: Assignment 1 :

AE461 - Aircraft Design

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Question1

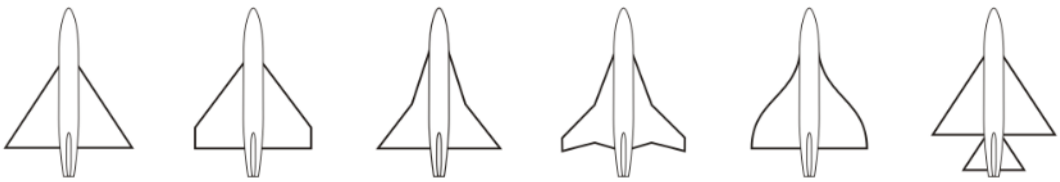
Q. Carry out literature survey on generic/utility aircraft and prepare a report on four different designs.The report should contain specification along with available aerodynamic and geometric data.

Ans: A utility aircraft[1] is a general-purpose light airplane or helicopter, usually used for transporting people, freight or other supplies, but is also used for other duties when more specialized aircraft are not required or available.

The term can also refer to an aircraft type certificated under American, Canadian, European or Australian regulations as a Utility Category Aircraft, which indicates that it is permitted to conduct limited aerobatics. The approved maneuvers include chandelles, lazy eights, spins and steep turns over 60° of bank. In the United States, military utility aircraft are given the prefix U in their designations.

Design 1: Compound Delta Wing

Conventionally, delta wing designs have not been used for general purpose utility aircraft. However, attempts at building Concorde aircraft (retired in 2003), did provide the delta wing design certain qualifications for it to be considered as a special case of utility aircraft. It can carry passengers and perform limited acrobatic operations. The name Delta wing, comes from the shape of the aircraft that looks like the greek letter (Delta, Δ). There are severals types of delta-wing designs. However, for this assignment we will consider a compound delta wing, which is a simpler version of Concorde aircraft that has ogival delta wing design.



The aerodynamic and geometric data available for compound delta wing design are as follows:

- **Geometric Data** A compound delta wing design has two distinguishing design factors - first sweep angle (or leading-edge angle) and second sweep angle. As shown in the figure above, using a symmetric design of first-sweep and second-sweep, a compound delta wing aircraft gets it's shape.

Figure 1: Image of ogival wing design of Concorde Aircraft[1]

- **Aerodynamic Data** The data was available for compound delta of design - first sweep angle of 50°, second sweep angle of 62.5° and 4° forward sweep. It has edge bevelled at an angle of 14° for 53 cm[2].

Data was available for both subsonic and supersonic regimes, however for our case; the data for subsonic case is sufficient.

