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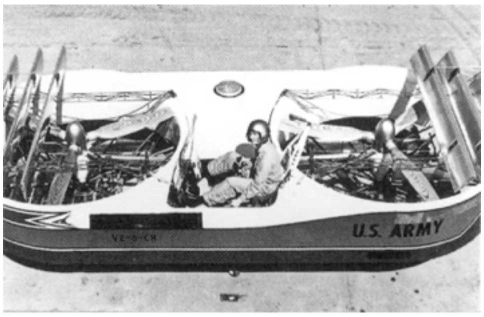


Aircraft configurations – or: why aircraft look the way they do

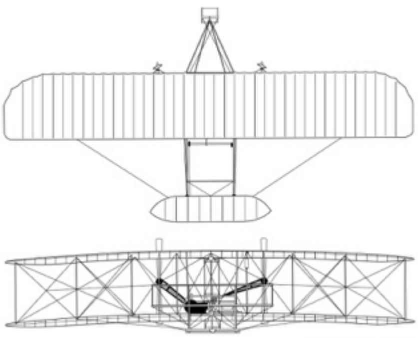
Recommended reading:

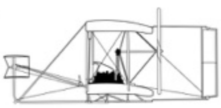
Howe: Chapter 2
Torenbeek: Chapter 2
Stinton: Anatomy of the Airplane

2

Configuration concept

- Payload/fuselage layout
- Lifting surface arrangement
- Control surface(s) location
- Propulsion system selection
- Landing gear





Wright Brothers example

- Innovative control concept
  (and control more important than stability)
- Light weight propulsion
  (own design+manufacture)
- Continual design evolution/refinement

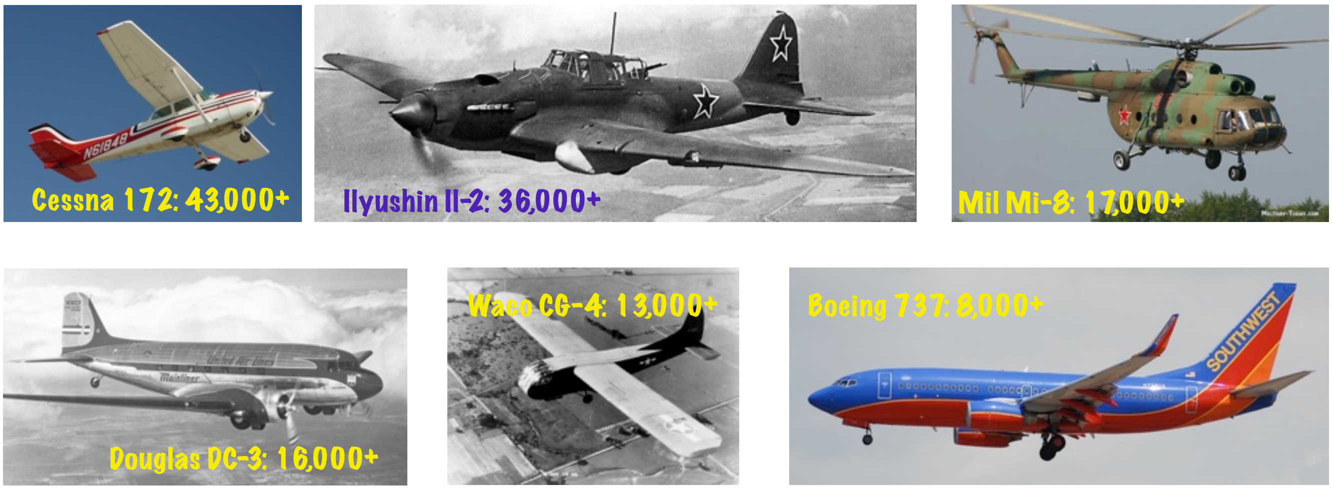
Adapted from Mason

3

Good aircraft

- Aerodynamically efficient, including propulsion integration.
- Must balance near stability level for minimum drag (CG placement).
- Landing gear must be located relative to CG to allow rotation at TO.
- Adequate control authority must be available throughout flight envelope.
- Designed to build easily (cheaply) and have low maintenance costs.
- Today: quiet, low emissions.

Example high-production aircraft (in fact, the highest production runs in their class).



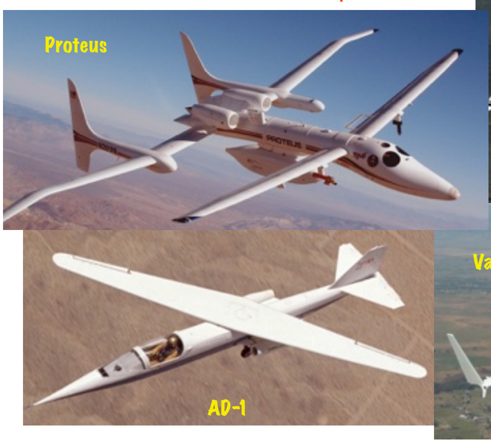
Adapted from Mason

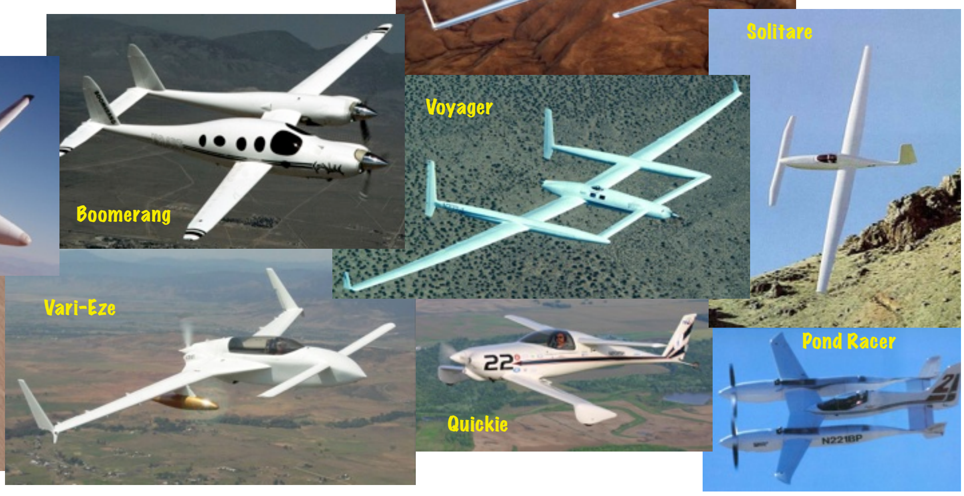
4

Configuration options

- Where do you put the wings?
- Where do you put the engines (and what kind)?
- Where do you put the control surfaces, and what options are available?
- How to arrange the seating/cabin space
- Do you have room for the landing gear? Fuel?
- Possible innovative designs?

Original configurations from
Burt Rutan /Scaled Composites

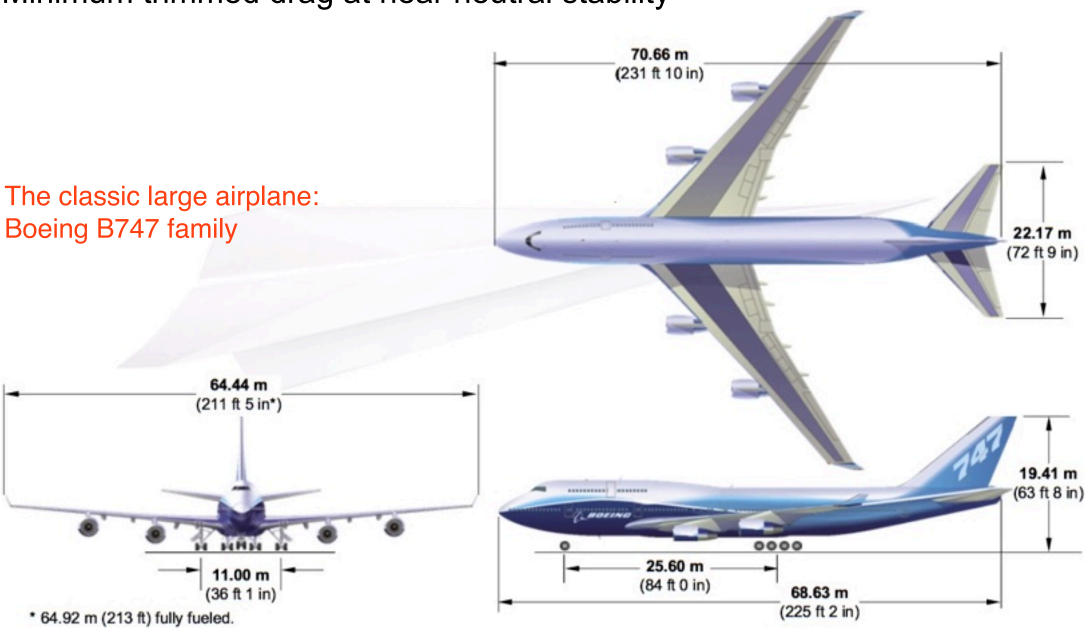




Adapted from Mason

Conventional baseline subsonic

- Payload distributed around CG
- Longitudinal control power from tail (with moment arm)
- Vertical tail for directional stability, rudder for control
- Wing/fuselage/landing gear setup works
- Minimum trimmed drag at near neutral stability

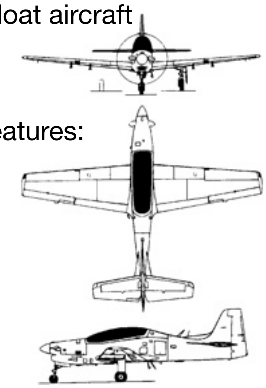


Adapted from Mason

Aircraft categories — review of configurations

We'll look at **typical configurations** within categories.

1. Homebuilts
2. Single-engine propeller-driven aircraft
3. Twin-engine propeller-driven aircraft
4. Agricultural aircraft
5. Business jets
6. Regional turbopropeller-driven aircraft
7. Jet transports
8. Military trainers
9. Fighters
10. Military transport, patrol, bomber aircraft
11. Flying boats, amphibious and float aircraft
12. Supersonic cruise aircraft



According to Howe and other references, the **conventional configuration** has these features:

1. A cantilever monoplane wing;
2. Separate horizontal and vertical tail surfaces;
3. A single discrete fuselage to provide volume and airframe connectivity;
4. A retractable tricycle landing gear.

