
# AEROELASTIC ISSUES IN THE DESIGN OF HIGH ASPECT RATIO STRUT-BRACED WING AIRCRAFT

E. Roncolini, F. Toffol, S. Ricci

Politecnico di Milano, Department of Aerospace Science and Technology, 20156 Milano, Italy

## Abstract

Globalization has headed to a wide employment of carbon-based fuels, whose released $CO_2$ is identified as the main responsible for climate change. All the transport sector is involved, with no exceptions for aviation. Several initiatives have been proposed in the European Union to limit the usage of these fuels, such as the Clean Sky 2 U-HARWARD project. One of the tasks was to study a promising unconventional configuration: the Strut-Braced Wing (SBW). Particular attention must be payed on its design: it can cause unexpected deformations. After having created a suitable SBW model, classical aeroelastic analyses have been studied. Finally, some parametric investigations have been conducted to understand the influence of wing and strut material, strut geometry and wing-strut attachment chordwise position on the results. If both wing and strut are made of composites, their weights reduce significantly (c.a. 30%).

**Keywords:** Strut-Braced Wing (SBW), nonlinear aeroelasticity, composites

## 1. Introduction

Climate change should happen because of nature. Unfortunately, starting from the last century human activities have become the main reason for these phenomena to occur. Carbon-based fuels released $CO_2$ is one of the principal concerns. Being these fuels employed practically in every sector (e.g. industry, agriculture, energy, transportation), also the aviation world is involved. Indeed, as reported by the International Energy Agency in [1], in 2021 air transports were responsible for over 2% of global $CO_2$ emissions. Being well aware of the situation, in the last decades several effort has been spent to produce and employ advanced technologies such as composite materials, modern aerodynamic profiles, efficient propellers, but it must be admitted that a sort of plateau has been reached and following this path does no longer allow for the required gains. A change in perspective is needed. This justifies the lately renewed interest in unconventional configurations such as Blended Wing Body (BWB), Box-Wing (BW), Strut-Braced Wing (SBW) and Truss-Braced Wing (TBW), which can represent a gamechanger. An overview of these concepts can be found in [2].

In this context, a EU funded Clean Sky 2 project leaded by Politecnico di Milano started in May 2020, as a response to the call JTI-CS2-2019-CFP10-THT07, named U-HARWARD, acronym of Ultra-High Aspect Ratio Wing Advanced Research and Designs [3]. The aim of the project was to investigate the use of innovative aerodynamic and aeroelastic designs exploiting a multi-fidelity multi-disciplinary optimal design approach to develop ultra-high aspect ratio wings for medium and large transonic aircrafts. One of U-HARWARD tasks was to study the SBW configuration, which appears to be particularly promising.

After a revision of SBW working principle and history, the present work focuses on SBW aeroelastic model generation. Some issues concerning the design are reported and a possible solution is proposed. In the next section a summary of the computed aeroelastic analyses is given. The correspondent results are then reported, along with some parametric studies concerning wing and strut material, strut geometry and wing-strut attachment chordwise position.

## 1.1 SBW working principle

The well-known Breguet range formula

$$R = \frac{V_{TAS}}{g}\left(\frac{L}{D}\right)\frac{1}{SFC}\ ln\left(\frac{W_{MTOW}}{W_{MTOW}-W_{fuel}}\right)$$

illustrates how aircraft efficiency is influenced by aerodynamics (L-to-D), propulsion (SFC) and structure (logarithmic term). An effective way to reduce aircraft emissions is therefore to increase aerodynamic efficiency. Drag is subdivided in several contributions, e.g. wave, friction, induced drag. The latter is the most relevant component. Indeed, as reported in [4], for large transport aircraft it covers around 43% of total drag during cruise. Induced drag coefficient

$$C_{D_i} = \frac{C_L^2}{\pi ARe}$$

depends proportionally on the square of lift coefficient ($C_L$) and inversely on Oswald coefficient ($e$) and wing AR ($AR$), hence: augmenting the AR lowers the induced drag. However, high ARs lead to an increase in wing bending moment, and, consequently, in wing weight, possibly withdrawing the benefits of having such a high AR. The introduction of a strut at a certain wingspan allows to keep wing weight limited, by alleviating its bending moment, as qualitatively shown in Figure 1, where the compared aircraft configurations are Classical Tube and Wing (CTW), Classical Tube and Wing with high Aspect Ratio (CTW – high AR) and Strut-Braced Wing (SBW).

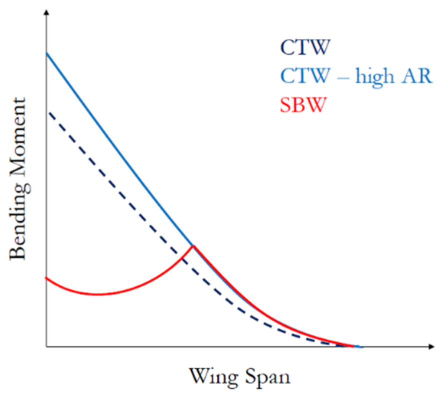


Figure 1 - Qualitative behavior of wing bending moment for different aircraft configurations

However, strut presence leads to an overconstrained system, which is intrinsically complex, while the increased AR leads to a very flexible wing. Both these aspects can play a role on aeroelasticity outcomes.

