engineering proceedings

MDPI

Proceeding Paper

Technology for eVTOL Cementing and Co-Curing Composite Wing Box Segment †

Shutao Qi *, Jiannan Cheng, Jichuan Ma and Jun Wang

Harbin Aircraft Industry Group Co., Ltd., Harbin 150066, China; 301cjn_301@163.com (J.C.); majichuan123@126.com (J.M.); wangj112@avic.com (J.W.)

* Correspondence: qist001@avic.com

† Presented at the 2nd International Conference on Green Aviation (ICGA 2024), Chengdu, China, 6–8 November 2024.

Abstract: In this paper, the status quo of manufacturing technology of the wing structures of large and small general aircraft at home and abroad is reported. The existing problems in the manufacturing technology of double-beam, multi-rib composite wing structures are analyzed. The application of adhesive co-curing technology to manufacture eVTOL double-beam, multi-rib integral composite wing box segment structures is proposed. Composite-material wing box segment adhesive co-curing manufacturing technology realizes the high-quality manufacturing of double-beam, multi-rib integral wing box segment structures and the optimal lightweight design of such structures. It can be applied to the manufacture of this type of integral wing box segment structure or the manufacture of other complex integral composite components.

Keywords: eVTOL; wing box segment; co-curing; secondary bonding; gluing and co-curing

check for updates

Citation: Qi, S.; Cheng, J.; Ma, J.; Wang, J. Technology for eVTOL Cementing and Co-Curing Composite Wing Box Segment. *Eng. Proc.* **2024**, *80*, 21. https://doi.org/10.3390/engproc2024080021

Academic Editors: Weihong Zhang, Shichun Yang, Leiting Dong, Xungang Diao, Shijun Yin, Lixin Guan, Zuxi Xia and Xue Zhang

Published: 10 January 2025

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The aviation industry has set the goal of reducing greenhouse gas (GHG) emissions [1] and reducing operating costs. The concept of VTOL aircraft has developed dramatically in recent years, and nearly 100 VTOL aircraft projects are being developed worldwide [1]. Evtol (Electric Vertical Take-Off and Landing) is a kind of aircraft that is electric and can take off and land vertically without a runway. Compared with traditional helicopters, manned eVTOL is purely electrically driven, low-noise, cost-effective, more environmentally friendly, and is a product that is more in line with the future urban air traffic system. In recent years, China has made great achievements in the reverse direction of green industry. In terms of transportation, the new energy automobile industry has developed rapidly. The upgrading and transformation of electrification has also ushered in new opportunities in the aviation industry [2,3]. EVTOL is expected to play an important role in the future air travel scene, and it is also a rare overtaking opportunity for the domestic aviation industry. At present, hundreds of enterprises around the world have invested in the air traffic industry [4].

EVTOL has strict requirements on structural weight, so almost all enterprises use composite materials in the main body structure without exception. EVTOL airframe structures usually consist of wings, fuselage, and a tail. The wings are the most important aerodynamic component of the aircraft, as they are responsible for providing lift and giving the aircraft certain lateral stability and maneuverability and need to deal with various flight tasks including take-off, landing, cruising, maneuvering, and climbing [5].

As Fang Yiwu and others put forward [6], at present, most foreign large aircraft wings adopt all-composite integral panels, and the wing box structure is in the form of double beams and multi-ribs. The wing panels adopt composite skin-stiffened structures, and the ribs adopt the forms of "T" or "I" shapes. The wings of a small general-purpose aircraft are similar to the tail of a civil helicopter, which is generally a double-beam, multi-ribbed wing box skeleton with a skin structure [7].

At present, the common forming processes of stiffened panel structures of large aircraft wings are often secondary bonding, co-curing, and bonding co-curing. At present, the adhesive co-curing process is widely used to form large-scale wing composite panel structures. Compared with secondary adhesive bonding, adhesive co-curing has better adhesive quality, saves the use of a one-time autoclave, and has higher forming efficiency. Compared with co-curing, the die structure of adhesive co-curing is relatively simple, the tooling design and processing costs are low, and the forming quality and processing accuracy of the stringer can be guaranteed at the same time; the bonding quality of the stringer can be easily guaranteed when it is bonded and co-cured with the preformed skin [8–10].

