



begins with Conceptual Design where the designers look at a wide range of aircraft configuration concepts, perform trade studies of both the design and, with significant customer input, select a well-balanced set of requirements. 8.3 illustrates two common problems with "real" wings. This is one of the most important lessons that a student of aircraft design must absorb. I.. Furthermore, our derivation of Eq. (17.24) implicitly assumed that CDo and] (do not vary as velocity changes when we solve for V in Eq. (17.25), which we also know to be only a rough approximation. (14.21) and (14.22) using the centroids and areas of the simple shapes. This is not to say that "outsiders" have no role to play or have no chance to get funding for a design project. To determine the effect of building the aircraft out of composite materials, the designer must adjust the empty-weight equation. 8.3. 21 7 218 A i rc raft Desi g n : A C o n c e pt u a l A p p r o a c h Another approach, commonly used on large airliners, is to "pull" the wing root isobars forward by using a strange airfoil shape at the root that is specially designed to have its pressure peak very near its nose. It is nose. as defined in Eq. (12.3), L qSCr qSCD (12.1) (12.2) 1 q -2 pV2 (12.3) = D = where = By definition, the lift force is perpendicular to the flight direction. 1 2.6 1.0 1.5. Mach n u m be r 2.0 2.5 3.0 Lift-curve slope vs Mach number. Even homebuilders can now obtain an airfoil design computer program and use it to create optimal airfoils just for their design. C = W1 /time thrust = Cpower Y'/V - P = Cbhp 550VY'/ {fps} --- (3. Furthermore, separate pieces of titanium are diffusion-bonded at the same time, forming a joint that is indistinguishable from the original metal. The digital product definition also improves prototype fabrication and aircraft production. The initial sizing provides the specific data needed to develop an initial design layout (Fig. CAD tools used during conceptual design. One of the main causes of drag-producing pressure forces is viscous This was the source of considerable confusion during the early aration. Another broad source of design requirements can be considered legalis tic, namely, the civilian or military design project at a major aero space company. Tl,..c,(fb-U S.L.l_80(){) s.1...Lgoao .o // O 'l!i/11/ .%/,60 .D'f/. In some cases, a quicker method can be employed to determine the forces in selected struts without having to solve the whole truss as in the method of joints. The drag polar is simply a plot of the coefficient of lift vs the coefficient of drag. MfDI Fighter/Attack Weights (British Units, Results in Pounds) = Wwing 0. In one CAD program the hydraulic system designer can simply indicate, in three dimensions, the desired path of a hydraulic line, and the system will create the tubing at the proper diameter, construct bends with diameters that can be fabricated without cracking, and include the proper fittings, couplings, and brackets all automatically. 3 Typica l Jet SFCs: l /hr { mg/Ns} Pure turbojet Low-bypass turbofan High-bypass turbofan Specific Fuel Consumption, c Cruise Loiter 0.376 q0. Most tita nium alloys must be formed at temperatures over 1000°F { 538°C} and at very high forming stresses. An upsweep of about 25 deg can be tolerated for a rear-loading transport aircraft provided that the fuselage lower corners are fairly sharp. Propeller engine SFC is normally given as Cbhp ' the pounds of fuel per hour to produce one horsepower at the propeller shaft (or one brake horse power: bhp = 550 ft-lb/s). Takeoff-Weight Buildup Design takeoff gross weight is the total weight of the aircraft a s i t begins the mission for which it was designed. u_, s o T o 0 ->p eJ.>) 9-. 544 454 227 91 1 200 1 000 500 200 0.1 2 Wmissile 250 550 1 90 113 250 86 60 32 11 27 15 5 1 -2 each 0.5 - 1 4-6 each 40 1.11 NJa ; 0.31 NJa ; 0.30 NJa ; 0.002 0.008 0.003 0.06 Wdg Wdg Wdg Wdg Wdg Wdg 2-3 18 0.5 NJa ; 0. Aircraft aren't cars, and wings aren't fenders, but still the presence of detail design and production personnel from the earliest stages of design can only be beneficial. The most modern form of airfoil design actually analyzes the entire air craft using computational fluid dynamics (CFD). In a sense, you "design" the requirements as you are designing the aircraft. A poorly designed fuselage can have excessive flow separation, unnecessary interference drag, a bad transo nic drag rise, and high supersonic wave drag. For a given volume, wetted area is minimized with a low fineness ratio. Other cross-sectional properties such as the product of inertia and the principal axes will not be used in this overview of structures. Also, the p values in Table 14.6 can be used to approximate I for the given shapes. This book was written primarily to provide the basic tools and concepts required to produce good designs that will survive detailed analysis with Design: Creating minimal changes. The method usually begins at a free joint with an applied external load, in this case at the engine load. Transference of the design data to computer-aided manufacturing (CAM) becomes almost trivially easy, and the resulting parts fit together perfectly. CD The greater the lift. 38 2.7 1 .35 2 . When the aerodynamics department tells you to set an airfoil at, say, two degrees incidence, you must always ask "with respect to what reference axis?" The front of the airfoil is defined by a leading-edge radius, tangent to the upper and lower surfaces. 'I I tan ALE 6 II v-r-... I !:> v I T. 013Nen0 .795 T0 . The reference wing is partly ficitious. This usually resulted in superior producibility but often at some expense in size but will have to grow as the design is matured. In the ASW design exam ple, the required range of 1 500 n miles (each way) is probably less than the customer would really like. 290 no . At the upper and lower surfaces, this shear force is zero. #JfJ Supersonic Lift-Curve Slope For a wing in purely supersonic flow, the lift-curve slope is ideally defined by Eq. (12. 14), repeated next as Eq. (14.29)]. 2 Lno. The geometry for flight mechanics is shown in Fig. 1 4.38 Shear Typica l aircraft spar in bending and shear. 1 2.3 A i rfo i l Airflow separation . 14.28). l5l Care must be taken that an IPT doesn't substitute for, or tie the hands of an experienced aircraft designer doing the layout portions of the conceptual design process. Every single one of those parts has to be designed with its own drawing or CAD file, as does its relationship to the parts it attaches to. The ones most relevant to aircraft design are summar ized in the Appendices. 498 (Ls /Ld) - 0.373 De x Nen Wei g hts (15.8) (15.9) - where for Kd and this ratio. A column can usually be considered in block compression if the slenderness ratio is less than about 12. Figure 14.38 shows a typical aircraft wing spar consisting of thick "spar caps, so the caps absorb virtually all of the bending force (stress times area). It starts with requirements, but they evolve as you learn more. mfl Conceptual Sketches Figure 3.9 shows four conceptual approaches considered by the designer in response to these mission requirements. Not all airplanes are designed for military or commercial utility. 1500 Weight budget. CHAPTER 14 Structu res and Load s A column with an open or highly irregular cross section might fail at a l ower lo ad due to cross-sectional twisting or deformation. During configur ation layout, the designer must consider their impact in a qualitative sense and try to "do the right thing." 213 214 A i r c raft Design : A C o n c e pt u a l A p p r o a c h Aerodynamic Considerations Aerodynamic analysis will be discussed in Chapter 12 where various estimation methods and "rule-of-thumb" approxi mations for initial estimation of design parameters. MIL-F-87858 addresses flying qualities of piloted air planes. 65 > < - . 1 . 33) A flat sheet or panel under compression fails by buckling in a manner sim ilar to a column. This downwash momentum in the air adds up to and equals the lift on the wing. 10) P Table 3.3 provides typical SFC values for jet engines, while Table 3.4 provides typical Cbhp values for propeller engines. Lissa m a n 7 769 c c ==--===- Ga (W)- 1 ::... 0 (1 + Vp / Vi)N? 'Tl 🗞 c (/) -< CJ> If a line of holes fo rms a natural "zipper" at an angle off the perpendicular, the part might fail there if the cross-sectional area along the zipper line is less than the smallest perpendicular cross section. We know how far it goes. Several mathematical solutions to this problem have been found for simple bodies-of-revolution, with the Sears - Haack body (Fig. aiaafoundation.org. The wing aspect ratio of the complete reference planform. I n the ideal truss, the struts are weightless and connected by frictionless pins. In this chapter a conceptual sketch was made, but no guidance was provided as to how to make the sketch or why different features may be good or bad. The simplest level just adopts past history. Note that for a propeller aircraft, the thrust and the SFC are a function of the flight velocity. The empty weight includes the structure, engines, landing gear, fixed equipment, avionics, and anything else not considered a part of crew, payload, or fuel. 209 210 A i rc raft Des i g n : A C o n ceptu a l A p p roach , - \ Fig. 207 208 Aircraft D e s i g n : A Con ceptu a l Approach computer. the geometric There is more to design than just the actual description of a thing to layout. Note the locations indicated for the landing-gear stowage, crew station, and fuel tanks. CE NTCll!. The best of our candidates, sized to its minimum weight to perform the required mission, yields the right answer-we presume. 12.6). Sometimes a design will begin as an innovative idea rather than as a response to a given requirement. This implies that the lightest longeron structure occurs when the upper and lower longerons are as far apart vertically as possible. Figure
4. and again, and maybe again! CHAPT E R 1 Fig. Furthermore, the perform ance capabilities of the design are calculated and compared to the requirements just mentioned. (\§' IfIII Sustained Turn Rate CHAPTER 1 7 Performance and F l i g ht Mec h a n ics In a sustained turn, the aircraft is not permitted to slow down or lose alti tu de during the turn. For an aircraft where the internal components can be rearranged and the cross-section diameter can be reduced as The greatest needed, the optimum fineness ratio for subsonic air compliment a craft is somewhere between 6 and 8. All of the forces are shown as radiating outward from the joints so that a positive force is a tension and a negative force is a compression. While the delta design has a total wetted area of just over two times the wing area, the conventional design has a wetted area of over six times the wing area. Following chapters address these issues and illustrate how to develop a complete three view drawing for analysis. In part a), all fibers are aligned with the principal axis so that the composite has maximum strength in that direction and has little strength in other directions. CAD capabilities for rapidly locating rivets or cutter paths are worthless at this early stage of design, but a CAD capability to change the wing's sweep and automatically revise the geometry of the spars and ribs accordingly would be of tremendous use. Sometimes this leads to changes in already 17 18 A i r c ra ft Des i g n : A C o n c e p t u a l A p p r o a c h fabricated parts or tools, at enormous expense. One can create a "virtual fence" by placing a notch or snag at the location just outboard of where the stall begins. 37 1 (Nz Wdg X 10 - 4) 0 . 1 6. CAD tools for detail design are now very well developed. 933 2 . Ply orientation was varied to give specific properties. By definition, the "trailing edge" defining the back of the reference axis is vertically located at the midpoint of this thickness. For recovery, the rudder is deflected against the spin. Because of its material properties, titanium lends itself to a unique forming process called "superplastic forming/ diffusion bonding" (SPF /DB). 0 Good corrosion resista nce } Widely used. Also, manufacturing experts were brought in for reviews throughout the advanced design process. An airfoil with a concave lower surface was known as "undercambered" airfoil, generating a lot of lift but a lot of drag too. Use of an airfoil at a greatly different Reynolds number (half an order of magnitude or so) can produce section characteristics much different from those expected. When the component weights are estimated using these or similar methods, they are tabulated in a Group Weight Statement (see Table 1 5.1) and are summed to determine the empty weight. These can also be used to help select a reasonable weight estimate for the components by comparing the component weights as a fraction of the empty weight for a similar aircraft. (") 0 .0087 0 .022 0 . The Mach 2 F- 1 5 fighter uses the 64A airfoil modified with camber at the leading edge. 13) () (i Vp) N0.066Noen.052 (T1000) 0.249 v: -0. This is a 9% takeoffweight savings, resulting from only a 5% empty-weight saving. The climb angle y is the angle between the X axis and the horizon. Also, the separation point is affected by the amount of energy in the flow. The designer should now immediately begin preparations for redrawing the aircraft for the next design iteration. = A i rfoi l a n d Wing /To i l Geometry Selection C H A PT E R 4 Actual airfoil shape y \ Angle o f attack t C h o rd length "c" carnb e r lin e * + 1 in e * + 2 in I. What Is Design? Air Force photo). There is a common misunderstanding by people who've never actually worked in aircraft design-that outsiders can come up with a design concept and go sell it to somebody. It has a better strength-to-weight ratio and stiffness than aluminum and is capable of temp eratures almost as high as steel. The lift-curve slope is needed during conceptual design for three reasons. 0 x 50. The spar is only one element of the overall structure of the aircraft that will be defined in preliminary design, and extensive analysis (and sometimes testing) will be done of the whole structural concept to assess and optimize the overall concept. The total horizontal force on any element is the horizontal stress at the element's vertical location times the elemental area. Analysis of the as-drawn aircraft will also check a variety of design requirements and other needs. If the air molecules far away from the aircraft skin are moving with it, there must be a slippage (or shear) between these molecules far away from the aircraft. We don't have a team vote on whether the wing will flutter off-the best technical expert makes that judgment. Slope discontinuities (breaks) in the longitudinal direction are very bad. In the case of three-dimensional wing data, the mathematical parabolic shape is actually obtained from a theoretical drag due to lift calculation, but for two dimensional airfoil data, there is no such thing as drag due to lift. Mach numbers is discussed in Chapter 1 2, but for initial layout purposes the minimization of wave drag at Mach 1.0 is a suitable goal in most cases.) However, it is usually impossible to exactly or even approximately match the Sears-Haack shape for a real aircraft. V.,.. I S AT W I N E> ei A 🗞 o. Engines and payload were carried in this nacelle, which created a strong shock on either side with greatly increased static pressures behind the shocks. 1 20 5 :: J c : swept-back tip, leading-edge strake, and trailing-edge kick. This moment is equal to the sum mation of the discrete loads times their distance from the cut. The coordina tes of the centroid (Xe, Ye) of an arbitrary shape (Fig. The bottom of Fig. The velocity term seen in the jet 645 646 Aircraft Design : A Conceptual Approach range equation has disappeared. 76 NJa*; Weig hts 57 1 572 Aircraft Design : A Conceptual Approac h Design Example weight calculations t o "prove i t could b e done" and then made exactly this mistake-now corrected! The RDSwin Student computer program, available for purchase with this book, was created in part to help students with these calculations. (14.47) and (14.48). Although these calculational takeoff gross weight of the Lockheed S-3A, as quoted in [6], is 52,539 lb {23,831 kg}. [4] IPD refutes the traditional hierarchical structure of large, bureaucratic engineering organizations and calls for decision making to be pushed down to the lowest possible level. Perimeters can be measured using a professional's "map-measure" or approximated using a piece of scrap paper. Secondly, the methodology for calculating drag due to lift for high performance aircraft uses the slope of the lift curve, as will be seen. This tends to "suck" the flow rearward, promoting laminar flow-if bug guts don't ruin the flow. Another important task during the detail design phase is production design. If the local air velocity increases, the dynamic pressure has increased, so the static pressure must decrease. The effect of Mach number on the lift-curve slope is shown in Fig. In a later chapter, the concepts introduced here will be expanded to a sizing method capable of handling all types of missions and with greater accuracy. The Euro-fighter Typhoon uses SPF /DB titanium for its canards rather than the originally intended composites because of its better producibility. Sometimes firm cost limits are provided by the customer community and can be used to bound the requirements trade studies and finalize the aircraft sizing. Because the wing geometric aspect ratio is the square of wing span divided by the wetted-area ratio (Swet /Sref) as defined above. As was shown, the aircraft flies at a velocity that is 76% of the velocity for best L /D. If the steel is slowly cooled by steadily reducing the temperature in the furnace (a process called annealing), a coarse grain structure is formed, and the steel is very ductile but weak. rw:s.d·'Af\ a i.-fi>l '!>O fl = Sb b'+S ::::. C H A PT E R 3 Sizi n g from a Conceptu a l Sketch The low-level strike mission includes "dash" segments that must be flown at just a few hundred feet off the ground. 1 /.27 .010/.oJz. J 73/l't3 ts-/.l'l .oif o; 2 //n . 07 WAPU installed > 2.2 WAPU uninstalled \Vjnstruments 4.509KrKtp N2 · 54 1 N;n (Lj + Bw) 0 · 5 Whydraulics 0.2673Nj (Lj + Bw) 0 · 937 o .782 L0 .346Ngen o . loa tained Note that the drag-due-to-lift factor J(is a function of lift coefficient, as described in Chapter 12. This would increase the risk of fire in the fuselage during an accident and is forbidden in commercial aircraft. If the empty weight is higher than expected, there might be insufficient fuel to complete the design mission. Such "vortex 221 222 Aircraft De s i g n : A C o n c e ptu a l A p p roa c h 0& 0a, Ø J Vortex generators S n a g or notch Fence & notch 0a,9-Y S h a r k nose Nose stra ke Fig. Methods for trade studies are discussed in detail in Chapter 19. Lateral stability calculations tell you if the vertical tail, rudder, and ailerons need to be revised. To regain some ductility, the steel must be tempered by reheating it to about 1000°F {538°C} for an hour or more. The techniques presented here are good preliminary methods, suitable for assessing the design and performing trade studies, but they should not be viewed as the "final answer." These methods were carefully chosen to allow the design student to see the whole design process, not get bogged down in detailed analysis. The aspect ratio of the delta L/D L/D 37 38 A i rc raft Desi g n : A C o n c e p t u a l Approach s, r swetted Span Swe/Srer Aspect ratio Wetted a s pect ratio U/Dmax I nter n a l vol u m e Fig. To counter the pitching moment of the wing, the tail surfaces produce a lif force generally in the downward direction. g0 I NC:.. Other examples include the inlet front and the back end of a fuselage or nacelle, where the
exhaust or intake areas must not be included. In the end, it is the company that sets the design, then reaps the rewards or suffers the consequences. The rate at which the steel is then cooled defines the grain structure, which determines strength and ductility. In Preliminary Design, that selected concept is refined and studied in enough detail that the company can confidently commit to it, and in Detail Design the actual parts are designed. 1 (15.26) ht 0 0 0 0 22 w.vertical tail 0 · 0026(1 + Ht /H). For now it can be estimated as a fraction (We / Wo) using simpler methods. High-end CAD programs such as Solidworks, Siemens NX, Creo Elements/Pro, and CATIA have numerous tools to assist in the definition of typical production features such as Cutouts, pockets, radii, and holes. A kink over the wing box is avoided by passing the longeron under or through the wing box. We do it the other way around. Even so, the conceptual design analysis methods in this book are still useful-and used-even in the big companies. It depends upon the selected airfoils and the relative location, geome try, and twist of the wing and winglet. 676Nt0 . '(INVE@TE. Figure 4.3a illustrates the flowfield around a typical airfoil. Aff]: Loiter Optim ization-Jet For jet aircraft the only term in the endurance equation that varies with velocity is the L/D. w () = (15.46) 575 576 A i rc raft Desi g n : A Conceptual A p p r o a c h = () -0. That is the design weight of the F-1 5 and is probably a fair number to start with, if you are in a hurry. The other fuel includes "reserve fuel" as required by civil or military design specifications (mostly to allow for degradation of engine performance) and also includes "trapped fuel," which is the fuel that cannot be pumped out of the tanks. 1 5. The vertical location in the beam at which there is no span wise force due to bending is called the "neutral axis" and is at the centroid of the cross-sectional shape. This must be corrected by resizing and opti mizing the aircraft (which would invalidate the component weight predictions that were based on the as-drawn takeoff weight). 1 5 determined (see Chapters 5 and 6). 55 56 A i rc raft D e s i g n : A C o n c eptu a l A p p r o a c h "Camber" refers to the upward-bowing curvature characteristic of most airfoils. Instead, the designer's time is spent doing something called "design," creating the geometric description of a thing to be built. C H A PT E R 8 Spec i a l Considerations i n Confi g u ration Layout "Su personic a rea rule" Cross-section a rea Cross -sect ion area (M = 1 .0) S moother a rea prog ression Lower maxi m u m c ross-section Fuselage Fig. These part design layouts include the smallest details such as the exact radius of the corner of a pocket cutout on a wing rib, and the locations and dimensions of the holes that must be drilled for fasteners. What tradeoffs should be considered? Design takeoff gross weight, and the remaining (or "empty") weight, fuel weight, and the remaining (or "empty") weight. Composites consist of a reinforcing material suspended in a "matrix" material that stabilizes the reinforcing material and bonds it to adjacent reinforcing materials. One cannot exist without the other. Six-series airfoils such as the 64A series are still widely used as a starting point for high speed wing design. - 1 2. CHAPTER 2 Overview of the Des i g n Process The top of Fig. The column experiences inelastic buckling, so the Euler equation cannot be used as shown. There still haven't been enough composite aircraft to develop good statistical equations just for them, so we usually fake it. sep theoretical development of aerodynamics. 3.5 indicates that a maximum lift-to-drag ratio of about 16 would be expected. In this I NTERMISSION " author/professor's opinion, my plane is great, let's build it" rates a C. 1 Origin of aerodynamic forces. Peter Garrison's Technicalities column in (Nov. There is a simple relationship between range and endurance based on the Breguet range and loiter equations. On the other hand, an overly fat leading edge gives more drag. 2 37 + 26.4(1 + Nci) 13 5 6 l v/. Methods have been developed for designing an airfoil such that the pressure different tial between the top and bottom of the airfoil quickly reaches a maximum value attainable without airflow separation. The induced drag depends largely upon the wing, the minimum drag CDo occurs when the lift is zero. Loiter 5. Even with this extreme level of design sophistication, the actual airplane when flown will never exactly match predictions. Real ones are much smaller and touch the airfoil only at the very front. (... Second d erivative cont i n u o u s N o t a s l i kely t o sepa rate ... (Note: It is very important to use consistent units! Convert all values to feet-lb-s, or to m-k-s. Inconel was used exten sively in the X-15, and Rene 41 was to have been used in the X-20 Dynasoar. The exponents are small negative numbers, which indicates that the empty-weight fractions decrease with increasing takeoff weight, as shown by the trend lines in Fig. 4.7 Laminar airfoil. This thicker root airfoil should extend to no more than about 30% of the span. In the past this has been a problem for homebuilt and sailplane designers, but 71 72 A i rcraft D e s i g n : A C o n c e p tu a l A p p roa c h there are now suitable airfoils designed especially for these lower Reynolds number aircraft. According to Bernoulli's equation, the total pressure (static plus dynamic) along a subsonic streamline remains constant. 8.7 Compression l ift. 13) A more accurate estimation of wetted area can be obtained by graphical integration using a number of fuselage cross sections. When you are flying upside down, normal twist makes the tips stall sooner! +, fff Other Airfoil Considerations Another important aspect of airfoil selection is the intended Reynolds number. Use of the planimeter is a dying art as the computer replaces the drafting board. This is when the actual parts get designed, in "detail." Then you fabricate the parts, assemble them together, and fly. 3.8 Sample m ission profile. The moments about the pin are readily summed and solved for the unknown strut force, which is found to be 3919 lb. Modern CAD systems are amazingly powerful and offer excellent graphi cal user interfaces, accurate surface definitions, realistic photo-like rendering capabilities, and sophisticated data management systems, even on a personal Cross-section area Vol u m e = a rea under curve Fig. 16 show the key geometric parameters of the refer ence wing, which is also called the "trapezoidal" or "trap" wing due to its obvious shape. Ob(c.L. v('C:) S.L. jro'I] c..; 1vh ::: This is discussed below. This is very ben eficial, resulting in a structural weight reduction as well as more volume for fuel and landing gear. Figure 1 2.2 presents the various drag terminologies using a matrix that defines the drag type based upon the origin of the drag force (shear or pressure) and whether or not the drag is strongly related to the lift force being developed. 4tm steel A major early advance in aircraft structures was the adoption of welded mild-steel tubing for the fuselage. This example serves to illustrate an important principle of aircraft design-there is no such thing as a free lunch! All aircraft design entails a series of tradeoffs. Folding down the wing tips helps this problem, too. First, it is used to properly set the wing incidence angle. 21 5 216 Ai rc raft D e s i g n : A C o n c e pt u a l Approach The air inflow induced by a pusher-propeller will "pull" the air around the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and the corner, preventing separation despite contour angles of up to 30 and deg or more. The vertical velocity (sink rate) can b e determined b y substituting Cr cos cf> for Cr in Eq. (17.70). You also get a substantial com pression load in the internal wing structure inboard of the strut attachment 549 550 A i rcraft Desi g n : A C o n c e pt u a l A p p r o a c h which promotes spanwise buckling. For these reasons, the space shuttle uses an aluminum struc ture with heat-protective tiles. The disadvantages of wood are its sensitivity to moisture and its suscep tibility to rot and insect damage. The Eurofighter Typhoon uses aluminum-lithium in the wing and tail leading edges. 41111fl Compression The
compression Stress is also given by Eq. (14.29) (load divided by area) We do this by climbing, but eventually that will change specific fuel consumption C because it is a function of altitude for jet and prop engines. The Hughes H-4 looks virtually new today because it was kept in a climate-controlled hangar. c. Note that this technique, where applicable, all ows direct solution for the desired unknown forces. Wi ng Geometry The "reference" wing is the basic wing geometry used to begin the layout. Such adjustments are described in Section 15.4. Needless to say, these equations are complicated, and it takes a lot of time to apply them successfully. This can go up to 15 deg on the bottom because the higher pressure air tends to push the air around the corner The U.S. military has its own Mil-Specs and Mil-Standards. 70 2 . 2.s- L b · - c ...) Wo c.... Figure 2.3 illustrates this for a typical piece of aircraft geometry, the front wing spar. 83} - 0 . Even a solid C HA PT E R 7 Configur ration Layout a n d Loft model could accidentally give the wrong answer in this case, failing to understand that the "hole" isn't there! For this reason it is STRONGLY recommended that all CAD users start by doing a trivially simple "aircraft design" consisting of a tube-plus-cone fuse lage and a simple wing, where the correct wetted areas and volumes can be easily calculated by hand and compared with the answer from the CAD system. 10 W.electrical 7 291Rkva 0 .98 3 Wavionics 1 · 73 Wuav furnishings 0 · 0577Nco .1 Wc0 .393;:c,...0j 75 = = = = Wairconditioning = 62.36N + 2 5 (Vpr /1000) 0 · 604 w + 2 5 (Vpr 543 544 A irc raft Desig n : A Conceptual Approach station, or the integral of a distributed load. = n W/qS) (T n = /W) (L/D) q (W qW/S) n = J ---- Equation (17.78) can be solved for turn radius as expressed in terms of either bank angle or load factor [Eq. (17.79)). Everyone, from students to grizzled industry veterans, now uses a CAD system of some sort for most design work. The 7075 is alloyed with zinc, magnesium, and copper. If the empty weight to maintain the capability to perform the places, mostly toward the nose, the air is slowed down. Kelly Johnson, the legendary leader of the Lockheed "Skunk Works," who developed such revolutionary aircraft as the F-104 and SR-71, was a firm advocate of a "strong but small" project office, emphasizing the authority of the project manager and team to get the job done without micromanage ment from above. 1 1 9 .2 2 1 .3 1 0.0 1 0.0 1 2 .0 1 4.0 1 8 .0 23 .0 6 10 22 24 30 30 Three-pa rt Name 18 21 28 37 47 52 x x x x 4 .25-1 0 7 .25-1 0 9.00-1 2 1 4.0-1 4 1 8-1 8 20. Figure 4.7 shows a typical laminar flow airfoil and its pressure distribution. This equivalent truss can be solved by several methods. 230 1 2 (5 Dig it) � 64 AOI 0 (6 Dig it) • c: ====---=- 44 1 2 (4 Dig it) 65 A008 (6 Dig it) Fig. • 4;., (. 5 21 522 A i rcraft Desi g n : A Conceptual design by the major airframe companies and cover fighter/attack, transport, and general aviation aircraft. This causes a drag increase from the tendency of the rapid pressure rise across Liebeck L R l 022M 1 4 c:::-cp =-=-=- "Rooftop" () - (+) Fig. The stainless-steel alloys are commonly used where corrosion resistance is important. 1 2 Box 3.3 Payload Trade Payload = 5000 lb; Wo 5800 = 1 - 0. The only unknowns are the fuel weight and empty weight 1 4.37 Relationship between shear and bending. A centroidal axis is any axis that passes through the centroid. An expertly-designed winglet may have a 25% higher value for the h / b term. (Z 1-ID't)1;-0 ENG1Nc e -[,, ... In concept three, the wing is low and the engines are mounted over the wing as in concept two. *QI Takeoff-Weight Sizing From Table 3.3, initial values for SFC are obtained. - - - - - - Lower su rface Thickness a re exaggerated for i l l u stration. 2.3). The area under the resulting curve is the volume, as shown in Fig. Fly model airplanes, especially your own original designs. A Dash-50 is not unheard of Design is before the design that will be built is locked in. Once the flow separates, the pressures at the back of the body are not quite as large as they should be. sref CHAPTE R 1 2 Aerodyna m i c s a ctual parasite drag will be larger than this value because some pressure drag is added. 8.6 Supersonic shocks. 1 250 42 35 35 30 1 00 4. Aerodynamics disci pline into many parameters with strange names, defined by peculiar coeffi cients. This is primarily skin-friction drag, and as such is directly proportional to the total surface area of the aircraft exposed ("wetted") to the air. wing is lower, not because of a reduced span, but because of a reduced span, but because of an increased chord length. Several special cases can be readily solved. .q,/1000 -i:z.. The shape of the cross section is unimportant in most cases. ::::. All weights analysis includes a lot of judgement and best. n A C on c e p t u a l A p p r oa c h On a drafting table, the three-view layout is done in some convenient scale such as 1 / 10, 1 /20, 1 /40, or 1 / 100 (depending upon the size of the air plane and the available paper). A more correct optimum condition for range can be found by exhaus tively searching throughout the flight envelope at the current aircraft weight, looking for the place where the range parameter (V/C) (L/D) is at a maximum. With a more-horizontal strut, the strut i: very long and runs close to the wing, so the strut drag is quite high. A computerized, "active" flight control system can remove the requirement for natural stability and thus allow a non-reflexed airfoil. 3.1. Note that these are all exponential equations* based upon takeoff gross weight (pounds or kilograms). 985 0.995 CHAPTER 3 Sizi n g from a Conceptual S ketch where R = range (ft or m) C = specific fuel consumption (see following section) V = velocity (ft/s or m/s) L/D = lift-to-drag ratio Loiter weight fractions are found from the endurance equation (also causes the flow to separate somewhere on the back half of the body. 2 Historical Mission-Segment Weight Fractions Mission Segment Warmup and takeoff Climb Landing (W;/W; - 1) 0. In industry, a real but subtle problem is that, with a CAD system, everybody's designs look good whether they are or are not! When everybody was using a drafting table, you could usually tell from drafting technique that a design was done by a beginner and therefore whether the design needed to be reviewed extra carefully. · · ··· - · · 0 2 T (M V) rr (= 35''' U./ft'L c,.,c, =0,, .\$ C L TOT!t l.. Fortunately, major drag reductions can be obtained simply by smoothing the volume distribution shape. 75 2 .00 0 . Also note that C and L/ D vary with speed and altitude. The shear stresses due to torsion are calculated with Eq. (14.45) and are a1 a maximum at the surface of the shaft (r = R). For low angles of attack, this is approximately equal to the lift-curve slope so we ignore the difference. This is especially true for the laminar-flow airfoils and is most crucial when an airfoil is operated at a lower-than-design Reynolds number. 1 1 Graphical sizing method for ASW example. Don't use that result-it isn't "real world" and the sizing equation will not converge. I Fixed . In certain early canard home built designs using laminar flow airfoils, entering a light rainfall caused the canard's airflow to become turbulent, reducing canard lift and causing the aircraft to pitch downward. If an aircraft could be designed with a volume distribution, it would have the minimum wave drag at Mach 1.0 for a given length and total internal volume. In the 1930s, the NACA developed a widely used family of mathematically defined airfoils called the "four-digit" airfoils. 873 W'.vertical tail v lOOt/c - 0. First, the aerodynamic center moves consider ably to the rear. Fuel fraction can be estimated based on the mission to be flown using approximations of the fuel consumption and aerodynamics. Titanium is seriously affected by any impurities that might be accidently introduced during forming. In some cases, the moments about some selected the
