling Framework (EMF) [9]. The elements, such as the landing gear, its components and the aircraft, and their relations between each other are modeled using principles of the Unified Modeling Language (UML) [10]. This means that the different elements are created as classes with associated connections between each other, which determine their dependence. Fig. 8 shows a simplified class diagram of the developed data model. At the top level an aircraft is defined, which contains the landing gear system, the fuselage and the wing. The landing gear system contains the single landing gears, as for example the main landing gears. Each landing gear consists of an arbitrary number of structural components with a cross section. The layout of the landing gear is defined by connecting the components with each other. Therefore, so-called ports are defined, which are placed at the exact position of the connection between two components. Furthermore, a class for functional elements, such as the shock absorber, is defined in an own component assembly class.

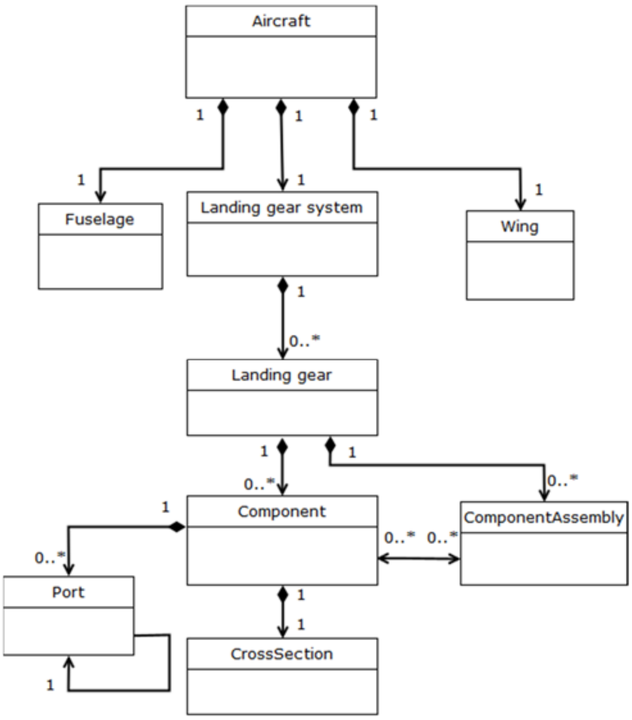

Fig. 8: Simplified class diagram

3 Validation of landing gear design method

For the validation of the landing gear design method and process a landing gear model of an existing aircraft is set up. The results of the structural optimization are compared with results obtained from statistical methods based on a database of existing aircraft [3]. The main landing gear of a regional aircraft is selected and refers to the Embraer E195 [11]. Tab. 2 shows the parameters of the aircraft and the landing gear used for the validation.

Tab. 2: Used parameters for validation

Parameter	Value	Unit
MTOW	52290	kg
MLW	45800	Kg
Landing speed	86	m/s
Sink speed	3.048	m/s
Safety factor	1.5	-
Shock absorber efficiency	0.75	-

Fig. 9 displays how the landing gear is modelled with the presented design method. Fig. 10 shows the results of the validation in comparison with the statistical method. As can be seen the developed method predicts the weight of the shock strut in very good agreement with the statistical method. However, the side stay weight is predicted too low. For the total structural weight the difference between both methods is relatively low as the weight of the side stay is much smaller than the one of the main strut. The difference between both methods has different reasons. The weight bookkeeping is very important. On the one hand, the developed method simplifies the structure of the landing gear. Only the main components are modelled. For example the torque link is not part of the model. On the other hand, is not clear which components are considered for the mass estimation in the statistical method. Another reason is that the structural sizing loop depends strongly on assumed material properties and geometric assumptions. Additionally, the statistical method is based on different landing gear configurations, For example, different number of tyres and side stay layouts. However, the weight estimation of the side stay requires , no geometrical information.

