# Title

AT and AT or ABOVE Waypoint Speed Constraints

# Background

Industry initiatives brought about changes/additions to RTCA DO-236C RNP MASPS which may require functional changes/additions to the flight management computer system (FMS). This proposal addresses those updates in the RNP MASPS that related to AT and AT or ABOVE waypoint speed constraints.

# Describe What Is Needed

Historically, all speed constraints in the navigation database and entered by the crew were treated as AT or BELOW speed constraints. DO-236C mandated support for an AT and AT or ABOVE speed constraint capability (§3.2.8.2), and the ARINC 424 source now includes a speed descriptor field with each waypoint speed constraint. While the RNP MASPS define a minimal set of requirements, they do not provide any guidance in terms of what takes precedence when an ABOVE speed constraint conflicts with the speed schedule, airport speed limit, ICAO limit, or other waypoint speed constraints. Clarification is needed to ensure sufficient understanding and standardization across aircraft when designing and flying navigation procedures with AT and AT or ABOVE speed constraints.

# Recommended Changes

## 4.3.3.2.2.6 Speed and Altitude Restrictions

* Original text

Speed and altitude restrictions encountered in the climb should be observed by

the vertical function to prevent the aircraft from accelerating or ascending

beyond those restriction values until the associated restriction has been passed.

At this point, the next restriction (if any) should become the limiting case.

Restrictions encountered in descent should be handled similarly except that in

the case of speed restrictions, sufficient deceleration distance must be provided

in order to achieve the restrictive speed prior to passing the associated

restriction.

* Updated text

## 4.3.3.2.2.6 Altitude Constraints

The system should allow insertion of AT, AT or ABOVE, AT or BELOW, and both AT or ABOVE and AT or BELOW (WINDOW) altitude constraints at waypoints in the flight plan. Waypoint altitude constraints may be inserted directly via crew entry or indirectly via selection of a procedure in the navigation database. The system should allow for entry and modification of WINDOW altitude constraints.

*Historically, crew entry and modification of WINDOW altitude constraints was not possible on some systems. On such systems, WINDOW constraints could only be inserted via selection of a navigation database procedure. Per RTCA DO-236, the system should support crew entry of each type of altitude constraint.*

The system should avoid automatic deletion of altitude constraints above cruise altitude.

*Upon cruise altitude modification or procedure insertion, some systems will automatically delete altitude constraints that are above cruise altitude. This design has lead to airline and ATC complaints as it is susceptible to order of operation and situational awareness issues. System designs where altitude constraints are retained and ignored and/or where altitude constraints are retained and the cruise altitude modified are preferable.*

The system should designate altitude constraints as either CLIMB constraints or DESCENT constraints. The system should designate an altitude constraint on a waypoint in the departure or missed approach procedure as a CLIMB constraint. The system should designate an altitude constraint on a waypoint in the arrival or approach procedure as a DESCENT constraint.

*The system may incorporate additional rules to designate an altitude constraint as either a CLIMB or DESCENT constraint when the constraint is on a waypoint which is not part of a procedure listed above.*

They system should apply CLIMB constraints to the takeoff and climb phases of flight in accordance with Table 4.3.3.2.2.6-1 below. The system should apply DESCENT constraints to the descent and approach phases of flight in accordance with Table 4.3.3.2.2.6-1 below.

|  |  |  |
| --- | --- | --- |
| Altitude Constraint Type | Altitude Constraint Phase/Applicability | |
| CLIMB | DESCENT |
| AT or BELOW | Do not exceed PRIOR to and AT | Do not exceed AT and AFTER |
| AT or ABOVE | Do not go below AT and AFTER | Do not go below PRIOR to and AT |
| AT | Do not exceed PRIOR to, cross AT, do not go below AFTER | Do not go below PRIOR to, cross AT, do not exceed AFTER |
| WINDOW | Do not exceed upper bound PRIOR to and AT  Do not go below lower bound AT and AFTER | Do not exceed upper bound AT and AFTER  Do not go below lower bound PRIOR to and AT |

Table 4.3.3.2.2.6‑1 Altitude Constraint Applicability

*PRIOR to, AFTER, and AT in Table 4.3.3.2.2.6-1 refer to sequence of the waypoint with the altitude constraint.*

*The descent path is typically constructed using a series of straight line segments. For waypoints with a descent AT constraint, the descent path will typically cross at the specified altitude. When flown using the Vertical Guidance function, some systems may cross above or below the altitude constraint value due to a vertical fly-by transition. RTCA DO-236 defines the acceptable altitude deviation for a vertical fly-by transition.*

The Vertical Guidance function of the system should prevent the aircraft, when in takeoff or climb and under vertical guidance control, from ascending through the upper bound of a climb AT, AT or BELOW, or WINDOW altitude constraint. Likewise, it should prevent the aircraft, when in descent or approach and under vertical guidance control, from descending through the lower bound of a descent AT, AT or ABOVE, or WINDOW altitude constraint. Aside from altitude captures, it should be a basic philosophy that the Vertical Guidance function should never descend in takeoff or climb flight phase in order to satisfy an altitude constraint; likewise, it should never ascend in descent or approach in order to satisfy an altitude constraint. When the system detects that the aircraft is in violation to an altitude constraint or will be unable to satisfy an altitude constraint within a given tolerance due to insufficient climb or descent rate, the system should provide an appropriate indication(s) to the crew.

