

Fighter aircraft design

Aerospace Design Project 2017-2018

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General configuration

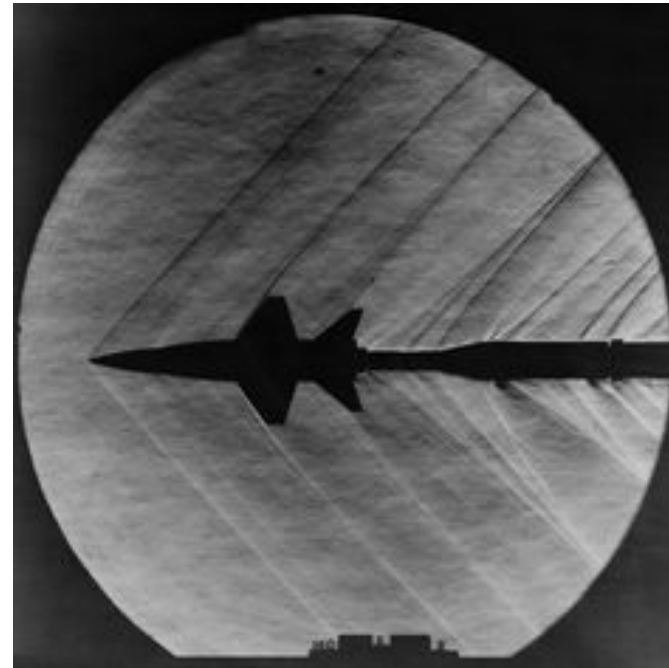
- The elements of the general configuration are the following:
 - Wing
 - Wing placement
 - Airfoil
 - Number of engines
 - Number and placement of engine air intakes
 - Horizontal tail
 - Canards
 - Number of fins
 - Other control surfaces

Wings

- Modern high performance fighters have one of three wing types:
 - Trapezoidal
 - Delta
 - Sweptback with low aspect ratio
- Lower performance fighters (trainers, ground attack aircraft etc) can also have high aspect ratio sweptback wings, just like transport aircraft.
- Trapezoidal, Delta and low aspect ratio sweptback wings can fly at subsonic or supersonic speeds.
 - Such wings have low aspect ratios and are thin in order to minimize wave drag (drag due to shock waves).
- Aircraft with high aspect ratio sweptback wings cannot fly supersonic, except under special circumstances (e.g. powered dives).
 - Such wings have high aspect ratios and are thicker in order to accommodate a thick main spar.

Shock waves

- All wings must lie inside the conical shock wave generated by the fuselage nose of an aircraft flying at supersonic conditions.



Delta wings

- Advantages:

- Delta wings have a long root chord and therefore can have a thick main spar while retaining a low thickness-to-chord ratio.
- They also have larger wing area than trapezoidal wings with the same aspect ratio. This means low wing loading even during maneuvers.
 - There is a lot internal volume for fuel and landing gear.
- At low speed conditions they can produce a lot of additional lift when placed at high angle of attack, thanks to the leading edge vortices.
- Delta wing aircraft do not require a horizontal tail.

- Disadvantages:

- Higher viscous drag due to the large wing area.
- High induced drag at subsonic conditions due to low aspect ratio.
- Bad deep stall.
- Pitch control is achieved by deflecting upwards the trailing edge control surfaces in order to produce a nose up moment. This reduces the total amount of lift generated by the wing.
 - This problem can be overcome by incorporating a horizontal tail or lifting canards.

Aircraft with Delta wings

MiG-21: Cropped Delta with tail



Eurofighter Typhoon:
Cropped Delta with canards



JAS 39 Gripen:
Cropped Delta with canards



Mirage III, IV, V, 2000:
Tailless cropped Delta



IAI Kfir: Upgraded Mirage V
with canards



F-102 Delta Dagger and
F-106 Delta Dart: Tailless
cropped Delta



Aircraft with Delta wings (2)