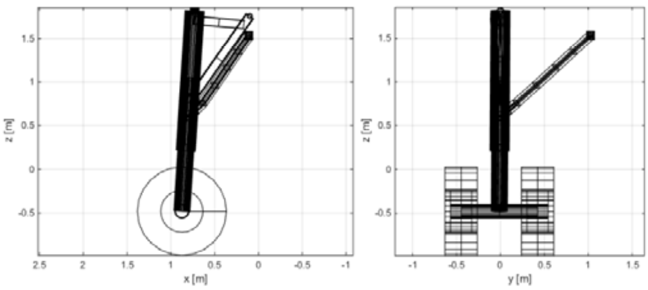

Fig. 9: Landing gear model for validation

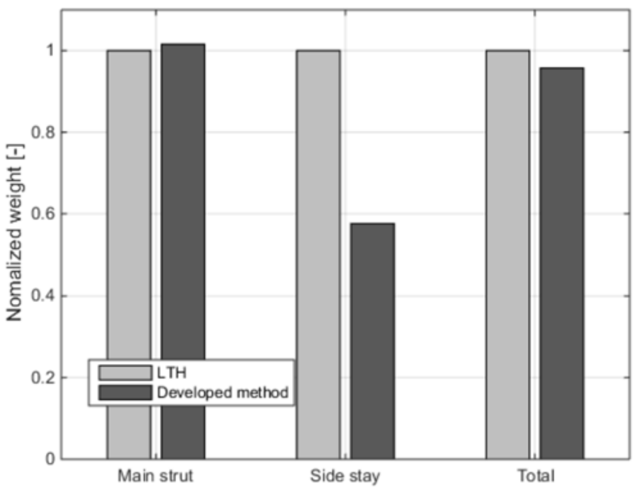

Fig. 10: Results of validation

4 Fuselage integrated landing gear

A case study using the developed framework is presented in this section. In Section 4.1, the considered aircraft and assumptions are introduced. In Section 4.2, a fuselage integrated body landing is compared to a conventional landing gear with a telescopic shock strut. This comparison is done on landing gear level. Section 4.3 discusses first structural integration possibilities of the body landing into the fuselage.

4.1 Aircraft configuration and assumptions

For the comparison of the fuselage integrated body landing gear with a conventional landing gear, a single aisle aircraft configuration with high bypass ratio engines is assumed. The engines are placed under the wing for the conventional landing gear configuration and over the wing for the body landing gear. A comparison of the two configurations is displayed in Fig. 11. As can be seen, the distance between the ground and the fuselage for the conventional landing gear configuration, h_{conv}, is larger than for the body landing gear configuration, h_{fuse}.

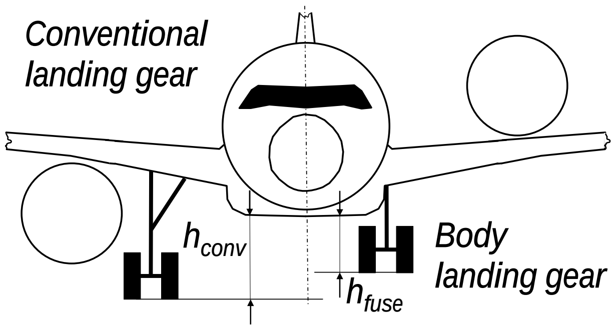

Fig. 11: Comparison of body landing gear with a conventional landing gear configuration

Previous studies [12] showed that without the restrictions of the nacelle clearance the landing gear can be shortened significantly by still fulfilling the tipping, turn over and wing tip requirements. An appropriate upsweep angle of the aft fuselage section, $\alpha_{T/O\ rot}$, has to be applied to comply with the take-off rotation requirement, see Fig. 12.

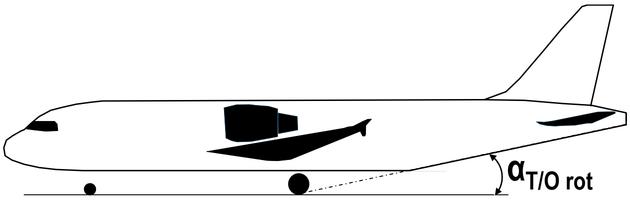

Fig. 12: Take-off rotation angle for an aircraft with body landing gear

No change of the position of the center of gravity of the aircraft is assumed for both landing gear configurations. Therefore, the position of the body landing gear is only moved inwards closer to the center plane of the aircraft. Fig. 13 shows the position of the body landing gear compared with the considered conventional landing gear. Tab. 3 shows the used aircraft properties for the studies.

