Retirement: Something I seem to have not considered, but it appears sensible now. That said, some history, starting with my finishing a BS in aeronautical engineering at the University of Illinois in 1961. Prof. Allen Ormsbee suggested that I start graduate school in the fall and he would arrange a summer internship at the Douglas Aircraft Company in Santa Monica. So, a kid who had never been west of the Mississippi headed for California in his Austin Healey 3000 with the top down. Wow, a pad on the beach in Santa Monica, parties every weekend, and working on the effect of density gradients on the star tracker of the Skybolt missile. At the end of the summer, Douglas suggested a leave of absence, and this process continued through my finishing a PhD in 1968.

Prof. Ormsbee was a competitive sailplane pilot, and he suggested a thesis on airfoil design. At the time, the cold war was indeed hot, and President Kennedy challenged us to get to the moon. I had been working in the Missile & Space Systems Division of Douglas on these problems, and subsonic airfoil design was not included. Prof. Ormsbee drove me from Santa Monica to Long Beach in the summer of 1965 to meet with A.M.O. Smith and his legendary Aerodynamics Research Group. Also, during the summer of 1965, Boeing had offered a grant for "Doctoral Dissertations in Aeronautics", and I flew north to present my thesis topic to Ted Nark, Paul Ruppert and Bernie Gratzer. This resulted in a $2500 award from Boeing. The summers of 1966 & 1967 were spent in AMO's group, and they were indeed special. Regular consultants included several icons of aeronautics from Caltech: Hans Liepmann, Anatol Roshko, Madge Klein, Brad Sturtevant, Ernie Sechler, and Peter Lissaman. By the summer of 1967, I had amassed a set of equations for the design and analysis of airfoils, but what specifically should I design? AMO said "Why don't you see how much lift you can get from an airfoil? Bingo – an objective function! Within three months I had a thesis; "Optimization of Airfoils for Maximum Lift". Fast forward to 1992. The late R.T. Jones of NASA Ames called and offered congratulations for my election to the National Academy of Engineering. He went on to say that my PhD thesis by itself was the basis for my election.

Recently, my wife Cindy and I created the Allen I. Ormsbee Professorship in Aeronautics at the University of Illinois. It was payback time. The two recipients are Prof. Phillip Ansell and Prof. Jason Merritt. They are working on a very unique design of a safe and practical vertical takeoff and landing electric airplane. Substantial support has also come from Virgil Bourgon, a fellow Douglas engineer in the '60's who departed after Apollo to do remarkably well in commercial real estate. Virgil remains an engineer at heart, so we are back together. Phil's theoretical aero background and Jason's 10 years at Gulfstream as a lead designer of the G550 & G650 are making it happen.

March 1968, back at what was then called McDonnell Douglas (the company has now changed names twice, so far). Full time, having never interviewed for the job. Began developing the high lift airfoil stuff, and a colleague in the Aero Research group, Malcolm James, was developing an exact inverse airfoil design code. (I had been using a second-order linear inverse airfoil theory in my thesis to demonstrate that the high lift airfoil designs were feasible.) The combination of my airfoil velocity distributions and Malc's design code yielded an exact family of airfoils with unique performance. This airfoil technology (particularly the capability at low

Reynolds numbers) was recognized by the government agencies doing high altitude long endurance reconnaissance airplanes. This yielded several years of sole-source support. Example results include the Boeing Condor and the Boeing Dark Star airfoils (while I was at MD) and the NASA Helios solar-powered airplane that almost reached 100,000 feet. Several remain classified. Other airfoil design successes include that for Henry Haigh's Ratsrepus champion aerobatic airplane, and the keel for America[3], winner of America's Cup in 1991.

During this period, the addition of wings to race cars was embryonic, and I was contacted by Dan Gurney's All American Racers Company. Aviation Week had published an article on the successful wind tunnel test of two of my high lift airfoil designs. Thus, I became involved with race car wing design. Two early successes were the wings on the car that Bobby Unser won the 1975 Indianapolis 500, and that A. J. Foyt won the 1977 Indianapolis 500. However, some of the aerodynamic design credit goes directly to Dan Gurney. A few years earlier, Dan had been driving a new Ferrari coupe for Le Mans and found it to be unstable at higher speeds. He added a small vertical plate at the back that both stabilized the car and added downforce to enhance speed in the corners. Dan thought this might help race car wings, and he added a very small vertical flap (one percent chord). Birth of the Gurney Flap! During practice at Indianapolis, addition of the flap appeared to both increase downforce and reduce drag. Back at Douglas I tested an airfoil in the Long Beach low speed wind tunnel and confirmed this behavior. In turn, I published a paper on my airfoil work and included the Gurney Flap results. It remains one of my most referenced papers. A high-speed version of the Gurney Flap, called a trailing edge wedge, was incorporated on the MD-11 wing. Dan invited me to drive the Indy-winning 1975 Eagle at the Ontario racetrack where they were filming a Budweiser commercial. Coming out of turn 2, I spun and hit the wall, removing the right rear wheel and destroying my wing. Dan said I had to get back on the horse that threw me, and two weeks later, in a repaired race car, I accomplished some successful laps.

