OPTIMIZATION OF GLIDER DEVELOPMENT FOR MASS PRODUCTION

by Ruying Zhang, Chinese Society of Aeronautics and Astronautics

Prepared for the XXII OSTIV Congress, Uvalde, Texas, USA (1991)

SUMMARY

Using the experience of designing the Project HU-11, an entry has been made to the FAI "World Class" glider design competition phase I, 1990, for developing a glider of high quality and low price. The optimization work should be approached in several aspects, as is done in mass production industry, i.e.:

- Optimization in strategy,
- Optimization through innovations,
- Optimization with CAD,
- Optimization in procedure.

The highlights are: 1) Introducing a novel multi-pin wing and fuselage juncture design with a multi-stringer monocoque FRP wing structure. This can simplify construction and greatly reduce weight. 2) An optimized management procedure for highest efficiency, least investment and final approach to optimum after (say) a third CAD optimization. 3) Applying the modular concept in glider and mould design to share the developing investment and reduce unit costs.

1. INTRODUCTION

After making a proposal for the World Class glider design competition entry phase 1, it is realized that this

Table 1. COMPARISON OF MAN-HOURS AND SELLING PRICE AT DIFFERENT PRODUCTION VOLUMES		
Production volume/year	Estimated man hour of HU-11	Estimated selling price of HU-11
36-48	4160	
170	3000	23,760 DM
330	1600	19,662 DM
1000	800	17,251 DM

kind of development should be much more similar to those for mass production, which is a totally different approach to the usual design practice for amateur building or manufacturing sailplanes of competitive performance, but at low volume.

The World Class is aimed at "one-design glider," that is, no alteration, even very good improvements, will be allowed after its acceptance. Therefore, it should be carefully and thoroughly developed as is done in mass production industry, to be perfect in all aspects for serving its purpose and remain so for a period of decades. In addition, the World Class is required to be low priced. The general relation between unit cost/production volume is shown in Figure 1. The cost for building one or two prototypes, or at low volume, is much higher than at high volume where the investments for development and production can be shared by all the products. This can be illustrated by the author's project HU-11, for which man-hours and selling price have been estimated for production volumes of 500, 1000 and 3000 in three years, respectively, according to the documents of "World Class" competition. [3]

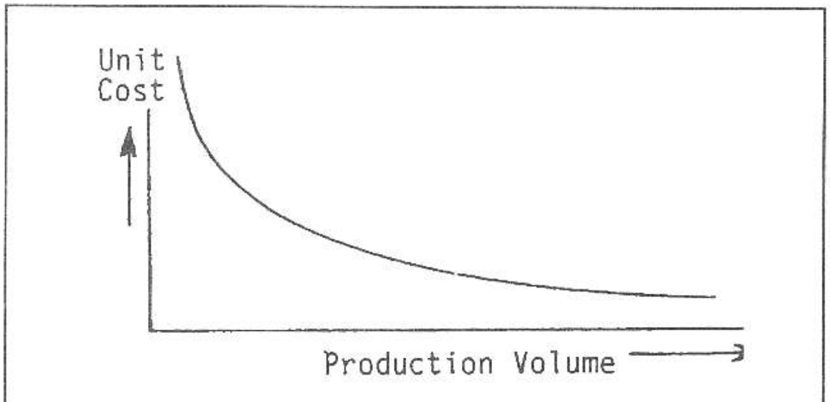

FIGURE 1. Relation between cost and production volume.

It is clear that World Class sailplanes will be cheap if produced at very high volume.

For these reasons, the Project HU-11 is prepared with a consideration of:

- Optimization in strategy,
- Optimization through innovations,
- Optimization with CAD,
- Optimization in procedure,

and, for further efforts, suggesting
- Optimization through team work.

2. OPTIMIZATION IN STRATEGY

The most important first step is to find a correct General Concept of Design, that is, the strategy of designing. The considerations are as follows: Lightness takes priority over low cost, though the latter is the ultimate main requirement.

1) Lightness - This is the leading factor for optimum performance, to be achieved by choosing:

- the smallest wing area with optimum result, this is the starting point of many relevant components and hence smallest empty weight, least material required and subsequently lower cost;
- the proper type of construction and sizing with best strength/weight ratio;
- the latest research achievements of aerodynamics and technology, not to aim at highest L/D, but to get the lightest and cheapest solution to the competition rule;
- careful and ample stressing and testing to eliminate unnecessary weight.

