AIAA JOURNAL
Vol. 44, No. 12, December 2006

Aerospace Letters

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Airplane Design Methodology: Setting the Gold Standard

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DOI: 10.2514/1.27756

THE present author is researching and studying the intellectual evolution of the methodology of airplane design in the twentieth century. A common notion is that the intellectual methodology used in aircraft design has evolved over the century, and indeed must still be evolving today what with the stunning new aircraft such as the Boeing "Dreamliner" and the Lockheed-Martin F-35 Lightening II. But my research and study into this basic premise has changed this notion, and my purpose with this letter is to float an entirely different viewpoint on how the intellectual methodology of conceptual airplane design has evolved. The root of this is based on the work of the airplane designer Frank Barnwell (1880–1938).

On 9 September 1916, at Filton flying field, near Bristol, England, the newly designed Bristol F.2A fighter was ready for its first flight. This strut-and-wire biplane, shown in Fig. 1, embodied a design methodology that was anything but conventional. At a time when first flights of new aircraft designs were somewhat problematic and fraught with danger, the F.2A lifted off the ground with no trouble and was soon out of sight. In the first 15 minutes, the airplane climbed easily to 10,000 ft. Indeed, the official trails were so successful that in November 1916 a first order was placed for 50 aircraft, and two squadrons were to be ready for the 1917 spring offensive in France [1]. Ultimately over 5500 Bristol Fighters were produced. They were so valued that the last F.2B was not taken out of Royal Air Force (RAF) service until 1932.

The Bristol Fighter was designed by Bristol's young Chief Designer, Frank Sowter Barnwell (Fig. 2), who was Britain's leading airplane design engineer. Even so, his was not a household name in Britain, and he was virtually unknown in the United States. For the next two decades he proceeded to design almost every new Bristol aircraft. When he was killed in a crash of the new home-built airplane he was flying at Bristol Airport, his obituary in *The Aeroplane* [2] stated, "Frank Barnwell was beyond question one of the best airplane designers in this country or in the World. No other designer has turned out so many first-class aeroplanes which have become historic."

Today's modern methodology for conceptual airplane design is described by Daniel Raymer [3]. As synthesized in [4], this methodology boils down to seven consecutive "intellectual pivot points" for conceptual design: 1) determine the requirements; 2) make a first estimate of the weight (frequently based on previous aircraft); 3) determine the necessary critical performance parameters such as maximum lift coefficient, lift-to-drag ratio, wing loading, and thrust-to-weight ratio; 4) make an initial configuration layout: shape and size of the airplane on a drawing board or a computer screen; 5) obtain a better weight estimate; 6) carry out a performance analysis: Does the design meet or exceed requirements? If not, return to step 3; and 7) at the end of the preceding iterative process, carry out an optimization procedure: is it the best design? Although airplane design today is a massively complex and sophisticated process that differs in detail from one organization to another, buried deep in these processes is an underlying methodology that reflects these seven intellectual pivot points.

The question, then, is how this method evolved and who was involved. The phenomenal technical advancements that drove the development of the airplane from the era of the strut-and-wire biplane, through the era of the mature propeller-driven airplane, and into the era of the jet-propelled airplane are laid out in [5]. It is easy, therefore, to assume that the very basic intellectual methodology for conceptual design also went through similar advancement, evolving as the airplane evolved. The purpose of this letter is, however, to argue that this basic intellectual methodology was set in 1916 by Frank Barnwell, and what we think of as the continued and sometimes spectacular advancements made in airplane design since then have, in reality, been due mainly to the application of new and advanced technology hung on the framework of Barnwell's original design philosophy. Airplane advancements during the twentieth century (streamlining, all-metal construction, the NACA cowl, retractable landing gear, variable-pitch propellers, the jet engine, swept wings, supercritical airfoils, the area rule, etc.) are advancements in technology, and do not reflect any fundamental advancement in the intellectual methodology for conceptual airplane design.

