Design Considerations for Stability: Civil Aircraft

From the discussion on aircraft behavior in a small disturbance, it is clear that both aircraft geometry and mass distribution are important in the design of an aircraft with satisfactory flying qualities. The position of the CG is obtained by arranging the aircraft components relative to one another to suit good in-flight static stability and on-ground stability for all operational envelopes. The full aircraft and its component moments are estimated semi-empirically (e.g., DATCOM and RAE data sheets) as soon as drawings are available and followed through during the next phase; the prediction
is improved through wind-tunnel tests and CFD analyses. In the conceptual design stage, the control area on the wing and empennage (i.e., flap, aileron, rudder, and elevator) are sized empirically from past experience (and DATCOM and RAE data sheets). However, the CG position relative to the aircraft NP is tuned afterwards. The important points affecting aircraft configuration are reviewed as follows:

1. *Fuselage*. The fuselage has a destabilizing effect – the fuselage lift (although minimal) and moment add to instability – and its minimization is preferred. In addition to keeping costs down, the fuselage may be kept straight (with the least camber). Mass distribution should keep inertia close to the fuselage centerline.
A BWB requires special considerations.
The fuselage length and width are determined from the payload specifications.
The length-to-average-diameter ratio for the baseline aircraft version may be around 10. The closure angles are important, especially the gradual closure of the aft end, which should not have an upsweep of more than what is necessary – even for a rear-loading door arrangement that must have an upsweep.
The front closure is blunter and must provide adequate vision polar without excessive upper-profile curvature.
For a pressurized cabin, the cross-section should be maintained close to the circular shape. Vertical elongation of the cross-section should be at a minimum to accommodate the below-floorspace requirements. For small aircraft, fuselage-depth elongation may be due to placement of the wing box; for larger aircraft, it may be due to the container size. Care must be taken so that the

wing box does not interfere with the interior cabin space. Generous fairing at the wing–body junction and for the fuselage-mounted undercarriage bulge is recommended. An unpressurized fuselage may have straight sides (i.e., a rectangular cross-section) to reduce the production costs. In general, a rectangular fuselage cross-section is used in conjunction with a high wing. The undercarriage for a high-wing aircraft has a fuselage bulge.

2. *Wing*. Typically, an isolated wing has a destabilizing effect unless it has a reflex at the trailing edge (i.e., the tail is integrated into the wing such as all-wing aircraft like the delta wing and BWB). The larger the wing camber, the more significant is the destabilizing effect. Optimizing an aerofoil with a high L/D ratio and with the least *Cm wing* is a difficult task not discussed herein. Wind-tunnel tests and CFD analyses are the ways to compromise. It is assumed that aerodynamicists have found a suitable aerofoil with the least destabilizing moment for the best L/D ratio. The coursework worked-out example uses an aerofoil from the proven NACA series.

Sizing of an aircraft, as described in Chapter 11, determines the wing reference area. The structures philosophy settles the aspect ratio; that is, maximizing the wing aspect ratio is the aim but at the conceptual design stage, it starts with improving on past statistics on which a designer can be confident of its structural integrity under load. The wing sweep is obtained from the design maximum cruise speed. It has been found that, in general, a wing-taper ratio from 0.4 to 0.5 is satisfactory. The twist and dihedral in the conceptual design stage are based on past experience and data sheets.

Positioning of the wing relative to the fuselage depends on the mission role, but it is sometimes influenced by a customer's preference. A high- or low-wing position affects stability in opposite ways (see Figure 12.6). The wing dihedral is established in conjunction with the sweep and position relative to the fuselage. Typically, a high-wing aircraft has an anhedral and a low-wing aircraft has a dihedral, which also assist in ground clearance of the wing tips. In extreme design situations, a low-wing aircraft can have an anhedral (see Figure 12.7) and a high-wing aircraft can have a dihedral. There are case-based "gull-wing" designs, which are typically for "flying boats." Passenger-carrying aircraft are predominantly low-winged but there is no reason why they should not have high wings; a few successful designs exist. Wing-mounted, propeller-driven aircraft favor a high wing for ground clearance, but there are low-wing, propeller-driven aircraft with longer undercarriage struts. Military transport aircraft invariably have a high wing to facilitate the rear-loading of bulky items.