solution with less effort. However, it is easier to graphically integrate by starting at the tip and working inward, adding to the total the area under the shear dis tribution at that station. If a body is small and flying at low speed, the Reynolds number will be so low that the flow will remain laminar resulting in separated flow very near the front. However, at the beginning of a new aircraft project the company's advanced design staff must usually invent a set of requirements to begin that first layout. - °bf.S IMJ : S lt'tT!c.. The leading edge outboard of the wing notch can be cambered downward fu to rther reduce the outboard wing panel's tendency to stall. 11251 Given a known aircraft statistica l Weights Method A more refined estimate of the aircraft component weights can be done using statistical equations based upon sophisticated regression analysis, 569 570 A i rc raft Desig n : A Conceptual Approac h i n some cases initiated with physics-based models. For ductile metals this is a conservative assumption as they never actually fail, but merely "squish" out and support the load by the increased area. The term "wetted aspect ratio" was not in use back then, so the horizontal axis is given as sqrt[A/(Swet /Sref)]. Historically, product development has been done serially. This is permitted pro vided that the fuselage is increasing in cross-sectional area toward the wing trailing edge, this can "push" air onto the wing, thus reducing the tendency to separate. In a flying wing the lift and weight forces can be located at virtually the same place. The point at which a line from the origin is just tangent to the drag polar curve is the point of maximum lift-to-drag ratio. In fact, the B-70 is an excellent example of synergistic design. Rather than attempt to iterate to the correct answer as just done, we simply graph these answers with Wo guess OI! the horizontal axis and Wo calculated on the vertical axis. w (15. 67 {]. The lift coefficients for the wing and tail are simply the lift-curve slopes times the wing or tail angle of attack (measured with respect to the zero-lift angle). (The author did joint three wrong the first time!) Joint one is at the engine load of 4000 lb. V = t /S k.ts .O ! 'b{(.1' 6 : 1'1. In a typical aircraft part, the direct substitution of graph ite-epoxy composite for aluminum yields a weight savings of 25%. Land (Table 3.2) Wi / Wo = 0.97 (Table 3.2) W2 / W1 = 0.985 R 1 500 nmi. Chapter 6 pro vides a more refined method for initial sizing than the quick method presented in the last chapter and concludes with the use of the sizing results to calculate the required wing and tail area, engine size, and fuselage volume and length. The appendices with the use of the sizing results to calculate the required wing and tail area, engine size, and fuselage volume and length. contain additional information useful in conceptual design, such as unit conversions, atmosphere tables, and data on airfoils and engines. There just aren't that many jobs, entry level or otherwise, in the new aircraft concept development field. 7 7 1.1.r[1 - o. 00 1....) # \$D 4£) bO 22. The question is: what does it do then? 1! " \$... The second half of the book covers concept analysis and optimization of the design, with emphasis on learning how the design can be improved during the next iteration. 3 3 times the averaged value. This can increase the bending moment by as much as a third compared to an analysis that ignores this compression effect. In the civilian world these requirements are typically set by the aircraft company based upon customer input, market analysis, study of the competition, consideration of current products, and sometimes just gut feelings. 1 60 0. What didn't work out so well on the first drawing? The maximum stresses due to bending are at the upper and lower surfaces. Nickel alloy honeycomb sandwich is used for the stealth nozzles of the F-1 17. Somehow, the landing gear fits, the fuel tanks are near the center of gravity, the structural members are simple and lightweight, the overall arrangement provides good aerodynamics, the engines install in a simple and lightweight are simple and lightweight. wing design today, the uncambered four-digit airfoils are still commonly used for tail surfaces of subsonic aircraft. Thunderbird F-1 6 showing strokes (U.S. "Cost factors" of double or triple were applied to cost estimates of the same part, but this requires a kink to pass over the box. [7) Airfoil selection would consider aerodynamic factors such as the airfoil drag during fuel tank, designed and optimized solely for that mission and highly impractical for any normal application. Cruise Simple Ta keoff Cruise out Low-level strike Ta keoff Weight d rop Su periority Fig. For final determination of the best aspect ratio, a trade study as discussed in Chapter 19 should be conducted. Properly done, this can also greatly reduce spin tendencies and promote spin recovery and is highly recommended for general aviation and training aircraft. That takes a lot of people. The top illustration of Fig. No handbooks. Unlike the parameters just estimated, the L/ D is highly dependent upon the configuration arrangement. Introd uction W hen we design a new airplane, we don't just draw wings and tails that look "right" and then measure their span and area. This first-order sizing process is diagrammed in Fig. Simply supported sides are equivalent to a pinned end on a column and can rotate about their axis but cannot bend perpendicularly. In some designs similar to Fig. It is common, even mandatory for "fudge factor" adjustment of any equation result. Rather than buy the outsider's design, they'd either develop their own design study contract. The presence of wind also affects the optimal cruising speed for maxi mizing range. A supercritical airfoil can be about 10% thicker (i.e., conventional airfoil thickness ratio times 1.1) than the historical trend. Thus, for any span Shear Su pport shear reaction Moment reaction due to spa nwise com p ression a n d tension Fig. The slope of the lift curve is essentially linear excep near the stall angle, allowing the lift coefficient below stall to be calculated simply as the lift-curve slope times the angle of attack (relative to the zero-lift angle). They just have to understand how the process works and realize that nobody is going to buy a completed concep tual design from them. In fact, wave drag is calculated using the second derivative (i.e., curva ture) of the volume-distribution plot as shown in Fig. This suggests a new parameter, the wetted aspect ratio, which is defined as the / * Earlier editions showed the B-47 and Avro Vulcan to illustrate this effect. A critical term Wdg is the flight design gross weight. Thus, Sizi n g from a Con ceptu a l Sketch CHAPTER 3 Eq. (3.1) becomes Wo = Wcrew + Wpayl oad + (*) Wo - (*) (*) = Wo - Wo (;*) Wo (3.2) Wo = Wcrew + Wpayl oad (3.3) This can be determined if (Wj / Wo) and (We/Wo) can be estimated. The pressure forces produced in the generation of lift are at right of the generati angles to the oncoming air. 12.1 are caused by changes in velocity. Q3 0.96 {0. F = 1.07 (1 + d/b)2 (12.9) Sometimes the product (Sexp osed / Sref)F is greater than one, implying that the fuselage produces more lift than the portion of the wing it covers. These calculations are shown in Box 3.2, and the results are plotted in Fig. For a major commercial or military project, it would typically take six months or so to properly study the requirements, technologies, and configuration alternatives, and then wisely down-select to a best concept. 1 52Nco. The resulting lift-curve slope looks like that of a low aspect-ratio wing and in fact, the two effects are additive. However, the designer's real work is mostly mental. AIAA is committed to devoting resources to the education of both practicing and future aerospace professionals. 1 1). This schedule milestone is crucial because it allows other designers to begin serious development of structure and subsystems without fear that their work will be invalidated by later changes to the overall design configuration. The sweep of the wing tends to push the air outward, especially in the boundary layer where the air is low in energy. 34 {2 . This will usually converge in just a few iterations. The dimples on a golf ball are an example of this. 2.6) . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o.
Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 Aircraft conceptual design process. 1 } 0 .8 {22 . o. Also, a four state of this. 2.6} . 7) C HAPTE R 1 5 Wfirewall = 1. 2.4 A man crew is required, totaling 800 lb {363 kg}. It takes a long, laborious process and a lot of iterations until a "clean" set of requirements, done by experts. This chapter discusses various intangible considerations that the designer should consider when making the initial layout. - see drouge at the sign : A C on ceptual Approach 887 888 A i rc raft De sign : A C on ceptual Approach 887 888 A i rc raft De sign : A C on ceptual Approach 887 888 A i rc raft De sign : A C on ceptual Approach AIRCRAFT DESIGN STAE I L.li'I' E = sb i.... IterativeThe revised drawing. each of whom ensures that the design meets the requirements of that specialty. MtQI Titanium Titanium Would seem to be the ideal aerospace material. 0103KdwKvs (WdgNz) o . Note that the terms "profile drag" and "form drag" are often inter mixed, although strictly speaking the profile drag" and "form drag" and the skin-friction drag. Specific cost goals can be written down including development costs, purchase price, operating costs, and others. For a cambered wing, the minimum drag CDmin occurs at some positive lift CLmin dra The drag polar also has a parabolic shape but is offset vertically as defined by Eq. (12.5). A fence can also be used to cure a problem common in highly swept wings. 1 100,000 10,000 10,000 10,000 10,000 10,000 10,000 10,000 10,000 W0 (lb) Empty-weight fraction trends. Finally, would be the weight at the end of the landing segment, which is also the end of the landing gear = o Weight at the end of the total mission. 4Nmw T/m (15.29) CHAPTER 1 5, vr w nose landing gear = o Weight at the end of the total mission. weight but will suffer a reduced maneuverability. 9 {25.5} 0.8 {22. Most of the advanced composites used in aircraft structure are of the filament-reinforced type because of outstanding strength-to-weight ratio. Drag is normally spoken of as so many "counts" of drag, meaning the four digits to the right of the decimal place. What we do not know, and will find out by the sizing calculation, is how big to draw it. 49) Wmainlandinggear 0.095(Nt W1) 0 · 768 (Lm/l2) 0 . 0 1 7 >< 0. If you can easily calculate the volume of a complicated tank wrapped around the inlet duct, guess which one you are likely to design! Another problem is the actual calculation of the volumes, wetted areas, and other dimensions critical to your analysis of your design. This causes shocks near the wing root and is a very real problem. This causes shocks near the volumes, wetted areas, and other dimensions critical to your analysis of your design. We / Wo), it's always better to develop your own trendline. - Ly. dA · e- A x - e 1111 (1 4 .2 1) - (14 .2 2) The centroid of a cross section is the geometric center, or the p oint at which a flat cutout of the cross-section shape would balance. Most pilots today use a special pocket calculator that does all such calculations instantly-as long as you type in the correct values. 1 0 2 . 0 Free 0 Pin . This chapter discusses the airfoil and the wing and tail geometric par ameters and presents some quick methods for initially selecting them. Furthermore, through the industry usage of modern CAD systems the entire aircraft is being designed digitally, allowing the use of virtual rather than actual mock-ups. Performance and Flight Mechanics derived from s i m p l e physics, mostly Newton . During detail design, the testing effort intensifies. CL CL Effect of ca m b e r Effect of ca m b e r Effect of as pect ratio --+-[amax Lift Fig. A thin-walled, closed, cross-sectional member with constant wall thickness t, total cross sectional area A, and cross-sectional perimeter s has shear stress and angular deflection as defined by Eqs. Having a vortex on only one side of the forebody creates a strong suction force that can pull the nose to one side, causing a spin. Later on, it is too difficult to change the overall geometry, so if unexpected problems are found, they must be fixed in some other way. 1 4.32 Method of joints. See below. 0046 0 .0 1 2 0 .0065 - 350 350 350 350 350 350 350 350 350 0 .0 1 9 0 .006 2 1 .00 2 .34 2 5 .00 2 .38 30 20 7 . Phases of Ai rcraft Design Aircraft design can be broken into three major phases, as depicted in Fig. The six-series airfoils were designed for increased laminar flow and hence reduced drag. 3.6 Wetted area ratios. Thus, the end of preliminary design usually involves a full-scale development proposal. The mission fuel fraction must therefore be equal to (1 Wx/Wo). 14.33 shows the use of the method of shears to solve for the inner strut. If the wing weighs less than the budget implies, don't add rocks until the budget is met! It merely acts as a guide and a reality check while the detailed calculations described below are being performed. The buckling load [Eq. (14.34)] depends upon the 537 538 A irc raft Design : A Conceptual Approach 160 Al loy steel Ftu 1 80,000 psi Ftu 125,000 psi /, 140 120 v; 100 ·c.. 1 54 = 0.866). 'tS Gci"I I Ftu 1 80,000 psi Ftu 125,000 psi /, 140 120 v; 100 ·c.. 1 54 = 0.866). 'tS Gci"I Ftu 1 80,000 psi Ftu 125,000 psi /, 140 120 v; 100 ·c.. 1 54 = 0.866). 'tS Gci"I Ftu 1 80,000 psi Ftu 1 80,000 psi Ftu 1 80,000 psi /, 140 120 v; 100 ·c.. 1 54 = 0.866). 'tS Gci"I Ftu 1 80,000 psi Ftu 1 80,000 psi Ftu 1 80,000 psi /, 140 120 v; 100 ·c.. 1 54 = 0.866). 'tS Gci"I Ftu 1 80,000 psi Ftu 1 80, ratio, that is, the ratio between the fuselage length and its maximum diameter. Cost goals also include some assessment of what the market will bear, and the economic value of the new airplane to the customers. To fix this, a number of small plates are bent into an "L" shape and attached just before the region of separation, set at an angle to the flow. The X-3 1 was a classic example of these tradeoffs, 121 and the author spent many long months leading such cost-vs-capability trade studies before the "sweet spot" was determined and the design concept was validated. Design capabilities allow creation of every imaginable type of geometry, and various CAD systems have specific geometry buckling." An important parameter is the column's slenderness ratio: the column's effective length L e divided by the cross-sectional radius of gyration [Eq. (14.30)] . 162. Sometimes the opposite is done. At very low aspect ratios, the ability of the high-pressure air to escape around the wing tips tends to reduce the lift. This will yield noticeable Vbest range CL best range D best range D best range Performance and F l i g ht Mecha n ics = (17. depends upon both the induced and parasitic drags. This was based upon rough estimates of the aircraft's aerodynamics, weights, and propulsion characteristics. 68) (16.69) WjS μ, = -- (16.70) pgb This empirical estimation technique is dominated by the ability of the rudder, vertical tail, and aft fuselage to oppose the aircraft's rotation in the spin. The three-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, or space structures, are solved similarly to the two-dimensional trusses, time of existing aircraft is often needed for evaluation of their usability for other missions. The severed part of the structure is analyzed as a free body, summing either the vertical and horizontal forces, which must total zero. /3 C:/ - J? The end product of all this will be an aircraft design that can be confi dently passed to the preliminary design phase, discussed above. Today, these problems are largely solved and titanium has become the preferred material for high temperature environments such as fusel age structure around the engine, and for many fittings and complicated parts. Because n is also a function of lift coefficient, iter ation is required to solve Eq. (17.54). To fix this, small upright strakes were added to the top of the aircraft to create vortices that divert the wing strake vortices. The design layout began with initial sizing, back in Chapter 3. This has the effect of reducing the buckling load compared to the Euler load. S'f''''''': 'trlc:.) p < 0.. For civilian
aircraft, the United States has the FARs, or Federal Aviation Regulations. When this low-energy air is asked to turn a corner, it simply can't and separates instead. 4 5 2Krht (l + Ht /Hv) 0 5 (WdgNz) 0 · 488 se/ 1 8M0 · 34 1 i . 12) f3 = VM2 - 1 (12. 13) M > 1 /cos A LE (12. - de);;rn () N - 'DES. Figures 4. This pro duces a higher dynamic pressure in that region, hence higher skin-friction drag. B Table 1 4.6 J Area Properties of Simple Sections centroid _ I BH X Y B/2 H/2 y Moment of Inertia Ix _ Iy BH3 12 BH3 - bb3 12 HB3 - bb3 12 HB3 - bb3 12 (BH - bh) R/2 4 4 H _ Py HB3 - bb3 12 (BH - bh) 7r(R 2 - r2) BH 2 R R I H/ 3 1 4 w(R4 - r4) 4) R2 + r2 2 ... These estimates are used to make a first estimate of the required total weight and fuel weight to perform the design mission, by a process called "sizing." The conceptual sketch may not be needed for initial sizing if the design resembles previous ones. 8.9). It is possible to improve on these statistical numbers. 1 7. Longerons are heavy, and their weight should be minimized by designing the aircraft so that they are as straight as possible. 02.SO + .DOZ.'!- 1Y A 6 : e == K ::: • = T ooo .../ Weight d i stribution Wingtip store Nacelle Fuselage & Wing 1--"""\] "T .../ Weight d i stribution Wingtip store Nacelle Fuselage & Wing 1--"""\] "T .../ Weight d i stribution Wingtip store Nacelle Fuselage & Wing 1--"""\] "T .../ Weight d i stribution Wingtip store Nacelle Fuselage Fig. -- MIT Daedalus human-powered aircraft (NASA photo) . This happened during the development of the X-3 1, shown in Fig. This last approach offers better access to the engines. xxx Aircraft Design: A Conceptual Approach Design-A Separate Discipline • Aircraft concept u a l design is a special i st skill and is more than just drafting a n d CAD, or calculation a n d optimization. For this reason, this arrangement is commonly seen in a composite-wing-box shear web. The aspect ratio term should be increased by the use of wing endplates or winglets, both of which work by increasing the effective span of the wing. They cannot wait for the customer community to make up its mind-by then, another company is already working with them. Look for ways to optimize, simplify, and verify. As discussed at the beginning of this section, a very short "column" experiences pure compression without any danger of primary column buckling. Ls are from Fig. An aircraft designer needs to be well versed in these and many other specialties, but will actually spend little time performing such analysis in all but the smallest companies. "tlc.. What We've Learned Configuration design layout is the heart of the design process: you build the drawing. Figure 14.31 shows a typical truss structure, a light aircraft motor mount. The value of J(will be discussed later. 7 14 Structu res and Load s Torsion Constants --1 .00 1. If this is a train track, the train comes off the track right where the arrow points. Thus, the wing has accelerated the air downwards requiring a force to have been applied to the air, and by application of Newton's laws this means that the air has applied an equal and opposite force to the wing. Luckily, some of them have been publis h ed and are presented below, selected by this author as the best available methods having a reasonable number of inputs. Aspect ratio could be used to estimate subsonic lift-to-drag ratio but for one major problem. In 1880 the Railroad Gazette published the solution called the "Track Transition Curve," also known as an "E uler Spiral." This is a curve whose curvature (I /radius) changes linearly with curve length, reducing to zero when the straight segment is reached. The shear stress depends upon the cross-sectional area above the point of interest and is therefore essentially constant within the thin shear web, as shown to the right. These can drive the cost up significantly. This will be discussed later. 3 i.-.. forces. (In several text books this term is dropped by assuming that T/ = 1.0 at all Mach numbers.) Sexposed is the exposed wing planform, that is, the wing reference area less the part of the wing covered by the fuselage. I t has an excellent strength-to-weight ratio, is readily formed, is of moderate cost, and is resistant to chemical corrosion. A ircraft Design is a separate discipline of aeronautical engineering different from the analytical disciplines such as aerodynamics, structures, controls, and propulsion. Freestream velocity (Pressu res a re with res pect to a m bient a i r pressu re. Top-level design requirements usually include some overall cost target, either explicit or implied. principal axis direction. 09 { 1 . P eople continue to have arguments over this distinction, often in the popular aviation magazines. 31 32 A i rcraft D es i g n : A C o n c e p t u a l A p p roa c h As a first approximation, the fuel used can be considered to be pro portional to the aircraft weight, so that the fuel fraction (WJ / Wo) is approximately independent of aircraft weight. Now that the aircraft is drawn, we can analytically deter mine if the selected tail sizes are adequate, and also check control surface 389 390 Aircraft Design : A Conceptual Approach sizing, dynamic stability responses, spin recovery, and more. Any body shape will create shock waves at supersonic speeds, forming at the nose and at anyplace else where the cross-section area is increasing. 50 l. Loiter 7. Chapter 3 presents a "first-pass" design procedure to familiarize the reader with the essential concepts of design, including design layout, analysis, takeoff-weight estimation, and trade studies. If you don't have a customer who has carefully spelled out a proper set of aircraft design requirements, you need to get requirements come from several flavors. If the result doesn't match the guess value, a value between the two is used as the next guess. 7 • 1 .46 1 . 14.39. If Jll Subsonic Lift-Cu rve Slope Equation (12.6) is a semi-empirical formula from[68] for the complete wing lift-curve slope (per radian). But we don't go into aircraft design based on a rational analysis of career options. 70 1 .31 1 .30 0 -0 -0 0 0 0 :; Ta ble 1 4.5 H igh strength Graphite-epoxy Material High strength Graphite-epoxy High-modulus Graphite-epoxy Boroun-epoxy Graphite-polyimide S-Fi berglass-epoxy Ara mid-epoxy { 🔶 { * 5 ! . Designers, then and now, sometimes get "comfortable" with a certain airfoil and reuse it for many different airplane designs. Remember that wing and nacelle weights are multiplied by the aircraft load factor to determine the load on the wing. 74 {0.72} - 0. 88} - 0.0? 1. //g '[, Co T Is -(.,;,... Instead, they follow a transition curve in the transonic curve and the downward-trending subsonic curve in the transonic curve in the transon methods are presented in Chapters 12-19, starting with the aerodynamic analysis in this chapter. 401 402 Ai rc raft Des i g n : A C o n c e p tu a l A p p r o a c h a) 7 'O 6 Q; -3-5 • -7 ~ 2 4 £ - ,,,,,, / Fig. \ A Ai rcraft centerl i n e \ LE \ Fig. 14. Two airplanes with similar span and total wetted area will have a similar lift-to-drag ratio, even if they look completely different and their aspect ratios are dissimilar. 8.4; see [251) having the lowest wave drag. Previously, aircraft such as the Sopwith CHAPTER 1 4 Structu res and Load s ca mel had fuselages of wire-braced wood construction that required con stant maintenance. A flat board at an angle to the oncoming air will produce lift. Below is the revised trapezoidal geometry after the aspect ratio, taper ratio, and sweep are changed in response to some optimization. 0 1 1 >< 0. The beam is shown cut to depict internal . 2.3. Ml] Preliminary Design Preliminary Design Can be said to begin when the major changes are over. 12 and see a maximum L/D of 50 or more. 15 16 A ir c raft Des i g n : A C o n c e pt u a l A p p r o a c h In today's environment, this can result in a situation jokingly referred to as "you bet your company." The possible loss on an overrun contract or from lack of sales can exceed the net worth of the company! Preliminary design must establish confidence that the airplane can be built on time and at the estimated cost. Notice also that different types of aircraft exhibit different types of aircraft exhibit different slopes to the trend lines of empty-weight fraction vs takeoff weight. common being the should be used use of limit load factor, where ultimate load factor instead. At higher or lower lift coefficients the flow will become turbulent or even separate, causing higher drag. To reduce some of the enormous expense of Mil-Spec compliance, the military has carefully "deactivated" some of the old specs, either relying upon commercial practice, trusting the contractors, or transferring the spec to an outside organization. By multiplying them together, the total mission weight fraction Wx/ Wo can be calculated. 13.1 1; (IS'"o) = (e s r 7'ib .. In the former Soviet Union, the production design was done by a design bureau completely separate from the conceptual and preliminary design staff. Concurrent engineering is an important part of the IPT environment. C HAPTE R 7 Config u ration Layout and Loft A top Fig. A mockup may be constructed at this point, either physically or electronically using a modern CAD system. The creation of lift results from changes in the pressure around the aircraft. This produces

