9th ANKARA INTERNATIONAL AEROSPACE CONFERENCE AIAC-2017- 116
20-22 September 2017 - METU, Ankara TURKEY

EVALUATION OF VERTICAL FLIGHT EFFICIENCIES DURING DEPARTURE OPERATIONS

Hakkı AKSOY[1], Öznur USANMAZ[2] and Enis T. TURGUT[3]
Anadolu University
Eskişehir, Turkey

ABSTRACT

The objective of this study is to characterize the vertical inefficiencies of departure operations at Antalya International Airport (AYT) and Mugla Milas-Bodrum International Airport (BJV) in Turkey. In this regard, the purpose is to investigate and characterize level offs that occur in the departure phases, and to quantify the potential time and fuel savings in the event of a shift of inefficient low level flight segments to the cruise segment of equal distance. Initial analyses results show that the percentages of air traffic with level off are 6% for both BJV and AYT airports. The average durations of the level offs are found to be 51 and 77 seconds for BJV and AYT airports respectively, and also great fuel saving potential exists in case of shifting low level flight segments to upper flight levels.

INTRODUCTION

In order to mitigate the negative environmental impact of aviation and minimize the operational cost of operators, technological improvements have been made on aircraft airframe and engine efficiency and material used in aircraft construction [Lee and Mo, 2011]. In addition to these technological improvements, another way to decrease fuel consumption and associated emissions is minimizing vertical inefficiencies occurring in the arrival and departure phases of a flight. A vertical inefficiency is defined as a temporary level off at low altitude before top of climb (TOC) for the departure phase and after top of descent (TOD) for the descent phase. Figure 1 illustrates basic flight phases with temporary level offs in departure and descent phases.

[1] Research Assistant in Air Traffic Control Department, Email: hakkiaksoy@anadolu.edu.tr
[2] Associate Professor in Air Traffic Control Department, Email: ousanmaz@anadolu.edu.tr
[3] Associate Professor in Airframe and Powerplant Maintenance Department, Email: etturgut@anadolu.edu.tr

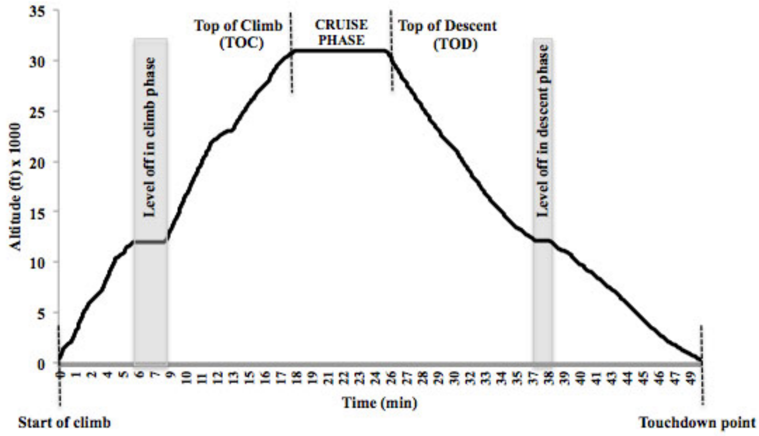

Figure 1: Illustration of level offs in departure and descent phases

In order to conduct fuel efficient departure and arrival operations, aircraft should climb and descend with an optimum vertical profile. Optimum vertical profile is defined as a flight path that, for departing aircraft, is one with a continuous climb at optimum climb thrust and speed until an aircraft attains cruise flight altitude. For descending aircraft it is one with a continuous descent at low thrust setting and with minimum drag configuration that results in a reduction of fuel and emissions [ICAO Doc 9931, 2010; ICAO Doc 9993, 2013]. These operations with optimum vertical profiles are known as continuous climb operations (CCO) for departure operations and continuous descent operations (CDO) for arrival operations.

The focus in this study is put on the vertical inefficiencies of departure operations and a vertical inefficiency analysis of departure operations at Antalya International Airport (AYT) and Mugla Milas-Bodrum International Airport (BJV) in Turkey, is performed using in-real time flight data recorded by flight data recorders (FDR). In this regard, the purpose is threefold; (i) to analyze the vertical profiles of departure traffic at BJV and AYT airports; (ii) to characterize level offs that occur in the departure phases, and (iii) to quantify the potential time and fuel savings in the event of a shift of inefficient low level flight segments to the cruise segment of equal distance.

