

A CO₂ versus noise trade-off study for the evaluation of current air traffic departure procedures

A case study at Gothenburg Landvetter Airport, Sweden

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Abstract — This paper considers, for the first time, the environmental effects of Air Traffic Management speed constraints during the departure phase of flight. We present a CO₂ versus noise trade-off study that compares aircraft departures subject to speed constraints with a Free Speed scenario. A departure route at Gothenburg Landvetter Airport in Sweden is used as a case study and the analysis is based on airline flight recorded data extracted from the Airbus A321 aircraft.

Results suggest that CO₂ emissions could be reduced by 180 kg per flight for a high-density configuration A321 operating in the upper region of the maximum operational take-off mass if departure speed constraints were removed. This decrease in CO₂ emissions is countered by an increase in the maximum A-weighted noise exposure below 70 dB(A). The relevance of these speed constraints is discussed and potential solutions for removing them are presented.

Keywords-aviation; departures; environment; CO₂; noise.

I. INTRODUCTION

The growing concern about CO₂ emissions as a catalyst for climate change has generated increased awareness about the contribution from aviation. It is predicted that aviation is responsible for 2-3% of all anthropogenic CO₂ emissions [1]. The SESAR target for 2020 is to enable 10% fuel savings per flight as a result of Air Traffic Management (ATM) improvements alone, leading to a 10% reduction of CO₂ emissions per flight [2].

The arrival and departure phases of flight have been identified as key areas where substantial reductions in CO₂ emissions could be enabled via improvements to existing ATM procedures and regulations [3]. To date considerable effort has been invested in designing more environmentally friendly arrival procedures with the introduction of continuous descents and Required Navigation Performance (RNP) curved approaches [4]. For example, the SESAR VINGA project has demonstrated up to 100 kg of fuel savings from improvements to arrival procedures. In contrast, the departure phase has received little attention.

The ATM procedures applied to aircraft during the departure phase of flight are commonly based on recommendations in the ICAO procedure design manual, PANS-OPS, Document 8168 [5]. However, some of these procedures are based on the performance characteristics of an older generation of aircraft and may be penalising modern, state-of-the-art aircraft, such as the Airbus A321. An example of such a procedure is the turn-related speed constraint applied to a Standard Instrument Departure route (SID) containing a sharp turn in the low altitude region. The speed constraint is recommended to ensure primary area containment within the Controlled Airspace (CAS), as well as flyability of the nominal track. The severity of the speed constraint is dependent upon the track change of the turn, altitude, assumed meteorological conditions, maximum allowed bank angle of the aircraft in the design and flight technical tolerances. It is fair to say that the total operational performance envelope of the aircraft is seldom used, thus generating a situation where the full benefit of the aircraft performance is not used.

The effect of applying speed constraints during the early departure phase is to force the aircraft to climb in an unclean aerodynamic configuration with flaps and slats extended instead of accelerating to an optimum climb speed. This increases the overall aerodynamic drag of the aircraft and thus the fuel consumed and CO₂ emitted during the departure phase. It is thus desirable from an environmental perspective to minimise the use of speed constraints.

Until recently, minimising the noise exposure to local communities has been the primary environmental objective when designing ATM departure procedures [6]. This has led to the design of SIDs that create minimum noise disturbance, but that are very fuel-inefficient.

An integral part of a paradigm shift in ATM must be to assess the trade-off between anthropogenic CO₂ emissions and noise exposure for departure procedures. It is the aim of this paper to evaluate these trade-offs and identify measures that are able to reduce CO₂ and other harmful emissions.

This paper considers, for the first time, the effects of ATM speed constraints on aircraft CO₂ emissions during the departure phase of flight. The analysis is based on real flight data and uses the airframe manufacturer's software to compute aircraft performance and noise emissions during the climb-out. Five departure scenarios are considered based on real ATM procedures, where different speed constraints are applied. The trade-off between CO₂ emissions and noise exposure associated with each speed constraint is assessed. The TOPLA 1M SID route at Gothenburg Landvetter Airport in Sweden has been used as a case study.

II. DEPARTURE PROCEDURES AT GOTHENBURG LANDVETTER AIRPORT

Gothenburg Landvetter (ICAO airport code ESGG) is a medium size airport on the west coast of Sweden. It is the second largest airport in Sweden (after Stockholm Arlanda) and has an average of 220 movements per day. The airport has a 3300 m single runway, which may be operated as Runway 03 or 21 depending on the prevailing wind direction.

Several of the SIDs at ESGG have been designed with sharp low-altitude turns either to avoid overflying noise-sensitive areas or because the active runway direction is non-preferential for the required route. These SIDs carry a speed constraint of 210 Knots Indicated Air Speed (KIAS), which is applied until the aircraft has cleared the turn.