As it turned out, my credibility in the race car industry was not primarily based on being an aeronautical engineer – I rode motorcycles. Thus, I was soon riding in the desert almost every Sunday. The challenge was that most of my new riding buddies were either retired or active pro racers. Even at play, they were fiercely competitive. During this time, Douglas was attempting to win the KC-10 contract, and I met our lead marketeer Col. Russ Schleeh (ret). Russ had been Gen Curtis LeMay's lead B-17 pilot in WW2, and after the war he became a test pilot. He was the last pilot to fly the Northrop YB-49, and his advice was valuable on the development of the BWB. Russ also drove unlimited hydroplanes (Shanty) at the Seattle Sea Fair, with one of three results; the boat broke, he crashed, or he won. Back to the KC-10. By then, some of Russ' direct reports were now generals. And, I had access to the Indianapolis Gasoline Alley. Wright Patterson was next door.

Dan, Russ, plus an Indianapolis driver from Seattle, Jerry Grant, and I went on to ride motorcycles in the mountains and desert together for 35 years. They taught me that "second pace is first loser", and such. My close friends, and all are gone now. On reflection, motorcycles and racing have had a fundamental effect on my career as an engineer. Winning is the only thing, and the race is on Sunday. Several years ago, Dan's wife Evi invited me to a special dinner at their house. Phil Hill (first American Formula 1 champion), Carroll Shelby (Ford v Ferrari), and Bernard Cahier (Europe Editor for Road & Track) and their wives were there. The Gurney's have a lampshade in their living room signed by several of fame in racing. Dan said "Bob, you are a racer, please sign".

In the fall of 1988, Dennis Bushnell, Chief Scientist at NASA Langley (he still is), announced a conference to address the question: "Is there a renaissance for the long-haul transport?". Or, why do all subsonic transports look like DC-8's and B707's? A brief preliminary design study was conducted at Douglas, and Jerry Callaghan (then director of aerodynamics at Douglas) and I presented a conceptual subsonic transport design that resembled a B-2 at the conference in April 1989. NASA liked it, and we received a $89K contract in 1990 to compare what is now called the Blended Wing Body (BWB) with the conventional tube and wing subsonic transport. Mark Page, Blaine Rawdon and I went to work on this. The basic BWB, as we know it today, evolved in this initial study – thanks to Mark and Blaine. A $93K contract followed and shortly afterward a $350K contract. We were in business! How did this happen? Mark is an exceptional aeronautical engineer and an artist, and Blaine is a basic physics guy and an architect. I was the cheer leader.

The BWB evolved rapidly with significant support from NASA. Then in, December 1996, we became Boeing. Several advised me that BWB would shortly be history. However, Boeing Commercial gave us a thorough audience, and began supplementing our NASA funding. Development of the BWB at Long Beach progressed rapidly, and by circa 2000 we had demonstrated the remarkable and unique capability of this subsonic transport configuration. Features include:

1. The capability to size a single basic design from 200 to 500 passengers where the "stretch" is accomplished laterally by simply adding centerbody bays. Thus, the wingspan and area naturally increase with payload, while the outer wings and cockpit remain constant. In addition, since a BWB is simply a big wing with no wing/fuselage/empennage intersections, the part count is on the order of 60% of a conventional tube & wing configuration.
2. As a military tanker/transport the BWB offers an increase in fuel off-load versus radius due to its available fuel volume and efficiency, plus the option for two refueling booms due to the stiffness of the centerbody.
3. The BWB is naturally area-ruled, and thus it can be designed for a cruise Mach number in excess of 0.90 if desired, with no basic change in the geometry.
4. A BWB offers an airport noise reduction in excess of 50db below Stage IV. This enables 24/7 operation at many airports. The engines are above the centerbody which blocks forward-radiated fan noise, and the exhaust is not reflected by the lower surface of the wing.
5. Several rigorous comparisons have been conducted between a BWB and tube and wing configuration for various subsonic transport design missions. In all cases, the BWB has shown a fuel-burn reduction of between 15 and 20 percent.