Chengdu J-10: Cropped Delta with canards



Dassault Rafale: Cropped Delta with canards



Saab 37 Viggen: Compound Delta with canards



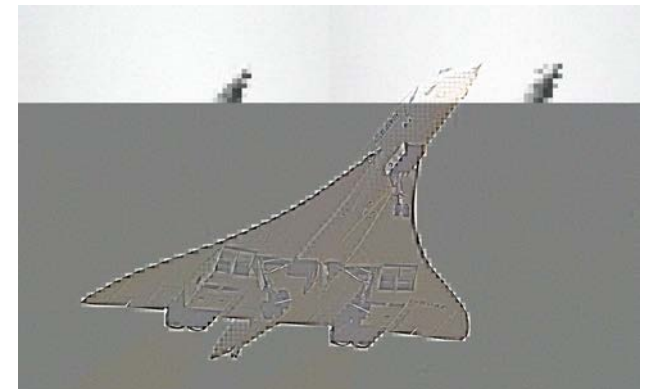
Saab 35 Draken: Compound Delta



Shenyang J-8: Delta wing with tail



Concorde: Ogive Delta



More on Delta wings

- The pitch control and bad deep stall disadvantages of Delta wings led to several variations:
 - Compound Delta or Ogive Delta: the inboard sweep is generally higher so as to create even stronger leading edge vortices and delay stall to even higher angles.
 - Exception: Saab 37 Viggen.
 - The Ogive Delta also reduces supersonic drag.
 - Horizontal tail: Provides additional stability in pitch and therefore the wing can produce more lift. Tail elevator provides pitch control
 - Canards: They are usually all-moveable and provide additional pitch control. The aircraft is usually statically unstable.
- Note also that flaps are difficult to use with a tailless Delta configuration.
- Delta wings are generally cropped. The pointy wingtip is difficult to manufacture and structurally weak. Furthermore, cropped Delta wings delay vortex bursting.
- The centre of lift lies aft on a Delta wing. This means that the horizontal tail can only be effective if it lies even further aft. Usually the tail is highly swept and can be placed on a highly swept fin.

Specifications of some delta wing aircraft

| Aircraft | Aspect Ratio | Maximum Mach | | Service Ceiling | Range |
|--------------------------------|--------------|--------------|---------------|-----------------|----------|
| | | Sea level | High altitude | | |
| MiG-21 | 2.22 | 1.05 | 1.8 | 57,400 ft | 1,470 km |
| Eurofighter Typhoon | 2.205 | 1.25 | 2 | 65,000 ft | 2,900 km |
| JAS-39 Gripen | 2.13 | 1.06 | 2.31 | 65,000 ft | 1,600 km |
| Mirage 2000 | 2.03 | 1.2 | 2.2 | 59,000 ft | 1,550 km |
| F-106 | 2.10 | ? | 2.3 | 57,000 ft | 2,900 km |
| Chengdu J-10 | 2.33 | 1.2 | 2.2 | 59,055 ft | 550 km |
| Dassault Rafale | 2.6 | 1.1 | 1.8 | 50,000 ft | 1,852 km |
| Saab-37 Viggen | 2.45 | 1.1 | 2.1 | 59,100 ft | 2,000 km |
| Concorde | 1.7 | ? | 2.04 | 60,000 ft | 7,222 km |

Trapezoidal wings

- In trapezoidal wings, the leading edge sweeps back but the trailing edge sweeps forward.
 - Some Delta wings also feature a slight sweep forward angle at the trailing edge.
- Advantages
 - Better performance than Delta wings at transonic speeds and during transition to and from supersonic conditions.
 - They do not require upwards deflection of the trailing edge control surfaces for pitch control and therefore do not lose lift.
 - Their centre of lift lies further forward and therefore the tail must not lie too far back on the fuselage.
 - They are preferred for stealth applications.
 - Flaps can be easily used.
- Disadvantages:
 - High wing loading.
 - They stall at much lower angles of attack than Delta wings.
 - This problem is overcome using Leading Edge (Root) eXtensions (LEX or LERX) and/or canards.

Aircraft with trapezoidal wings

F-18: Trapezoidal wing with tail F-16: Trapezoidal wing with tail F-22: Trapezoidal wing with tail



Su-57 (T-50): Trapezoidal wing with tail



F-35: Trapezoidal wing with tail



F-104: Trapezoidal wing with T-tail



Specifications of some trapezoidal wing aircraft

| Aircraft | Aspect Ratio | Maximum Mach | | Service Ceiling | Range |
|--------------------------|--------------|--------------|---------------|-----------------|-----------------------------------|
| | | Sea level | High altitude | | |
| F-18 | 3.52 | ? | 1.8 | 50,000 ft | 2,017 km |
| F-18 Super Hornet | ? | ? | 1.8 | >50,000 ft | 2,346 km |
| F-16 | 3.2 | 1.2 | 2 | >50,000 ft | 550 km |
| F-22 | 2.1 | ? | 2.25 | >65,000 ft | 2,960 km with external fuel tanks |
| Su-57 | 2.38 | ? | 2 | 65,000 ft | 3,500 km |
| F-35 | 2.663 | ? | 1.6 | 60,000 ft | 2,200 km |
| F-104 | 2.45 | ? | 2.2 | 58,000 ft | 1,600 km |