In early 1915, the British journal *The Aeroplane* published a series of articles on airplane design by Frank Barnwell, stemming from his paper read before the Engineering Society of Glasgow University. In 1916 they were republished in book form [6]. In this book, and in his personal papers, memos, reports, and letters now collected in the library of the Royal Aeronautical Society in London, Frank Barnwell laid out a precise intellectual framework for the methodology to use for the conceptual design of an airplane. He started with a need for the precise understanding of the requirements for the new design, commercial, military, or other. In his day these might have been as straightforward as, for example, the design of a two-place machine with stipulated minimum and maximum speeds, rate-of-climb,

Received 13 September 2006; revision received 13 September 2006; accepted for publication 16 September 2006.

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Fig. 1 The Bristol Fighter, designed by Frank Barnwell, reflecting the aeronautical technology of 1916.

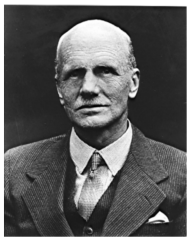

Fig. 2 Frank Sowter Barnwell (1880–1938).

time-to-climb to altitude, range, and payload. Next, and before any other aspects, he estimated the weight of the airplane, primarily based on past experience with earlier but similar airplanes. He then examined the existing technical data for the aerodynamics of wings and bodies (available to him from wind tunnel tests carried out at such places as the National Physical Laboratory), and surveyed the characteristics of existing engines and propellers, all to make some estimates of the critical performance parameters (lift-to-drag ratio, thrust-to weight ratio, etc.) that dictate the basic flight performance of the design. He then drew on paper an initial configuration to examine

Fig. 3 The Lockheed-Martin F-22, carrying the genes of Barnwell's design methodology and reflecting the aeronautical technology of today.

placement of the wings, tail surfaces, engine, fuel tanks, pilot and payload, etc., with particular attention to the estimated locations of the center-of-gravity and center-of-pressure of the machine. Using this layout, he obtained a better weight estimate by examining the weights of all the individual structural components, the choice of engine with related fuel and oil tanks, plumbing, landing gear, etc. He also estimated the longitudinal, lateral, and directional stability of the design, calculating the areas of the horizontal and vertical tails, and the amount of wing dihedral. He carried out a performance analysis to see if the design meets the original specifications. If not, the process was repeated until the design did indeed meet the specifications. In Barnwell's words, "If this be decently over the requirement we can consider the preliminary design as finished" [6].

With the exception of the use of formal optimization procedures, which did not exist in Barnwell's time, the intellectual methodology outlined in his book is essentially the same as the "intellectual pivot points" that underlie modern conceptual design as discussed earlier. In my opinion, Frank Barnwell established the intellectual thought process that underlies the methodology of conceptual airplane design to this day. The only fundamental difference between the airplane designs of Barnwell in 1916 and the modern airplanes of today (Fig. 3) is the airplane technology available at the time. Such airplane technology, as it existed in 1916, is covered in a 72-page book by Barnwell [6] whereas a survey of the airplane technology of today requires more than 700 pages in Raymer's book [3].

In the foreword to Barnwell's book [6], the noted aviation writer and editor of *The Aeroplane*, C,G. Grey, stated in 1916, "It is to be noted that his (Barnwell's) general method of design is approved by other aeroplane designers who have been successful in producing efficient and effective aeroplanes. Consequently the new arrival in the aircraft industry may take it that he is fairly safe in following that method." The wisdom of Grey's comment is still alive and well today.

As a final comment, the history of technology is itself an evolving intellectual pursuit. What was believed yesterday may be completely revised by new scholarship today, which in turn may be upset tomorrow. My belief about the intellectual evolution of the methodology of conceptual airplane design has been completely revised by the thinking that I have shared with you in this letter. But I recognize that it could be upset and changed tomorrow. Indeed, this letter is simply a mechanism to invite such change.

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