MATERIAL AND METHOD

In this study, a wide range *FDR database*, *gpsvisulizer* and *excel macro* are used. The flights from which obtained FDR records were performed by Pegasus Airlines, one of the largest scheduled airlines operate in Turkey. The FDR system records many flight parameters almost every second, such as latitude, longitude, altitude, aircraft speed, heading, fuel flow, flight path angle (FPA) and so on. These parameters were used to calculate the fuel, time and emission savings and to filter the level off segments. Amount of analysed departure traffic for AYT and BJV airports are 120 and 100, respectively and in order to systemize and expedite the calculation of savings and filtering operations, *excel macro* has been used. Gpsvisualizer software was used to visualize the track of real flight using the latitude, longitude and altitude data of the aircraft.

Level Off Detection Algorithm

The level off segments of departing flights were found using FDR parameters of air/ground logic, flight phase, altitude, FPA and time. In order to accept a level flight as a low level flight segment, three parameters are defined and utilized in an excel macro algorithm for identifying level off segments. These parameters are maximum altitude threshold, instant altitude and FPA change threshold, and duration threshold. The maximum altitude threshold is that level off segment altitude during the departure phase and should be below 25,000ft, otherwise it is accepted as a cruise flight. This altitude constraint is determined with respect to an upper limit of the terminal maneuvering areas (TMA) of selected airports (i.e., AYT:

24,500ft, BJV: 24,500ft). The instant altitude and FPA change threshold is instant change of altitude in the range of ± 10ft or instant FPA change in the range of 0-0.35 degrees, and these segments are considered as level off. The final condition, duration threshold, is that if the level off segment duration in total is shorter than 20 seconds, this segment is not accepted as a level off. This duration is determined as a result of an FDR data examination. It can be seen that level off segments shorter than 20 seconds, for instance in the climb phase, are inadequate for seeing a change in fuel flow rate with transition from climb to the level off segment. Therefore, level off segments longer than 20 seconds are taken into consideration for the statistical analysis of level off segments.
In order to evaluate the vertical profile efficiency of departure operations, certain useful metrics have been derived from studies in the literature [Roach and Robinson, 2010; Dorfman et al., 2012; DeArmon et al., 2014; McConnachie et al., 2015]. These are defined below with short descriptions:

- Amount of traffic exposed to level off: This shows frequency of traffic including at least one level off in arrival or departure
- Amount of level offs in each altitude: This shows the amount of traffic in each altitude bin exposed to level offs.
- Time in level offs: This shows the determined average duration of level offs.
- Geographic location of level offs: This is used to visualize and determine the position of level offs
- Amount of fuel used: This is used to compare fuel consumption in level off to the fuel consumption in cruise for the same distance.
- Specific Range (SR): SR is the distance an aircraft travels per unit of fuel consumed. This is used to demonstrate the inefficiency of a low level flight with respect to a cruise flight.

Potential Time and Fuel Benefit Analysis Steps
Three possible ways to the mitigate level off segments in arrival and departure operations can be listed as reducing distance and duration of level offs, raising the altitude of level offs, and completely eliminating level offs [Dorfman et al., 2012]. In this paper, the best scenario is considered and therefore, potential time and fuel and benefits, in the case of eliminating and replacing inefficient low level flight segments with the cruise segment of equal distance, are calculated (Figure 2). In other words, potential benefits by conducting continuous climb procedures are calculated.

