Recent Developments of the FanWing Aircraft

George R Seyfang
Formerly Principal Concepts Engineer ~ BAE Systems, UK

Keywords: *STOL, Wind Tunnel, High Lift, Cross-flow Fan, Cargo*

Abstract

FanWing is an aircraft configuration that uses a simple cross-flow fan mounted in the wing to provide distributed propulsion and augmented wing lift at very low flying speeds. One of the current flight-test vehicles has been modified to accept both a novel OHS twin-tail arrangement and a new wing section and this has shown both increased flight stability and reduced drag, leading to significantly higher cruise speeds.

The good slow flight capability, inherent safety and relatively quiet propulsion of the FanWing rotorcraft could fit well with cargo operations close to urban areas. A comparison with aircraft and helicopters showed that the recent developments of the FanWing concept could now uniquely offer short-field performance close to that of helicopters and tilt-rotor aircraft, but with operating economies close to that of conventional aircraft.

1. Introduction

This paper briefly reviews the history of the FanWing aircraft concept and then reports some of the author's recent aerodynamic activities to improve flight characteristics and to increase flying speeds. Finally it reports an economic study of short-field cargo operations comparing this configuration with established aircraft configurations.

FanWing is a powered-lift aircraft configuration that uses a simple cross-flow fan mounted in the wing to provide distributed propulsion and augmented wing lift at very low flying speeds. The fan's tip speed is considerably lower than the tip speeds of conventional aircraft propellers or helicopter rotors, so it offers unique opportunities for improved propulsive efficiency and reduced noise footprint. The result is that FanWing may offer many of the advantages of both fixed-wing aircraft and helicopters.

2. Background

Although several earlier, and more complex, horizontal-axis rotor concepts [1] had been explored since the early 1900s, it was only in 1998 that the simple FanWing concept was evolved and first flown by Patrick Peebles.

Fig. 1 Early flight model of FanWing

Early wind tunnel tests confirmed the key performance parameter to be the ratio of fan blade tip speed to aircraft speed.....the Tip Speed Ratio, TSR [2, 3]. Maximum lift coefficient values of over 10 have been measured at low speed on the original FanWing section, and this offers remarkably low take-off speeds and true STOL performance.

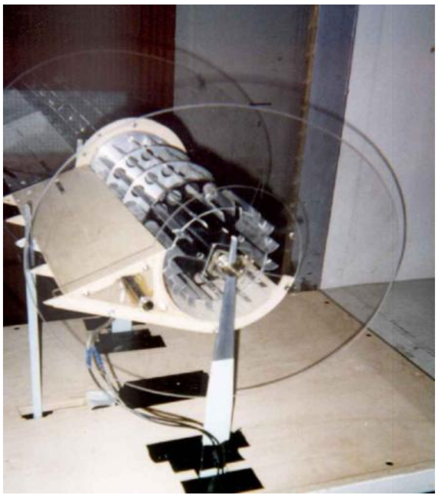

Fig. 2 A 2-D wind tunnel model at ICL

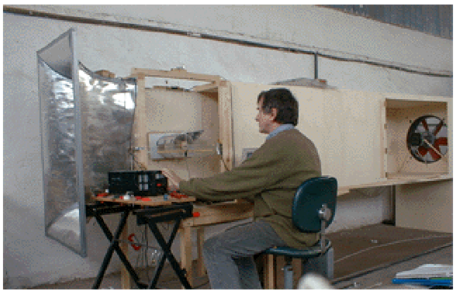

Fig. 3 Early wind tunnel testing

Other models of increasing size and power efficiency have flown and most recently there were daily flight demonstrations of a UAV variant of FanWing during the Farnborough Air Show in 2010.

Fig. 4 FanWing at Farnborough in 2010

Thus far the FanWing concept has demonstrated the ability to fly slowly and safely in the regime of helicopters, and efficiently in the regime of fixed-wing aircraft. This economical loitering capability would be ideal for surveillance UAVs.