More on trapezoidal wings

- Trapezoidal wings are mostly used by the US.
- They are nearly always combined with a conventional horizontal tail and single or twin fin.
- They are nearly always combined with LEX.
- Some trapezoidal wings look like highly cropped Delta wings (F-16 for example).
- Modern trapezoidal wings have very highly swept leading edges, approaching the sweep of Delta wings.

Sweptback wings

- Both the leading and trailing edges are swept back.
- Sweptback wings have very similar characteristics to trapezoidal wings but have larger wing area.
- Advantages:
 - Higher wing area and hence lower wing loading.
 - The centre of lift lies between that of trapezoidal and Delta wings.
 - They have the trapezoidal wing advantages compared to Delta wings.
- Disadvantages:
 - They require LEX, just like trapezoidal wings.
 - They create higher viscous drag than trapezoidal wings.

Aircraft with swept wings

MiG-29, 35: Swept wing with tail



MiG-25, 31: Swept wing with tail



Mirage F1: Swept wing with tail



Su-27, Su-35: Swept wing with tail



Su-30, Su-34: Swept wing with tail and canard



F-15: Swept wing with tail



Specifications of some swept wing aircraft

| Aircraft | Aspect Ratio | Maximum Mach | | Service Ceiling | Range |
|-----------------------|--------------|--------------|---------------|-----------------|-----------------------------------|
| | | Sea level | High altitude | | |
| MiG-29 | 3.4 | 1.21 | 2.25 | 59,100 ft | 1,430 km |
| MiG-35 | ? | 1.17 | 2.2 | 62,340 ft | 2,000 km |
| MiG-25 | 2.94 | 0.97 | 3.2 | 67,915 ft | 1,730 km |
| MiG-31 | 2.94 | 1.21 | 2.83 | 67,600 ft | 3,000 km with external fuel tanks |
| Su-27 | 3.5 | 1.13 | 2.35 | 62,523 ft | 3,530 km |
| Su-35 | 3.5 | 1.13 | 2.25 | 59,100 ft | 3,540 km |
| Su-30 | 3.5 | ? | 2.0 | 56,800 ft | 3,000 km |
| Su-34 | 3.5 | 1.2 | >1.8 | 49,200 ft | 1,100 km |
| Mirage F1 | ? | 1.2 | 2.35 | 65,600 ft | 1,400 km |
| Super Etendard | ? | 0.97 | 1.3 | 44,900 ft | 2,000 km |
| F-15 | 3.01 | 1.2 | 2.5 | 65,000 ft | 1,967 km |

More on swept wings

- Swept wings are mostly associated with the Soviet design tradition.
- The leading edges of swept wings are highly swept, more than those of previous generation trapezoidal wings.
- All aircraft with swept wings have a conventional but several modern Sukhoi fighters also have canards.
- Most of these aircraft are heavy fighters with two engines and twin fins.

Wing aspect Ratio

- Statistical data from Raymer

Jet fighters and trainers have Aspect Ratios ranging from 4 to 5.5.

Table 4.1 Aspect ratio

| Sailplane equivalent* aspect ratio = 4.464 (best L/D) ^{.69} | | |
|---|---|--------|
| Propeller aircraft | Equivalent aspect ratio | |
| Homebuilt | 6.0 | |
| General aviation—single engine | 7.6 | |
| General aviation—twin engine | 7.8 | |
| Agricultural aircraft | 7.5 | |
| Twin turboprop | 9.2 | |
| Flying boat | 8.0 | |
| Jet aircraft | Equivalent aspect Ratio = aM_{\max}^C | |
| | a | C |
| Jet trainer | 4.737 | −0.979 |
| Jet fighter (dogfighter) | 5.416 | −0.622 |
| Jet fighter (other) | 4.110 | −0.622 |
| Military cargo/bomber | 5.570 | −1.075 |
| Jet transport | 7.50 | 0 |

*Equivalent aspect ratio = wing span squared/(wing and canard areas)

