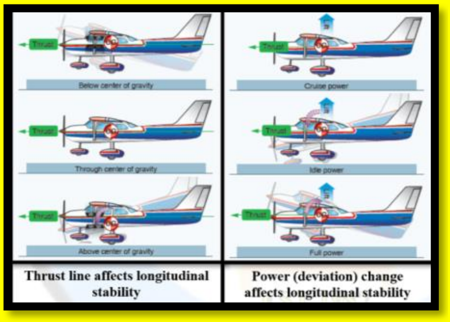
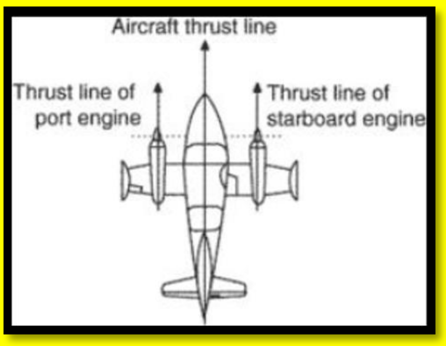
WAMASC Newsletter

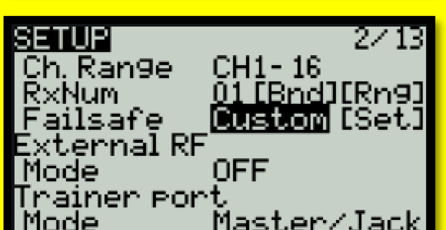
September 2020

Aircraft Thrust Lines





Failsafe



*should any individual have anything at all they would like to contribute, share or add to this newsletter, please feel free to contact the **editor** through the **Club Secretary** via ✉ **secretary@wamasc.com.au** – enjoy*

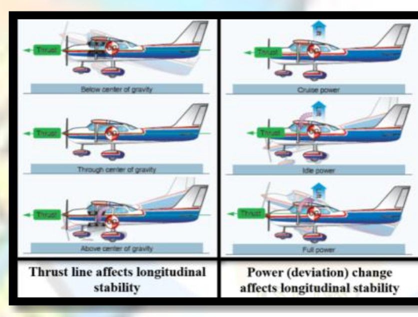
Aircraft Thrust Lines

Thrust is a reaction force described quantitatively by **Newton's third law** - simply put when a system expels or accelerates a mass in one direction, that accelerated mass will cause a force of equal magnitude but opposite in direction on that system. The force applied on a surface in a direction perpendicular or normal to the surface is also called **thrust**.

Force, and thus thrust, is measured using the **International System of Units** (SI) in **newtons** (symbol: N), and represents the amount needed to accelerate 1 kilogram of mass at the rate of 1m/Second (one metre per second). In **mechanical engineering**, force orthogonal to the main load (such as in parallel **helical gears**) is referred to as thrust.

So how does the line of thrust affect longitudinal stability in an aircraft?

One must remember that power or thrust can also have a destabilizing effect in that an increase of power may tend to make the nose rise or dip.



Aircraft designers often offset this problem by establishing a 'high thrust line' wherein the line of thrust passes above the CoG (centre of gravity). In this case, as power or thrust is increased a moment is produced to counteract the down load on the tail (empennage).

On the other hand, a very 'low thrust line' will tend to add to the nose-up effect of the horizontal tail surface.

The simple conclusion here is with the CoG forward of the CL (centre line) and with an aerodynamic tail-down force, the aircraft usually tries to return to a safe flying attitude.

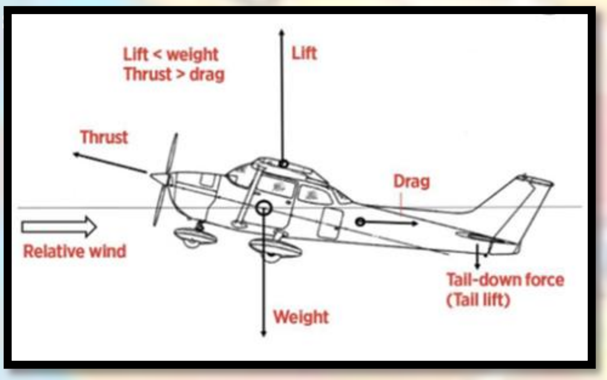
Longitudinal stability, in a broad sense, describes any- longitudinal motion. For airplanes this involves pitch or speed. (Altitude is a different axis and even a different frame, although we'll need to consider it in some cases). These are linked but different motions, and we can talk about them separately to some extent. It just happens that for most airplanes, the characteristic times of these **angular** vs **linear** motion is so different that we can very well analyse them independently.