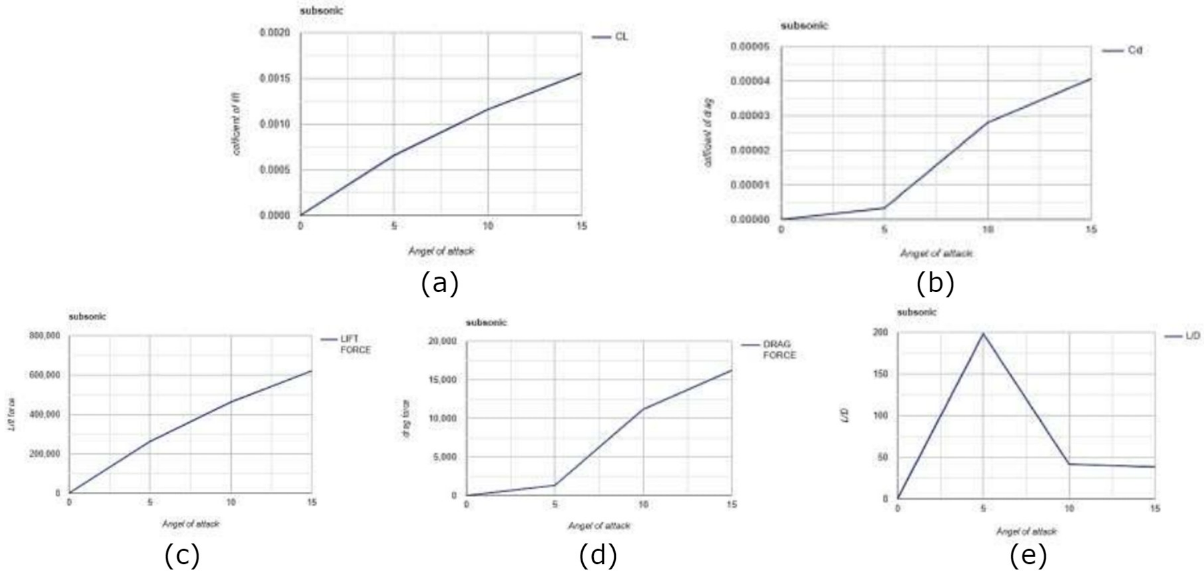


Figure 2: (a) Cl vs AoA (b) Cd vs AoA (c) Lift Force vs AoA (d) Drag Force vs AoA (e) L/D vs AoA, for AoA variation from 5° to 15° [3]

Design 2: YAKOVLEV YAK-40

Figure 3: Yakovlev Yak-40

- In the mid-1960s, the Soviet Yakovlev organisation was tasked to develop a small jetliner, which emerged as the trijet "Yak-40" and proved popular. It was followed by a larger trijet airliner, the "Yak-42", which did not have the same success. This document provides a history and description of the Yak-40.

- The Yak-40 was primarily built of aircraft aluminium. Each long-span wing had a large three-section slotted flap to help provide good short-field performance, with a two-section manually-actuated aileron outboard, the inboard section featuring a trim tab. The variable-incidence tailplane was unswept and featured manually-actuated elevators; the tailfin was swept less for aerodynamics than to increase the tailplane's moment arm on a relatively short aircraft. The rudder was manually actuated and featured a trim tab.[3]

- The engines were Ivchenko AI-25 turbofans – with a low bypass ratio of about 2:1 – providing 14.7 kN thrust. Three engines were chosen instead of two larger engines to provide redundancy for greater safety. Engine start was provided by an Ivchenko AI-9 auxiliary power unit (APU) in the tail, which also provided ground power. Engine bleed air was used for de-icing the flight surfaces; apparently, the windscreen was electrically de-iced. Fuel storage was in tanks in the centre wing section.

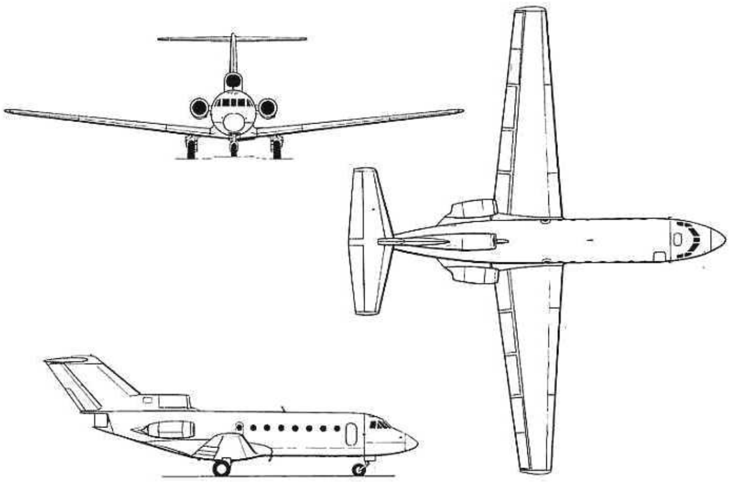


Figure 4: Yakovlev Yak-40 3 view angles

Measurements and Specifications[4]

Wing span	25 meters
Wing area	70 sq_meters
length	20.36 meters
height	6.5 meters
Empty weight	9,400 kg
Maximum takeoff weight	16,000 kg
Maximum cruise speed	550 kmph
Takeoff distance	700 meters
Landing distance	360 meters
Cruise altitude	7,000 meters
range	1,800 km
Fuel capacity	3910 liters

