Everything You Ever Wanted to Know About Vertical Navigation

Part 2 - Performance
By David Rogers

This multi-part series will attempt to de-mystify vertical navigation (VNAV) on Honeywell's Business and General Aviation avionics. Each article will reference multiple sources of regulatory information, and will provide simple, easy to follow explanations in "pilot speak".

> ***NOTE:*** *In some cases, analogies may be used to illustrate a point. While not completely accurate, they provide an example that applies to operational use.*

> ***NOTE:*** *There are operational differences between Honeywell FMS platforms (NZ, EPIC, and NG) and writing a one-size-fits-all article is nearly impossible. Therefore, the series will begin with the conventional logic used with legacy NZ FMS and EPIC FMS systems and allocate one section of the series for differences between those and NG FMS.*

> ***NOTE:*** *Because each aircraft manufacturer (OEM) has slightly different requirements and methodology for implementation, this article will thoroughly cover the principles of VNAV. There will, however, be slight variations between OEMs than what may be described below. Refer to the Honeywell Pilot's Guide for the specific aircraft flown. This document will cover the NZ and Epic architecture and show FMS calculations in magenta, even though some OEMs use cyan.*

Performance

Part two of this series on VNAV will take a closer look at performance entries and discuss each input and where the entry will impact the performance in the flight plan. Next, a typical flight profile will be disected to show which performance calculations the FMS will use, followed by a discussion of how the FMS predicts performance.

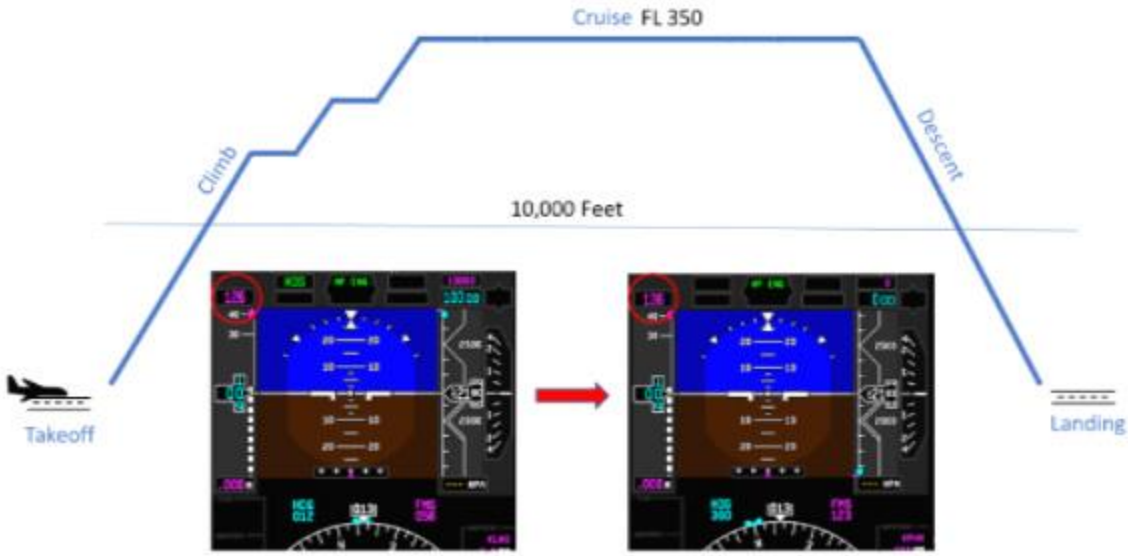
Most people know the required inputs when entering a flight plan, but there is confusion about when modes transition, which speeds will be used, and where they come from. To begin, here is a quick overview of a flight profile.

The example flight profile below encompasses takeoff to landing along with descriptions of where the FMS generates its performance information and what logic the pilot can expect during transitions. The flight begins with the airplane on ground and all initializations (PERF and TAKEOFF) are complete.

