1. Introduction to Configuration Aerodynamics

1.1 Purpose

This text describes the role of aerodynamics in aircraft design. Although students take the basic aerodynamics theory classes, several topics are, of necessity, omitted, and other topics need additional reinforcement. Configuration Aerodynamics was developed to provide a design-oriented perspective into the development and analysis of aircraft aerodynamics typical of what a career as an aerodynamicist might entail. We assume that the student has had an introductory aerodynamics class.

Experience has shown that the analysis-oriented basic aerodynamics class doesn't provide an understanding of how to approach the configuration aerodynamic design process. Although many of the classical approaches to aircraft design are now highly refined, we are currently in a period where many innovative designs are being investigated. We need to be able to understand these innovative designs and project their performance potential.

Some of the innovative designs crossing my desk or of interest to me are illustrated below. To develop an appreciation of these concepts requires assessing them using first principles. Many concepts are proposed that don't obey the laws of physics. A successful design must!

To get some insight into aerodynamic thinking, it is worthwhile to read about the experience of one of the more successful recent aerodynamic designers, Irving Waaland. His 1991 Wright Brothers Lecture shows how an aerodynamicist approaches design.[1]

1.2 Examples of innovative concepts

A brief collection illustrating the range of concepts currently being explored is useful. Some of these are impractical for aerodynamic or other reasons. Yet all have required an aerodynamic assessment, and several could benefit from a better aerodynamic design foundation based on the physics of flowfields.

Figure 1-1 shows an example of the strut-braced wing concept, as it might be implemented on an A-7 to demonstrate the concept. This model was the result of a senior design class study[2] of the strut braced wing concept studied for several years at Virginia Tech.[3,4]

Figure 1-1. The strut-braced wing concept as it might be demonstrated on an A-7.

The next concept, presented in Figure 1-2, illustrates the result of some Imagineering. It is a concept by Prof. Joe Schetz of Virginia Tech. The model was made using rapid prototyping.

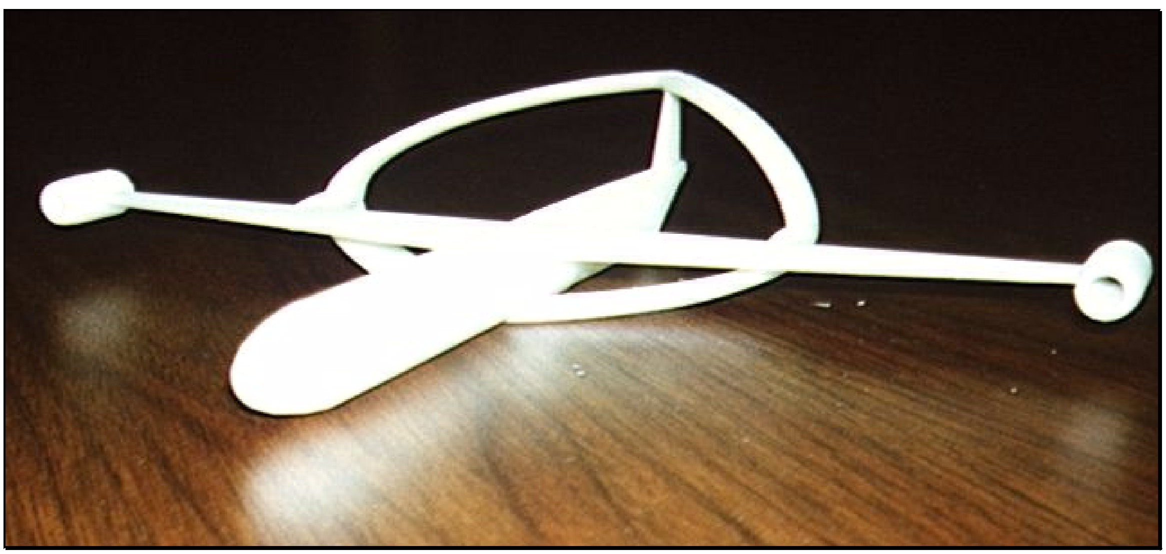

Figure 1-2. Imagineering, inspired by the strut braced wing concept illustrated above.