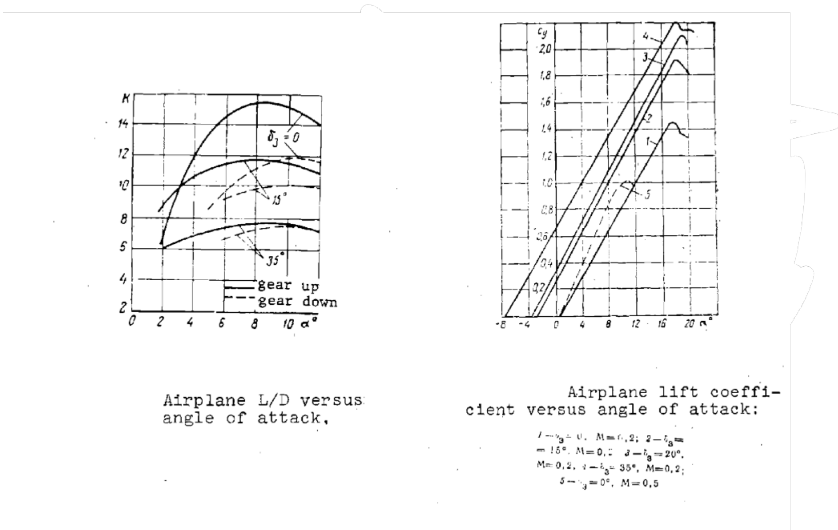


Figure 5: Aircraft L/D vs AoA (left) and Cl vs AoA (right)

Design 3: Boeing 747-400

The Boeing 747 is one of the most recognizable and loved aircraft in the world. At the time of its launch, it changed the economics and possibilities of aviation in many ways. The Boeing 747-400 is a wide-body airliner produced by Boeing Commercial Aeroplanes, an advanced variant of the initial Boeing 747. Boeing 747-400 has six million parts.The 747- 400 is alone in having four engines and it has a choice of General Electric (GE), Pratt Whitney (P W), or Rolls-Royce (R-R) power. Compared to other aircraft, the electronic flight instrumentation system (EFIS) of the 747- 400 uses larger cathode ray terminal (CRT) screens that provide more attitude and navigational data in digital form than the other models.The 747-400 uses tougher/ graphite-based materials in panels and bulkheads. The aircraft has four main fuel tanks in the wings, two reserve tanks farther out on the wings, and additional tanks in the center fuselage and stabiliser. The 747-400 has the largest passenger interior volume of any commercial airliner which is equivalent to more than three houses, each measuring 1/500 square feet (135 square meters).

Measurements

Range	13,450 Km
Length	70.6 Mtrs
WingSpan	64.4 Mtrs
Tail Height	19.4 Mtrs
Cabin Width	6.1 Mtrs
Cruise Speed @35000' - (Mach Number 0.85)	565 MPH
Fuel efficiency	747-400 s
Wing area	525.45 square meters

Weight

Maximum Take off weight	396,890 Kg
Maximum Landing weight	285,762 Kg
Maximum Zero fuel weight	246,754 Kg
Maximum Fuel capacity	216,840 Litres
Winglets length	1.8 meter

Technical specification:

1. Two pilot cockpit:

   From the beginning, the 747-400 was designed for an electronic flight instrumentation system (EFIS). The captain's right-hand navigation display screen uses a silhouette of the aircraft as a guiding symbol. This display has four modes, and provides information on approach, very-high-frequency omnidirectional range (VOR), map, and flight plan.

2. FlightDeck:

   The two pilots sit on a flight deck situated fully 29 feet above the ground, roughly 100 feet in front of the main landing gear, and 12 feet in front of the nose gear. The pilots manoeuvre this large aircraft around busy terminals while being so high up and so far forward.

3. Engines:

   From the beginning, the plan was that the 747-400 would be offered to airlines with engines from the world's three principal engine builders: General Electric, Pratt Whitney, and Rolls-Royce. The engines on a Dash Four Hundred would enable the aircraft to fly straight up.

4. Rolls power:

   Rolls-Royce (R-R) provides 747- 400 airliners operated by British Commonwealth airlines with its RB211-524G and -524H turbofan engines. These engines are rated at 58,000 pounds (258.1 kN) and 60,000 pounds (267 kN) thrust respectively.

5. Fuselage:

   The basic 747-400 airframe was actually much lighter than the 747- 300 "classic," but when the aircraft was fitted out for revenue operations it was heavier and more robust.