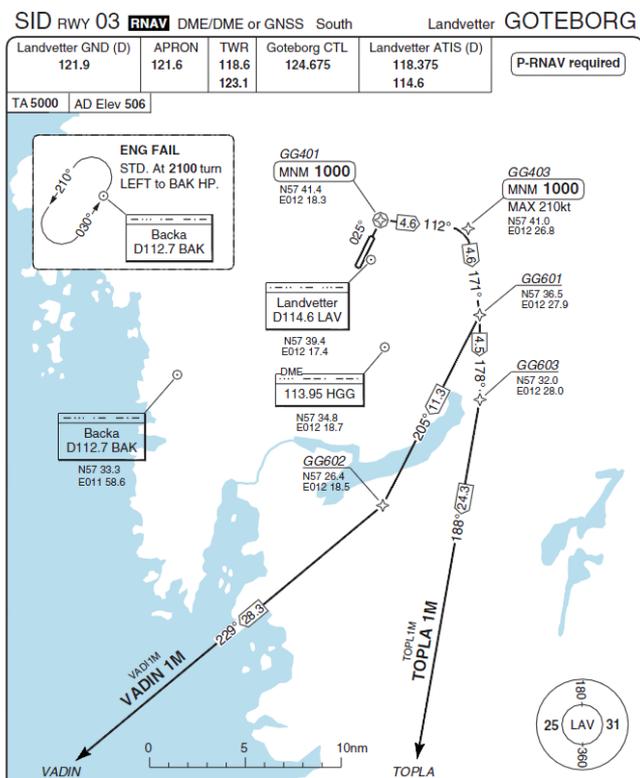


Figure 1. Published southern RNAV SIDs from Runway 03 at ESGG. Copyright European Aeronautical Group (Navtech).

Fig. 1 shows the published southern SIDs for Runway 03 [7] at ESGG for aircraft equipped with Area

Navigation (RNAV) capability. The TOPLA 1M SID shown is an example of a SID carrying a turn-related speed constraint of 210 KIAS. The TOPLA 1M SID contains a straight segment for 2.1 NM followed by a sharp right turn of 87° and then a second right turn past the waypoint GGG403. A 210 KIAS speed constraint applies until the aircraft has passed waypoint GGG403 and is established on the 171° track; this is approximately 10 Nautical Miles (NM) from the start of take-off roll.

III. AIRCRAFT PERFORMANCE AND NOISE MODELLING

Aircraft flight data was provided by the Scandinavian airline operator, Novair, for an Airbus A321-231 aircraft with V2533-A5 engines that departed along the TOPLA 1M SID. Data was extracted from the onboard Flight Data Recorder (FDR). The flight data contained information about the aircraft's position, altitude, speed, engine rotational speed, fuel flow and flap settings, updated eight times per second for the duration of the flight. In addition, Take-Off Data Calculation (TODC) information was provided by the airline, which contained information about the characteristic take-off parameters and the meteorological conditions.

A sample flight was selected that departed on a typical Scandinavian winter day with a mass in the upper region of the Maximum Take-Off Mass (MTOM) for an A321. This flight is considered to represent a worst case scenario with respect to noise exposure for an A321 departing with TOGA thrust due to the reduced climb rate achieved by a heavy-loaded aircraft. The initial conditions for the sample flight are summarised in Table I.

TABLE I. INITIAL CONDITIONS FOR SAMPLE NOVAIR A321 FLIGHT.

Take-off parameter	Value
Take-off Mass	85 500 kg
Outside Air Temperature	0°C
Barometric Pressure adjusted to sea level pressure (QNH)	1008 mb
Aircraft rotate speed (V_R)	168 KIAS
Aircraft initial safe climb speed (V_2)	175 KIAS
Thrust setting	Take-Off Go-Around (TOGA)
Air conditioning	Off
Engine Anti-Ice	On

The Airbus Performance Engineer's Program (PEP) was used for all aircraft simulations described in this study. The PEP suite of software consists of several modules dedicated to the computation of aircraft performance during different flight phases. The performance calculations are based on Airbus aircraft databases. The Operational Flight Path (OFP) tool within PEP was used to simulate the flight described in Table 1. OFP is designed to compute operational trajectories as well as flight paths specifically designed for noise analysis. It uses information about the aircraft take-off configuration (e.g.

mass, flap and slat settings, thrust selected), environmental conditions (wind, temperature, pressure and runway conditions) and vertical climb profile as inputs. OFP also allows the lateral path followed by the aircraft to be defined (i.e. the SID layout), accounting for any turns in the track.

Fig. 2 shows the fit of the Airbus PEP model (blue line) to the sample flight data (green line) for the entire climb phase. The residuals plot beneath shows an average error of only 100 ft comparing the PEP model to the flight data. This demonstrates the capability of the Airbus PEP software to accurately replicate a real flight.