In an early attempt to widen the FanWing's flight speed envelope there have been further development flight tests. At the low speed end of the envelope, exploratory tethered flight tests have demonstrated the potential to hover and fly vertically.

Fig. 5 Tethered VTOL hovering tests

3. Recent Aerodynamic Developments

3.1 Objective -- Higher Cruising Speed

Recent developments of FanWing have concentrated on further widening the flight envelope, in particular with three aerodynamic modifications to allow flight at higher speeds. The combination of ultra-short field performance and moderate cruising speeds would greatly widen the field of potential applications of FanWing.

3.2 OHS Tail Configuration

One of the current flight-test vehicles has been modified to accept a novel OHS twin-tail arrangement which moves the tails from the intense fan-stream and wing downwash flow directly behind the wing, to positions where they can exploit the upwash flow from the wingtip vortices.

The OHS tail arrangement was first developed and flown on radio-controlled models over 20 years ago by Professor John Kentfield at Calgary University, [4, 5]. The current author has derived design rules for the optimum use of OHS and estimates of the performance advantages of OHS [6].

Flight testing of FanWing with the OHS twin-tail has shown both increased flight stability and reduced drag, leading to higher flight speeds.
In addition, when the elevators of the OHS tails are used differentially, they can provide roll control as well as pitch control. This allows the wing to be built as a simple lifting surface without ailerons.

Fig. 6 FanWing model with OHS tails

Fig. 7 Twin-tail OHS model 2011

3.3 High-Speed Wing Section Design

The fixed wing section of FanWing has recently been modified following a series of 2-D and 3-D wind tunnel tests of many alternative fan and wing combinations.

Fig. 8 2-D wind tunnel tests in 2010

Examples are shown below of the wing section with its trailing edge lengthened to reduce profile drag at lower lift coefficients whilst retaining the excellent CLmax values.

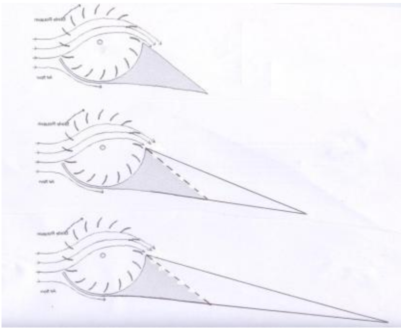

Fig. 9 Baseline (top) and two high-speed sections

Wind tunnel tests of the 2-D model did indeed show that the CLmax values were little changed, but the longer section was found to have less drag and a much improved thrust margin at cruise.

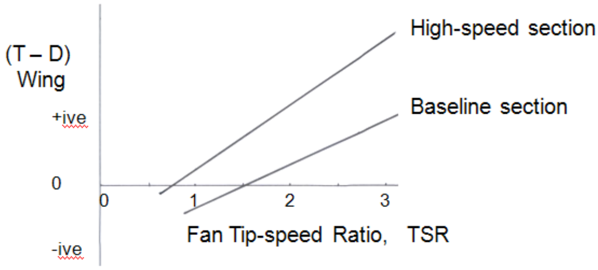

Fig. 10 Cruise (Thrust – Drag) margin

Based on the results of these 2-D model tests and using appropriate 'fan laws', it is estimated that a full-size FanWing aircraft will have a cruise speed near to that of a helicopter.

The opportunity was taken with the 2-D model to measure lift, drag, thrust and power characteristics over a much wider range of TSR values than had been possible previously. This was done to provide data which could be used in take-off and cruise performance calculations, as reported later in section 5.

An example is shown of the CLmax vs TSR and it is seen that very high values were achieved.

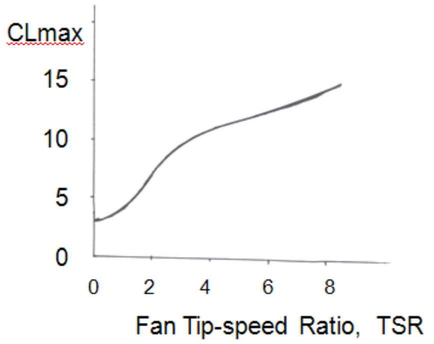

Fig. 11 Maximum lift vs fan tip-speed ratio

In addition to improving the cruise drag characteristics, the long chord section greatly improved the ‘gliding’ performance in the power-off, auto-rotation mode.