Figure 1-3 is a concept that is the result of a senior design project between Loughborough University and Virginia Tech. This concept draws on the idea of increased efficiency available from the use of the box-plane concept.

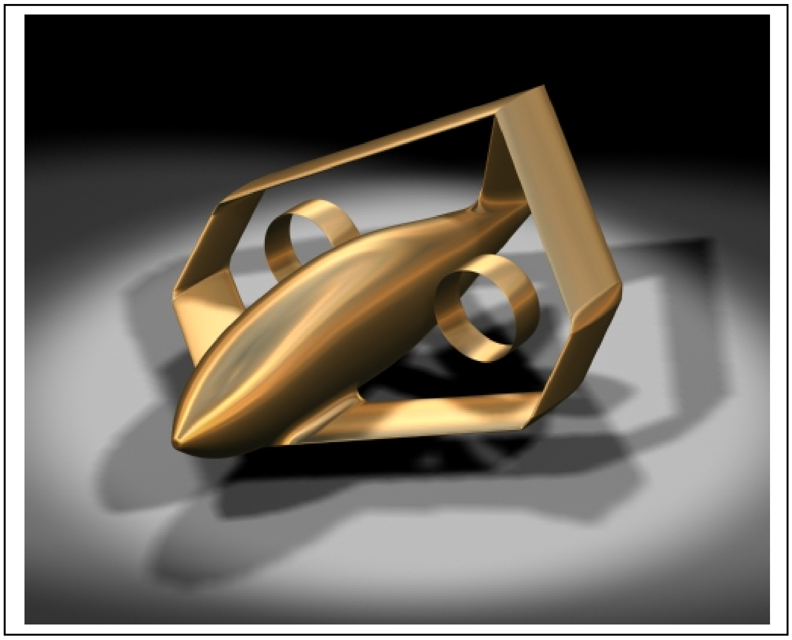

Figure 1-3. Ikelos (Dave Etchells, Loughborough Univ, UK)

Figure 1-4 is also from a senior design project,[5] and is a roadable aircraft, sometimes called a flying car. Some of the details of this concept, and some further refinement were also studied.[6]