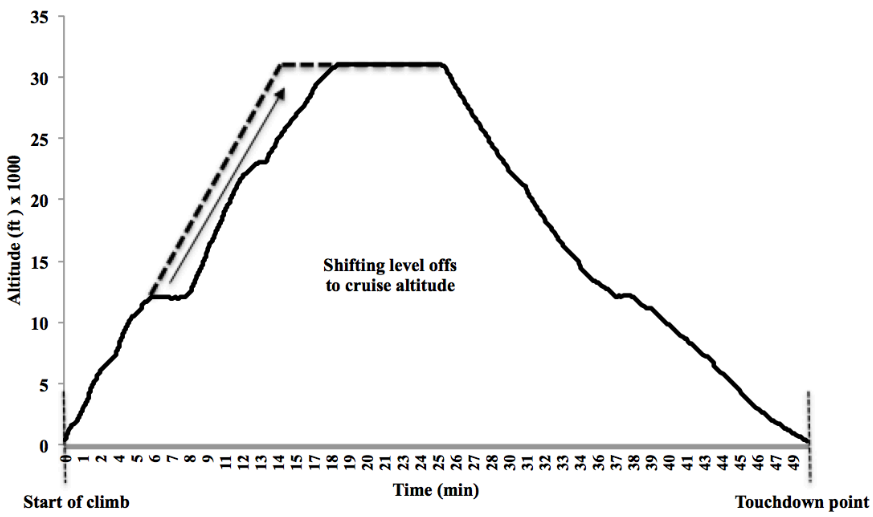

Figure 2: Comparison of actual flight profile and proposed continuous climb profile

For this purpose, all of the level off segments in departure operations are detected and duration, distance flown, fuel consumed in each of the temporary level offs are calculated with reference to FDR records. The calculated distance in each one of the temporary level offs is then shifted to its own cruise conditions and in answer to the question of what would be the time and fuel savings if temporary level offs distance is conducted in cruise phase is investigated and compared with the low level flight segments' results.

RESULTS

AYT results

For AYT departures, 120 departures from ESB airport to SAW airport were analyzed and it was found that only 7 of the departure flights were exposed to at least one level off during the departure phase. Tracks of the examined departures were created via gpsvisulizer using latitude, longitude and altitude as shown in Figure 3.

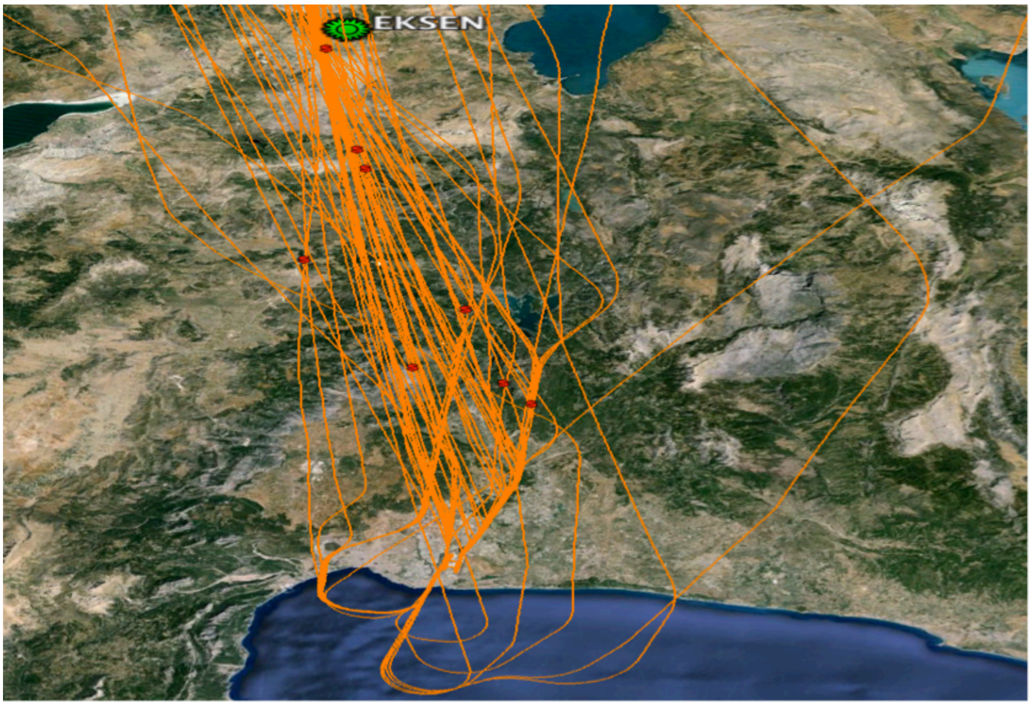

Figure 3: Profile view of tracks of departures from AYT to SAW airport

Departure paths of AYT traffic mostly overlap with published RNAV SID routes. However, some of these differ from the RNAV SID routes because air traffic controllers (ATCOs) give 'direct to' clearance when traffic density is lower. There exist a number of level offs during the departure phase, so it is not possible to give statistical information about average duration or the altitude bins of the level offs. However, the altitudes of level off's do not seem to be coincidental because they overlap with the Antalya TMA sector separation altitudes of 11,500ft, 18,500ft and 24,500ft that are published in the AIP.

