Stockholm 04 May, 2011

1. Background

By this document SAS want to argue against a common statement that goes: *"Green departures are much more fuel/emission efficient than green arrivals due to the fact that climb-out is a high energy phase of flight whereas the descent is a low energy phase."*

We believe it is important to mitigate this myth as many ANSPs today are in the process of developing new procedures and new TMA design to provide more Green Flight operations. It is then imperative that we move in the right direction by making rational decisions.

2. Summary and conclusion

Continuous Climb Departures[1], CCDs and Continuous Descent Approaches[2], CDAs are *both* very beneficial from a fuel/emission efficiency perspective, but ***it is not correct that CCDs are more beneficial than CDAs***. When imposing a strategic[3] constraint the effects on a departing CCD and an arriving CDA are very similar. In frequent cases when imposing a tactical[4] constraint on either a departing CCD or an arriving CDA, it is more fuel efficient to leave the arriving CDA undisturbed and impose the tactical constraint to the departing CCD.

From a fuel efficiency perspective there is a fundamental difference between restrictions (leveloffs or track extensions) known well in advance of Top of Descent, ToD, and restrictions imposed once the aircraft has commenced its descent or is close to its ToD. It is important that procedure designers and traffic controllers are aware of this difference.

3. Flight efficiency parameters

From the airline perspective we identify three efficiency parameters in the realization phase of the flight mission:

- ***Lateral Fuel Efficiency*** covers the effects of extending or shortening the flight track in the lateral plane, without considering restrictions in the vertical plane. Maximum lateral fuel efficiency is obtained when the flight is allowed to fly shortest track between two points[5] .
- ***Vertical Fuel Efficiency*** is how well we can optimize the vertical path of the aircraft, without considering its lateral track. Maximum vertical fuel efficiency is obtained when the flight is allowed an unrestricted climb and unrestricted descent.
- ***Process Efficiency*** includes not only the fuel efficiency of individual flights but also the ground process efficiencies of an airport including turnaround processes and transfer of passengers, crews and aircraft between flights.

Let's compare these parameters for a constraint imposed on a departing CCD versus a ***corresponding*** constraint imposed on an arriving CDA. Two different types of constraints are considered:
- a 10NM track extension, and
- a 10NM level flight constraint at FL70 (leveloff).
Example figures[6] are given for a typical Airbus A321 flight from EKCH[7] to ESSA[8].

[1] CCD in this sense is a flight without vertical constraints from takeoff up to cruising level
[2] CDA in this sense is a flight without vertical constraints from ToD to configuration for landing
[3] Strategic = Procedural constraint or a constraint known by the aircraft well before Top of Descent
[4] Tactical = A constraint not known by the aircraft well before Top of Descent
[5] Disregarding meteorological effects
[6] Fuel figures are expressed in kilograms of fuel. For kilograms of CO_2; Multiply by a factor of 3,15
[7] Copenhagen/Kastrup Airport
[8] Stockholm-Arlanda Airport

4. Effects of track extensions

For a departing CCD aircraft a track extension will ***only affect the lateral fuel efficiency*** as the flight can still be flown at the optimum vertical path, illustrated in Figure 1. For the example flight, the 10NM extension costs ***52 kg*** of additional fuel consumption.

For an arriving CDA aircraft there is a fundamental difference whether or not the track extension is known to the pilots well in advance of the optimum ToD:

- *If known well in advance of ToD*, the track extension will cause the pilot to postpone the ToD and the track extension ***will only affect the lateral fuel efficiency***, which is illustrated in Figure 2. For the reference flight, the 10NM extension costs ***52 kg*** of additional fuel consumption, which is the same as for the departing CCD aircraft.
- *If a track extension is imposed after the ToD*, the descending aircraft will not only have a track extension, but it will also find itself too low on the vertical profile and there will be a penalty on ***both lateral and vertical fuel efficiency***, illustrated in Figure 3. Depending on how well the pilot can handle the situation by "energy management", the penalty will be **63-94 kg** of additional fuel consumption for the reference flight.

In summary, a track extension has the same effect on a departing CCD and an arriving CDA when it is known well in advance of the optimum ToD, but when imposed after ToD, a track extension is considerably more expensive for an arriving CDA.