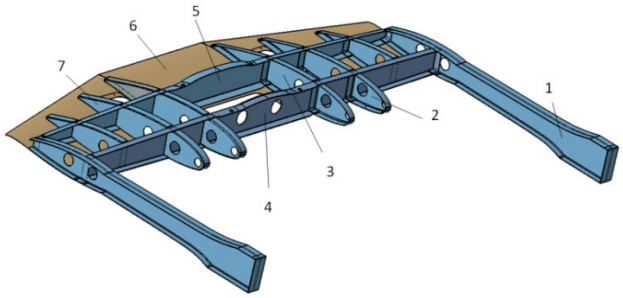
At present, the manufacturing processes of small general-purpose aircraft wings and helicopter tail structures are mainly (1) secondary bonding (combined riveting) and (2) co-curing [11]. For the wing structure of small general-purpose aircraft and the tail structure of helicopters, the secondary gluing process of the box-section structure requires complicated pre-assembly, gluing positioning, hole-making, pressure-pressing, and riveting after gluing, which has a long manufacturing cycle and complicated coordination process. At the same time, a large number of holes is made to reduce the static strength of the structure. Co-cured box segments are used to avoid riveting, reducing the number of connectors and weight, and at the same time greatly improving the static strength of the structure. However, the co-curing process of a double-beam, multi-rib wing box skeleton plus skin structure is difficult, and there is a high risk of defects such as out-of-tolerance gaps, indentations, and wrinkles, and the product qualification rate is low. There are few cases and introductions of manufacturing wing box segments with double-beam, multi-rib wing box skeleton and skin structures via adhesive co-curing processes.

In view of the advantages of adhesive co-curing processes in the manufacture of stiffened panel structures of large aircraft wings, this paper puts forward the application of an adhesive co-curing process in the manufacture of an eVTOL double-beam, multi-rib integral composite wing box structure (single skin + beam + rib).

2. Structure Introduction of eVTOL Composite Wing Box Section

The box section structure of the eVTOL composite wing involved in this paper is composed of a skin structure, a C-shaped front beam, a C-shaped rear beam, a C-shaped leading edge rib, a C-shaped middle rib, a C-shaped trailing edge rib, an H-shaped long cantilever end rib, and the lower skin, as shown in Figure 1.

The product features a variety of typical structures, among which the I-shaped structure is difficult to manufacture, and the rest are simple structures.



1. H-shaped long cantilever end rib
2. C-shaped leading edge rib
3. C-shaped intermediate rib
4. C-shaped front beam
5. C-shaped back beam
6. Lower skin
7. C-shaped trailing edge rib

Figure 1. Overall wing box segment structure.

3. Bonding and Co-Curing Manufacturing Technology of Composite Wing Box Section

In this paper, the adhesive co-curing manufacturing technology of composite wing box sections is introduced from three aspects: the technical route, technical scheme, and key technology.

3.1. Technical Route

The technical route of bonding and co-curing composite wing box sections combines the advantages of secondary bonding and co-curing, and three technical routes are introduced separately.

RQ1: *Co-curing technical route*.

The technical route of co-curing is as follows: firstly, the skin, the front beam, the back beam, the C-shaped rib, and the I-shaped rib are respectively laid on the laying fixture, and then pre-compaction is carried out to prepare preforms of various typical structures. Each preform is positioned and assembled on a co-curing tool. Finally, the vacuum bag is packaged and co-cured, as shown in Figure 2.

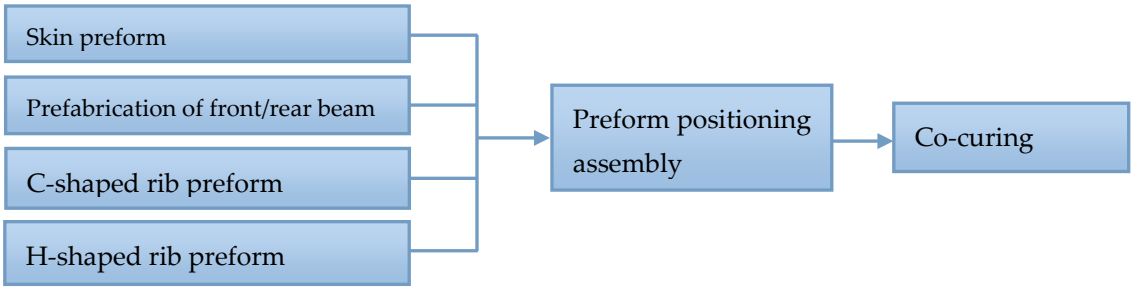


Figure 2. Co-curing technology route.