Important Notes

> *The following information is applicable to NZ and EPIC FMS only; NG FMS has a more complex VNAV solution that will be discussed in detail in part 5 of this series*
> *References to Line Select Keys LSK and FMS pages are for the NZ FMS*

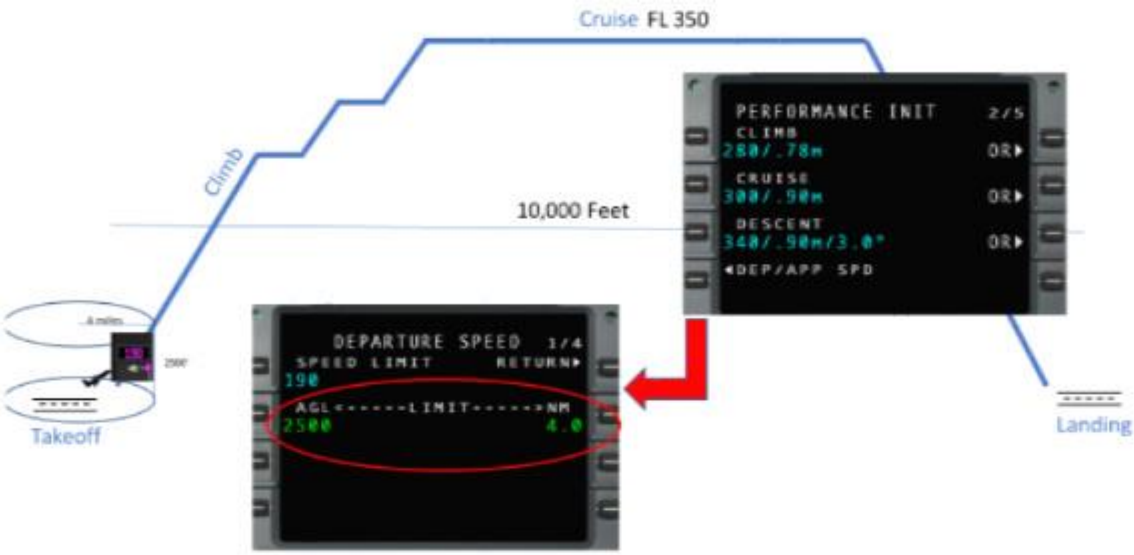
Climbs



This scenario begins with the aircraft on the runway. Takeoff speeds are computed, and the PFD should display V2 at the top of the airspeed tape. As the aircraft accelerates through V2, the speed target changes to V2+10 as long as the flaps remain in the takeoff configuration. Once the aircraft is airborne and the flaps are retracted, the FMS sequences to the departure speed (from the DEP/APP SPD page) available at LSK 4L on PERF INIT Page 2. This speed will be maintained until either the horizontal or vertical distance defined on that page is exceeded.

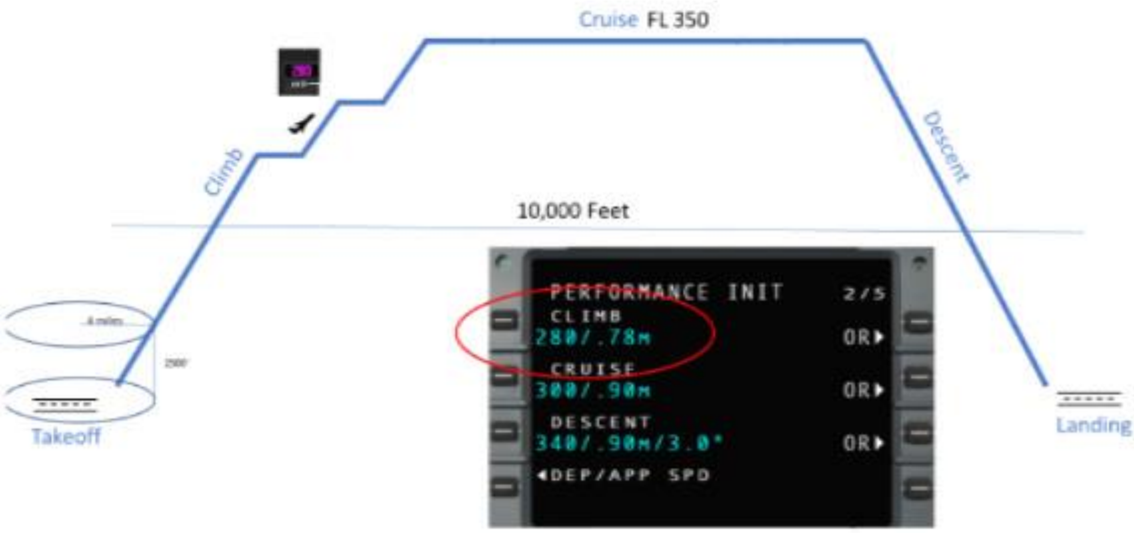
As long as the system is in VNAV for climb, it will only climb based on speed (VFLC). There are two ways this can happen:

1. On a departure with published altitude constraints (e.g. cross XYZ at or below 8,000), and in which case the preselect should be set to the top altitude, the FMS will honor the constraints that come from the database, then resume the climb automatically when the constraint is sequenced.
2. When VNAV is selected during a climb but ATC is controlling the steps (e.g.“climb and maintain 7,000”) the crew can leave the VNAV mode engaged and set the new altitude assignments with the preselect, then press the FLC button on the guidance panel to climb in VFLC. The system will stay in VNAV the entire time.



Reference the figure above. During the initial climb, the speed target will be the speed defined in the DEPARTURE SPEED page. Once the aircraft exits the Departure Speed boundaries, the next speed constraint comes from the SPD/ALT LIMIT on Perf Init Page 4 (usually set to 250/10000). This will limit the aircraft to 250 knots below 10,000 feet. For operators new to the system, it is worth mentioning that either of these values are modifiable for operating in different regions.

Passing 10,000 feet the FMS starts to bypass the SPD/ALT LIMit and accelerates to the defined climb speed. Even during intermediate level-offs before cruise altitude is reached, the FMS will stay at climb speed. It is extremely important to mention that if the crew levels off at an altitude lower than the initialized cruise altitude, they must manually go back into the Perf Init settings and update the cruise altitude to the lower value. Otherwise, the system will stay in climb mode, assuming there is another climb coming. This can cause problems when descent constraints are entered, as the FMS will not honor them in climb mode.



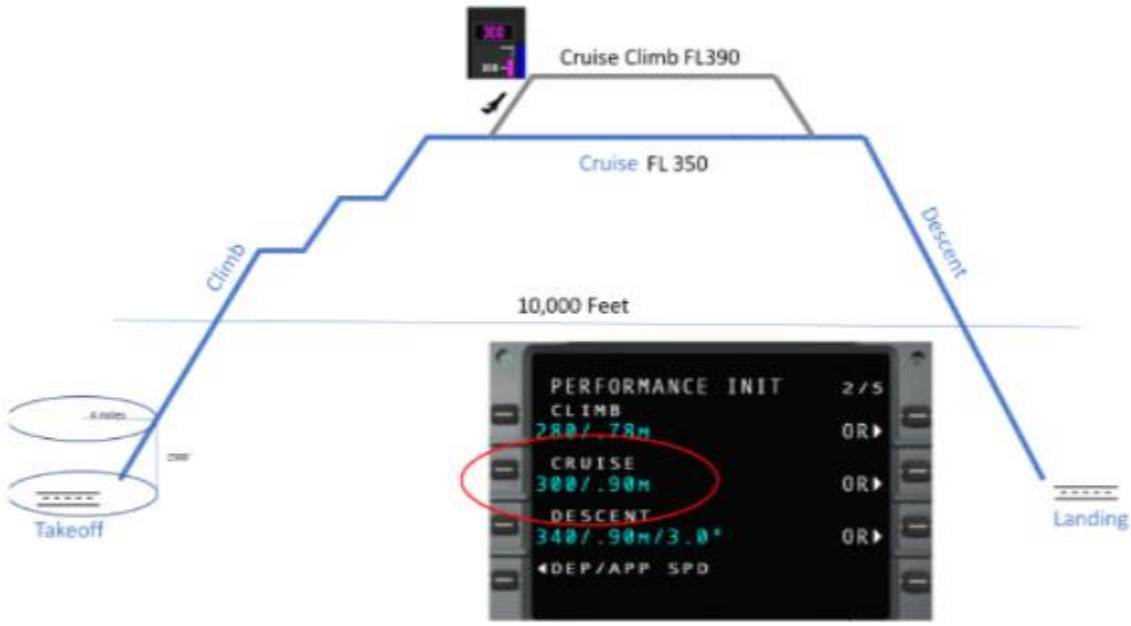
It's worth repeating that throughout the intermediate level-offs prior to reaching cruise, the system will remain in climb mode and will only use climb speeds until the altitude entered for cruise is met or exceeded. Once the INITial CRZ ALT is reached, the system will enter cruise mode. If a higher altitude is desired, the system will automatically adjust to the higher cruise altitude accordingly without the need to reset the CRZ ALT. Cruise climbs will be addressed in the next section.