6. For the past 30 years, the substantial funding by NASA of the BWB has been driven by the fact that it is the only subsonic transport configuration that provides significant reductions in both noise and fuel-burn. And, looking a bit further into the future, the BWB may be the only subsonic configuration that offers the internal volume for LH2 and the opportunity for a zero-emission airplane.

More about the BWB. A conventional tube and wing subsonic transport can be regarded as a linear design. The wing is independent from the fuselage, the engines are isolated via pylons to provide ideal inlet and exhaust flow, and the empennage is simply sized by stability and control requirements. In contrast, a BWB is a highly non-linear configuration. The wing is also the fuselage, it is tailless, and engine integration is a challenge. Touch it in one place, and it may be fundamentally affected in other places you have not thought of. Early in its development, two primary challenges were identified: 1. Creation of a tailless airplane with flight mechanics as robust as a conventional tube and wing airplane. 2. Design of a lightweight flat-sided pressure vessel structure for the centerbody. In turn, with substantial NASA support and encouragement, we successfully resolved these challenges.

1. Norman Princen was the architect/chief engineer of the BWB X-48B/C Subscale Flight Demonstrator Program. Michael Kisska managed the flight test operations at NASA Armstrong. Two 8 percent scale BWB X-48 airplanes were fabricated by Cranfield Aerospace in the UK. The X-48B completed 92 flights and the X-48C competed and additional 30 flights for a total of 122. Robust flight mechanics of the BWB were verified for the challenging low speed flight regime.
2. Alexander Velicki and Patrick Thrash created the PRESEUS (Pultruded Rod Stitched Efficient Unitized Structure) concept for the composite design and tooling of a composite skin/frame/stringer aircraft structure. An 80 percent full-scale centerbody structure was fabricated and tested in the NASA COLTS (combined loading test system) at Langley. Both flight mechanical loads and internal pressure loads were applied. The PRESEUS stitched resin infusion structure behaved like a fail-safe (2-bay arrested crack) aluminum structure, and a minimum-gage skin thickness of 0.052 in was confirmed.

Back to 1961 and graduate school at Illinois. Financial support initially came via a teaching assistantship (TA) that soon evolved into my becoming an instructor, the beginning rank of regular faculty. I found this rewarding and it also enabled a more thorough understanding of the principles of engineering. I was teaching aerodynamics and space vehicle design, the latter based on my summer intern experience at Douglas. Upon finishing the PhD in 1968, I considered seeking an academic job, however, I had the full-time job A.M.O. Smith's Aerodynamics Research Group awaiting me at the airplane factory. So, I went about designing and wind tunnel testing airfoils for high altitude airplanes for the next few years. AMO was strong on publishing, and I was giving an airfoil design paper in San Diego circa 1975 when the late USC Prof. H.K Cheng approached me about teaching airplane design. Things were currently tough at Douglas, and my initial response was that I was too busy. HK prevailed, and I asked, "If things go bad at Douglas, can I come to USC full-time?" His response "Why don't you simply join us now?" I became an adjunct professor at USC from 1976 to 2000, teaching aerodynamics, flight mechanics, and airplane design. At the Aerospace Engineering Department Christmas party in 1981, the late Prof. Dick Edwards said to me "Bob, you are going to have a striking young woman in your airplane design class in January, and she is also very bright." On the first day of class, I noticed several attractive women amongst the 80 students and wondered which Dick was referring to. Then, ten minutes late, the person arrived. Cindy and I celebrated our 36th anniversary this past July.

Universities offer three professional degrees: law, medicine and engineering. Law professors practice law, med professors practice medicine, few engineering professors have practiced engineering. Circa 1995, MIT elected to create an engineering faculty position titled Professor of the Practice of Aeronautics. The template included having managed an airplane program, an earned PhD, published, and member of the National Academy of Engineering. An atypical combination that I happened to meet. However, BWB was at a dynamic stage, and several urged me to remain. MIT responded with the part-time position I hold today.

In 1999, the UCI Dean of Engineering and three professors invited me to breakfast at a restaurant here in Irvine where we live. The proposition was simple; teach at UCI where I can see the campus from our house. Have just completed 20 years as an adjunct professor. A recent success story is Jacqueline Thomas. Jacquie did her undergraduate degree in aerospace engineering at UCI including the three courses I teach – no grades of B. I exported her to MIT for graduate school, again no B's. We had her as an intern in BR&T for four summers where her work in acoustics became important for her thesis. Jacquie successfully defended on April 3 – virtually. Her dream job was to be a professor at UCI. On July 1, she became a colleague.