RQ2: *Technical route of adhesive co-curing*.

The technical route of adhesive co-curing is as follows: First, the front beam, the rear beam, and the C-shaped rib are cured and shaped, and then positioned and pre-assembled into a box-section skeleton structure. Secondly, the skin and the end I-shaped rib structure are laid on the bonding and co-curing tool, and the box segment skeleton structure is positioned on the tool at the same time. Finally, the vacuum bag is packaged and co-cured by adhesive bonding, as shown in Figure 3.

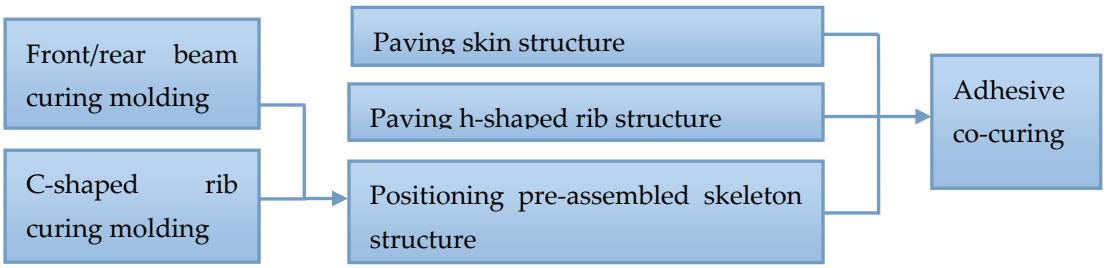


Figure 3. Bonding co-curing technology route.

RQ3: *Technical route of secondary bonding*.

The technical route of secondary bonding is as follows: firstly, the skin, front beam, back beam, C-shaped rib, and I-shaped rib are solidified and formed into parts. Secondly, all the parts are positioned and adjusted on the secondary bonding fixture, and the adhesive film is laid and riveted. Finally, the product is bonded and cured on the fixture, as shown in Figure 4.

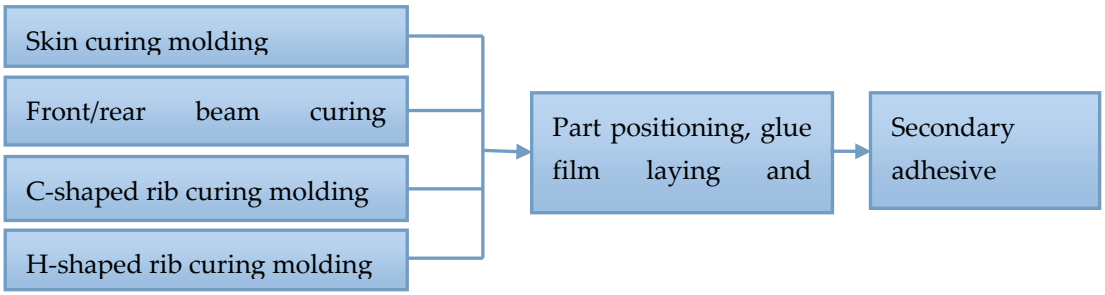


Figure 4. Secondary bonding technology route.

3.2. Technical Proposal

3.2.1. Division of Separation Surface of Adhesive Co-Curing

In the bonding and co-curing process of the wing skin of large aircraft, usually only two structures, T-shaped or H-shaped stringer and skin, are involved to form a type of interface, namely "prepreg-adhesive film-curing structure", and the bonding and co-curing process form is "skin prepreg-adhesive film-curing stringer" or "stringer prepreg-adhesive film-curing skin", as shown in Figure 5.