## 1.2 SBW historical review

### *1.2.1 General works on SBW*

The pioneer of SBW concept is globally identified in Pfenninger, who was the first to believe in the potential of this configuration, starting to work on the topic in the 1950s at Northrop [5], until its retirement in the 1980s. In [6], he declared that the presence of the strut is needed to reduce both bending and torsional moments and deformations, and that the best choice would be to use a wide-chord low-drag laminar strut.

At Boeing, the earlier work on the configuration was published in 1978. Park produced a work comparing block fuel consumptions of CTW and SBW. Strut buckling issue was pointed out and solved by increasing its thickness, which reflected on the amount of strut parasite drag [7]. At the same time, Kulfan et al discovered that the statistical formulas used at that time to estimate aircraft weights were inaccurate for very high ARs. Analytical formulas were needed [8].

Almost in those years other comparative studies between CTW and SBW were conducted at NASA

[9] [10]. In both the studies, SBW appeared to be the most efficient configuration thanks to the presence of the strut. Some strut-related topics were discussed: it was demonstrated that lifting struts are more convenient than non-lifting ones; for the first time the presence of juries to counteract strut buckling has been considered, leading to a Truss-Braced Wing (TBW) configuration; the wing-strut attachment spanwise position has been analyzed as well.

Some decades later, several studies on SBW and TBW were conducted at the Virginia Polytechnic. For instance, in [11] a parametric study was performed, resulting in optimal wing weight and flutter velocity for wing-strut attachment ranging from 55% to 70% of wing span.

In Europe, the first work regarding SBW was produced by ONERA inside the ALBATROS project [12]. Fuselage-mounted engines were chosen to keep as much as possible laminar flow on the wing. This led to a T-Tail configuration. Also, in this work some studies regarding the strut spanwise position resulted in an optimal range between 50%-70% of wing span. Some divergence problems were highlighted and solved by increasing strut thickness, meaning that if the strut is too flexible, aeroelastic problems could arise. In 2022, Delavenne et al focused on weight analyses of SBW during preliminary design stages [13]. Only a pull-up manoeuvre and some gusts were considered as load cases. A discussion on buckling was reported: either the phenomenon is considered during sizing, leading to significant increases in wing weight, or it can be bypassed by properly positioning wing-strut attachment along wing span.

### *1.2.2 Multidisciplinary Design Optimization*

To fully capture the potential of a configuration, all the interacting disciplines should be considered at the same time, leading to the so-called and well-known multidisciplinary approach. The first MDO work related to SBW was [14]. In 1996, NASA Langley commissioned a small group of researchers at Virginia Tech’s Multidisciplinary Analysis and Design Center for Advanced Vehicles a study for the feasibility of a transonic SBW using Multidisciplinary Design Optimization (MDO) approach. To address buckling problems, the strut was considered inactive under compression through a telescopic sleeve, as shown in Figure *2* [15].

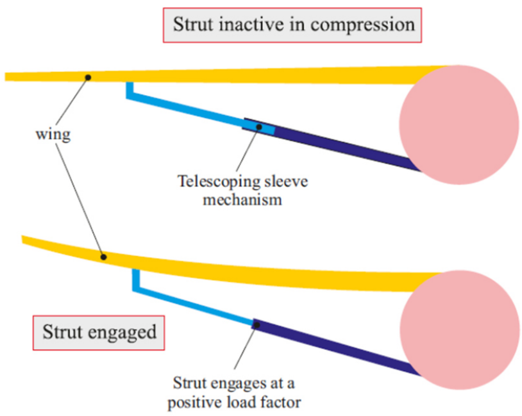


Figure 2 - Telescopic sleeve mechanism

Other studies conducted at the Virginia Polytechnic are reported in [16] and [17], where a new method for the evaluation of bending material has been introduced. With the partnership of Lockheed Martin, it was possible to develop a new model able to correctly capture both bending material and torsional stiffness of the wing, both needed for aeroelastic analyses. In [18] and [19] comparisons between CTW, SBW and TBW were studied by means of MDO. In both cases, SBW and TBW resulted as superior. From the optimization analyses, big strut dimensions emerged, opening to the possibility to store fuel not only in the wing but in the strut too, leading to a further reduction of wing weight. Recent MDO works are [20] and [21].

At the moment, the most advanced study on SBW and TBW is developed by NASA in collaboration with Boeing, inside the Subsonic Ultra-Green Aircraft Research (SUGAR) program [22] [23].

## 2. Aeroelastic model

The starting point is the model produced by ONERA and ISAE-SUPAERO inside U-HARWARD project, presented in [20]. The Airbus A321-LR was chosen as reference aircraft. The CTW configuration was modified into its SBW version. The wing was stretched to reach the desired AR (see Table 1).

| | A321-LR | SBW |
|---|---|---|
| **Wing Span** | 34.1 [m] | 55.13 [m] |
| **Wing Surface** | 126 [$m^2$] | 161.8 [$m^2$] |
| **Wing AR** | 9.23 | 19 |
| **Wing Sweep** | - | 19 [deg] |

Table 1 - Geometrical values of baseline configuration A321-LR and its SBW version

It has then been translated from the bottom to the top part of the fuselage, to accommodate the strut. To avoid potential interferences, fuselage-mounted engines were selected, along with a T-Tail configuration. The strut was chosen to be lifting.

### 2.1 Modeling choices

Up to this point, the present work followed the same path proposed by ONERA. However, discrepant results have been obtained. This outcome is due to the different adopted modeling choices, here listed.