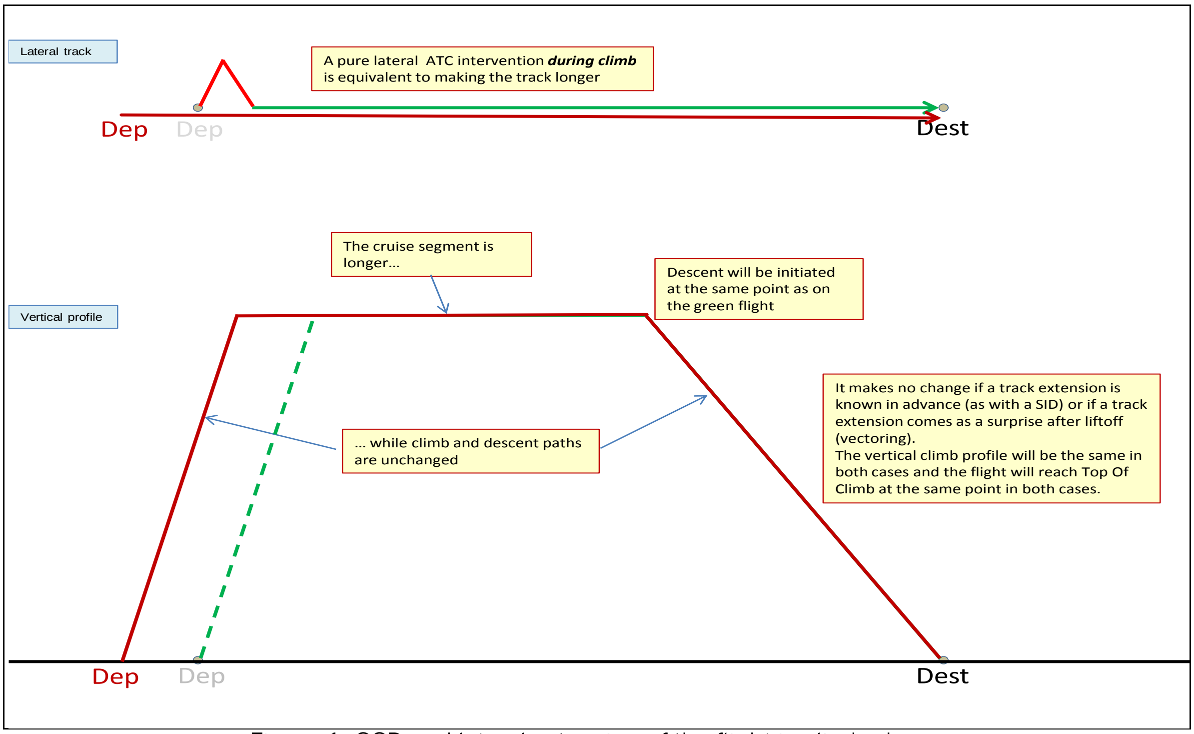

Figure 1. CCD and lateral extension of the flight in climb phase.