2) Low cost - by adopting innovations to get lightest and simplest construction which suits the mass production technology, and modular construction method both in the glider and the mould to share the development and production cost with other products. For instance: Figure 2 shows a wing with straight taper and a longer mould to enable future modifications of wing area and aspect ratio - either for improvements of HU-11, develop a two-seater version, or another airplane. Figure 3 shows a modular concept of various combinations in fuselage and its mould. It is possible to get another mould for a two-seater by only inserting a short center section. Similarly, different versions of tail unit (conventional or t-type) can be built by changing only the rear most part of moulds.

3) Reliability - this means: safety, longer life and lower maintenance cost; this is one of the factors that enable the "one-design" to stay in long service. Reliability can be achieved either by choosing well-proven aerodynamic design, construction and technology or

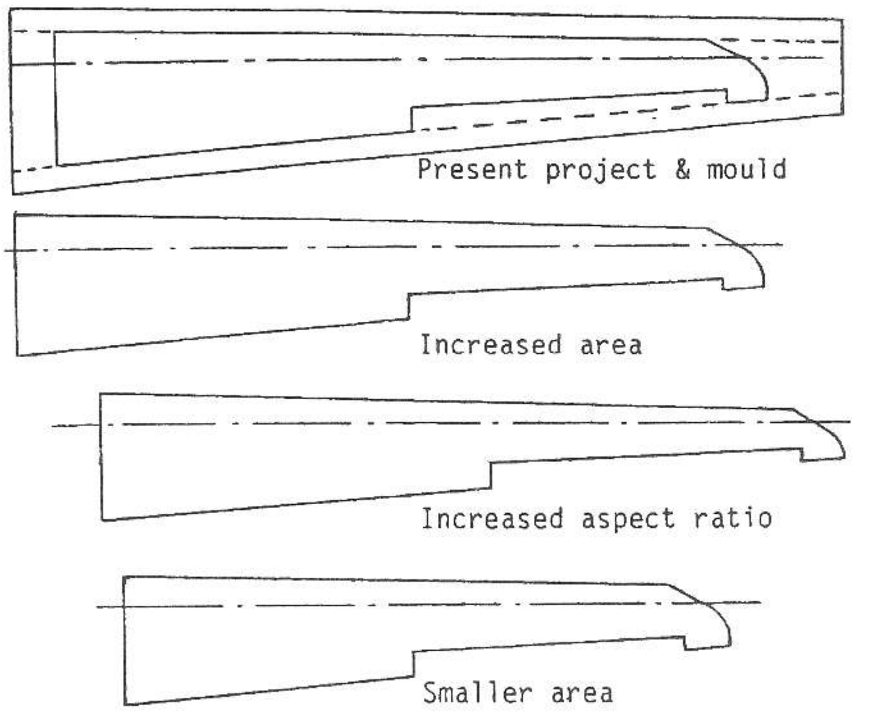

FIGURE 2. Modular conception of wing and mould.

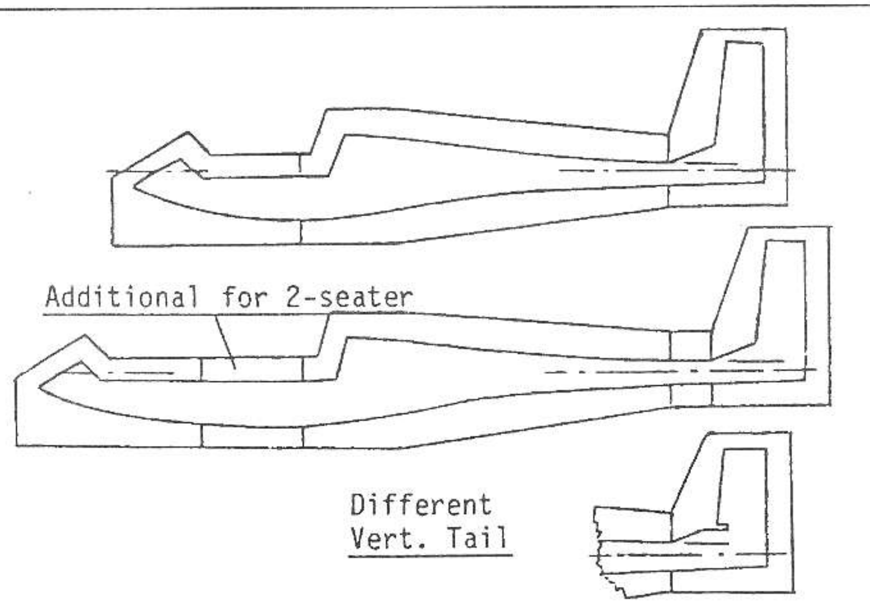

FIGURE 3. Modular concept of fuselage and mould.

making enough practical evidence (tests or operation) to prove the adopted innovations to be reliable.