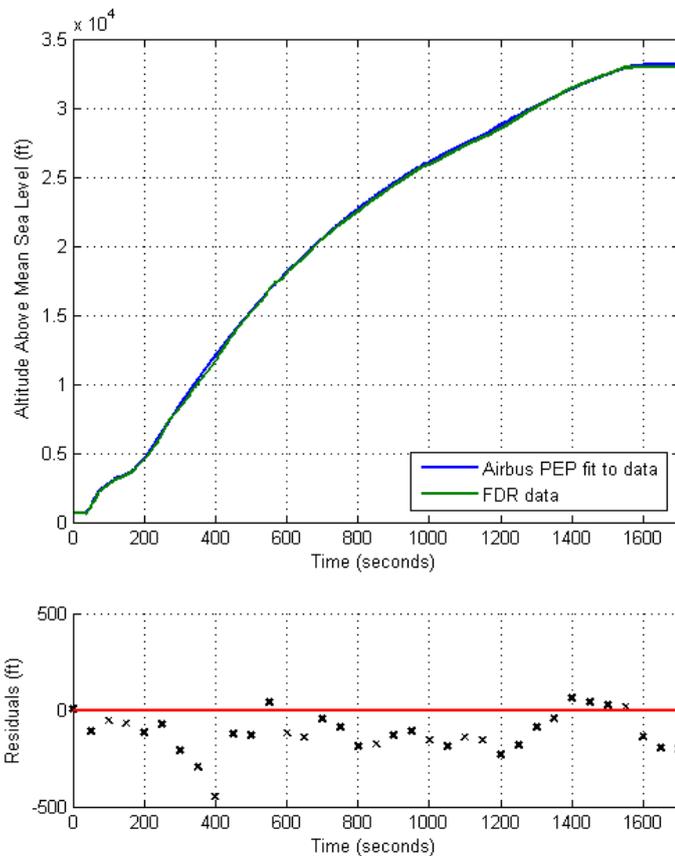


Figure 2. Airbus PEP model fit (blue line) to aircraft flight data (green line) for sample Novair A321 climb profile.

Once a real flight has been modeled, it is possible to use the PEP program to make deviations from the actual flight, for example, change speed or altitude constraints applied and assess the effect on the fuel consumption.

The Airbus Noise Level Calculation program (NLC) within PEP was used to predict the noise exposure from the A321 aircraft for each departure procedure modelled. NLC was used to calculate the aircraft noise emissions at specific points along the departure trajectory and also calculate iso-level noise contours.

The noise metric selected for the analysis was the maximum instantaneous A-Weighted noise level, L_{Amax}. This

is the noise in decibels weighted to the response of the human ear. L_{Amax} is the noise metric used by the Swedish Environmental Agency as guidance for ATM procedure development.

IV. SPEED CONSTRAINT SCENARIOS

The effect of varying and completely removing the 210 KIAS speed constraint along the TOPLA 1M SID was investigated. The sample Novair A321 flight modeled with the Airbus PEP program (described in Section III) was used as a basis for the study.

Five scenarios were considered, each based on a real ATM departure procedure where different levels of speed constraint apply. Each scenario was applied to the PEP model of the sample Novair A321 aircraft (Fig. 2). The five scenarios are described below:

1. A speed constraint of 205 KIAS is applied to a ground distance of 10 NM. The aircraft must climb with flaps and slats extended until reaching 10 NM. This scenario simulates the speed constraint used on the TROSA 4L SID at Stockholm Arlanda Airport [8].
2. A speed constraint of 210 KIAS is applied to a ground distance of 10 NM (speed constraint applied on TOPLA 1M today). Due to the high mass of the aircraft, it must climb with flaps and slats extended until reaching 10 NM.
3. A speed constraint of 220 KIAS is applied to a ground distance of 10 NM. The aircraft retracts flaps at 210 KIAS, but must climb with slats extended until reaching 10 NM. This scenario simulates the speed constraint used on the RESNA 4G SID at Stockholm Arlanda Airport [9].
4. No turn-related speed constraint is applied. The standard 250 KIAS speed constraint is applied until the aircraft reaches Flight Level (FL) 100 (10,000 ft above Mean Sea Level). Due to the mass of the aircraft, flaps and slats are retracted at 210 KIAS and 220 KIAS, respectively. This is the standard departure procedure for a SID with no additional turn-related speed constraints.
5. No speed constraints apply during the climb phase, which simulates when a 'Free Speed' instruction is granted by Air Traffic Control (ATC). Free Speed removes the 250 KIAS speed constraint below FL 100. Free Speed is regularly granted by ATC at ESGG during quiet periods. The aircraft accelerates to a climb speed of 304 KIAS, which is based on the selected Cost Index of the mission, inserted in the aircraft Flight Management Guidance System (FMGS).

Note that in scenarios 1, 2 and 3 described above, the turn-related speed constraints were applied to a ground distance of 10 NM to simulate the speed constraint distance on the TOPLA 1M SID (see Fig. 1).

In each scenario the total aircraft fuel consumption was calculated to a radius of 200 NM from the airport, which incorporates the entire climb phase and a short segment of cruise. A similar methodology has been used to calculate aircraft fuel consumption in a study by [10]. Fig. 3 shows the geographical extent of the 200 NM radius centred on ESGG and the trajectory of the aircraft is shown in red. The total CO₂ emitted for each scenario was derived using the linear relationship between fuel usage and CO₂ emissions, where 1 kg of JET A1 fuel corresponds to 3.16 kg of CO₂ [11].

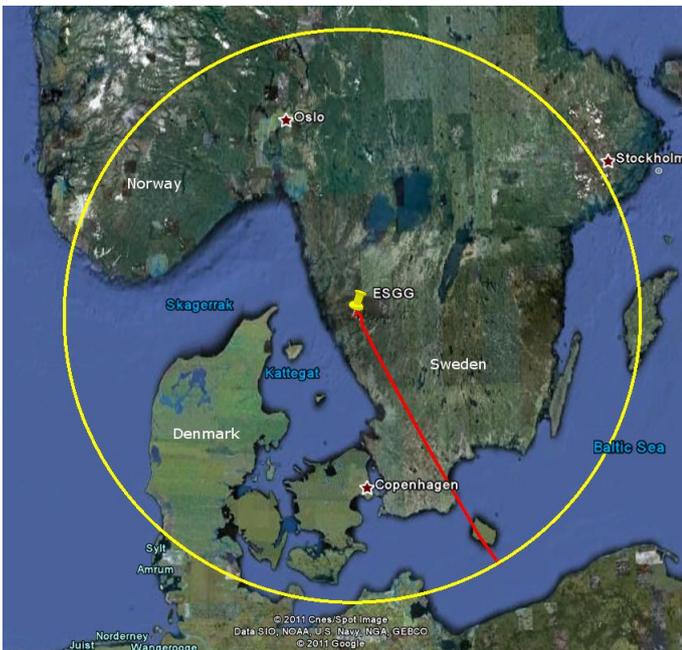


Figure 3. Geographical extent of 200 NM radius centred on ESGG. The real flight path of the Novair A321 aircraft is shown in red.

