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HIERARCHICAL MASS BREAKDOWN FOR TRANSPORT AIRCRAFT WITH TRUSS BRACED WINGS

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Abstract

This paper proposes a hierarchical mass breakdown for transport aircraft with truss braced wings. The contribution is not another standalone mass formula, but an integration framework that shows how empirical, semi-empirical, and physics-based mass-estimation methods can be combined without gaps or double counting when an aircraft contains components that are not represented well by conventional handbook mass statements. The need is strongest in novel configurations such as truss braced wing configurations, where the wing box, strut, jury members, and offset often require deeper structural sizing than conventional cantilever wing groups in preliminary design level. The proposed hierarchy maps aircraft mass from takeoff gross weight down to detailed items and, at the same time, visualizes the fidelity level at which each mass method operates. This makes *it possible to blend existing aircraft methods with newly developed methods and still roll all results back to operating empty weight and takeoff gross weight in a traceable, accurate way during conceptual and preliminary design phases.*

Keywords:
Truss Braced Wing, Mass Estimation, Mass Breakdown, Conceptual Design, Aircraft Design

1. Introduction

Novel transport-aircraft concepts are receiving attention as conventional tube-and-wing layouts leave limited room for further efficiency gains. Among these concepts, truss braced wings remain promising because they support high aspect ratio wings with lower bending moment penalties and improved aerodynamic performance [1]-[3]. However, the use of a truss introduces structural members and interfaces that are not represented explicitly in most conventional aircraft mass estimation methods. The strut, jury members, offset, local fittings, and related allowances are often hidden inside coarse wing-group estimates even though they may need dedicated sizing and mass prediction.

This mismatch matters because conceptual design studies rarely rely on one monolithic mass method. In practice, aircraft takeoff gross weight estimation is assembled from several methods with different scopes and fidelity levels. A designer may use a handbook method for fuselage, empennage, landing gear, or useful load, but a more detailed physics-based method for the wing group when the aircraft is truss braced. Without a clear hierarchy, combining such methods can create omissions, hidden overlaps, and inconsistent roll-ups.

Recent works by the present author has already produced detailed wing-mass methods for cantilever, strut braced, and truss braced wing configurations, including studies connected to distributed, hydrogen, and electric propulsion effects [4]-[7]. What is still missing is a compact aircraft-level framework showing where these detailed methods enter the total mass statement and how they can coexist with more conventional methods. This conference paper addresses that gap.

2. Mass Grouping as an Integration and Fidelity Map

The proposed framework organizes aircraft mass through hierarchical levels, from takeoff gross weight and operating empty weight down to detailed subcomponents. The upper levels are intended for aircraft closure. The deeper levels are activated only where the available method or the technology requires more detail. Hence, the hierarchy is not merely a reporting table. It is a controlled interface between methods of different fidelity and conventional handbook practice [8]-[11].

The central idea is selective fidelity. A conventional fuselage or landing-gear estimate may remain at a handbook level while the truss braced wing branch descends to detailed component sizing. All results still roll to the same operating empty weight and takeoff gross weight. The hierarchy therefore acts as both an integration map and a fidelity map.

This structure is especially useful when the analyst needs to add, wrap, connect, or hybridize different mass methods. Each method receives a fixed insertion point, a parent branch, and an expected roll-up path. As a result, the aircraft synthesis becomes auditable and the level of detail associated with each estimate remains visible rather than hidden.

2.1 TBW-Specific Role in Method Blending

Within the proposed tree, the truss braced wing sits under the structural branch and then under the wing group. The wing group is split into conventional wing-box items, truss-specific primary members, and secondary structure. The primary truss branch contains, at minimum, the strut, jury members, and offset. Depending on the configuration, the same branch can also host folding hardware, pivots, and local fittings as shown in Table 1.

This parent-child structure makes two decisions explicit. First, primary load-carrying members of the truss belong inside the wing structural branch, not as miscellaneous corrections elsewhere in the aircraft. Second, the level of detail is method dependent. If a designer uses a physics-based truss method, each primary component may be estimated separately at a deep level and then rolled back to the wing group. If a future lower-fidelity level empirical truss method becomes reliable enough, the same hierarchy can accept the result higher up the tree without changing the overall accounting logic.

The practical value is that double counting and under-counting become easier to detect. If a detailed truss method predicts the primary truss structure while a conventional wing-group estimate already includes implicit allowances for those same items, the overlap is visible. If those items are removed from the conventional wing estimate but not inserted elsewhere, the omission is equally visible.