3. OPTIMIZATION THROUGH INNOVATIONS

It is safer to choose conventional but reliable designs instead of innovational but uncertain constructions. However, it is often the latter that will lead in future decades, and bring optimum solutions in many respects.

1) Preparation - In addition to the study of soaring science, sailplane technology and light plane development for thirty years, special preparation has been made since the announcement of the World Class Competition–by visiting OSTIV Congress and the World Championships collecting OSTIV Publications, scanning airplane design texts, papers and documents in the local Aeronautical Institute, consulting experts in each field and keeping an eye on every Chinese innovation suitable. As a result, 65 references were selected and studied, the recommendations of which are being followed as much as possible.

2)Brain Storming - This is done several times with myself and selected groups of scientists, engineers or pilots after digesting the competition rules. More specialized institutes were visited. Many innovations were selected, carefully studied to be feasible and reliable and embodied harmoniously into the preliminary design of HU-11. We name a few for example.

3) Innovative Wing Juncture - We chose the new concept of wing and fuselage main junction of AD-100 (an ultralight of NAI). This juncture consists of many points around the root rib in contrast to the conventional practice of two or three points at the main and auxiliary beams, which must be very strong and heavy to take up the bending stress of the whole wing. Weight is also wasted at the leading and rear portions of the center wing, which are not designed to transmit bending. In our multi-pins design, the loads are spread to all pins, making each of them light, safe and easy to produce. The wing is made of monocoque FRP foamed sandwich (Figure 4) with strips of carbon fiber laid inside along the span and wrapping around the pins with enough radius to make a strong, efficient and tremendously lighter construction than the conventional. The other part of juncture at the fuselage is also made of FRP box con-

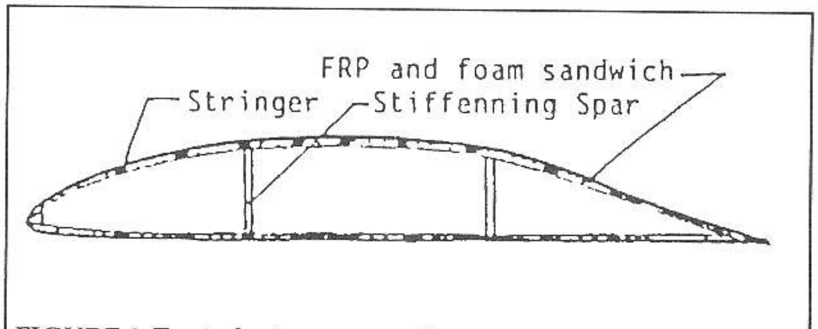

FIGURE 4. Typical wing cross section.

struction with carbon fiber or Kevlar taking up stresses at the pins. As illustrated in Figure 5, this part will be carefully designed to get good strength, rigidity and productivity. We did not take the aluminum structure of the said juncture of AD-100. We improved it to the form mentioned above according to the principles and optimization of composite materials.

Concerning reliability, this multi-pins juncture concept is being proven by test flights of five AD-100's. We shall make partial strength and fatigue tests of our multi-pin design and composite construction and also other necessary tests of the whole wing and fuselage juncture to pass the strict requirements for certification and mass production as well.

4) Applications from Research - Many of the latest reports in OSTIV Congress and publications have been adopted as given in the 65 references (see Appendix). For instance: the Marsden airfoil UAG 88-143/20 (20), Crawley's crashworthiness design of cockpit [37], Boermans' research on the fuselage shape, wing location, cockpit location [22], Galvao's note stating the 2/3 power law on fuselage form to maintain laminar flow [23] (except the front plexi-glass which is intentionally left single curvature for ease of making distortionless front view), Cijan's research on using large fillet and fairing between wing and fuselage[33], discussions on "deep stall" [25] and AIAA 81-44076 [62] report with pilots and Thomas' list[9], checking the space of cockpit with Roskam's 2.0m "pilot" [56] and locate the 1.5m "pilot" more forward than usual to keep the c.g. within aftmost (35%) position when the pilot and chute are 60kg, (see Figure 6), papers of Irving[17], Bennett[14], Marsden[16], Boermans [15], Kovacs[13], Roskam[54-57], Hoak[60] and others are used in CAD and many on materials and technologies, etc.