turbulent flow, which will remain attached longer than would laminar flow. Methods for analy si s of such members can be found in [1 06, 1 08]. lations that determine what should be modified to better meet the requirements. 7} 0. If the theoretical pressure forces in a perfect fluid are integrated over a streamlined body without flow separation, it is found that the pressures around the front of the body creating a rearward drag force are exactly matched by the pressures around the rear of the body, which create a forward force. 1:u vit/1q\) """" . Unless the wind is very strong, these will only change your airspeed by perhaps 5-10% or so, gaining just a few percent in range over the range if you flew at the no-wind optimal speed. The statistical empty-weight equation used here for sizing was based upon existing military cargo and bomber aircraft, which are all of aluminum CHAPT E R 3 Sizi n g from a Conceptual S ketch 70,000 \$60,000 40,000 +-- *** 1800 1000 Range Range trade. Drag forces that are a strong function of lift are known as drag due to lift. Also, magnesium should not be used in areas that are difficult to inspect or where the protective finish would be eroded by rain (leading edges) or engine exhaust. However, when maximizing range, the aircraft flies at a higher velocity [31.6% faster-divide Eq. (17.25) by Eq. (17.13)). Development of these equations represents a major effort as just described, and each comp any develops its own equations. Is the landing gear as simple as it could be? 37) Braced-Wing Analysis A wing braced with a strut will have the bending moments greatly reduced compared to a fully cantilevered wing. The low horizontal tail position shown in solid line would offer the lightest structure, but may place the tail in the exhaust stream of the engines. In 1 856 aluminum cost \$90 a pound. However, magnesium is very prone to corrosion and must have a protective finish. (cargo floor area, (15.41) (15.42) (15.43) (15.43) (15.44) (15.45) handling system Ifffl Genera l Aviation Weights (British Units, Results i n Pounds) () o. fi ber, l4 H @ 59. This ensures that there is always a joint with only two unknown struts, permitting solution by the method of joints. We., if Wo = < 11. To the rest of the aircraft community-pilots, detail design engineers, mechanics, military officers-our process of aircraft sizing seems backwards. Therefore, the vertical shear distribution must be related to the horizontal shears in the beam. By 1935 the cost had dropped to 2 3 cents per pound. This is done by guessing the takeoff gross weight, calculating the statistical empty-weight fraction, and then cal culating the takeoff gross weight. Unfortunately, a short, fat fuselage has a lot of separation in the back causing a huge pressure drag. Table 3.1 does not provide an equation for statistically estimating the empty weight fraction of an antisubmarine aircraft. The camber also increases lift by increasing-the circulation of the airflow. *UI L/D Estimation For initial sizing of the fourth concept, a wing aspect ratio of 10 was selected. The warm-up, takeoff, and landing weight fractions can be estimated his torically. Compression lift was 219 220 A i r c raft Desi g n : A C o n c e p t u a l A p p r oa c h apparently conceived by two researchers at NACA Langley in 1954 and used by Richard Child and George Owl of North American Aviation to configure a huge supersonic bomber that literally rode its own shock wave, the B-70. At that time we could not calculate the actual design layout. 1 41 0. Outward arrows represent pressu res below a m bient.) Fig. These mission-segment weight fractions can be estimated by a variety of methods. The lift and wing-weight loads are distributed, while the nacelle weight is concentrated. CJ) 2 - (") c (j) (J) c :: J a. An axis of symmetry is always a centroidal axis. 1 0 1 } #Ill L/D Estimation The remaining unknown in both range and loiter equations is the L/D, or lift-to-drag ratio, which is a measure of the design's overall aero dynamic efficiency. It is common for promising interns to be offered real jobs when they graduate, and often at slightly higher pay since their true work abilities are known. These laminar flow airfoils work by having the pressure continuously drop from the leading edge to a position close to the trailing edge. a = P/A (14.29) Remember that the stress level at the limit load should be equal to or less than the yield stress or, for composite material, the stress level correspond ing to a strain equal to the ultimate strain capability of the material divided by the selected factor of safety (often 1.5, matching that used for metals). Design: How Does It Start? 17; • I' ::::. Also, the 45-deg orientation is frequently used in structure that must resist torque. There will be an increase in up-front costs, but in the long run, those are trivial compared to the benefits. wary of automatic CAD systems and always check the results for reasonable ness using rough approximations such as those provided in Chapter 7. Wortmann, Richard Eppler, and Robert Liebeck. Complicated adjustments can be made to the range optimization equations for optimizing for range is not the preferred method anyway. 88 35 w - 0 · 07 0 W0, calculated 5 1 ,8 10 5 1 ,598 5 1 , 59 1 5 1 ,597 5 7 ,597 5 1 ,597 CHAPTER 3 Sizing from a Conceptu a 1 S ketch The use of composite materials reduces the takeoff gross weight from 56,702 lb {23,399 kg}, yet the aircraft can still perform the same mission. Table 3.2 gives typical historical values for initial sizing. 1 4.22. The methods presented here will get you close, and then the analysis and optimization methods described later will help to finalize things. No loads are applied except at the pins, and no moments are applied except at the pins, and no moments are applied except at the pins, and no moments are applied except at the pins. introduction to the design process, this chapter presents a quick sizing method, which will allow you to estimate required takeoff weight from a conceptual sketch and a sizing mission. 0.8 c,. These resemble the FARs and even share the same numbering scheme. For a positive bending moment such as shown, the internal forces produce compression on the upper part of the beam and tension on the lower part. However, we need to know about those that do affect the overall configur ation design and its analysis. This also delays stalling at high angle s of attack, as described in Chapter 4. For propeller aircraft, the endurance is obtained by using the equivalent C obtained from Eq. (17.4). Also note that the term "profile drag" is sometimes used for the zero-lift drag of an airfoil, which is sometimes called the wing profile. Cost? A key ability is a collection of tools that permit one to rapidly develop a notional design concept (in approxi mately one day), and to continuously revise design concepts and perform geometric trade studies. The center of pressure is usually behind the aerodynamic center, and it moves back and forth as the angle of attack is changed. (14.27) can be used to transfer the moments of inertia of the simple shapes to the combined centroidal axes. Note that this is not the point of minimum drag! • • Lift Figure 12.5 shows typical wing lift curves, how lift increases as angle of attack increases. They are all correct. 14) An accurate estimate of internal volume can be found by a graphical integration process much like that used for wetted-area determination. Circula tion is usually represented by r and is shown as a circular flow direction as in Fig. 97 {0. The company sets the requirements and designs the airplane, and then the customers decide if they want it. 16 allows converting from one sweep angle to the other. While strict accuracy should not be expected, this simple sizing method will usually yield an answer in the "right ballpark." Figure 3. C H A PT E R 3 Sizi ng from a Conceptua I S ketch has nearly the same center of gravity as when its fuel is almost gone. The extensive ASW avionics would not be included in that equation, so it is treated as a separate payload weight. 3 9.4 I I 8. Truss structure was used extensively in welded steel-tube fuselages. Trade studies will be done to determine the best combination of design parameters (T/W, W/S, aspect ratio, etc.) to meet all mission and perform ance requirements at the minimum weight and cost. A statistical approach can be used to determine if there is enough room in the design is an iterative process. 307 0.3 1 3 0.333 Solid rectangular members can be analyzed with Eqs. Box 3.3 shows the sizing calculations assuming payload weights of 5000 and 20,000 lb. 82 0.8 = compression. These are legally defined by Title 14 of the U.S. Code of Federal Regulations and have the weight of law. The given payload requirement is 10,000 lb of avionics equipment. 8.3. At the upper left there is an airfoil with its pressure contours shown, and four pressures are depicted with dots. The right side of the beam being a free body, the sum of the vertical forces, and the sum of the moments must equal zero. The charts in Fig. Typically, one can assume hp 0.8 except for a fixed-pitch propeller during loiter, where Y/p 0.7. These can be used for rough initial sizing. However, this reduced wing area is offset by the wetted area of the fuselage, nacelles, and tails. The appen dix describes a supercritical section suitable for transports and other high subsonic aircraft, along with a typical modern NASA section for general aviation. as John Roncz did for many of Burt Rutan's record setting airplanes. A true Exponential Equation is of form [constant times constant raised to a variable power]. Prototypes are usually built on "soft" or temporary tooling and are often built with fabrication processes different from those envisioned for the pro duction run. Fig. (/) 2 ,. By placing a "fence" just outboard of where the stall has been found to begin, the stall can be prevented
from spreading outward until such a high angle of attack is reached that the outboard part of the wing stalls on its own. The reference wing areas where the wingtips have been rounded. A K value between the clamped and simply supported values should be used in such a case. At joint three, there are three unknown struts at this Fuselage n \$gine = 22 1 o: '- \$4000 1 b - 50 2: : 20 0; 2 - - - \$4000 1 b - 50 2: : 20 0; 2 - - - \$ substantial write-up on what was learned and what will be done in the next iteration. 1) summarizes the takeoff-weight buildup: Wo = Wcrew + Wpayl oad + Wfue l + Wempty (3 . Actually, the wing sweep theory is based not just on leading-edge sweep, but on the sweep of the wing pressure "isobars." Isobars are lines connecting regions with the same pressure. Total airfoil camber is defined as the maximum distance of the mean camber line from the chord line, expressed as a percent of the chord. CHAPTER 8 (Spec i a l Considerations i n Confi g u ration Layout Di sconti n u ity in seco n d de rivative Ten d s to sepa rate here. As men tioned earlier, mission legs involving combat, payload drop, and refuel are not permitted in this simplified sizing method but will be discussed in a later chapter. 545 546 A i rcraft Des i g n : A Conceptu a l A p proach This shear force must be the sum of the horizontal stresses times th(elemental areas above the cut. Note that Figure 4. The center of pressure moves rearward as well, causing a CHAPTER 4 Lift cm (+) A i rfoi l a n d Wing /Ta i l Geometry Selection Pitc h i n g moment a bout a i rfoi l q u a rter-chord D rag polar U nsta ble brea k () - Fig. 4 J0 [0 i Fig. 1 2 0.25 0.803 0.373 0. By definition, the lift force is perpendicular to the flight direction while the drag force is perpendicular to the flight direction. Today, wood is used largely in homebuilt and specialty, low-volume production aircraft. Figure 12.3 shows typical separation points for various shapes, but realize that the actual separation point is complicated and changeable. Also, the camouflage paints used on military aircraft are ,rough compared to bare metal or composite skins, This must be considered before selecting certain airfoils 1 1) Awetted S b (S wetted wet /Sref) Figure 3.5 plots maximum L/D for a number of aircraft vs the wetted aspect ratio and shows clear trend lines for jet, prop, and fixed-gear prop air craft. / er i' * C.G- IS ho..., e bvi 1 13 A 1>.J * C.G- IS ho..., e bvi 1 CHAPTE R 2 Overview of the Desig n Process During detail design, the actual parts get designed including all the indi vidual structural components, and all the rest. This is avoided with a pusher propeller and is the reason that few modern jets have conformal nacelles in which the exhaust rubs along the aft fuselage. p/ In the past, the aircraft designer would select airfoils from a "catalog," most likely the famous book by Abbot and Von Doenhoff. For example, in the simple cruise mission the legs could be numbered as 1) warm-up and takeoff, 2) climb, 3) cruise, 4) loiter, and 5) land (see the example mission at the end of this chapter). The required amount of mission fuel depends upon the mission to be flown, the aerodynamics of the aircraft, and the engine's fuel consumption. They are too good! Typically, they've been tailored for production part design, not the "everything will change" environment of conceptual design. cross-section Fig. Do these req u i rements p rod uce a viable & sa lable plane? Furthermore, during conceptual design a number of alternative designs are studied to determine which design approach is preferred. [xce.(-6 -4 < 0 . Chapter 21 covers vertical flight including helicopters and vertical takeoff jets. might be preferable today. We sometimes "cancel" the pounds and say "per hour" (1/h) as the units-but it is just a joke! In metric terms we use the more reasonable mg/Ns. Figure 3.3 shows trend lines of SFC vs Mach number. 4.8. The speed at which supersonic flow first appears on the airfoil is called the "critical Mach" Merit · At higher speeds, the shock gets stronger. This is illustrated by the ratios of wetted area to wing reference area (Swet Sref). For the determination of the limit stress, this equation can only be applied to parts that are laterally constrained (such as spar caps and sandwich face sheets). 0025 0.01 2 0 .0036 11 - 10 - 0 .025 0 .01 8 23.2 1 1 0.0 1 6 .9 1 95 204 219 1 05 200 23 .2 4.0 1 6 .9 1 0.4 4 .85 7.4 1 0 .2 4.3 23.9 1 00 18 353 111 73.9 69 40 I I I I I I I 23.9 20 18 40 1 8.5 22 .4 33 20 mw+llJllH 3.6, it would appear that the wetted area ratio (Swet /Sref) is about 5.5. This yields a wetted aspect ratio of 1 .27 (i.e., 7 /5.5). They are to be collocated as much as possible to maximize communication between team members. Heat treatment begins by raising the temperature of the steel to about 1400-1600°F {760-8700°C} at which point the cambered wing has no lift at zero angle of attack, while the cambered wing has no lift at zero angle of attack. The trend lines of Fig. The team is typically larger too, going from a handful of people to 50 or more in a large company. The main concern in the development of a good structural elements by whic h opposing forces are connected. 5 Wihydraulics = 1' h wdg Welectrical 12.5 7 (Wfuel system + Wavionics) 0. T his type of trade study comprises the majority of the design effort during the conceptual design process. Control. A negative angle of attack is required to obtain zero lift with a cambered wing. It is different from cargo handling gear, which includes the powered rollers that move pallets into position and lock them down. she) can see air." Good lofting also produces good aerodynamics. A base area fill-in effect is difficult to predict. 1 7 .6 ;,. This, however, imposes some drag penalty during regular flight. Design is an iterative process. A i rfoi l a n d Wing /Ta i l Geometry Selection CHAPTER 4 Fig. As carbon content increases, strength and brittle ness increase. An Excel spreadsheet of this sizing example illustrating both methods is available at the author's website, www. f Wo = 0. A typical fuselage with a trapezoidal wing will have an irregularly shaped volume distribution with tht= maximum cross-sectional area located near the center of the wing. The aerodynamic center is not the same as the airfoil's center of pressure, the location where the vertical forces balance. - - - b) Freestream velocity vector su btracted from local vector 🕏 - ---.... In fact, Roncz wrote his own computer codes for airfoil design, starting with the methods of [?]. 1 8 0 . Flying Magazine 5 6 A i rc ra ft Des i g n : A Conceptual A p proa c h The Book: What Is Here and How It Is Organ ized Aircraft Design: A Conceptual Approach describes the process used to develop a credible aircraft conceptual design from a given set of require ments. We'll approximate the empty-weight fraction for a composite aircraft by multiply ing 0.95 times the appropriate statistical empty-weight fraction calculated from the table. The strakes do add to the aircraft wetted area, which reduces cruise aerodynamic efficiency. The portion of the strut is analyzed as before, and the bending moment at the strut location is determined The root bending moment at the strut strut location is determined. load P. 2.2 Three phases of aircraft design. Enter the AIAA student design competition. Its size. • W e d o n 't j ust d ra w s o m et h i ng-we p i ck certa i n p a ra m eters that relate to des i red ft i g ht cha racteri sti cs. Cruise 4. 93 W -0 · 07) 0 10, 8 00 We 1 - 0.3773 - Wo 0.4 1 43 50,000 5 1 , 550 0.4 1 37 0.4 1 37 0.4 1 34 137 0.4 1 34 137 0.4 1 34 137 0.4 1 34 137 0.4 1 37
0.4 1 37 0.4 1 3 0.4 1 34 5 1, 585 0.4 1 34 20,7 1 3 2 1, 291 2 1, 3 1 0 2 1, 323 = 0. These can be used to improve flow over the wing flaps, or to fix a flow problem at the horizontal tail, or both. 7.39 \\\ Automated revision of wing geometry. 4flf Aluminum Remains by far the most widely used aircraft material. However, the wing is located aft of far the most widely used aircraft material. the center of gravity whenever a canard is used, so that the fuel located in the wing is also aft of the center of gravity. The major fuselage loads are carried to the skin. At a later date, an airfoil/wing optimization code will be run to define the best airfoil geometries. 3 Effects of wind. The properties of steel are strongly influenced by heat treatment and tem pering. A more sophisticated density checking method called net design is the evaluation and refinement, with the customer of the design requirements. I terate Calcu lated W0 & Wtuel First-order design methods as discussed later will tell you that you should revise the T/W, W/S, and wing planform parameters. 7 .37 Fuselage wetted-area plot. Strangely enough, the vortex generators cause almost no increase in parasitic drag, even on a flat plate. The odds are minuscule that the "outsider" would then submit a proposal better than those of the major aircraft companies, even with a small-business set aside. (12.4). Since there is only one concept under consideration the tools used can be more sophisticated and expensive, including complete never build the Dash-One. The terms in Eq. (17.31) that vary with velocity are expanded, and the derivative with respect to velocity is set to zero in Eq. (17.32). 8 75 (cos Avt) - 1 A e .35 (t/ c) � O · 5 L 0 · 2 5 5] 302 04 0 10 (15.28) X (1 + Kws P (L/D) · where Kws = 0.75 [(1 + 2A)/(1 + A)] (Bw/L) (tan A) to correct for effects of . There are many levels of aircraft sizing procedure. Many military missions include aerial refueling. M1 16 14 12 10 J(8 6 4 J 2 r / S i m ply supported edges I f l f L; T 2 Fig. This called the "aerodynamic center" and is usually close to a point 25% back from the airfoil leading edge. The angular deflec tio n iii radians is determined from Eq. (14.46). FF 4000 Fig. But, to draw a new aircraft concept you need to have firm numbers for parameters such as wing area and engine size, and those can be properly cal culated only from specific requirements. Gyro horizon, directional gyro Heads-up d isplay Lavatories Long-ro nge a i rcroft Short-range aircraft Business/ executive aircraft Arresting gear Air Force-type Navy-type Catapult gear Navy carrier-based Folding wing Navy carrier-based Folding wing Navy carrier-based * Mass equiva lent of weight. #fII Airfoil Lift and Drag An airfoil generates lift by changing the velocity of the air passing over and under itself. 8.4 Sears-Haack volume distribution. 39) D2 - Di cos(L/j) Di sin(L/j) (14.40) ' where $j = Ci = V \pm i7P$ D2 - Di cos(L/j) sin (L/j) ---- (14.41) (14.42) C2 = Di = Mi - wj2 (14.43) D2 = M2 - wj2 (14.44) From a design point of view, most wing struts seem to be set at around 40 degrees up from horizontal as seen from the front. A cheap design doesn't prove much, but an expensive design may never get built. in detail in cussed dis are []]1.4 [] Beam Shear and Bending A common problem i n aircraft design is the estimation of the shear and bending stresses in the wing spars or fuselage. 039 x --(15.48) vt cos 2 Avt (If Avt is less than 0.2, use 0.2) 1.086 (Nz Wdg) 0.1 77Lt-0. Those involved in design can never quite agree as to just where the design process begins. Then the appropriate line is selected by calculating the wing aspect ratio times the tangent of the leading-edge sweep, and the vertical-axis value is read. Sizing & perform a ri ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & perform a ri ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & perform a ri ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing - -, I Refi ned sizing & performa n ce optim ization Fi rst-guess sizing & performa n ce optim ization Fi rst-guess sizing & performa n ce optim ization Fi rst-guess sizing & performa n ce optim ization F previous chapter discussed stability and control, which concerns the rotational motions of the aircraft. This shows the critic al case of a rolling pull-up with the additional lift load of full aileron deflection . A design concept is developed to meet the requirements as initially imagined, based on sizing calculations as initially performed. :: 8. Modern airfoil design is usually based upon inverse computational sol utions for desired pressure or velocity distributions on the airfoil. > i" o 8" @ 63. During preliminary design the specialists in areas such as structures, landing gear, and control systems will design and analyze their portion of the aircraft. If a chart for the actual taper ratio of a wing is not provided, interpolation must be used. 1 3) 41 42 A i rc r a ft Des i g n : A Conceptual A p p ro a c h Takeoff-Weight Ca lcu lation Using the fuel fraction found with Eq. (3.13) and the statistical empty weight equation selected from Table 3.1, the takeoff gross weight can be found iteratively from Eq. (3.4). LJ a) O deg b) O deg/90 deg c) ±45 deg d) O deg/±45 deg/90 deg �� 1 \$1\$ was also explained that theoretically this could be proven to depend not on the actual velocity perpendicular to the leading edge. However, the compression stresses experienced due to bending in a buckled column are much greater than the applied load would directly produce. 70 4 .23 11 L = Longitudinal direction: T = transverse range. The i mpact of rigid welded connections in a typical aircraft application is con side re d only in the definition of effective length in the column-buckling equation (see Fig. 8.6. In the B-70, the inlet duct was faired back into a wide nacelle, with a steadily widening cross-sectional area until a maximum was reached (Fig. 78 1 .28 l . As a result, the actual drag while flying at the velocity for best range will be higher than the drag at the velocity for best L /D. by -f.j • f>rcfe f/e,... O. Furthermore, all the "little pieces" not even considered during preliminary design must be designed during this phase. If the later calculation says that a general aviation (GA) airplane wing of 100 ft2 should weigh 90 lb, something is prob ab ly wrong! Another tool commonly used early in a design project is the "weight b udget." This is simply a listing of the major components of the aircraft, with rough estimates of their weight based on statistical ratios for typical air craft in that class. Section lift coefficient: C1 - Section lift qc (4. Flight simulators are developed and flown by both company and customer test-pilots. Some of these things are equipment such as antennas and lights, and some of these things are minor design details such as fuel drains and cooling vents that are not normally considered during conceptual design. They have been taken from (113-115] and other sources. Discovered in 1827, it remained an expensive novelty until an electrical extraction method was developed in 1 885. 8.9 Spanloading for weight reduction . But remember, this is based on the concept of the "mean aerodynamic chord," as shown in Fig. Real wings fall below these curves as shown. Figure 3.6 shows a spectrum of design approaches and the resulting wetted-area ratios. The T-38 has such a
base area between its nozzles. This initial layout is analyzed to determine if it really will perform the mission as indicated by the first-order sizing. 579Nz w:enginemounts w: = (15.4) L (15.6) (15. >f vai .ble bl11.1; ... and H and I in g Qualities CHAPTER 1 6 rTT 1.2 a) 1.0 x. With a rounded forebody, at some high angle of attack such vortices will form, but the vortex on one side might form sooner than on the other. Actual airfoils have lift-curve slopes between about 90 and 100% of the theoretical value. If it is being designed to be built in the more distant future, then an estimate of the technological state of the art must be made to determine which emerging technologies will be ready for use at that time. While initially cheaper, this may not be a good idea in the long run. If it is easy to retract the landing gear directly inward with your CAD system, you may do so even if a better design would result from having it retract inward and forward at a difficult-to-construct oblique angle. When they think they've found one, they design an airplane and contact the airlines to try to get them interested. Its programs enhance scientific literacy and advance the airlines to try to get them interested. load of 9463 lb. Instead, the induced drag for an idealized wing with no camber or twist is determined, and then profile drag and twist/camber effects are estimated on the air, and lift equals the integrated vertical component of pressures on the wing. The pitching moment in the middle graph is nearly constant because we are deliberately measuring it about the guarter-chord point. Also, the curvature of the surface can either prevent or encourage the transition from laminar to turbulent flow. An airfoil designed to operate in supersonic flow may have a sharp or nearly-sharp leading edge to prevent a dragproducing bow shock. This points to a serious barrier to entry for someone starting up a new aircraft company. Bending stresses C H A PT E R 1 4 Structu res and Load s Shear stress m a g n itude Spar a pprox i m ations Q ''''' k 🕏 Bending stresses C H A PT E R 1 4 Structu res and Load s Shear stress m a g n itude Spar a pprox i m ations Q ''''' k To use these charts, the wing aspect ratio, taper ratio, and leading-edge sweep are employed. If the designer is talented, there is a lot more than meets the eye on the drawing. CHAPTER 4 A i rfoi l a n d Wing /Ta i l Geometry Selection change both thickness and camber. While ideal span-loading is rarely possible, the span-loading concept can be applied to more conventional aircraft by spreading some of the heavy items such as engines out along the wing. (17.20) and (17.21). More recently, the low-speed airfoils designed by John Roncz were instrumental to the success of Burt Rutan's radical designs. 0& I A ConceptualApproach Conceptual Desig n Exa m p les C H A P T E R 24 AIRCRAFT DESIGN J>ROfVL.S ION • This is a two-step process. 10, the lower longerons are placed near the bottom of the aircraft. to disappear. There are many trade studies that could be conducted other than range, payload, and material. Note the stainless-steel heat shield and nozzle interface, required because of the high temperatures around the engine. become turbulent at a lower Reynolds number if there is substantial skin roughness. 3.5 b 1Swet = A/(SwetfSref) Maximum l ift-to-drag ratio trends. There is not enough time in a semester course to really learn how to do conceptual design, and ANY time spent learning which button produces which geometry is time NOT spent learning the philosophy, methods, and techniques of aircraft conceptual design. But you have to start somewhere. To the uninitiated, "designer spends the day hunched over a draft ing table or computer terminal. 1 3 Payload trade. As shown in the illustration on the right, we normally plot drag coeffi cient vs lift coefficient, not vs angle of attack as one might imagine. (It looks more like a bucket when plotted with the drag coeffi cient as the vertical axis.) If an airfoil is designed to maintain a lot of laminar flow, it will have substantially less drag, as long as it is operating near its design lift coefficient. An ongoing trend for cost reduction is to use CAM technologies and innovative design concepts to minimize such hard tooling. A key aspect of conceptual design is that it is a very fluid process. They don't represent the actual physics of airflow over a vehicle. 1 Railroad curves reduce drag. " /.A/ l bTH DE:516N 60ALS : RAf>I/;) PE&F'OIV·MNCE : v,.,4,.. 1 Design -A Sepa rate Discipline Design wheel. 1 2.4 Drag polar. 3 (Et /R) (14. As shown in Fig. Also, at supersonic speeds the effectiveness of a vertical tail usually reduces. 0 4 6> < 0 . 14.29 are usually used for design (see [100, 108]). E m pty-Weight Esti mation After the aircraft has been drawn, the actual empty weight will be calcu lated by estimating and summing the weights of all of the components of the aircraft. This is necessary so that the aircraft when loaded Fig. 4.4). Other, similar weights equations can be found in [IG, Is, 40]. It is only near the stall angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the moment "breaks" up or down., depending upon the shape of the aircraft angle that the air n c e p t u a l A p p r o a c h What We've Lea rned Calculation of the static margin tells you i f the wing needs t o be moved, while trim, pull-up, and turn calculations tell you if the elevator and horizontal tail are large enough. The drag polar has an approximately parabolic shape, as defined by E q. The engine produces thrust via the propeller, which has an efficiency 1/p defined as thrust power provided to the propeller [Eq. (3.9)]. 05} - 0. This design concept is then subjected to design ana lysis such as aerodynamics and performance calculations. Aerodyn a m ics calculations i n c l u d e maxi m u m s u pe rs on i c wave d ra g. The resulting accelerations on the aircraft mass (W/g): (F "i.Fx = T cos (a + L) = V (CL + c c cD0) f Kc 2W/pVS (17. There are many of them, but for aircraft design purposes the most important are FAR Part 23, the Air worthiness Standards for Normal, Utility, Acrobatic & Commuter Category Airplanes, and FAR Part 25 for Transport Category Airplanes. It can be seen that the effect of the airfoil is to introduce a change in airflow, which seems to circulate around the airfoil in a clockwise fashion if the airfoil nose is to the left. (16.13) and (16.14) based upon the angle of-attack definitions from Fig. For a rectangular wing the span divided by chord. 1 4.28 Column effective length . m ::0 .,.. 0 50 . Nose strakes, or the similar sharp-sided "shark nose," are used to force vortices to form simultaneously on both sides of the forebody at higher angles of attack. The Wittman Tailwind, which is remarkably efficient, uses this approach. Military missions are specified in MIL-C501 1A). To this was added a separately-optimized thickness distribution (or that of a suitable existing airfoil). However, such an aircraft is basically designed for subsonic cruise efficiency so that the equation for military cargo /bomber can be used. The advanced design departments of CH A PTER 1 Desi g n-A Sepa rate Disci pline the major aircraft companies are not very large, and the smaller companies are not very large, and the reference wing is the airfoil of the trapezoidal reference wing at the of the aircraft, not where the actual wing connects to the fuselage. You will see flat-bottomed airfoils plot ted using a reference axis oriented along the flat bottom, so that the leading-edge point is given as a positive value on the vertical axis. da To y the truss structure is largely used in piston-engine motor mounts, the rib s of large aircraft, and landing gear. Odd as it sounds, an airfoil in two-dimensional inviscid flow does not experience any drag due to the creation of lift. The disadvantage of this concept is the difficulty in reaching the engines for maintenance work. 49 A o. It is difficult and unnecessary to build a perfectly sharp trailing edge, so most airfoils have a blunt trailing edge with some small finite thickness. $Cr_{,,} = (21TA) - --, = = 2 + \tan 2A$ max t A 2 {32 4+71 + {32 re (F) (1 2.6) where {32 T/Amax t = 1 - M2 (12.7) 2 7T/f3 (12.8) = Cc_{,,}} is the sweep of the wing at the chord location where the airfoil is thickest. First, the shear and bending moment distributions must be determined, and then the resulting stresses must be found. A conceptual design layout can't show all of the internal components that will be packed inside by the time the airplane flies. 0.6 A tan /3 ALE 41 x•. Square cross-section three-dimensional trusses, such as a typical welded-tube fuelage, can sometimes be solved separately in side view and top view as two-dimensional structures. For example, controls experts will