V. RESULTS

A. Altitude and speed profiles of speed constraint scenarios

Figs. 4a and 4b show the aircraft altitude Above Ground Level (AGL) and Indicated Airspeed (IAS) as a function of ground distance, respectively, for each of the five speed constraint scenarios described in Section IV. Note that ground distance is referenced from the start of take-off roll.

Figs. 4a and 4b reveal that the climb and speed profiles of the scenarios are identical until the aircraft reach a ground distance of 5 NM and an altitude of 2300 ft AGL. After this distance the aircraft profiles start to diverge. This suggests that removing the current 210 KIAS speed constraint will not affect the noise or CO₂ emissions within the first 5 NM of the flight.

The aircraft which is restricted to 205 KIAS until reaching a ground distance of 10 NM attains the highest altitude

between 5 NM and 12 NM compared to the four other cases. The aircraft which are restricted to 210 KIAS and 220 KIAS until 10 NM have similar profiles, with the latter scenario achieving the best altitude gain per unit distance between 6 NM and 10 NM.

The 250 KIAS to FL 100 and Free Speed scenarios exhibit identical climb and speed profiles until reaching a ground distance of 7 NM and an altitude of 2800 ft AGL. At this point the aircraft restricted to 250 KIAS must continue to climb with a constant IAS until reaching FL 100 and thus all available excess energy is used for climbing. In contrast the aircraft able to carry out a Free Speed profile continues to accelerate to a climb speed of 304 KIAS (selected by the FMGS), which it attains at approximately 12 NM and 4100 ft AGL. The altitude gained by the Free Speed aircraft is limited due to a prolonged acceleration phase and thus this aircraft remains at the lowest altitude during the entire climb phase in relation to the traversed distance.

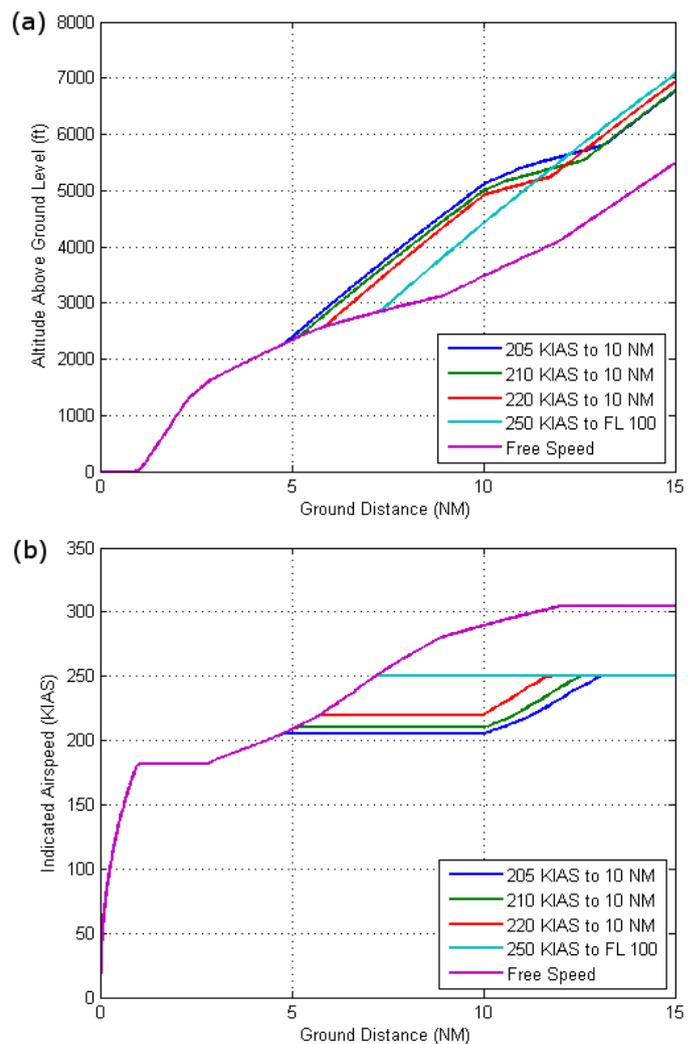


Figure 4. Profiles for five speed constraint scenarios showing (a) Altitude Above Ground Level as a function of ground distance and (b) Indicated Airspeed as a function of ground distance.

B. Noise characteristics of speed constraint scenarios

Although the turn-related speed constraints described in Section IV are not primarily used for noise abatement purposes, the locations of the turns in the SIDs are typically close to noise-sensitive areas. This means that any increase in perceived noise from removing the speed constraints would need to be well understood before departure procedures could be changed.

