185th Fuel Management in the Climb

by FlyingStone

The F-16 as a multi role fighter contains a fairly limited fuel capacity, even with external tanks. The exception is in the late blocks with conformal fuel tanks like the IAF F-16I. Furthermore, when the F-16 is loaded with heavy external stores like bombs and drop tanks, the thrust to weight ratio decreases dramatically as altitude increases. This means that preserving fuel and maintaining efficient flight becomes a priority. Different levels of proficiency in how to maintain efficient flight can damage the integrity and co-operation of a flight, for example when a wingman falls too far back to support his lead or when he runs bingo much earlier than the rest of the flight.

The main objectives here are two things;

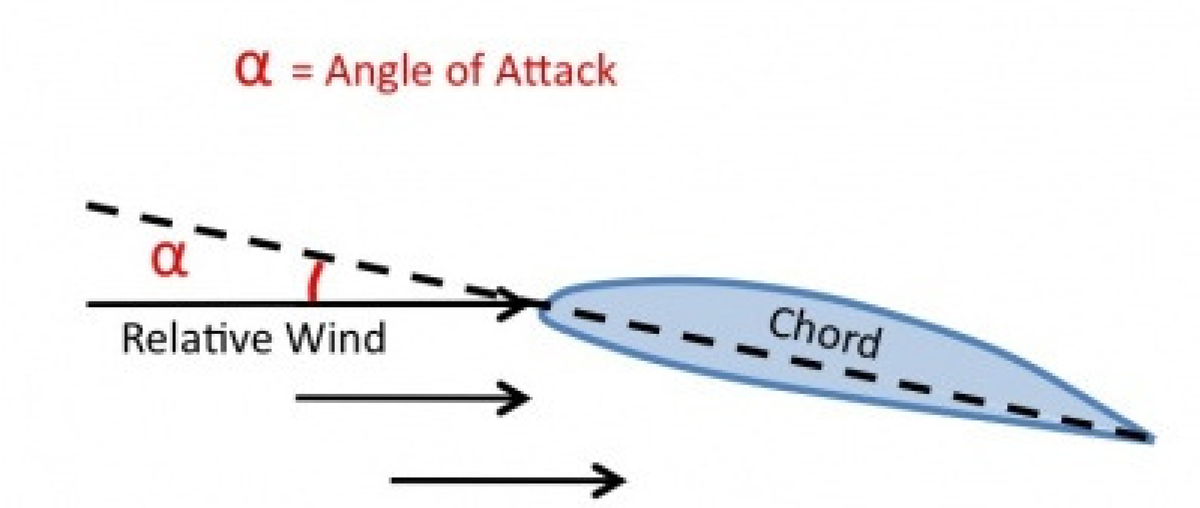
A) Avoid the need to use afterburner during the ascent and high altitude while still maintaining formation.

B) Maintaining fuel, time and energy efficient flight - these three things are actually achieved at the same time.

Why does it matter how I climb? Climbing is always an equal trade between Kinetic(speed) and potential(altitude) energy right?

Wrong!

It all has to do with one aerodynamic concept: Angle of Attack (AoA). Angle of Attack is the angle at which the wind approaches the plan of the wing, as illustrated here.



Angle of Attack can be visualized in the cockpit by looking at the HUD. The distance from your gun cross at the top of the hud to your flight path marker (FPM - the meatball) is equivalent to your angle of attack, thus if they are on top of each other, you would have 0° angle of attack.

The higher the angle of attack, the higher the drag. Drag slows you down, and impairs or prevents acceleration entirely. The higher the altitude the lower your engine output will be (due to decreasing oxygen levels) As engine output decreases drag becomes a bigger factor. Drag decreases with lower air density, with the result of high mach number at high altitude, but low airspeed (amount of air molecules passing through the pitot tube, and over the wing producing lift)

why is this relevant?
Because: (hang on now)
In order to maintain an intended velocity, for example a 5° climb, you need to keep an angle of attack higher than that to produce enough lift. The faster you are moving through the air(1) the lower an angle of attack you will need to maintain the same amount of lift.
The higher the angle of attack the more drag your aircraft will have(2).

Thus the lower the angle of attack is, the less thrust will be needed to maintain a certain speed (at a certain altitude)

(1) (airspeed, not mach)
(2) (this is not the only source of drag though, but it is a major one.).

This in practice means that if you climb at a high speed (say 450 knots) you will have a relatively low angle of attack and be able to maintain higher speeds until you reach the ceiling of the F-16.

Here comes the main point:
If you climb at low speed (say 300 knots) you will have higher angle of attack, and more drag. As your altitude increases and engine output decreases, you will start to loose speed; less speed means higher angle of attack to maintain the climb angle. If you then pitch back to maintain the climb angle you will eventually stall out, tip over and start falling. If you nose over, you will be stuck halfway to your intended flight level, at low speed, high angle of attack and unable to accelerate due to the high drag without burning large amounts of fuel in the afterburner.

Therefore it is important to maintain a good speed during ascent. This becomes increasingly important as altitude increases and engine performance decreases.
300 knots is too little, 400 knots is good, but doesn’t leave much overtake margins for the wingmen to form up and maintain formation. 350 knots is a good compromise.