perform a six-degrees-of-freedom analysis to ensure that the designer's estimate for the size of the control under all conditions required by design specifi cations. This is typical for short columns with very thin walls. Simply stretching the airfoi in the vertical direction will / t/c *To a very rough approximation, a one percent increase in C1-max. Only a trade study can ultimately determine which approach is lighter for any particular aircraft. Then there are the various "customer-centric" requirements, the actual mission and performance capabilities needed by the potential customers. A fighter aircraft has several hundred thousand parts. 75 {2 . For example, a canard should not be located such that its wake might enter the engine inlets at any possible angle of attack. We do it because we love it so much that we to do it. IfIU Range Optimization-Prop for Substituting Eq. (17.4) into Eq. (17.23) yields the Breguet range equation pro peller-powered aircraft [Eq. (17.28)). These compression or tension stresses are found from Eq. (14.35) (for derivation, see [99]), where M is the bending moment at the spanwise location and is the vertical distance from the neutral axis. In industry, designs are typically given a project and drawing number such as D645 5. A i rfoil a n d Wing /Ta i l Geometry Selection CHAPTER 4 Wright 1 908 c== - Bleriot c ---- RAF-6 c=-:::::--.... similar to those shown. • lift, para s itic d ra g, d ra g due to l ift, and C l a ssica l m ethods a re presented, and mod ern CFO i s d i scussed . The Global Hawk has a wetted aspect ratio of 6.8 and attains an L/Dmax of over 35. 93} - 0.06 Kvs = variable sweep constant = 1.04 if variable sweep We and Wo data for aircraft similar to your project, plot the data onto Figure 3.1, and draw a reasonable trendline with slope. For many aerodynamic calculations it has been traditional to separate the airfoil into its thickness distribution and a zero-thickness camber line. The critical slenderness ratio depends upon the material used. MOST- A-FT C. 8.5 Design for low wove drag. Whisker reinforcing is sometimes used in advanced metal matrix composites such as boron-aluminum. Aspect ratio C H APTE R 1 2 Su personic 2-D t h eo retical S u bson ic 2-D t h D theoretical L a - $/M24_-lc 107 \oplus 6$ Qj a. 1 4.33 LM = 0 = -69.9 (4000) - 30 FF FF = -9463 cos LFH = 0 = 3919.2 + FE 22 h = 5775 cos 1 1 sin 11 Method of moments/method of shears. Titanium is also corrosion-resistant. The steel-tube fuselage, used extensively by Fokker, g reatly improved strength and required less maintenance. For military aircraft this is often less than the maximum takeoff weight. r.J..," '. For typical aircraft, Eq. (7.13) provides a reasonable approximation. To prevent separation of the airflow, the aft-fuselage deviation from the freestream direction should not exceed 10 or 12 deg (Fig. To reduce drag, it is common to sweep the leading edge behind the Mach cone. For example, the drag on a wing includes forces variously called airfoil profile drag, skin-friction drag, separation drag the reinforcing material are randomly located throughout the matrix. For "indeterminate" trusses, more complicated methods based upon deflection analysis can be performed (see [98, 108]), or a finite element structural analysis can be used (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite element structural analysis can be performed (see [98, 108]), or a finite e is speeded up relative to the freestream velocity. We. Pt or =- 1 10'2. r- 0 c a. The £ terms are the x and y distances from the simple shapes' centroidal axes to the new axes (see Fig. 02.. It is the CAD database developed in detail design that is actually passed to computer-aided manufacturing machinery. 43 44 Aircraft Des i g n : A Conceptual A pproach due to the exhaust over the wings and also provides greater ground clearance for the engines, which reduces the tendency of the jet engines to suck up debris. CHAPTE R 8 Spec i a l Considerations i n Confi g u ration Layout D B-70 bottom view Fig. Structures a n d Loads Trapezoidal approximation for each span station is the sum of the vertical loads outboard of that station. This is sometimes done before working with steel to make it easier to cut, drill, and bend. For a subsonic aircraft the best SFC values are obtained with high-bypass turbofans, which have typical values of about 0.5 for cruise and 0.4 for loiter. A similar point can be found for the complete trapezoidal wing, where the pitching moment doesn't change with angle of attack. The equation at the bottom of Fig. Canards offer the potential for reduced trim drag and may provide a wider allowable range for the center of gravity. If this load is in excess of what the engine can with stand, a vertical motor-mount strut should be welded between joints two and three. 2Npo. 27i $\phi_{0:..t}$ "bo ϕ) 891 892 A i rcraft Desi g n : A C o n c e p t u a l A p p roa c h AIRCRAFT DESIGN SPIN 'REC.OVER.V ($\phi_{..}$ 1'-.3-1) fva\..., ϕ 1-c.,,t'-> L.= 230, ..., : 1"1.'2. These areas are not "wetted." 205 206 A i rc raft Desi g n : A C o n c e p t u a l A p p roa c h AIRCRAFT DESIGN SPIN 'REC.OVER.V ($\phi_{..}$ 1'-.3-1) fva\..., ϕ 1-c.,,t'-> L.= 230, ..., : 1"1.'2. These areas are not "wetted." 205 206 A i rc raft Desi g n : A C o n c e p t u a l A p p roa c h AIRCRAFT DESIGN SPIN 'REC.OVER.V ($\phi_{..}$ 1'-.3-1) fva\..., ϕ 1-c.,,t'-> L.= 230, ..., : 1"1.'2. These areas are not "wetted." 205 206 A i rc raft Desi g n : A C o n c e p t u a l A p p roa c h AIRCRAFT DESIGN SPIN 'REC.OVER.V ($\phi_{..}$ 1'-.3-1) fva\..., ϕ 1-c.,,t'-> L.= 230, ..., : 1"1.'2. These areas are not "wetted." 205 206 A i rc raft Desi g n : A C o n c e p t u a l A p p roa c h AIRCRAFT DESIGN SPIN 'REC.OVER.V ($\phi_{..}$ 1'-.3-1) fva\..., ϕ 1-c.,,t'-> L.= 230, ..., : 1"1.'2. These areas are not "wetted." 205 206 A i rc raft Desi g n : A C o n c e p t u a l A p p roa c h AIRCRAFT DESIGN SPIN 'REC.OVER.V ($\phi_{..}$ 1'-.3-1) fva\..., ϕ 1-c.,,t'-> L.= 230, ..., : 1"1.'2. These areas are not "wetted." 205 206 A i rc raft Desi g n : A C o n c e p t u a l A p p roa c h AIRCRAFT DESIGN SPIN 'REC.OVER.V ($\phi_{..}$ 1'-.3-1) fva\..., ϕ 1'-.3-1) fva\..., ϕ 1'-.3-1 ϕ 1 back at approximately the Mach angle [arcsine (1/M)], as shown in Fig. Vol • 3.4 (A top) (A side) 4L (7. The aspect ratio improvement for winglets estimated by Eq. (1 2. 8.10 are high enough that they pass over the wing-carrythrough
box. Note that they pass over the wing-carrythrough box. = = chord length dynamic pressure = p angle of attack slope of the lift curve V2 /2 = 2'1T (theoretical thin airfoil) When calculating any moment, one has to choose which point to use as the reference location. C H A PT E R 1 4 2 Structu res a n d Loads Joint 2 cos 2 7 sin 2 7 'LFH 0 Fe FA FD FA 'LFv 0 Fe = -39 1 9 (T) FD = (C) = = = - - - 2000 Joint 3 l, fH 0 = FA Uv 0 = FA = = FA Fs = = cos 27 FB cos 2 7 sin 27 - F8 sin 27 - 4000 + 4400 (C) Fig. The calculations in Box 3.1 indicate a takeoff gross weight of 56,702 lb {25,720 kg}. (14.23) and (14.24)] and has units of length to the fourth power. 25 L0. The illustration on the left is commonly called the "lift curve" although it is mostly straight. That's their job. Each airfoil is designed for a certain Reynolds number. 8.3 Isobar tailoring for shock suppression . construction. 1 4.36 distributed loads. $======.,,,,,,,,,,,,\ldots$ the aircraft weight at each part of the mission can be numbered. I state beam placed at the bottom of the fuselage bending loads is the "ke elson." This is like the keel on a boat, and it is a large beam placed at the bottom of the fuselage as shown in Fig. There is a joint effort to make the FARs and CSs absolutely identical, which will simplify aircraft certification and operation worldwide. The steps of conceptual design are described in more detail in Sec. Similarly, the most efficient cruise for a jet aircraft occurs at the velocity yielding an L/D of 86.6% of the maximum L /D: Jet Prop Cruise 0.866 L/Dmax L /Dmax Loiter L/Dmax 0.866 L /Dmax For initial slZlng, these percentages can be multiplied times the maximum L/D as estimated using Fig. 2 Typical mission profiles for sizing . t I t ileron i rload I V Nacel l e (f} 1 1 1 t t t l ". _ J ! * * t l 1 t t t l ". _ J ! * * t l = 0.866 L /Dmax L /Dmax L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f} 1 1 1 t t t l = ... t l = 0.866 L /Dmax L /Dmax L /Dmax L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f} 1 1 1 t t t l = ... t l = 0.866 L /Dmax L /Dmax L /Dmax L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f} 1 1 1 t t t l = ... t l = 0.866 L /Dmax L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solution profiles for sizing . t I t ileron i rload I V Nacel l e (f) = 0.866 L /Dmax Solut Fig. However, the analysis is more complex because of the spanwise compression loads exerted upon 547 548 A i rcraft D e s i g n : A Conceptu a l A p p roach the wing by the strut. (See [67] for a more detailed discussion.) So the solution to d'Alembert's paradox is that a viscous phenomenon, normally associated with skin-friction drag, actually triggers this unexpected pressure drag. This book attempts to balance both design and analysis, tie them all together, and present them in a manner consistent with industry practice. (Data are metric, but actual numbers don't matter here.) By design, both have exactly the same wing span and the same total internal volume. Finished design layout For a tailless or flying-wing aircraft, one way to get natural stability is to use an "S" -shaped camber line, with an upwards reflex at the trailing edge. 1 2.5 Wing lift curve. Learn to fly, or at least pass the FAA Private Pilot's Written Exam. Such quick results can also be used to check the results of the more detailed statistical methods later. The importance of well-designed wing fillets has already been discussed. 14) w.starter(pneumatic) - 0 · 025Te0 .760Neno . Watch this carefully when you are managing a program. Considerations for observability, and sup portability are also discussed. Drag varies with altitude and velocity. This method involves severing the structure along 54 1 542 Ai rcraft D e s i g n : A C o n ceptu a l A p p roa c h t--- 69.6 0 30 4000 - Fe ...,..,- h? 2010) said, "The book is a big buffet of all kinds of stuff . Definitions of the terms follow the equations. These alloys are substantially heavier than aluminum or titanium and are difficult to form. This results in the low pressures being applied to the rearwardfacing area creating "base drag." The air can't even go around a forward-facing corner if it is too sharp or the body is too blunt. Also, the jet exhaust is certainly turbulent, and the propwash is likely C H AP T E R 1 2 Aerodyna m i c s to b e, which increases drag even more. This eventually leads to Eq. (17.33), the velocity condition for maximum loiter time for a C H A PTE R 1 7 prop e ller aircraft. 1 96 0.2 1 4 0.229 0.249 0.263 0.28 1 0. Often to meet a sche dule the fabrication of some parts of the aircraft must begin before the entire detail design effort is completed. CHAPTER 2 & Ne co-;, ce pt : - Design req u i rements Tech nology ava i l a b i lty Overview of the Des i g n Process - - , ideas 22, all designs had to fit into the existing hardened shelters. These form a vortex that, like a fence, CHAPTER 8 Spec i a l Considerations i n Confi g u ration Layout acts to separate the stalled from the un-stalled flow and stop the stall from spreading. It provides a close-up of the human lives inside the gig antic and impersonal-seeming Rockwells and Lockheeds of this world". Also, filament composites can have their structural properties tailored to form vortices and do something good. It may not be perfect, but it has enough realism and definition to allow an "as-drawn" analysis rather than relying upon statistical and "eyeball" estimates. The results also include required revisions to the engine and wing sizes. Other materials such as chromium, molybdenum, nickel, and cobalt are alloyed with steel to provide various characteristics. If a larger aileron is required, the designer must ensure that it can be incorporated into the design without adversely affecting something else, such as the flaps or the landing gear. For more information, please visit www. The customer, civilian or military, feels that the design begins with requirements. Slenderness ratio: (14.30) 535 536 A i rc raft Des i g n : A C o n c e p tu a l A p p roa c h 0 Pin. In the past, the various nations of Europe and beyond each had their own certification standards. Also, real wings don't go to infinity at Mach one, as implied by the Prandtl-Glauert correction. If the flow separates more towards the rear. 7.36. In the past, fabrication was always considered from the very first initial layout, and good conceptual designers learned enough about detail design and con struction to avoid doing anything stupid. - 2 · 1 17W.uav Wav10mcs (15.21) Wfurnishings = 217. Learn to weld and to operate basic machine tools, and learn to fabricate things from composites. To s olve for the sustained load factor in terms of the basic aerodynamic and set equal to the ef co ficients, the drag is expanded using (CL leads to Eq. (17.54), which defines the maximum available sus This thrust. "Base area" is any unfaired, rearward-facing blunt surface. 18) Whydraulics = 37.23KvshN • 664 o . The leading-edge sweep is the angle of concern in supersonic flight. As already mentioned, this can be approximated in the early stages of design by taking 95% of the empty-weight fraction obtained for a metal aircraft. "" 0 "" a 🏶 CJ c.0. ::; :I> 0 0 Table 1 4.4 Ash Birch African mahogany Douglas fir Western pine Spruce 0.024 0 .026 0.01 9 0 . This percentage of the theoretical value is sometimes called the airfoil efficiency Y/· Reduction of aspect ratio reduces the liftcurve slope, as shown. 8.8. These mostly work by creating and controlling "good" vortices. Metals and whisker-reinforced composites are isotropic, having the same material properties in all directions. would be the weight after cruise, and after loiter. 57 58 A i rc raft Desig n : A C o n c e p t u a l Approa c h atmospheric Pressu re a bove atmospheric Pressu r Pressu re components in lift d i rection Fig. However, they are both dependent on the total aircraft weight. I Fig. Material Properties This section covers various commonly used aircraft materials. Then they "threw it over a wall" to the manufacturing people, who usually said, "How can I build this stupid thing?!" With concurrent engineering, detail design and production personnel are brought in at the earliest stages of design, in an IPT environment. This frequently requires a new or revised design layout in which the designer incorporates these changes and any others suggested by the effort to date. , , Al a n d fi berg lass (FG) lea d i n g edge Wing materials. This value, obtained from an initial sketch, initial sizing, wing geometry selection, lofting, inboard layout, integration of propulsion, crew station, payload/passenger compartment, fuel system, and landing gear. Obtain CHAPTE R 3 Ta ble 3 . For this textbook example, only
the last approach will be illustrated. Chapters 12-18 address the detailed analysis of the resulting design layout. However, these equations should provide a reasonable estimate of the group weights. While further changes should be expected during preliminary design, major revi sions will not occur if the conceptual design effort has been successful. Here the engines are shown mounted over the wing. Analytically, this "resets the clock." The onloaded fuel brings the aircraft weight up to or even greater than the takeoff weight, so that the post-refuel segments are treated as an entire separate mission. Note that the second cruise segment is identical to the first, indicating that the aircraft must return to its base at the end of the mission. Because this simplified sizing method does not allow mission segments involving payload drops, all weight lost during the mission must be due to fuel usage. These specify a wide variety of performance, design, and operational matters, down to the accep table color of fuel. 1 54. Obviously, a wise company is in close com munication with potential customers throughout the design of, say, a certain wing rib would be improved as a result. /9 .'f 3 't / 2-7 tt Jc ...) -= "7. ± 5 0 0 0 0 0 Fsu (LT) l o3 { { psi 12 65.5 9.0 43.2 1 5.3 8.5 - 7 .9 9 I : Typical Composite Material Properties (Room Temperature) 60 60 60 50 0 . For example, instead of the re quired 1500 n miles, we will calculate the cruise weight fractions using 1000 and 2000 n miles and will size the aircraft separately for each of those ranges. If the wing is thicker out near the tips, it is more likely to stall at the root. This makes it a poor choice for a reference location. 27 28 A i rc raft Des i g n : A C o n c e p t u a l A p p r o a c h T o get the "right" answer takes several years, many people, and lots of money. 3 Tip back (Ta i l strike) Angle ' The next four chapters discuss the design of flight vehicles that are in some way different from "normal" vehicles. As you go through the conceptual, preliminary, and detail design phases, the level of detail of the design steadily increases. The design concept is then revised, based upon everything that has been learned. The air can't go around a rearward-facing sharp corner such as the back of a cutoff fuselage. 8 4. Conceptual design is the focus of this book. This is shown in Fig. Steel is also easy to fabricate. Viscous separation drag is also easy to fabricate. Series; then, navigate to the desired book's landing page by clicking on its title. 307 0. This causes the relative velocity of the air to vary about the aircraft. 35) The vertical shear stresses within a beam are not evenly distributed from top to bottom of the cross section, so the maximum shear stresses within a beam are not evenly distributed from top to bottom of the cross section. total shear divided by the cross-sectional area. If you' re good at it, you'll get a better airplane with more capability at less cost. 4.3b, the freestream velocity vector caused by the presence of the airfoil. For wings of moderate camber, this offset is usually small which implies that CD0 approximately equals CDmin and that Eq. (12.4) can be used. You never build the very first design layout. 1 1) is for a typical modern winglet. Simple statistical methods will not work-we need to "fly" the aircraft over its required mission. The statement that the pitching moment is almost independent of angle of attack about the quarter-chord is actually true only in slower subsonic flight. Kneeling landing gear is uncommon but is seen on the C-5 where the landing gear can lower the aircraft closer to the ground for loading. --1 "". (a.u o/ = turn rate Fig. :::;. Today the technology has improved, and the cost of titanium fabrication is just slightly higher than aluminum fabrication. (1-10 F1trE&Gt.lfSS) .f.; 5"l> le.T'S ...-ese.-ve (1... The proper horizontal reference axis for an airfoil starts at the "leading edge," but the exact definitions of those terms might not be obvious. It is possible in many CAD systems to forget to account for, or double-account for, the wing root airfoil "wetted area" that must be removed from the fuselage and not included with the wing! This potential problem is minimized if true "solid models" are (properly!) employed. The sizing specialist the weight is made. Sometimes a CAD system may confidently display an incorrect answer! For example, we might model the wing as a collection of airfolis connected by a mathematical surface and might readily calculate the weight is made. using spanwise control lines to place and scale the selected airfoils. o X-3 1 design: early layout to final configuration (the author headed the air-vehicle design during the concept development phase). However, in actual viscous air, the profile drag increases as the angle of attack is increased, leading to some confusion. For initial design purposes, aspect ratio can be selected from historical data. This material proved strong at high temperatures but was extremely difficult to fabricate. Flying boats are heavy because they need to carry extra weight for what amounts to a boat hull. So, get ready! Make notes on what to do next. Airfoil moments are measured about the quarter-chord point where the subsonic airfoil pitching moment is essentially constant with changing angle of attack, i.e., the airfoil aerodynamic center. While area-ruling was developed for minimization of supersonic drag, there is reason to believe that even low-speed aircraft can benefit from it to some extent. Such design tricks are beyond the scope of early conceptual design but can be approximated on the initial design layout based on similar aircraft. Once production begins, problems are often uncovered, and the tooling and production processes must be modified. (17.13) and (17.14): (17.2s; Aff11 Loiter Endurance The amount of time an aircraft can remain in the air is simply its fuel capacity divided by the rate of fuel consumption (thrust multiplied by specific fuel consumption). * This is an exaggeration, to make a point. And it's in the brilliant concept that a major advance is achieved". The sizing method presented in this chapter is most accurate when used for missions that do not include any combat or payload drops. 4£ft] Cargo/Transport Weights (British Units, Results i n Pounds) W, - 0.4 (1 + A) O. 53 54 A i r c ra ft Design : A C o n c e p t u a l A p p ro a c h I t isn't possible t o pick initial values that will b e perfect i n the end, no matter how much time you spend or how many computer programs you write. Other textbooks , old reports, and online sources can be used to find other such weights. IlQI Composites The greatest revolution in aircraft structures since the all-aluminum Northrop Alpha has been the ongoing adoption of composites and a p p r o a c h relevant for conceptual design. If the severed part of the beam is to remain in vertical equilibrium, the externally applied vertical forces must be opposed by a vertical shear force within the cross section of the material, as shown. Me... For example, the lower longerons in Fig. In general, the stronger the aluminum, the more brittle it is. This vortex wraps over the top of the wing and energizes the boundary layer while acting like a stall fence. The design layout is always being changed, both to incorporate new things learned about the design and to evaluate potential improvements to the design. Steel is very cheap, costing about one-sixth what aluminum does. 1 3) : - aircraft design. However, the interactions among all the different components are so crucial that it requires years of experience to create a good conceptual design. E -...] 20 18 16 14 12 10 8 6 4 2 0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2 Blue Jets at Mach 1 . 14.18) was constructed largely of brazed steel ho neycomb. 3.1, is called the "exponent" hence the common verbal transposition. However, where that wing intersects the fuselage we must cut away the surface of the wing directions yields Eqs. 14.31 shows an equivalent truss that includes the lines of force to the e.g. of the engine, and the vertical resisting forces due to the rigid attachment of the fuselage and engine to the truss. There is far more than meets the eye. It was quite costly to certify an aircraft to operate all around the world, so the European Union launched a major effort to define a single set of specifications. ! -----• Mean aerodyna m i c chord (c) C roat c = (2/3) C root Y = (b/6) [(1 + (1 + A, + A, 2) / (1 + 1)] (assu m i n g lift is p roportional to c hord) Y m u st be d o u b led for a vertical ta i l Fig. d factor for a given flight condition. The climb gradient G is the tangent of the climb angle and is found as the vertical velocity divided by the horizontal velocity. Unless specifically mentioned, takeoff gross weight, or Wo, is assumed to be the design weight. 849 w0. Analysis of three-dimensional space structures will be discussed later. Could the wetted area be reduced some other way? Some of these things, though, are fixes to aerodynamic problems discovered later in design development or flight test. 17.3. Note that the aircraft has its nose pointed to the left of the desired ground track to compensate for the wind. For aircraft designers, typical items in the specifications include landing sink-speed, stall speed, stall speed A i rcraft Design- A Conceptu a l A p proach K e y concept: " l o a d paths" E n g i n e mou nts 🗞 - 🗞 🗞 cl ... Modern CAD systems have excellent data management tools-use them! rtu Detai l Design Assuming a favorable decision for entering full-scale development, the detail design phase begins. Wing: (16. In British {fps} units, SFC is in pounds of fuel per hour, per pound of thrust. Another form of friction drag is called "scrubbing drag." This is caused by the propwash or jet exhaust flowing over or near the aircraft's skin. Among other things, the location of the separation point depends
upon the curvature of the body. length of either one 1 or 100, and are scaled to fit the desired chord length at an actual location on the wing or tail. My suggestion-get to an initial layout quickly and use it to assess relative importance and finalize the requirements. Instead the designers are addressing top-level issues such as the number of engines required, the sweep of the wing, and the type and size of the tails. 12)], or you can directly use Fig. Instead force the soft ware to use a negative number 'C' term like those in Table 3.1 and find the constant term with the lowest square error. • Sizing finds how big and heavy the airplane must be to attain the required mission range carrying the design payload. These created small vortices that stir up the air near the surface, bringing high-energy air into the boundary layer. This helps the pilot keep control of the airplane during a stall and is especially useful for aerobatic aircraft where you cannot use twist to fix tip stall. Iii Lio. Figure 12.4 illustrates the drag polar, which is the standard presentation format for aerodynamic data used in performance calculations. The change in weight due to fuel consumption compli cates the equation. Civilian missions are defined by the a.ircraft designers, provided that they follow the various requirements defined in the US Federal Aviation Regulations (FARs) and/or European Certifications (CSs). • is. Rivet and bolt holes are included in the cross-sectional area calculation for compression because the rivets or bolts can carry compression because the forces. (Do not be confused by this presentation; the shear forces are exerted in a vertical direction, but we show the magnitude to the right to illustrate the distribution of magnitude from top to bottom.) (14.36) bly Jh/2 zdA Equation (14.36) bly Jh/2 zdA Equation (14.36) are exerted in a vertical direction, but we show the magnitude from top to bottom.) (14.36) bly Jh/2 zdA Equation (14.36 Cruise-segment mission weight fractions can be found using the Breguet range equation (derived in Chapter 17): W4 Ws (Wi / Wi - 1). The center of pressure is sometimes called the "center of pressure the air that is "stuck" to the aircraft. During concept layout, the designer must consider the requirements for aerody namics based upon experience, understanding, and a "good eye." The overall configuration arrangement and "cleanliness" of an aircraft has a major effect upon aerodynamic efficiency. CAD tools in preliminary design should allow rapidly reshaping the overall configuration as the design evolves, but must also permit definition of the entire design is done on a drafting table, it should be understood that today most aircraft design work is done on a drafting table entire design is done on a drafting table. Instead, we pick values for certain parameters that set their shapes and lytically. 8.8 Body or nacelle strakes Aerodynamic fixes. This results in the point at the exact leading edge is at Z = 0.043, -0. The methods presented here are sufficient and give reasonable results for most categories of aircraft. "Viscosity" is the honey-like tendency of air to resist shear deformation. 2.1. Furthermore, during the operational life of any airplane, its roles and missions will change far beyond those envisioned when the initial design requirements were established. Notional Design Layout: Advanced Technology Commuter/Cargo Jet (D. Once the distributed loads are replaced by concentrated loads, determi nation of the shear and bending moment distributions is easy. Thus, Wo is the beginning weight (takeoff gross weight). [The FAA requires 30 min of additional cruise fuel for daytime flights under visual flight rules (VFR), and 45 min of fuel at night or under instrument conditions (IFR) .] Under commercial IFR regulations, you also need fuel to fly to an alternate airport after loitering and attempting to land at your intended destination. In metric, power SFC is given in mg/W-s (mg/J, or in µ,g/J to make "nice" numbers) . For a very long body such as the fuselage of an airliner, the turbulent boundary layer will become so thick that the air near the skin loses most 393 394 A i rc raft Des i g n : A Conceptual Approach E 1 l i psoid I -- ... A complete listing of titles in the AIAA Education Series is available from AIAA's electronic library, Aerospace Research Central (ARC), at arc.aiaa.org. Av'IO NlC...S FU I I I i psoid -r V -- ... A complete listing of titles in the AIAA Education Series is available from AIAA's electronic library, Aerospace Research Central (ARC), at arc.aiaa.org. Av'IO NlC...S FU 4 CHOTE F U E' L (Ave1 i1,i.1c. Ai rcraft Conceptual design will usually begin with specific design requirements as described above, established either by the prospective customer or as a company-generated guess as to what future customers may need. These are proprietary, complicated, and highly computerized. CHAPTER 3 Sizing from a Conceptual S ketch 7 Warm up & ta keoff Crew weight = 800 lb Avionics payload = 1 0,000 lb Fig. A A Swet * 3.4 top : side () (7. The compression load P is the horizontal component of the force on the strut S. Concept one is the conventional approach, looking much like the Lockheed S-3A that currently performs a similar mission. The use of smooth longitudinal control lines in developing the fuselage contours will reduce the drag. Sl 0 . 3.5 to determine total wing drag. 5l 0 . 3.5 to determine total wing drag. used as a measure of the reason ableness of a new design. Also, obtaining a large enough budget to include the production and operations experts was always a struggle (man agement would say "we'll bring them in later, when we need them!"). While loitering on-station, this type of air craft uses sophisticated electronic equipment to detect and track submarines. Instead, this two-dimensional airfoil drag polar curve results entirely from airflow separ ation effects. The conventional design has an aspect ratio typical for Boeing and Airbus airliners, and attains a typical L/ Dm ax of 15. It is for this reason that airplanes with propellers in front and back generally fly better on the back propelle r than the front. 16. If it is supposed to be a stealth design, the radar cross section can be calculated. 9030 W? Historically, this has been a massive and expensive jigs and fixtures being built. In the larger companies, aircraft analysis is done by the sizing and performance specialists with the assistance of experts in aerodynamics, weights, propulsion, stability, and other technical specialties. Base area causes extremely high drag due to the low pressure experienced by the rearward-facing surface (see Chapter 12). Wake ingestion can stall or even destroy a jet engine. The best modern CAD systems have virtually automated design of certain parts, such as hydraulic tubing and access doors. However, the configuration designer 223 224 Aircraft Design: A Conceptual Approach does create the overall structures staff-the major fuselage frames, longerons, wing spars, carrythrough structure, and attach ment locations for the major load items. Aspect ratio is something that you select (see Chapter 4). A well-run project quickly found a collocated home of its own and brought together a diverse group of specialists to accomplish the project. Because the corrosion resistance is lessened by alloying, aluminum sheet is frequently clad with a thin layer of pure aluminum. If you assume, typically, a Sizing: the most 6% allowance for reserve and trapped fuel, the total important calculation in fuel fraction can be estimated as in Eq. (3 . Requirements also include civil or military design specifications. Integrated Prod uct Development and Ai rcraft design is often done in what is now called an integrated product development (IPD) environment, and the best range velocity and the best L/D velocity is determined as the ratio of drag coefficients (1.33/2.0) multiplied by the ratio of dynamic pressures (1.3162), or about 1. It is in conceptual design that the basic questions of configuration arrangement, size and weight, and per formance are answered. Design begins with all of these simultaneously, at a low level of sophistication, then iterates towards a solution as more and more sophisticated methods are employed. The modulus of elasticity must be replaced by the tangent modulus, described earlier. Concepts three and four explore the canarded approach. This is important-you cannot use airfoil data obtained at one Reynolds number and apply it to an airplane that will be flying at a very different Reynolds number. This delays separation and reduces boattail drag. The flow tends to separate right at the discontinuity. Also note that the lift curve becomes non linear for very low aspect ratios, due to the suction lift from the wingtip vortex. CHAPTER 7 Config u ration Layout a n d Loft C-17 Globemaster (NASA photo by Jim Ross). 0 5 2 2 4 (15.06 (1-0.06)
(1-0.06) (graphical tools such as the so-called "House of Quality" to help define requirements, assess their relative importance, and even to select design features a more, on to the next step of initial sizing and subsequent design layout. Design o bjectives & sizing m ission Aspect ratio selection E n g i n e SFC data W0 g uess * W l W.0 e q u a ti o n e --..... • N o weight d rops permitted Ass u mes subsonic speeds. It goes as far as the requirements say it goes. Equation (14.31) implies that, as column length is reduced to zero, the Euler l oad goes to infinity. Warmup and takeoff 2. A big airliner has several million different parts (plus fasteners) and hundreds of miles of wiring. P"Oft.l{e, cvh1\l-r c00oditr'oi., 5• s t- b/ITLIM 10 liferent parts (> \ \>O Lb lb \bullet - i> O ,, " 't O 10 "13 /*° 9.S2.0 I:. Later chapters will focus on the provisions for specific internal components, such as the crew station and landing gear. The appropriate cross section is the smallest area in the loaded part. The aspect ratio of the wing has historically been used as the primary indicator of wing efficiency. A 45-deg line from the origin represents where the guess equals the calculated value, so that the intersection of this line with the line of the answers is the solution. They were defined in [69] and have been used in a number of textbooks. 7, where t is the thickness of the member and b is its width. A large LE radius helps the air stay attached at higher angles of attack, giving a higher stall angle and more lift for takeoff and landing. As the airflow moves around a body, it is accelerated until about the point of maximum thickness, then it slows back down as the rear is approached. The analysis techniques are simplified enough to permit the student to experience the whole design process in a single course. 8.5, the main