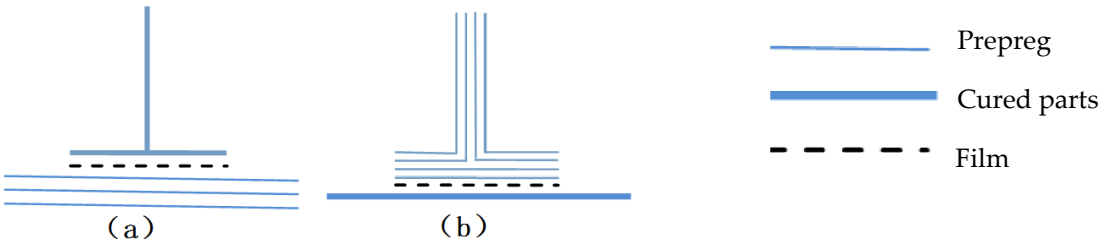


Figure 5. "Skin prepreg-Film-Cured Reinforced structure" (**a**) and "Reinforced structure prepreg-film-cured skin" (**b**).

The composite wing box described in this paper involves five types of structural interfaces, as shown in Figure 1: C-beam and C-rib, C-beam and H-shaped end rib, C-beam and skin, C-rib and skin, and H-shaped end rib and skin. In order to reduce the overall manufacturing difficulty of bonding and co-curing, the technical route shown in Figure 3 is formulated. First, C-shaped beams and C-shaped ribs are solidified and pre-assembled into a box-section skeleton structure. Secondly, the skin and H-shaped end rib structure are laid, and at the same time, they are bonded and co-cured with the integral skeleton structure. Based on the technical route, a process separation plane is divided, that is, the cured and pre-assembled C-beam/C-rib integral skeleton structure and the skin/H-shaped end rib structure under wet paving, as shown in Figure 6.

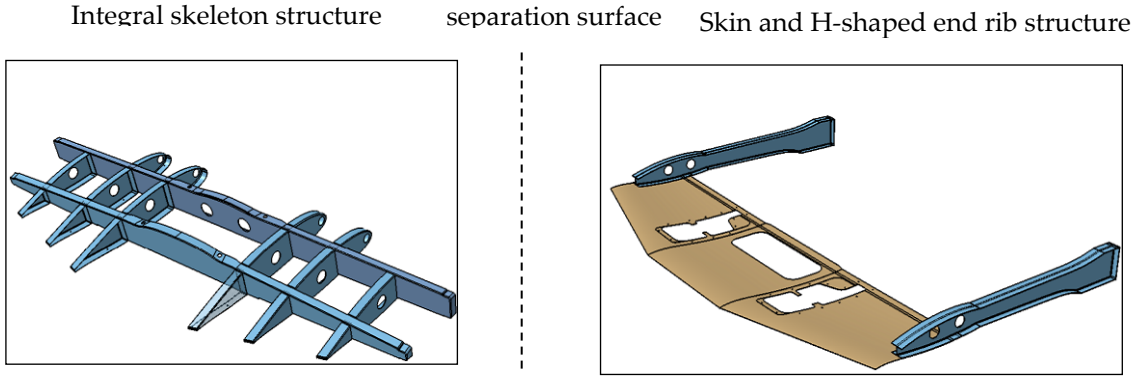


Figure 6. Division of adhesive co-curing separation surface.

The adhesive co-curing technology of the composite wing box section described in this paper involves three process types: secondary adhesive bonding of "cured beam-adhesive film-cured rib", adhesive co-curing of "skin prepreg-adhesive film-beam/rib", and co-curing of "skin prepreg -H-beam prepreg", as shown in Figure 7.

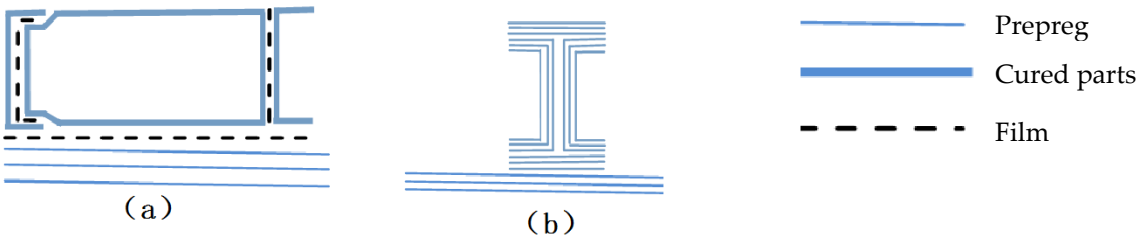


Figure 7. "Beam film-rib" secondary bonding and "Skin prepreg-Film-Cured beam/rib" co-bonding (**a**). "Skin prepreg-I beam Reinforced prepre" co-bonding (**b**).