6. Landing Gear:

   The 747-400 landing gear was extensively modified in contrast to the earlier 747 "classics," resulting in a 844-kilogram weight savings. The 747-400 has 16 main landing-gear tires and 2 nose landing-gear tires. The main gear consists of four-wheel bogies; two, mounted side by side under the fuselage at the wing's trailing edge, which retract forward; two, mounted under the wings, which retract inward.

7. Wing:

   When the aircraft(Boeing 747-400) is fully fueled the wingspan is around 213 feet (64.92 meters). And when it is not fully fueled it is around 211 feet 5 inches (64.6 meters). It is swept at 37.5 degrees at quarter chord, and has an aspect ratio of 7.0. The wing is 17 feet (5.2 meters) greater in span than the wing of the 747-300.

8. Tail:

   The horizontal tail has a 3,300-gallon integral fuel tank between its front and rear spars. The fuel tank increases range by about 400 miles (644 kilometers). The horizontal tailplane has a span of 72 feet 8 inches (22.10 meteres) and it actually boasts more area than the entire wing of a 727 airliner.

Design 4: Gulfstream G700

Figure 6: Gulfstream G700 [5]

Figure 7: Gulfstream G700 [6]

G700 is a Sweptback configuration Business Aircraft; its plush interior separates it from the Commercial aircraft of similar design(but of larger size)

It has seating capacity for upto 19 passengers

Technical specification: [6]

Measurements

Finished Cabin Height	1.91 m
Finished Cabin Width	2.49 m
Cabin Length (excluding baggage)	17.35 m
Total Interior Length	19.41 m
Cabin Volume	73.71 cu m
Baggage Compartment Volume	5.52 cu m
Exterior Height	7.75 m
Exterior Length	33.48 m
Overall Wingspan	31.39 m

Systems

Avionics	Gulfstream Symmetry Flight Deck
Engines	Two *Rolls-Royce Pearl 700* (turbofan)
Rated Takeoff Thrust (each)	81.20 kN

Weight

Maximum Takeoff	48,807 kg
Maximum Landing	37,875 kg
Maximum Zero Fuel	28,463 kg
Basic Operating (including 4 crew)*	25,567 kg
Maximum Payload2	2,896 kg
Maximum Payload/Full Fuel*	1,014 kg
Maximum Fuel	22,407 kg

* Stated weights are based on theoretical standard outfitting configurations. Actual weights will be affected by outfitting options and other factors.

Performance

Maximum Range**	13,890 km
High-Speed Cruise	Mach 0.90
Long-Range Cruise	Mach 0.85
Maximum Operating Mach Number (Mmo)	Mach 0.925
Takeoff Distance (SL, ISA, MTOW)	1,905 m
Initial Cruise Altitude	12,497 m
Maximum Cruise Altitude	15,545 m

**NBAA IFR theoretical range at Mach 0.85 with 8 passengers, 4 crew and NBAA IFR reserves. Actual range will be affected by ATC routing, operating speed, weather, outfitting options and other factors. All performance is based on preliminary data and subject to change.

Swept Wing[7]

Any aircraft operating in the transonic regime ($0.8 <= M_{\infty} <= 1.2$) requires special attention on the geometry of airfoil; so that the phenomenon of wave drag can be delayed .

• For a swept wing even if the local speed of the air on the upper surface of the wing becomes supersonic, a shock wave cannot form there because it would have to be swept at the same angle as the wing - ie., it would be an oblique shock. Such an oblique shock cannot form until the velocity component normal to it becomes supersonic. **Swept wing planforms are favoured for Transonic and Supersonic flying.**

There are three type of swept wings:

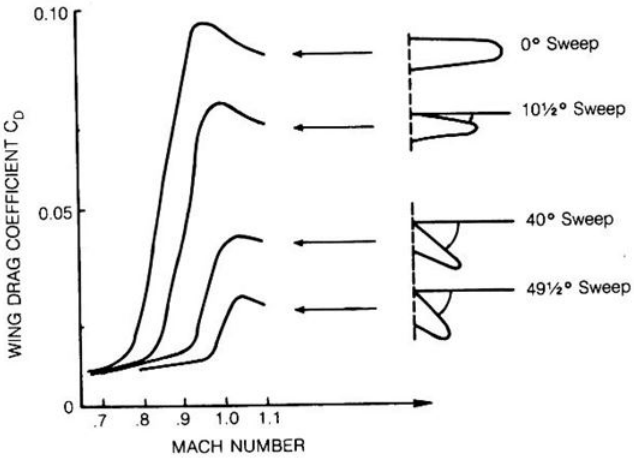


Figure 8: Cd vs Mach number at various sweep angle [7]