contributors to the cross-sectional area are the wing and the fuselage. 020 0.01 6 0.01 6 1 4 .8 1 5.5 1 0 .8 1 1 .5 9. The airflow over the wing tends to separate toward the trailing edge. Vv - ft/; s 1...l_Soo 2... This design technique, developed by R. This solution is seen on the Beech Starship among others. fUSE L.A, € 16..?.S) 6ltS j., AT (s. 2 3 Composite material types. Strakes below the cockpit were found to cure this problem, even though they are located about 100 ft {30 m} ahead of the tail. 8.3 was configured for compression lift as well as isobar sweep. In the ideal case, the weight of the aircraft would be distributed along the span of the wing exactly as the lift is distributed (Fig. 42 1 9 0.42 1 9 2 1,803 33,756 33,835 33,839 33,842 W0, calculated 89,6 7 1 80,265 80,22 1 80,2 1 9 80,2 1 7 sizing equation (3.4) is parametrically varied by assuming different payload weights. Also, the real world usually offers a wind that is neither a headwind n or a tailwind. and SR2). 0 ALE r--v .,;/ I \bullet 1 I I \bullet 1 - I c: 7 - 4 - , - 3 ... I 2 L- 1 e-- ... i. \bullet - I I I Subsonic \bullet 1 I U ns wep t I i 5 f3 ta n v- I I tan LE 4 - 0 f3 '3 0.2 = 1 A L- / - :1.-0 \bullet / / -.(/. 7 . Bernoulli's equation shows that higher velocities produce lower press ures, so that the upper surface of the airfoil tends to be pulled upward by the airfoil tends to be airfoil tends to be pulle lower-than-ambient pressures while the lower surface of the airfoil tends to be pushed upward by higher-than-ambient pressures. No textbook can contain the methods actually used in industry, which tend to be proprietary and highly computerized. 14.27, bottom). that modification can have a major impact on performance or weight. An example for a new general aviation is shown as Fig. The laminar airfoils require extremely smooth skins as well as exact control over the actual, as-manufactured shape. It is also assumed that the shear is constant within the web, and therefore the maximum shear stress equals the average shear stress (shear divided by web area). It is only in three-dimensional flow that drag due to lift is produced. An old rule of thumb is that the negative angle of attack for zero lift in degrees equals the airfoil's percent camber (the maximum vertical displace ment of the camber line divided by the chord). All of the aerospace companies have developed their own design handbooks and "best practices," which have served them well. The further along a design progresses, the more people are involved. In this author's experience, it is more common for the companies to get the initial idea, do some design studies, and then take them to the potential military customers. * There is another way of looking at lift-behind the wing there will be a downwash, geometrically caused by the airfoil angle of attack and camber. Optimization techniques are used to find the lightest or lowest-cost aircraft that will both perform the design mission and meet all performance requirements. over its upper surface is increased. Appendix D provides geometry and section characteristics for a few air foils useful in conceptual design. Airfoil lift changes linearly with angle of attack, up to an angle near stall where flow separation starts to occur. Welded steel tubing structure is usually normalized after all welding is completed to return the steel around the welds to the original strength. There is a big problem when airfoils go fast. Figure 14.30 provides the buckling coefficient K for Eq. (14.34) based upon panel length-to-width ratio and end constraints. I S u percruise l ig htweight fig hter Fig. Because this is a jet aircraft, the maximum L/D is used for loiter calculations. 14. This is not necessarily the same as the maximum takeoff weight. The goal at this point is to see if it actually meets the required mission range as estimated in the initial sizing. 3.1, developed by the author from data taken from f61 and other sources. To reduce cost, some airplanes have been designed with simple square cross-section shapes. r,.;;r"- - I - -r tan AL\$;6 i 1-1 I? 0.2 0 --- L I I 0 1 .4 1.2 1.0 x•. Chapter 2 discusses how the conceptual design process works and how it fits into the overall process of aircraft development. 09 1 w.e1ectnca . Sizing literally determines the size of the aircraft development. 09 1 w.e1ectnca and how it fits into the overall process works and how it fits into the overall process works and how it fits into the overall process works and how it fits into the overall process of aircraft development. carrying its intended payload. \. By "squeezing" the fuselage at that point, the volume-distribution shape can be smoothed and the maximum cross-sectional area reduced. This offers a tremendous weight savings. A rough estimate for the crippling stress of a thin-wall cylindrical tube is shown in Eq. (14.33), where t is the wall thickness and R is the radius. In preliminary design, our example wing spar's overall geometry as defined in the conceptual design phase is refined, including the actual shaping of the spar's cross section. 2.2. Starting with the requirements as discussed above, the process CHAPTER 2 Overview of the Des i g n Process Conceptual Design What req u i rements d rive the des i g n ? L z. Various chapters discuss aerodynamics, weights, installed propulsion characteristics, stability and control, performance, cost, and sizing. This injects realism into requirements definition, even if that design is not ultimately built. Visit ARC frequently to stay abreast of product changes, corrections, special offers, and new publications. 'b - c. F or ill ustration purposes this will be analyzed as if it were a two-dimensional 12 11 10 9 8 / Clamped sides and ends 7 K 6 5 4 3 2 One side clamped, one side free, ends t simply supported One side free, one side and ends simply suppo ed 1 0.385 0 0 3 2 4 alb Fig. The lower illustration of Fig. Wing stall tends to start at the wing root and spread outward. 12.. For reasons that will be derived later, the most efficient loiter for a jet air craft occurs at a slower velocity that yields an L/D of 86.6% of the maximum L/D. The drag at subsonic speeds is composed of two parts. It should be understood that there are no "right" answers in weights esti mation until the first aircraft flies. Look for problems. Ix = 2-yz dAi (14.23) Iy = 2-xz dAi (14.24) Ip = J = 2-rf dAi = Ix + fy (14.25) Note that there are two properties called "moment of inertia." Here we refer to the "area" moment of inertia which is purely a property of the geometry and is used in structural calculations. These results will form the basis of the Dash-Two drawing, and beyond. Equation (14.37) defines the critical buckling shear stress for a shear web. Therefore, the endurance for jet aircraft is maximized by maximizing the L/D, as determined from Eqs. We airplane designers just call it a railroad curve, and eyeball it to look like this. SPF /DB is a process where the titanium is placed in a press mold under extreme temp erature and pressure such that it virtually "flows" to the shape of the mold. 5 wdg.556Nz .536Lt- .5 x 5 3 5 K . At the top level, sometimes so obvious that they are ignored, are the overall assumptions and framework for the new design project. Aluminum is the most abundant metal in the Earth's crust, occurring mostly as silicates in clays. And remember, you never build the Dash-One. The fuselage and similar bodies should be designed using a deliberate longitudinal control scheme, as illustrated by classic conic lofting. The aircraft may burn almost as much fuel during the low-level dash segment as it burns in the much-longer cruise segment. 39} - 0. In most cases the requirements will include or imply some specific equip ment that is needed to perform the aircraft's mission, ranging from bombs and radars, to toilets and cargo handling gear. Raymer, courtesy Conceptua l Research Corp.). The actual wing and tail sizes are set later using methods discussed in Chapter 5, which also addresses the selection of engine size. Camber gives lift at zero angle of attack and increases the maximum lift of an airfoil,* but also increases drag and pitching moments. 15.3. If Ls/Ld is less than (15. To obtain a solution from the two equations (vertical and horizontal), the solution must begin at and always proceed to a joint with only two unknown struts. 3.5 is more relevant to the actual physics of drag. 75 I n let front face Fig. During conceptual design though, those parameters are constantly being changed, almost every week in the early stages. Fshear buckle = KE (t ltll1p / b) 2 (14. 13Sfw Wengine section = 0 .01 W ? 1 7NenNz v Ld0 . Note the effort to ensure consistent dimensions, including the conversion of cruise velocity (Mach 0.6) to ft/s by assuming a typical cruise altitude of 30,000 ft {9144 m}. This is analytically related to the longitudinal change in the aircraft's total cross-sectional area. The primary forces to be resolved are the lift of the wing and the opposing weight of the major parts of the aircraft, such as the engines and payload. Furthermore, it is flammable! M il Specs advise against the use of magnesium except to gain significant weight savings. 7 are probably the best approximate method available. (3. V TV TV 7/p = p- = 550 hp { fps} (3.9) 35 36 A i rcraft D e s i g n : A C o n c e p t u a l A p p roach 60 u u.. Figure 8.10 illustrates a structural arrangement for a small fighter. Here is another common source of confusion-the pitching moment itself is not usually zero around the quarter-chord point, just its derivative. This is a three-view drawing complete with the more important internal arrangement details, including typically the landing gear, payload or passenger compartment, engines and inlet ducts, fuel tanks, cockpit, major avionics, and any other internal components that are large enough to affect the overall shaping of the aircraft. In the military
world, while the various military services do have design offices studying future aerospace needs, it is rare that they would identify a need and develop a detailed set of requirements without working closely with the airplane companies. (14.31) n2E Fc - n2EI AL + (14.32) are failure stresses and do not have any margin of safety. If there needs to be a longitudinal break, it should be smoothed following a radius roughly equal to the fuselage diameter. Before a new aircraft design can be started, a decision must be made as to what technologies will be incorporated. The six charts each represent data for wings of a differ ent taper ratio. Fd is found to be -2000 lb, a compression load on the engine due to the motor mount. While easy to build, this can increase drag by 30-40% due to separ ation when the high-pressure air underneath tries to flow around the sharp edges to the sides and top. 357 /0. Vortex generators are also used on wing and tail surfaces (see Chapter 8). Later we'll analyze the weights in some detail, and learn if this was about right. The induced drag is actually a subset of the drag due to lift, being the drag that is directly caused by the mechanism that creates lift. Once inside an aerospace company, you can build your reputation should be calculated from the airfoil geometry, scaled ver tically, and then added back to the original camber line to produce the new, scaled airfoil. The polar moment of inertia (] or Ip) is the moment of inertia ab out an axis perpendicular to the cross section [Eq. (14.25)]; 1 is important i n torsion calculations. The integrated differences in pressure between the t9P and bottom of the airfoil generate the net lifting force.* Figure 4.2 shows typical pressure distributions When you have to for the upper and lower surfaces of a lifting airfoil do something bad to at subsonic speeds. They think that their own identification of some mission need will, like the better mousetrap, cause customers to beat a path to their door. If this is an airfoil or a fuselage, the air "comes off the track" causing a lot of drag and a loss of lift. These are numerically analyzed in later stages of the design process, but that is possible only when the initial layout is completed. Don't waste a lot of time on picking the perfect airfoil-it'll change soon. Friction drag is literally calculated as a coefficient times the wetted area, so an excess of wetted area is always to be avoided. To day, steel is used for applications requiring high strength and fatigue resistance, such as wing attachment fittings. Few actually do. Everything changes as you go through the design process-even the requirements. This is primarily a function of the wing span. 4324 0.4322 2 1 .803 25,832 24.227 24.428 24,508 W0, calculated 57.863 56, 1 98 56, 8 1 4 56,733 56, 702 Box 3 . Th{l nacelle strakes fixed the separation and increased maximum lift. Even if one could convince some company or military office that a certain design concept really had merit, they'd go off and study it on their own, looking to see if a design with those capabilities really would be desirable. The "mean camber line" is the line equidistant from the upper and lower sur faces. Whatever pitching moment the airfoil has, measured around the quarter chord, it remains the same as angle of attack is changed. -b't.S-::. Even in such a simple decision, aircraft design is always a compromise. Fbuckling 4111fl = /h) KE (t 2 (14.34) Truss Analysis A truss is a structural arrangement in which the structural members (struts) carry only compression or tension loads ("columns" and "ties"). 1) Section drag qc ---- (4.2) 59 60 A i r c raft Desi g n : A C o n c e p t u a l A p p r o a c h Section moment coefficient: Cm = :;J � HEI GHT VsTb.I/) DOO - .S Ll&HTt.. The XB-70 uses a substantial amount of titanium in the fore body area. 11241 This determines the minimum allowable tail-damping power factor (TDPF), I:= � 2 Fig. .fo11111 • A"' . But today, we do it better and more deliberately. 1) o . s.,..eit c:\iffe � • w'� S- No"'' t{. + Ife • w' S- No"'' t{. + Ife * No" S- No" S- No" S- No"'' t{. + Ife * No" S- No" S- No" S- No"'' t{. + Ife * No" S- NO" "tricks" to make something fit? For a long, thin body circular in cross section, this average projected area times 1T will yield the surface wetted area. 2.f' At.£ :q.r" x-c Fig. For a bea T= 🌵 z = m of rectangular cross section, the maximum shearing stress (at the neutral axis) is 1 .5 times the averaged shearing stress (total shear divided by cross-section) nal area). It cannot go around the corner, which causes separation near the tail of the aircraft and a high "boattail drag." To prevent this, small vanes perpendicular to the skin and angled to the airflow are placed just upstream of the separation point. Note in Eq. (14.3 1) that the total load a column can carry without buckling does not depend upon either the cross-sectional area or the ultimate compressive stress of the material! Only the column's effective length, its cross-sectional moment of inertia, and the material's modulus of elasticity affect the buckling load if the column is long. 3 E ng i n e fro nt face Inlet duct geometry. For example, the vertical tails of the F- 18 were having structural fatigue problems resulting from an unexpected tendency of the vortices from the wing strakes .to hit the vertical tails. This is the circulation about the airfoil that, for a three dimensional wing, produces vortices ip the airfoil that, for a three dimensional wing sweep at the root, at least according to the wing sweep at the root. theory. Wetted area ratio can be "eyeball" estimated from the sketch, using Fig. Many aeronautical engineering students dream of becoming an aircraft concepts poses a problem for high-end CAD systems. wing causes this velocity to appear to be reduced, so shock formation is delayed. As can be seen, these reflected the shocks from the nacelle creating even more shocks under the wing more free lift! Furthermore, they solved the two big stability problems inherent in supersonic flight. Selection would also consider the thickness available for structure and fuel as well as the ease of manufacture. The results are plotted in Fig. This chapter introduces flight mechanics, the study of aircraft translational motions. 16.3 1). Of course it is, but how important is it relative to a host of other concerns such as weight or ground clearance. 12. These are then fabricated, assembled, and with luck, flown. /6N : • Fro 1\ e.i 13. To its right is the wing created from it, with a swept-back tip, leading-edge strake, and trailing-edge kick. 1 Airfoil geometry. Wood makes a natural bending beam for wing spars because of the lengthwise fibers. 80+ 93 b2t)C. q To handle the aerodynamic heating of Mach 3 + flight, the structure of the SR-71 is about 93% titanium. Referring back to Fig. A perfect example is the wing trapezoidal geometry. This is accurate up to the drag-divergent 399 400 A i rcraft Des i g n : A Concept u a l A pproach (SexSposedf) Mach number and reasonably accurate almost to Mach 1 for a swept win g. Unfortunately, the aerodynamic effi ciency of an aircraft, expressed as lift-to-drag ratio (L/ is greatly reduced during low-level, high-speed flight, as is the engine efficiency. The growth versions of the DC-9 had flow problems at the vertical tail, leading to directional stability reduction at moderate sideslip. If the molecules shear in a disorderly fashion, the flow is "turbulent." This produces a thicker boundary layer, indicating that more air molecules are dragged along with the aircraft, generating more skin-friction drag. 095 47 1 7.45 + V Wfuelsystemandtanks = t° I and ing, which affects the aft-fuselage upsweep and/ or landing gear length. The airfoil angle of attack and / or camber causes the air over the top of the wing to travel faster than the direct compression stress below the applied load and is called "primary column buckling." If the bending action after buckling involves stresses below the proportional limit, the column is said to experience "elastic buckling." The highest compression load that will not cause this elastic column buckling-the so-called Euler load, or critical load Pc -will be determined from the Euler column buckling." The bending moment must be analyzed with special equations provided next. 3.12. At the root, the isobars from the left and right sides of the wing cannot meet in a "V." Instead, they are joined by a rounded-off corner. 4.14 can be used. Because all other terms are constant wiU respect to velocity, it follows that propeller aircraft range will maximum L /D, as was determin ec with Eqs. is a second and lift coefficient for maximum L /D. o20 = 0. The basic process of design, analysis, optimization, and re-design is the same regardless of analytical techniques. But if thi strut angle is too steep (vertical), you leave a lot of the wing still cantileverec and therefore still heavy. Your chances are best if you follow a few simple suggestions. ., The former provides the major influence on the profile drag, whereas the latter provides the major influence upon the lift, the drag due to lift, and the airfoil pitching moments. Standard heat-treatment and tempering processes are defined in material handbooks along with the resulting material properties. 519 520 Ai rcraft D e s i g n : A C o n c e p tu a l A p p roa c h However, titanium is difficult to form for these same reasons. If the angle is too flat (small) you get huge tension loads in the strut and large pulling f o ads at the side of the project is to validate the overall design approach or to prove and mature certain technologies. However, handbook graphs such as Fig. Reynolds number, the ratio between the dynamic and the viscous forces in a fluid, is calculated as airflow velocity V 61 62 A i r c raft D e s i g n : A C o n c e p tu a l A p p r o a c h l, times the length the fluid has traveled down the surface multiplied
by the ratio of fluid density to fluid viscosity /L A typical aircraft wing operates at a Reynolds number of about one to ten million, depending on the aircraft's size and speed. The remainder of the book presents better methods for design, analysis, sizing, and trade studies, building on the concepts just given. For those with a burning desire to become an aircraft designer, don't give up! It isn't easy, but it isn't impossible. multiple of the uninstalled engine weight. Instead, we use a computer program that will exhaustively search throughout the flight Vairspeed vground track Fig. Alternatively, the area can be measured by tracing onto graph paper and "counting squares." The wetted area of the fuselage can be initially estimated using just the side and top views of the aircraft by the method shown in Fig. Reference [18] tabulates group weight statements for a number of aircraft. 45 46 A i rc raft D e s i g n : A C o n c e p tu a l A p p ro a c h Box 3. Structural calculations usually require the moments of inertia about cen troidal axes. pressure. (17.25-17.27) are not exactly correct in the real world. After forming, titanium must be treated for emb rittle ment by chemical "pickling" or through heat treatment in a contro lle d environment. Well, the only way a force is exerted on the wing is through pressures, so this author leans towards that explanation-but it really does not matter Most aircraft panels are clamped, but with some flexibility to rotate about the side axes. At high angle of attack, the flow experiences a disastrous form of separation called wing stall. Unless they have enough money to build a design themselves, they'll have to develop the design concept in response to a cus tomer's requirements, and then convince that customer that their design best meets those requirements-and that they can build it, fly it, produce it, and support it. Modern airfoil design methods can also produce pressure distributions that maintain laminar flow over much of the wing. 1 4.30 Panel buckling coefficient (NACA TN378 l). Figure 14.32 shows the forces at the joints. 12), as shown in Fig. The moment of inertia I is a difficult-to-define parameter that appears in bending and buckling equations. 09 0 . 24 . [L 'U 'U 900 900 800 90 1 80 1 85 70 1 63 1 50 70 1 73 1 58 54 1 08 1 20 29 29 29 11 11 11 Widely used 600 1 90 1 70 1 79 1 23 29 11 B-70 honeycomb materia l 250 250 55 61 32 45 32 37 33 37 1 0 .4 1 0. Get good grades and take a broad range of aeronautical engineering subjects including aerodynamics, structures, controls, and propulsion. Layer Friction-The Origins of As the aircraft moves forward, the air molecules Aerodynamics slide over its skin. This is done using statistical plots of total internal volume vs aircraft takeoff gross weight for different classes of aircraft. This includes all lift-related effects. Specialists determine how the airplane will be fabricated, starting with the smallest and simplest subassembly process. This would allow the main landing gear to be stowed in the wing root, probably saving some weight and drag. technological risk. For high strength applications, the 7075 alloy is widely used. This is seen on the B- IB and was featured on the North American Rockwell F-X (F- 15 Proposal) design, shown at the right of Fig. One is to exaggerate the wing sweep near the root, blending the wing in a smooth fashion into the forebody of the fuselage. In addition to the mission profile, requirements will be established for a number of performance parameters such as takeoff distance, maneuverabil ity, and climb rates. 10) 0.25, use 0.25 (15. As the aircraft moves forward, the air molecules are pushed aside. When aircraft total drag vs lift is presented, the drag can be calculated with some fixed elevator deflection, or it can be calculated using the varying elevator deflections required to trim the aircraft at each lift coeffi cient. These include adjustments for different technologies (especially what we always call "advanced"), different fabrication methods, geometric different fabrication methods, geomet analyst's gut feeling. This can be expanded as shown to express instantaneous endurance in terms of L /D and weight. For a solid circular cross section, the maximum shearing stress is 1. Whandling gear covers things like jacking pads, tiedowns, towhook attach ments, and the like. leading to reductions in drag and weight. This design arrangement includes wing and tail overall geometry, the overall fuselage shaping, and the internal locations of the crew, payload, pas sengers, equipment, engine installation, landing gear, and other design features. 3.1. The differ ences in exponents for different types of aircraft reflect the different slopes of their trend lines and imply that some types of aircraft are more sensitive in sizing than others. The force required to overcome viscosity CHAPT E R 1 2 Shear Shear Freestrea m velocity "Stuck" molecules Aerodyna m ics Pressure Loca l . Also included is a summary of the current civil and military design requirements, taken primarily from Federal Aviation Regulations (FAR) and Military Specifications (Mil-Specs). The aircraft meets up with a tanker aircraft meets up with a tanker aircraft such as an Air Fo ce KC-135 and receives some quantity of fuel. 208 0 .231 2 . Still, no airplane ever flew without the designer thinking, "I wish I could go back and change . In fact, an airfoil with camber will produce lift even at zero angle between the chord line and the oncoming air ("angle of attack"). The first drawing of a project such as D645-1 is often called simply the "Dash-One." An important thing to realize is this: The Dash-One is a tool for making the Dash-Three, which is . Again, 1? I is highly nded. Confusion about the appropriate sign is the most common error in truss analysis. +- t t 6 alb 8 10 Shear web buckling (NACA TN378 1). This can be ingested by the inlets, with bad results, and can have an unpredictable effect upon the wing or tail surfaces. Those w h o d o n 't u n derstand t h i s a lways wa nt to j ump to deta i l d e s i g n too ea rly ensuring disaster. 50 24.1 5 29.40 35. With the area of the wing and canard both included, this is equiv alent to a combined aspect ratio of about 7. Unfortunately, this works both ways. These methods are only applicable if the truss structure is "statically determinate." In general, a truss is statically determinate if every strut can be cut tradeoff between aerodynamics, structures, and the needed geometry for such necessities as landing gear and fuel tanks. There may also be specific dimensional constraints for the whole airplane, or the payload, avionics, or other equipment. These methods are especially problematic when they amount to little more than a consolidation of guesswork. summarizing expert opinion on scales from 1 to 10 as to whether, for example, a high-aspect-ratio wing is important to attaining long range for the aircraft about to be designed. 3.13. 4239 0.4224 0.4224 3 1, 790 32,97 1 33,285 33,3 1 1 84, 651 79,456 78,994 78,875 78,866 49 50 Airc raft D es i g n : A C o n c e p t u a l Approach 80,000 +---- 60,000 40,000 20,000 + 60,000 20,000 + 60,000 20,000 + 60,000 1 3,000 1 3,000 1 3,000 1 3,000 7000 Payload Fig. design req u i re m e nts such as stall, rate of climb, turn rate, • Perfor m a nce equations a re • Ai rplane m u st meet accel e ra t i o n, a n d ta keoff a n d l a n d i n g d i stances. If there is a specific layout requirement that forces a certain crosssection area, such as side-by-side seating for two people, then a fineness ratio of about three is the best answer. 9 5. S-0 2-0 1 00 882 u. As long as the stresses vary linearly with vertical distance from the neutral axis regardless of the cross-sectional shape. 2.0 / 1 8 't/ I S- 893 894 Ai rcraft D e s i g n : A C o n c e p tu a l A p p roach AIRCRAFT DESIGN z.o 1 00 O +---t +-++ +--+- Sb '° .So 10 V + 80 c ... 9 277 W5 / W4 = 0.858 E = t hr = 1200 s C = 0.0001 1 1 1 1/s L/D = 16 W6 / W5 = e - 0.0083 = 0. AUD Loiter Optim ization-Prop Substituting Eq. (17.31), the endurance equation for propeller aircraft. Leading-edge (LE) radius has a huge effect on aero dynamics including lift, drag, and stall characteristics. The CAD system should make this easy. Tailless designs are discussed in detail in Chapter 22. (.8't) .: f.?.1 2 "i{e_.fiJ. " clauses. This simple definition answers the key questions for the initial conceptual layout: How big can the wing box, wing fuel tank, and leading-edge flaps be? This result was presented without proof in Chapter 5. Only part of the aircraft's fuel supply is available for per forming the mission ("mission fuel"). In many ways, IPTs are like the old "project" side of a matrix management structure, and the best of the old projects were run almost exactly as a best-practice IPT is run today. generators" are commonly found on the tops of wings and near the back of a long fuselage, but can be found almost anywhere on airplanes except right at the nose! The best locations for vortex generators to fix some particular problem are found by trial and error, both in the wind tunnel and in flight test. This enables the aircraft to achieve far more range, but adds to the overall operating cost because a fleet of tanker aircraft must be dedicated to supporting the bombers. 395 396 A i rc raft Desi g n : A C o n c eptu a l A p p r o a c h In supersonic flight there is a component of wave drag that changes as the lift changes. Most people would assume that we draw a new aircraft design and then determine how far it goes. This holds true until high angles of attack where the flow separation leading to stall causes the center of pressure to move forward or rearward, leading to nose-up or nose-down moments. This wetted-area ratio can be used, along with aspect ratio, for an early estimate of L/D. 3.5 can then be used to estimate the maximum L/D. While this seems crude, keep in mind that the entire