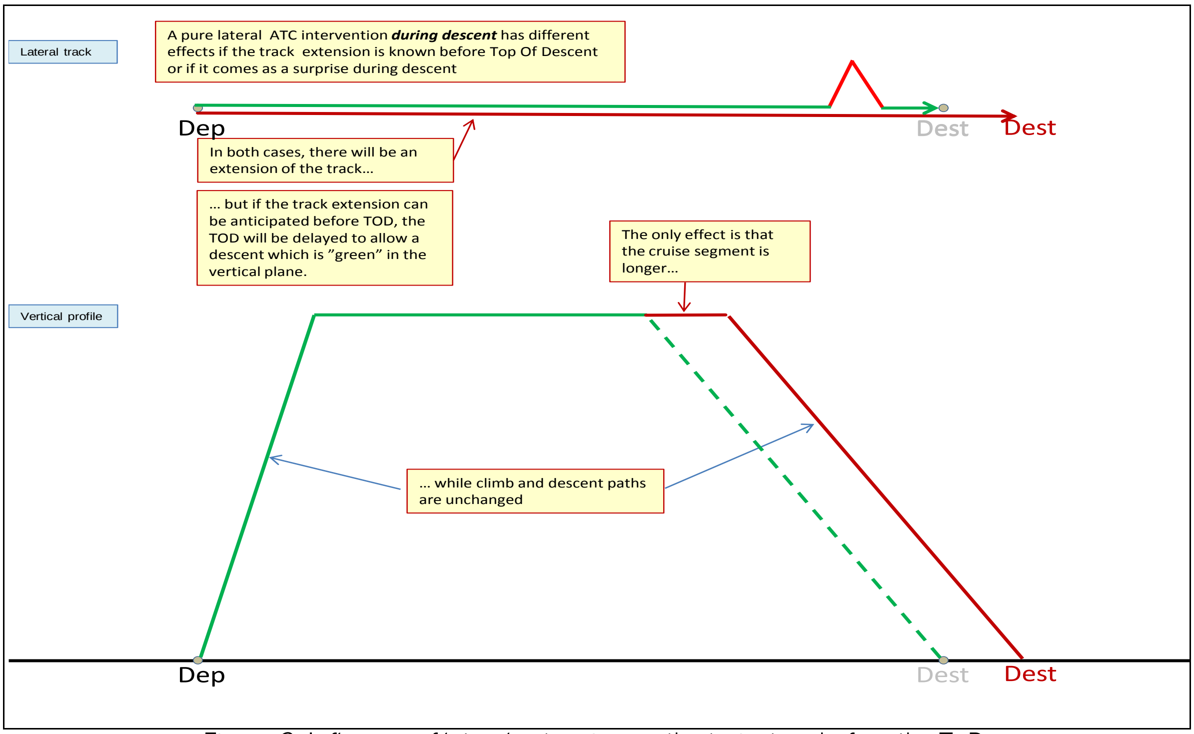

Figure 2. Influence of lateral extension on the trajectory before the ToD.

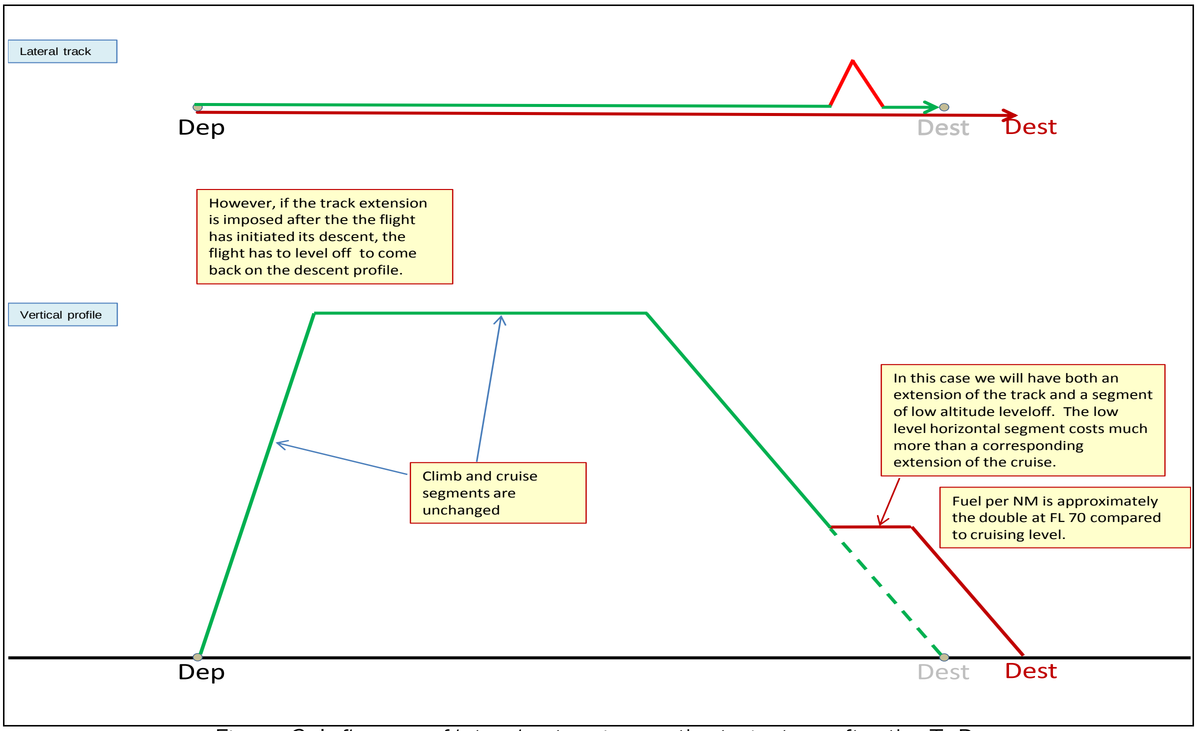

Figure 3. Influence of lateral extension on the trajectory after the ToD.