The heavier the airplane (and/or higher its wing loading), the better it holds.

In a strict sense, when aircraft designers (but not pilots) talk about '**longitudinal stability**', they mean the short-period pitch stability, or more accurately, **angle of attack** (AoA) stability. This means that when AoA is disturbed (by a gust or control input), a moment immediately arises that counteracts this AoA change (which is done via pitch change).

The mechanism behind AoA stability involves purely aerodynamic moments/forces (this explanation involves the concepts of neutral point and moment derivatives). Notably, it does not involve thrust nor airspeed. Both of them change too slowly compared to AoA/pitch and so play practically no role in longitudinal stability per se.

The thing is that when it comes to airspeed stability, with which **pilots** are more intuitively familiar, the situation is different. Airspeed stability is linked to AoA stability via an indirect mechanism – increased thrust, increased speed, increased lift, plane rises vertically, vertical "up" pushes tail down, pitch changes.



The important result is that a statically stable aircraft will also be stable in speed. But even that holds only if drag doesn't grow faster than lift; that is, on the front side of the power curve (Pilots know it very well). At high (but pre-stall) AoA, the airplane will remain stable in AoA but will become unstable by speed. Technically, this is still speed stability, not thrust stability. We are not concerned how airspeed changed: thrust, gust, dive, whatever. A statically stable airplane will try to pitch up and climb as a response to increased airspeed, slowing down as a result.

But when we analyse speed changes as a specific result of thrust changes, other factors come into play.

Namely, apart from speed, changing thrust can disturb the moment balance of the airplane. In general, multiple effects can be important here, not only the location of line of thrust with respect to CoG, but also with respect to 'centre of drag'; and the changed slipstream may cause aerodynamic changes. Either way, it may happen that these extra moments may augment or negate the natural tendency that comes from AoA stability.

For simplicity, let's analyse a few obvious cases of reaction to increased thrust (leaving everything else unchanged, particularly trim).

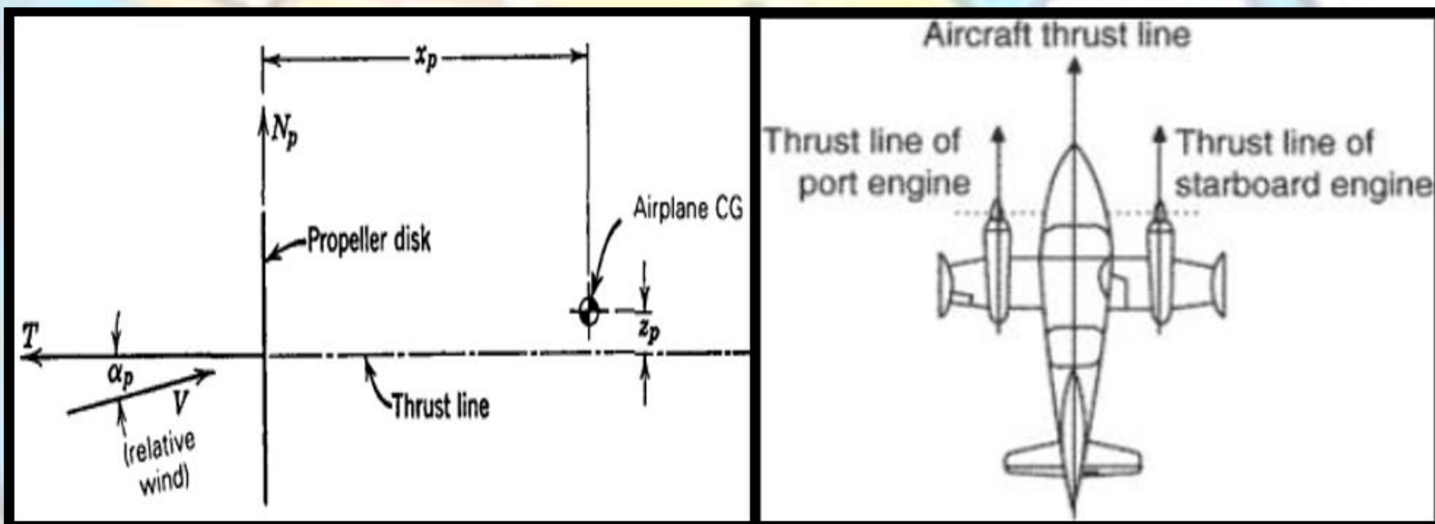
- Thrust is in line with CoG. The airplane will start to climb (or reduce descent) and will settle on the same AoA and roughly the same speed.
- Thrust line below CoG (the case of most airliners with underwing engines). This will produce an added pitch-up moment, which will cause the aircraft to slow down more than necessary, despite the added thrust! This is an unstable condition. It can be particularly nasty in go-around situations. Fortunately, unlike AoA, the changes are slow enough to react with active trim changes.