Note that decibel scale is logarithmic, so that an increase of 3 dB(A) represents a doubling of sound intensity; however, due to the human hearing response, an increase in sound pressure level of 10 dB(A) will be perceived as a doubling of 'loudness'. For reference, 60 dB(A) is the sound level of conversational speech at a distance of 1 m and 70 dB(A) is the sound level of traffic on a busy road at a distance of 25 m.

Fig. 5 shows the L_{Amax} as a function of ground distance for each of the five speed constraint scenarios described in Section IV. The noise is calculated at a height of 1.2 m above ground level directly under the track of the aircraft, in accordance with ICAO international aircraft noise certification standards [12].

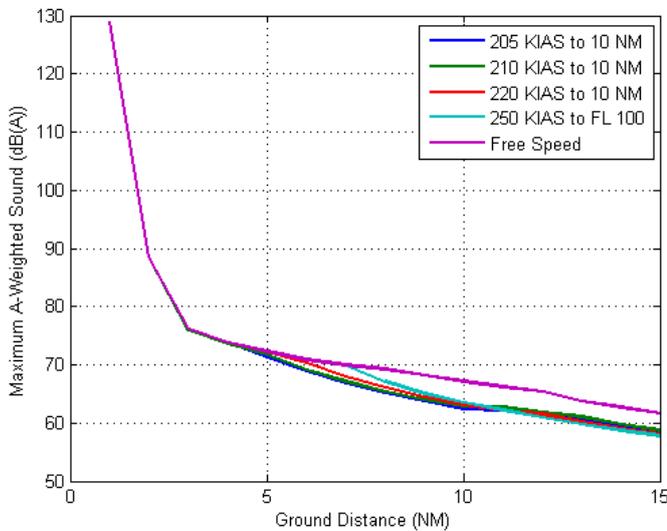


Figure 5. Maximum A-Weighted Noise as a function of ground distance for five speed constraint scenarios.

As expected from inspection of Figs. 4a and 4b, the noise profiles for all five scenarios are identical until the aircraft reach a ground distance of approximately 5 NM. Fig. 5 reveals that, at ground distances greater than approximately 7 NM, the aircraft following a Free Speed profile has the highest associated L_{Amax}. The higher L_{Amax} values associated with the Free Speed scenario can be explained by the climb profile of the aircraft (Figure 4a); at ground distances greater than 9 NM, the aircraft is at least 1000 ft closer to the ground compared with all other scenarios, thus producing the greatest noise exposure.

The 205 KIAS and 210 KIAS to 10 NM speed constraint scenarios exhibit very similar noise profiles with less than

1 dB(A) difference at any given distance. These scenarios have the lowest associated L_{Amax} directly under the flight path at ground distances between 5 NM and 10 NM. The 250 KIAS to FL 100 scenario has the lowest associated L_{Amax} directly under the flight path at ground distances between 11 NM and 15 NM.

Fig. 6 shows the L_{Amax} directly under the flight path as a function of altitude AGL for each speed constraint scenario. It reveals that the noise curves for each speed constraint scenario are almost identical. The aircraft noise produced is thus directly dependent on altitude regardless of the speed profile of the aircraft (if initial conditions are the same). For example, an aircraft restricted to flying at 205 KIAS until a ground distance of 10 NM produces approximately the same L_{Amax} at 5000 ft as an aircraft flying a Free Speed profile [~62 dB(A)].

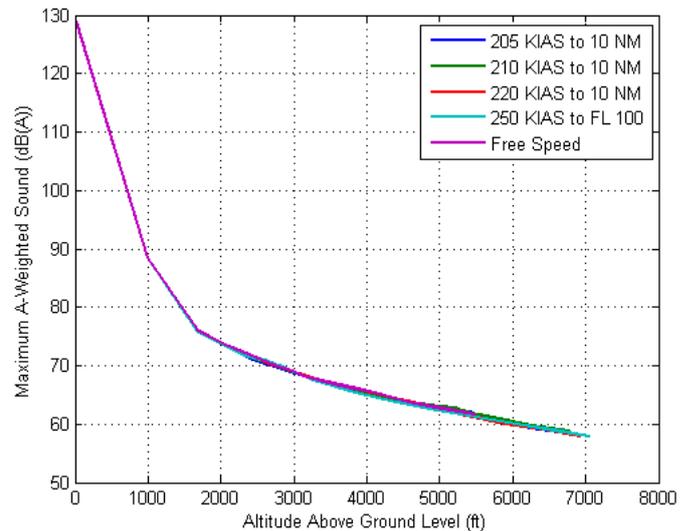


Figure 6. Maximum A-Weighted Noise as a function of altitude for five speed constraint scenarios.

Fig. 7 shows the L_{Amax} noise contours along the TOPLA 1M SID for the five speed constraint scenarios described in Section IV. Contour levels are shown at 75 dB(A), 70 dB(A), 65 dB(A) and 60 dB(A). The SID centerline is shown in red and the positions of the waypoints are marked. Table II lists the surface area in km² covered by the L_{Amax} noise contours for each speed constraint scenario.

TABLE II. SURFACE AREA CONTAINED BY L_{Amax} NOISE CONTOURS FOR FIVE SPEED CONSTRAINT SCENARIOS.