aircraft arrangement is being determined at this stage of design, and the interactions between com ponents are more important than the exact geometry of any one part. 3 1 4 ': 30 '' 51 5 Typical truss structure. However, there can be problems with too great of a willingness to "let the CAD system do it." First of all, with a CAD system there is a tendency to let the computer lead you in the "easy" direction. :::::J (Q G> ,)... 1 greatly exaggerates the leading-edge radius, for clarification. i"t :: '+.iS" c ,.., w "'- 0 ei }- a CONTOOL. 1 5 and 4. Thus, the maximum load fac to r for sustained turn can be expressed as the product of the thrust- to- weight and lift-to-drag ratios [Eq. (17.53)], assuming that the thrust axis is approximately aligned with the flight direction. They often have empty weight fractions below 10%! Don't expect that for an airplane with wings, landing gear, and other things that launch vehicles don't need (see Chapter 21). 8.12. This is usually a reason able approximation inboard of the strut. #:fD Supersonic aircraft, the greatest aerodynamic impact upon the configuration layout results from the desire to minimize supersonic aircraft, the greatest aerodynamic impact upon the configuration stability calculations (Chapter 16), is a meas ure of a body's tendency to resist angular accelerations. L /D depends primarily on the wing span and the wetted area. In earlier days, most airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms, and the wetted area. airfoils. This involves simultaneous solution of equations, for example, with a simple com put er ite ration program. Instead, Boeing and Airbus continuously work to identify market needs. weldable Affordable (homebuilts) 0 Q () ::r Clad 7 1 78-T6 (78 st)-(sheet/plate) extrusions Clad 7075-T6-(sheet) forg ings extrusions I I 0. 52 0.65 6.46 0.41 I nternal shear stresses Solid circular shaft in torsion. This is mostly due to airfoil considerations and the effects of sweep and aspect ratio. E. o (1 + sr ISvt l o .348Aei223 x 0 .323 x (1 + A) 0. Aerodynamic problems are most often attributable to two phenomena: separation of the flow, or the formation of an unwanted, "bad" vortex. 0 (II M ission Profiles Typical mission profiles for various types of aircraft are shown in Fig. CHAPTE R 1 4 Structures a n d Loads Th e strut loads calculated with these ideal assumptions are called primary trus s loads. That is the respon sibility of the structural design group. r=x - 1 s ---The bending moment can be found for each span station by multiplying the S (a + b) X = s 2a + b l load at each outboard station times its dis F = 3a + 3 b j 2 tance from the span station. The wetted aspect ratio divided by the w (such as aspect ratio). 19) (15.20) (15.23) (15.24) 573 574 Ai rcraft D e s i g n : A C o n c e p tu a l A p p roach D 0 O D J(d = S p l it d uct / 2 L s 2 . While an understanding of the factors important, an aircraft designer should not spend too much time trying to pick exactly the right airfoil in early conceptual design Later trade studies and analytical design tools will determine the desired airfoil characteristics and geometry. A professional designer will have access to a "planimeter," a mechanical device for measuring areas. For this reason, a small body can actually have a lower total drag when its skin is rough. There's nothing wrong with that! An Airplane Designer: How Can I Become One? Of course, the final 3 4 Ai rcraft Des i g n : A Conceptu a l A p p roach requirements for a major new aircraft project do, in the end, come from the military customer, but only after a lot of work by the whole community. For the military customer, the final design requirements are set by the customer as "deliverables" in the Request for Proposal, based upon extensive study and analysis by both contractors and the customer community (military officers and civilian staff). For example, MIL-C-8785 covers aerodynamics, stability, and control. These are provided instead of numerous example calculations throughout the text to illustrate how the different aspects of design fit together as a whole. These are both set as ratios to aircraft weight, namely, the wing loading and the thrust-to-weight ratio (or horsepower-to-weight ratio for a propeller aircraft). In fact, they are good enough to be used to check the results of the sophisti cated computerized methods, and if they are far apart, the computer results are probably wrong! Optimization methods are covered in Chapter 19, including classic aircraft carpet plots, parametric trade studies, and genetic algorithms. Newer alloys such as 7050 and 701 0 have improved corrosion resistance and strength. Many of them won't be designed until much later in the development process. The aircraft must cruise at 0.6 Mach number. These include flap tracks, brackets, structural clips, doors, avionics racks, and similar components. 5 8 1 6 W1 / Wo = 0.4435 10, 800 Wo = ----- 2 V We 1 - 0.4435 - Wo •i•!i[i[j 50,000 80,200 80,200 80,21 0 80,21 10 80,21 10 80,21 10 80,21 10 80,21 10 weight fractions and fuel fraction are unchanged, but the numerator of the 47 48 A i rc raft Des i g n : A C o n c e pt u a l A p p r oa c h Box 3.2 Range Trade 1000 n miles Range W3 / W2 = Ws / W4 = e- o. L is the fuselage length. 39 40 Ai rcraft D e s i g n : A C o n c e pt u a l A p p ro a c h Box 3.2 Range Trade 1000 n miles Range W3 / W2 = Ws / W4 = e- o. L is the fuselage length. 39 40 Ai rcraft D e s i g n : A C o n c e pt u a l A p p ro a c h Box 3.2 Range Trade 1000 n miles Range W3 / W2 = Ws / W4 = e- o. L is the fuselage length. based on a number of sailplanes and high aspect ratio UAVs. There is an equivalent technique going back at least to the 1940s that plots L /D vs the square root of wetted aspect ratio. The actual reference wing area S is calculated from the required wing loading W/ S and can be determined only after the takeoff gross weight is centerline C HAPTE R 4 A i rfoi l a n d Wing /Ta i l Geometry Selection S = Reference wing a rea = Chord (distance L.E. to T.E.) = Aspect ratio = b = Span C tip/C root 1 ---Ctip -- 1 Given WIS, A, A : S = W!(W!S) b = ,,r;r:s 2 S/[b(1 C root = · + ?..)] J h/2 tic = A i rfoi l thickness/chord) C tip = A · C roo_t Wing geometry. In Chapters 4-11, the techniques for the development of the initial configuration layout are presented. In general, aft-fuselage upsweep should be minimized as much as possible, especially for high-speed aircraft. The key requirement is the ability to loiter for 3 hr at a distance of 1 500 n miles {2778 km} from the takeoff point. The landing gear may be shown only as a circle for the tire and a stick for the gear leg. Win it. (Remember that our simple sizing method doesn't permit mission segment divided by its weight at the beginning of that segment is called the "mission segment weight fraction." This will be the basis for estimating the required fuel frac tion for initial sizing. A specific aircraft design project can begin in almost as many ways as there are aircraft designs. For cruise, a value of 0.866 times the
maximum L/D, or about 13.9, is used. 8.12). This iterative nature of design is shown in the "Design Wheel" of Fig. When trade studies are then performed from these real numbers, the results are far more believable. W h a t s h o u l d it l o o k l i ke? 1 ASW Sizing Calcu lations Mission-Segment Weight Fractions (British Units) 1. Figure 7.39 shows such an automatic revision of the nontrapezoidal geometry from changes to the geometric trapezoidal parameters, done with the RDS-Professional program. Control laws for the flight control system are tested on an "iron-bird" simulator, a detailed working model of the actuators and flight control system are tested in Eq. (17. Because the pitching moment is almost independent of angle of attack about the quarter-chord, the derivative of pitching moment with respect to angle of attack (or lift) is near zero. 1 2) C HAPTE R 3 Sizi n g from a Conceptual S ketch How d o you estimate wetted aspect ratio before you've made the con figuration design layout? Methods for estimation of thin wall crippling are found inl 1 081. You might possibly get a summer internship or a work-study position at a major aerospace company that contracts with them. CHAPTER 3 Sizi n g from a Conceptual S ketch 55,000 -0 2 I :> u u -;;; 50,000 Sizing g ra p h a n swer is at 172 2/(,meRkva 0 . 24 1 + Wp ress X (L /D) (15. 9 9.5 7.9 8.0 6 .0 6.2 I ::; Wood Properties (ANC-5) 7 .0 7.3 5.7 5 .3 7.0 5.3 5.0 5.6 4 .2 5.5 4.3 4.0 2 .3 1 .6 1 .4 1 .3 0.8 0.8 1 .4 1 .3 1 .0 0.8 0 .6 0. The wing sweep will prob ably change after every optimization study or wind-tunnel test. 4.3c. For example, the old MIL-STD-1 374, Weight & Balance Data Reporting for Aircraft, has been turned over to the Society of Allied Weights Engineers, which administers it as SAWES. This causes a vortex flow pattern that reduces the drag penalty. you CHAPTER 2 Overview of the Des i g n Process CFD, FEM, 6-DOF, wind tunnel test, and much more. These range optimization equations were based on the assumption that the range parameter (V/C) (L/D) does not vary with weight as Eq. (17.23) is integrated, which we attempt to provide by holding a constant lift coefficient during cruise. 1 (15.25) csw Whorizontal tail 0.0379Kuht (1 + Fw/Bh)- 0 · 2 5 Wfg63 9N · 10 x 50 .75 L - 1. O KO .7 04 (co s A) - 1 . oo3 5cs0 .489Ns0 .484Nc0 . Figure 14.37 shows a beam in bending, with the vertical distribution of compression and tension stresses. Design requirements must be rigorously analyzed and then used to develop a number of times. The same basic design techniques are used whether on a drafting table or computer scope. Maximum lift is obtained at the stall angle of attack, beyond which the lift rapidly reduces. (/) UI w w 534 A i rc raft Desi g n : A Concept u a l Approach the elemental areas times the square of the distance to the select d axis [Eqs. time, so we select joint two. 1 2) or Fig. The lift distribution can be determined with Schrenk's approximation, just described. 1 5.3) f(d 1.0 if no cargo door; = 1 .06 if one side cargo door; I u; The lift-curve slopes of the wing and tail are obtained with the methods presented in Chapter 12. Typical values range between 3 and 8. If the opposing lift and weight forces cannot be located at the same place, then some structural path will be required to carry the load. And the job. The same is true for the following loiter optimiz ation methods. The airfoil thickness ratio refers to the maximum thickness ratio refers to th condition ing Wei g hts 2000 56 4 0 Flight controls Ill! Engine inst 0 Engine D La nding gea r D Fuselage 272 Illl Ta ils Il!! Wing 0.0000 0.0500 Fig. spin is opposed by damping forces, primarily from portions of the aft fuselage and vertical tail underneath the horizontal tail (SF -see Fig. The shear b a is found by starting at the wing tip and working inward, adding the load at each station to the total of the outboard stations. /ij4T c.\...A "JC. They are so small that they are mostly in the bound ary layer, and their own effect on drag is negligible whereas, if they prevent separation, they can greatly reduce the total drag of the aircraft. u(.i;*'s.1.. This is sometimes called "block compression." The compression yield value is used as the * imit load, providing a cutoff value for the buckling load of a short column with relatively thick walls (structural tubing) . For safety you would be wise to carry extra fuel in case your intended airport is closed, so a loiter of typically 20-30 min [at 10,000 ft {3048 m}] is added. If a short column with relatively thick walls (structural tubing) . I \. This is commonly confused. 1 6.30 Forces in spin. i, Wx Wo. Wx/Wo (3 .5) or Wi = exp -RC Wi-l V(L/D) (3.6) -- Table 3 . However, the air going over the top of the flat "airfoil" will tend to separate from the surface, thus disturbing the flow and therefore reducing lift and greatly increasing drag (Fig. Structura l Considerations M:fll Load Paths Except in the smallest of projects, the configuration designer does not actually do the detailed structural design of the airplane. c.t.., {u ?"'.-.. * More-properly called "Power Equations" being of form [constant times variable raised to a con stant power]. Thus, a "good" volume distribution from a wave-drag viewpoint has the required total internal volume distributed longitudinally in a fashion that minimizes curvature in the volume-distribution plot. It may be as important to test the prototype aircraft. However, when that push propeller stops working, the flow separates causing a drag increase to compound the thrust loss. Another solution, shown on the sketch, is to add a wing strake full of fuel. The critical question is, "Can any affordable aircraft be built that meets the requirements?" If not, it may be necessary to revise or relax the require ments. Analyze the current baseline. These are dis cussed in Chapter 5 and other places in the book. Several of the weights categories below need explanation. Empty-weight fractions vary from about 0.3 to 0.7 and diminish with increasing total aircraft weight. / 1 7 C l.-I M.B : A?>:rv.S Tf"t E:>J r 1_:; '?, z. Then more sophisticated methods of analysis, sizing, and trade studies will be provided. 1 1 illustrates an alternative way to size the aircraft, by a graphical method. What We've Lea rned We've learned a quick way to size the aircraft. perform initial sizing and a parametric way t o do trade studies . Solving the equations yields Fe of 3919 lb (tension) . At this altitude the speed of sound is 994.8 ft/s {303.2 m/s} (see Appendix B). CHAPTER 2 Overview of the Des i g n Process In an extreme form of concurrent engineering, the designer trying to develop a new aircraft concept would see, on the next CAD scope, a pro duction designer trying to develop tooling for the aircraft that hasn't been designed yet! This is actually done in the automotive industry, where the parts and overall geometries from one car to the next don't change very much. Please realize that these are all "accounting fictions." They are defined just to make calculation easier. The last chapter, 24, contains two complete design project examples that use the methods presented in the previous chapters. E Performance a n d F l i g ht Mecha n ics -(!:_) (CpowerY/p V) en (\wfi) w (!:_) (550YJ Cbhp VP) en (\rj"i) D = D (17.31) (17.32) (17.33) This last equation is identical to Eq. (17.19), the velocity condition for minimum power required. A range trade can be calculated to determine the increase in design takeoff gross weight if the required range is increased. In subsonic cruising flight of a well-designed aircraft, the parasite drag consists mostly of skin-friction drag, which depends mostly upon the wetted area. Induced drag is the drag caused by the generation of lift. These notional designs show it better because they have exactly the same span and volume. k:..>l..-rc..;. Chapters 2 and 3 provide an overall introduc tion to the design process. (It looks like a miniature engine pylon that lost its engine!) At high angle of attack, the local flow at the leading edge is diverted outward toward the wing tip so that the vortilon finds itself at an angle to the local flow and produces a vortex. Good thing we have computers to do this stuff. Inflation has raised this to several dollars per pound today depending upon its form. The weight of structural members can be reduced by providing the shortest, straightest load path possible. Quite frankly, we confuse ourselves with our notations and all of the different lifts and drags that we separately calculate. At the stall, the 397 398 A i rc raft D es i g n : A C o n c e ptu a l Approach lift curve has become nonlinear such that the angle for maximum lift is greater than the linear value by an amount shown as * a at CLmax in the figur e. 12.6. The twodimensional airfoil lines represent upper boundaries for the no sweep, infinite-aspect-ratio wing. 1 8 1 .51 { 1 .4 } - 0. There can also be supersonic expansion fans in which the flow accelerates around a rearward-facing corner, causing a reduction in pressure. At a lower slenderness ratio, the stresses at buckling exceed the pro portional limit. The pitching moment is usually negative when measured about the aerody namic center, implying a nose-down moment. The aircraft's engine size and wing area are generally set by the requirements for maximum speed, stall speed, CHAPTER 2 Overview of the Desig n Process rate of climb, takeoff distance, and similar performance items. The parasite drag depends on the aircraft's total wetted area, not just the wing area as expressed by aspect ratio. But the iterative process is similar. The NAAF-X proposal shown in Fig. Additional loads such as those caused by the attachment of an air craft c omponent to the middle of a strut must be calculated separately a n d added to the primary load during analysis of each individual strut. The new Chapter 20 covers C H A PT E R 1 Desi g n -A Sepa rate D i s c i p l
i n e Electric Aircraft, including motors, controllers, power supplies, analysis and more. Lift, drag, and pitching-moment characteristics for a typical airfoil are shown in Fig, 45. And finally, some airplanes are designed j ust for fun. Similarly, an experienced aircraft configuration designer should have final say over the configuration arrangement, and the IPT itself). The conceptual sketch can be used to estimate aerodynamics and weight fractions by comparison to previous designs. You don't build it. 51 52 A ir c raft Des i g n · A Conceptu a l Approa c h Airfoil and Wing/Tail Geometry Selection • From the sizing res u lts, we s e lect the a i rfo i l s and d efin e the geometries of the wings and ta i l s. Another type of vortex-generating strake called a "vortilon" is placed just below the sizing res u lts, we select the a i rfo i l s and d efin e the geometries of the wings and ta i l s. of a number of cross sections are measured and plotted vs longitudinal location. A weight budget is NOT a target. Besides, you don't need such detail to estimate performance using the tools of conceptual and preliminary design. If you have a tailwind, the cruise range is improved. The typical air superiority mission includes a cruise out, a combat consisting of either a certain number of turns or a certain number of minutes at maximum power, a weapons drop, a cruise back, and a loiter. An airplane that is too small just cannot carry enough fuel to do its job. 73 74 A i r c ra ft Desi g n : A C o n c eptu a l A p p r o a c h Sweep i s a key parameter for wing geometry and i s usually denoted either by 42,000 0.436 1 0.4429 0.44 1 4 0.44 1 1 0.44 1 2 42,400 42,370 2 1 ,803 1 7, 7 1 7 1 8, 540 1 8, 704 1 8,692 W0, calculated 4 1 ,544 42,670 42,4 1 7 42,369 42,372 2000 n miles Range W3 / W2 = W5 / W4 = e-0 · 2040 = 0.81 54 W7 I Wo = 0. The configuration arrangement can be expected to remain about as shown on current drawings, although minor revisions may still occur. Increasing the wing sweep reduces the lift, roughly by the cosine of the sweep angle. 14) where when The actual lift-curve slope of a wing in supersonic flight is difficult to predict without use of a sophisticated computer program. Compromises are inevitable, but the design must still meet the original requirements. These equations also apply to circula1 tubing under torsion, using the appropriate value of Ip as provided earlier. The only way to determine whether a canard is a good idea for this or any aircraft, one with and one without a canard. This result sounds erroneous, but is actually typical of the "leverage" effect of the sizing equation. (12.1) and (12.2). Figure 14.40 shows a typical braced wing. 1 0 0 . And, with the col located team working toward a common and understood goal, the all-important constant power, the non-integer "C" term that defines the slope turboprop Flying boat Jet trainer Jet fighter Military cargo/bomber Jet transport UAV-Tac Reece & UCAV UAV-high altitude UAV-smal l Sizing from a Con ceptu a l S ketc h Empty Weight Fraction vs W0 - {A-metric} {0. The delta design has an aspect ratio of only 3, yet it attains the same L /D-even better.* The explanation for this curious outcome lies in the actual drivers of L /D. The shear at t l b/i n . r- 0 0 Q. New design projects usually begin in the aircraft companies more so than in the customer community. 7 { 1 9.8} 0 .4 { 1 1 .3} CHAPTER 3 Propeller: Typical Table 3.4 C Propeller:) lb/h r/bhp {mg/W-s} Piston-prop (fixed pitch) Piston-prop (variable pitch) Turboprop Cbhp -0 .4 {0.068} 0.4 {0.068} 0. The lift coefficient and drag for maximum prop endurance are therefore identical to the minimum-power results defined by E qs. Up to here, the book has shown how to take a set of requirements and create a credible "Dash-One" initial design layout. A propeller thrust SFC equivalent to the jet-engine SFC can be calculated. Although this example is a military aircraft, fire safety should always be considered. These equations can also be applied to members bent up from flat sheet metal by "unwrapping" the member to find the total effective width. 0 9 2 > . Fcrippling * 0. This is also true for the design requirements. Use of an "improper" axis system is not really a problem for the designer except that one must be very careful while placing the airfoils at the desired incidence (pitch) angle. 747 (3 . c.i. 9 5) (0. 70 0 . At high subsonic speeds, the shocks form first on the upper surface of the wings because the airflow is accelerated as it passes over the wing. These include aerodynamics, structures, detectability, vulnerability, roducibility, and maintainability, roducibility, and maintainability. Links to airfoil data websites are available on the author's website, www.aircraftde sign.com. E & J:- Tdw & J: c () (17.30) Equation (17.30) integrates for total endurance E. For jet engines, specific fuel consumption is measured in fuel mass flow per hour per unit thrust force. The easiest way to calculate the shear and moment distributed loads. The most general truss solution, the "method of joints," relies upon the fact that at each joint of the truss, the sums of the vertical and horizontal forces must each total zero. For example, 38 counts of drag mean a drag coefficient of 0.0038. Wfurnishings typically includes items needed by the crew such as crew oxygen, fire suppression, and similar gear. Both aircraft have about the same wing span, and both have about the same wetted areas, so both have about the same L/D. Note that the spar design in the preliminary design phase is still not "buildable." Full consideration has not yet been given to attachments, cutouts, access panels, flanges, manufacturing limitations, fuel sealing, and other "real-world" details. A key activity during eliminary design is "lotting." Lotting is the math number of minutes of flight at cruise speed. We call this the "quarter-chord" point and choose it as our reference location for airfoil lift, drag, and pitching moment data. This quicker method is actually two methods, the "method of moments" for the upper and lower struts and the "method of shears" for the inner struts. cla = . . Fixed LE = O.SL Perfectly rigid LE = 0.71L Welded ends LE = 0.82L Riveted or bolted Fig. The U.S. Air Force (USAF) Materiel Command Guide on Integrated Product Development, a major impetus for the adoption of these methods by U.S. aircraft contractors, defines the IPD as a "philosophy that systematically employs a teaming of functional disci plines to integrate and concurrently apply all necessary processes to produce an effective and efficient product that so tisfies customer's needs". Selection of the next joint to analyze depends upon the number of unknown struts. fue l tanks, and even wings. The chord of the airfoil is defined as the distance along a straight line from the leading edge to the trailing edge, obviously following this horizontal reference axis. 7.38. 3.8 illustrates the mission require ment for a hypothetical antisubmarine warfare (ASW) aircraft. Each influences the other. The resulting compressive stress is found from Eq. (14.32). = = v = wing geometry, especially sweep, on the fuselage weight. Also, steel is used wherever high te mperatures are encountered such as for firewalls and engine mo unts. In 1 996, the AIAA Founda tion was founded. 59 { 1.47} - 0. Conceptual design can take as little as a week (done poorly!) or as much as several years. 1 27 instruments - 8 · 0 + 36 · 37Nen0. These historical data are surprisingly useful as an early L /D predictor, and for double-checking the results obtained from detailed aerodynamic calculations. The linearity of the data makes a useful equation for predicting L /Dmax [Eq. (3. This book aims to do just that, suitab l e tor academia but foll owin g industry practice. Which one truly "causes" the lift? Starting from here, the book shows how to analyze and optimize that design, and describes how to develop an improved "Dash-Two" which is iterated until a design freeze can be declared. 0 72 q0. " Airfoil Selection The airfoil, in many respects, is the heart of the airplane. An endplate rather crudely prevents the high pressure air beneath the wing from "escaping" to the top, providing an increase in lift and some benefit to the drag due to lift. 2.3) and are typically considered only after the aircraft structural concept as a whole has been validated during the Preliminary Design phase. Find solutions. The wooden Hughes H-4 Hercules Flying Boat was built like a modern composite aircraft. Also, wood is produced by nature with poor " quality control!" Each piece of wood is uni que, so it requires craftsman-like skills to manufacture aircraft with wood. The F-22 and F /A-1 8E / F are about 25% composites by structural weight, while the newer F-35 is about 30% composites. The future will see more and more such automation of the design of common parts and systems. 68 5 L · (15.5) 0 .52 5 nose landing gear = (W:INI) 0 . 1 gives the calculations for sizing this example. Preliminary design such as a supersonic transport or stealth fighter. / 3 80 66 / 97 -W. Use of Computer-Aided Design (CAD) in Conceptual Design Today, the previous discussion of drafting table techniques sounds almost quaint. 2 1 .00 2 .38 30 1 7 .4 6 .80 4 .43 11 I } 1 . Equation (3. In Conceptual Design, the design requirements are used to quide and evaluate the development of the overall aircraft configuration arrangement. This "volume distribution plot" is also used predict and minimize supersonic wave drag and transonic drag rise. 63 64 A i r c ra ft Des i g n : A C o n c e p t u a l A p p r o a c h These airfoil optimization techniques result in airfoils with substantial pressure differentials (lift) over a much greater percent of chord than a clas sical airfoil. Weight is minimized when the stringers are all straight and uninterrupted. Hastelloy is used primarily in engine parts. Using production problems earlier
and should reduce the total program cost, even if the initial costs are higher. Climb 3. The thickness distribution of the airfoil is the distance from the upper surface, measured perpendicular to the mean camber line. C H A PT E R 3 Sizi n g from a Conceptual Sketch wing span squared divided by the total aircraft wetted area [Eq. (3. Geometry and characteristics of these classic NACA airfoils are summarized in [2]. 14.37 shows the resulting vertical distribution of shear forces, expressed as magnitude toward the right. 1 4 NJa : 1. This is referred to as "spanloading" and eliminates the need for a heavy wing structure to carry the weight of the fuselage to the opposing lift force exerted by the wing. These specifications have far too much detail for aircraft conceptual design purposes and are sometimes difficult to interpret due to the numerous cross-references and "excepting for . A good conceptual sketch will include the approximate wing and tail geome tries, the fuselage shape, and the internal locations of the major components such as the engine, cockpit, payload/passenger compartment, landing gear, and fuel tanks. 7.35 can be measured from the drawing in several ways. (4.1 -4.3). The midbody of the F-22 is largely titanium due to engine heating. • /n]; Teoc]. TDPF {x 10-4) 28 - Rudder alone recovery Rudder and 24 elevator 20 16 14 8 4] 0 40 -240 -200 - 160 -120 -80 -40 0 Spin recovery [lx - ly Body heavy criterion lb2W!g Fig. At some point the company believes that it has sufficient information to "freeze" the design, forbidding further changes to the overall design arrange ment. If a structural element such as a spar cap is to carry substantial load in only one direction, all of the fibers can be oriented in that direction. If possible, put flow-disturbing com ponents like wheel well bumps and wing struts on the bottom. In the first edition, this author used a pocket calculator for the Nz CHAPTE R 1 5 Table 1 5.3 Miscellaneous Weights (Approximate) Weight C omponent M issiles Harpoon (AGM-84) Phoenix (AIM-54 A) Sparrow (AIM-7) Sidewinder (AIM-9) Pylon and launcher M61 Gun Gun 940 rds ammunition Commercial a ircraft passenger (includes carry-on) Seats Flight deck Passenger Troop Instruments Altimeter, airspeed, accelerometer, rote of climb, clock, compass, turn & bank, Mach, tachometer, manifold pressure, etc. If this ratio is greater than 1 .0, it is inverted, and the right side of the chart must be used. 84 - 0.51 0 .3 :i: > "O m ::0 Unfortunately, airfoil coordinates tables are often found which use an "improper" horizontal reference. In a small company, this may be done by the same person who does the layout design. These include the definition of the aircraft operator, the time frame of development, and the level of acceptance of 9 l0 A i rc raft Des i g n : A C o n c e ptu a l A p p r o a c h _____ Fig. Mathematically speaking, they define the curvature exactly at the point of minimum radius (usually the LE). Its name comes from its use as the reference area for aerodynamic coeffi cients. l25(Nt W1) 0 · 566 (Ln /l2) 0 · 845 (reduce total landing gear weight by 1.4% of TOGW if nonretractable prop aircraft 13 for high-aspect-ratio aircraft 15 for sailplanes 8 Boei ng 2 Avro Vu lcan * I n c l u d i n q ca n a rd a rea Fig. It communicated with customers early and often and single-mindedly focused on the creation of the best product. CFD is discussed in Chapter 12. Typical steel alloys have about 1 % of carbon. 0 9 8> < 0. Wood has one additional advantage for homeb uil ders in that almost everyone knows how to saw, drill, and glue wood. This can be especially important for a transport aircraft, in which the floor must be level during cruise. OZ.77 +- O. MtOI Wood The Wright Brothers selected spruce as the primary structural material for their aircraft, and it remained the material of choice for many years. 1 7 Mean aerodynamic chord . Changes can be made in every aspect of the design including wing geometry, tail arrange ment, and even the number of engines. 8 8 5 > 0.6 9 o C.L. = &e. These "vortex gen erators" produce vortices off their ends, which mix the boundary layer with higher-energy air from outside the boundary layer. 1 2 Whorizontal tail 0.016(Nz Wdg) 0 . and so on. Columns in compression usually fail at a load well below that given by applying the ultimate stress to Eq. (14.29). What ever you think the design requirements should be on that first day of the project, you can be certain that they will have changed before the air plane flies. What tech nologies should be used? For really-crazy numbers look at launch vehicles. These are described next. 1 22 Svto. For example, an aircraft with full reliance on all-electric actuators has yet to enter production as of 2018, but that technology poses no great risk based on successful flight demonstration. As the tangent modulus is a function of the stress, iteration is required to find the buckling load for a particular column. For the "final answer" in preliminary design, the major aircraft companies will use their own methods. 3 / IS 0 / zz, 299 0. F is the fuselage lift factor [Eg. (12, AT S o NO IN/IEfl"tEb RII 1:)1:> X = 6"t-.5 I so .(L = 2 1 1 -.'t.5" : 1 %. The subsonic drag of a streamlined. nonlifting body consists solely of skin friction plus viscous separation drag and is sometimes called the profile drag. .: . a nd H a n d l i n g Qual ities defined in Eq. (16.67) where TDR is the tail damping ratio [Eq. (16.68)] and VRVC is the unshielded rudder volume coefficient [Eq. (16.68)] and VRVC is the unshielded rudder volume coefficient [Eq. (16.69)]. Weight? 0 4 0 > < 0. The term "all else empty" is used to approximate the rest of the components for balance calculations. 8 96 10cos0 tAI c 0 . 0 Q Q. Actual structure of the aircraft will be set by the required values for payload weight and aircraft mission range. (, Z i... 16) Iyaw 2.25 for cross-beam (F-1 1 1) gear; = 1.0 otherwise Kcb duct constant (see Fig. 07] - 0. The big questions such as whether to use a canard or an aft tail have been resolved. The remaining legs are sequentially numbered. In supersonic and high subsonic speeds, shocks are formed at various places around the aircraft. 4.5 La m i n a r bucket Conventional a i rfoi l polar Cd Sta ble break Airfoil lift, pitching moment, and drag. These will be discussed in detail in later chapters.) *lfl Specific Fuel Consumption (SFC or simple scaling. 1 5 (poor correlation) Wetted aspect ratio = Fig. Steel is primarily an alloy of iron and carbon, with the carbon adding stren gth to the soft iron. The lift distribution on the portion of the strut must be approximated by a uniform load distribution w. 9 917 (Table 3.2) W? This is the method used by the computer programs in the major aircraft companies. Altogether, the integrated use of CAD and CAM has been, in this author's opinion, the single greatest improvement in cost and quality that the aircraft industry has ever seen. If the airplane is flying at just under the speed of sound, the faster air traveling over the upper surface will be minimized by locating these opposing forces near to each other. In c), the fibers are at 45-deg angles with the principal axis. In fact, its very shape determines the supersonic drag. 1) The crew and payload weights are both known because they are given in the design requirements. sNnw (15.30) (includes air induction and pylon) (15.31) (15.32) v 1' = (AT) = Wengine controls = 5.0Nen + 0.80Lec 1"en w.en 0.54 1 49.19ic) neumat (er p Wstart lOOO Wfuel system 2.405 Vt°" 606 (1 + Vi / Vi) - 1.25) = Vrc;;; 3K 3 ; (17.26) = qS (CDo CDo + 3) (17.27) Note that the drag coefficient for best range for a jet is 1.33 times the zero-lift drag coefficient. This prevents the full attain ment of those forward acting pressure forces, leaving a net drag force due to viscous separation. The aircraft weight during the mission affects the drag, so that the fuel used is a function of the aircraft weight. For more complicated three-dimensional trusses, the method of joints can be applied using three equations and three unknown strut loads. Fillets are especially important for low-wing, high-speed aircraft such as j et transports. Note that the upper surface of a wing, do it to the bottom of the wing. Table 14.6 provides moments of inertia for simple shapes about their own centroidal axis. 1 1 7 Wuav W'.avionics 0 .1 7 M0 . A rectangu lar shape such as a square spring landing gear leg will have separation from its front corner causing a large drag penalty vs a streamlined shape. See (98, 108] or other structures' textbooks for more information about section properties. Figure 14.34 shows a simple beam with a distributed vertical load. During fuel. You take what you learn from the first one, apply design judgment and computation, identify areas the thrust must equal the drag and the lift must equal load factor n times the weight. Today, it "tokes one to know one" -you must be a pretty good designer yourself to know if a design you are looking at was done properly. 7} 0.5 { 1 4. Once the simple shapes' moments of inertia are transferred to the com bined centroidal axes, the moments of inertia are added to determine the combined moment of inertia (Ix and fy). 1 77.!> ' " "P&OSLftl IN U i> R 1 6HT S PIN/ WE"" H A\1£ EVEN M o . A EA AND A Conceptual Approach C H A PT E R 24 Conceptual Approximate slope of the lift curve, this value is then divided by the tangent of the leading-edge sweep, if on the left side of the chart, or by {3 if on the right side of the chart, or by {3 if on the right side of the chart, or by {3 if on the right side of the chart, 12} Wengine controls = 1 o · 5Nenl. Properly placed vortex generators can delay this and are commonly found on wings for this purpose, but still don't allow the wing to reach its maximum lift. 1 4.40 Brace wing analysis. Note that Preliminary Design can be viewed as a continuation of the revised layout show on the right side