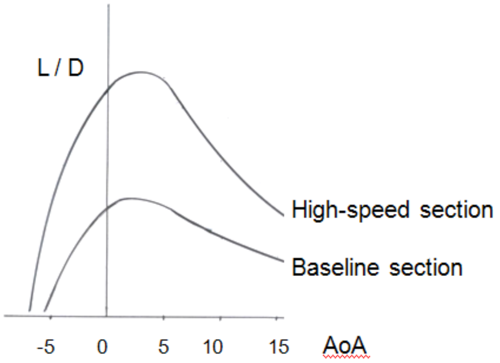

Fig. 12 Glide ratio in auto-rotation mode

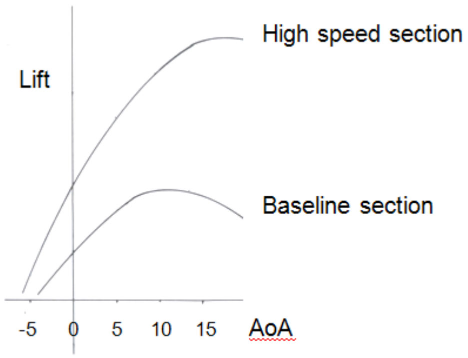

Fig. 13 Lift in auto-rotation mode

Other testing with a short rounded nose extension was found to further improve the performance in the auto-rotation mode.

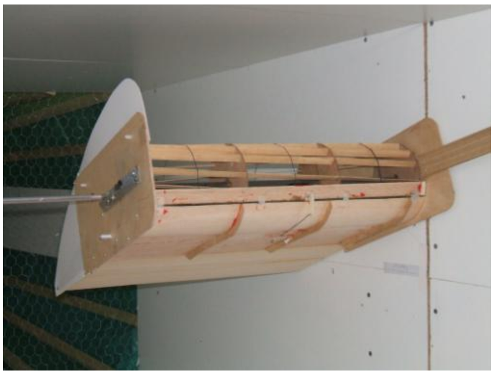

Fig. 14 3-D wind tunnel model 2011

The long chord high-speed section was also tested at 3-D on a half-model, mounted at one side of a larger wind tunnel, and similar improvements performance were obtained.
The 3-D model was also used to examine the horizontal wing-tip extensions fitted to earlier flight models. These were found to add little benefit and have since been removed for simplicity.
Flight testing of the new, longer wing section on a large FanWing model has confirmed the improved flight performance characteristics and has achieved much higher cruise speeds.

Fig. 15 Flight tests of high-speed section 2011

Fig. 16 Example of flight test telemetry

3.4 Fan Blade Design

The fan blade sizes, numbers, cambers and setting angles have been evolved to satisfactory performance levels in an ad hoc way with wind tunnel and flight models. There have also been several partially successful attempts to model the complex fan airflows with CFD. [7, 8, 9].

Recent activities have included testing many fan blade arrangements in a simple water channel at different TSRs.