3.2.2. Adhesive Co-Curing Process

Based on the technical route and process separation surface of adhesive co-curing of composite wing box section, the adhesive co-curing manufacturing process is shown in Figure 8.

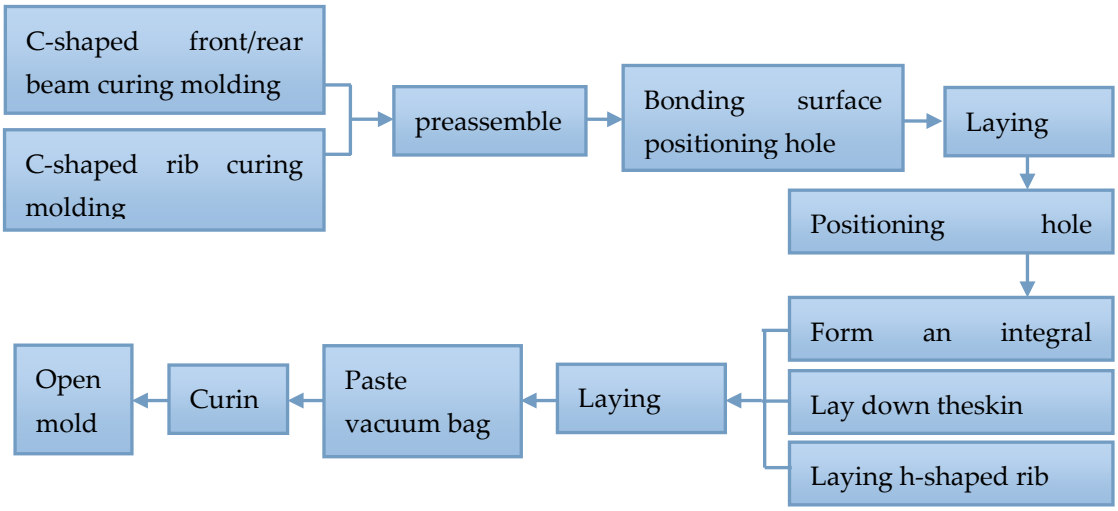


Figure 8. Flow chart of gluing and co-curing.

3.3. Key Technology

There are three key technical points in the adhesive co-curing technology of composite wing box sections described in this paper, which are as follows: (1) division of separation surface of adhesive co-curing process; (2) design of adhesive co-curing molding die; (3) pre-assembly technology of integral skeleton.

3.3.1. Separation Surface Division of Adhesive Co-Curing Process

In order to reduce the technical difficulty and manufacturing cost of the whole manufacturing process, the C-shaped beam and C-shaped rib in the composite wing box section structure described in this paper are divided into secondary bonded integral structures; the skin and the H-shaped end rib are divided into co-curing integral structures; and the two parts of the structure are bonded and co-cured. The division method of process separation surface is not fixed, and the influence of parts manufacturing difficulty, tolerance distribution, precision of key intersection points, and difficulty of vacuum bag packaging should be considered. In addition, the division should be carried out according to the specific structure of the product.

3.3.2. Design of Adhesive Co-Curing Mold

The bonding and co-curing molding die realizes the following functions: (1) Pre-assembling the integral skeleton structure of C-beam and C-rib; (2) laying the skin and H-shaped end ribs; (3) bonding and co-curing the integral box segment structure.

In order to realize the pre-assembly of the integral skeleton structure of the C-beam and C-rib by adhesive co-curing molding die, key profiles and intersection-located pieces are set on the molding die, as shown in Figure 9, to ensure the accuracy of key interfaces or intersections. The positioning parts of key profiles and intersections need to be designed as simple structures, as shown in Figure 10, which can realize vacuum bag packaging and can be used for positioning key profiles and intersections during bonding and co-curing at the same time, so as to ensure the consistency of positioning benchmarks of key profiles and intersections in the whole process. The position of the H-shaped end rib is established with an outer surface module, which has a unidirectional slidable structure and has a guiding function. During the curing process, the module can continuously compact the cloth layer in the specified direction under the pressure of the autoclave.