Speed constraint scenario	Surface area of L _{Amax} noise contours (km ²)			
	75 dB(A)	70 dB(A)	65 dB(A)	60 dB(A)
205 KIAS to 10 NM	7.09	14.86	31.90	74.93
210 KIAS to 10 NM	7.09	14.99	32.04	75.01
220 KIAS to 10 NM	7.09	15.36	34.16	74.27
250 KIAS to FL 100	7.09	15.09	35.49	73.08
Free Speed	7.09	15.08	42.47	93.31

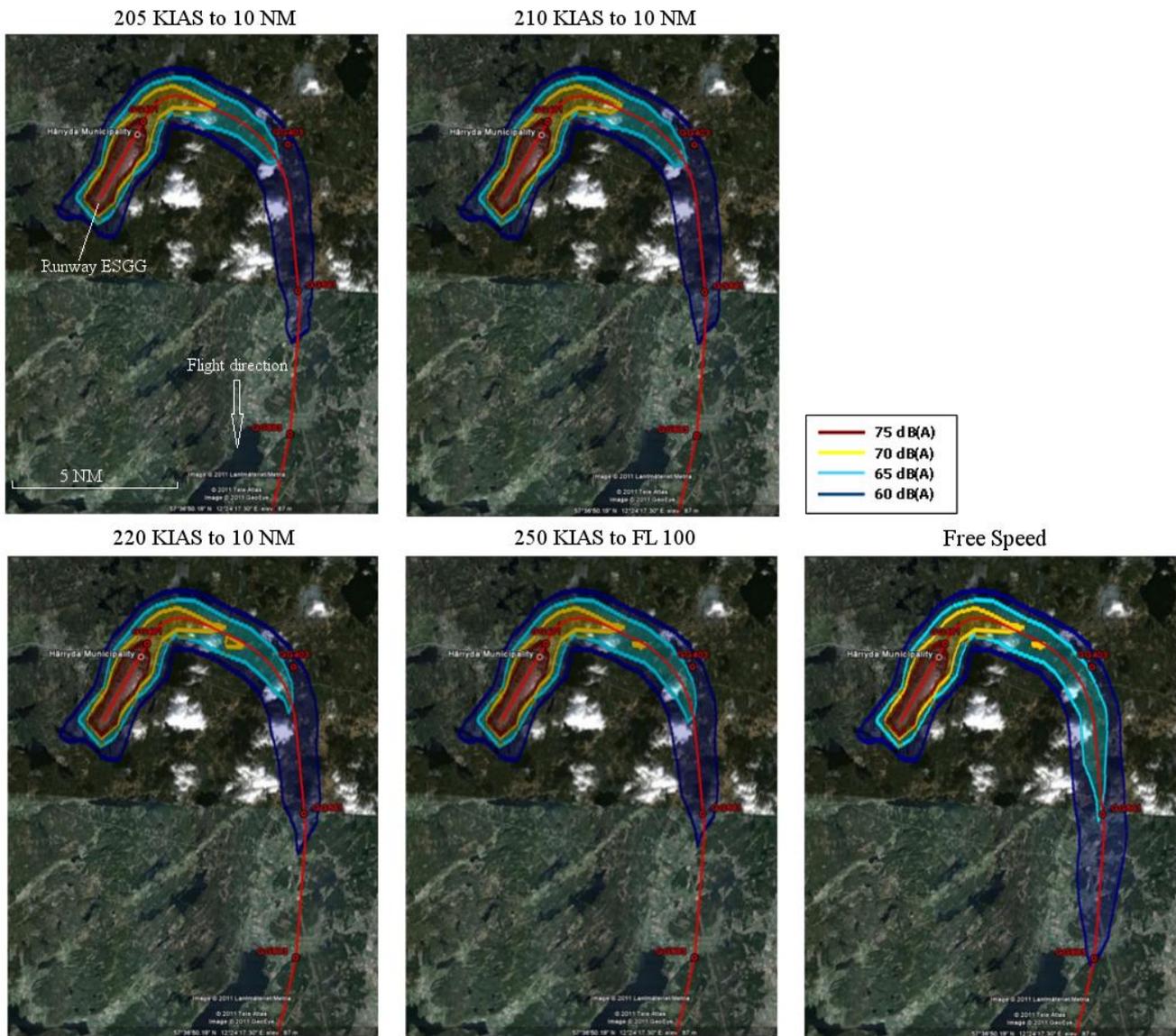


Figure 7. Geographical representation of the TOPLA 1M SID (shown in red with virtual waypoints indicated) with LAmox noise contours overlaid for five speed constraint scenarios. Contours are at levels of 75 dB(A), 70 dB(A), 65 dB(A) and 60 dB(A).

A comparison of the 75 dB(A) LAmox noise contours in Fig. 7 and Table II reveals that the contour covers the same surface area in each speed constraint scenario. Inspection of Fig. 6 shows that the aircraft creates 75 dB(A) LAmox at approximately 1800 ft AGL and Figure 4a reveals that this altitude is reached before the climb profiles for the scenarios diverge. Therefore, removing the existing 210 KIAS speed constraint would not increase the geographical area subject to an LAmox of 75 dB(A) if the rate of climb during the first acceleration phase was in the order of 1000 ft per minute (observed to be a typical climb rate from the airline data). Changes to this rate of climb would of course change the vertical climb profile and thus the noise distribution.