1. Wing-strut attachment: in [20] it was modeled through a sleeve aligned with the wing Elastic Axis (EA) that allows the strut to be inactive in compression, to avoid buckling problems. Since no dedicated studies were conducted on this connecting mechanism, which was firstly proposed by NASA in the 1990s [15], it has been here considered a non-realistic solution, at least for the moment. Therefore, the attachment has been modeled by a double hinge: one along fuselage and one along vertical direction. This choice leads to a significant conceptual difference with respect to [20]. An increase in weight is expected.
2. Loads sustained by the strut: in [20] the strut has been sized considering only axial tensile loads. However, being the strut lifting, shear and bending due to lift play an important role. For this reason, in the present work, the strut has been modeled following the same path of the wing: semi-monocoque structural concept has been adopted for both components and a fully-stressed design approach has been applied.
3. Load cases for sizing: in [20] the wing was sized through a 2.5g and a -1g maneuver, while the strut, basing on the aforementioned considerations, was sized only through the 2.5g. In the present work, the same set of maneuvers, reported in [24] (Table 2.5), sized both components.

### 2.2 Model generation and validation

#### *2.2.1 Software*

The SBW model has been generated through NeoCASS [25] [26], an open-source code developed at Politecnico di Milano, whose principal aim is to consider aeroelasticity yet at the conceptual design phase of an aircraft. This is particularly useful for unconventional configurations such as SBW, whose high flexibility could generate non-expected behaviors that, if discovered earlier, allow for a more effective design. Structure is represented by a stick model, while aerodynamics is introduced through VLM/DLM. A layout of the software is reported in Figure 3. It is subdivided in modules, where: AcBuilder is the graphical editor, GUESS is dedicated to sizing, SMARTCAD to analyses (e.g. modal analysis, static aeroelasticity and flutter), NeOPT [27] [28] to optimization. The latter allows to correct the symmetrical wingbox generated in GUESS, accounting also for couplings. Indeed, a Finite Element solver is used in each section and up to ten separate variables can be defined, enriching each element stiffness and mass matrices.

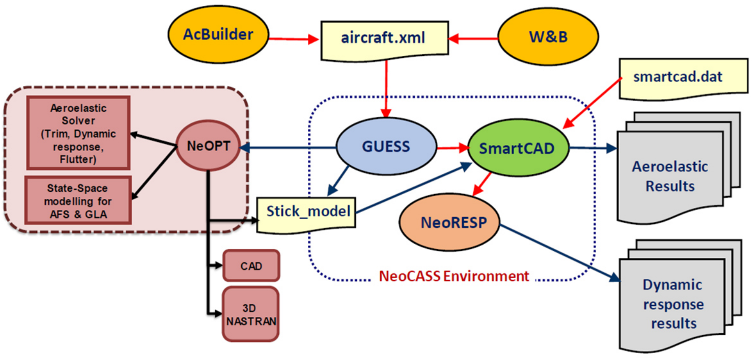


Figure 3 - NeoCASS layout

### 2.2.2 *Adopted procedure*

A schematic representation of the adopted procedure is presented in Figure 4. Since some underestimation of torsional stiffness has been found from GUESS sizing, NeOPT has been exploited: to increase the property, a constraint of aileron efficiency ≥ 30% has been introduced, along with strength requirements.

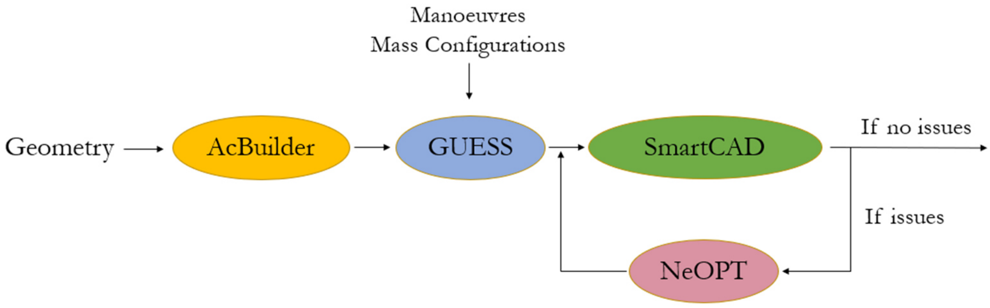


Figure 4 - Procedure for model generation and validation

## 2.3 Modified Model Configuration

To validate the model, both linear and nonlinear trim in dive condition (Table 2) have been studied.

| | M | h | $N_z$ |
|---|---|---|---|
| **Dive condition** | 0.89 | 6760 [m] | 1 [g] |

Table 2 - Dive definition

Some changes to the original model have been introduced. A total of four models, summarized in Table *3*, have been considered.

| | Geometry | Wing twist | Strut twist |
|---|---|---|---|
| **Model 1** | Original | Original | Original |
| **Model 2** | Original | 2 [deg] | Original |
| **Model 3** | Original | 3 [deg] | 3 [deg] |
| **Model 4** | Updated | 2 [deg] | Original |

Table 3 - Compared models

The objective was to qualitatively evaluate the impact that wing twist has on trim solution, both for linear and nonlinear analyses. Since the strut has been chosen to be lifting, its twist was varied too. Finally, also an update in strut geometry has been considered. For each model, the deformed configuration, along with wing and strut lift distribution, are reported in Table 4. First row corresponds to first model, second row to second model, and so on.