Now some thoughts on the creation of an airplane design. Computational fluid dynamics (CFD) and Multidisciplinary Airplane Optimization (MDAO) are valuable tools for confirming and refining an airplane design. However, these tools contribute little to the creation. Creation must come from first principles and the laws of physics. The two contributions that I claim some credit for, high-lift airfoils and the BWB, were spawned in this fashion, however, I was not conscious of this at the time.

1. The Kutta-Joukowski theorem states that lift is directly proportional to the circulation (integral of the velocity distribution) around an airfoil. Next, define the various physical limits for a velocity distribution about the airfoil. However, while every airfoil has a corresponding velocity distribution, the inverse, an arbitrarily prescribed velocity distribution does not necessarily define a physically possible airfoil. The high-lift airfoil design problem was then reduced to creating an airfoil shape that achieved, as close as possible, the idealized velocity distribution. This was in 1968. In 2010, I was awarded the Daniel Guggenheim Medal, and a member of the Guggenheim Board of Award told me that I had created the equivalent of the Carnot Cycle for high lift. Until then, I had not thought of it that way.
2. A subsonic transport has three sources of drag: skin friction (directly proportional to aerodynamic wetted area), drag due to lift (proportional to 1/wingspan^2), and drag due to compressibility (sets wing sweep). For a given volume (say payload and equipment),

> a sphere has the minimum wetted area. Define a wing using Prandtl's lifting line theory, sweep the lifting line for the cruise Mach number, place the sphere at the 25% mean aerodynamic, flatten the sphere appropriately, and you have a BWB. Conception of the BWB was also cited as the basis for the Guggenheim.

A recent very significant development. For perspective, I was adopted by George and Laurette Liebeck twelve days after my birth on February 1, 1938. Dad was an electrical engineer for AT&T and Mom was an economics graduate. They enabled me to become whatever I am. Both passed away shortly after I finished school, and I sincerely regret not having the opportunity to show them I could be a successful engineer. Circa one year ago, I learned via the efforts of wife Cindy and 23 & Me, I have a sister (a psychologist) and three brothers (all MD's). Also, one year ago (November 22), I was to be inducted into the San Diego Air and Space Museum Hall of Fame. I invited my new siblings to the event, and we met one another, for the first time, the day before. The existence of my new family dwarfed the honor of the induction. COVID has precluded our visiting since, as they live in Portland Oregon, Cambridge Maryland, and Boston Massachusetts. However, we have regular Zoom meetings which are special. Looking forward to a COVID vaccine so I can return to MIT and visit my new sister Jill in Boston. As an aside, my career goal was to become an MD. However, hot rods and girls detracted from my academic performance in high school, and 8 years of college appeared infinite. Math was easy, so I decided to take engineering – and wound up taking 8 years! My siblings are now evidence I could have become a real doctor.

Back to 1981. Dick Edwards was correct, Cindy is bright. Upon graduation she joined Hughes Aircraft in Newport Beach, but as a newly minted aerospace engineer, she went to the dark side: design of gate arrays, AKA electrical engineering. The chip industry (my words) is dynamic, and within a few years, she rose to become a director of ASIC chip design for Phillips. In turn, she successfully migrated to several start-ups, doing financially better than her former professor. About six years ago, she de-facto retired, although she threatens to return to the fray. Hiking the John Muir Trail for the past 5 years, and successfully showing bulldogs has become a focus.

More on the subject of family, two sons, Kevin (an attorney) and Tod (a software developer doing Toyota's infotainment systems) plus two grandchildren, Jack (junior in HS) and Kaylee (freshman in HS). Kevin and Tod are my invaluable consultants on many things. Jack is interested in everything, while Kaylee is focused on becoming a heart surgeon. She has identified the University of Illinois for pre-med, and Stanford for med school (a significant contrast with her grandfather's career planning).

In summary, I have been indeed fortunate to have the opportunity to be an engineer at the best aerospace company in the world, and to teach at three of the best universities in the world. Regarding accomplishments, I would list the airfoil work and the BWB, however, these are topped by the 100+ students (BS to PhD) I have had each year since 1976. Two awards stand out: the Daniel Guggenheim Medal, and my signature on the Gurney's lampshade. Acquired a 2020 Corvette in July, Dan would have enjoyed a test drive.

This note may be long, however, for me it is preferable to a retirement event. Looking forward to just being a professor, but Naveed mentioned that he may drag me back into the airplane factory as a consultant. Yes, I will sincerely miss the regular contact with all at Boeing.

Bob Liebeck
November 18, 2020