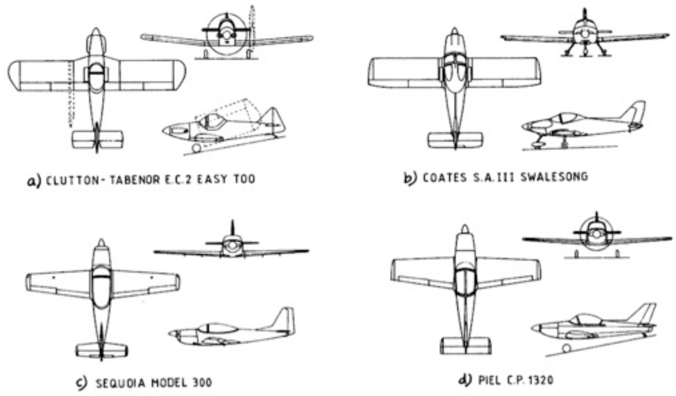
It is best to also choose this as the 'default configuration', since it often gives the best performance, and change from it only for good reason associated with specific requirements.

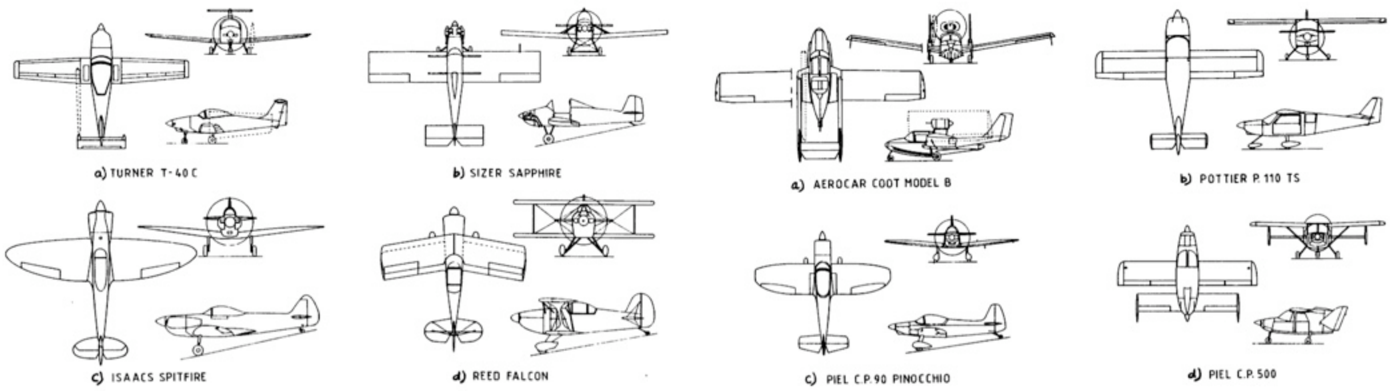
The number of powerplants should be the minimum necessary for power and operational requirements.

Faced with a number of choices previously adopted in any aircraft category, students can spend too much time selecting a suitable configuration. It is best to make an early choice about configuration and stick to it, perhaps highlighting any problems. In design office practise, a number of alternative configurations would be examined by different teams.

Homebuilts

1. A range of sophistication, but most are fairly simple.
2. Typically one- or two-place seating.
3. Most are of conventional layout aside from landing gear.
4. Predominance of tractor engine position (ahead of CG, engine behind propeller).
5. Predominance of fixed landing gear. Both tricycle and taildragger.
6. Folding wings for storage purposes quite common.
7. General preference for low cantilever wings, landing gear attached.
8. Wide variety of wing planforms, some biplanes.





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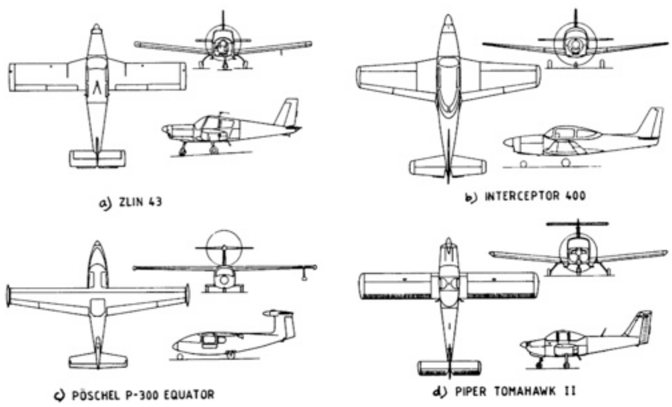
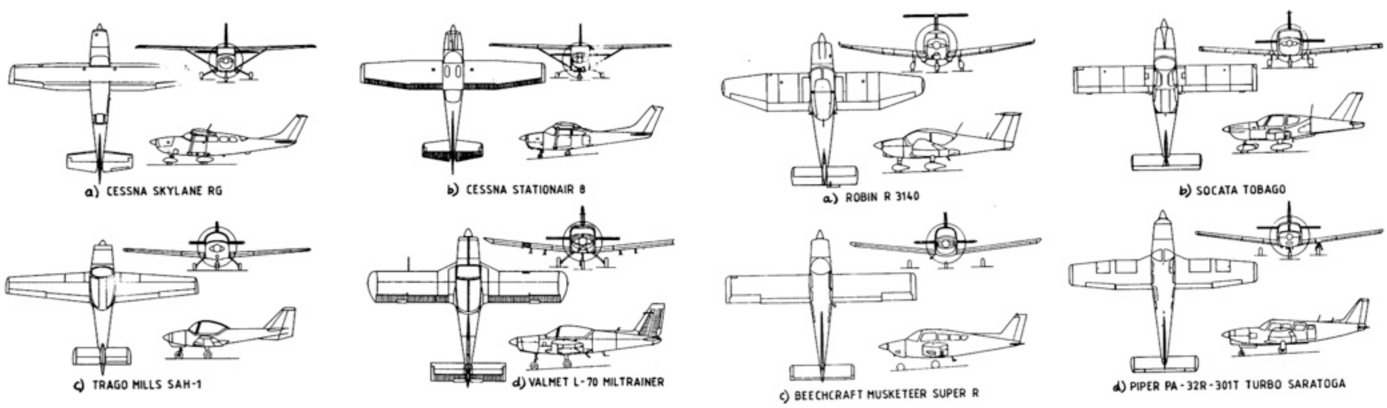
Single-engine propeller

1. Typically two- to six-place.
2. Most have cantilever low wings.
3. High wings are also used, often externally braced.
4. All engines are of tractor type (except the Poschel).
5. T-tails are hard to inspect and since (except Poschel) the horizontal surface is out of prop slipstream, may be harder to rotate aircraft on take-off.
6. Quite common to place H-tail behind rudder hinge line for good spin recovery.
7. V-tail is often swept, partly to increase moment arm/ effectiveness.
8. Fixed landing gear predominates. All are tricycle.





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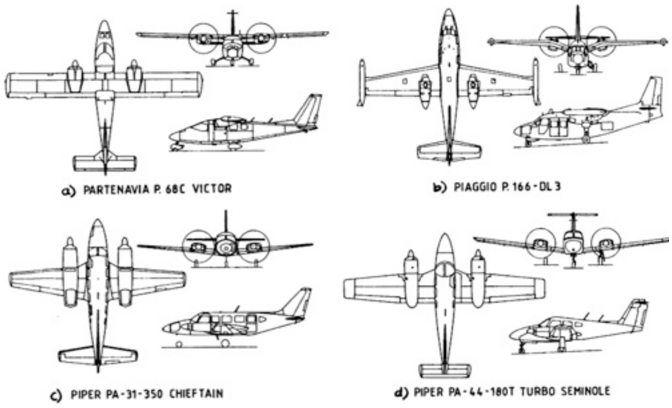
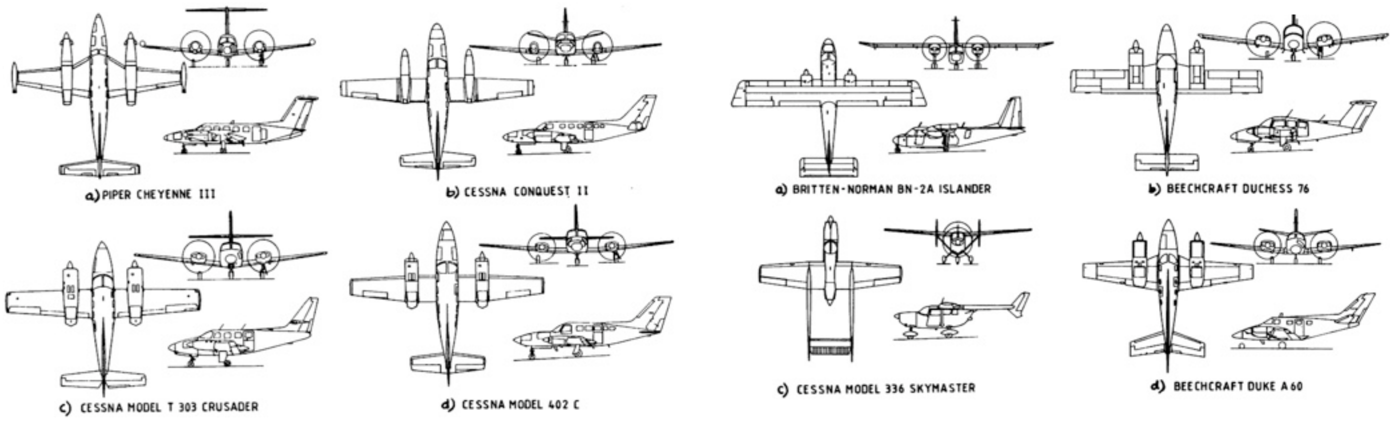
Twin-engine propeller

1. Typically 6-place or above — at the high end (e.g. Islander) these could be considered regional transport aircraft.
2. Especially for twins, engine-out controllability is a large issue in design. Vertical tails typically larger, often with dorsal extension to avoid fin stall at high yaw angles.
3. Horizontal tails may be T-type, vertically elevated, or with dihedral to place them out of prop slipstream.
4. Mostly tractor engined, Piaggio is a pure pusher, Cessna Skymaster is tractor/pusher (and the least conventional).
5. Retractable landing gear starts to dominate, all are tricycle, single-wheel main and nose.
6. Most with retractable gear stow it in the wing.
7. Widely differing engine nacelle integration. Baggage may be stored in nacelles.