Cruise

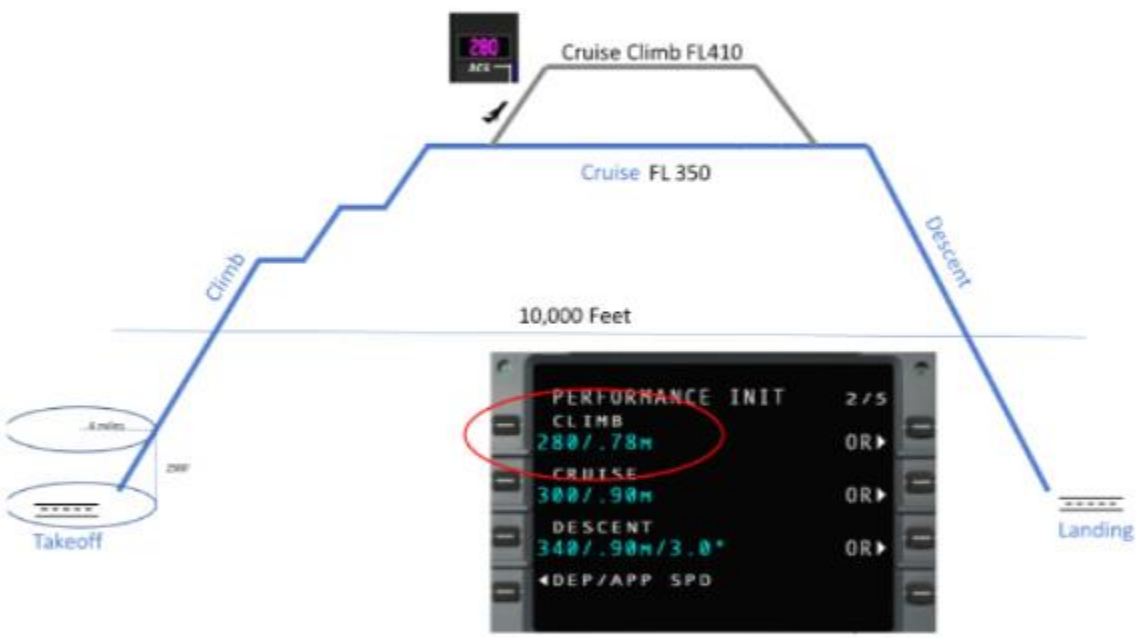
The cruise phase is the segment that starts at the completion of the climb phase and ends at the beginning of the descent phase. When computing the vertical portion of the flight plan, the FMS builds the descent profile from the destination field elevation. It will incorporate any altitude constraints, whether pilot-defined or from the nav database. It also computes the climb phase similarly. Once Top of Climb and Top of Descent points are calculated, the two are connected to establish the cruise segment.

Cruise Climbs

Once the aircraft reaches the cruise altitude as entered in the Performance Initialization, the speed schedule will change from climb to cruise speed, and the FMS will enter the cruise phase of flight. It will remain in cruise until the aircraft begins the descent phase or the crew elects to climb to a higher altitude. If climbing, the speed used for the cruise climb depends on the altitude selected. If the aircraft altitude change is 5000 feet or less, the aircraft will climb at the cruise speed. If the altitude change is more than 5000 feet, the FMS will command the speed back to the climb speed.