So how do you do this in practice?:
1) Level out, accelerate and THEN start climbing. Always!
If you need speed and altitude, speed first, THEN altitude.

2) When you as a flight lead initiate a climb you attempt to maintain a specific climb angle and attempt to maintain a specific speed. If your speed is too high you can pitch back a little more and if it’s dropping too low you reduce the climb angle.

You need to be very proactive about this though, if you only start reducing the climb angle once your speed drops through the intended speed, it will already be too late, and you might need to **unload** to recover. I will explain this later in this document.

You should reduce the climb rate as soon as you see your speed starting to drop. If you are climbing and maintaining 350 knots you can (and should) do so at mill power (100%). You won’t need afterburner. The big thing here is that your wingman won’t need afterburner either, even though you’re at mill power.
Why is that?
Because if a wingman needs to catch up to his lead who’s climbing at 350 knots, the wingman simply needs to level out, accelerate to a higher speed, say 400 knots or more, and then start a climb to maintain 400 knots or more.
At 400 knots he will have a lower angle of attack -> lower drag -> higher speed -> higher climb rate. The difference is enough to allow him to catch up and overtake his lead, in both

altitude and speed without using afterburner at all.

For example, if you had two F-16's race to 30.000 feet, one maintaining 300 knots and one maintaining 350 the latter would get there first, and would also be way ahead. Simply because of the difference between the drag due to different angles of attack. Furthermore the latter would get there first (time efficiency) and he would get there with higher speed- Higher kinetic energy. (energy efficiency) and he would get there with more fuel (fuel efficiency) This is simply because while they are both climbing at mill power, the latter would get there earlier, and thus use less time burning fuel than the other. He would also get to higher altitude with causing lower fuel consumption earlier.

An important example here is the zoom climb that we in the 185th VFS have been using, in which we accelerate to mach 0.8 and then execute a 45 degree climb. When doing this, it is important to level out before speed drops below 300-350 knots, or you will be stuck in the aforementioned inefficient stage with insufficient power to accelerate and not enough speed to climb. The only way out is by unloading, which takes time and fuel. It is better to level out early while still at or above 350 knots and resuming a normal "slow climb". Slow but efficient. The pilot who levels out at 350 knots and 14000 ft. will in short order overtake the pilot who levels out at 18000 ft. and 250 knots.

What happens if you end up with a high angle of attack?
If you are down low it should be no problem to accelerate out of it, even without mill power, due to the high thrust/weight ratio at low altitude. However as you will most likely be at medium to high altitude you won't have the required power. Using afterburner is slow, inefficient and massively fuel consuming, and thus a terrible option.

The answer is a manoeuvre called **Unloading**.
Simply you push your stick forward enough to put your gun cross on top of the flight path marker, thereby reducing your angle of attack to 0° (or close enough anyway). To maintain it there you will need to maintain a steady pitch over forward. (This will also cause you to hit 0G, hence the term Unloading)

You do this until you are pitched down to the desired angle. You then continue a dive until your speed recovers and increases to a level at which you can resume climbing. Once back to 350 or more you pitch back again. Do not do this too aggressively or you will bleed off your newly gained energy. I usually aim for a 2.5G pull back. Be proactive and start the pull before you reach the desired speed or min altitude.

The result is that from being in an unsustainable position of high AoA, rapidly decreasing speeds and in turn a further increasing AoA, you have reduced your AoA to 0, regained speed to maintain a low AoA and resumed the climb. By resuming the climb at low AoA and therefore much more efficiently, you can easily recover the sacrificed altitude and gain much more, as well as maintaining higher speed than you had initially. At high altitudes it becomes more important to execute this manoeuvre correctly in order to gain any energy (speed and/or altitude). You can use afterburner while diving to quicken the acceleration. The fuel burned will give you much more speed at 0° AoA, (0 to 1G) than it would at high AoA and high drag. Likewise when resuming the climb. This should be judged between the need for preserving fuel versus the need to hasten the climb.

Unloading should be something a pilot does on his own initiative when he recognizes the need to be climbing at a higher speed. Typically in order to keep up with his lead. It is always better to do an unload than it is to push afterburner while still climbing. Unloading can be done to any extent the pilot deems necessary. Be it a 10 degree dive a mill power and pull back after just 2000 feet in order to gain 20 knots extra for the climb. Or if it's a 40 degree dive at full AB, diving for 6000 feet before pulling back and zoom climbing up another 10.000 ft. with the result of having gained 4000 feet. (this is an example using arbitrary numbers)

To sum up
Climbing at higher specific and maintained speed gives lower AoA -> lower drag -> higher fuel, time and energy efficiency.

It also makes it easier for wingmen to stay with the lead as they know they are aiming to maintain a specific speed.

If a pilot recognizes the need to increase his climb speed / reduce his AoA, he will Unload and resume climbing once he has regained speed and thus is able to climb at a lower AoA.

If you have any questions feel free to ask, preferably on the 185th forum.

I highly recommend everyone to try this out and notice the difference between climbing at 300 and 400 knots. Note the amount of time and fuel it took from one altitude to another while maintaining each speed, or maintaining a specific climb angle. This will be most noticeable with external stores.