**Speech Pre**

**Topic: The Blended Wing Body: A New Conception for the Airplane in the Next Generation**

Good morning, everyone! Today, I would like to

**Materials:**

Most planes look the same: a tube with some wings and a tail. But for nearly a century now, since Vincent Burnelli built the UB-14 in the 1930s, engineers have been plotting the end of traditional aircraft design. Instead of just relying on wings, they thought, why couldn't an aircraft's body—its fuselage—generate enough lift to keep the aircraft aloft?

The idea tantalizes, and recent advances in flight control systems and materials science have pushed this blended wing concept from pipe dream to reality. Elements of the concept can be seen in airplanes like the B-2 Spirit bomber and the Navy's X-47B experimental carrier drone. Yet the enduring triumph of tubular airplanes is on obvious display at every airport and airfield in the world, while the blended wing airplane remains on aviation's periphery.

Boeing's Norm Princen is a believer. He has spent two decades pursuing the blended wing dream and sees concept coming of age for 21st century airplanes. "We get smarter all the time, and so we keep evolving the concept and improving it," he says. "There are still benefits left to find. We've only scratched the surface."

Princen has the enviable position of working within Boeing Research & Technology, the arm of the company tasked with developing aerospace breakthroughs that other units can use to build airplanes. In other words, they toil in labs to make up the real mind-bending stuff. "We are working on technology now so that we are ready for any future application that comes along," he says. "In 10 to 15 years we'll be ready with subsonic blended wing transports."

Today is a big day for the engineer, as Princen reveals new blended wing research that solves a thorny problem for such airplanes: the loss of control they suffer when the cargo door is open during flight. This may seem like a strange problem for civilians, but military cargo aircraft drop combat-ready paratroopers, pallets of GPS-guided humanitarian aid or military vehicles, and the occasional fuel air explosive from their rear doors.

The problem, as you could imagine, is that this plays hell on the aerodynamics of an airplane. The disrupted air from an open door throws off the airplane's balance, which makes for very uncomfortable or even dangerous airdrops. Modern cargo haulers, like the C-17, have distinctly upturned aft sections, an unnatural kink in the airplane's profile that minimizes the impact of the open door. Aircraft also install strakes and other devices that help smooth the airflow and help pilots keep the transport steady. None of this is ideal for the weight and fuel efficiency, though.

Princen wanted to solve this problem as it applies to blended wing airplanes. The video shows a new clamshell design: Two independent doors open, one going up and the other down. "Because the doors are almost symmetrical, it doesn't change the pitch characteristics of the airplane," he says.

通过翼身融合，飞机可以获取更好的气动性能。翼身融合体的优点是结构轻、容积大、阻力小，这些有利于飞机进行超音速飞行。多数第三代超音速战斗机如F-15、F-16、“幻影”2000、米格-29、苏-27等，都采取翼身融合体布局，机翼和机身作为一体来设计制造，有的飞机还把机身边条和机身前体融合在一起。

此外，翼身融合体布局还有利于飞机的隐身性能。采用翼身融合体后，机翼与机身结合后以平滑曲面过渡，消除了二面体反射效应。美国早期的SR-71战略侦察机和B-1B轰炸机以及前苏联的图-160“海盗旗”战略轰炸机，包括美军最先进B-2轰炸机都采用了翼身融合体技术，从而提高了隐身能力。正是由于翼身融合体布局的气动优势，它也将成为新一代作战飞机的首选气动与隐身一体化设计形式之一。

NASA也采用翼身融合技术设计了X-48C，这款飞行器具有较大的内部空间，噪音低，油耗率低，具有非常稳定的低速性能，是未来概念型客机的候选者，更加环保、安静。NASA航空项目主管称在整个飞行包线测试中，X-48C表现出较好的低速性能，翼身融合技术可以满足NASA未来飞机的设计要求。

**11.11 APPLIED AERODYNAMICS: THE BLENDED WING BODY**

This book began with images of six flight vehicles that illustrate six good reasons to learn about aerodynamics. In particular, Figure 1.6 shows an artist’s conception of the blended wing body, a new vehicle concept that promises to create a renaissance in long distance air transport. The aerodynamics of the blended wing body (BWB) is deeply rooted in the aerodynamic fundamentals discussed in this book, and so we take this opportunity to examine some of the applied aerodynamics associated with the BWB.

As background, the BWB was the outgrowth of a challenge issued by Dennis Bushnell to the aircraft industry in 1988. Bushnell, the chief scientist of the NASA Langley Research Center, asked if new, innovative thinking could result in a commercial jet transport that would provide a quantum leap in efficiency and performance in comparison to the standard tube-fuselage, swept wing airplane with jet engines pod-mounted under the wings, such as pioneered by the historic Boeing 707 (Figure 1.2). After 50 years, this configuration remains the same for virtually all transport aircraft, as reinforced by Boeing’s latest design, the 787 Dreamliner shown in Figure 2.2. Responding to this challenge, a small group of aerodynamicists at McDonnell Douglas led by Dr. Robert Liebeck conceived the blended wing body, one version of which is shown in Figure 11.24.

When McDonnell Douglas was absorbed by Boeing, Liebeck continued his work on the BWB funded by NASA. Figure 11.24 shows a conﬁguration obtained from a baseline study of the BWB carried out by Boeing circa 2002. Now a Boeing senior technical fellow, Liebeck continues to spearhead the BWB concept at Boeing.