5. Effects of vertical restrictions (leveloffs)

For a departing CCD it makes no difference on the overall fuel consumption, if the leveloff is known in advance or not. In both cases the leveloff segment at low altitude will replace a flight segment of equivalent traversed distance at a more fuel efficient cruise altitude. For our reference flight, imposed with a 10NM level off at FL70, the effect will be a **43 kg** penalty of additional fuel consumption to the ***vertical fuel efficiency***, illustrated in Figure 4.

For the arriving CDA, there will be a difference in fuel consumption depending on *when* the leveloff constraint becomes known to the aircraft:

- *If known well in advance of ToD*, the leveloff will have an effect very similar to the one for the departing aircraft. The aircraft will plan an early descent and a 10NM cruise segment will be replaced with a 10NM less efficient leveloff segment, illustrated in Figure 5. The penalty to the ***vertical fuel efficiency*** will be ***42 kg*** of additional fuel consumption for our reference flight.
- *If the level off is imposed when the aircraft has left its cruising altitude, or is close to its optimum ToD,* the flight is already committed to its descent profile. When confronted with a leveloff, the aircraft needs to add thrust, which will add potential energy to the aircraft and, when free to descend again, the flight will be above the intended vertical profile and needs to dissipate this additional energy by prolonging the track, or by adding drag, illustrated in Figure 6. To some extent the problem can be mitigated with "energy management". Our reference flight will suffer a ***63-94 kg*** of additional fuel penalty to the ***vertical fuel efficiency*** depending on the degree of energy management used.

A common argument is that a leveloff imposed on a heavy departing aircraft is more detrimental than the same leveloff imposed on an arriving aircraft which is, relatively, less heavy. The argument is theoretically correct, but in the example above the difference is only 1 kg (43 kg versus 42 kg). Also for longer flights, with larger difference between departure and arrival gross mass, it can be shown that this effect is *very marginal*. As seen from the figures above, the effect of a leveloff constraint imposed to arriving aircraft after ToD is much greater.

In summary, a leveloff has the same effect on a departing CCD and an arriving CDA when it is known in advance of the optimum ToD, but when imposed close to, or after ToD, a leveloff is considerably more expensive for an arriving CDA.