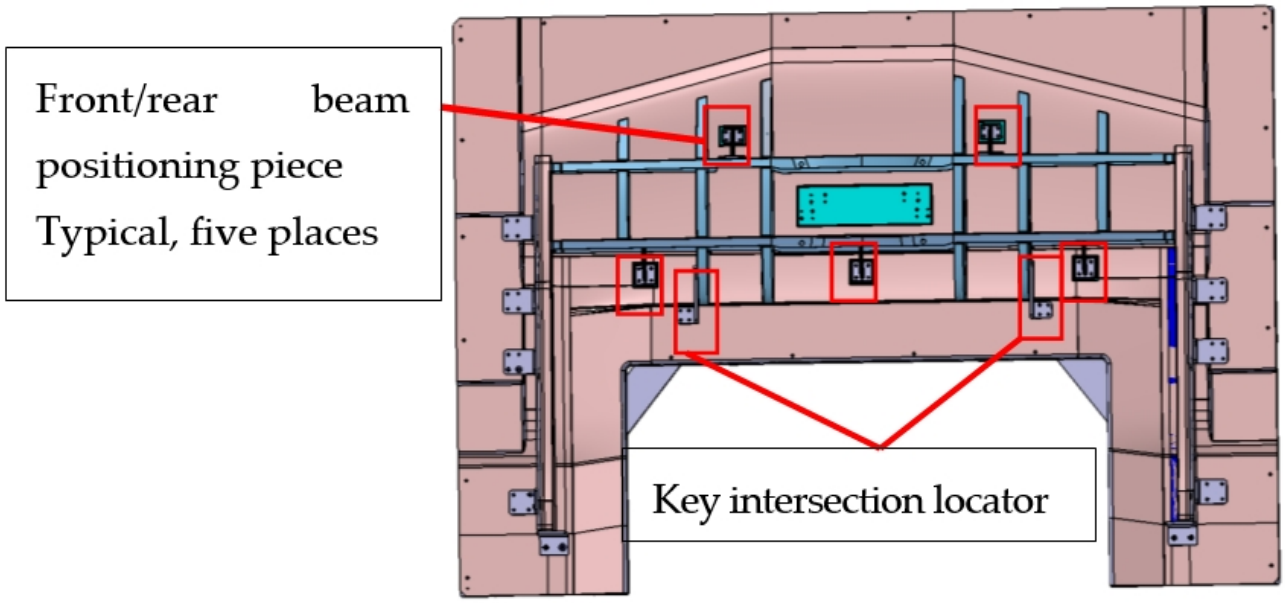


Figure 9. Gluing and co-curing molding die for skeleton structure preassembly.

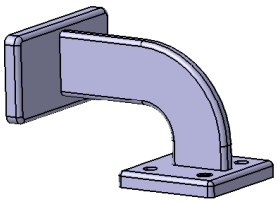


Figure 10. Positioning parts of key profile surfaces and intersection points.

3.3.3. Pre-Assembly Technology of Integral Skeleton

The whole skeleton is glued and pre-assembled on the forming die, and the C-beam and key C-ribs are positioned by the positioning pieces. The rest of the C-ribs requiring low position accuracy are positioned by laser projection or line drawing. After the positioning is completed, the bonding positioning holes of the C-beam and the C-rib are made in turn, the bonding surface is cleaned and polished. Then, the adhesive film is pasted, and the core-pulling rivets are punched according to the positioning holes to complete the pre-assembly of the whole skeleton.

4. Application of Adhesive Co-Curing Manufacturing Technology for Composite Wing Box Section

This technology has been applied to manufacture a box section structure of an eVTOL wing. The precision of key interfaces of the box section structure meets the requirements, and there are no defects such as delamination, debonding, or out-of-tolerance gaps. See Figure 11 for a depiction of the product.



Figure 11. Wing box segment product.