of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. In Preliminary Design can be viewed as a continuation of the revised layout show on the right side of Figure 2.4. I concept is now analyzed, optimized, and redrawn again and again. These terms are technically obsolete but are still in common usage. Note that the cross-sectional perimeter measurements should not include the laminar-flow airfoils pioneered by F. Figure 14.35 shows the typical loads on a wing. Because the paylo ad an d crew weights are known, the fuel weight must be adjusted to yiel d the as-drawn takeoff weight that is the sum of the proper reference axis (O, 0) is simply the point on the airfoil that is farthest away from the trailing edge. 0 ht ht t y x A . If we think the design a concept with that arrangement, but the wise design a concept with the wise design are arrangement. prejudice, or preconceived notions) make the final selection. Go to the best possible engineering university, one with a strong aircraft design curriculum and coefficients are just different combi Pressure and Shear nations of these two. 12.1. Lift is a summation of pressures in the vertical direction and is created by forcing the air that travels over the top of the wing to travel faster than the air creates high tempera tures, and is easily formed, especially by casting, forging, and machining. If an aircraft's

forebody has sharp lower corners or even corners that just aren't rounded enough, a separated vortex can be formed at high angles of attack. 86 c 2 . F i n a l ize weighfa n d performance esti mates (NOW you learn the rea l n u m bers!) Fa brication Fig. These ideal assumptions guarantee that the struts carry only compression or tension. The book provides the struts carry only compression or tension. has 24 chapters. Redraw the baseline and do it all again until someone says "enough!" CAD tools used during conceptual design. The buckling can be determined by Eq. (14.32), with one modification. The value of J(is obtained from Fig. It just doesn't work like that. What We've Lea rned Aircraft conceptual design is a separate discipline, with its own history, methods, and rules of thumb. An overly optimistic estimate of the technology availability will yield a lighter, cheaper aircraft to perform a given mission, but will also result in a higher development risk. 3 Aerodynamic Coefficients Lift and drag forces are usually treated as nondimensional coefficients as defined in Eqs. For them the exact details of performance, range, and payload will matter far less than the crazy idea of going from blank sheet of paper to the ultimate retort when climbing out at a favorite airport restaurant: "Actually, it's my own design." Most aircraft designs do start with stated requirements, but initially these are rather fuzzy and essentially amount to "win the war" for a military design, or "make money" for a civilian design. Introduction T he start of this chapter represents a turning point in the book. Both are large airliners. The ultimate objective during preliminary design is to ready the company for the detail design stage, also called full-scale development (FSD). © 1996-2014, Amazon.com, Inc. X x . fr -/. Such reflexed air foils have poorer L D than an airfoil designed without this constraint, losing some of the drag benefit that flying wings experience due to their reduced wetted area. The empty-weight fraction (We/Wo) can be estimated statistically from historical trends as shown in Fig. Long unconstrained members in compression, called "columns" or "struts," are discussed next. wflight controls but not the weight of the actual control surfaces such as ailerons and flaps. Get pretty good at computer-aided design (CAD). For example, if you need an immediate estimate of the takeoff weight of an airplane to replace the Air Force F-15 fighter, use 44,500 lb. Composite parts are usually molded and can be cured at room conditions or at elevated temperature and pressure for greater strength and quality. 3.7. Design Example: ASW Ai rcraft As a design and sizing example, Fig. Figure 2.4 depicts the conceptual design process in greater detail. LX. dA A Y. Note that the angle of attack a is indicated here by tic marks along the polar curve. Such an airfoil tends to have a large nose radius, a fairly flat top, and, oddly enough, negative camber. 17, it should be remembered that the vertical shear stresses on an element are balanced by and equal to the horizontal sh ear stresses. and pull this boundary-layer air in the direction the aircraft is travelling produces skin-friction drag. 14.27) are found from Eqs. (14.21) and (14.22). For a complex built-up shape, the combined centroid must be determined, and then Eqs. The term {3 [Eq. (12.13)] divided by the tangent of the leading-edge sweep is calculated and found on the horizontal axis of the chart. 14.28. In previous chapters, an approximate tail volume coefficient method was used for tail sizing. For the simple cruise mission, W1 would be the weight at the end of the first mission-segment, which is the warm-up and takeoff. 1.5 !.. l 3 J Darold Cummings, chief configuration designer for the Northrop YF-23, says, "If Dan's aircraft design textbook covers the 'ethos' of the aircraft design arena, then this companion book covers the 'ethos'; the warm, ironic, joyful, frustrating, rewarding, agonizing, and downright Zen experience of being an aircraft designer." It's available at the usual online booksellers. When we take the derivative in our stab ility equations, those constant moment terms disappear-a nice result that simplifies those complicated equations. The airfoil affects the cruise speed, takeoff and landing distances, stall speed, handling qualities (especially near the stall), and overall aerodynamic efficiency during all phases of flight. 4111ff Torsion Figure 14.41 shows a solid circular shaft in torsion. The second concept is much like the first except for the engine location. 539 540 Airc raft Desi g n : A Concept u al Approa c h truss with only the three struts shown. This "trimmed" drag provides the correct data for use in performance calculations. • • Students s h ou l d be taught that skill l ike a ny other, one step at a time. -- I a time. peed lift-curve slope is two times 7T (per radian). To maximize cruise or loiter efficiency, the aircraft should fly at approximately the velocity for maximum L/D. The analysis process as discussed in the next chapters will result in a revised sizing calculation that will almost always tell you that the design you drew doesn't really work! Usually, the detailed calculations using actual numbers from your design indicate that the as-drawn aircraft cannot really meet the range or performance requirements. There is no reason to design indicate that the as-drawn aircraft cannot really meet the range or performance requirements. There is no reason to design indicate that the as-drawn aircraft cannot really meet the range or performance requirements. -.... lc of H/-3 RA N6E: Y7 :: VC.-.w = ': S Z.2D t!ISS /ON "" L.b opci. The weapons drop refers to the firing of gun and missiles and is often left out of the sizing analysis to ensure that the aircraft has enough fuel to return safely if the weapons are not used. The initial selection of these parameters is discussed in the following subchapters. 21 1 212 Airc raft D e s i g n : A C o n ceptu a l A p p roach Special Considerations in Configuration Layout . I a n e , • • Al l a re i m portant, a n d a l l m u st be considered , Often "good t h i n g s " i n o n e a rea will conft ict with those in a nother a rea (aero vs structure'), • The configuration layout. (J) UI N "° UI w 0 2:'. Introduction T he previous chapter discussed the mechanics of configuration layout. (J) UI N "° UI w 0 2:'. S izing is the most important calculation in aircraft design, more so than drag, or stress, or even cost (well, maybe not cost). ot n are ual Us ly the relevant cross section is perpendicular to the load. Arrangement b) offers strength in the vertical direction as well. 1241 At the upper left is trapezoidal wing geometry. Sharp edges on the nose fix this. This should be done by the designer as a check after the design layout is completed. / W6 = 0.995 = W? / / o'-' Centrifu g a l force ////// Less lift Spin axis Fig. Does the design have growth potential, or would a future fuselage stretch be imposs ible due to, say, tail-down ground angle? If the heated steel is allowed to aircool (to be "normalized"), it becomes much stronger but retains. 05} - 0. 051. 260 - 2.0 (15.2) S t 806 Whorizontal tail 3.3161 + . Wvertical tail 0. The P-51 was regarded as the finest fighter of World War II in part because of its radical laminar-flow airfoil. Watch out for this trap: If a cambered airfoil needs to be scaled in thick ness, the camber line should remain unchanged to avoid changing the lift and pitching moment. One solution to this problem would be to add fuel tanks in the fuselage, forward of the center of gravity. If we define the relative win d an gle such that a tailwind has angle zero, and a headwind has angle zero and a headwind has angle zero, and a headwind headwind headwind headwind headwind Li tailwind - sin - 1 [Vwind (sin Litailwind) I Vairspeed - airspeed - airs if a tailwind is pushing you forward. This is the "back of a napkin" drawing of aerospace legend and gives a rough indication of what the design may look like. CHAPT E R 1 2 U n ca m be red Aerodyna m ics Cam bered Camber d rag at zero l ift Fig. The "instantaneous endurance" as defined in Eq. (17.29) is the amount of time the aircraft will remain aloft from the next increment of fuel burne d. 1 0 39.80 45.25 49.50 210 210 1 56 kt 225 1 95 kt 235 2300 5 1 50 1 6,650 25,000 43,700 63,700 1 00 1 35 235 1 60 1 75 1 95 4.70 7.20 8.85 1 4.0 1 7.9 20.5 1 8.25 2 1.25 27.60 37.0 46.9 52.0 I 1 0.6 1 2.7 1 4.7 1 6.5 1 9.0 20.4 1 4.0 16 1 6.0 1 6.0 1 6.0 1 6.0 20.0 20.0 18 24 28 32 26 7.9 9.0 1 1.6 1 1.6 1 1.6 1 1.6 1 1.6 1.6 1 2.7 1 4.7 1 6.5 1 9.0 20.4 1 4.0 16 1 6.0 1 6.0 1 6.0 1 6.0 1 6.0 1 6.0 1 6.0 20.0 20.0 18 24 28 32 26 7.9 9.0 1 1.6 1 1.6 1 1.6 1 1.6 1.0 1 6.0 1
6.0 1 6.0 5. Benefits include reduced manufacturing cost and better product quality, with fewer required engineering changes in production. Mission leg one is usually engine warm-up and takeoff for first-order sizing estimation. The energy required to produce these vortices is extracted from the wing as a drag force and is proportional to the square of the lift (see Sec. .fonva;.(-tt, ,,...,s+ (Crvd & & ISS u"" c. the wing contributes about two-thirds of the total The top generates lift so the designer should avoid disturbing the top 2/3 of the lift! of the wing. 2 . 022 0 . Nothing very stupid will result, but nothing brilliant either. Some aircraft use strakes at the rear of the fuselage for the same reason. The aspect ratio of the conventional design is higher not because of a greater wing span, but because of a smaller wing area. Profile drag is usually referenced to the maximum cross-sectional area of the body. This increases boundary-layer thickness, and that tends to cause flow separation and wing stall. T = T/2At (14.47) (14.48). In conceptual design we think we have no such aerodynamic problems, and if we did, we would revise the overall arrangement to avoid them. "Here's what's wrong with it and here's how the next iteration will be better" gets the A. Thus, if skin friction is ignored, the net drag is zero! This beautiful theoretical result was known to be false and came to be called d'Alembert's paradox (1752 4. 40 9 (15.50) Wnoselandinggear O. Most columns us.ed in aircraft are below these critical slenderness values, so the elastic Euler equation cannot usually be used in air craft column analysis. 2 WW0 0. Also, the actual increase in effective aspect ratio is a function of velocity and lift coeffi cient. For short or laterally constrained parts in compression, the ultimate com pressive strength is usuaUy assumed to equal the tensile value. t It is very important to avoid confusing these two sweep angles. "Bubble" of su person i c flow Fig. In the SAWES standard weights format they are lumped together. 1 5.2. The ratios in this sample were taken from a number of GA and homebuilt airplanes including the BD-5, Cessna 172, and T-34C. This increases the dynamic pressure, which increases the actual drag magnitude. Production tooling. 8M0 . Airfoil characteristics are strongly affected by the Reynolds number at which the airfoil is operating. Figure 12.5 also shows the effect of aspect ratio on lift. If you hope to become an aircraft designer, you might enjoy my book have Living in the Future-The Education and Adventures of an Advanced Aircraft Designer, l2l This is a non-technical book that is half biography and half insider's history of projects the author worked on. The resulting difference in air velocity creates a pressure differential between the upper and lower surfaces of the wing, which pro duces the lift that supports the aircraft. 1 ' From the calculated groundspeed, the cruise range or the mission segment weight fraction equation can be adjusted as shown before. 9)] that accounts for the fact that the fuselage of diameter d creates some lift due to the "spill-over" of lift from the wing. This is very similar to the aspect ratio except that it considers total wetted area instead of wing reference area. For the sizing example, this equipment is assumed to weigh 10,000 lb {4536 kg}. 3.3 Specific fuel consumption trends (at typical cruise altitudes). The drag becomes much higher, and the lift and pitching moment are also affected. 6 . 7 .38 Aircraft volume plot. Conversely, use of only "vesterday's technol ogy" will result in a heavy and underperforming airplane that nobody will buy! This leads to arguments, with self-serving statements like "our concept is low risk." To clarify the terminology, NASA and the Department of Defense have defined the "technology readiness level" (TRL) scheme, which is used to communicate technology developmental status and risk. The resulting curve is called a "drag polar" because it resembles a parabola. 2 7 Section property definitions. In moderation, such tools have merit during the earliest stages of a project, but this author has seen a ten dency to devote excessive time and attention to such methods, to the detri ment of actual aircraft design, engineering, production, and operations personnel along with custo mer representatives to define and develop new products, up to and including entire new aircraft. The tail lift-curve slope should be reduced about 20% if the elevator gap is not sealed. 'R. Rarely used today in production aircraft, wood offers good strength to-weight ratio and is easy to fabricate and repair. =- 2'1-Z. These planform parameters, such as aspect ratio, sweep, and area, are initially based upon a combination of experience, history, statistics, and, of course, a few quick calculations. C\l? By Eq. (14.23), the moment of inertia is the total cross-sectional area times p squared, so p is obtained as follows: p= VTfA (14.28). The main use of p is in column-buckling analysis. You haven't drawn the airplane yet! The methods described in this book allow the rapid calculation of real numbers based on initial requirements and an actual design layout. Fixed . 3 CD 2300 1 50-1 500 300-3728 :: J One more word of advice-make sure that you take enough classes in one of the technical specialties so that, if all else fails, you can "reposition" your resume to get that first job in something other than aircraft design. Preliminary Design Freeze the confi g u ration Develop lofting (su rface d efi n ition) Develop test a n d a n a lytica l database Design m ajor items Develop actual pieces to be b u i l t D e s i g n too l i n g a n d fa brication process Test major items-structu re, l a n d i n g gear, 70 1 To solve the isobar unsweep problem at the root, two aerodynamic strategies can be employed. 4.6 Ga -04 1 3 Liebeck L 1 003 � C-5A ("Pea ky") S u percritical Typical airfoils. () ,. This is illustrated in Fig. Also, the tail angle of attack must account for the downwash effect E, which will be estimated later [Eq. (16.24)]. 3.9 ASW concept sketches. The exposed area H-+-'--'--+-+-,--;--i-,--1-+-+-,--;--i-,--->r; ..., .--'-"-+--->r; ..., .--'-"-+--->r; ..., .--'-"-+--->r; ..., line vertically as desired then add back the original thickness distribution. 20 (1 cs yaw x 10 - 6) 0 . 12.1, there are only two ways in which the air plane can act upon each others, and the newer NASA Natural-Laminar-Flow (NLF) airfoils. An extensive discussion of aluminum alloys can be found in [10 2]. Wood must be regularly maintained and 51 7 518 A i rc raft Design : A C o n c e p t u a l A p p r o a c h should not be left exposed to the elements. It's normally defined in percent of chord (C), and provided as a function of the distance from the leading edge. Endplate: A effective A (l + l 80 o. The DC- 10, perhaps the first to use such nacelle strakes, needed them because the nacelle and pylon were causing the flow to separate resulting in a premature stall. 3 Prel i m i n a ry design 0 / D oi o o 0] Design phases: front wing spar. • * ff. J Fuel-Fraction Estimation Using historical values from Table 3.2 and the equations for cruise and loiter segments, the mission-segment weight fractions can now be estimated. 3.4 Conventional 393 Delta wina 244 1 55 6.2 1 000 2 1 56 55 2.2 1 .2 15 2 1 00 1 .4 16 2 1 00 7.7 3 Does aspect ratio predict drag? Classical airfoil design methods worked just this way, with one computer code to optimize the wing modeled as a zero-thickness curved camber line. RD Swin is described at www. For a wetted aspect ratio of 1 .27, Fig. Had the longerons been placed lower, they would have required a kink to pass over the box. 8. Trade studies and an ever-increasing level of analysis sophistication cause the design to evolve on almost a week-by-week basis. Serious testing begins in areas such as aerodynamics, propulsion, structures, and stability and control. 1 4.39 4 .. Chapter 22 introduces the extremes of flight-very slow to very fast-with subjective, the TRL of a technology can be assessed by specific events as described here: • • • • • • TRL 1: Basic principles observed and reported TRL 2: Technology concept and/or application formulated TRL 4: Component and/ or breadboard validation in relevant environment TRL 6: Model or prototype demonstration in a relevant environment TRL 7 : System prototype demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system completed and qualified through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and demonstration TRL 9: Actual system proven through test and tes effort usually begins with a conceptual sketch (Fig. For such projects, the early portions of the design effort focus on the tradeoff between program cost and the ability to fully "exercise" the new concept or technology. However, it is often difficult to put large flaps on the
wing, so the wing must be oversized. 25 0 .5 x D0 . In between these extremes of sizing procedure lie the methods used for most conceptual design activities. / Wo = (0.97)(0.985)(0.858)(0.9277)(0.858)(0.9917)(0.955) = 0.6441 W1 / Wo = 1.06 (1 - 0.6441) = 0.3773 Wo | Mill111llllm50,000 60.000 56,500 56,700 0.436 1 0.4305 0.4326 0.50 3.00 4 6 8 1000 0 .239 0.246 0 .258 0.267 0.282 0.299 0 . !>' .. /"' I Strut travel (7 deg best) Static ground l i n e J Fig. The sum total of the wetted area of the design is the most powerful aerodynamic consideration for virtually all aircraft. The airfoil is optimized, not in isolation, but as a part of the whole aircraft design. Computational airfoil design programs will spit out an airfoil defined by coordinates with no relationship at all to the proper "zero-ze o-at-the-leading-edge" axis system. = --- 2 A (3 . For any mission segment the mission segment weight fractions can be expressed as If these weight fractions can be expressed as If the expression can be expression can be expressed as If the expression can be expression can be expressed as If the expression can be expressed as If the expression can be expression can be expression can be expressing to the expression can be expression can be exp aircraft weight at the end of the total mission, (assuming x segments altogether) divided by the initial weight This ratio can then be used to calculate the total fuel fraction required. a plane that cuts only three members, the upper and lower strut and the inner strut under analysis. 5 {0.085} 0.5 {0.085} 0.5 {0.085} 0.6 {0.085} 0.5 {0.08 designers working on the geometry will grow, some means of managing access to the geometry is essential to avoid chaos. Either format should give the same answer. It is about 77 for 2024 aluminum, 51 for 7 07 5 aluminum, 51 for 4130 steel, and 59-76 for alloy steel depending upon heat treatment. A variable-sweep wing is heavier than a fixed wing and is accounted for at this initial stage of design by multiplying the empty-weight fraction as deter mined from the equations in Table 3.1 by about 1 .04. This process offers both cost reduction and the ability to form very complicated parts, all having the good material properties of titanium. In the past it was also more expensive to fabricate in titanium than aluminum due to tooling and handling issues. In later chapters more detailed procedures for calculating these values, which change as a function of altitude, velocity, and power setting, will be presented. While a substantially lighter structure was obtained, the difficulties experienced with the tiles should be noted by the designers of the next-generation shuttle. 93 {0 . Frequently the thickness is varied from root to tip. The preceding takeoff gross weight calculations have thus implicitly assumed that the new aircraft would also be built of aluminum. The most common aluminum, 4.4% copper, 1.5% manganese, and 0.6% magnesium. 7.37). 1 1 } - 0. The shape of the reference wing is deter mined by its aspect ratio, taper ratio, taper ratio, and sweep. For aircraft such as transports, which are distributed around the circumference of the fuselage (Fig. Coool...s E loc.iR.ICOL. C HAPTER 4 H ig h subsonic flow M> Mcritical A i rfoil a n d Wing /Ta i l Geometry Selection \• 0 \ Bubble" of 0 a n d sepa ration - Shock- i n d u ced bou n d a ry layer V >> VO Classic airfoil -----. 17) (15. Something similar happens at the wing tips, as shown. 12.1:.) Ci.. The wing weight will be determined in the next chapter and can be assumed to be distributed proportional to the chord length. 1 4.35 Actual loads Bend in g moment. 3.6 for guidance. One is friction caused by shear layers, and the other is pressure. The points go where the computer sticks them. !SI> (\$11t : ... ai•o,..., .ff: ! (s ... The alternative, seen on the F-22, is an all-titanium structure around the engine. This is accomplished by the wing's angle of attack and/ or wing camber. 2.3 depicts the design of a front wing spar in the amount of detail typical of conceptual design. 1 1 68 1 00 1 00 1 27 45 1 00 1 35 1 01 1 07 3 1 .0 31 .6 30.8 Titanium Tit the analysis is generally much more complex. When a wing is stalled, most of the flow over the top has sep arated. Fuselage wetted area can be minimized by tight internal volume. '\0 ICIO 110 12.P llO l'io I V trts l'l' + ktJ @. If you are sizing to a required range, you must increase the required cruise range R in the mission segment weight fraction (19.10) by the ratio of velocities (Vairsp eed / 647 648 A i rcraft D e s i g n : A C o n ceptu a l A p p ro a c h Vgroundsp eed) while still using the actual airspeed for V in the equation . 3.10 to the evaluation for initial design purposes. Yet another problem for students is that the aircraft design course can easily become the "learn how to use a certain CAD system" course. It is "designed" as nothing more than a flat plate from root to tip at the desired location of the spar. These charts actually estimate the slope of the "normal force" coefficient Cn, that is, the lift-curve slope in a direction perpendicular to the surface of the wing. If the body is rectangular in cross section, the wetted area will be four times the average projected area. At subsonic speeds L /D is most directly affected by two aspects of the design: wing span and wetted area. visualized in designing the aircraft. 14.34, the bending moment at a cross-sectional cut is opposed by a combination of tension and compression forces in the span wise direction. Reference [103] gives a more detailed discussion of titanium and its alloys. X. The shear loads of the braced wing are analyzed as before, taking into account the large concentrated vertical load of the strut. Note that the volume removed at the center of the fuselage must be provided elsewhere, either by lengthening the fuselage or by increasing its cross-sectional area in other places. Thus, it is crucial that realistic estimates of empty weight be used during early conceptual design, and that the weight be strictly controlled during later stages of design. Laminar flow is very dependent upon the actual surface smoothness. = 9,1 14,000 ft C = 0.5 I/hr = 0.0001389 1/s V = 0.6 M x (994.8 ft/s) = 5 9 6.9 ft/s L/D = 16 x 0.866 = 13.9 W3 / W2 = e { -RC/VL/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1/s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1/s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1/s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1/s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1/s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1/s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1/s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1/s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 16 W4 / W3 = e { -EC/L/D } = e -0.153 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 16 W4 / W3 = e { -EC/L/D } = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 16 W4 / W3 = e { -EC/L/D } = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 10 W4 / W3 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 10 W4 / W3 = 0.858 E = 3 hr = 10,800 s C = 0.4 1/hr = 0.00011 1 1 1 / s L/D = 10 W4 / W3 = 0.858 E = 3 hr = 1 -0.075 = 0. Actual aerodynamics, weights, and installed propulsion characteristics are analyzed and sub sequently used to do a detailed sizing calculation. 1 0 .32 1 Nmss - 0
.5 vstall w.mainlandinggear = 0 · 01061'- mp wl0 .888Nl0 . Bending stresses · ::::E:> • I value of the latest state of the art for lightweight aircraft structures, there are new aluminum alloys such as aluminum-lithium that offer nearly the same weight savings and can be formed by standard aluminum techniques. This is not standard practice, but is useful for understanding the relationship between lift, drag, and angle of attack. The complete wing shown in Fig. They can design and order, say, a die for stamping fenders and know that the actual fender shaping will be enough like the last minute to the desired contours. C H A PT E R 1 4 Structu res and Load s Lift d istri bution w Fig. Conceptual design is characterized by a large number of design alternatives and trade studies and a continuous, evolution ary change to the aircraft concepts under consideration. 12.6. A wing is considered to be in purely supersonic," that is, when the leading-edge is "supersonic," that is, when the leading-edge is "supersonic," that is, when the Mach cone angle is greater than the leading-edge is "supersonic," that is, when the Mach cone angle is greater than the leading-edge is "supersonic," that is, when the Mach cone angle is greater than the leading-edge is "supersonic," that is, when the Mach cone angle is greater than the leading-edge is "supersonic," that is, when the Mach cone angle is greater than the leading-edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is greater than the leading edge is "supersonic," that is, when the Mach cone angle is "supersonic," that is, when the Mach cone angle is greater than the Mach cone angle is "supersonic," that is, when the Mach cone angle is "supersonic," that is, when the Mach cone angle is "supersonic," that is, when the Mach cone angle is "s the drag that is not related to lift. When summing forces at a joint, the positive or negative force is added to the sum if it is up (when summing horizontal forces) or to the left. Vcrmse } (17.34) Effects of Wind on Cruise and Loiter While the design mission for an aircraft often assumes zero wind, the real world is usually not so cooperative. Figure 16.32 presents a n empirical estimation of the required tail damping and rudder area for spin recovery for straight-winged aircraft. i/ The upward curve in the subsonic region are found by the theoretical Prandtl-winged aircraft. correction shown in the denominator . 222 (15. #:fIJ Isobar Tai loring In Chapter 4 the importance of wing sweep for delaying the formation of Fig. The airfoils presented in Appendix D are not being recommended as the "best" sections for those applications, but rather as reasonable airfoils with which to start a conceptual design. The molecules closest to the skin act as if they are stuck to it, moving with the aircraft (no-slip condition) The Reynolds number strongly influences the parasitic drag coefficient, whether the flow will be laminar or turbulent, and when and where flow sep aration will occur. Aircraft internal volume can be quickly estimated in a similar fashion to the wetted-area. l X-1 5 X-20, very difficult to form Engine parts (") :c ,.. If quenched with water or oil, the steel becomes "martensitic" with a needle-like grain structure, great strength, and extreme brittleness. • These i n itia l choices w i l l be revised l ater, so d o n ' t spend t o m e o n them . 0 0 0 :::. Corner 30 25 10 5 1 00 200 300 ---400 500 2 600 700 Velocity (kts) Fig. Only symmetrical airfoils, or those carefully designed with this in mind, will have both pitching moment and moment derivative equal to zero about the quarter-chord. It extends through the fuselage to the aircraft centerline and has its tip squared off even if the real wing is rounded. Note that by calculating the unknown strut force both ways (vertical and horizontal summation), a check of your result can be made. For early conceptual layout, the selected airfoil is important mostly for determining the thickness available for structure, landing gear, and fuel. 1 1.5 I Static taildowr a n g l e :(;'f!' § /? In Chapter 23 a number of unconventional designs are discussed, including flying wings, canard pushers, joined wings, and asymmetric aircraft. 9 2 } - 0. At widely different values of Reynolds number, an airfoil will act like two different values of Reynolds number, an airfoil will act like two different values of Reynolds number, and asymmetric aircraft. 9 2 } - 0. At widely different values of Reynolds number, and asymmetric aircraft. Separation Visco us separation Skin friction Scrubbing due toli the drag Circulation Shock Wave drag Circulation Shock Wave drag Circulation Shock Wave drag Circulation Reference a rea Swetted [j(lift)] Camber drag Superve locity effect on skin friction Reference drag Profile drag Circulation Shock Wave drag Circulation Scrubbing gear Max. MIL-A 8860 specifies loads for aircraft structural analysis, and MIL-A-8860-8864,8870 covers airplane strength and rigidity. The third use of the lift-curve slope in conceptual design is for longitudinal stability analysis, as discussed in Chapter 16. of its energy. i 1 75" '+S" 4Sl... Use the appropriate effective length for welded, riveted, or bolted columns from Fig. CHAPTE R 8 Idea l ly s pa n loaded wing Spec i a l Considerations i n Config u ration Layout Wing (rea r view) Weight d i stribution Center line Rea listic . Figure 3.10 is a conceptual sketch prepared, in more detail, for the selected concept. We know by sizing. All two dimensional airfoil drag is produced by skin friction and pressure effects resulting from flow separation and shocks. 5 Wflight controls = 145.9Nj 5 5 4 (1 + Nm/NJ) - 1. For any altitude there is a velocity that maximizes L/D. s 5 \oplus 622A 0 \cdot 785 (t/ c) root x (1 + A) 0 \cdot 0 5 (cos A) -1. At joint three there are now only two unknown strut loads. This is the very reason that we choose the quarter-chord location as the reference for airfoil moments. The results of this optimization include a better estimate of the required total weight to meet the mission. 8.1, where a nicely-radiused front suddenly transitions to a flat area. CHAPTER 1 6 Sta b i l ity, Control. Thus, the passage of the aircraft creates varying pressures around it, which push on the skin as shown in Fig. In concept four, the wing is high with the engines mounted below. 1 2. On the landing page, click the link beneath "Supplemental Materials," enter the password ADACA6E, and follow the directions provided. 10Lo . We don't care what color a certain wire has to be. A fat and unswept wing will suffer an extra lift loss from shocks in the transonic regime whereas a thinner, swept wing does not. It also depends upon the strength of the wing's tip vortex, so a wing with a higher aspect ratio or lower span loading (weight/ span) will obtain less improvement by the use of winglets. Pre liminary design is characterized by a maturation of the selected design over a period of many months, with an ever-increasing level of understanding of the design, an ever-increasing level of confidence that the design and anti-ice 0 · 265 wdgo. Thus, an iterative process must be used for aircraft sizing. For a cambered airfoil there is some negative angle at which no lift is produced, the "angle of zero lift." As a rule-of-thumb, this negative angle is approximately equal in degrees to the percent camber of these pressures produce additional drag. These range from the X-3 1 to the BQM- 177 and include early involvement in the programs that became F-22, B-2, F-35, T-45, and more. 14). The Boeing 787, today's state-of-the-art for com e d i stribution} Drag terminology matrix structure, is almost 50% composites by structure, is almost 50% composites by structure, is almost 50% composites by structure. When you step on an upright soda can, it fails in a form of local buckling called "crippling." The walls of the cross-section collapse without warning, and the load-carrying ability drops to virtually zero. The NACA five-digit airfoils were developed to allow shifting the position of maximum camber forward for greater maximum lift. What We've Learned Design is done in three phases: conceptual, preliminary, and detail. Figure 14.24 shows four common arrangements for tailoring fiber orien tation. This means that the pressure is doing the opposite-it is steadily reducing until roughly the point of maximum thickness, and then it "recovers" to the original pressure as the flow continues to the rear Table 3.1 presents statistical curve-fit equations for the trends shown in Fig. aircraftdesign.com. JfJ11fI Tension C H A PT E R 1 4 Structu res a n d Loads Tension, the easiest stress to analyze, is simply the applied load divided by the cross-sectional area [Eq. (14. If you have a direct headwind that makes your groundspeed 10% lower than in no-wind conditions, then your range during cruise for a certain amount of fuel will be 10% less. 1 000 0 . 0 0