4. OPTIMIZATION WITH CAD

This is one of the most important innovational methods we have adopted. The entire sizing of glider HU-11 is decided by a program 'NAI 186' after several trial designs and a CAD optimization of some 1600 search. It is presented in another paper: "CAD optimization of glider design with program 'NAI 186'." As it is explained in that paper, the relations used in the program are based on general industrial statistics; there might be a 10% deviation from our case — the present CAD optimization is only at the preliminary stage. We shall refine our program with the statistics collected during prototype construction and will get more accurate results. Figure 7 gives the first 3-view drawing of HU-11; the dimensions are subject to change at the final stage.

5. OPTIMIZATION IN PROCEDURE

In mass production industry, the word "development" is used more often for the pre-production period, which includes: research, design, part testing, prototype construction, test flying and then refining — and maybe repeating the whole procedure once or even twice again until the aircraft is satisfactory for produc-

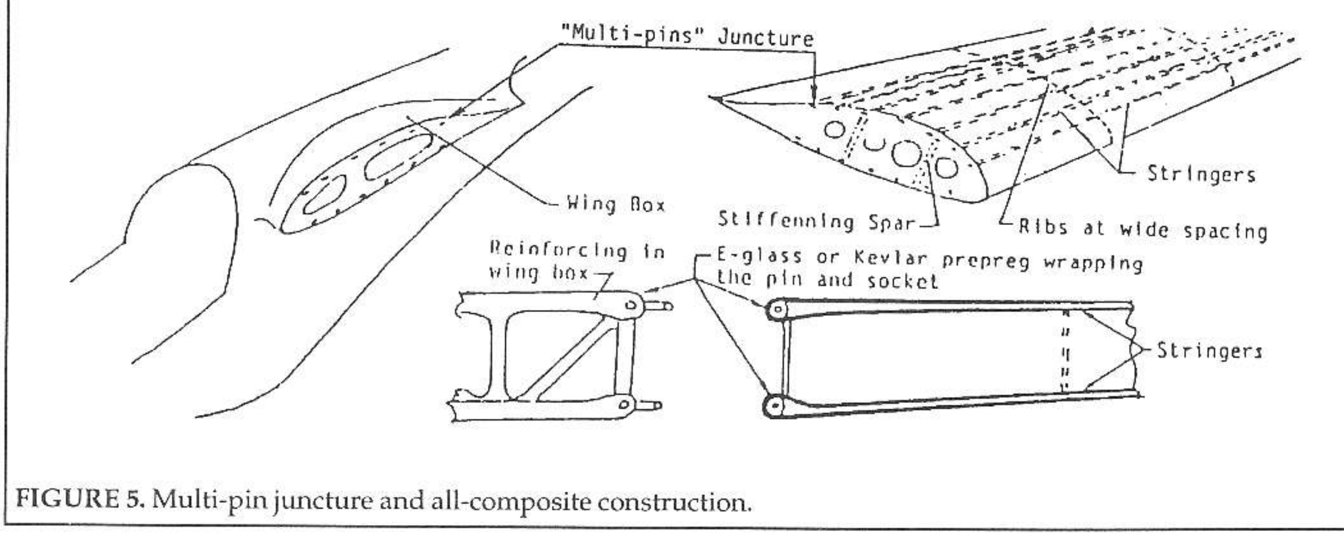

FIGURE 5. Multi-pin juncture and all-composite construction.