5. Technical Advantages of Adhesive Co-Curing Manufacturing of Composite Wing Box Section

Compared with the whole co-curing manufacturing technology, the adhesive co-curing technology for manufacturing composite wing box sections described in this paper adds a very small amount of process core-pulling rivets between the C-beam and the C-rib for positioning, which realizes the integrated manufacturing of the composite wing box section, greatly simplifies the tooling structure, reduces the operation difficulty, and improves product quality.

Compared with the secondary bonding technology, the bonding and co-curing manufacturing technology of the composite wing box described in this paper greatly reduces the number of rivets required, and the weight reduction effect of composite materials is obvious. The variation in tooling required is reduced, and the one-time curing of the skin and the H-shaped rib at the end reduces overall curing time.

6. Conclusions

(1) In this paper, the application of adhesive co-curing technology to manufacture a double-beam and multi-rib integral wing box structure is proposed, which realizes the high-quality manufacturing of the double-beam and multi-rib integral wing box structure and ensures the optimal lightweight design of the structure.

(2) Compared with the co-curing manufacturing technology of the material wing box section, the adhesive co-curing manufacturing technology has the advantages of high product quality, good stability, strong operability, simple tooling structure, and portability. Compared with the secondary bonding manufacturing technology of the material wing box section, the bonding co-curing manufacturing technology has the advantages of an obvious weight reduction effect, less variation in tooling, and reduced curing times of products in cans.

(3) Bonding and co-curing manufacturing technology of composite wing box sections can be popularized and applied to the manufacture of this type of integral wing box section structure or other complex integral composite components.

Author Contributions: Conceptualization, S.Q. and J.C.; methodology, S.Q.; software, J.M.; validation, S.Q. and J.C.; formal analysis, S.Q.; investigation, J.W.; resources, J.C.; data curation, S.Q.; writing—original draft preparation, S.Q.; writing—review and editing, S.Q.; visualization, J.M.; supervision, S.Q.; project administration, S.Q.; funding acquisition, S.Q. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: All the authors were employed by the company Harbin Aircraft Industry Group Co., Ltd. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Ito, Y.; Tsuge, H. Operations Study on a Multimodal Transport using Cargo eVTOL Aircrafts and High-Speed Rail. In Proceedings of the VFS 78th Annual Forum, Fort Worth, TX, USA, 10–12 May 2022.
2. Le Bris, G.; Nguyen, L.-G. Safety Consideration son the Operation of Electric Vertical and Takeoff Landing (VTOL) Aircraft at Airports and Vertiports. In Proceedings of the VFS 78th Annual Forum, Fort Worth, TX, USA, 10–12 May 2022.
3. Stoll, A. Development of eVTOL Aircraft For Urban Air Mobility At Joby Aviation. In Proceedings of the VFS 78th Annual Forum, Fort Worth, TX, USA, 10–12 May 2022.
4. Ji, Y.; Su, N. Review of the development of electric VTOL air craft in 2023. *Int. Aviat.* **2024**, *3*, 21–26.
5. Nie, R. Research on Key Technologies of Variant Wing Structure. Ph.D. Thesis, Nanjing University of Aeronautics and Astronautics, Nanjing, China, 3 January 2018.
6. Duan, Y.; Zhou, X.; Hou, J. Development status of composite wing of large air craft. *Aviat. Manuf. Technol.* **2012**, *18*, 34–37.
7. Lv, C.; Wu, X.; Wu, Q. Development status and design innovation of advanced helicopters. *Aviat. Manuf. Technol.* **2013**, *17*, 1–4.
8. Liu, D. Structural Optimization Design of High Aspect Ratio Composite Wing. Master's Thesis, Nanjing University of Aeronautics and Astronautics, Nanjing, China, 2019.
9. Liu, Q. Research on the Application of VARI Technology in Civil Aircraft Flap Structure. *Aviat. Manuf. Technol.* **2013**, *22*, 80–83.
10. Chen, T. Design, Manufacture and Analysis of Light weight Composite Wings. *Acta Aeronaut.* **2008**, *29*, 51–52.
11. Wu, X. Current situation, trend and development ideas of helicopter technology. *Aviat. Sci. Technol.* **2012**, *4*, 13–16.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.