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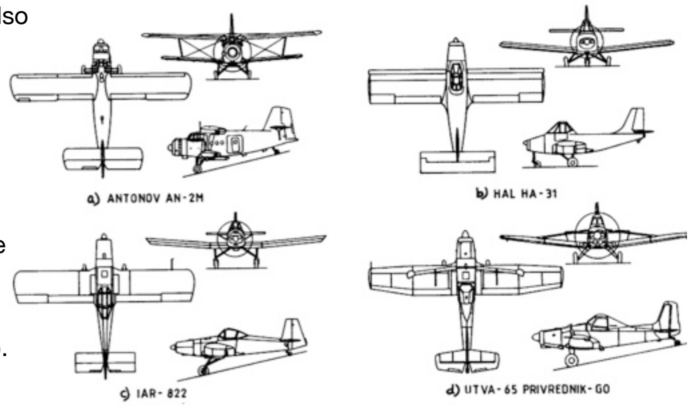
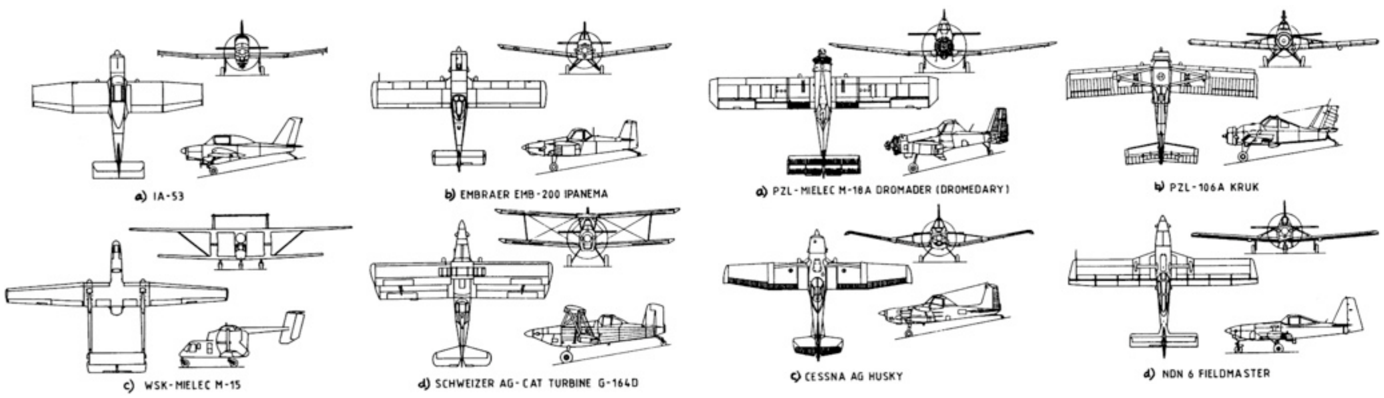
Agricultural aircraft

1. Mostly low-wing, some externally braced. Biplanes are also quite common, as low-speed load capacity is key.
2. All have fixed gear, mainly taildragger type.
3. All are rugged and designed for crash survivability. Good visibility for pilots/high cockpits. Wire cutters ahead of cockpits, bird-proof windshields, pilot roll cage.
4. Hoppers are often ahead of cockpit for crash energy absorption. Cabins may be lightly pressurized to displace chemicals.
5. Spray-bar system typically mounted at/below wing TE.
6. Mostly conventional tractor layout (other than jet biplane).
7. Two turboprops, likely to become more common for this category.





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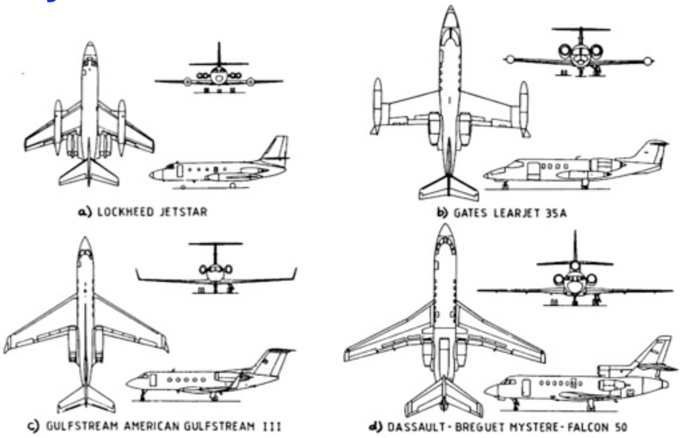
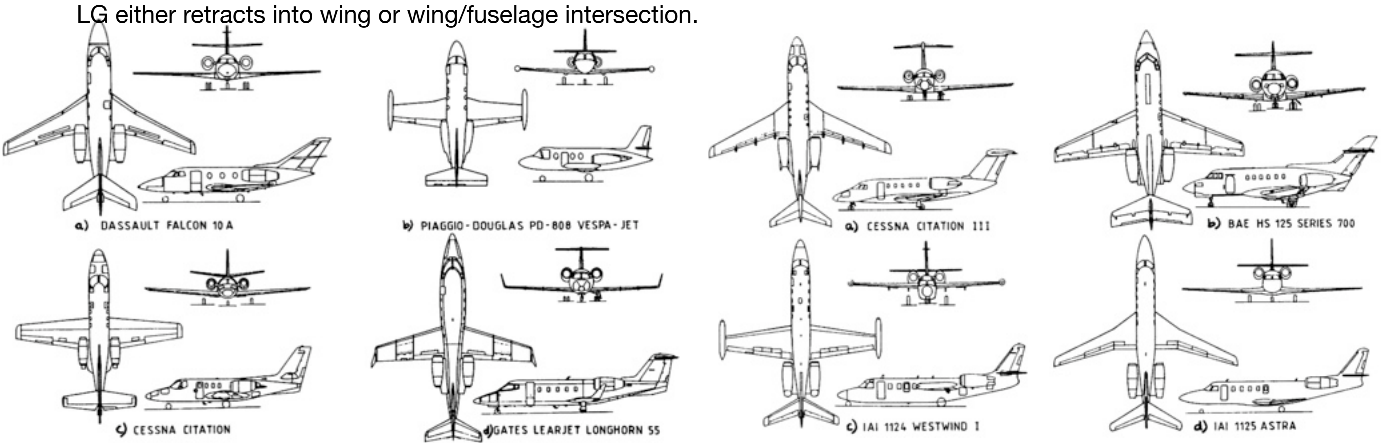
11

Business jets

1. Mostly twin-engine. All have rear-fuselage engine nacelles.
2. Almost all are of ‘conventional’ configuration, except Westwind which has a mid wing (and was developed from a turboprop aircraft).
3. Four have T-tails, others are cruciform.
4. Early bizjets had fuel volume problems, owing to high fuel consumption of early turbojets. Hence wing-tip/wing-external fuel tanks for earlier types.
5. Winglets are a common upgrade to an existing wing.
6. Wing sweep is common, but some wings have essentially zero sweep: implies supercritical airfoil, thin wing, or speed limitation.
7. All have tricycle landing gear, both single and twin wheels. LG either retracts into wing or wing/fuselage intersection.





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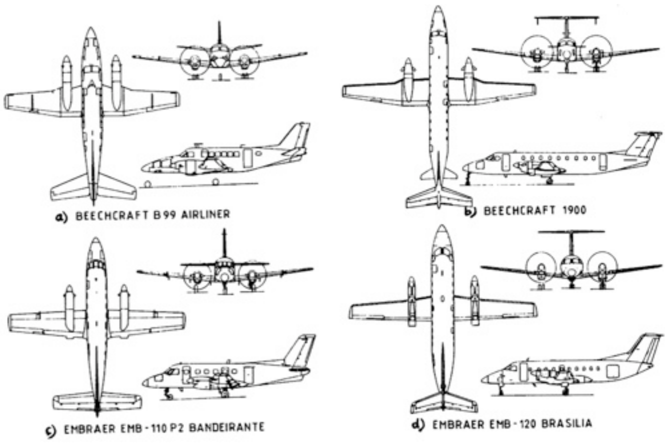
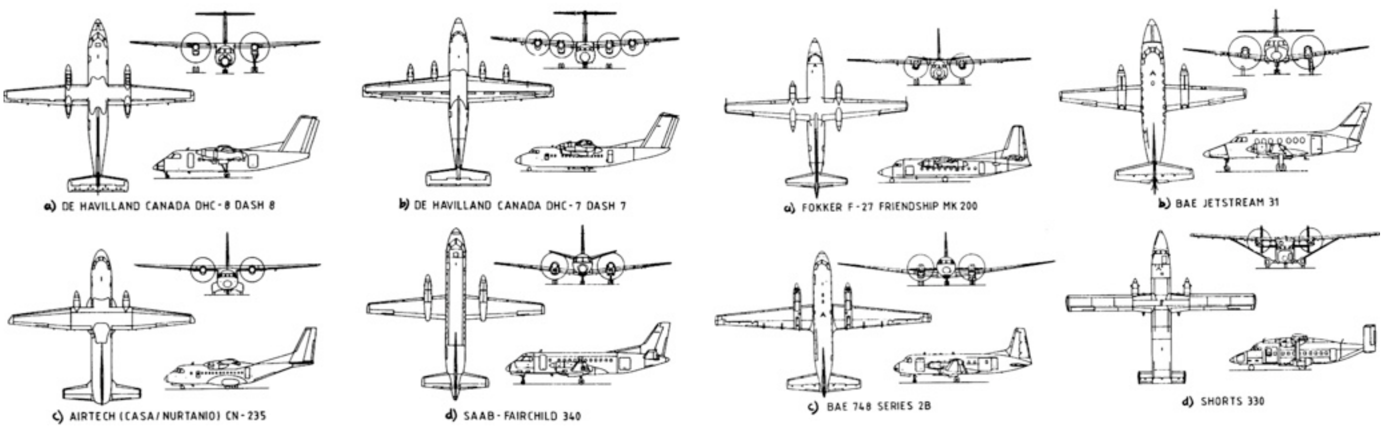
12

Regional turboprop

1. About equal numbers of high and low wings.
2. Wing aspect ratios are moderately high (up to 12.8) for efficient prop-powered cruise.
3. Mostly cantilever wings, but Shorts has external bracing.
4. Four are T-tail. Large vertical tail with dorsal extension is typical.
5. All have tractor engines installed in wing nacelles. Twins are dominant. With low wings, nacelles are typically above wing to give prop clearance.
6. Most retract main gear into engine nacelle. Fuselage-side gear blisters add drag but can save gear weight. Twin-wheel LG is common.