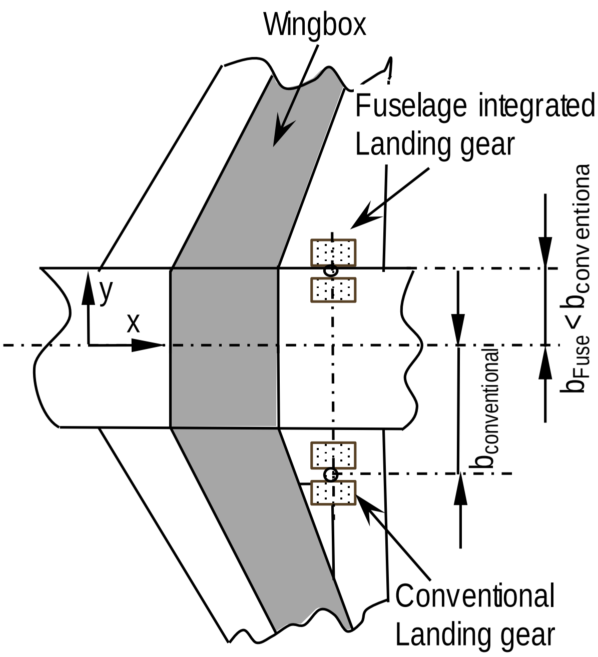

Fig. 13: Assumed position of the fuselage integrated landing gear compared to the conventional landing gear at the wing

Tab. 3: Used aircraft properties

Parameter	Value	Unit
MTOW	75000	kg
MRW	75412	kg
Fuselage diameter	4	m
Take-Off rotation angle ($\alpha_{T/O\ rot}$)	12	deg
Distance ground – fuselage conventional landing gear (h_{conv})	2.5	m
Distance ground – fuselage body landing gear (h_{fuse})	1.4	m

4.2 Comparison with conventional landing gear

The layout of the conventional landing gear and the fuselage integrated body landing gear are displayed in Fig. 14.

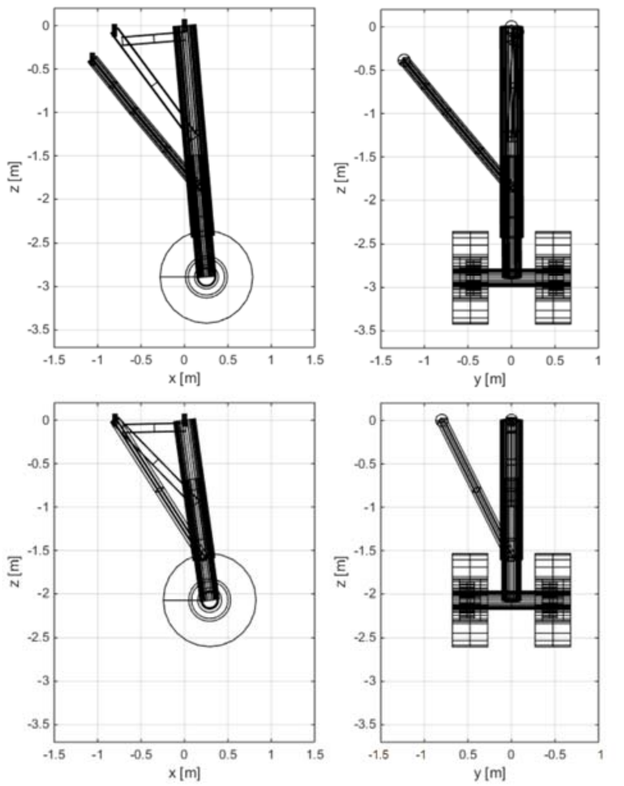

Fig. 14: Dimensions of the conventional landing gear (above) and the fuselage integrated body landing gear (below)