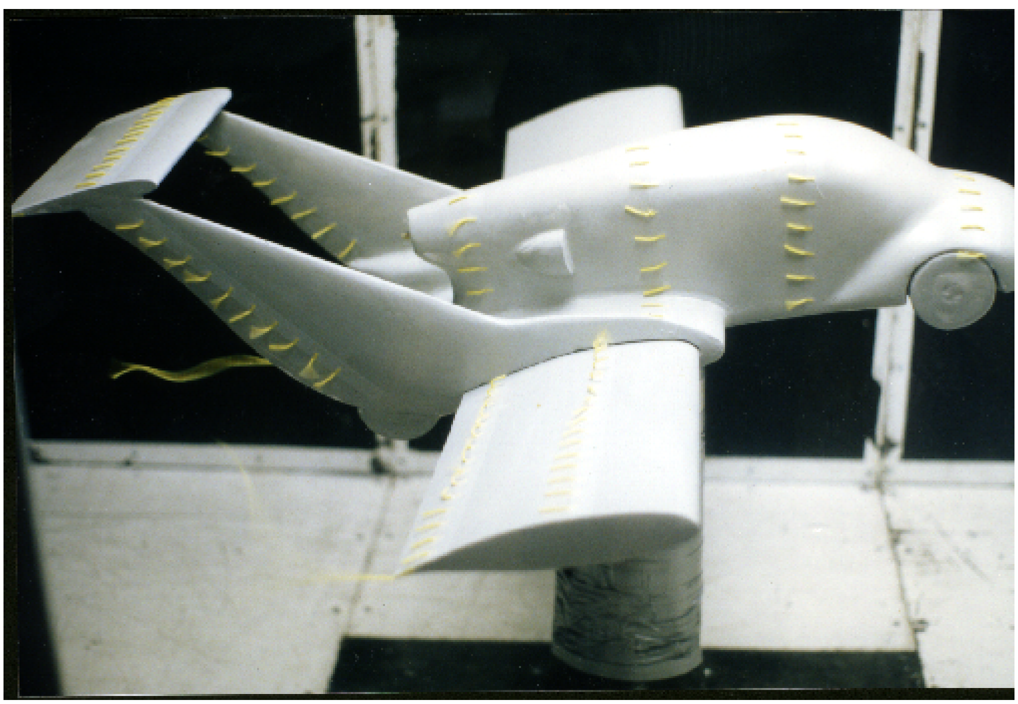

Figure 1-4. Pegasus in the Virginia Tech Stability Wind Tunnel (photo by J.F. Marchman, III)

The next example is Askin Isikveren's innovative X-Wing concept[7], known as "TOLS" for Twin Oblique Lifting Surfaces. Shown in Figure 1-5, this concept is intended to take advantage of the strut braced wing concept advantage by using the engine pylons to bring provide wing weight reduction and the advantages of an oblique/forward swept wing to reduce drag (described in more detail below).

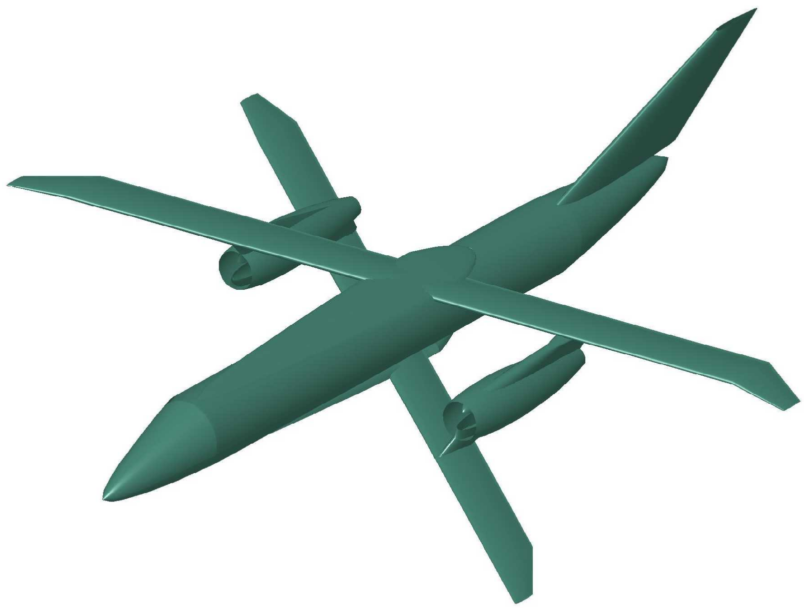

Figure 1-5. Askin Isikveren's X-Wing TOLS concept.

Figure 1-6 is an example of the so-called inboard wing concept proposed by Leroy Spearman.[8,9] This concept is intended to address the issue of the need for very large aircraft. Spearman expected to reduce, or even eliminate, induced drag by having the fuselages act as endplates to the wing. An assessment of the viability of this concept requires the aerodynamicist to test the validity of Spearman's flow hypothesis. Note that although we don't show it, there is another variation of the twin fuselage concept due to Houbolt that has wings extend outboard of each fuselage.[10] That concept may have a stronger basis in physics.