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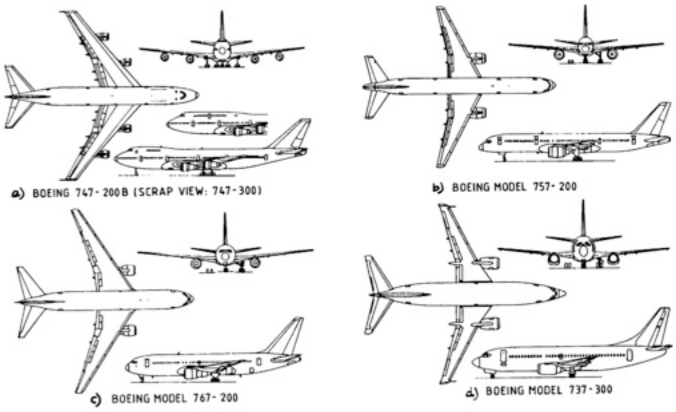
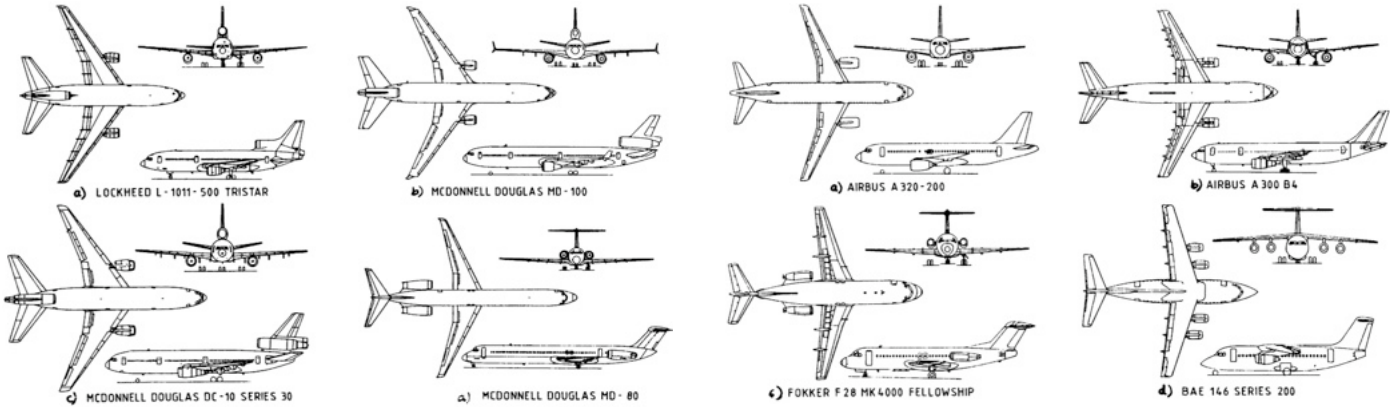
Jet transports

1. All except BAE are low-winged, and retract main LG into wing-fuselage intersection, where there is typically a glove fairing to reduce interference effects, and a wing crank or 'yehudi' (straight portion of TE), partly to accommodate a LG sub-spar, partly to improve flap effectiveness.
2. All have engines installed in nacelles under wings or on rear fuselage. Tristar has an engine buried in fin-fuselage intersection with an S-duct.
3. Most have moderately swept wings for high-subsonic cruise. Those with lower sweep are (slower) regional jets.
4. Twin-engine high-bypass turbofan are becoming the preferred option except for very largest in category (A380).
5. Most have wing-mounted spoilers/airbrakes, and all have engine thrust reversers.
6. 747 has four, DC-10 has three, main gear struts.





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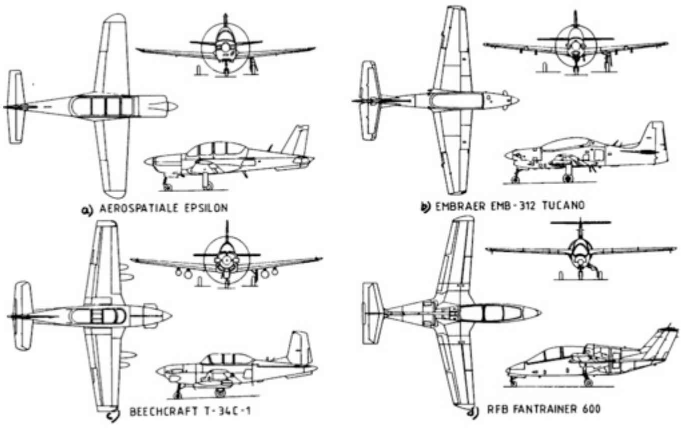
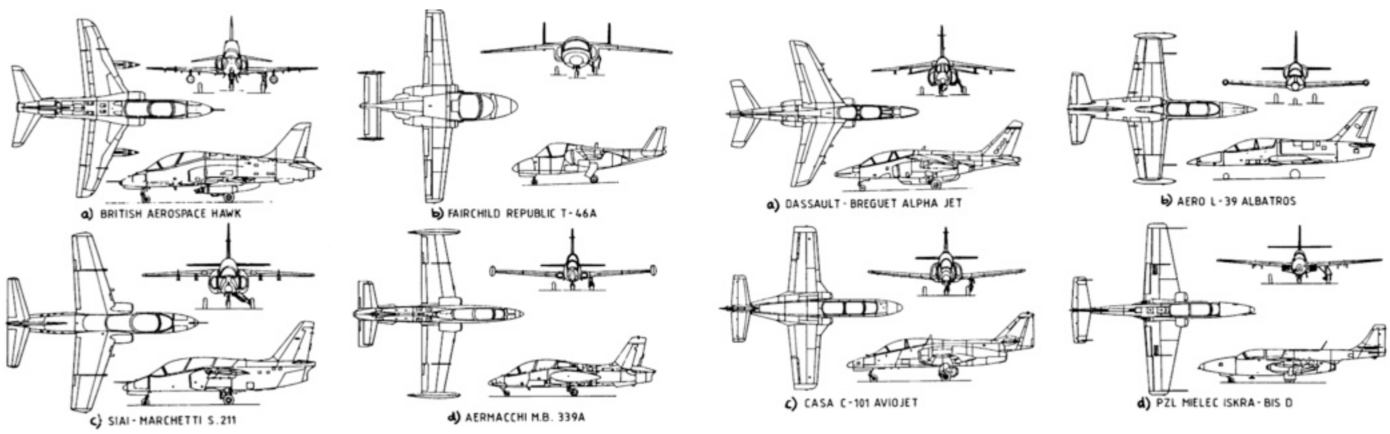
Military trainers

1. Prop-driven types are typically for basic training, jets for advanced training. Ducted fan is basic/intermediate.
2. All are capable of being equipped with guns or external store racks, and aircraft may be used for light air support. Some have separate attack variants (e.g. BAE Hawk).
3. All have tricycle retracts with single wheels on each strut.
4. No one wing position is dominant. Most wings have low or little sweep.
5. All jet engines are buried in fuselage to some degree; this requires good duct design and intakes with BL diversion.
6. Most use low cruciform tails. Quite a number have dorsal fins/strakes to aid spin recovery/docility.





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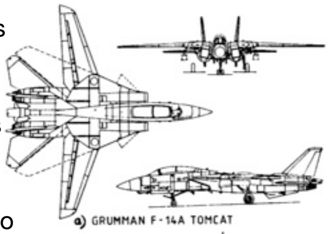
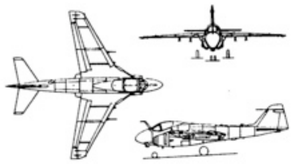
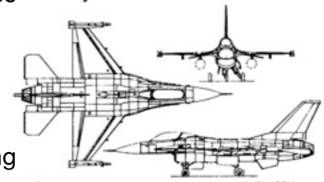
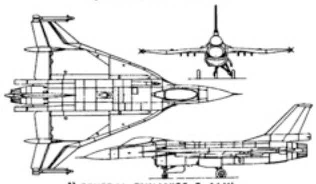
Fighters

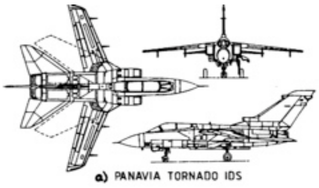
1. We cover a variety here, some (A-6, A-10, Pucara) are really ground attack aircraft, others may be called into this use. All true fighters are jet-engined and supersonic-capable.
2. Most have single-wheeled main LG, but twin nose wheels are common. All are tricycle.
3. Variable sweep allows efficient subsonic cruise and supersonic flight, subsonic combat manoeuvreability. Also it is costly, heavy, high-maintenance.
4. Twin vertical tails allow good lateral controllability during extreme high-α manoeuvres.
5. Delta wings are good for high-acceleration interception role. To maintain good turning capacity, a low wing loading is also needed.
6. The coupled delta-canard of the Viggen type gives favourable interference to reduce lift-induced drag.