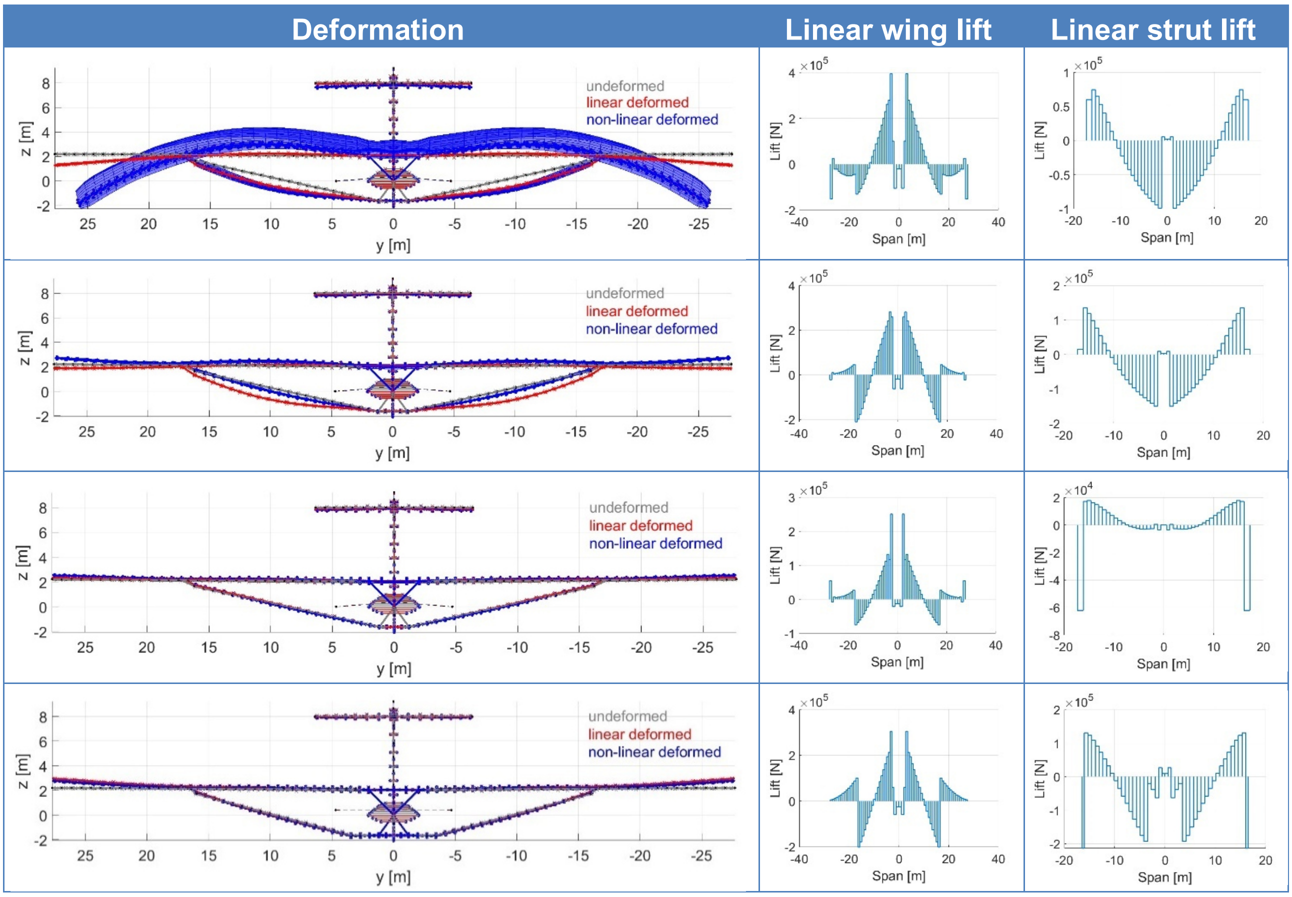


Table 4 - Linear and nonlinear trim in dive results for compared models

As one can notice, linear and nonlinear deformations differ significantly in the first two rows. This means that, if possible, both linear and nonlinear analyses should be computed for particularly flexible models (as the considered ones).
For what concerns twist angles: negative lift has been obtained at wing outer portions for the original model, as one can notice in wing lift distribution of the first row. This effect is canceled by updating wing twist. Acting on strut twist affects the results too. Indeed, recalling that second and third models only differ because of strut twist, comparing second and third rows one can appreciate that not only strut lift distribution changes, but also the deformed configurations are significantly affected.
Finally, keeping the same strut twist and updating its geometry influences the results as reported in the last row.
From these analyses, the importance of multidisciplinary approach is stressed: to define the aircraft geometry, not only aerodynamics but also aeroelasticity should be considered at the same time.

From now on, the present work will focus on the last model, i.e. the one with the modified strut, and its aeroelasticity will be assessed. Figure *5* shows the main geometrical differences between the original and the updated model. Strut-fuselage attachment has been translated toward the tail, leading to a change in strut sweep. The inboard portion of the strut is horizontal, to reduce strut oblique length, for buckling considerations.