Wing placement

- High-wing:
 - Stable in roll and therefore anhedral is generally required to reduce stability.
 - Affords good ground clearance for external stores/engine pods/propellers.
 - Short landing gear.
 - High wings can block upwards pilot visibility (bad for turning and climbing).
- Low-wing:
 - Unstable in roll and therefore dihedral is generally required to increase stability.
 - Very bad ground clearance for external stores/engine pods/propellers.
 - Long landing gear if external stores/engine pods/propellers are necessary.
- Mid-wing:
 - Neutral roll stability, the dihedral can be zero.
 - OK ground clearance for external stores/engine pods/propellers.
 - Short landing gear.
- NB: Sweep can have an effect similar to dihedral. According to Raymer, 10 degrees of sweep have the same effect as 1 degree of dihedral.
 - Supersonic aircraft have sweep angles up to 60 degrees, i.e. effective dihedral of up to 6 degrees.

Wing aerodynamic centre

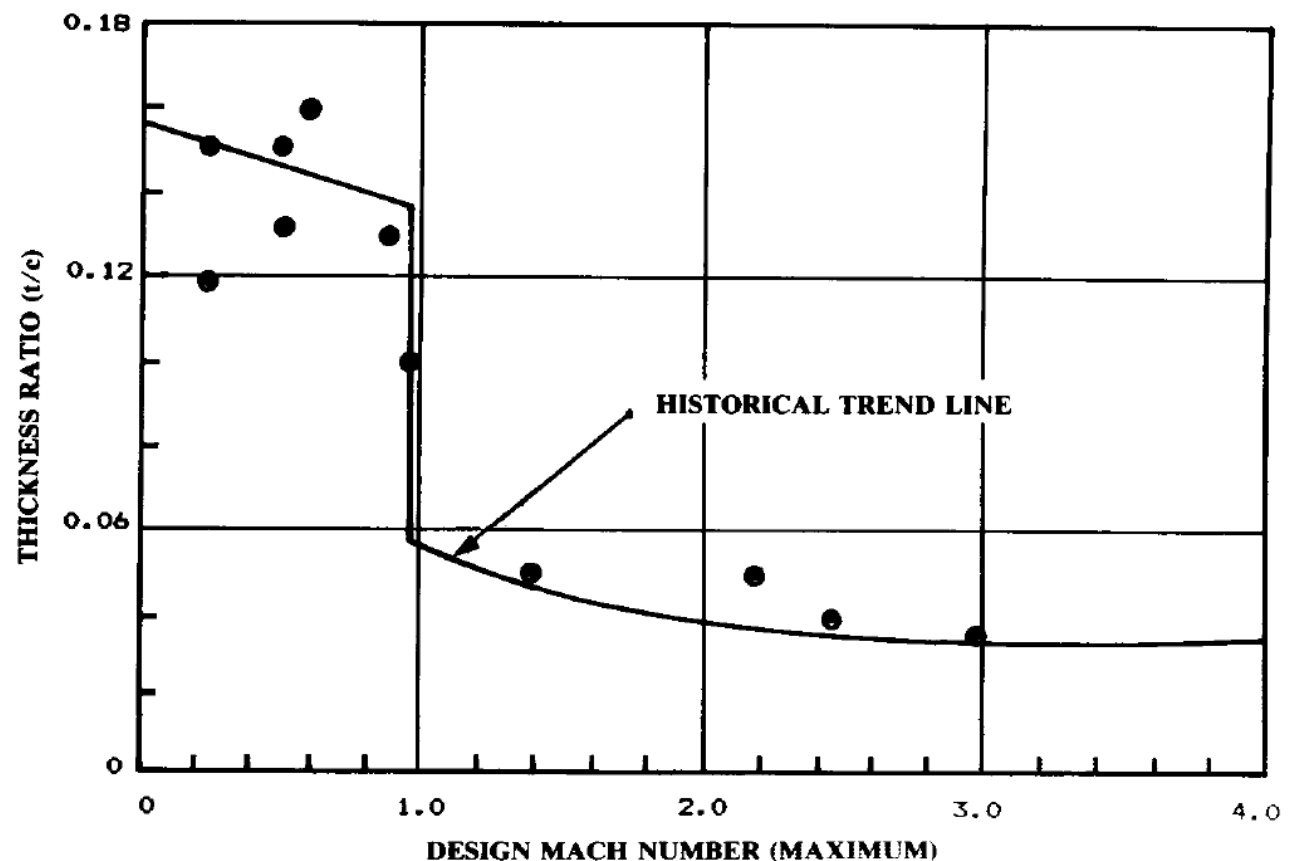
- Position of trapezoidal and swept wing aerodynamic centre:
 - Subsonic conditions: $\frac{1}{4}$ of the mean aerodynamic chord
 - Supersonic conditions: 0.4 of the mean aerodynamic chord (Raymer).
- For Delta wings, the aerodynamic centre lies at $\frac{2}{3}$ of the root chord from the apex of the wing.
 - Cropping the wing tends to move the aerodynamic centre forward
- More details:
 - J.E. Lamar and W.J. Alford, Jr., Aerodynamic-centre considerations of wings and wing-body combinations, NASA TN D-3581, October 1966
 - J.H.B Smith, J.A. Beasley and A. Stevens, Calculation of the lift slope and aerodynamic centre of cropped Delta wings at supersonic speeds, Aeronautical Research Council Current Papers, C.P. No. 562, 1961