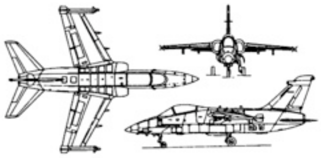

a) GRUMMAN F-14A TOMCAT

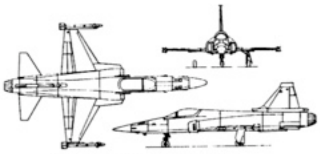

b) GRUMMAN A-6E/TRAM

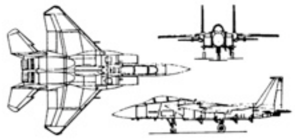

c) GENERAL DYNAMICS F-16A FIGHTING FALCON

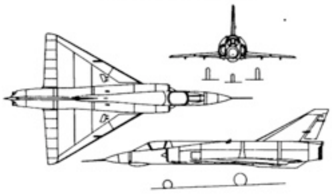

d) GENERAL DYNAMICS F-16XL

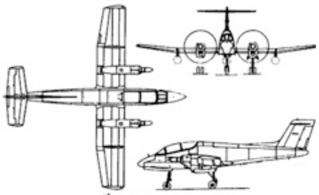

a) PANAVIA TORNADO IDS

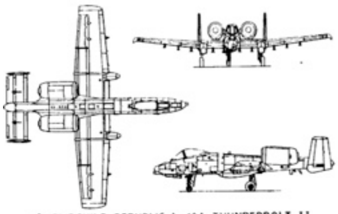

b) AERITALIA/AERMACCHI/EMBRAER AM-X

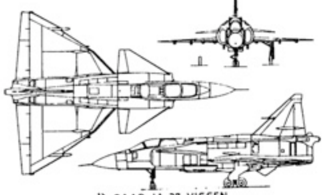

a) NORTHROP F-20 TIGERSHARK


b) MCDONNELL DOUGLAS F-15C EAGLE


c) DASSAULT-BREGUET MIRAGE III-E


d) FMA IA 58A PUCARA


c) FAIRCHILD REPUBLIC A-10A THUNDERBOLT II


d) SAAB JA 37 VIGGEN

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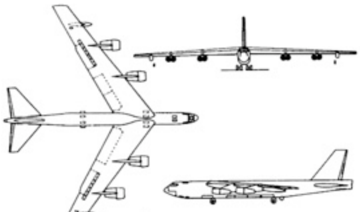
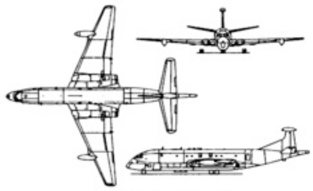
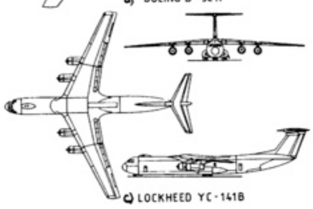
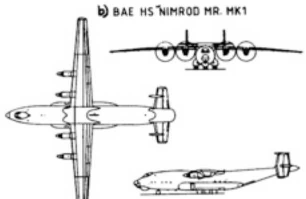
Military patrol/bomb/transport

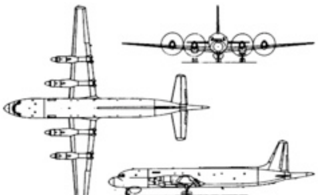
1. All are of conventional layout except in respect of landing gear options.
2. Note B-52 which uses high wing and tandem gear. This was a solution to a requirement for a long bomb bay. Plane cannot rotate for takeoff and requires long fields.
3. High wings are common especially for transport aircraft which need roll-on/roll-off cargo floors.
4. In fact the low-winged aircraft were all developed from passenger transports.
5. All jet-engined aircraft have significant sweep, while turboprop aircraft have unswept wings, reflecting different design cruise speed regimes.
6. The Hawkeye AWACS is carrier-based: storage-space restrictions partly accounts for the use of four vertical tails.


a) BOEING B-52H


b) BAE HS NIMROD MR. MK1

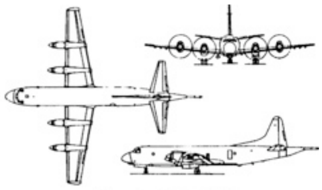

c) LOCKHEED YC-141B


d) ANTONOV AN-22 ANTHEUS

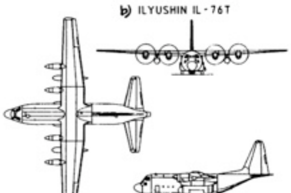

a) ILYUSHIN IL-38

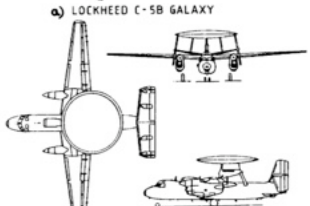

b) ILYUSHIN IL-76T

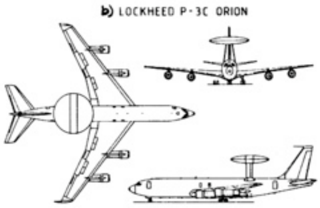

a) LOCKHEED C-5B GALAXY


b) LOCKHEED P-3C ORION


c) MCDONNELL DOUGLAS KC-10A EXTENDER


d) LOCKHEED C-130E HERCULES


c) GRUMMAN E-2C HAWKEYE


d) BOEING E-3A AWACS

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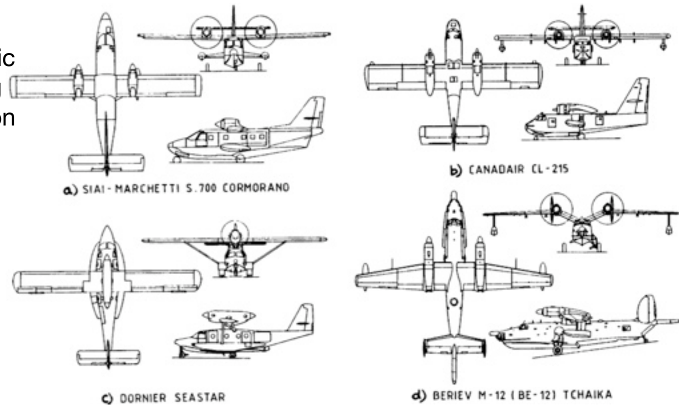
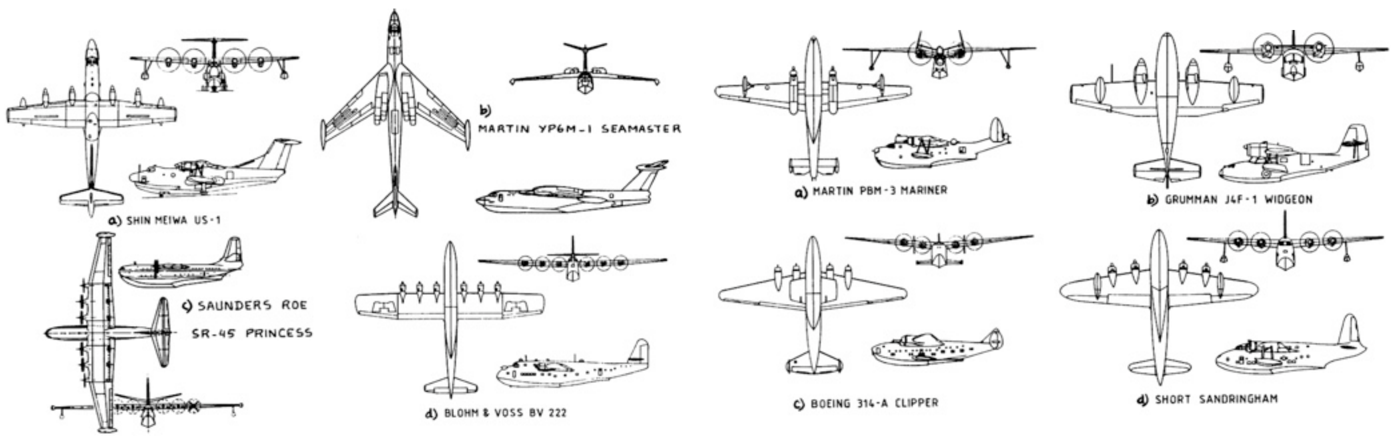
17

Flying boat/amphibious/float aircraft

1. Aircraft design dominated by requirement for large hydro-dynamically shaped hull. This gives a much larger parasitic drag than comparable conventional types. Hulls (including gear bays) must be sealed and contain watertight floatation compartments.
2. A major design consideration is to keep (salt) water away from engines. All have high wings/high-mounted engines. This may give significant nose-down pitching at high thrust.
3. Most also have tricycle landing gear (Beriev is exception).
4. Most modern aircraft in this category are turboprop, but (Russian) jets are making a comeback. The `Seamaster' was a failure, partly owing to poor timing and complexity.