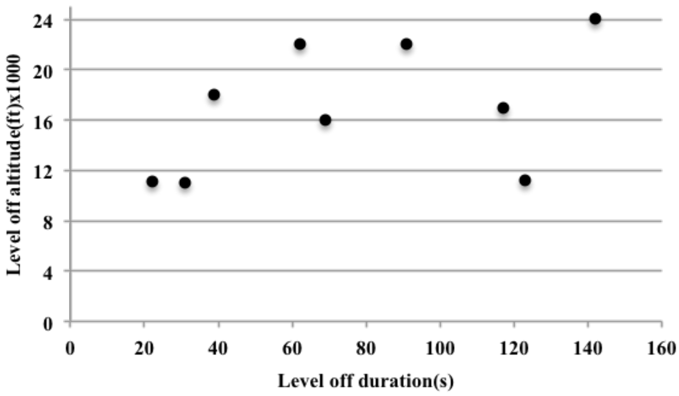

Figure 4: Altitude distribution off level offs and their durations

As can be seen from Figure 4, level off occurred mostly just before the sector separation altitudes. On this point, one reason for low level flights is said to be the lateness of ATCOs in transfering traffic to other sectors.

BJV results

For BJV departures, 100 departures from BJV airport to SAW airport were analyzed and it was found that only 6 of the departure flights were exposed to at least one level off during the departure phase. Tracks of the examined departures were created via gpsvisulizer using latitude, longitude and altitude as shown in Figure 5.