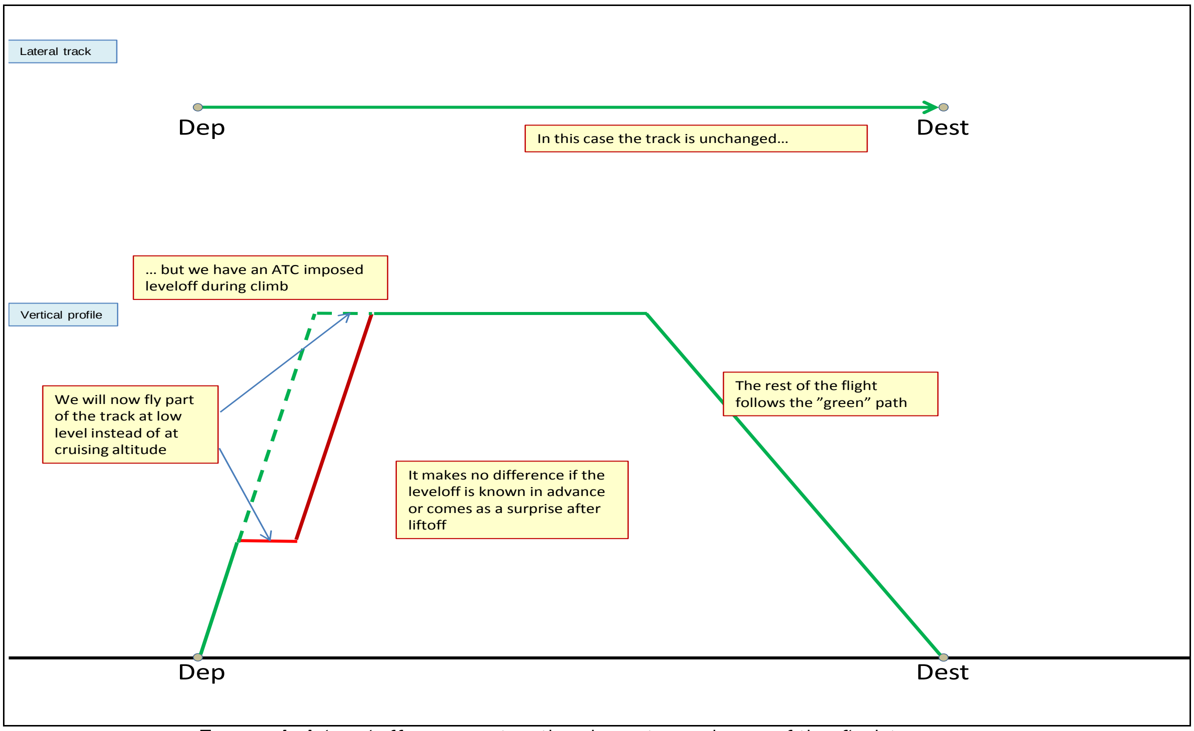

Figure 4. A leveloff segment in the departure phase of the flight mission.

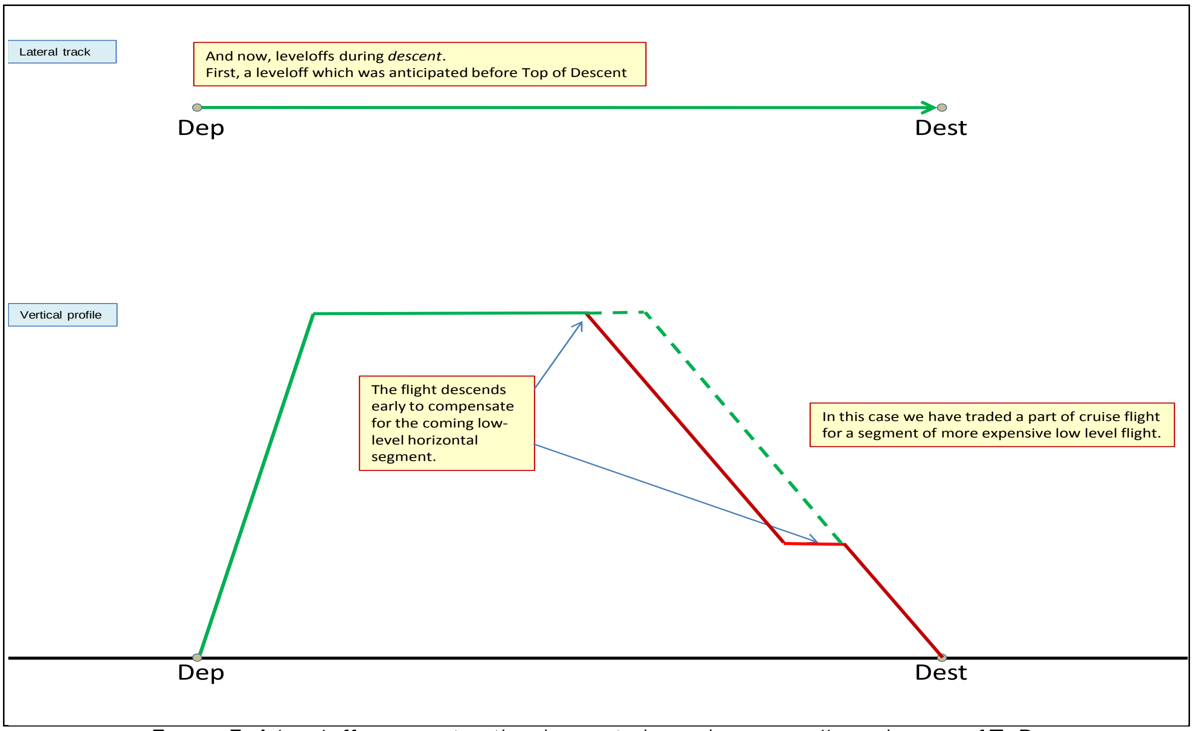

Figure 5. A leveloff segment in the descent phase, known well in advance of ToD.