- Thrust line above CoG. This is the opposite of the above and, in moderate amounts, can have stabilising effect and easier trim changes. The airplane will settle at a higher speed, which is presumably what the pilot wants. When the line is too high, the airplane may even descend and accelerate more than necessary, until the aerodynamic moment balances out the thrust moment, but overall, the condition is stable. (**Note**: that in most cases thrust starts to fall with increased speed, which helps to find the balance).

Conclusion:

- In a strict sense, **line of thrust** (and thrust as such) does not affect **longitudinal stability** per se; that is, the **AoA stability**.
- However, it does affect **airspeed stability**, which many pilots understand as **longitudinal stability**.
- It certainly affects **trim changes**, which, again, pilots perceive as a measure of **longitudinal stability** (not entirely without reason).

The diagram below illustrates the forces from a propulsor (in this case a propeller) and its relative location to the airplane CoG. As illustrated, the thrust line is below the CoG. Therefore, as power is increased, more thrust is generated, and you get a nose-up moment.



Longitudinal stability, by the letter of the law, is defined by whether increasing elevator control force is needed to change and maintain an airspeed, and whether the aircraft returns to the same airspeed with elevator released.

From an engineering perspective, it can be expressed as a single criterion.

This expression states that, with a constant stick force, the pitching moment must be nose down when lift increases from the trim point (i.e. airspeed decreases from trim speed), and vice-versa.

Thrust to propulsive power

A common question often asked is how do you compare the thrust rating of a jet engine with the power rating of a piston engine.

Such comparison is exceedingly difficult, as these quantities are not equivalent. A piston engine does not move the aircraft by itself (the propeller does that), so piston engines are usually rated by how much power they deliver to the propeller. Except for changes in **temperature** and **air pressure** (ambient conditions), this quantity depends basically on the throttle setting.

$$\frac{\mathrm{d}m}{\mathrm{d}t} = \rho A v$$

$$\mathbf{T} = \frac{\mathrm{d}m}{\mathrm{d}t} v, \mathbf{P} = \frac{1}{2}\frac{\mathrm{d}m}{\mathrm{d}t} v^2$$

$$\mathbf{T} = \rho A v^2, \mathbf{P} = \frac{1}{2}\rho A v^3$$

$$\mathbf{P}^2 = \frac{\mathbf{T}^3}{4\rho A}$$

The **power** needed to generate **thrust** and the **force** of the thrust can be related in a non-linear way. In general, $\mathbf{P}^2 \propto \mathbf{T}^3$. The proportionality constant varies and can be solved for a uniform flow using the formula adjacent left.