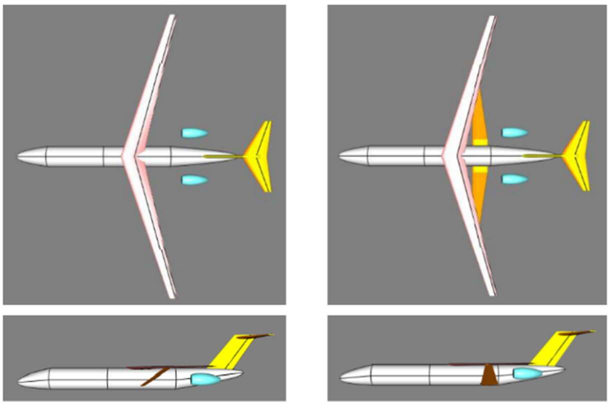

Figure 5 - Comparison between original and updated models

Updated model weight is reported in Table 5, compared to the original one, where original is the model with the sleeve mechanism presented in [20]. The increase in weight discussed in Subsection 2.1 is encountered.

| | Original ONERA | Updated | Δ% |
|---|---|---|---|
| **OEW** | 45719 [kg] | 63284 [kg] | +27.8 |

Table 5 - Comparison of Operative Empty Weight (OEW) between updated and original models

## 3. Aeroelastic analyses

NeoCASS allows to compute several linear aeroelastic analyses:

- static, such as trim and divergence;
- dynamic, such as gust response and flutter.

Recently, the possibility to compute also nonlinear trim and flutter has been introduced [29]. Nonlinearity should be considered when large displacements can be reached, such as for very flexible aircrafts. This is the case of the studied model, being wing AR=19, as reported in Table *1*. Stiffness matrix description is the main difference: in nonlinear analyses the total stiffness is given by the sum of material stiffness, i.e. the classical linear one, and geometrical stiffness, the latter accounting for the presence of a pre-load. Tangent stiffness matrix is therefore obtained, and it affects not only the equilibrium solution, but also the modal base employed to reduce the model. For the interested reader, a more thorough discussion in given in Chapter 3 of [24] and in [29].

## 4. Results

Linear and nonlinear trim in cruise, linear gust, linear divergence, and linear and nonlinear flutter have been studied for the updated model, named 'reference' inside this Section. Then, a parametric study has been performed to quantify how changing wing and strut material, strut geometry and wing-strut attachment chordwise position affects the results.

### 4.1 Reference model results

A summary of the main characteristics of reference model (visible in the last row of Table *4*) is given:

- material: aluminum alloy AL7075-T6;
- mass configuration: OEW;
- strut geometry: straight;
- wing-strut attachment chordwise position: on wing Elastic Axis (EA).

#### *4.1.1 Trim*

The outcomes of linear and nonlinear trim in cruise (Table 6) are reported in Figure 6 and Table 7.

No big differences between linear and nonlinear results have been found for the model.

| | M | h | $N_z$ |
|---|---|---|---|
| **Cruise condition** | 0.78 | 11000 [m] | 1 [g] |

Table 6 - Cruise definition

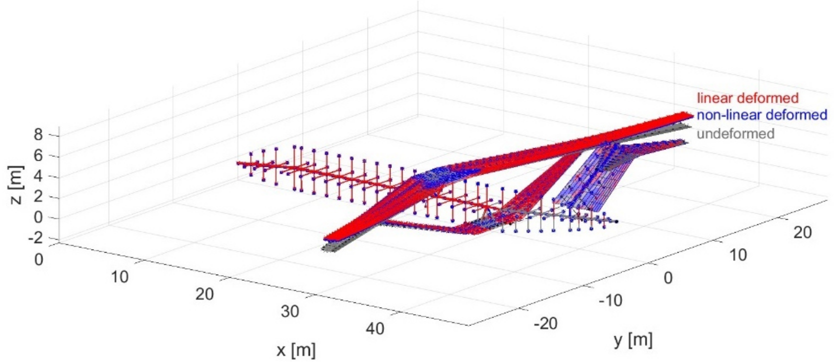


Figure 6 - Linear vs nonlinear trim in cruise, reference model

| | Linear | Nonlinear | Δ% |
|---|---|---|---|
| **Vertical displacement [m]** | 1.16 | 1.01 | -13 |
| **Torsional rotation [deg]** | -1.75 | -1.6 | -8.5 |

Table 7 - Wing tip results for trim in cruise, reference model

### *4.1.2 Gust response*

Figure 7 shows the set of flight points considered for gust analyses.

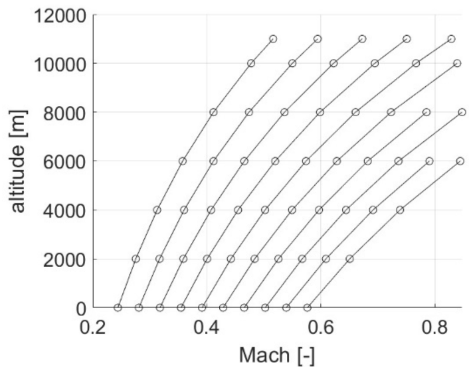


Figure 7 - Flight points for gust analyses

For each point, three trim analyses with different load factors have been performed ($N_z$=-1, $N_z$=1, $N_z$=2.5). The correspondent internal forces are evaluated and the envelope of their maxima and minima along wing span is traced. Then, gust analyses are executed, and the resulting loads are summed to the ones of trim analysis with $N_z$=1, accordingly to the regulations. The envelope of maxima and minima internal forces due to gust are generated and compared to the trim one. If gusts generate higher loads, i.e. gust envelope exceeds trim one, then it must be verified if the structure is still able to sustain such loads. If not, a re-sizing of the structure considering the critical gusts must be performed.