The body landing gear is considerably smaller than the conventional landing gear. However, as described in Section 2.3.1 the inner diameter of the shock absorber, and hence, the main fitting is

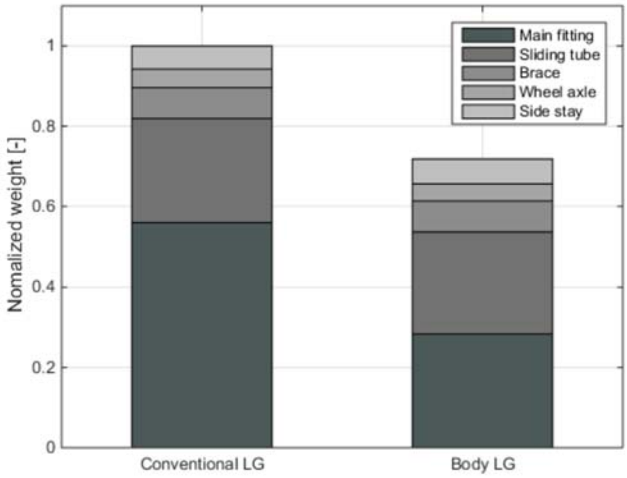

Fig. 15: Comparison of the results of the structural optimization of conventional landing gear and the fuselage integrated landing gear

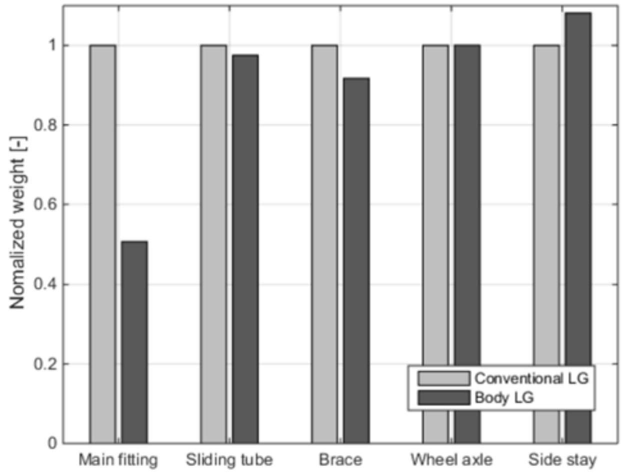

Fig. 16: Comparison of the components of the conventional landing gear and the body landing gear, each normalized by the component of the conventional landing gear

a function of the weight of the aircraft. Both configurations are structurally dimensioned with the optimization process established in Section 2.3.2. Fig. 15 shows the result of the design process for both landing gears with the main structural parts. The fuselage landing gear is ~28% lighter than the conventional landing gear. Fig. 16 shows a comparison on structural component level. As can be seen the main fitting is the main part where the fuselage landing gear saves mass compared to the conventional landing gear. The sliding tube and the wheel axle have almost the same weight in both cases. This is reasonable as both sliding tubes have the same diameter and length due to design rules. The wheel axle are also optimized for the same load derived from the same aircraft weight in both cases. The brace and side stay are heavier for the fuselage integrated body landing gear, but this is determined by the geometrical layout It has to be highlighted that the weight strongly depends on the given configuration. Therefore, the difference cannot be used as a general conclusion.