Comparison of the 70 dB(A) LAmox noise contours in Fig. 7 reveal that they are very similar for each scenario and

Table II shows that there is only a 0.50 km² difference in the surface area.

Inspection of the 65 dB(A) LAmox noise contours in Fig. 7 and Table II reveals that the contour size increases for less stringent speed constraints. Table II shows that there is a 10.57 km² difference in the surface area between the Free Speed and 205 KIAS to 10 NM scenarios at the 65 dB(A) level. Fig. 5 shows that the aircraft generate 65 dB(A) LAmox at approximately 4000 ft AGL; the aircraft restricted to 205 KIAS until 10 NM reaches this altitude at a ground distance of 8 NM, whilst the aircraft following the Free Speed profile does not reach 4000 ft AGL until 11 NM.

Comparison of the 60 dB(A) LAmox noise contours in Fig. 7 reveals a different trend to that observed for the 65 dB(A) contour; the surface area covered by the noise

contour does not increase for less stringent speed constraints as before. The 250 KIAS to FL 100 scenario has the smallest 60 dB(A) noise contour, followed by similar areas covered by the 205 KIAS, 210 KIAS and 220 KIAS to 10 NM scenarios. The Free Speed scenario has the largest 60 dB(A) contour, which covers a surface area approximately 20 km² larger than the 250 KIAS to FL 100 scenario. The A321 produces an L_{Amax} of 60 dB(A) at approximately 6100 ft AGL and out of the five speed constraint scenarios, the aircraft flying 250 KIAS to FL 100 reaches this altitude in the shortest ground distance (~13 NM). In contrast, the Free Speed scenario reaches 6100 ft AGL at a ground distance in excess of 15 NM.

Overall, reducing or removing the 210 KIAS speed constraint on the TOPLA 1M SID will not affect the highest L_{Amax} noise contours, but will, in general, increase the geographical area exposed to noise levels below 70 dB(A).

C. CO₂ versus noise trade-off study

A CO₂ versus noise emissions trade-off study has been performed for each of the five speed constraint scenarios considered. The noise has been calculated at three arbitrary microphone locations at ground distances of 6 NM, 10 NM and 14 NM along the SID centreline. The locations of the microphones are shown in Fig. 8.

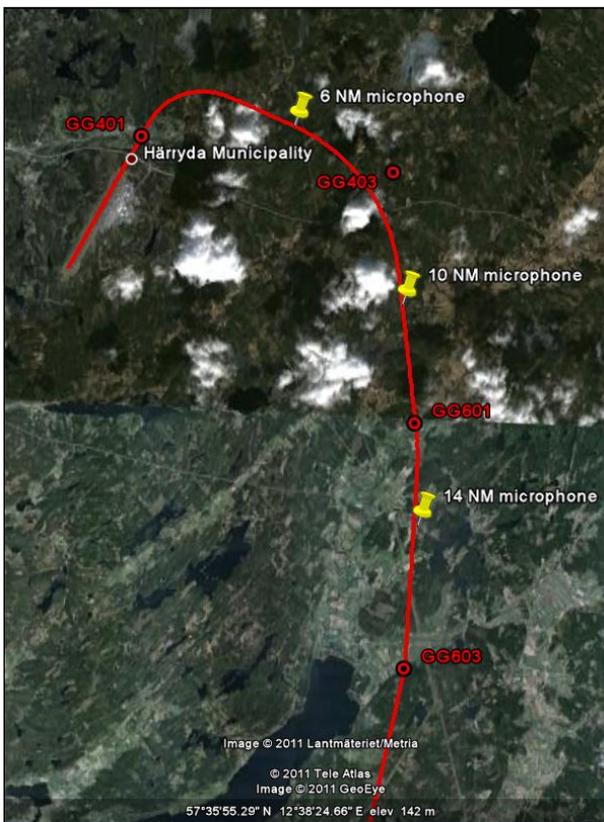


Figure 8. Geographical representation of TOPLA 1M SID (outlined in red with virtual waypoints indicated) with locations of three microphones shown at 6 NM, 10 NM and 14 NM.

As described in Section IV, the total fuel consumption and corresponding CO₂ emissions have been calculated to a radius of 200 NM from the airport for each speed constraint scenario. The CO₂ produced by the Free Speed scenario has been taken as a baseline case for a relative comparison study. Fig. 9 shows the L_{Amax} noise produced at the three microphone locations for the five speed constraint scenarios versus the additional CO₂ produced compared with the Free Speed scenario. Fig. 9 therefore shows the trade-off between CO₂ and noise emissions for five different ATM speed constraints.