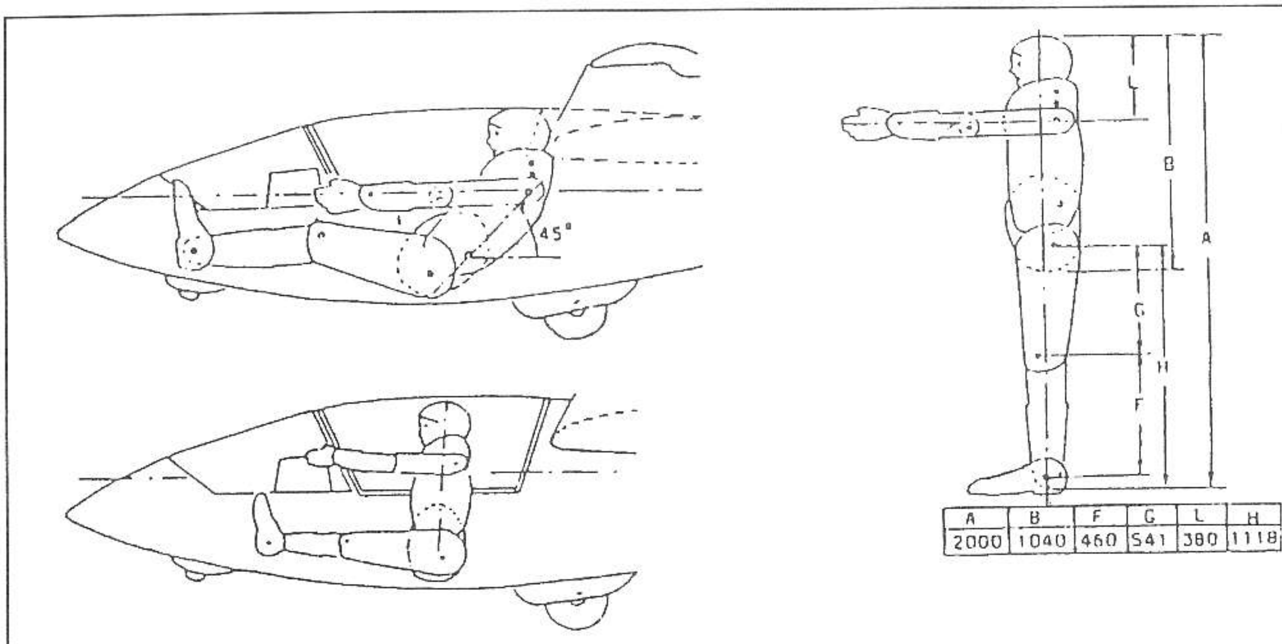

FIGURE 6. HU-11 with 2.0 m and 1.5 m pilot in cockpit. Dimensions in millimeters.

tion. This is because in mass production there need to be many jigs, fixtures, moulds and tremendous paper work prepared; any more changes would be very difficult. That is why we think the development of a World Class glider should be very similar to that for mass production. In addition, in our aviation practice, we used to build two prototypes, one for static test up to failure and one for test flying. And for reliability, the test flights need to be very long and strict at least one should fly to its ultimate life. Combining all this work, the development period would be very long and expensive. In our entry for World Class competition phase I, we have

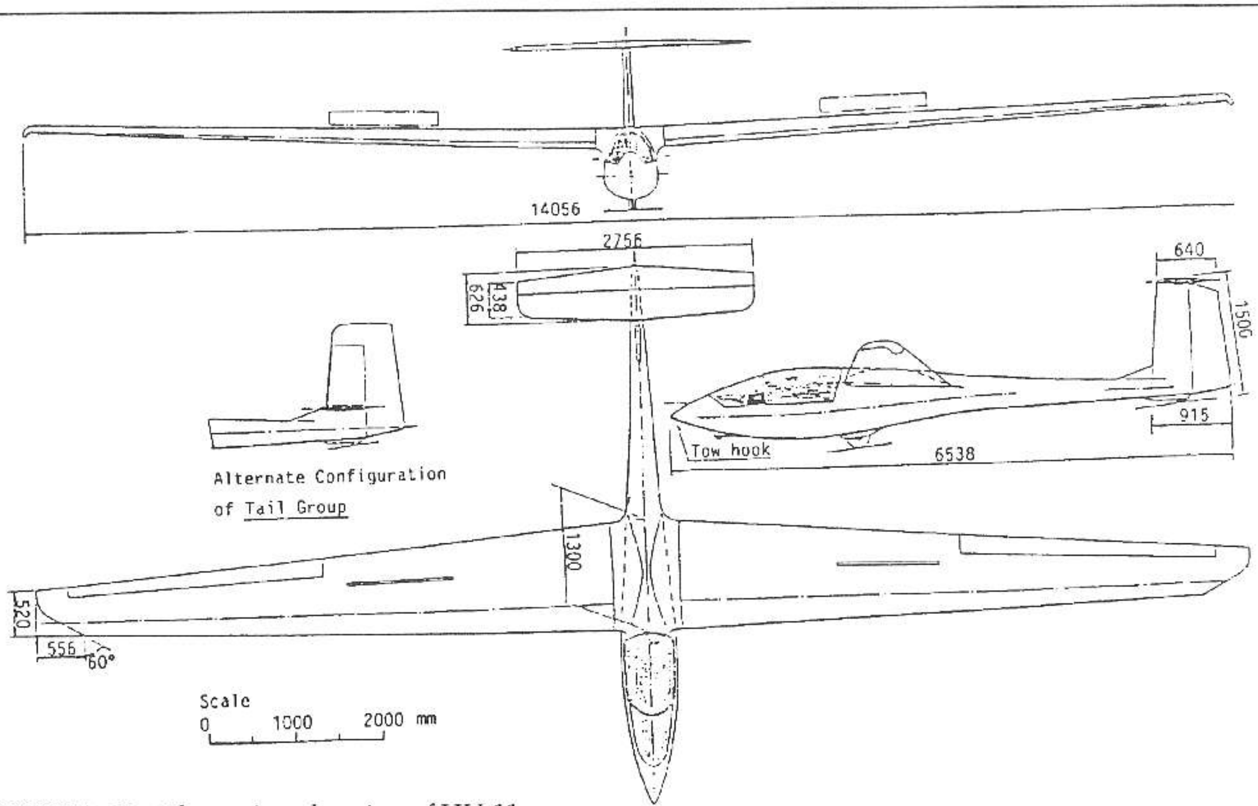

FIGURE 7. First three view drawing of HU-11.