*In takeoff or climb, upon engagement or insertion of a flight plan with an altitude constraint below the aircraft, the Vertical Guidance function may find the aircraft is in violation to (i.e. above) a downstream AT/BELOW altitude constraint. Some systems will prevent engagement of the Vertical Guidance function into an altitude constraint violation while others allow engagement into a violation. Some systems prevent engagement and disengage when a violation occurs while the Vertical Guidance function is engaged. On those systems where Vertical Guidance can engage or be engaged in a violation condition, some will provide an indication and level-off to minimize the violation of the altitude constraint whereas others will provide an indication and maintain a climbing attitude. An analogous situation exists in descent for AT/ABOVE altitude constraints.*

When under vertical guidance control and in violation to the lower bound of a descent AT, AT or ABOVE, or WINDOW altitude constraint and, the Vertical Guidance function should level-off to minimize the violation of the altitude constraint as the constraint may exist for obstacle clearance.

*Refer to the Predictions and Vertical Path Construction sections of this document for more details regarding use of altitude constraints in the vertical trajectories.*

*Upon procedure selection, most systems combine common waypoints between departure, arrival, and/or approach segments. In rare situations, the altitude constraint coded in one procedure differs from the altitude constraint coded in the other procedure (e.g. STAR and APPROACH). <Advice>*

## 4.3.3.2.2.7 Speed Restrictions

The system should allow insertion of AT, AT or ABOVE, and AT or BELOW speed constraints at waypoints in the flight plan. Waypoint speed constraints may be inserted directly via crew entry or indirectly via selection of a procedure in the navigation database.

The system should designate speed constraints as either CLIMB constraints or DESCENT constraints. The system should designate a speed constraint on a waypoint in the departure or missed approach procedure as a CLIMB constraint. The system should designate a speed constraint on a waypoint in the arrival or approach procedure as a DESCENT constraint.

*The system may incorporate additional rules to designate an altitude constraint as either a CLIMB or DESCENT constraint when the constraint is on a waypoint which is not part of a procedure listed above.*

The system should apply CLIMB constraints to the takeoff and climb phases of flight in accordance with Table 4.3.3.2.2.6-2 below. The system should apply DESCENT constraints to the descent and approach phases of flight in accordance with Table 4.3.3.2.2.6-2 below.

|  |  |  |
| --- | --- | --- |
| Speed Constraint Type | Speed Constraint Phase/Applicability | |
| CLIMB | DESCENT |
| AT or BELOW | Do not exceed PRIOR to and AT | Do not exceed AT and AFTER |
| AT or ABOVE | Do not go below AT and AFTER | Do not go below PRIOR to and AT |
| AT | Do not exceed PRIOR to, cross AT, do not go below AFTER | Do not go below PRIOR to, cross AT, do not exceed AFTER |

Table 4.3.3.2.2.7‑2 Speed Constraint Applicability

*PRIOR to, AFTER, and AT in Table 4.3.3.2.2.6-2 refer to sequence of the waypoint with the altitude constraint.*

In accordance with Table 4.3.3.2.2.6-2 above, the system should apply ABOVE climb speed constraints after sequence of the speed constraint waypoint until transition to the climb MACH or transition to cruise flight phase. The system should apply ABOVE descent speed constraints upon transition to the descent CAS (from the cruise flight phase or descent MACH) until sequence of the speed constraint waypoint.

*BELOW constraints may be applied in cruise flight phase in accordance with* Table 4.3.3.2.2.6-2 above*. This is recommended for missed approach and low(er) cruise altitude scenarios where the aircraft may encounter procedural waypoint speed constraints while in cruise.*

The system should support altitude-based speed limits such as airport speed limits (e.g. 250/10000) and ICAO limits for procedure legs. For airport speed limits and other limits which apply to a region or block of airspace, the aircraft airspeed should remain AT or BELOW the speed limit while the aircraft is below the specified altitude. For ICAO limits, the aircraft should remain AT or BELOW the speed limit while the aircraft is both flying the procedure leg and below the specified altitude.