3. *Nacelle*. The stability effects of a nacelle are similar to those of a fuselage. An isolated nacelle is destabilizing but, when integrated to the aircraft, its position relative to the aircraft CG determines its effect on the aircraft. That is, an aftmounted nacelle increases stability and a forward-mounted nacelle on a wing decreases stability. The stability contribution of a nacelle also may be throttledependent

(i.e., engine-power effects).

The position of the nacelle on an aircraft is dictated by the aircraft size.

The best position is on the wing, thereby providing bending relief during flight.

The large forward overhang of a nacelle decreases air-flow interference with the wing. For smaller aircraft, ground clearance mitigates against wing-mounting; for these aircraft, nacelles are mounted on the aft fuselage. An over-wing nacelle mount for smaller aircraft is feasible – a practice yet to gain credence.

Even a fuselage-mounted nacelle must adjust its position relative to how close the vertical height is from the aircraft CG without jet efflux interfering with the empennage in proximity.

4. *Fuselage, Wing, and Nacelle*. It is good practice to assemble these three components

without the empennage in order to verify the total moment in all three planes of reference. The CG position is established with the empennage installed; then it is removed for a stability assessment. This helps to design the empennage as discussed herein. Figure 12.10 shows the typical trends of pitching moments of the isolated components; together, they will have a destabilizing effect (i.e., positive slope). The aim is to minimize the slope – that is, the least destabilizing moment. 5. *Empennage*. The empennage configuration is of primary importance in an aircraft

design. The reference sizes are established by using statistical values of tailvolume coefficients, but the positioning and shaping of the empennage require considerable study. This is another opportunity to check whether the statistical values are adequate. The sweeping of the empennage increases the tail arm and may also enhance the appearance; even low-speed, smaller aircraft incorporate sweep. Chart 4.2 and Figures 4.24 and 4.25 show several possible empennage configurations.

A conventional aircraft H-tail has a negative camber, the extent depending on the moment produced by an aircraft's tail-less configuration, as described previously. For larger, wing-mounted turbofan aircraft, the best position is a low H-tail mounted on the fuselage, the robust structure of which can accommodate the tail load. A T-tail on a swept V-tail increases the tail arm but should be avoided unless it is essential, such as when dictated by an aft-fuselage–mounted engine. T-tail drag is destabilizing and requires a larger area if it is in the wing wake at nearly stalled attitudes. The V-tail requires a heavier structure to support the T-tail load. Smaller turbofan aircraft are constrained with aft-fuselagemounted engines, which force the H-tail to be raised up from the middle to the top of the V-tail. The canard configuration affords more choices for the aircraft CG location. In general, if an aircraft has all three surfaces (i.e., canard, wing, and H-tail), then they can provide lift with a positive camber of their sectional characteristics. It is feasible that future civil aircraft designs of all sizes may feature a canard.

Typically, a V-tail has a symmetric aerofoil but for propeller-driven airplanes, it may be offset by 1 or 2 deg to counter the skewed flow around the fuselage (as well as gyroscopic torque).

The discussion is the basis for the design of any other type of empennage configuration, as outlined in Table 4.2. If a designer chooses a twin-boom fuselage, the empennage design must address the structural considerations of twin booms. (Tail-less aircraft are less maneuverable.)

An H-tail also can be dihedral or adhedral, not necessarily for stability reasons but rather to facilitate positional clearances, such as to avoid jet efflux.

6. *Undercarriage*. A retracted undercarriage does not contribute to the aerodynamic load but when it is extended, it generates substantial drag, creating a nose-down moment. To address this situation, there should be sufficient elevator nose-up authority at a near-stall, touch-down attitude, which is most critical at the forwardmost CG position. Designers must ensure that there is adequate trim authority (i.e., the trim should not run out) in this condition.

7. *Use of Any Other Surface*. It is clear how stability considerations affect aircraft configurations. Despite careful design, an aircraft prototype may show unsatisfactory flying qualities when it is flight-tested. Then, additional surfaces (e.g., ventral fin and delta fin) may be added to alleviate the problem. Figure 12.15 shows two examples of these modifications. It is preferable to avoid the need for additional surfaces, which add penalties in both weight and drag.