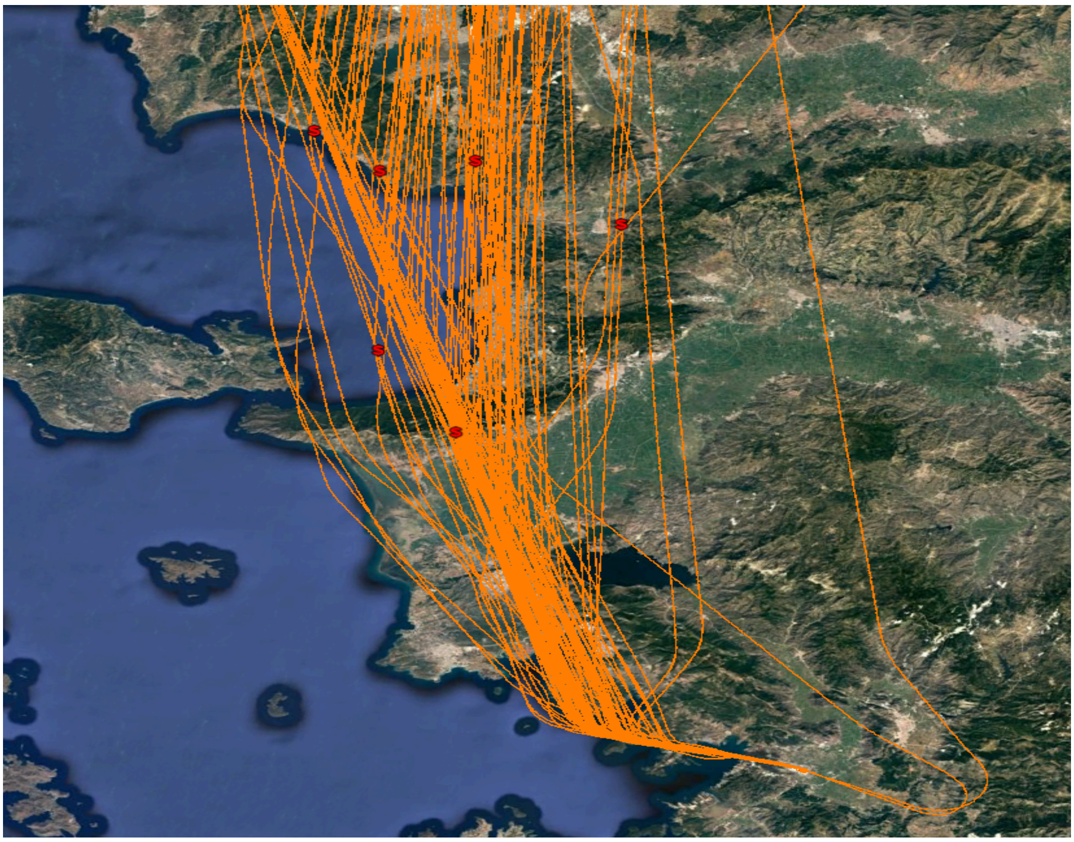

Figure 5: Profile view of tracks of departures from BJV to SAW airport

Departure paths of BJV traffic mostly overlap with published RNAV SID routes. Aircraft have to climb at a minimum 4% gradient up to 2,400ft due to higher obstacles on the departure path and proceed to the next waypoint. A few level offs exist during the departure phase and mostly overlap with the Milas TMA sector separation altitude of 24,500ft as it is for AYT departures. Level off points again overlap with sector boundaries (Figure 6) and this shows the importance of the transfer of traffic between sectors.

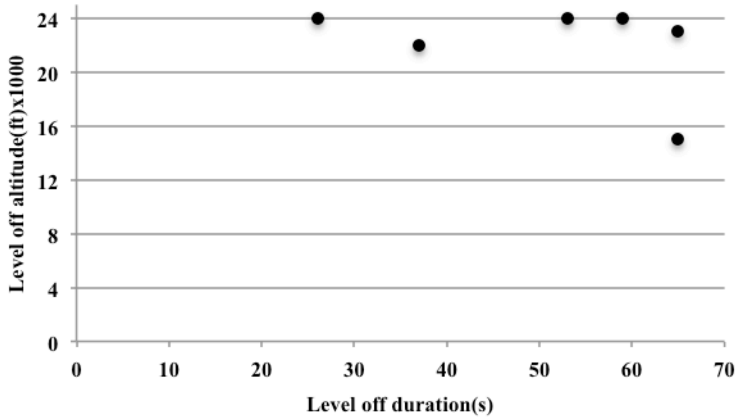

Figure 6: Altitude distribution off level offs and their durations

Time and fuel benefit analysis

Departure traffic analyses of AYT and BJV airports show that the percentage of departure traffic that is exposed to at least one level off is noticeably smaller. The percentages of traffic exposed to at least one level off and average durations of level off's are given in Figure 7.

