FanWing -- Developments and Applications

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

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Abstract

FanWing is an aircraft configuration that uses a simple cross-flow fan mounted in the wing to provide both 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 flown by Patrick Peebles, Fig.1.

Fig 1 Early flight model of FanWing

Early wind tunnel tests, Fig.2 and Fig.3, 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 coefficients of over 10 have been measured on the original FanWing section, and this offers remarkably low take-off speed and true STOL performance.

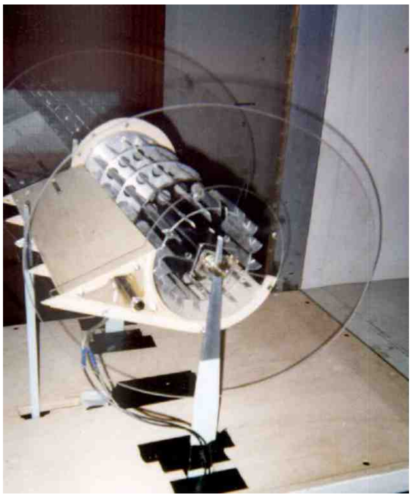

Fig 2 2-D wind tunnel model at ICL

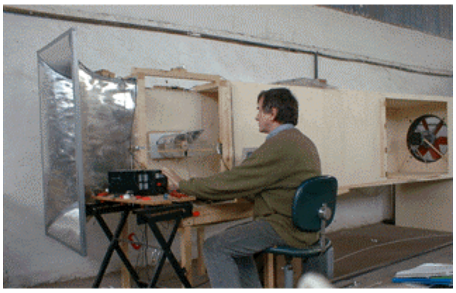

Fig 3 Early wind tunnel tests

Radio-controlled models of increasing size and power efficiency have been flown and most recently there were daily flight demonstrations of a UAV variant of FanWing during the Farnborough Airshow in 2010, Fig.4.

Fig 4 FanWing UAV, Farnborough 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 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.

Fig 5 Tethered VTOL hovering tests

3. Recent Aerodynamic Developments

3.1 Objective -- Higher Cruising Speed

Recent developments of FanWing have centered on further widening the flight envelope, in particular with aerodynamic modifications to allow flight at higher speeds. The combination of ultra-short field performance and moderate cruising speeds may offer an attractive transportation capability leading to greater use of air-cargo. This interest in future air-cargo applications has focused our recent FanWing development activities into three phases reported here.

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 sizing of OHS tails and estimates of the performance advantages of OHS, [6].

Flight testing of FanWing with the OHS twin-tail, Fig.6 and Fig.7, has shown increased flight

stability, increased lift and reduced drag, leading to both lower and higher flight speeds.
In addition, when the elevators of the OHS tails are used differentially, they can provide adequate roll control as well as pitch control. This leaves the wing as a simple lifting surface without ailerons (or flaps).

Fig 6 FanWing model with OHS tails

Fig 7 Twin-tail OHS model 2011

3.3 Wing Section and Tip Design

The wing section of FanWing has recently been modified following a series of 2-D wind tunnel tests of many alternative fan and wing combinations, Fig.8.

Fig 8 2-D wind tunnel tests in 2010 & 2012

Examples are shown in Fig.9 of the wing section with its trailing edge lengthened, with the aim of reducing the section profile drag at lower lift coefficients but retaining high CLmax values.

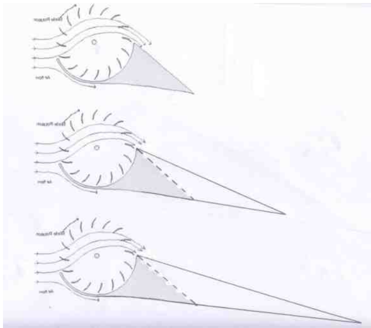

Fig 9 Baseline and high-speed sections

Wind tunnel tests of the 2-D model did indeed show that the CLmax values and the AoA for CLmax were little changed, but the longer section was found to have less drag and a much improved Thrust-Drag margin at cruise, Fig.10.