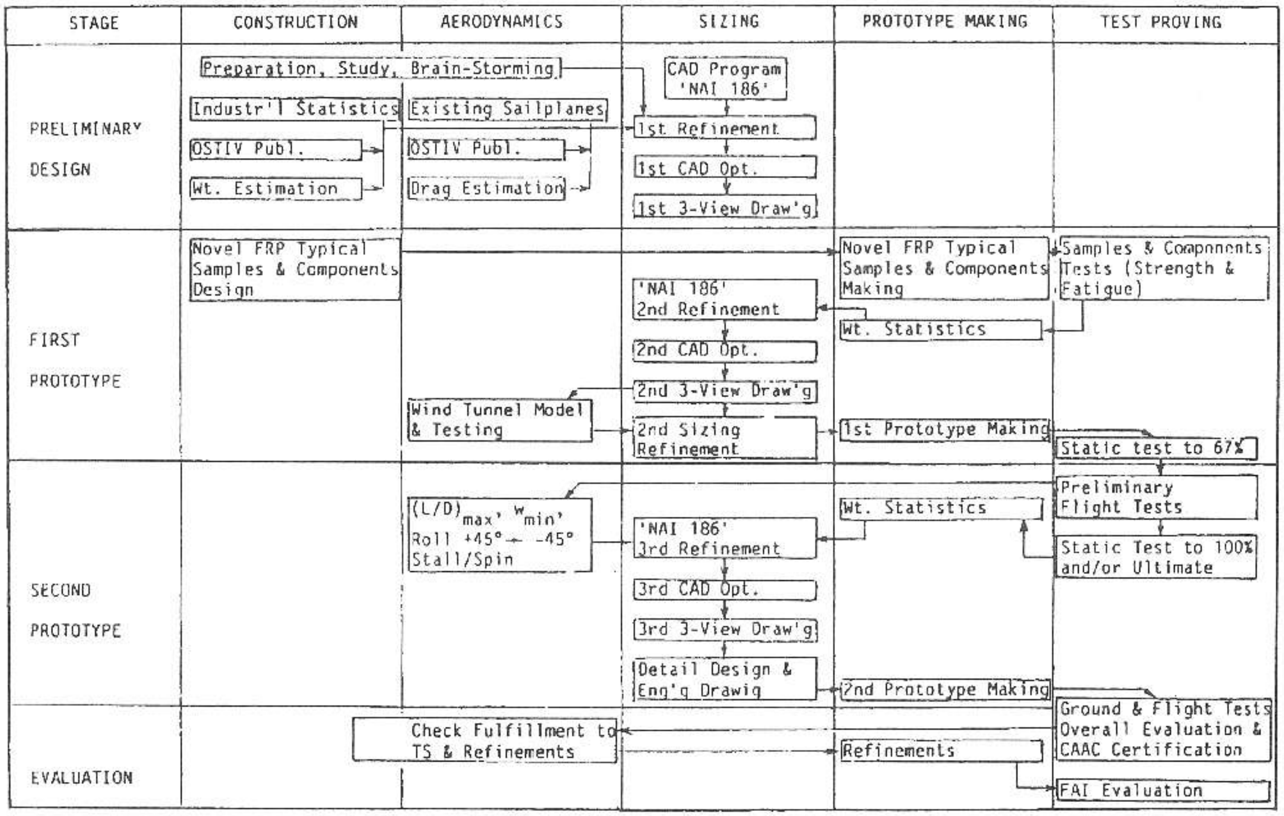

FIGURE 8. Schematic diagram of development procedure for HU-11.

designed a management procedure in order to arrive at the highest satisfaction, reliability, safety and yet with the least investment, that is to optimize the whole "development" system. As shown in the schematic diagram in Figure 8, we can finally come to very close optimization.

APPENDIX

BIBLIOGRAPHY

1. FAI, IGC, Doc. 1: Technical Specifications for the "World Class" glider

2. FAI, IGC, Doc. 2: Rules for the selection and production of the World Class glider

3. FAI, IGC, Doc. 4: Documentation required for entering competition phase 1

4. Piero Morelli: A Single-type Glider for the "World Class," presented at the International Soaring Symposium, Australia, 1988.