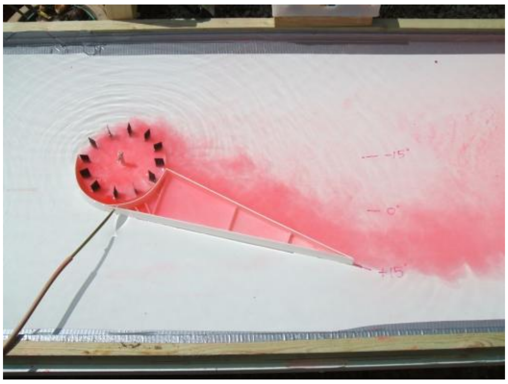

Fig. 17 Water channel tests 2011

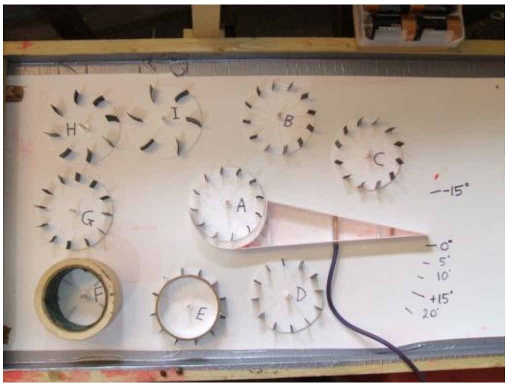

Fig. 18 Examples of the fan-blades tested

Indications from the flow-visualisation tests suggest that the optimum fan blade arrangement is not overly-critical. It is intended to repeat this wide-ranging fan blade study in a wind tunnel to capture the thrust, drag and power requirements at various airspeeds and fan rotation speeds.

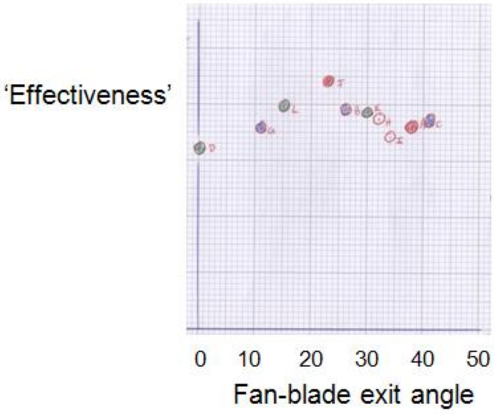

Fig. 19 Fan-blade efficiency measurements

4. Operational Features of FanWing

4.1 Flight Safety

Relative to conventional twin-engine aircraft with propellers, the FanWing concept has three inherent safety features.

Firstly, it does not stall in the way that a normal wing stalls. This is because the wing is blown by the fan and the air does not separate if the rotor is sufficiently powered.

Secondly, it avoids any asymmetric thrust and lift in the event of a single engine failure. FanWing aircraft will have the fans on each wing connected by a cross-shaft so that both fans continue to be powered equally at all power levels. The mounting positions for the engine do not affect this feature and engines may be positioned centrally in the fuselage, at mid-wing span or at the wing tips, depending on operational or structural needs.

Thirdly, even in the event of total power loss then the FanWing is able to auto-rotate and continue to develop lift at low speeds and so provide a safe and controllable glide.

4.2 Flyover Noise

Relative to conventional propeller aircraft and helicopters, the FanWing will cause less fly-over noise nuisance for several reasons. The fan has a larger projected area, it has lightly loaded blades and they are moving at much lower tip speeds. These factors all reduce the noise generated at source. In addition, the fan exhausts above the wing surface and so is partially shielded from observers on the ground.

However, there is an additional noise source on FanWing due to the moving blades passing close to the fixed wing surface. Solutions have included a slight skew to the rotor blades or to the fixed structure to spread the interaction, and minor changes to the separation gap between blades and fixed structure.

5. A STOL Cargo Study

5.1 Opportunities for STOL Operations

Previous economic studies have suggested that there would be a greater demand for air-cargo operations if they could be operated from multiple short airstrips close to industrial areas, and away from crowded regional airports. The demonstrated safe, slow flight capability and relatively quiet propulsion of the FanWing rotorcraft would fit well with such operations close to urban areas.

Other potential applications of a STOL cargo aircraft might include short-range military transportation and civilian operations in countries and terrains which do not have an extensive road, rail or water infrastructure.

This STOL study was carried-out privately with the objective of answering two questions; 'what is the cost of designing for short-field performance and which aircraft technologies are most appropriate?'

Fig. 20 A notional FanWing cargo aircraft

5.2 Types of Aircraft Compared

This study considered four types of aircraft; Conventional STOL, FanWing STOL, Helicopter and Tilt-Rotor. Each type offers different combinations of cruise speed, airfield length and operating cost. The comparisons shown here were done at a design concepts level, with a sizing mission to transport a 5000kg shipping container over a range of 500km.