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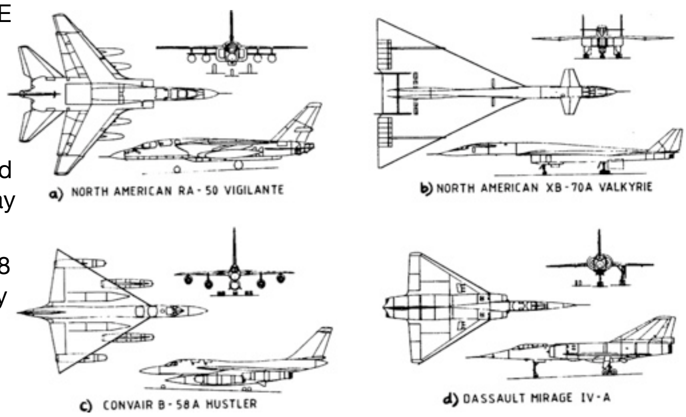
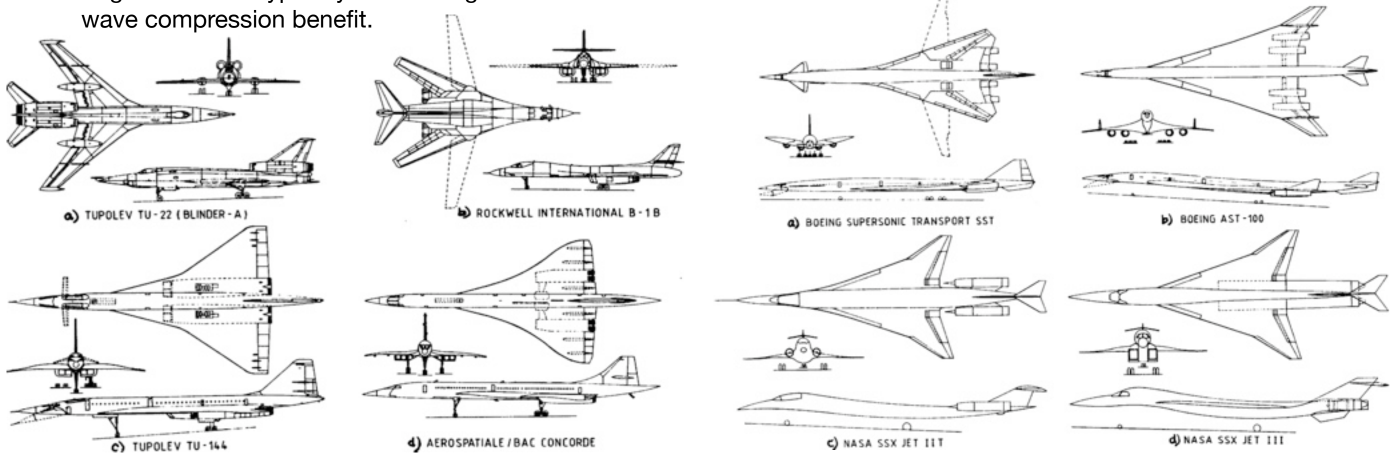
18

Supersonic cruise aircraft

1. Large sweep angles are typically used to keep the wing LE 'subsonic' — i.e. behind the wing's Mach cone. This minimizes wave drag and lowers heating of the wing.
2. Large sweep lowers lift-curve slope and large angles of attack are needed at low speed, when separated vortex flow will also contribute significant lift (and drag). Drooped noses may be employed. Alternatively, variable sweep may be the solution to the wide speed-range requirement.
3. Lift/drag ratio of these aircraft is low (e.g 7 to 9 vs 14 to 18 for transonic-cruise). This has not (yet) been overcome by increasing the speed (the range parameter is *ML/D*). Aircraft are thirsty/uneconomic for civil use.
4. Sonic boom noise is a significant problem in civil use.
5. Engines intakes typically below wing and aft for shock-wave compression benefit.





Roskam

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Unusual configuration/canard

1. Of the unusual configurations, canard is the most often used. Part of the attraction is that when trimmed, the canard surface provides lift instead of down-force as in conventional types. It is possible to achieve slightly greater lift:drag ratio with canard layout.
2. Very often these are also pusher-engined, which tends to reduce cabin noise.
3. Canard surface must stall first, but also must have a high maximum C_L when wing flaps are lowered. (These are somewhat contradictory requirements.)
4. Typically, these are ‘almost’ flying wings; the canard is small in area and highly-loaded.

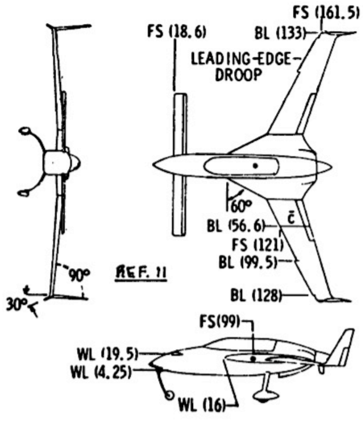

Figure 3.41 Rutan Varieze

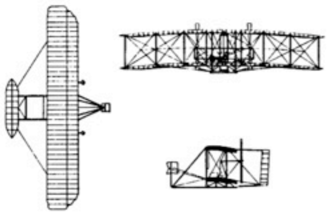

Figure 3.37 The Wright Flyer

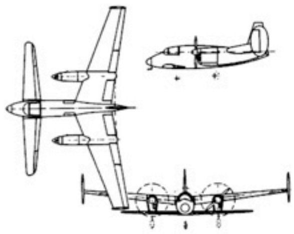

Figure 3.38 Miles M39B Libellula

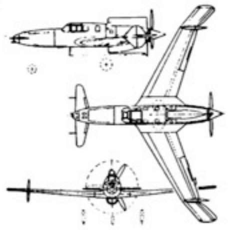

Figure 3.39 Curtiss XP-55 Ascender

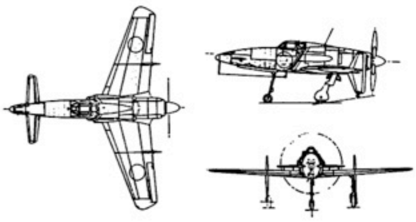

Figure 3.40 Kyushu J7W1 Shinden

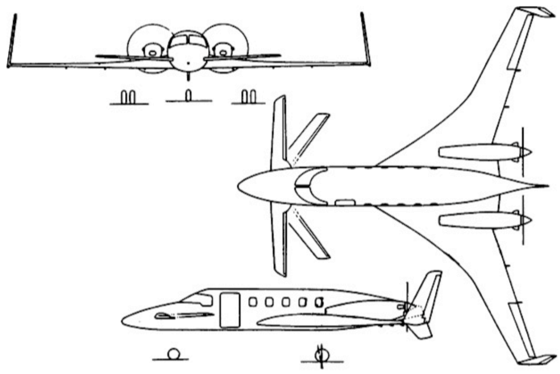

Figure 3.42 Beech Starship I (Tentative Threeview)

Roskam

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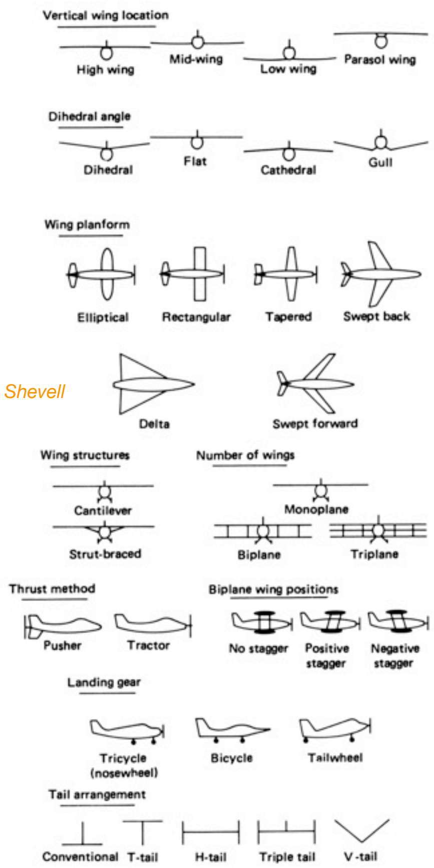
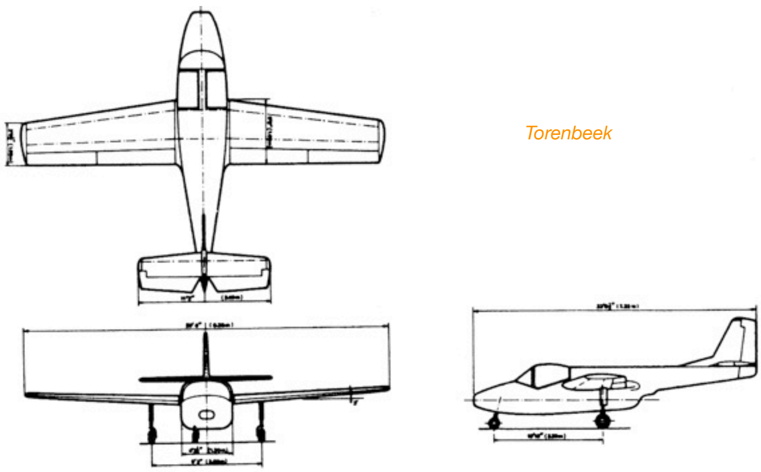
Choosing the ‘General Arrangement’



A wide varieties of aircraft layout exist, and choosing the general arrangement of components requires some thought.



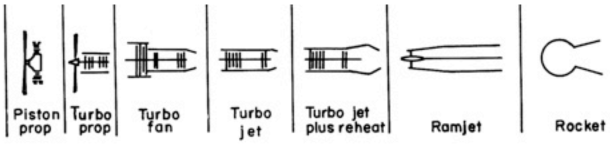
Torenbeek

The ‘conventional layout’, with

1. A cantilever monoplane wing;
2. Separate horizontal and vertical tail surfaces;
3. A single discrete fuselage to provide volume and airframe connectivity;
4. A retractable tricycle landing gear.

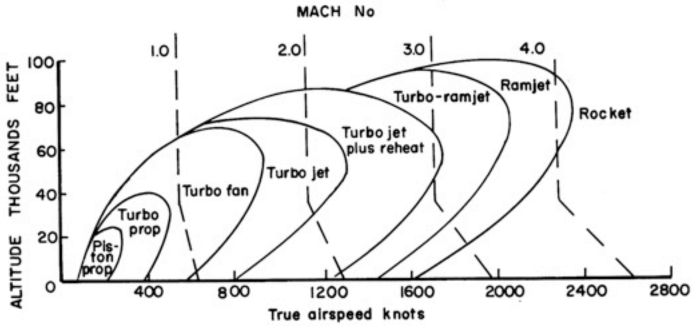
is generally best. Decisions to select other layouts should be the result of rational responses to special design requirements.

Powerplant selection



The choice of powerplant is primarily determined by the requirement for reasonable propulsive efficiency η_P at the Mach number regime of the dominant flight task (typically, cruise).

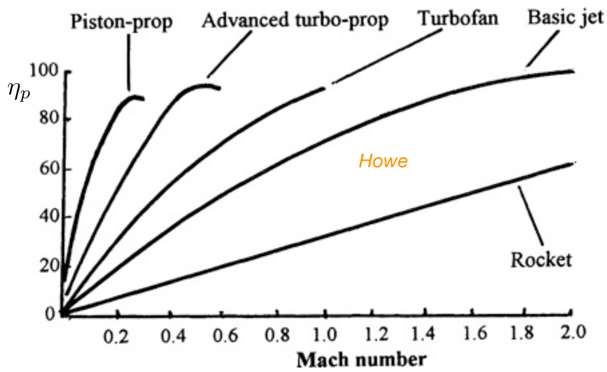
Nicolai



$$\eta_P = \frac{\text{available propulsive power}}{\text{total power transferred to air}} = \frac{2}{1 + V_j/V_\infty}$$

where V_j = average exhaust jet speed and V_∞ = flight speed. Mach number $M = V_\infty / a$.