5. Paul A. Schweizer: An International One Design Class and the Olympics, presented at the XX OSTIV Congress, 1987; Technical Soaring, April, 1989.

6. Ann Welch: The Light Glider, OSTIV Publication XVIII.

7. P.K. Squires: Configuration Optimization of a 13-meter span Sport Sailplane, OSTIV Publication XIV.

8. Hans Zacher: Flugmessungen mit Segelflugzeugen von 12 bis 13 m Spannweite Presented at the X OSTIV Congress, 1965; OSTIV Publication IX.

9. Fred Thomas: Grundlagen fur den Entwurf von Segelflugzeugen, Motorbuch Verlag Stuttgart, 1984.

9. Zhang Ruying: China's Sailplanes & Motorgliders - An Overview. Presented at the XXI OSTIV Congress, 1989.

10. Shenyang Sailplane Factory: Sailplane X-10 (documents).

11. Nanjing Aeronautical Institute, Light Aircraft Institute: Ultralight Aircraft AD-100 (Manuals and relevant data).

12. Zhao Dongbiao: Preliminary Design and Analysis of Light Canard Airplane and Numerical Analysis of Canard Wing Interference, Masters Thesis, Nanjing Aeronautical Institute, 1990.

13. J. Kovacs: Evolution of High Performance Sailplanes. Presented at the XVI OSTIV Congress, 1978; OSTIV Publication XV.

14. George Bennett and others: Pilot Evaluation of Sailplane Handling Qualities. Presented at the XVI OSTIV Congress, OSTIV Publication XV.

15. L.M.M. Boermans: Development of Computer Program for Parametric Sailplane Performance Optimi-

zation. Presented at the XVI OSTIV Congress, OSTIV Publication XV.

16. D.J. Marsden: Sailplane Performance Estimation, OSTIV Publication XV.

17. Frank Irving: Boundaries for World Class sailplanes. Presented at the XXI OSTIV Congress, 1989; Technical Soaring.

18. H.C.N. Goodhart and others: The Handling Characteristics of High Performance Sailplanes, OSTIV Publication IV.

19. Ernest Schweizer: Development and Design History of the SGS 2-32 Sailplane. Presented at the X OSTIV Congress, 1965, OSTIV Publication VIII.

20. D.J. Marsden: Wind Tunnel Tests of an Ultralight Sailplane Wing Section. Presented at the XXI OSTIV Congress, 1989, Technical Soaring.

21. L.M.M. Boermans: Aerodynamic Design of the Standard Class Sailplane ASW-24. Presented at the XX OSTIV Congress, 1987, Technical Soaring, July, 1989.

22. L.M.M. Boermans: Wind Tunnel Tests of Eight Sailplane Wing Fuselage Combinations, Presented at the XVIII OSTIV Congress, 1983, OSTIV Publication XVII.

23. F.L. Galvao: A Note on Low Drag Bodies. Presented at the XI OSTIV Congress, 1968, OSTIV Publication X.

24. D.M. Somers: Experimental and Theoretical Investigation of Differences Between a Manufactured and the Corresponding Design Airfoil Section, OSTIV Publication XIV.

25. H. Millicer: The Deep Stall of Sailplanes. Presented at the XV OSTIV Congress, 1976, OSTIV Publication XIV.

26. E.E. Larrabee: The Aerodynamic Design of Sailplane Tail Asseblies. Presented at the XV OSTIV Congress, 1976, OSTIV Publication XIV.

27. Piero Morelli: Static Stability and Control of Sailplanes, 1976, OSTIV.

28. F. Irving: The Optimum Center of Gravity Position for Minimum Overall Energy Loss. Presented at the XVII OSTIV Congress, OSTIV Publication XVI.

29. F. Irving: Computer Analysis of the Performance of 15 m Sailplanes Using thermals with Parabolic Velocity Distributions, OSTIV Publication XI.

30. G.R. Whitfield: Presented at the XII OSTIV Congress, 1970, OSTIV Publication XI.

31. Paul Bikle: Sailplane Performance Measured in Flight. Presented at the XII OSTIV Congress, 1970, OSTIV Publication XI.

32. H.C.N. Goodhart: A note on the Measurement of the Induced Drag Factor (K) of a Glider. Presented at the XII OSTIV Congress, 1970, OSTIV Publication XI.