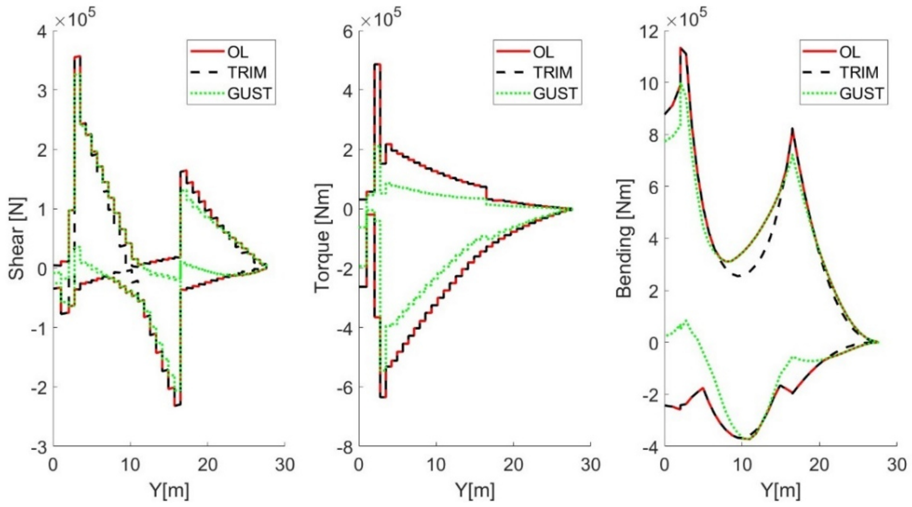


Figure 8 - Wing maxima and minima spanwise envelopes, reference model

As one can notice, in Figure 8 the green curve exceeds the dashed black line for both shear and bending, being particularly evident in the latter plot for wing central region. The red curve is the envelope of the envelopes and it is labeled as Open Loop (OL). It has been verified that the green curve loads do not generate stresses that exceed the allowables, meaning that in this case there is no need to update the sizing. Hence, no critical gusts have been found.

### 4.1.3 Divergence and flutter

Divergence and flutter have been studied in the red diamonds reported on Figure 9, accordingly to the regulations, which require to demonstrate the absence of flutter up to a velocity that is 1.5VD (dive velocity). Since for aerodynamics DLM was used, the black line represents a limit, therefore point 3 has been translated on 1.05VD.

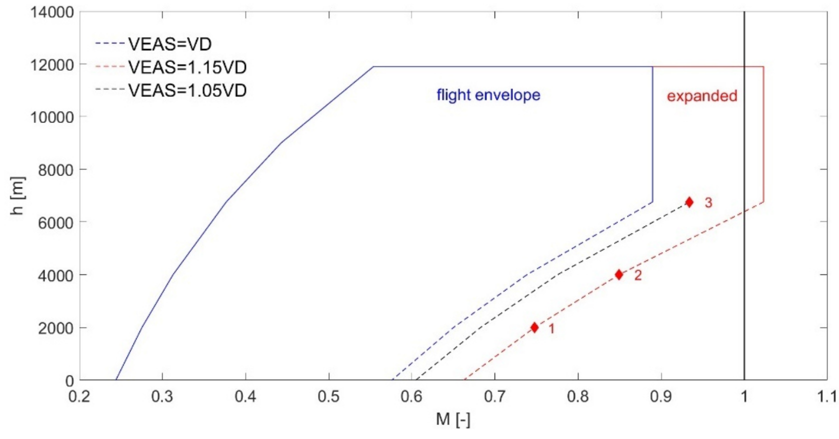


Figure 9 - Flight points for divergence and flutter analyses

| | $q_{max}$ [Pa] | $q_{div}$ [Pa] |
|---|---|---|
| **Point 1** | 31118 | 72771 |
| **Point 2** | 31118 | 66486 |
| **Point 3** | 25942 | 51326 |

Table 8 - Divergence results, reference model

In Table 8 are reported the linear divergence results computed for each point. As one can notice, the maximum reachable dynamic pressure is well below divergence solution, meaning that divergence is not an issue for the model.

Figure 10 compares linear and nonlinear flutter results, presented in terms of V-g plots, for point 3. Even though some differences are present, for both cases flutter does not occur inside the considered envelope. Indeed, in the nonlinear case a curve that reaches zero damping is present, i.e. the light blue one. However, it has been verified that the associated mode is due to the constraint system applied to the model while computing nonlinear analyses, i.e. it is not a physical mode. This means that the aircraft at that velocity would not flutter. Hence, flutter is not an issue for the model.

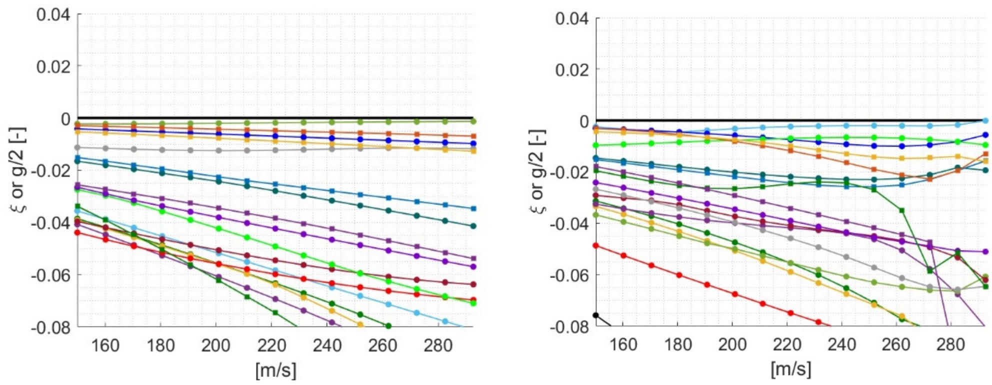


Figure 10 - Linear (left) vs nonlinear (right) flutter results for point 3, reference model

## 4.2 Parametric study

The impact of wing and strut material, strut geometry and wing-strut attachment chordwise position on the results has been assessed. The complete set of results can be found in Chapter 4 of [24].