For a constant propulsive efficiency (say 70% – 80%) it is evident that V_j must increase with flight speed, and it is this that determines the most appropriate type of powerplant.



Adapted from Howe

Powerplant location

Now we will run through some of the main options for layout, starting with usual powerplant locations.

1. Nose location (propeller propulsion). The traditional location for 1-engined prop aircraft. Allows powerplant unit to be relatively self-contained.
2. Fuselage central/aft buried location. Common for single and twin jet-engined aircraft of trainer/combat type. Good for compact layout but engine access for maintenance or removal needs very careful consideration. Generally try to limit length of jet exhaust pipe – tends to force engines aft, within constraints imposed by centre of gravity requirements.
3. Wing mounted. Most larger aircraft use this option. Gives load relief and reduces wing-root bending moment, leading to reduced structure weight. For jet aircraft, engines usually in pods below wing – simplifies access and maintenance. For propeller aircraft, engines typically mounted directly on wing. Adequate ground clearance can be a problem. Inner engines typically at approximately 33% of semi-span, outer engines, if any, at 55% of semi-span.
4. Rear fuselage podded. A possibility for jet aircraft, though wing mounted engines are now generally preferred. Not uncommon for small transport aircraft such as business jets, where ground clearance could be a problem with wing-mounted engines.
5. Upper or lower podded powerplant. Very uncommon for larger aircraft but does simplify fuselage layout.

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Adapted from Howe

(Jet) Engine air intakes

The choice of jet engine air intake is heavily dependent on design Mach number regime.

The basic task of the intake is to deliver air to the front of the fan/compressor stage at $M < 0.5$, regardless of flight speed, with as uniform a velocity distribution as possible, and with lowest drag.

1. Podded gas turbine intakes are inevitably of Pitot (tube end) type. For subsonic application the tube length can be of order 50% of fan diameter. For supersonic application a longer diffuser length will be needed and possibly of variable geometry. For $M > 1.7$ a centrebody is typically also needed.
2. For engine buried in fuselage, there are a number of options. (a) Nose intakes generally not preferred as they have long inlet ducts with substantial drag/losses, and ductwork consumes fuselage volume. (b) Side intakes above wing – generally associated with low wings – have low duct length and consume less fuselage volume, but need careful design to avoid flow separation. (c) Side intakes below (high) wing are generally better. (d) Ventral intakes are another common solution, good for high angle of attack. (e) Upper fuselage dorsal intakes use rarely used except for tri-jet layouts.

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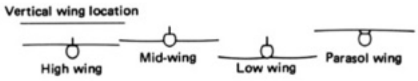
Adapted from Howe

Wing vertical position



Wing vertical location w.r.t. fuselage axis obviously also affects fuselage layout too.

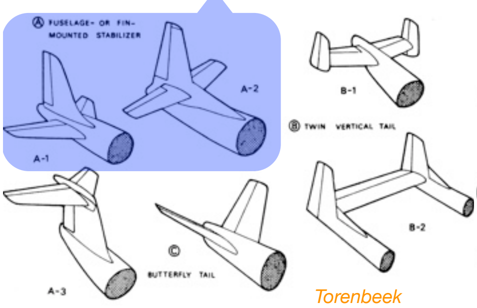
The advantages of a high wing are in many ways the disadvantages of a low wing and vice versa.

1. Mid-wing position gives lowest interference drag, while high wing has more efficient spanwise lift distribution and hence lower induced drag than other options (other things equal).
2. Structurally the primary spanwise wing beam should normally be continuous through the fuselage. This may be relaxed with connections to bulkheads for low-aspect ratio wings e.g. on combat aircraft.
3. A high wing typically implies a very long wing-mounted main landing gear or narrow-track fuselage-mounted.
4. Combat aircraft often have mid- or high wings for good air intake design and under-wing stores access.
5. High wings are often used for cargo transport aircraft so that there is a long unimpeded cargo floor.
6. Low wings are the dominant choice for passenger jet transports, for combined luggage+seating.

Adapted from Howe

Empennage (tails)

The basic configuration is a fixed horizontal tailplane and vertical fin, each with a hinged rear portion that is deflectable to provide pitch and yaw control. Unless there is a pressing need it is best to stay with this conventional layout, though many variations are possible.



Torenbeek

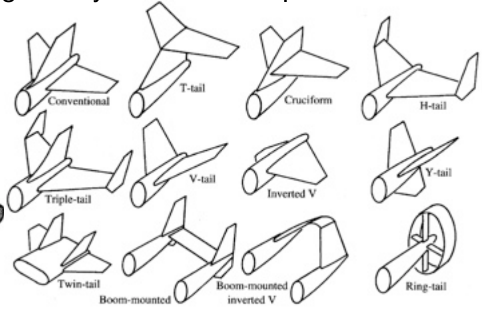


Fig. 4.30 Aft tail variations.

Raymer

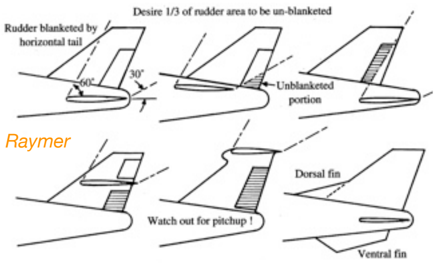
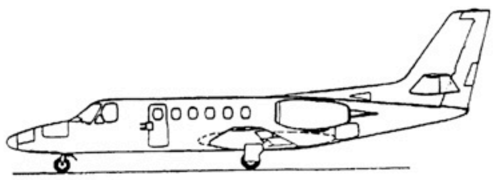


Fig. 4.36 Tail geometry for spin recovery.

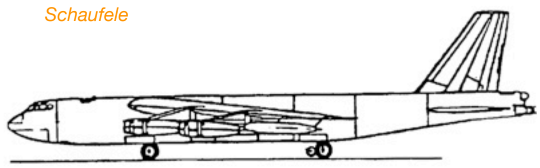
1. The whole horizontal tailplane may have variable incidence in addition to a deflectable rear. This is to cope with trim changes required when large high-lift systems are deployed, but still allow conventional elevator control. Common on large jet transport aircraft.
2. The whole horizontal tail surface can be used as an elevator (called a 'flying tail'), often with differential deflection for roll control. Common on supersonic-capable combat aircraft. Rarely, the vertical tail may also be of this type.
3. Tails of end-plate type (twin vertical at end of horizontal, or T-tail in the case of horizontal at top of vertical) can make the other surface more efficient (by reducing tip vortices) but may be over-flexible and for T-tails, subject to blanketing by separated flow from the wing in a heavily-stalled situation - a number of aircraft have been lost as a result: use with care.
4. Butterfly or V-tails at first seem an efficient rational solution but often offer little real aerodynamic advantage. In addition they lead to undesirable cross-coupling effects (e.g. yaw-roll coupling) and are difficult to set up.
5. In general, care must be taken to ensure that tail surfaces provide effective control especially if the aircraft is stalled/spinning.

Landing gear (undercarriage)

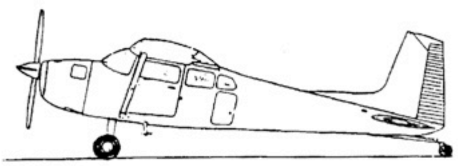


Tricycle Gear

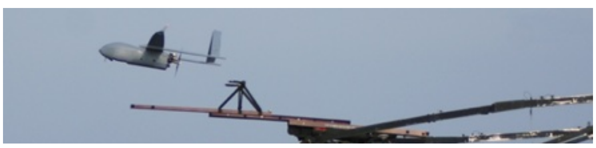
Schaufele



Bicycle Gear



Tailwheel Gear



The basic configuration has <u>retractable, tricycle</u> landing gear.

Retractable to cut drag: exposed undercarriage may increase C_{D0} (zero lift drag coefficient) by as much as 30%.

Tricycle because this will track in a straight line across the ground in a stable manner.

For simple/slow/light aircraft, non-retractable gear is OK and often this is also of tailwheel type for simplicity and ruggedness. However, this tail-dragger gear layout will not track a straight line without control input (unstable).

Bicycle gear is not often used partly because aircraft will not rotate on take-off – this forces a long runway length.

For tricycle and tailwheel layouts, the main gear (nearest the centre of gravity) takes most of the static load, and local structure must be strong enough to survive/distribute this.

Retractable gear requires careful thought about retraction mechanism, as well as reserved volume within the airframe to accommodate the retracted wheels and legs.

Main gear must have sufficient lateral spread to prevent the aircraft overturning during ground manoeuvres.

Unmanned aircraft may dispense with landing gear and use a catapult launcher, sometimes a landing net as well.