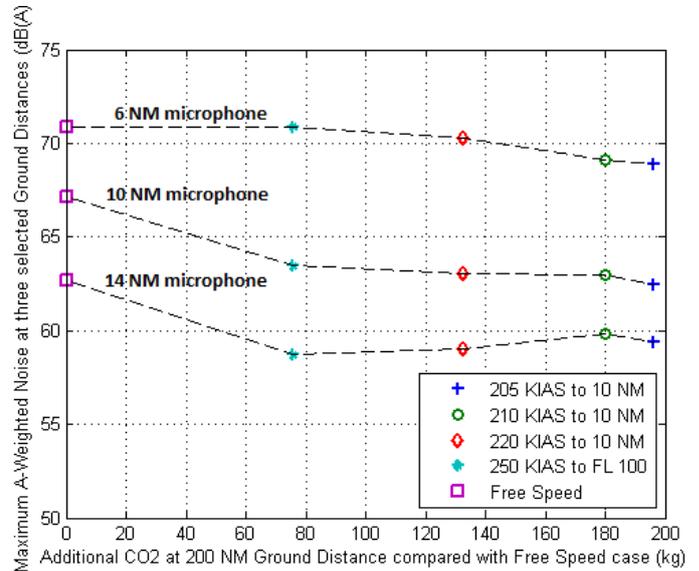


Figure 9. Noise versus CO₂ trade-off comparison for five speed constraint scenarios. The y-axis shows the L_{Amax} noise generated by each scenario, as measured at three hypothetical microphone locations (6 NM, 10 NM and 14 NM). The x-axis shows the CO₂ emitted to a radius of 200 NM relative to the Free Speed scenario.

Fig. 9 reveals that if the 210 KIAS speed constraint was removed on the TOPLA 1M SID, but the standard 250 KIAS to FL 100 was still applied, this would result in a reduction in CO₂ of 105 kg for a heavy-loaded A321 aircraft. This equates to a fuel saving of 35 kg per flight. Close to the airport at a ground distance of 6 NM, removing the 210 KIAS speed constraint would result in an increase to the L_{Amax} directly under the flight path from 69 dB(A) to 71 dB(A). At a ground distance of 10 NM there is predicted to be less than 1 dB(A) difference in noise. By 14 NM there is expected to be a decrease in L_{Amax} by 1.5 dB(A) because the aircraft climbing at 250 KIAS has reached a higher altitude compared with the 210 KIAS speed constraint scenario. Therefore, at distances greater than ~10 NM from the airport, it is predicted there will be benefits in both CO₂ and noise reduction if all turn-related speed constraints are removed.

Fig. 9 also shows that if the 250 KIAS constraint was also removed (i.e. Free Speed permitted), this would result in a total fuel saving of approximately 60 kg and a reduction in CO₂ of 180 kg compared with the procedure where a 210 KIAS turn-related speed constraint is applied to 10 NM. At a ground distance of 6 NM from the airport the removal of the

250 KIAS speed constraint does not affect the L_{Amax} noise; however, at ground distances of 10 NM and 14 NM, an increase in L_{Amax} of approximately 4 dB(A) is predicted.

VI. POSSIBLE SOLUTIONS FOR THE REMOVAL OF DEPARTURE SPEED CONSTRAINTS

The results presented in Section V clearly demonstrate the potential environmental benefits of removing turn-related speed constraints along SIDs. Using a heavy-loaded A321 departure along the TOPLA 1M SID at ESGG as a case study, the results suggest that a 105 kg reduction in CO₂ emissions could be achieved if the 210 KIAS turn-related speed constraint was removed from the SID. If we take a conservative assumption that, on average, aircraft will reduce CO₂ emissions by 50% of that achieved by a heavy-loaded A321 (i.e. ~50 kg per flight) then given that there are typically 3500 departures along the TOPLA 1M SID per year, this would give a reduction in CO₂ emissions by 175,000 kg per year. Note that these benefits are in the order of those achieved in the arrival phase when Constant Descent Operations are being implemented

The environmental benefits are even greater from an air pollution perspective if the 250 KIAS speed constraint applied to FL 100 were to be removed; it is predicted that the amount of CO₂ emitted by a heavy-loaded A321 would be reduced by 180 kg per flight compared with the present day situation.

Naturally any discussion of removing existing speed constraints must also consider the implications for noise exposure on the ground and aircraft operational capabilities. The results in Section V show that the reduction or removal of speed constraints in the departure phase generally comes at a cost of increased noise emissions *below* 70 dB(A). The Swedish Environmental Agency uses an L_{Amax} of 70 dB(A) as a benchmark for classifying noise disturbance; aircraft are legally required to remain within ± 1 NM of a published SID centreline until the L_{Amax} perceived on the ground has reduced below 70 dB(A). Therefore, it may be argued that whilst the removal of speed constraints does increase noise exposure, the increase is within an acceptable audible limit (i.e. below 70 dB(A)).

The removal of turn-related speed constraints would require either deviation from the current PANS-OPS guidance based on a local safety validation case or an alternative interpretation of the recommendations. Three different solutions for how this might be achieved are stated below:

1. Use of statistical winds rather than worst-case tail winds when designing the SID procedure. This would not require any deviation from PANS-OPS;
2. Removal of turn-related speed constraints for aircraft capable of banking at least 30° as PANS-OPS guidance currently assumes a maximum bank angle of 25°. The majority of modern commercial aircraft can comfortably bank at 30°;

3. Demonstrate that modern aircraft equipped with GNSS navigation can remain within the required ± 1 NM from the SID centreline without the need for turn-related speed constraints. This would be facilitated by validation flights.

Although an additional substantial reduction in CO₂ could be achieved with the removal of the 250 KIAS speed limit to FL 100, this would be more difficult to facilitate operationally in high-density airspace as the speed limit is used by ATC for aircraft separation purposes.

In conclusion, there are clearly significant environmental benefits to be gained from the removal of SID speed constraints, and this should be considered when developing new environmentally friendly departure operations within the framework of SESAR.

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