Cruise Climb Less Than 5000 Feet

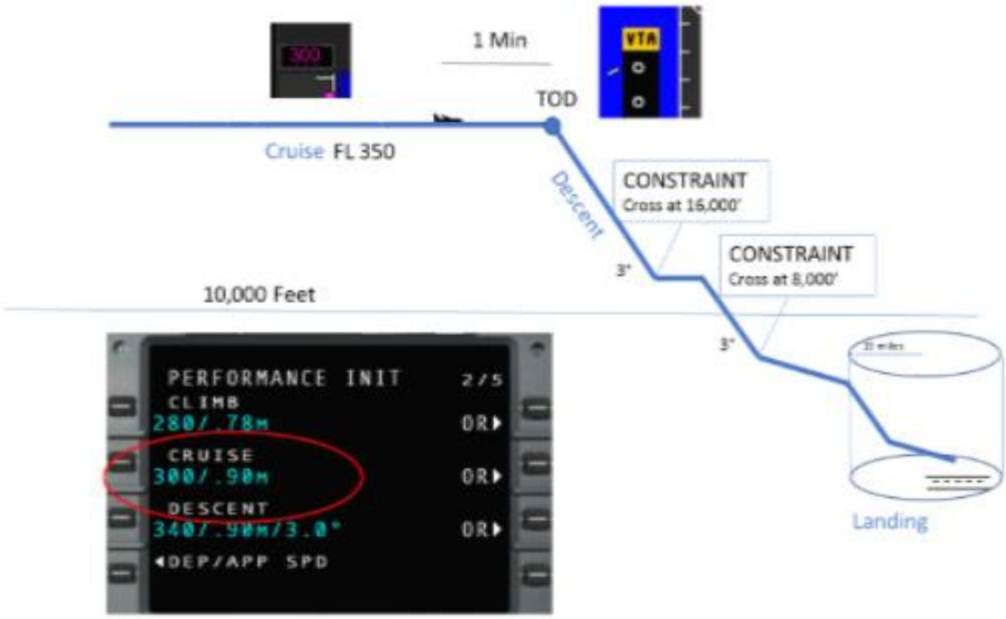


Cruise Climb More Than 5000 Feet

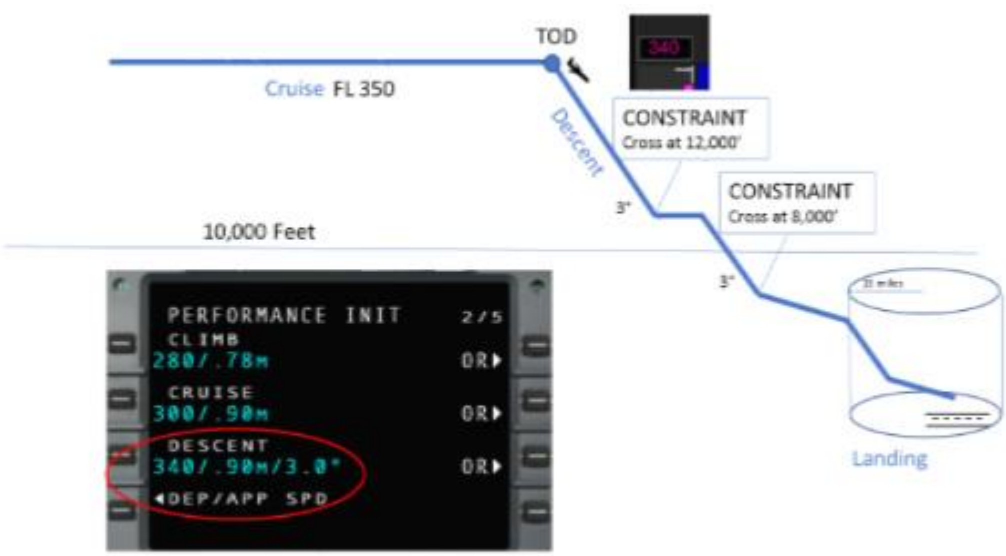
Descents

The descent phase typically begins with the Top of Descent (TOD) point as calculated by the FMS. The TOD is the intersection of the cruise altitude and a line from the highest descent constraint based on the FMS defined descent angle (typically 3 degrees).