Airfoil thickness

- Airfoil thickness ratio as a function of Mach number (from Raymer)

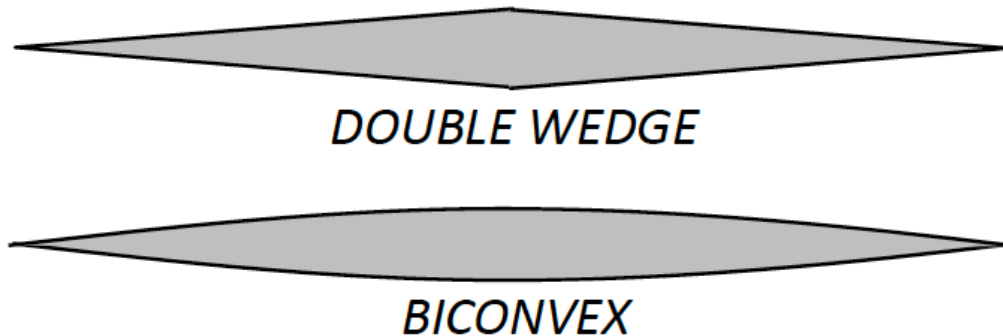
Subsonic aircraft: 12-16%

Supersonic aircraft: 4-6%



Supersonic airfoils

- Most supersonic airfoils are variations of two shapes:
 - Double wedge (or diamond)
 - Biconvex (or circular arc)



- More examples:
 - W.F. Lindsey, B.N. Daley and M.D. Humphries, The flow and force characteristics of supersonic airfoils at high subsonic speeds, NACA TN 1211, March 1947

Number of engines and intakes

- For modern aircraft, the choice of engine number is relatively simple:
 - Heavy fighter aircraft: 2 engines.
 - Light fighter aircraft and trainers: 1 engine.
- There are several possibilities for intake placement:
 - A single intake in the fuselage nose.
 - A single or double intake under the fuselage.
 - Two intakes on the side of the fuselage.
 - Above the wing for a low-wing configuration.
 - Below the wing for a high-wing configuration.
 - In front of or below the wing for a mid-wing configuration.
- Note that the inlet shape, number and placement depends not only on the engine flow requirements but also on the flight Mach number (due to shock waves).

Tail and canards

- In modern fighter aircraft both tails and canards are generally all-movable.
- There is no elevator, the entire tail (or canard) can rotate around its root axis.
- An all-movable tail is often referred to as a stabilator.



Deflected stabilator
of a F-16

Mach tuck and buzz

- Aircraft flying at high transonic and supersonic speeds experience a severe nose-down moment known as Mach tuck.
 - The aerodynamic centre of the wing moves backwards; the moment of the lift around the centre of gravity increases in the nose down direction.
 - The downwash of the wing decreases; the effective angle of attack of the tail increases and so does the tail lift.
- All-movable tails are much better at dealing with this phenomenon than fixed tails with elevators.
- If a shock wave forms on a fixed tail behind the elevator hinge it can cause elevator buzz.
 - All-movable tails can overcome this phenomenon but aileron buzz is still common in fighter aircraft at transonic conditions.