The aerodynamics of the blended wing body is a graphic illustration of the application of many of the fundamentals highlighted in this book. For this reason, the blended wing body is chosen for attention in this applied aerodynamics section. We will see that the BWB is an advanced futuristic ﬂight vehicle applying the very fundamental aerodynamics that is the subject of this book, underscoring the fact that such fundamentals are timeless.

To begin with, examining Figure 11.24 shows that the BWB is clearly a ﬂying wing merged with a center body that is also an airfoil shape with a bullet nose. By replacing the conventional tube fuselage with a center body that itself is an efﬁcient lifting surface, the spanwise lift distribution from one wing tip to the other is closer to the ideal elliptical distribution. Our study of the aerodynamics of ﬁnite wings in Chapter 5 underscored that an elliptical lift distribution yields the minimum induced drag. The BWB is designed to preserve such an elliptical lift distribution, as illustrated in Figure 11.25. Here we see the BWB lift distribution along with plots of the spanwise airfoil lift coefﬁcient cl and the airfoil thickness-to-chord ratio t/c. There is a direct connection between the variations of cl and t/c. The center body must be large enough and thick enough to accommodate the passenger and cargo load, which drives the increase of both the airfoil chord length and t/c for the center body section. In order to preserve the elliptical lift distribution over the center body, the airfoil section of the center body is different from that used for the outer wing panels. It is chosen to have a lower lift coefﬁcient to counterbalance the larger chord length and thus preserve the smooth spanwise elliptical lift distribution. (Recall that the lift distribution is the variation of the lift force per unit span, and this lift force is proportional to both the local value of cl and the chord length.)

The BWB is a high-speed subsonic airplane intended to ﬂy at the lower end of the transonic ﬂight regime. Hence, major efforts are made to obtain as high a drag-divergence Mach number as possible. Toward that end, the BWB incorporates two design features, both of which deal with aerodynamic fundamentals discussed in this chapter.

1. **Supercritical airfoils.** The function of a supercritical airfoil is discussed in Section 11.9. The outer portions of the BWB wing incorporate a modern supercritical airfoil section with aft camber, similar to that shown in Figure 11.19c. The center body proﬁle is also an airfoil section. In the ﬁrst generation of the BWB development, the airfoil shape chosen was a Liebeck LW102A airfoil (Ref. 93) point designed for *cl* = 0.25 at a Mach number of 0.7. A side view of the resulting center body proﬁle is shown in Figure 11.26a. The new-generation BWB uses an advanced customized transonic airfoil design for the center body proﬁle. Taking into account the constraints in cross-sectional area required to effectively hold passengers, baggage, and cargo, the new transonic airfoil design dealt with a careful three-dimensional contouring of the center body smoothly blending into the outer wing panels. The resulting center body proﬁle is shown in Figure 11.26b, giving a cleaner, more streamlined appearance than the original proﬁle in Figure 11.26a, and providing a higher critical Mach number. Indeed, the new centerbody proﬁle in Figure 11.2b increased the BWB lift-to-drag ratio by 4 percent.
2. Area rule. The notion of the area rule is discussed in Section 11.8. The blended wing body, with its smooth contours and smoothly varying cross section, is almost naturally area-ruled. Figure 11.27 compares the cross-sectional area distributions as a function of longitudinal coordinate for the BWB (solid curve) and a conventional subsonic transport, the MD-11 (dashed curve). Clearly, the BWB area distribution is much smoother than that of the MD-11, thus exhibiting good area-rule qualities. Liebeck (Ref. 94) states that for the BWB “there appears to be no explicit boundary for increasing the cruise Mach number beyond 0.88.” Indeed, a set of blended wing bodies have been designed for Mach numbers of 0.85, 0.9., 0.93, and 0.95.

The role of computational ﬂuid dynamics (CFD) in the calculation of tran-sonic inviscid ﬂows is discussed in Section 11.10. This discussion is extended in Chapter 20 to CFD solutions for viscous ﬂows via numerical solutions of the Navier-Stokes equations. Computational ﬂuid dynamics is an essential tool in modern aircraft design, and this is particularly important for the blended wing body as discussed by Roman et al. (Ref. 95) and Liebeck (Ref. 96). For exam-ple, Figure 11.28 shows the static pressure contours over the top surface of the BWB obtained with a Navier-Stokes CFD solution. Shock waves are indicated by regions where the pressure contours cluster together. These results show that the typical transonic shock wave, which is well deﬁned on the outboard wing, becomes smeared into a weaker compression wave on the center body. The CFD solutions showed that the ﬂow pattern on the center body was relatively insensitive to the angle of attack. Also, the results indicated the initiation of ﬂow separation in the kink region between the outboard wing and the center body. More CFD results are compared in Figure 11.29 with experimental data obtained on a blended wing body model tested in the National Transonic Facility (NFT) at the NASA Langley Research Laboratory at almost full-scale Reynolds number. Figure 11.29a gives the variation of drag coefﬁcient CD with lift coefﬁcient CL (a portion of the drag polar). Figure 11.29b is a plot of CL versus angle of attack, and Figure 11.29c gives lift coefﬁcient versus moment coefﬁcient. Even though, for proprietary reasons, numbers are not given on the axes of these graphs, the most important conclusion from these comparisons is that CFD results for the BWB agree within 1% with experimental data. In the words of Robert Liebeck (Reference 96), “The remarkable agreement indicated that CFD could be reliably utilized for the aerodynamic design and analysis.”

In summary, we offer this applied aerodynamics section as a clear example of how the understanding of the fundamental aerodynamics presented in this book is so essential to the design of the ﬂight vehicles of the future. For more information on the blended wing body, see References 93–96.