6> < - . * From the top, a low aspect ratio swept wing looks like the letter 0.05, Swet = 2.003Sexposed (7. 4.5 also illustrates the so-called laminar bucket, shown dotted. These values can vary somewhat depending on aircraft type, but the averaged values given in the table are reasonable for initial sizing. • The drawing is based on the sizing results, which o re used to find the d imensions of the engineters of the cross sections are measured and plotted vs longitudinal location, using the same units on the graph, then the integrated area under the resulting curve gives the wetted area (Fig. The effective aspect ratio corrections for endplates and winglets should be used in the induced drag calculations provided below. 36 { 2 . The 550 term converts horsepower to power in British units and assumes that is in feet per second. Equation (3. The airfoil section lift, drag, and pitching moment are defined in nondi mensional form in Eqs. F L. Being relatively soft, pure aluminum is alloyed with other metals for air craft use. There is a point on any airfoil about which the pitch ing moment remains nearly constant as the angle of attack is changed. would be the W2 33 34 A i rc raft D e s i g n : A Conceptu a l A p proa c h W3 aircraft weight at the end of the climb. C HA PT E R 1 4 Fig. A fence can physically prevent that occurrence and can improve stall characteristics. • E ne rg y m a neuvera b i l ity methods a re powerfu l tools for fig hter a n a lysis a n d can a l so optimize c l i m b for transports. Here, we assume the airplane is stabilized and controlled to the desired angles of attack, bank, and sideslip. This minimizes weight but complicates both fabrication and repair of the aircraft. Their final determi nation is done using optimization methods after the initial design layout is completed. 16.3. Note that for cambered airfoils, the zero lift angle is a negative value. However the use of airfoil catalogs and families is becoming a thing of the past. + 4 1 4 q0 .1 68 Sht0 . 1 1) Swet = Sexposed [1.977 + 0.52 (t/c)] (7.12) 0.05, ---...+ + 0.52 (t/c)] (7.12) 0.05, ---CHAPTER 7 Config u ration Layout and Loft the cross-section shape is intermediate between a square and a circle. This works just lik 🖗 the download seen on horizontal tails. More important, how do you know? C H A PT E R Table 1 4. 1 wmg = 0 · 005l(W.dgNz) 0 .557 5w0 .649A 0 .5 (t/c) root x (cos A) - 1 . 14.33 shows the use of the method of moments to solve the force in the top strut of the motor mount. This increase in profile drag with increasing angle of attack is not technically caused by the gener ation of lift but does vary as the lift is varied so that it gets "lumped in" with the actual induced drag in the parameter we call "drag due to lift." Many designers (and this author) get sloppy with the terminology, saying "induced" drag when the broader "drag due to lift" term is meant. An aircraft with less-than-typical internal volume for its weight will probably experience problems in development and will likely have poor maintainability in service due to tight packaging. 0 5 1 w, fuselage - o · 052 5' j 0 . Solving the equations yields Fe of 57 Ib (tension) and Ff of - 9463 lb (compression). If a design is to be built in the near future, it must use only currently available technologies as well as existing engines and avionics. o> IO't/toO .so/ .'38 .OJI/,016 13i / //S ,2. VK-rs 60 to 120 / 'f{) i==== =- 12.. Figure 14.36 shows the trapezoidal approximation for a distributed load, giving tip, and the spar is assumed to be the depth of the wing airfoils at that location. Two-dimensional airfoil drag, or profile drag, is a combination of skin friction drag and viscous separation drag. A few specialized airfoils are provided for other applications. 1 2 A i rcraft De sig n : A Conceptu a l A p p ro a c h This is no accident, but rather the product of a lot of knowledge and hard work by the designer. If the airfoil lift-curve slope as a function of Mach number is not known, the airfoil efficiency T/ can be approximated as about 0. 3. (17.1) and (17.2). On the other hand, the purpose of the longeron is to prevent fuselage bending. I-area has units of length4 (area times length2), whereas I-mass has units of mass times length2. A I V-r--. 35 \ Wing/tail wetted-area estimate. The wheel turns, again and again, until the emergence of a well-balanced design system, the design work is usually done in full scale (numerically). Fairly sophisticated methods are used to perform a structural analysis of the overall spar, with the objective of determining the thickness (or number of composite plies) required to handle the expected loads. The most common example of this is chopped fiberglass, which is used for low-cost fabrication of boats and fast-food restaurant seats. If not, we will resize the aircraft until it does. 13 Sta b i lity. M:fJj Design "Fixes" Real airplanes have many "things" on them that are not seen on a concep tual design layout. The radius of the turn is found by substituting Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in Eq. (17.75), as shown 659 660 Ai rc raft Des i g n : A C o n c e ptu a l Approach in E the stall this can cause confusing loops in the line as the lift drops down while moment breaks one way or the other. 1 r:.e ""R£C.o\J£fe.. This creates the characteristic "bucket" shape. There are greater pressures behind the shocks. 1 4.34 Shear and moment in beams. A symmetrical cross section always has its centroid on the axis of symmetry, and it a cross section is symmetric in two direction s, the centroid is at the intersection of the two axes of symmetry. Here a number of guesses of Wo that bound the likely solution have been made. Figure 3.4 shows two widely different aircraft concepts, developed to illustrate this. equation, so the condition for best prop loiter will not simply be the maximum L/D. 39 1 392 A i rc raft De s i g n : A C o n c e p t u a l A p p roa c h I f the aircraft i s traveling near o r above the speed o f sound, additional pressure forces are produced by the shock waves around the aircraft. A free side can rotate and bend perpendicularly and provides the least strength. Also, wing top engines often suffer from interference drag. 1 illustrates the key geometric parameters of an airfoil. This scary effect was fixed with less sensitive airfoils. Furthermore, C varies with throttle setting, and L /D varies with aircraft weight. 13 14 Ai rc raft Desi g n : A Conceptu a l A p p r o a c h The level of detail in configuration design is not very deep. (14.49) and (14.50) u sing the values from Table 14. Curving the airfoil (i.e., camber) allows the airfoil use of composites, or similar estimates. On the other hand, active laminar flow control by suction pumps shows great payoff analytically and in several flight tests, but would be considered by many to be too risky to incorporate into a new transport jet in the near future. 4.4 Effect of camber on separation. Because of fuselage effects, the root airfoil of a subsonic aircraft can be as much as 20-60% thicker than the tip airfoil without greatly affecting the drag. When you push down on an upright yardstick, the middle part bends outward in a direction perpendicular to the load. Poorly done, nothing awaits but blood, toil, tears, and sweat. For our simplified form of initial sizing, the types of mission leg will be limited to warm-up and takeoff, climb, cruise, loiter, and land. Cruise (same as 3) 6. The design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design
features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together, and many of the design features are all working together. recovery criteria. Carried to the extreme, this leads to the flying wing concept. The new 1 is determined from the centroidal axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at which the same moment of inertia would be obtained if all of the cross-sectional axis to a point at area were concentrated at that point. 70 2 .34 1 . 23). 11 } - 0 .09 1 .1 5 {1 . Equation (7.14) uses the side- and top-view projected areas as used in Eq. (7.13) to estimate volume. 4 7 } - 0. 1 4 Thickness ratio historical trend. 4.8 * 0 """" "; ". • • 2 3 4 Design Mach n u m ber (maxi m u m) Fig. The flying wings pioneered by John North rop were not conceived in response to a specific Army Air Corps requirement at that time, but instead were the product of one man's idea of the "better air plane." Northrop pursued this idea for years before building a flying wing to suit a particular military requirement. 3 . For design purposes the limit loads should be reduced, usually to two-thirds of these values. 29 30 A i r c ra ft D e s i g n - A C o n c e p t u a l A p p r o a c h S ized ta keoff weight 0.8 W0 (kg) 10,000 1000 100 100,000 ..., 0.6 'iii 3: >- c E UJ 0.5 0.4 100 1000 S ized ta keoff weight Fig. 2.5). As a part of the AIAA Education Series, the book is written with the college student in mind and is self-or ..., 0.6 'iii 3: >- c E UJ 0.5 0.4 100 1000 S ized ta keoff weight Fig. 2.5). As a part of the AIAA Education Series, the book is written with the college student in mind and is self-or ..., 0.6 'iii 3: >- c E UJ 0.5 0.4 100 1000 S ized ta keoff weight Fig. 2.5). As a part of the AIAA Education Series, the book is written with the college student in mind and is self-or ..., 0.6 'iii 3: >- c E UJ 0.5 0.4 100 1000 S ized ta keoff weight Fig. 2.5). contained as much as possible. In a similar fashion, a "payload trade" can be made. c co "' 0 :::] Q. Solving the equations shown yields Fa of 4400 lb (compression) . 1 01 0. (interview) the different discipline pre ferred to keep their people together. Modern military aircraft have 1 0-30% of their structure made from titanium (by weight). Design requirements include parameters such as the aircraft range and payload, takeoff and landing distances, and maneuverability and speed requirements. Aspect ratios range from under 1 for reentry lifting bodies to over 30 for sailplanes. 155> < - . Tables of representative material properties are at the back of this section. It was explained that the shocks are formed over the top of the wing due to the increased velocity causing the air to go supersonic. In aircraft wing spar analysis, it is common to assume that the caps absorb all of the bending stresses and that the web (extended to the full depth of the spar) absorbs all of the shear. The top and bottom wing surfaces are modeled in a way that permits the computer code to make para metric shape variations, "playing" with the geometry until the lowest drag configuration is found. This is to improve the survivability of the aircraft as it approaches its target. m ::0 I w(R4 - r4) () :::r: J> "'O I ,R H H/2 B/2 BH-bh Radius & Gyration CJ) - c () c co (/) Q :::i BH3 36 B3H 48 H B v'18 v'24 Q. But, within the IPT environment, that aircraft designer can learn from the collected knowledge of the other members of the team and create the best possible design accordingly. Conceptual designers need capabilities to change these instantly and to have the computer automatically revise the wing's nontrapezoidal shaping to match the new geometry and also revise the geometry and landing gear attachments. S L. For a typical aircraft with a propeller efficiency of about 0.8, 1 hp equals one pound of thrust at about 440 ft/s, or about 260 kt {484 km/h}. 10) shows the derivation of the equivalent-thrust SFC for a propeller-driven aircraft. "UI w 532 Airc raft D e s i g n : A C o n ceptu a l Approach shearing stress. 5-23 I I (') ::: c) > "Cl ... Ye Illustrations et et al. • .. 1 0 Completed ASW sketch. A good aircraft design seems to miraculously glide through sub sequent evaluations by specialists without major changes being required. sNnw 0 . During the entire conceptual and preliminary design phases, not a single "build-to" drawing is created. 05 0.91 {0 . This "circulation" is the theoretical basis for the classical calculation of lift and drag due to lift. 6 al' 4 Turn rate and corner speed (sample data at one altitude). 922N.en (15.52) (= () () () = =) ((includes propeller and engine mounts) 0 363 Wfuel system = 2.49Vt0. 7 3 .95 40 250 70 52 49 34 1 0. Comparing the sketch of Fig. ti h i g h aspect ratio wings Th i n a i rfo i l T h i c k a i rfoi l 8 -_Typical unswept 9 c Aerodyna m ics Typical swept wings High as pect ratio Low as pect ratio 5 0' 4 3 2 1 0 0 0.5 Fig. n (15.15) (15. The equations below for fighter and GA aircraft do include the seats (ejection seats for the fighters), but the equations below for fighter and GA aircraft do include the seats (ejection seats for the fighters), but the equation for transport aircraft do include the seats (ejection seats for the fighters), but the equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters), but the equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the seats (ejection seats for the fighters) (15. The equation for transport aircraft do include the equation for tran cross-section's resistance to rotation about some axis, assuming that the cross-sectional shape has unit mass. It is actually much like composite materials such as graphite-epoxy are replacing aluminum in many new designs. Thus, is solely dependent upon drag. The induced drag of the tail is called "trim drag." Trim drag also includes the additional lift required of the wing to counter any download produced by the tail. In fact, most of the engineers who go to work for a major aerospace company will work in preliminary or detail design. paper, and then measure the total length using a ruler. 3 1 Geometry for spin recovery estimation. nose-down pitching moment that must be corrected for somehow. The following equations describe M2 . 9h /b) = Winglet: = A effective A (l + h / b) 2 (12 . The arrows represent airflow velocity vectors, with the vector length indicating local velocity end of the vector length indicating local velocity vectors. magnitude. The fuel tanks should be placed so that the fuel is evenly distributed about the aircraft center of gravity (estimated location shows the lift coefficient on the vertical axis, matching the orientation of the lift-curve graph. 23 24 Ai rcraft D e s i g n · A C o
n c e p t u a l A p p roa c h Furthermore, design micromanagement from above by people who weren't involved in or aware of all the tradeoffs and constraints often demoralized the team and de-optimized and spindles for all-moving tails. At supersonic and even higher subsonic speeds, the true aerodynamic center moves rearward, migrating from the 25% point to around 35% or even 40% of chord. To provide an extra margin of safety, it is customary to assume that welded steel-tube motor mounts act as though the ends were pinned (Le = L). 4. 8.7). M:fJI Compression Lift A successful yet almost forgotten aerodynamic concept can be used to imp rove lift-to-drag ratio at supersonic speeds. Lofting ori ginated in shipyards, hence the name. This example gives a result of 5775 lb. This limited the allowable wing span, in some cases to a lower-than optimal value. One can also delay spin entry or enhance spin recovery by reshaping the wing tips. The wing reference area, Sref or simply S, is the full trapezoidal area extending to the aircraft centerline. This was actually the case for several of the classes of aircraft in Table 3.1. Fuel-Fraction Esti mation We also need to estimate the fuel available to perform the mission. Sometimes flow separation is forced by geometry, not the effects of vis cosity. At some point, as column length is reduced the internal compressive stresses produced at the onset of buckling will exceed the pro portional limit, and the column will no longer be experiencing elastic buckling. 3773 M/M!! [jifid 50,000 32,000 33,300 30,300 30,300 30, 3,376 33,32 1 33,31 8 We Wo 1 - 0. However, the various composite materials have largely replaced wood in homebuilt aircraft. 9 7 } - 0. Also, for a production fighter the windshield would be a bulletproof material. TDPF = (TDR) (URVC) (16.67) (1 and nitrogen. But aerodynamic design doesn't start with calculations, it starts with the initial design layout. Aspect ratio is defined as the square of the wing span divided by the smallest cross-sectional area mpl xa e bably be where the holes are located because the areas of the holes ro p l wil included for tensional calculations. Laminar flow is discussed below. For a poorly-designed winglet, little CHAPTER 1 2 Aerodyna mics more than a fin stuck on the winglip, there may be no benefit at all. Highly swept wings of low aspect ratio get far less lift than a "normal" wing of the same area. Flow separation over a wing or fuselage often occurs because the air near the aircraft has been slowed down too much by viscous effects and no longer has much energy. 4.3 Airfoil flowfield and circulation . Figure 14.23 shows the two major composite forms, filament-reinforced and whisker-reinforced. Aluminum will remain importan in aircraft design for many years to come. You must solve for the groundspeed along the desired flight direc tion using the Law of Sines and a wind vector diagram as shown at the botto m of Fig. 1 74 } } H igh strength, not weldable, common in high-speed aircraft High-temp & strength 1. 0 1 2. 006 A0 . ICfU High-temperature nickel Alloys In conel, Rene 4 1 Hastelloy B 0.300 0 .298 0.334 1 1 .0 1 2. 006 A0 . ICfU High-temperature nickel-based alloys suitable for hypersonic aircraft and reentry vehicles. Obviously, the new design should not cost more than the other ways to accomplish the same mission, when all factors are con sidered. These include obvious things like range, payload, and speed, and often add more subtle requirements such as low observability, or an ability to fit into an existing commercial aircraft parking spot. 68 Wavionics Wfurnishings = 0.0582Wdg - 65 1 vr = = = w v = Wei g hts E q u ations Term i n o l ogy A Bh aspect ratio (with subscript vertical tail) horizontal tail intersection, ft "t" or "h" for horizontal tail intersection, ft fuselage structural depth, ft engine diameter, ft fuselage width at horizontal tail intersection, ft horizontal tail height above fuselage, ft Ht 0.0 for conventional tail; 1.0 for "T" tail Ht /Hv vertical tail height above fuselage, ft Hv yawing moment of inertia, lb-ft2 (see Chap. Analysis techniques include all manner of computer code as well as cor relations to wind-tunnel and other tests. ,,.... 2 - btacleci. Whitcomb of the NACA, [26] is referred to as "area-ruling" or "coke-bottling" and can reduce the wave drag by as much as 50%. = = = } Heat treatments 80 60 40 20 0 0 40 20 60 80 100 120 140 Column buckling loads (round tubing). Even curvature (second derivative) discontinuities should be avoided as much as possible. Titanium is still relatively expensive, costing about five to ten times as much as aluminum per pound. '. Much of the Wright Brothers' success can be traced to their development of airfoils using a wind tunnel of their avaitation of those airfoils in their glider experiments of 1 90 1 - 1 902. MOST-f\FT • C. 3.2. The Simple Cruise mission is used for many transport and general-aviation omebuilts. 04 cos A 100 t I c - 0 · 3 (N W) o .49 x z dg cos A (ignore second term if Wfw O) w, . In level flight, the lift is known, It must equal the aircraft weight. The resulting CHAPTER 14 Structu res a n d Loads strut loads are then summed for the various members. The aircraft is sized to provide some required cruise range. 0) • (1) 0:i () "O c 0 l> "O "O 0 0 ():: r 24 30 36 40 46 50 x x x x x 5.5 7.7 11 14 16 18 1 74 kt 225 225 1 1 .500 1 6.500 26,000 33,500 48,000 4 1 .770 355 270 235 200 245 1 55 .75 7 .85 1 1 .50 1 4 .00 1 6.00 1 7 . c, 2 5 (cos Avt) (15 . It's a good idea to calculate the weight of each com ponent using several different equations and then select an average, reasonable result. Sweeping the C H A PTE R 8 Speci a l Considerations in Confi g u ration Layout Isobar l i nes of constant p ressu re Isobar sweep with "peaky" root a i rfoil Restore isobar sweep with pla nform Fig. The L /D when flying at the minimum power velocity was shown to be 86.6% of the best L /D. As can be seen, the type of aircraft also has a strong effect, with flying boats having the highest empty-weight fractions and long-range military air craft having the lowest. 1 7 .5 Level turn geometry. The airplane relative density parameter µ, is defined in Eq. (16.70). Drag forces not strongly related to lift are usually known as parasite drag or zero-lift drag. Remember that the two
dimensional airfoil characteristics are denoted by uppercase subscripts (i.e., Cr). Weng section is primarily the motor mounts plus engine-associated equip ment. Once the loads in each member of the truss are known, the struts can be analyzed using the equations just presented for tension or compression. This format is useful because the data become fairly linear, but the plotting in Fig. This negative camber tends to create negative lift, so that it must be placed at a high nose-up twist angle to maintain a good spanwise lift. distribution. Quite simply, what is done during conceptual design, the things that are critical, and the tasks that are boring and repetitive (and therefore ideal for computerization) are different from those in other, later phases of aircraft design. In inviscid flow there is no drag due to lift for the two-dimensional airfoil because the lift force is perpendicu lar to the freestream direction. [z crx = Mz/Iy (14. Multiple thin plies of wood were placed in molds along with a resin glue and subjected to pressure during cure. However, Johnson warns "there is a tendency today, which I hate to see, toward design by committee-reviews and recommendations, conferences and consultations, by those not directly doing the job. 9 8. 536B0. By placing the wing above these shocks, the increased pressure beneath the wing provided free lift-roughly 30% of the total lift required! The B-70 also used fold-down wing tips. In the pre-computer era, we built and flew airplanes based on analysis methods much like these. How do we know? 5 1 5> < 0. D), *If] M ission-Segment Weight Fractions For analysis, the various mission segments, or "legs," are numbered, with zero denoting the start of the most famous forces can create considerable confusion because of overlapping terminology. 1 4. Some of the most famous airplanes, starting with the very first, were designed for concept validation and experimental research. Shock waves result whenever supersonic flow is being slowed down or turned. good ductility. ht controls = 36 · 28Mo . This reaches a maximum at the neutral axis. The shear web will fail in buckling long before the material maximum shear stress is reached. The calculations for resizing the aircraft using composite materials are shown in Box 3.4. Box 3.4 Composite Materia l Trade We / Wo = Wo = (0. I I. Turbulent air has more energy than laminar air, so a turbulent boundary layer actually tends to delay separation. This increase in two-dimensional airfoil drag is due to an increase in viscous separation caused by a greater pressure drop on the upper surface of the airfoil as the angle of attack is increased. 24 1 2 (4 Dig it) c:===::---... The same alloy can have moderate strength and good ductility or can have moderate strength. Supersonic wind tunnel tests alone will take many months, and you'll need sufficient time to take the results, modify the design, and test it again. It is not uncommon for the boundary-layer air from the root of the wing to travel outward, all of the way to the tip of the wing. Camber lines are expressed mathematically, as in the old NACA airfoils, or are given as an x-versus-z table. It works. For swept-wing supersonic aircraft, the NACA 64A and 65A sections are good airfoils for initial design. 88} - 0.05 1 .19 {1. ' £N61/UE: ::. 4.6. The early airfoils were developed mostly by trial and error. To the right is a top view of part of the wing with those same four dots shown and lines (isobars) connecting those dots with other points on the top of the wing having the same pressure. To simplify the calculation, both fuel and empty weights can be expressed as fractions of the total takeoff weight, that is, (itj / Wo) and (We/W0). The vertical component of S is found from summing the moments about the pin at the wing root, using the equivalent concentrated lift loads as discussed earlier. The applied torgue | produces a twisting deformation cp that depends upon the length of the shaft As shown at the right of the stresses remair within the elastic limit. Lb@ b'l-S "" fro.,, f)Oc.t: of s pi-This provides extra lift 2-Over-wing nacelles 1 -Conventional 0 4-Ca n a rd, h i g h wing 3-Ca na rd, low wing Fig. Today's best methods worked quite well for their day and can now be run on a laptop computer rather than the room-sized tape-driven monstrosities of the 1960's. This is done by recalculating the weight fractions for the cruise mission segments, using arbitrarily selected ranges. This is a lower drag coefficient than the drag coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient than the drag coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient than the drag coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift coefficient for best L/D, which was shown to be 2.0 times the zero-lift Design Process • 1C \ 0 \ 0 \ 0 \ 0 \ A i rcraft design is done in phases that have different goals, methods, and often, d ifferent goals, methods, and often , d ifferent goals, methods, and often , d ifferent goals, methods, and find out how to make it better. With 3-D goggles and gloves, the best systems let you see the whole design in full scale, walk around it, and even grab things and move them around. = = Table 3. The horizontal reference axis is then properly defined by these two points. Wave drag is a pressure drag due to shock formation, and any changes in the pressures around the aircraft will change the location and strength of the shocks around it resulting in "wave drag due to lift." This drag is fairly small and is usually ignored in early conceptual design. IPTs and the IPD environment make it very clear that those problems must be fixed, and the IPT way of doing business is almost universally accepted in industry today. 7 0 0 > < 0. However, a base area between or very near the jet exhausts can be "filled-in" by the pressure field of the exhaust, partially alleviation, which leads to design changes and can even result in changes to the requirements, trying to find a more cost-effective solution to the customer's real needs. This will be discussed in Chapter 12. Sometimes we plot the pitching-moment coefficient vs the lift coefficient vs about the pin prevented by the unknown force in the strut under analysis. As can be imagined, they were not on the conceptual design layouts! Many airliners have similar strakes on the engine nacelles. The designer thinks it starts with a new airplane concept. 6Nc (includes seats) (15.22) - a Wairconditioning and antHce = 201 .6 [(Wuav + 200Nc)/1000] o .735 Whandlinggear = 3.2 X 10 -4 wdg (15. If it looked worthwhile, they'd develop a set of mission requirements, probably changing them based on what they'd learned. The Mach 3 XB-70 (Fig. It's a skill that takes education and experience to perfect. This action permits the flow to follow a much greater turn. Table 15.3 tabulates various miscellaneous weights. Note that two-dimensional airfoil characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by uppercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing
characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted by lowercase subscripts (e.g., Cz) whereas the three-dimensional wing characteristics are denoted b of the airfoil, various pressure recovery schemes are employed to prevent separation near the trailing edge. The small team that took the aircraft through conceptual and preliminary design is augmented-or replaced-by an army numbering in the hundreds or thousands (big company project). DO' some independent-study design pro jects, and if possibly get wind-tunnel experience. 10Ngen o . Design also depends upon the many calcu be built. .. Centroids for simple shapes can be determined using E qs. 1 1) where h = endplate or winglet height; b = wing span. bending-moment distribution, maximum bending moment, and spanwise location of the maximum bending momend 1 0 8l : M(x) = Ci sin(x/j) + C2 cos(x/j) + wj2 Mmax = tan (Xm) j = (14.38) Di j + WJ2 cos(x/j) + wj2 mmax = tan (Xm) j = (14.38) Di j + WJ2 cos(x/j) + wj2 mmax = tan (Xm) j = (14.38) Di j + WJ2 cos(x/j) + wj2 mmax = tan (Xm) j = (14.38) Di j + WJ2 cos(x/j) + wj2 mmax = tan (Xm) j = (14.38) Di j + WJ2 cos(x/j) + wj2 mmax = tan (Xm) j = (14.38) Di j + wj2 cos(x/j) + wj2 mmax = tan (Xm) j = (14.38) Di j + wj2 cos(x/j) + wj2aircraft. A common assumption is that only 50-60% of the fuel remains. The effective length of a column is determined by the end connec tions (pinned, fixed, or free) as shown in Fig. In these, the first digit defined the percent camber, the second defined the percent camber, the second defined the percent camber and the last two digits defined the percent camber. thickness in percent of chord. This is shown at the bottom of Fig. The pressure forces shown in Fig. 8 7 -rr (X. cz1) ==-0. 11) (15. Folding down the wing tips does the former. Filament composites, like wood, are strongest in the direction the fibers are running. This is always a temptation but must be balanced against the needs of subsystems integration and of maintenance. 02 {0.17.1. Equations are written in a wind axis system, with the X axis being perpendicular and upwards. First, advanced design created the concept and took it through conceptual and preliminary design.

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