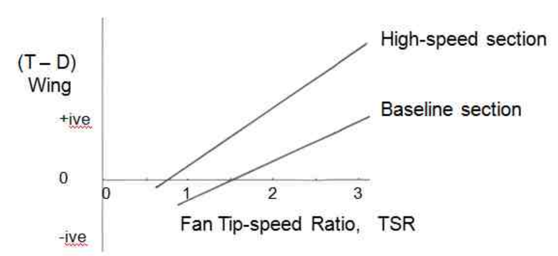

Fig 10 (Thrust – Drag) in Cruise

The opportunity was taken with the 2-D model to measure lift, drag and thrust 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 landing performance calculations, as reported later. An example is shown in Fig.11 of CLmax vs TSR and it is seen that very high values were achieved.

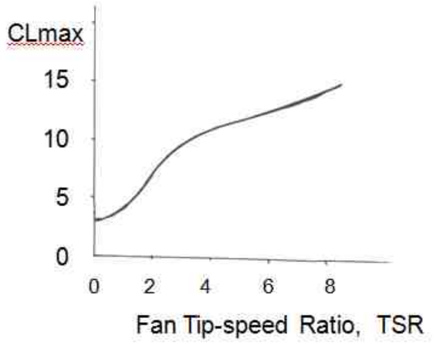

Fig 11 Maximum lift vs fan tip-speed ratio

In addition to improving the cruise drag characteristics, the long chord, ‘high-speed’ section greatly improved the ‘gliding’ performance in the power-off, auto-rotation mode, Fig.12 and Fig.13.

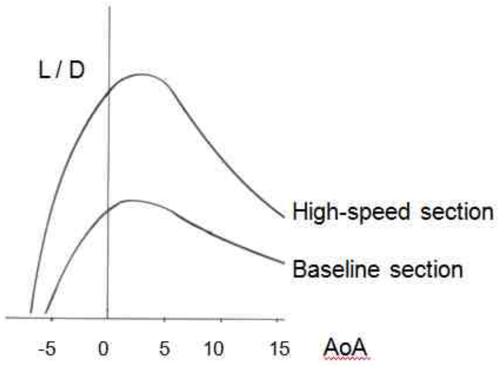

Fig 12 Glide ratio in auto-rotation mode

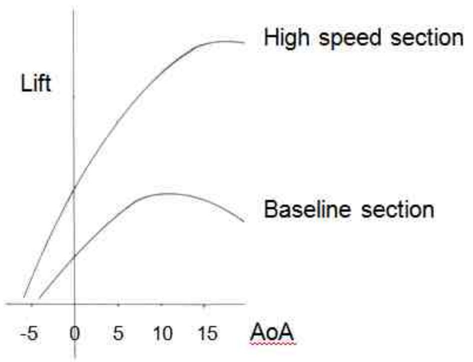

Fig 13 Lift in auto-rotation mode

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

Fig 14 3-D model in wind tunnel 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 were obtained.

Also tested on the 3-D model were variations of the horizontal wing-tip extensions fitted to earlier flight models. These were found to add little benefit and have since been removed and replaced with vertical end-plates, Fig.14.

Flight testing of the new, longer wing section on a large FanWing model, Fig.15 and Fig.16, 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 Flow Visualisation

The fan blade sizes, numbers, cambers and setting angles have been evolved to a satisfactory performance levels in an ad hoc way over several years of FanWing wind tunnel and flight testing. There have also been several, but only partially successful, attempts to model and visualise the complex airflows with CFD. [7], [8], [9]. Recent activities have included testing many fan blade arrangements in a simple water channel at different TSRs in an attempt to visualize the internal flow patterns, Fig.17 and Fig.18.