In the case of descent AT and AT or BELOW restrictions, sufficient deceleration distance should be provided in order to cross the speed restriction at or below the restriction speed. Once the descent speed restriction has been sequenced, it should be latched such that the descent target speed does not exceed the restriction speed unless the crew deletes the latched speed restriction or the aircraft transitions back to climb flight phase.

In general, the system should compute the target speed at any given point in the flight plan as the speed schedule limited to the lowest AT/BELOW of applicable speed restrictions. This target speed should always be limited to the speed envelope (e.g. VMO, MMO, stall, buffet, and placard limits) of the aircraft for the given or assumed aeroconfiguration. The Vertical Guidance function of the system should accelerate or decelerate as necessary to capture and track the limited target speed. When the system detects that the aircraft is in violation to a speed constraint or will be unable to satisfy a speed constraint within a given tolerance, the system should provide an appropriate indication(s) to the crew.

*Historically, all speed constraints in the navigation database and entered by the crew were treated as AT or BELOW speed constraints by the flight management system. Indeed, most of the optimizations performed by the flight management system were accomplished using speed schedules optimized for some criteria (e.g. fuel, time, cost, maximum angle/rate); the goal of the flight management system was to reach the optimum speed with speed restrictions preventing it from doing so. RTCA DO-236 mandated support for an AT and AT or ABOVE speed constraint capability, and the ARINC 424 source now includes a speed descriptor field with each waypoint speed constraint. While DO-236 defines a minimal set of requirements, it does not provide guidance in terms of what takes precedence when an ABOVE speed constraint conflicts with the speed schedule and other speed constraints and limits. To ensure a measure of interopability as this capability is incorporated into flight management systems, the following requirements and guidance are offered.*

When in conflict, the system should always give priority to altitude-based speed limits over waypoint-based speed constraints.

*Altitude-based limits are AT or BELOW speed limits which may be lower than a preceding AT or ABOVE climb waypoint speed constraints and/or subsequent AT or ABOVE descent waypoint speed constraint. In such cases, the altitude-based limit(s) should take priority. Airport speed limits are in place to ensure safety with slower moving VFR traffic while ICAO limits ensure aircraft remain within the designated airspace.*

When in conflict, the system should give priority to BELOW speed constraints over ABOVE speed constraints.

*In descent, a deceleration point should occur prior to an ABOVE speed constraint if necessary in order to ensure a safe, continuous deceleration to the landing speed. Moreover, altitude-based limits are BELOW speed constraints which are associated with airspace limitations.*

*The figures below illustrate various conflicts and the speed profiles that result given the rules in this section.*

*For the descent scenario illustrated in Figure 4.3.3.2.2.6‑4, an alternative is to insert a speed discontinuity into the theoretical descent profile (at AAA) and provide appropriate indications to the crew. This is deemed less preferable as it may lead to unrealistic deceleration assumptions which are only apparent once the ABOVE speed constraint is sequenced. Moreover, in the absence of special considerations, insertion of a speed discontinuity creates an inherent ETA error and may cause poor guidance behavior as the theoretical speed profile is often used as a reference for advisories and mode reversion logic.*



Figure 4.3.3.2.2.7‑1 250/10000 takes priority over 260 ABOVE at AAA (climb)



Figure 4.3.3.2.2.7‑2 250 BELOW at BBB takes priority over 260 ABOVE at AAA (climb)



Figure 4.3.3.2.2.6‑3: 250 BELOW at AAA takes priority over 260 ABOVE at BBB (descent)



Figure 4.3.3.2.2.6‑4: Decel to 240 BELOW AT BBB takes priority over 270 ABOVE at AAA (descent)

In general, in the absence of edits and tactical speed interventions, the system should produce a speed profile that is monotonic during a single phase of flight. For takeoff and climb, the speed target should continuously increase until reaching the climb speed schedule. For descent and approach, the speed target should continuously decrease from the descent speed schedule until reaching the landing speed. As such, the system should compute a climb speed schedule which is the maximum of the optimal climb speed and the highest ABOVE climb speed constraint; the system should compute a descent speed schedule which is the maximum of the optimal descent speed and the highest ABOVE descent speed constraint. This limitation should be applied to both the speed schedule CAS and MACH (when applicable).

*Without the MACH limitation, a higher ABOVE speed constraint will produce a lower crossover altitude at which point the ABOVE speed constraint will cease to apply. For this reason, it is suggested that the MACH equivalent of the ABOVE speed constraint evaluated at 25000 feet be used as the lower limit MACH value. This ensures that ABOVE speeds are maintained until at least 25000’ for most aircraft.*

*Obstacle clearance should take priority over ABOVE speed constraints.*

The system should not apply ABOVE speed constraints to hold speed schedules.

*Please refer to the Predictions and Vertical Path Construction sections of this document for more details regarding use of speed restricdtions in the vertical trajectories.*

# Information Sources

DO-236C, ICAO RNP Manual Doc. 9613