### *4.2.1 Impact of wing and strut material*

The models compared in this analysis differ only in terms of wing and strut material, as reported in Table 9. Table 10 shows the structural masses obtained from model sizing, in the two cases. Some interesting savings are gained, thanks to composite high performances.

| | Reference | Composite |
|---|---|---|
| **Material** | AL7075-T6 | CFUD [0/45/-45/90]s |
| **Mass configuration** | OEW | OEW |
| **Strut geometry** | Straight | Straight |
| **Wing-strut attachment** | On EA | On EA |

Table 9 - Compared models: change of wing and strut material

| | Reference | Composite | Δ% |
|---|---|---|---|
| **Half wing** | 5976.4 [kg] | 3946.7 [kg] | -34 |
| **Half strut** | 1796.9 [kg] | 1349.9 [kg] | -25 |
| **Total half** | 7773.3 [kg] | 5296.6 [kg] | -32 |

Table 10 - Structural mass comparison between reference and composite models

For what pertains to linear and nonlinear flutter analyses, the reported results only concern nonlinear flutter in point 3 (defined on Figure 9), as one can notice from Figure 11. The V-g plots differ for the two models, but in both cases no flutter was found inside the considered flight envelope.

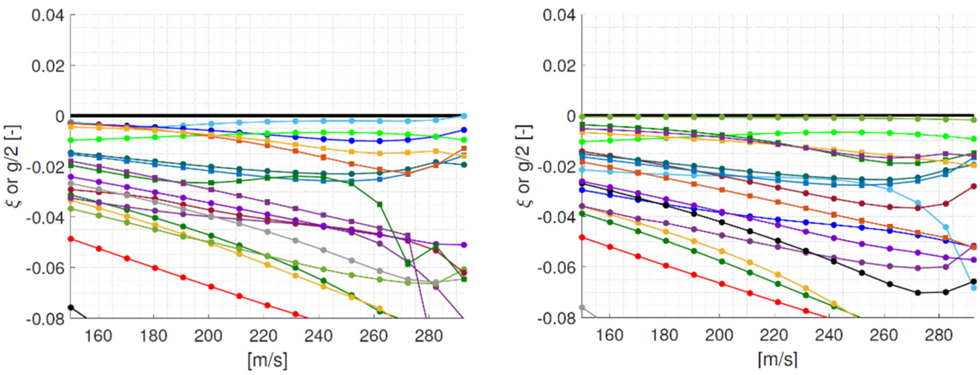


Figure 11 - Comparison of nonlinear flutter results for point 3 for reference (left) and composite (right) models

Table 11 shows divergence results. Also in this case, the obtained values differ for the two models, but divergence would occur outside the flight envelope. Hence, divergence is not an issue in both cases.

| | $q_{max}$ [Pa] | Reference [Pa] | Composite [Pa] |
|---|---|---|---|
| **Point 1** | 31118 | 72771 | 87401 |
| **Point 2** | 31118 | 66486 | 79925 |
| **Point 3** | 25942 | 51326 | 61927 |

Table 11 - Divergence results for reference and composite models

### *4.2.2 Impact of strut geometry*

Even if in the present work the employed methods do not allow for the estimation of interference drag caused by the interaction between wing and strut, some studies evidenced that a higher distance between the two components have beneficial effects on drag [30]. This change can be introduced by updating strut geometry. It could be interesting to see which is its effect on the results. The models compared are shown in Figure *12* and summarized in

Table *12*.

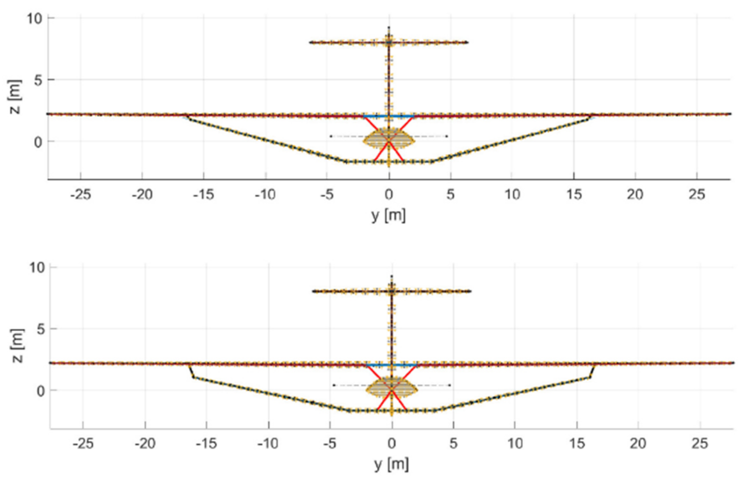


Figure 12 - Compared models: change of strut geometry (front view)

| | Straight | Curved |
|---|---|---|
| **Material** | CFUD [0/45/-45/90]s | CFUD [0/45/-45/90]s |
| **Mass configuration** | OEW | OEW |
| **Strut geometry** | Straight | Curved |
| **Wing-strut attachment** | On EA | On EA |

Table 12 - Compared models: change of strut geometry

As one can notice from Table 13, strut mass changes significantly between the compared models. On the contrary, wing was kept more or less equal.

| | Straight | Curved | Δ% |
|---|---|---|---|
| **Half wing** | 3946.7 [kg] | 4006.9 [kg] | +1.5 |
| **Half strut** | 1349.9 [kg] | 2098.8 [kg] | +35.7 |
| **Total half** | 5296.6 [kg] | 6105.7 [kg] | +13.25 |

Table 13 - Structural mass comparison between composite straight and curved models

Trim analyses led to a difference in terms of wing tip vertical displacements of 20% between the models, while torsional rotation was kept more or less unchanged. The curved model bends more than the straight one.