4.3 Fuselage integration

This section discusses several proposals of how a fuselage integrated body landing gear can be incorporated into the fuselage structure. As already mentioned above a body landing gear must fulfill the same requirements as a conventional landing gear. Depending on the position of the Center of Gravity (CG) of the entire aircraft, the integration possibilities vary. In the previous section, the body landing gear was assumed to be only moved towards the center plane of the aircraft. Depending on the position of the CG, the landing gear may be attached to the rear spar and to the center wing box as a conventional wing mounted landing gear. However, if the CG of the aircraft moves aft the position of the landing gear has to be changed as well. Fig. 17 shows three different attachment scenarios of the landing gear to the fuselage. The first one assumes that due to the most aft CG position, it is still possible to attach the landing gear at least with the brace and the side stay to the rear spar of the wing box, see Fig. 17 a). The second proposal, see Fig. 17 b), describes the possibility to attach the landing gear to the fuselage structure. That means all attachment points of the landing gear, main fitting, brace and side stay have to be attached to the frames of the fuselage. Especially for the side stay, a suitable attachment point has to be found in this case. The third option introduces a levered landing gear configuration instead of a configuration with a conventional telescopic shock absorber, which could be a possibility to use the wing box to attach the landing gear to despite of the most aft CG position moving further to the tail. One example for an aircraft equipped with a levered landing gear is the British Aerospace BAe 146/Avro RJ, which also has as fuselage integrated body landing gear [3]. Another important point aside from the CG position is the retraction of the landing gear. Here the position of the side stay plays an important role. Fig. 18 shows various possibilities of the integration in accordance with consideration of the CG position presented in Fig. 17. In Fig. 18 a), the brace and the side stay are attached to the wing box and the main fitting would have to be attached to a fuselage frame. This could be realized by the introduced configuration of Fig. 17a). Fig. 18 b) introduces the possibility of attaching the side stay to the keel beam of the fuselage. This layout is comparable to the landing gear configuration of the above mentioned British Aerospace BAe 146/Avro RJ aircraft. Fig. 18 c) describes the option of attaching the main fitting and the side stay to the rear spar and the brace to a fuselage frame.

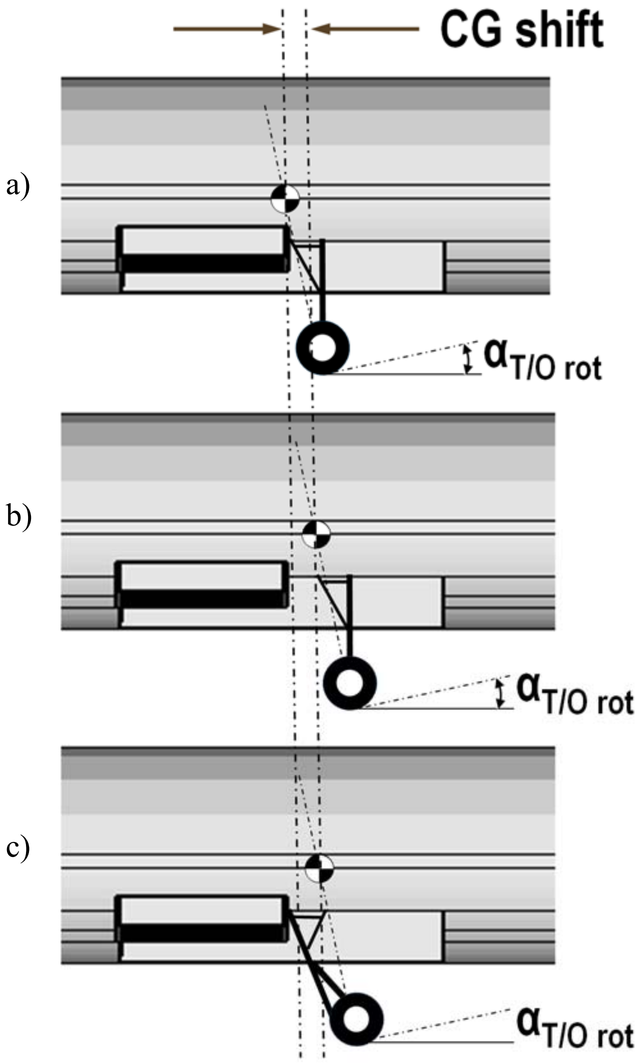

Fig. 17: Landing gear with integration for different CG positions: a) Wing box attachment and telescopic landing gear, b) Fuselage structure attachment with telescopic landing gear, c) Wing box attachment with levered landing gear