1. **Sweep Back [it is more common and this will be our focus]**
2. Sweep Forward
3. Variable Sweep

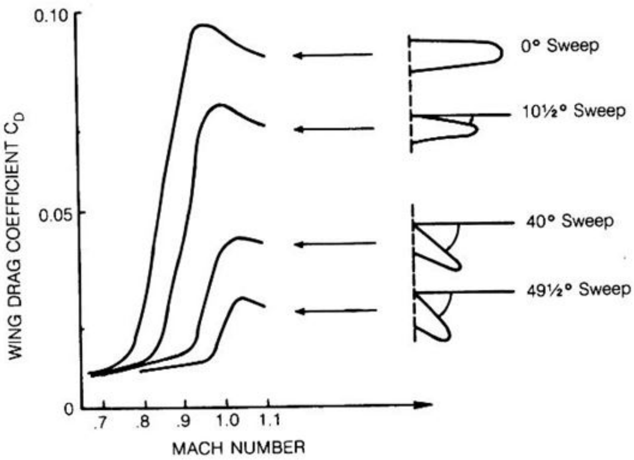


Figure 9: various swept wing[8]

• Wing sweep reduces the amount of lift produced for a given flight speed, wing area and angle of attack. Correspondingly, to give the same amount of lift as an unswept wing, the swept wing will need to be larger, and consequently heavier.[10]

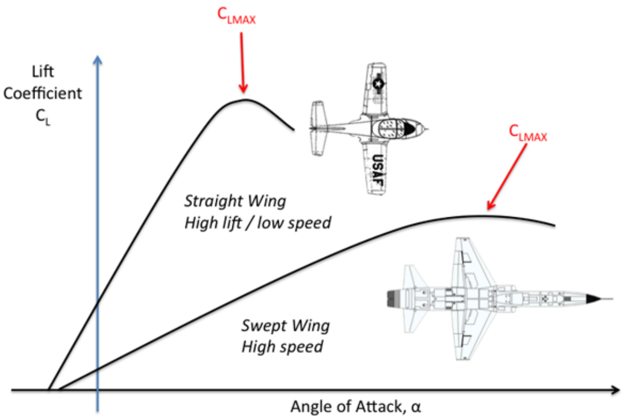


Figure 10: Cl vs Angle of Attack[9]

Question2

Q. Prepare mission specifications as per the instruction given in the class.

Ans: According to the details provided in the class. The sum of last two digits of roll numbers of group members are as follows: = 55+82+43+30 = 210 (even)

Mission Requirements:

1. Our aircraft must have an endurance of 210/2 = 105 minutes.

2. The total number of passengers to be carried = Professor(1) + TAs(2) + Group Members(4) = 7

3. Total Payload = Passenger Payload + Luggage = (80*7) kg + (25*7) kg = 735 kg
   (**Given, avg. weight of person = 80 kg, extra luggage allowed to carry = max. 25 kg**)

Reference aircraft: DA62 [11]

Inferences:

1. Based on the power requirements our engine should be a *turboprop engine* (as it is most optimal for operation at subsonic speeds)

2. Based on the given endurance of aircraft (105 mins or 1 hr 45min), our two turboprop engines (Austro Engine 180hp AE330) consume 44.7 l/h of fuel. Therefore, fuel tank capacity should be = (1.75*44.7) = 78.225 Litres

3. Size of aircraft = To be Decided

4. Aircraft is made of composite materials that include titanium, steel and aluminium.

The basic equation used for this inference is:

$$W_t = W_p + W_f + W_e \tag{1}$$

In (1) W_t = total weight of aircraft, W_p = weight of payload, W_f = weight of fuel, W_e = empty weight

References

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