Conventional STOL aircraft data was taken from an unpublished STOL cargo study. Variants with different field lengths were generated by changes of wing area and engine power, and re-sizing to the design mission.

FanWing STOL aircraft were based on the Conventional aircraft, re-computed for the effects of the FanWing propulsion and lift system, as measured in wind tunnel and flight reported in section 3.

Helicopters have true VTOL capability and data was based on open-source information for the Boeing CH-47 Chinook.

Tilt-Rotor aircraft also have true VTOL capability plus a much higher cruise speed and data was based on open-source information for the Boeing V-22 Osprey.

5.3 Comparison of Aircraft Types

The two key performance and economic parameters chosen for presentation here are the take-off run and D.O.C., the direct operating cost. D.O.C. is a very powerful parameter since it includes flying costs, maintenance costs and capital costs. In turn, these reflect such relevant flight performance features as fuel consumption and cruise speed.

The results of the study are shown in Fig. 21 below and it is seen that FanWing variants offer a niche capability between a Conventional STOL aircraft and the two VTOL types having significantly higher costs.

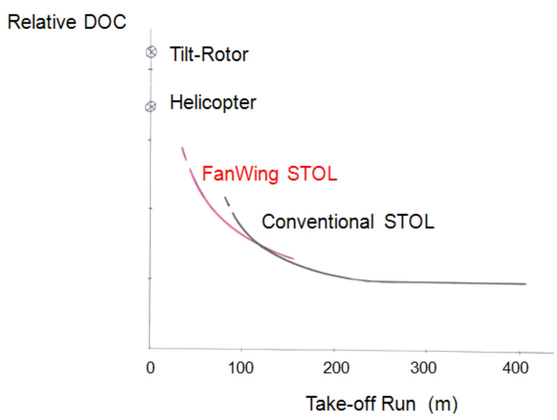

Fig. 21 Results of Cargo Study

6 Conclusion

Recent aerodynamic developments of the FanWing aircraft configuration have increased its cruise speed considerably.

A comparison of four different aircraft and rotorcraft configurations has shown that the FanWing concept now offers an interesting and unique capability, with short-field performance close to that of helicopters and tilt-rotor aircraft, but with operating economies close to that of conventional aircraft.

Acknowledgment

The author has received much help and encouragement with details of the history of FanWing, and the provision of wind tunnel models for testing, from Mr. Patrick Peebles, the inventor of FanWing.

References

[1] Foshag W.F., Boehler G. D., "Review and Preliminary Evaluation of Lifting Horizontal-Axis Rotating-Wing Systems (HARWAS)", Aerophysics Co., Washington DC, 1969

[2] Forshaw S., "Wind-Tunnel Investigation of FanWing" Final Year Project, M.Eng., Imperial College London, 1999.

[3] Kogler K.U., "FANWING, Experimental Evaluation of a Novel Lift & Propulsion Device" M.Eng. Thesis, Imperial College, London 2002

[4] Kentfield J.A.C., "Aircraft configurations with outboard horizontal stabilizers", Journal of Aircraft October 1991

[5] Kentfield J.A.C., "Drag reduction and improved fuel consumption of aircraft employing outboard horizontal stabilizers", AIAA Paper 2005-0811

[6] Seyfang G.R., "Aerodynamics and applications of the OHS configuration", Royal Aeronautical Society Conference on the Aerodynamics of Novel Configurations, London 2008

[7] Duddempudi D., Yao Y., Edmondson D., Yao J., Curley A., "Computational study of flow over generic fan-wing airfoil", Aircraft Engineering and Aerospace Technology, 2007 Vol. 79, Iss: 3, pp.238 – 244

[8] Askari S., Shojaeefard M.H., "Shape optimization of the airfoil comprising a cross flow fan", Aircraft Engineering and Aerospace Technology, 2009 Vol. 81, Iss 5, pp 407 - 415

[9] Chiang A. L., China N., Jie L., Xu-hui, "Research on the Wing Composition of FanWing Flight", ARIC Aeronautical Science and Technology 2009 (3)

[10] Website www.fanwing.com