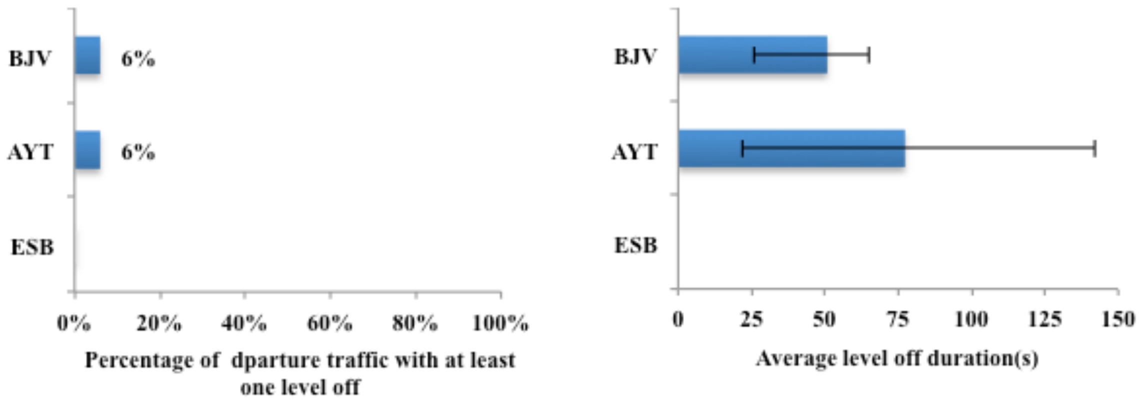

Figure 7: Percentage and average duration of level off segments

The percentage of traffic with level off are found to be 6% for both BJV and AYT airports. The average durations of the level off's are 51 seconds for BJV airport and 77 seconds for AYT airport. Aircraft are heaviest in the departure phase and low level flight at departure tends to cause more fuel consumption than low level flights in the arrival phase. In order to see the effect off level offs during the departure phase, three level offs were analyzed in terms of time, fuel and specific range and shown in Table 1.

Table 1 A sample potential savings for level offs in departure phase in AYT airport

Level off Altitude and Weight of Aircraft		Duration (s)	SR (NM/kg fuel)	Total Fuel (kg)
11,000 ft		123	0.124	92
(63 ton)	Cruise (24,000ft)	90	0.175	65
	Change	- %27	+%41	-%29
17,000 ft		117	0.129	105
(61 ton)	Cruise (30,000ft)	109	0.159	85
	Change	- %7	+%23	-%19
22,000 ft		91	0.149	76
(61 ton)	Cruise (34,000ft)	90	0.204	55
	Change	- %1.1	+%37	-%27

It is clear from the results that flying at higher altitudes provides significant time and fuel savings. The SR value of a flight in particular is an important indicator for flight efficiency and there are significant differences between the SR values of level off and cruise. For instance, if the level off segment in 11,000ft had flown in 24,000ft, duration to take the same distance and total fuel consumed would have decreased by%27 and %29 respectively; distance taken by 1 kg unit fuel would have increased by %41. These ratios may change according to aircraft speed, wind speed etc. but, it is obvious to save time and fuel by implementing continuous climb operations.

CONCLUSION

Vertical profiles of departure traffic at AYT and BJV airports are examined in order to determine the altitude, frequency, geographic location of level off segments during climb phase of flights. In addition to those statistical analyzes, potential time and fuel savings in case of shifting level offs to upper cruise levels are calculated using the real time flight data. According to the analyses results, percentage of flights that exposed to at least one level off during departure is lower, however, there exists an important point for departure traffic at both BJV and AYT airports. It is clear that both airports' departure traffic are exposed to level offs during the transferring the traffic between sectors. These level off altitudes are higher at BJV airport and lower at AYT airport with respect to BJV airport. Therefore, it is likely that the negative effects of levels offs are greater at AYT airport. As a result, a better coordination between sectors is an important factor for providing continuous climb operations.

Acknowledgments

This study was supported by Anadolu University Scientific Research Project Commissions (ProjectNo.1504F176) of Turkey. The authors gratefully acknowledge Pegasus Airlines as a partner in the projects which has provided access to actual flight data.

References

Alcabin, M., Schwab, R. W., Soncrant, C., Tong, K. O., Cheng, S. S. (2009). "*Measuring Vertical Flight Path Efficiency in the National Airspace System*", 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO), 2009

DeArmon, J., Mahashabde, A., and Hogan, B. (2014) "*Departure flow efficiency and the identification of causes for inefficiencies*", paper presented at Digital Avionics Systems Conference (DASC).

ICAO (2010). "*Doc 9931 Continous Descent Operations (CDO) Manual*", International Civil Aviation Organization, Montréal.

ICAO (2013). "Doc 9993 Continous Climb Operations (CCO) Manual", International Civil Aviation Organization, Montréal.

Lee, J. and Mo, J. (2011). "*Analysis of technological innovation and environmental performance improvement in aviation sector*", International Journal Of Environmental Research And Public Health, Vol. 8 No. 9, pp. 3777-3795.

McConnachie D., Bonnefoy P., Belle A. (2015) "*Investigating benefits from continuous climb operating concepts in the national airspace system*", 11th USA/Europe Air Traffic Management Research and Development Seminar , 2015

Roach, K. and Robinson, J. (2010). "*A terminal area analysis of continuous ascent departure fuel use at dallas/fort worth international airport*", 10th AIAA Aviation Technology, Integration and Operations Conference (ATIO), 2010.