Note: that these calculations are only valid for when the incoming air is accelerated from a standstill – for example when hovering. The inverse of the proportionality constant, the efficiency of an otherwise-perfect thruster, is proportional to the area of the cross section of the propelled volume of fluid (A) and the density of the fluid (*p*). This helps to explain why moving through water is easier and why aircraft have much larger have much larger propellers than watercraft. A jet engine has no propeller, so the propulsive power of a jet engine is determined from its thrust as follows:

Power

Power (P) is the force (F) it takes to move something over some distance (d) divided by the time (t) it takes to move that distance. ∴ $P = F\,{}^{d}/_{t}$

In the case of a rocket or a jet aircraft, the force is exactly the **thrust** (T) produced by the engine. If the rocket or aircraft is moving at about a constant speed, then distance divided by time is just speed, so power is thrust times speed (velocity) (v). ∴ $P = Tv$

This formula may look extremely simple and very surprising, but it is correct: the propulsive power (or power available of a jet engine increases with its speed. If the speed is zero, then the propulsive power is zero. If a jet aircraft is at full throttle but attached to a static test stand, then the jet engine produces no propulsive power, however thrust is still produced. The combination piston engine–propeller also has a propulsive power with exactly the same formula, and it will also be zero at zero speed – but that is for the engine–propeller set. The engine alone will continue to produce its rated power at a constant rate, whether the aircraft is moving or not.

Now, imagine the strong chain is broken, and the jet and the piston aircraft start to move. At low speeds:

The piston engine will have constant 100% power, and the propeller's thrust will vary with speed.

The jet engine will have constant 100% thrust, and the engine's power will vary with speed.

Excess thrust

If a powered aircraft is generating thrust (T) and experiencing drag (D), the difference between the two, T − D, is termed the **excess thrust**. The instantaneous performance of the aircraft is mostly dependent on that excess thrust. Excess thrust is a vector and is determined as the vector difference between the thrust vector and the drag vector.

Thrust axis

The **thrust axis** for an airplane is the line of action of the total thrust at any instant. It depends on the location, number, and characteristics of the jet engines or propellers. It usually differs from the **drag axis**. If so, the distance between the thrust axis and the drag axis will cause a moment that must be resisted by a change in the aerodynamic force on the horizontal stabiliser (notably, the **Boeing 737 MAX**, with its larger, lower-slung engines than previous 737 models, had a greater distance between the thrust axis and the drag axis, causing the nose to rise up in some flight regimes, necessitating a pitch-control system, MCAS – I wrote about this Manoeuvring Characteristics Augmentation System in a previous article).

The main point of all of the above is that one may very well help trim their aircraft by slightly off setting a motor or engine thus altering its thrust line(s). But be warned – the problem is that conversely should it not be correctly set-up for that aircraft, you have introduced an aerodynamic problem. This is why many model RC aircraft tend to seem to pull to one side or another. It's a little hard to perform aerobatics or pattern flying with such.

Failsafe

In the 2020 March edition of our WAMASC Newsletter I made mention and covered the topic of '**FAILSAFE**' and its **mandatory** requirement in Aeromodelling – it has also had further discussion in subsequent Newsletters prior to this edition. The term '**mandatory**' in its simplified sense means that it is compulsory, in this instance, it is law put in place by the MAAA.

Unfortunately, this requirement is still falling on deaf ears as it is not being used by all raising great concern and the need to re-visit and rehash what exactly this functionality is. The mere mention of the term '**FAILSAFE**' settings to some personnel creates a puzzled look of bewilderment and strange glances in return – many are blissfully unaware of its existence – what it exactly is – or what it even means.

The fact that all modern transmitters and/or receivers and satellites have the functionality to store failsafe positioning could be a clue.

Furthermore: should one take the time to visit the **MAAA's Manual of Procedures** and refer to **MOP 056, Safe Flying Code, Page 2, Radio Control** (*for your convenience, a hyperlink is provided for navigation to said below*: https://www.maaa.asn.au/images/pdfs/mops/MOP056-Policy-SAFE-FLYING-CODE.pdf) you will find more information on this mandatory requirement.