Table 1: *Illustrative application of the proposed hierarchy and roll-up logic in the conceptual mass estimation of Boeing 737*

No	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
1	45,716.7	22,242.3	12,663.8	4,700.7	1 Wing Box	1 WB Structure Mass	1 WB Shear Material	1 Skin Panels
2	TOGW	1 OEW	1 Structures	1 Wing				2 Spar Webs
3							2 WB Bending Material	1 Spar Caps
4								2 Stringers
5							3 Penalties or Relief to WB	1 Store
6								2 Main LG
7								3 Wing Fuel
8								4 Engine
9								5 Wing Fold
10								6 Other Con. or Dist. Loads
11							4 Rib Mass	
12						2 WB Other Mass	1 Aeroelastic Penalty	
13							2 Non-Optimum Mass	
14							3 Component Mounting	
15					2 Wing Other Mass	1 Bulkhead		
16						2 Leading Edge		
17						3 Trailing Edge		
18						4 Secondary Structure		
19						5 LG Doors & Mechanism		
20						6 Ail, Elevs and Decel		
21						7 Slats		
22						8 LE Flap Mass		
23						9 TE Flap Mass		
24						10 Spoilers		
25						11 Wing Speed Breaks		
26						12 Winglets		
27						13 Wing Folding Mass		
28						14 Pivot Mass		
29					3 Strut	1 Strut Box	1 Strut Box Mass	
30							2 Non-Optimum Mass	
31						2 Strut Other Mass	1 LE Mass	
32							2 TE Mass	
33							3 Strut Mounting	
34					4 Jury-1	1 Jury1 Box	1 Jury Box Mass	
35							2 Non-Optimum Mass	
36						2 Jury1 Other Mass	1 LE Mass	
37							2 TE Mass	
38							3 Jury Mounting	
39					5 Jury-2	1 Jury2 Box	1 Jury Box Mass	
40							2 Non-Optimum Mass	
41						2 Jury2 Other Mass	1 LE Mass	
42							2 TE Mass	
43							3 Jury Mounting	
44					6 Offset	1 Offset Box	1 Offset Box Mass	
45							2 Non-Optimum Mass	
46						2 Offset Other Mass	1 LE Mass	
47							2 TE Mass	
48							3 Offset Mounting	
49				2 Horizontal Tail				
50				3 Vertical tail				
51				4 Ventral Tail				
52				5 Fuselage				
53				6 Main LG				
54				7 Nose LG				
55				8 Other LG				
56				9 Engine Mount				
57				10 Firewall				
58				11 Engine Section				
59				12 Air Induction				
60			6,397.0	1 Flight Controls				
61			2 Equipment	2 APU				
62				3 Instruments				
63				4 Hydraulics				
64				5 Pneumatics				
65				6 Electrical				
66				7 Avionics				
67				8 Armament				
68				9 Furnishing				
69				10 Air Conditioning				
70				11 Anti-Icing				
71				12 Photographic				
72				13 Load&Handling				
73				14 Misc Equipment&We				
74			3,181.5	1 Engine(s) Installed				
75			3 Propulsion	2 Accessory Drive				
76				3 Exhaust System				
77				4 Engine Cooling				
78				5 Oil Cooling				
79				6 Engine Controls				
80				7 Starter				
81				8 Fuels System/ Tanks				
82			4 Empty Weight Allowance					
83		23,474.5	1 Crew					
84		2 Useful Load	2 Fuel-usable					
85			3 Fuel-trapped					
86			4 Oil					
87			5 Passengers					
88			6 Cargo/Payload					
89			7 Guns					
90			8 Ammunition					
91			9 Misc Useful Load					
92			10 Notlisted-1					

2.2 Representative Method Coverage

For this hierarchy to be useful in practice, each branch must be paired with a compatible estimation method. In the present terminology, wing-box primary structure denotes the shear- and bending-carrying material of the main box, wing-box other mass denotes aeroelastic penalties, non-optimum additions, and mounting-related items, and wing other mass denotes the leading edge, trailing edge, secondary structure, and high-lift and control-surface related items as shown in Table 1. The strut, jury members, and offset are treated as explicit truss branches rather than hidden corrections [7], [12]-[15].

Table 2 condenses the method-coverage logic reviewed in Refs. [5]-[7]. Its purpose is not to review every available formula, but to show how conventional handbook methods and the newer TBW-specific methods can coexist inside one mass statement with clear insertion points and roll-up paths. The methods shown in Table 2 were utilized together with the hierarchical mass grouping illustrated in Table1, in the mass estimation study explained in the following section using.

Table 2: *Representative method coverage for inserting mass-estimation methods into the proposed hierarchy*

Hierarchy branch	Typical items	Representative references	Fidelity / insertion level
Aircraft closure and major conventional groups	OEW, useful load, fuselage, tail, landing gear, equipment, propulsion	Raymer [8], Torenbeek [9], Roskam [10], Howe [11]	Handbook / empirical; inserted high in the tree
Whole wing-group methods	Legacy wing-group estimates used when no deeper split is activated	York and Labell [12], Chiozzotto [13], Raymer [8], Howe [11]	Semi-empirical; inserted at wing-group level
Wing box primary structure	Shear- and bending-resistant material	Present TBW methods [4]-[7]	Analytical / physics-based; inserted at deep wing-box nodes
Rib mass	Ribs within the wing box	Torenbeek [14], Howe [15]	Semi-empirical; inserted below wing-box structure
Wing box other mass	Aeroelastic penalties, mounting, non-optimum additions	Torenbeek [14]	Semi-empirical; inserted below wing-box other-mass branch
Wing other mass	Leading edge, trailing edge, secondary structure, high-lift and control-surface items	York and Labell [12], Chiozzotto [13]	Semi-empirical; inserted below wing-other branch
Explicit truss members	Strut, jury members, offset	Present TBW methods [4]-[7]	Analytical / physics-based; inserted as explicit TBW branches

3. Illustrative Application Structure

Table 1 shows the application and make the hierarchy visible together with representative aircraft-level values. The table is included here because it shows the complete roll-up logic more clearly than a simplified taxonomy. The retained example uses Boeing 737 closure values.