Canards

- Modern fighter canards are always all-movable and their function is pitch control only.
 - They are known as control-canards
 - In steady level flight their angle of attack is zero and, as they are symmetric, they do not create any lift.
 - They do not contribute to pitch stability, in fact their role is often to destabilize an otherwise stable aircraft.
 - As they are all-movable they cannot stall even at very high angles of attack.
 - The flight computer controls the canards, not the pilot.
- Lifting canards also exist but not for fighter applications. They may have a fixed part and they are also known as foreplanes.
- Canards also generate trailing vortices that fall on the main wing and delay stall, just like LEX.

Freeplay

- The support and actuation mechanisms for all-movable control surfaces are heavy and very expensive.
- Nearly zero freeplay is tolerated.
- MIL-A-870C(AS) Limits on total freeplay:
 - Outboard trailing edge control surfaces: 0.13°
 - Mid-board trailing edge control surfaces: 0.57°
 - Inboard trailing edge control surfaces: 1.15°
 - All-moveable control surfaces: 0.034°
 - Short tabs: 1.15°
 - Long tabs: 0.57°
 - Leading edge flaps: 0.25°
 - Wing fold: 0.25°

Fin(s)

- Fins in fighter aircraft have all the functions of fins in transport aircraft:
 - Fins ensure yaw stability.
 - Rudders can control yaw during take-off and landing.
 - Rudders can also stabilize the aircraft in the engine-out case.
- However, fighter aircraft fins have additional functions:
 - If an aircraft has double fins that are not vertical (i.e. they are canted, i.e. they lean outward or inward), the rudders can contribute to pitch control, in concert with the elevators. The rudders can deflect both in unison and in opposition (toe-in or toe-out).
 - Rudder toe-in or toe-out is also used to brake, just like airbrakes.

Rudder toe-in and toe-out

Rudder toe-in during take-off for the F-18



The horizontal tail is in the wake of the wing with flaps deflected, therefore less effective. Rudder toe-in provides additional pitch control.

Rudder toe-out in-flight for braking for the F-22



More fin(s)

- Fighter aircraft fly regularly at very high angles of attack.
 - A single fin can find itself in the wake of the fuselage at such conditions and lose effectiveness.
 - This means that single-fin fighters generally have very large fins.
- Twin fins are placed over the engines on either side of the fuselage and are therefore clear of the main fuselage wake.
 - In contrast they can find themselves in the wake of the LEX.
 - If the LEX vortices burst, the flow over twin fins can be very turbulent and cause buffeting.
- Highly canted twin fins have lower radar cross-section and are therefore stealthier.
- Twin fins also provide a certain amount of redundancy in case of battle damage.

Single vs twin fin

- In general, single fins are bigger.



F-18



Eurofighter Typhoon

Note that the Russian fighters with both tail and canards do not have canted fins. The canards+tailplane combination may be intended to play the same role in pitch control as toe-in/out+tailplane in aircraft with canted fins.

Control surfaces

- F-18
 - Stabilators (all-moveable tailplane).
 - Trailing edge flaps that operate as flaperons.
 - Leading edge flaps that can also be used during maneuvers.
 - Ailerons.
 - Rudders that can also toe in or toe out.
- F-22
 - Same as F-18.
 - Thrust vectoring (range $\pm 20^\circ$).
- All these control surfaces are not operated directly by the pilot. The flight computer operates them using pre-programmed settings, depending on the mission and on the flight condition.
- Many fighter aircraft have two different mission for which the controls must be used in a different manner:
 - Air superiority.
 - Ground attack.

Trainers/light attack aircraft

Bae Systems Hawk



Dassault/Dornier Alpha Jet



Aermacchi MB-339



Yak-130



Soko G-4 Super Galeb



PZL I-22 Iryda



Specifications of some trainer/light attack aircraft

| Aircraft | Aspect Ratio | Maximum Mach | | Service Ceiling | Range |
|----------------------|--------------|--------------|---------------|-----------------|----------|
| | | Sea level | High altitude | | |
| Alpha Jet | ? | ? | 0.8 | 50,000 ft | 2,600 km |
| Hawk | 5.3 | ? | 1.2 (dive) | 44,500 ft | 2,520 km |
| Aermacchi MB-339 | ? | 0.73 | 0.89 | 48,000 ft | 1,760 km |
| Yak-130 | ? | ? | 0.93 | 42,550 ft | 2,100 km |
| Soko G-4 Super Galeb | ? | ? | 0.9 | 42,160 ft | 1,900 km |
| PZL I-22 Iryda | ? | ? | 0.82 | 44,936 ft | 1,200 km |