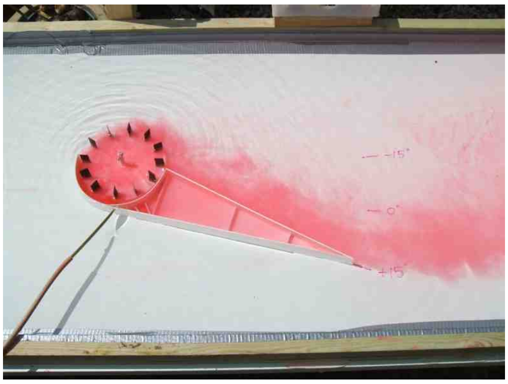

Fig 17 Water channel tests 2011

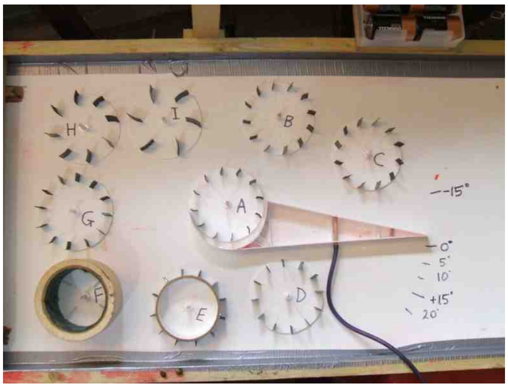

Fig 18 Some of the fan-blades tested

Indications from these qualitative flow-visualisation tests suggest an optimum fan blade arrangement that is not overly-critical.

3.5 Fan Design Optimisation

Following the qualitative flow-visualisation testing, an extensive series of 2-D wind tunnel testing has been carried-out. This has provided further quantitative data on thrust, drag, lift, pitching moment and power requirements for many fan blade geometries and at various key flight conditions. Results from this testing are being used to design the optimum fan configuration for the 2-seat Demonstrator.

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 and the air doesn't 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, 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 as shown in fig. 13 and so provide a safe and controllable glide and flared landing.

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 large 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, it has been noticed that there is an additional noise source on FanWing due to the moving blades passing close to the fixed wing surface. Initial solutions have included a slight skew to the rotor and/or the fixed structure to time-spread the interaction, and minor changes to the separation gap between blade and fixed structure. Further noise reduction is expected from detailed attention to the blade geometry.

5. Proof-of-Concept Demonstrator

To-date all FanWing flights have been made with a series of unmanned radio-controlled models. The next step is to build and fly a much larger, manned, proof-of-concept demonstrator aircraft in 2013.
This will be a 2-seat experimental aircraft aimed at developing and demonstrating the wide speed-range, ultra-short field performance and quiet, safe and efficient flight characteristics of the FanWing. An artist's illustration of the Demonstrator is shown in Fig.19 and its evolutionary position on the route to much larger FanWing aircraft is shown in Fig.20.

Fig.19 Proof-of-Concept Demonstrator

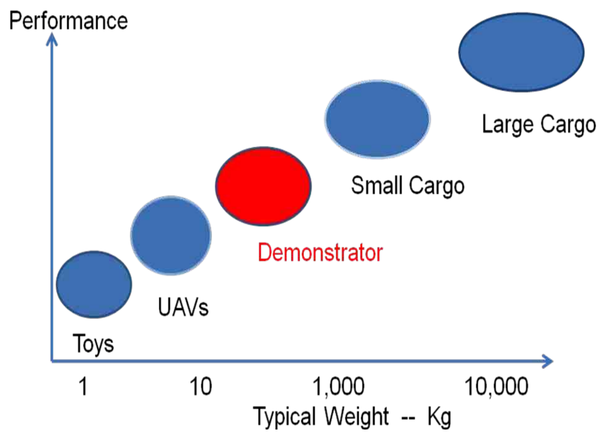

Fig 20 Various sizes of FanWing Aircraft

The 2-seat demonstrator is sized such that an affordable LSA variant might be produced for private sport flying. However it is also of a size that might be useful for other roles such as crop-spraying, where safe flight, versatility and economy of operation are welcome: Fig.21.

Fig.21 Crop-spraying

Another application might be as a UAV engaged on dangerous roles such as detection of buried land-mines using ground-penetrating radars at very low level; Fig.22.

Fig.22 Buried Mine detection

6 A Large STOL Cargo Aircraft

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 good slow flight capability, inherent safety and relatively quiet propulsion of the FanWing rotorcraft would fit well with such operations close to urban areas.

A study has been done to answer the fundamental question 'what is the cost of designing for and achieving short-field performance?' This was achieved by comparing different types of aircraft.