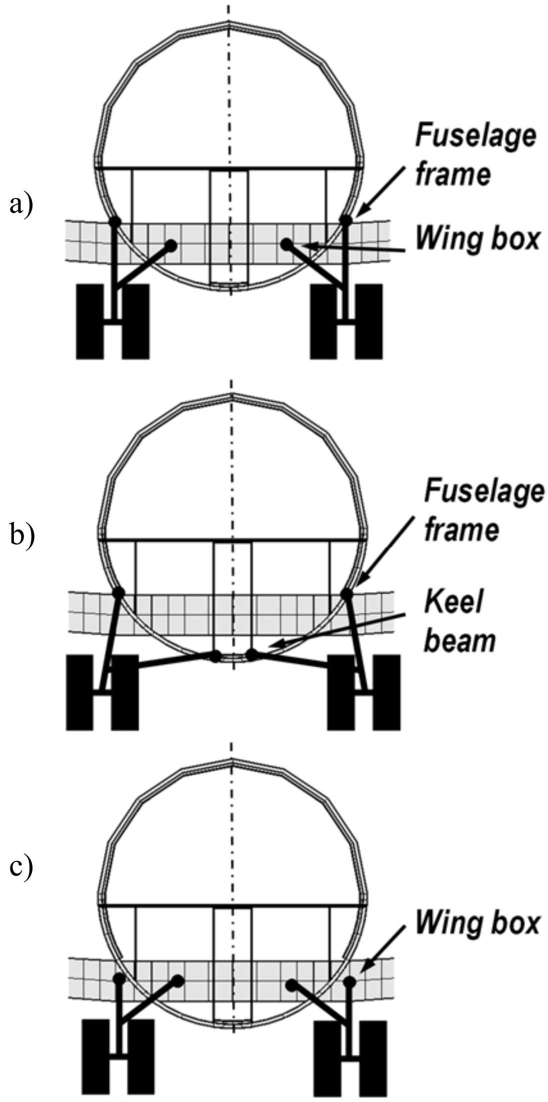

Fig. 18: Different integration possibilities of the landing gear regarding retraction and side stay attachment: a) Wing box attachment, b) Main fitting and brace to fuselage frames, side stay to wing box, c) Main fitting and brace to fuselage frames and side stay to keel beam

This corresponds to the side view of Fig. 17 c). In all three scenarios, the retraction of the landing gear has to be ensured. Sideway retraction depends strongly on the length of the landing gear and the attachment points. In this case, a shock absorber shortening mechanism [4] could be necessary. Retract the landing gear forward would probably need a change of the center wing box structure, which should be avoided. A highly reliable actuation system is needed if the landing gear is retracted aft wards as extension and down locking would have to be ensured despite of applied aerodynamic forces during approach. Extension and down locking due to gravity as emergency mode would not be sufficient.

5 Conclusion and outlook

This work presents a framework for the assessment of landing gear configurations. Based on a general data model conventional and unconventional landing gear configurations can be created. The shock absorber design is the first step in sizing a given landing gear. Afterwards a structural model using FEM beam elements of the landing gear is set up. The loads on the landing gear are calculated via load cases defined in the CS 25. Through a structural sizing loop a first detailed weight estimation for the landing gear configuration can be conducted. It is possible to evaluate different landing gear configurations on a detailed structural level and assess the different components. Moreover, the introduced framework adds parametric structural models of the fuselage and the wing of an aircraft to the design process to be able to assess the integration of the landing gear in the aircraft and to consider different integration possibilities. The method was compared to a statistical mass estimation method. The comparison showed good agreement for the overall structural weight estimation of the developed method with the statistical mass estimation method. In a first case study a conventional landing gear is compared with a fuselage integrated body landing gear. The comparison showed that, for the examined particular configurations, the fuselage landing gear is ~28% lighter than the conventional landing gear layout. The weight benefit of the fuselage integrated landing gear comes mainly from the much lighter main fitting. All other components have similar weights compared to the convention landing gear.

In a second step, several integration possibilities of how to integrate a body landing gear into the fuselage are presented and briefly discussed. Emphasis is placed on the aircraft center of gravity position and landing gear retraction modes.

Future work is intended to compare not only different landing gear configurations with each other, but also the impact on the integration. Especially for the presented fuselage integration scenarios.
Further studies for the integration of a landing gear into a high aspect ratio wing are also a possibility to use the developed methods.

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