The next unusual concept is R.T. Jones' Oblique Wing, shown in Figure 1-7. Aerodynamically this is likely the most important of any of the concepts given here. Jones discussed the concepts many times. Key references are by Jones and Nisbet[11] and Kroo.[12] A list of references is also available.[13]

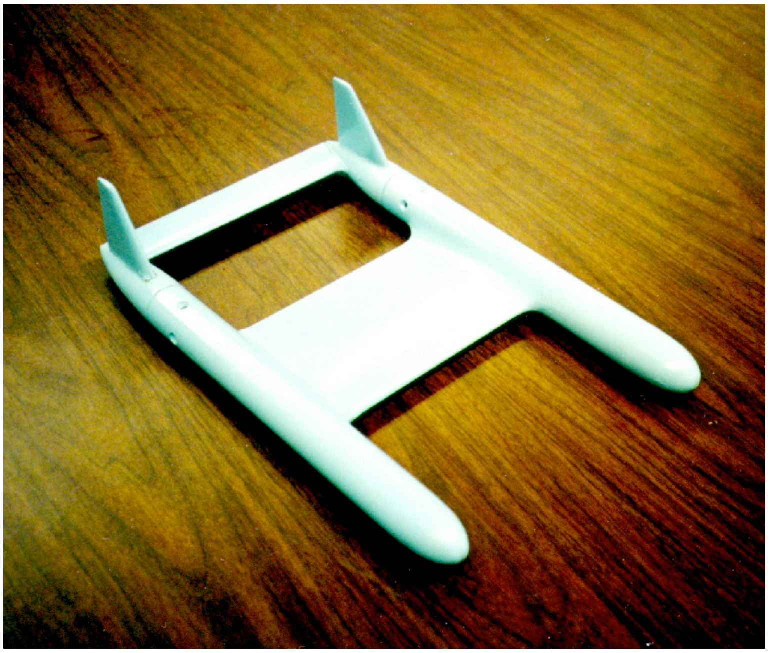

Figure 1-6. The inboard wing concept due to Spearman.

Figure 1-7. R.T. Jones's Oblique Wing Aircraft

Figure 1-8 shows the Boeing Sonic Cruiser, studied by Boeing as potential new aircraft concept in 2001 and 2002, before being dropped as a concept in 2003.[14,15]

Figure 1-8. The Boeing Sonic Cruiser (photo of unknown origin)

Figure 1-9 is the "Bird of Prey", a concept built and flown by the Boeing Phantom Works in the 1990s, presumably as a stealth concept.[16]

Figure 1-9. The Bird of Prey

There are a myriad of other examples: including UAVs, from MicroUAVs to Global Hawk.

Fig. 1-10 shows the Aerovironment Blackwidow microUAV.[17] This concept is remarkable, as has flown for nearly an hour, while sending a video feed back to a base station.

Figure 1-10. The Aerovironment Black Widow. (Courtesy of Joel Grasmeyer)

Recently, many studies are being made of morphing aircraft, which change shape according to the mission, to be optimal at each condition.

This brief survey of current unconventional concepts being investigated illustrates the wide range of shapes of interest. All require an aerodynamic assessment of their potential performance.

1.3 Overview of the material covered

This text can be considered in three parts. Initially we review the physical description of flowfields in the mathematical terms that are used in modern computational aerodynamics. This is followed by a discussion of drag, which is covered in more depth than a first course in aerodynamics. The next section examines some of the configuration options available to the aircraft designer, and then provides a discussion of the typical design conditions that the aerodynamicist must consider. Note that much of the effort is devoted to off-design conditions! This part concludes with an overview of the aerodynamic design process and role of computational aerodynamics. The last part, Chapters 6-11, address more specific configuration aerodynamics issues, including subsonic and transonic aerodynamics, high-lift systems, high angle of attack flight, and supersonic and hypersonic configuration aerodynamics.

An attempt is made to integrate case histories and "amazing stories" to the greatest extent possible.