6.1 Types of Aircraft Compared

Conventional STOL, FanWing STOL, Helicopter and Tilt-Rotor each offer different combinations of cruise speed, airfield length and cost. A conceptual comparison study has been made for these aircraft types, all designed and sized to transport a large shipping container over a range of 500km.

The Conventional STOL aircraft data was taken from an unpublished STOL cargo study. Variants with different field lengths were generated by changes of wing loading and power loading and re-sizing through several iterations.

The FanWing Ultra-STOL aircraft was based on the Conventional aircraft, re-computed for the effects of the FanWing propulsion and lift system on cruise and take-off; Fig.23.

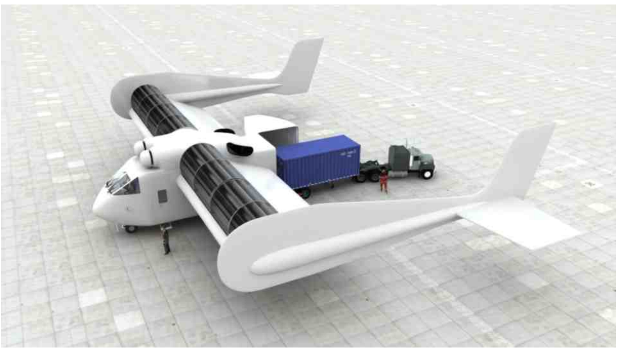

Fig 23 A notional FanWing cargo aircraft

The Helicopter has VTOL capability and was based on open-source data for the Boeing CH-47 Chinook.

The Tilt-Rotor aircraft has VTOL capability plus a high cruise speed and was based on open-source data for the Boeing V-22 Osprey.

Best estimates were made of weights, flight performance and costs for all the 4 variants which were studied in detail; Fig.24.

Fig 24 Cargo configurations studied

In addition to these 4 major types of aircraft compared above, there are several others configurations worthy of study, including hybrid types of airship and rotorcraft shown in Fig.25. These were briefly examined but not pursued in detail due to lack of data.

Fig 25 Other configurations (not studied)

6.2 Comparison of Cargo Aircraft

The two key performance and economic parameters chosen for presentation here are the take-off run and D.O.C., the direct operating cost. Take-off run is the major determinant of where an aircraft can operate and D.O.C. determines the operational economy since it includes flying costs, maintenance costs and capital costs. In turn, these reflect the relevant flight performance features such as fuel consumption, and cruise speed.

The results of the study are shown below in Fig.26, and it is seen that the FanWing offers an interesting niche capability between a conventional STOL aircraft and the two VTOL types which have significantly higher costs.

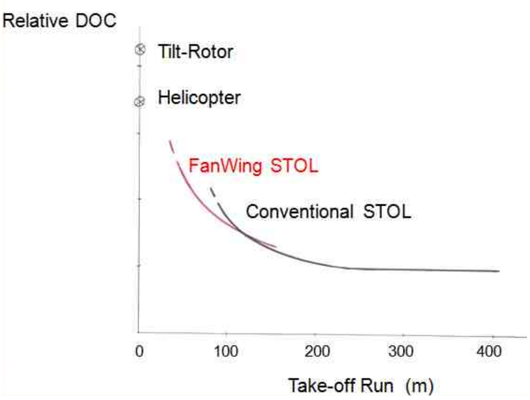

Fig 26 Results of Cargo Study

6.3 Other Applications of large aircraft

The large STOL Cargo aircraft might have several useful applications in addition to providing a unique commercial cargo service. An obvious role would be to deliver large quantities of supplies in disaster situations or military operations where normal airstrips are often unavailable.
Another interesting possibility would be to operate in the naval C.O.D. role and deliver large containers of urgently-needed equipment onto the aircraft carrier deck, beyond the flying range of helicopters; Fig.27.

Fig.27 Carrier-Onboard-Delivery Aircraft

7 Conclusion

Recent aerodynamic developments of the FanWing aircraft configuration have increased the economic cruise speed considerably. A proof-of-concept FanWing Demonstrator is in development and will fly in 2013.
A conceptual and costed comparison of four different aircraft and rotorcraft configurations has shown that, with these developments, the FanWing concept could now offer 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

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