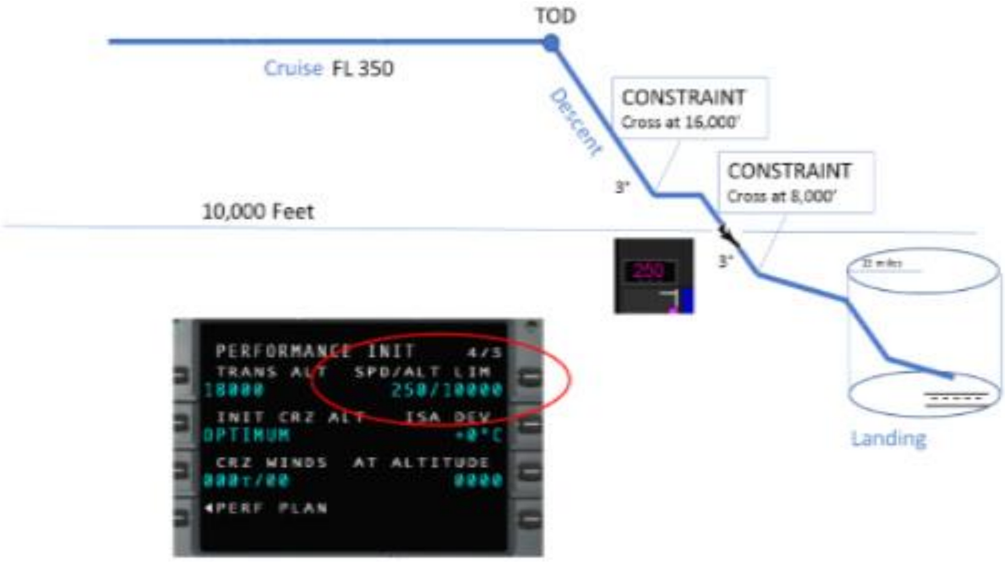
The descent phase can be initiated from several scenarios. The common requirement for each is that the altitude preselect must be set to a new altitude below the cruise altitude. Like the climb mode, the descent mode is flown based on descent speeds. The primary difference is, if there is a calculated glide path, the FMS will couple to it after providing an aural and visual notification called a vertical track alert (VTA). Then, it will depict the vertical path (VPATH) on the Primary Flight Display that will meet the constraints in the descent portion of the flight plan.



The FMS is now in descent mode using the entered IAS/Mach and angle for the descent portion of the flight. All of the settings are modifiable from the PERF INIT page shown below. While a 3 degree descent angle is the most common entry, many operators (especially those operating aircraft with lower drag coefficients) tend to use a shallower angle to help eliminate the energy build up. Once the aircraft begins its descent, it remains in descent mode, regardless of level-offs or smoothing adjustments, until it reaches the speed altitude limit and the approach speed volume.



An important note before continuing: the aircraft will enter a deceleration segment prior to reaching the speed constraint altitude. This allows the airplane to dissipate energy and cross the limit altitude at or close to the target speed. If the aircraft is descending through 10,000 at a speed higher than 250, it will show an FMS generated AT constraint on the PFD of 10,000 feet even though it will not appear in the flight plan. This is to notify the crew that the FMS intends to level off at 10,000 in order to disipate energy before continuing down. This could result in the system abandoning VPATH and potentially missing a crossing restriction. The airplane will remain at 250 until it reaches the “approach service volume” described next.