1.4 What's Left Out?

At present we omit discussion of numerous aspects of configuration aerodynamics in favor of the absolute essentials. Even the concepts discussed aren't necessarily covered in depth, and the interested reader can use the reference as a start toward more detailed studies of the concepts. Omitted topics include:

- aero-propulsion integration
- morphing aircraft
- unsteady flows, which may in fact become important in design, and aeroelastic effects.
- helicopter aerodynamics
- missile aerodynamics

1.5 Exercises

1.1. What characteristic controls induced drag?

Consider four rectangular wings

Wing	Span	Chord
1	10 ft.	1.00 ft.
2	10 ft.	2.00 ft
3	9 ft.	0.90 ft
4	9 ft.	1.11 ft

Explicitly stating your assumptions,

i) What is the wing area of each wing?

ii) What is the aspect ratio of each wing?

iii) At q = 40psf and a lift of 200 lbs.

- What are the lift coefficients for each wing?
- What are the induced drag coefficients for each wing?
- What are the values of the induced drags for each wing?

iv) Explain your results

1.2. Key aerodynamic relationships (this should be a repeat of a past assignment)

Assuming $C_D = C_{D_0} + \dfrac{C_L^2}{\pi ARE}$,

- Derive an expression for L/Dmax
- What is the corresponding C_L?
- Comment on the implications for aero design (physical statement of the L/D_{max} condition)

1.3. Developing a feel for key design parameters

Find the wing loading, *W/S*, and cruise C_L for the A380 and B737 transports, and the F-22 and F-35. Compare these values with typical values for a classic general aviation airplane, the Cessna 172. What can you say about these results?

R1. A start toward thinking like an aerodynamic designer

Read Irv Waaland's Wright Brothers Lecture Paper and write one page describing what you learned. (The complete citation is in App. F)

1.6 References

[1] Irving T. Waaland, "Technology in the Lives of an Aircraft Designer," AIAA Wright Brothers Lecture, Sept., 1991

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[5] Rebecca Gassler, et al, "Pegasus, A Report to the AGATE NASA/FAA General aviation design Competition," Dept. of Aerospace and Ocean Engineering, Virginia Tech, Blacksburg, VA, May 2000.

[6] James F. Marchman III, Nanyaporn Intaratep and William H. Mason, "A Design for a Dual-Mode Personal Vehicle," 2002 AIAA Aircraft Technology, Integration, and Operations Forum, Los Angeles, CA, AIAA Paper 2002-5877, October 1-3, 2002.

[7] Askin T. Isikveren, "High-Performance Executive Transport Design Employing Twin Oblique Lifting Surfaces," Paper 2001-01-3031, 2001 SAE World Aviation Congress and Exposition, Seattle, WA, Sept. 2001.

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[10] John C. Houbolt, "Why Twin-Fuselage Aircraft?" *Astronautics and Aeronautics*, April 1982, pp. 26-35.

[11] Robert T. Jones and James W. Nisbet, "Transonic Transport Wings-Oblique or Swept?" *Astronautics and Aeronautics*, Jan. 1974, pp. 40-47.

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[12] Ilan Kroo, "The Aerodynamic Design of Oblique Wing Aircraft," AIAA 86-2624, Oct. 1986.

[13] Oblique wing bibliography: http://www.aoe.vt.edu/~mason/Mason/ACiADoblique.html

[14] Martin Hepperle, "The Sonic Cruiser – A Concept Analysis," International Symposium "Aviation Technologies of the XXI Century: New aircraft Concepts snd Flight Simulation," 7-8 May 2002, Aviation Salon ILA-2002, Berlin, see: http://www.mh-aerotools.de/company/paper_7/astec_2002.htm

[15] Daniel J. March, "Boeing's Failed Concept: Demise of the Sonic Cruiser," *Flightpath, The International Journal of Commercial Aviation*, Fall 2003, pp. 14-16.

[16] Bill Sweetman, "First Look", *Popular Science*, October 18, 2002. http://www.popsci.com/popsci/aviation/article/0,12543,365576,00.html, see also the Boeing press release: http://www.boeing.com/news/releases/2002/q4/nr_021018m.html

[17] Joel Grasmeyer and Matt Keennon, "The development of the Black Widow Micro Air Vehicle," AIAA Paper 2001-0127, Jan. 2001.