Adapted from Howe

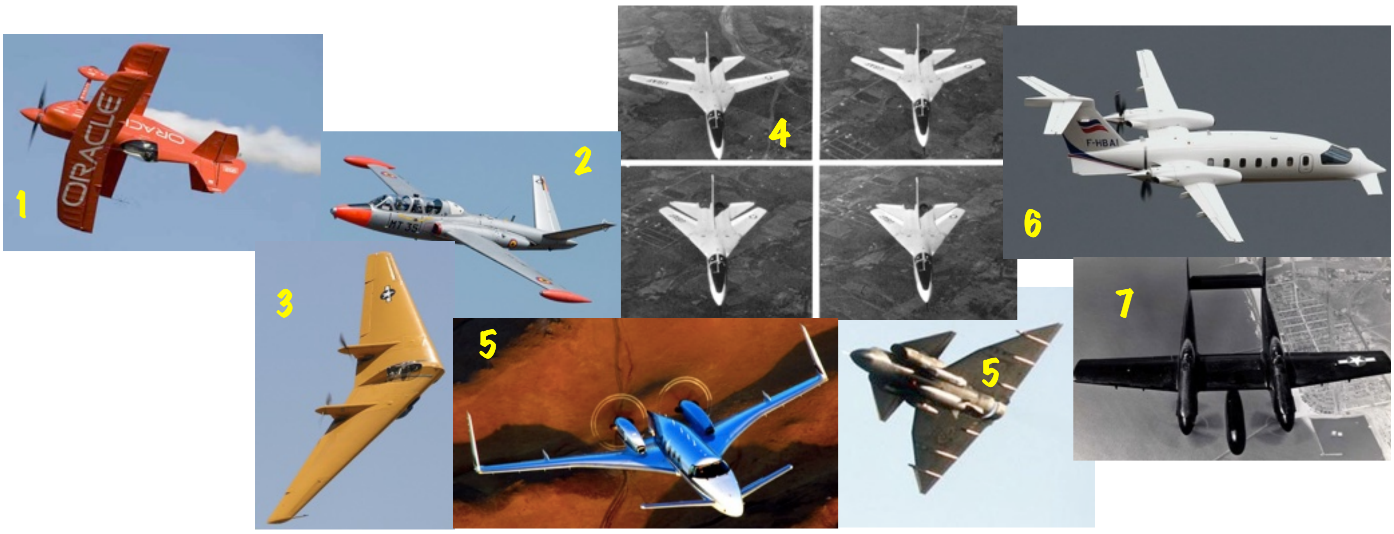
Variations on the basic layout

1. Wing struts – can significantly reduce structural weight but increases drag. Unusual on all except low-speed aircraft.
2. Wing sweep – used mostly to delay onset of wave drag to higher Mach number. Has a number of aerodynamic penalties/side effects so that, while effective, sweep should only be used with care, and the minimum suitable amount should be selected for the design Mach number. Forward sweep has broadly similar effect but is rarely used partly owing to aeroelastic divergence problems.
3. Winglets – used to increase effective aspect ratio of a wing without increasing span. Typically it's better to select a higher aspect ratio in the beginning but may be post-fitted to existing layouts or used when span is limited.
4. Twin tail fins at end of tailplane – now rarely used. Some mass penalty and hard to combine with dorsal extensions.
5. All-moving fin – sometimes used on supersonic aircraft but a conventional fin-rudder combination usually enough.
6. Twin tail booms – facilitates use of pusher propeller. Alternatively can aid rear-cargo loading. Wing mass penalty.

Adapted from Howe

Alternative configurations

1. Biplane – lightweight and compact for low wing loading but with large drag penalty. Now rarely used.
2. Butterfly tail – combines functions of horizontal and vertical surfaces. Potentially less total drag than conventional layout but gives control and stability cross-coupling issues. Generally to be avoided.
3. Tailless/flying wing – theoretically very efficient (and stealthy) but: can be difficult to accommodate payload/ passengers and has a variety of control and stability problems. Potential gains are rarely achieved in practice.
4. Variable sweep – ability/compromise to combine high sweep, low thickness-chord ratio airfoils (good for supersonic performance) with high aspect ratio (good for subsonic performance) but is heavy, costly and difficult to maintain.
5. Canard – potential advantage is that both tail and wing surfaces provide lift force but advantage tends to be small.
6. Three-surface – tailplane for stability and foreplane for control and trim with wide CG range. Limited advantage?
7. Twin fuselage – rarely-used hybrid.



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Adapted from Howe

Special considerations

1. Short/vertical takeoff and landing (STOL/VTOL) – STOL generally requires (a) small W_0/S (b) large P_0/W_0 (c) large C_{Lmax}. VTOL generally requires vectorisable thrust and $T_0/W_0 > 1$.
2. Stealth – either design for low radar return and then make aerodynamics work or vice versa. Align all surface outline angles, use only internal weapon bays, use long+bending air inlets to hide compressor face, hide engine exhausts.
3. Water-borne – add-on floats to existing landplane, or make buoyancy/planing integral with fuselage. Keep engines away from water spray.

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Aspect ratio isn't everything or: the Aspect Ratio Trap

recall: $L/D_{\max} = \dfrac{1}{\sqrt{4C_{D,0}K}} = \dfrac{1}{2}\sqrt{\dfrac{\pi Ae}{C_{D,0}}}$ Makes high *A* look good. But:

$$D = qSC_D = qS\left(C_{D,0} + \frac{C_L^2}{\pi Ae}\right)$$

where $q = \frac{1}{2}\rho V^2 = \frac{1}{2}\gamma p M^2$ and $A = \dfrac{b^2}{S}$

$L = W = qSC_L$ or $C_L = \dfrac{W}{qS}$

L = *W* always in level flight. What we care about for fixed *W* is *D*.

$$D = qSC_{D,0} + \frac{1}{\pi eq}\left(\frac{W}{b}\right)^2$$

W/*b* is called the span load.

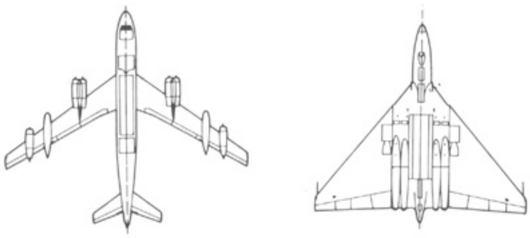
Span plays a bigger direct role in reducing drag than aspect ratio.

Classic Example: Boeing B-47 vs Avro Vulcan B-1

Adapted from Mason and Nicolai.

Same mission requirements: 20 klb bomb / 2600 nm range / 520+ kt cruise / 40 kft altitude

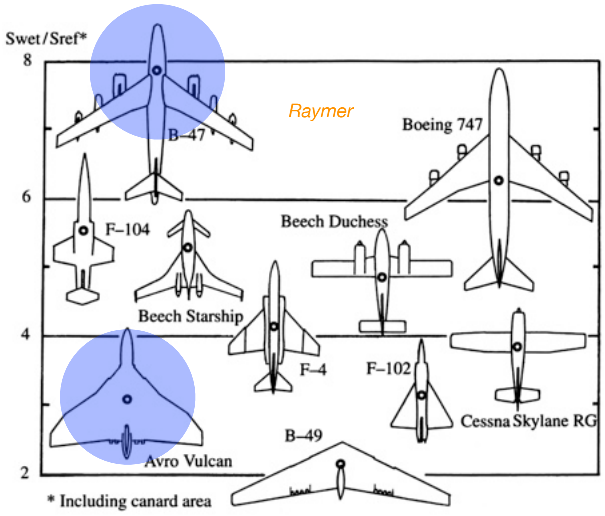
- Traditional idea: higher aspect ratio *A* gives higher *L/D*.
- But: low *A* wing with less wetted area overall competes with high *A* wing.



B-47 Vulcan

Similar L/D max achieved two ways

Same mission requirements: 20 klb bomb / 2600 nm range / 520+ kt cruise / 40 kft altitude



Parameter	B-47	Vulcan
Takeoff weight W_0 [lb]	230000	170000
Wing area S [ft^2]	1430	3446
Wing span b [ft]	116	99
Wing loading W_0/S [lb/ft^2]	140	43
Span loading W_0/b [lb/ft]	1980	1720
Aspect ratio $A = b^2/S$	9.43	2.84
Wetted area S_{wet} [ft^2]	11300	9500
$C_{D,0}$ (estimate)	0.0238	0.0066
Equivalent flat plate area $C_{D,0}S$ [ft^2]	34	22.7
Wetted area aspect ratio b^2/S_{wet}	1.19	1.28
L/D_{max}	**15.8**	**16.4**
C_L*	0.751	0.217

recall

$$L/D_{\max} = \frac{1}{\sqrt{4C_{D,0}K}} = \frac{1}{2}\sqrt{\frac{\pi Ae}{C_{D,0}}}$$

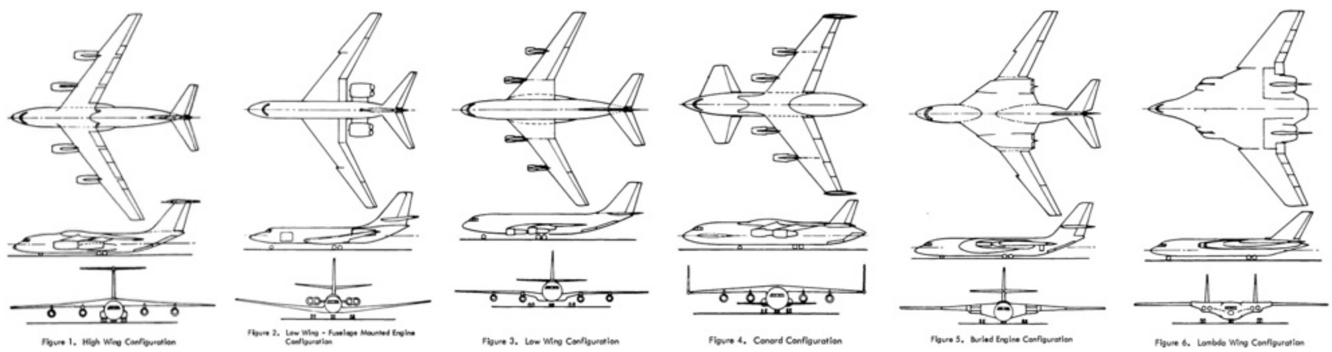
$$C_L^* = C_L|_{(L/D)\max} = \sqrt{\frac{C_{D,0}}{K}} = \sqrt{C_{D,0}\pi Ae}$$

Adapted from Nicolai & Carichner

Configuration studies - comparison of workable designs

As part of the C5 initial design study, the design team compared the influence of configuration variations around their existing C141 design.

Truck-bed height cargo floor desired.



Baseline. Existing C141.	Requires kneeling LG. +10% W_0.	Requires cranked wing and kneeling LG. +12% W_0.	Slightly heavier and more costly than baseline.	Slightly heavier and more costly than baseline.	5% heavier and 5% more costly than baseline.

So, they stayed with the original layout.

Note that one has to get all the way through to a workable design to make a fair comparison.

From AIAA Lockheed C5 case study.