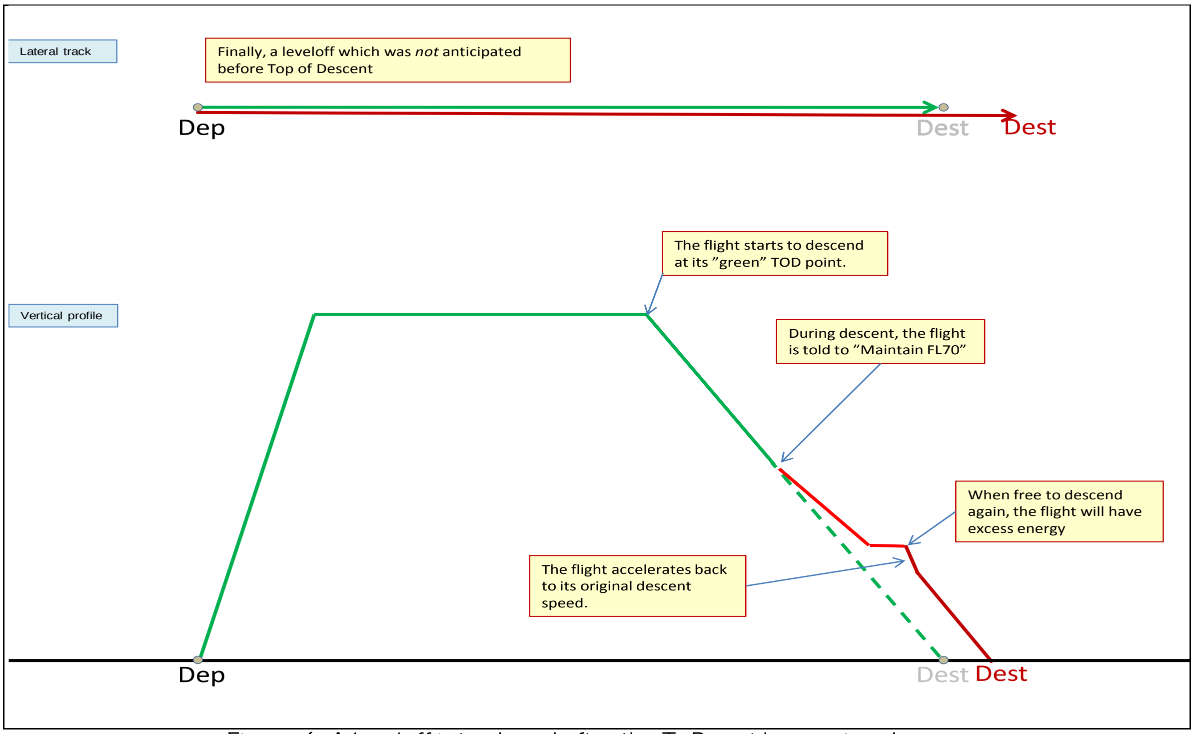

Figure 6. A leveloff introduced after the ToD, not known in advance.

6. Discussion

The comparisons above are example scenarios where the *same* track extension is imposed on *either* the departing CCD or the arriving CDA and where the *same* leveloff is imposed on *either* the departing CCD or the arriving CDA. In real life there is a wide variety of restrictions that can be made to arriving and departing flights. An example can be a minor track extension of an arriving CDA to avoid a leveloff of a departing CCD. It cannot, therefore, be put as a *general* statement that a constraint should always be applied to the departing CCD.

7. Process Efficiency

In the logistic complexity of a major airport, arrival flow predictability is imperative for ground process efficiencies, but today this predictability is poor. The arrival flow is a black hole with vectoring and prolonging/shortening of tracks, whereas the departure flow is tactically well controlled by takeoff clearances on the runway. The departure flow is, therefore, more dependent on prior ground processes and latently dependent on arrival flow from prior flights. Our view is that, as long as our main airports have limited or no control over their corresponding airports in the other end, better predictability of arrival CDA flows is the key to move to more green and efficient operations.

Best Regards,

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