The same structure can later host a truss braced transport without changing the accounting logic. Conventional methods listed in Table 1 are used to predict fuselage, empennage, landing gear, payload, and other legacy branches, while the detailed, physics based truss braced wing method predicts the wing box, strut, jury members, and offset separately [4], [7]. Those values then enter the proper nodes and are summed upward to the wing-group mass and finally to takeoff gross weight as presented in Table 1.

3.1 Implications for Conceptual Design

The main value of the proposed hierarchy is conceptual clarity rather than a new closed-form mass equation. It makes visible how detailed component-level methods relate to aircraft-level mass closure and why deeper modeling should be activated only in selected branches. For truss braced wings, this is especially important because the lack of strong historical datasets limits the direct use of fast empirical equations of the kind available for more conventional hardware.

The framework is also deliberately extensible. Although the present paper concentrates on the structural side of the truss braced wing problem, the same tree can later host additional emerging-propulsion items as explicit branches rather than loose corrections. The governing rule is unchanged: every new item must have a clear parent branch, a defined level of detail, and a transparent roll-up path.

4. Conclusion

This paper presented a hierarchical mass breakdown to be used in the mass estimation of novel aircraft in conceptual or preliminary level design studies. In this study an aircraft with truss braced wings is considered and argued that the proposed breakdown’s main role is to function as both an integration map and a fidelity map for aircraft mass estimation. The framework enables detailed truss braced wing methods to be inserted at the component level while conventional handbook methods can be used in mass estimation of conventional components.

By making parent-child relations explicit, the hierarchy helps avoid gaps, overlaps, and ambiguity when several mass-estimation methods from different fidelity levels are blended in one aircraft design synthesis. The present study stays focused on the structural side of the problem and show application of the methods with mass estimation of conventional aircraft. Future studies can cover the application of the proposed methods with novel configuration accompanying emerging propulsion technologies.

References

M. K. Bradley, T. J. Allen, and C. K. Droney, "Subsonic Ultra Green Aircraft Research: Phase II Volume I Truss Braced Wing Design Exploration," NASA Langley Research Center, Hampton, VA, USA, 2015.

R. Cavallaro and L. Demasi, "Challenges, Ideas, and Innovations of Joined-Wing Configurations: A Concept from the Past, an Opportunity for the Future," Progress in Aerospace Sciences, vol. 87, pp. 1-93, 2016.

G. P. Chiozzotto, "Wing Weight Estimation in Conceptual Design: A Method for Strut-Braced Wings Considering Static Aeroelastic Effects," CEAS Aeronautical Journal, vol. 7, no. 3, pp. 499-519, 2016.

M. Taflan, H. Smith, and J. Loughlan, "Sizing and Mass Estimation of Truss-Braced Wings, Considering Emerging Propulsion Systems," Journal of Aircraft, 2025.

M. Taflan, H. Smith, and J. Loughlan, "Parametric Analysis for Structural Design and Weight Estimation of Cantilever and Strut-Braced Wing-Boxes," AIAA SciTech Forum, 2023.

M. Taflan, H. Smith, and J. Loughlan, "Structural sizing and mass estimation of transport aircraft wings with distributed, hydrogen, and electric propulsions," The Aeronautical Journal, 2025, pp. 690-716.

M. Taflan, "Structural Sizing and Mass Estimation of Strut- and Truss-Braced Wings: The Effects of Moderate to High Aspect Ratios and Novel Technologies," Ph.D. thesis, Cranfield University, 2025.

D. P. Raymer, Aircraft Design: A Conceptual Approach. Reston, VA, USA: AIAA, 2018.

E. Torenbeek, Synthesis of Subsonic Airplane Design. Delft, The Netherlands: Delft University Press, 1982.

J. Roskam, Airplane Design Part V: Component Weight Estimation. Lawrence, KS, USA: DARcorporation, 2018.

D. Howe, Aircraft Conceptual Design Synthesis. London, U.K.: Professional Engineering Publishing, 2000.

P. York and R. W. Labell, Aircraft wing weight build-up methodology with modification for materials and construction techniques. NASA Ames Research Center, 1980.

G. P. Chiozzotto, "Initial weight estimate of advanced transport aircraft concepts considering aeroelastic effects," in AIAA SciTech Forum - 55th AIAA Aerospace Sciences

Meeting, 2017.
doi: 10.2514/6.2017-0009.

E. Torenbeek, Development and application of a comprehensive design sensitive weight prediction method for wing structures of transport category aircraft. Delft, 1992.

D. Howe, "The prediction of aircraft wing mass," Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, vol. 210, no. 2, pp. 135-143, 1996.
doi: 10.1243/pime_proc_1996_210_355_02.