Nonlinear flutter results, for point 3, are reported in Figure 13. Once again, even if the V-g plots differ, no flutter has been detected in both cases. Divergence was not affected by strut geometry change, and in both cases was widely outside the considered flight envelope.

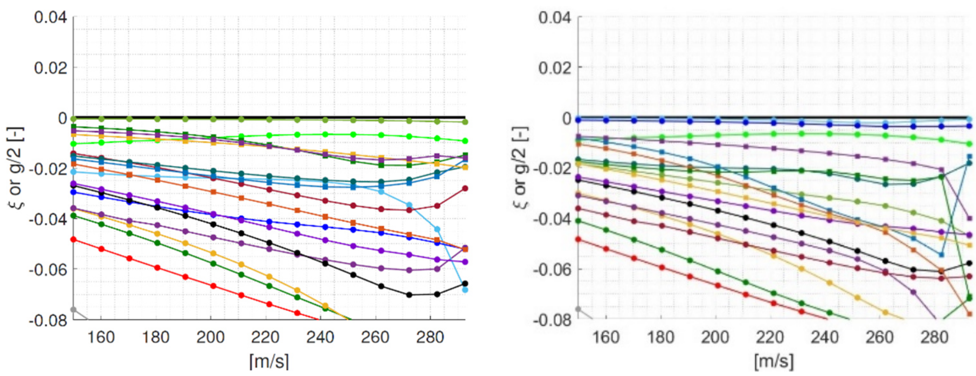


Figure 13 - Comparison of nonlinear flutter results for point 3 for straight (left) and curved (right) models

### *4.2.3 Impact of wing-strut attachment chordwise position*

As was anticipated earlier, during sizing, some issues concerning torsional stiffness have been found. This problem was somehow common in literature [17], due to the reduced wingbox dimensions of SBW.

Some studies were computed changing the position of the wing-strut attachment along wing chord, in order to introduce an offset with respect to wing EA, along with torsional moment that would be accounted for during sizing, possibly helping to increase stiffness. The compared models are summarized in Table 14.

Table 15 shows the obtained masses for the different strut chordwise position. The model with strut on front spar is the one with the heaviest wing and lightest strut, while the one with strut on rear spar is the opposite.

| | Front | EA | Rear |
|---|---|---|---|
| **Material** | CFUD [0/45/-45/90]s | CFUD [0/45/-45/90]s | CFUD [0/45/-45/90]s |
| **Mass configuration** | OEW | OEW | OEW |
| **Strut geometry** | Straight | Straight | Straight |
| **Wing-strut attachment** | On front spar | On EA | On rear spar |

Table 14 - Compared models: change of wing-strut attachment chordwise position

| | Front | EA | Rear |
|---|---|---|---|
| **Half wing** | 4233.4 [kg] | 3946.7 [kg] | 3638.2 [kg] |
| **Half strut** | 1307.9 [kg] | 1349.9 [kg] | 1425.6 [kg] |
| **Total half** | 5541.3 [kg] | 5296.6 [kg] | 5063.8 [kg] |

Table 15 - Structural mass comparison between composite front, EA and rear models

From both linear and nonlinear trim analyses, wing tip deflection resulted to be highest for strut on the front spar and lowest for strut on the rear spar.

Strut position does not have any particular effect neither on flutter nor on divergence. Both the phenomena do not represent an issue for any of the compared models.

## 5. Conclusions

An aeroelastic model of SBW configuration has been produced. Some design issues have been found concerning the strut and its interaction with the wing. Acting on wing and strut twists and on strut geometry may overcome the problem. Multidisciplinary approach is therefore suggested starting from the very beginning of design phase. Most common aeroelastic analyses have been computed, and, when possible, also accounting for nonlinearities. Some changes have been imposed to the model and their effect on the results have been investigated. Promising outcomes have been reached with composite materials, for both strut and wing, reaching around 30% of structural mass reduction. Neither critical gusts, nor divergence, nor flutter have been detected inside the considered flight envelope. For future work, possibly all the aeroelastic analyses should be extended to nonlinear field. Some dedicated aerodynamic studies should be computed on the updated strut geometry, which presents a higher wetted area that affects friction drag. Moreover, an investigation concerning fuel consumptions should be computed in order to compare not only possible weight savings but also the emissions.

## 6. Contact Author Email Address

Author email addresses are reported in the present section. E. Roncolini: elena.roncolini@polimi.it. F. Toffol: francesco.toffol@polimi.it. S. Ricci: sergio.ricci@polimi.it.

## 7. Disclaimer



## 8. Acknowledgements

This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 886552. The JU receives support from the European Union’s Horizon 2020 research and innovation program and the Clean Sky 2 JU members other than the Union.

## 9. Copyright



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