Although a little graphic the accompanying photograph, adjacent right, shows the aftermath of turning off a radio transmitter with the model still '**on**' and '**armed**' without **FAILSAFE** settings.

The transmitter no longer holding the throttle in the closed position suddenly allows the armed aircraft throttle servo to open to full scale deflection (full throttle) – the rest is history.

The aircraft actually climbed up his arm and attacked his face. It was a two-blade propeller and one could even forensically ascertain its pitch from the distance between cut marks should one desire.

The sad point is that all of this could have been negated during **binding** and setting failsafe parameters. With regard to safety, prevention is definitely better than the cure – especially when dealing with **electric models**. Good safety procedure and protocol should never be lacking. The potential danger due to the instant power availability when an electrical system is armed is **extreme**! Some, if not all electric motors, have the capability of causing serious injury and in extreme cases even death from major lacerations.

Now the reason for this article comes post visiting the WAMASC Field mid-week and watching an aircraft take-off toward and through the pit area after it lost bind post the pilot closing down the transmitter. Fortunately, the scenario was not one of injury and carnage, with the aircraft coming to rest after crashing into a plastic table.

The problem is that table could have been a person. Not programming **FAILSAFE** settings It's the precursor to a lot of grief. Many get away with not having Failsafe settings by turning off their model first and then their transmitter; thus, circumnavigating problematic situations. Unfortunately, should one eventually make the mistake of turning off a transmitter or lose bind then it is a disaster just waiting to happen.

Prior to arming your system - *please ensure that the aircraft is restrained and stay well clear of the propeller arc*! This safety issue is now extremely prevalent due to people not setting failsafe option(s) when **binding radio transmitter to an aircraft receiver** and should be adhered too at all times. The best-case scenario is to set all Servos at their mechanical neutral positions for flight control surfaces that have apposing deflection movement such as ailerons, rudder, and elevator. This simply means that the servo arm be centralized on the servo allowing it free 90° movement in alternate direction with the flight control surface set in the neutral position when the servo arm is centralized. The trim adjustment on your transmitter should also be set at zero (minor incremental adjustments can be made during flight with mechanical adjustment being carried out when happy with aircraft behavior).

Adjustments can be made mechanically by adjusting (lengthening or shortening) travel linkage arms to ensure the correct length of travel and position is adhered too.

Throttle, Flaps, Undercarriage and Speed-Brake servos require the full 180° length of travel and should always be bound to the correct setting (closed or idle for throttle etc.) where it will hold without transmitter assistance.

If set correctly, loss of '**bind**', will cause the aircraft to lower its MLG (Main Landing Gear) undercarriage (if fitted), reduce or cut power and set flight control surfaces at the optimum glide position(s) for a hopeful and safe return to terra firma.

In the event of loss of radio contact (signal loss or degradation (bind)) with an aircraft various functions on board the aircraft can be set to revert to desired settings - these should be set as follows:

- Internal combustion engines such as two or four stroke types should have the throttle set to idle. This immediately reduces the speed of the aircraft and can reduce damage, cut-off **is not** recommended as more often than not, radio contact can become restored and a dead stick or engine off situation doesn't follow. Jet turbines however should have the throttle set to engine cut-off in the event that the jet unfortunately meets the ground as a fire may ensue!
- Elevator should be set approximately 2-4° up from normal flight - if you are fortunate enough to be in straight and level flight configuration upon loosing connection (bind) - the aircraft will enter a gentle climb thus

increasing the time available for radio contact to be restored.

- Aileron and rudder should be left in the neutral position as the primary objective in a loss of radio contact situation is to: 1. Reduce power and thus reduce speed

  2. Begin a gentle climb, and

  3. Prevent the aircraft from rolling/turning excessively all to maximize the quantity of time available for radio contact to re-establish if possible.

This may not always save the aircraft, but it is a far safer option than not using the option when it is available.

"When once you have tasted **flight**, you will forever walk the earth with your eyes turned skyward, for there you have been, and there you will always long to return." ...