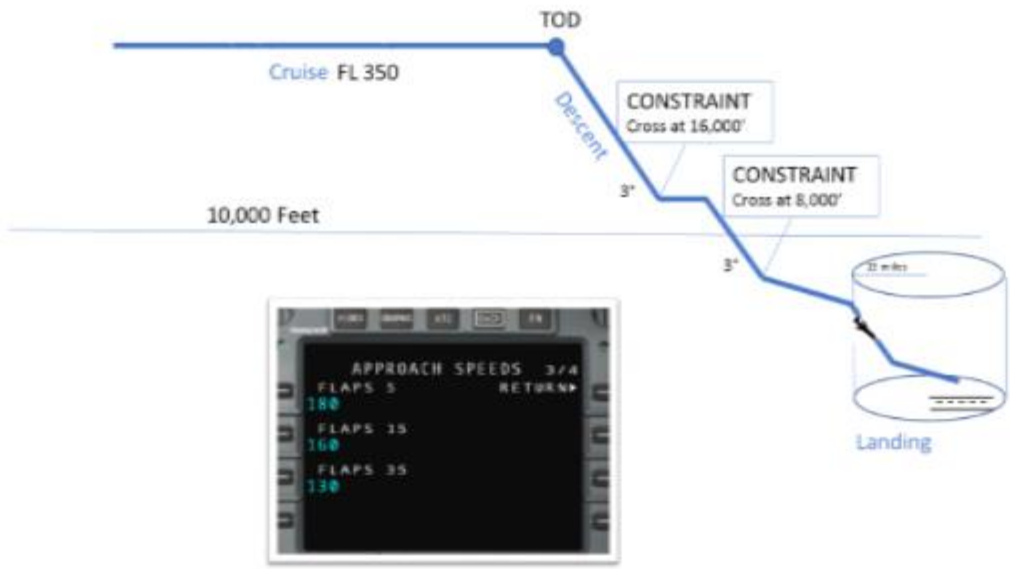
Approach Service Volume

Finally, the aircraft is below 10,000 feet. The final VNAV segment is referred to as the Approach Service Volume and is defined on the APPROACH SPEED page shown below (accessed from the DEP/APP SPD line select at the bottom of PERF INIT page 2).

Page 2 (APPROACH SPEED) defines approach volume in terms of miles-to-destination at which time the aircraft begins to slow to the approach speed. Pages 3 and 4 (APPROACH SPEEDS and GO-AROUND SPEEDS) contain speed inputs for approach and go-around configurations once the approach volume has been entered. These can be modified, and once they are entered are held through power cycles.

Once the aircraft enters the approach service volume, it will begin slowing to the clean configuration speed shown on the Approach Speed page. After that, each time a flap configuration is changed, the speed will change accordingly until the airplane is fully configured. It will continue to maintain the final flap setting speed plus any margins specified by the OEM (i.e. VREF+5).

Go-around speeds work the same way but in reverse of the process just described. In the case of a go around, the airplane will transition with a push of the TOGA button and will begin to accelerate accordingly with the reduction of flaps during the missed approach procedure.



Speed Protection

The last item of discussion related to PATH descents is speed protection. The FMS provides two types of speed protections: Automatic Speed Reversion (transition from VPATH to VFLC) and Latched Speed Protection.

During PATH descents, PATH control is primary, whereas speed control is secondary. If the PATH becomes too steep, the aircraft may continue to accelerate above the target speed. When this happens, the message INCREASED DRAG REQUIRED is displayed in the scratchpad. If the speed continues to increase above the MMO/VMO, the FMS transitions to speed reversion and will abandon the PATH in order to not overspeed the airframe limitation. This may cause the FMS to miss an altitude costraint.

The second speed protection mode is Latched Speed Protection. The FMS enters Latched Speed Mode during transitions from one VNAV submode to another in an effort to prevent uncomfortable vertical maneuvers. As an example, on the NZ FMS, the Bottom of Descent (BOD) occurs at the last altitude constraint in the flight plan. If any legs exist beyond this point, LNAV/VNAV operation is allowed to continue but not in VPATH mode. The latched speed mode is entered when the transition from VPATH to VFLC is more than 5 knots below the target speed. At this point the system will revert to VFLC and latch the speed target to prevent unwanted pitch maneuvers. When latched speed is active, the FMS displays the word LATCHED on the active flight plan.

This concludes part two of the series on VNAV performance through the flight profiles. Part three will look at more advanced VNAV topics such as Optimized Profile Descents, crossing constraints off airway, and climbing/descending via SIDs and STARs. Part 4 will go into detail on VNAV usage for various approach types and terminology, including creating vertical guidance for visual approaches. Finally, the series will conclude with some of the changes that were implemented with the Next Generation (NG) FMS architecture.

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