33. B.J. Cijan: The Aerodynamic Merging of Wings, Fuselage and Cockpit, OSTIV Publication IX.

34. R.H. Johnson: A Flight Test Evaluation of the Discus, Soaring, February, 1986.

35. Shan Dezong: The Application of Wortmann Airfoil and the Selection of Sailplane Parameters (in Chinese), Chengdu Sailplane Factory, 1982.

36. Chengdu Sailplane Factory: X-7, Chinese First All Composite Glider, 1966.

37. R.J. Hansman, Jr., E.F. Crawley and others: Experimental Investigation of the Crashworthiness of Scaled Composite Sailplane Fuselages. Presented at the XXI OSTIV Congress, 1989.

38. G. Sunderland: A Pilot Restraint System for Sailplanes. Presented at the XVII OSTIV Congress, 1981, OSTIV Publication XVI.

39. W. Lucker: A New Seatbelt System for Sailplanes. Presented at the XV OSTIV Congress, 1976, OSTIV Publication XIV.

40. R.G. Parker: Some Aspects of Glider Tow Release Performance. Presented at the XX OSTIV Congress, 1987, Technical Soaring, April, 1989.

41. Peter Disdale: Are You Sitting Comfortably? Sailplane & Gliding, June/July 1985.

42. Ch. Kensche: Fatigue of Composite Materials in Sailplanes and Rotor Blades, OSTIV Publication XVIII.

43. A.O. Payne: the Sensitivity of Fiberglass Gliders. Presented at the XX OSTIV Congress, 1987, Technical Soaring, April, 1989.

44. Giulio Romeo: Experimental Results of Advanced Composite Sailplane Structures. Presented at the XVIII OSTIV Congress, 1983, OSTIV Publication XVII.

45. Day Chahroudi: Outline of a Method for the Automated Manufacture of Laminar Wings. Presented at the XVIII OSTIV Congress, 1983, OSTIV Publication XVII.

46. R.T. Lamson: Advances in Material Science and Fabricating Techniques for Sailplane Construction. Presented at the XV OSTIV Congress, 1976, OSTIV Publication XIV.

47. G. Ramao: Sailplane Wing Box Design by Use of Graphite/Aramide/Epoxy Material, OSTIV Publication XVI.

48. C. Kensche: Fatigue Test of a Sailplane Wing in CFRP Construction. OSTIV Publication XVI.

49. Ursula Hanle: The Story of Fiberglass Sailplanes. Presented at the XII OSTIV Congress, 1970, OSTIV Publication XI.

50. E. Schoberl: Solar Powered Aircraft Design. Presented at the XXI OSTIV Congress, 1989.

51. W. Roger and M. Conradi: Evaluation of Canopy Jettisoning Systems for Sailplanes. Presented at the XXI OSTIV Congress, 1989, Technical Soaring, April, 1990.

52. P. Koivisto and E. Lehtonen: Effect of the Wing Section Drag Polar Shape on the Desirable Wing Area and Attainable Average Cross Country Speed of Standard Class Glider. Presented at the XIX OSTIV Congress, 1985, OSTIV Publication XVIII.

53. JAR 22.

54. J. Roskam: Airplane Design: Part I, Preliminary of Sizing of Airplanes. 1985.

55. J. Roskam: Airplane Design: Part II, Preliminary

Configuration Design and Integration of the Propulsion System. 1985.

56. J. Roskam: Airplane Design: Part III, Layout Design of Cockpit, Fuselage, Wing and Empennage: Cutaways and Inboard Profiles. 1985.

57. J. Roskam: Airplane Design: Part V, Component Weight Estimation. 1985.

58. Abbot and Von Doenhoff: Theory of Wing Sections. 1959.

59. Taylor: Jane's All the World Aircraft.

60. Hoak: USAF Stability and Control Datcom, Flight Control Division, Air Force Flight Dynamics Laboratory. 1978 revised.

61. Xu Rejuan and students: The Performance Analysis and Wind Tunnel Report on F3B Radio Controlled Model Glider (a thesis for graduation), Northwestern Polytechnical University. 1988.

62. B.W. McCormick: Equilibrium Spinning of a Typical Single-Engine Low-Wing Light Aircraft, AIAA 81-4076.

63. Richard Eppler, translated by Joachim Schneibel: The Optimum Design and Wing Section of a 15m Glider Without Flaps. Sailplane & Gliding, June/July, 1977.

64. Jozsef Gedeon: Improvements in Fatigue Testing of Sailplanes. Presented at the XII OSTIV Congress, OSTIV Publication XI.

65. Ch. Kensche: Fatigue of Composite Materials in Sailplanes and Rotor Blades. Presented at the XIX OSTIV Congress, OSTIV Publication XVIII.