Flight Profile Variations due to the Spreading Practice of Cost Index Based Flight Planning

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***Abstract*—The current paper stresses the increasing relevance of the cost index (CI) based flight planning process of the Airspace Users for the Air Traffic Management (ATM) system. Based on data analysis performed together with Lufthansa Systems this paper quantifies the speed and vertical profiles in dependence on the chosen CI. Realistic CI scenarios are developed to gain a better knowledge of the ranges of flight profiles that have to be expected by the air traffic controllers. The paper shows that in cruise a range of up to Mach 0.09 for one aircraft type due to CI variations is realistic. This corresponds to about 10% speed variations. During climb and descent the range of speed can even be higher and reach values of 96 knots, corresponding to 30% speed variations. Also the vertical speed during climb and descent is influenced by the CI. Exemplary investigations of the descent profile indicate that the optimum position of the top of descent can differ up to almost 20 NM in dependence on the CI. The paper gives a detailed overview about the achieved results and briefly discusses the implications to the ATM system.**

***Index Terms*—Cost Index, Time Costs, Fuel Management, Business Trajectory, Delay Management, Air Traffic Management, ECON Speed.**

I. Introduction

In 2008 a Safety Alert due to an increased range of observed speeds in the airspace between identical aircraft types was issued by Eurocontrol [1]. With it, Aircraft Operators and Air Navigation Service Providers were invited to share their experiences regarding the appropriate reasons and consequent effects on the ATM system. Responses clearly pointed out the current lack of information regarding the cost index (CI) based flight planning process respectively the associated effects on flight profiles. The resulting uncertainties in trajectory prediction affect the provision of the Air Traffic Control services regarding increased controller workload and reduced capacity as well as potential effects on the safe separation of aircraft. In view of the modernization of the ATM system within the next decade and the aspired service-oriented approach the appropriate challenges will even rise. Airspace Users' requirements including their wish to fly close to the optimum trajectory will strongly influence the future ATM system.

The current paper stresses the high priority of CI based flight planning for airlines and contributes to an improved overall understanding of the associated requirements for the ATM system. First a short introduction concerning the background of the CI and the appropriate cost factors as well as the optimization criteria for airlines is given. Afterwards, the effects of different CI on the flight profile are quantified based on data analysis performed together with Lufthansa Systems and its flight planning tool Lido/Flight (former Lido OC). Applied methodology includes different scenarios concerning aircraft types, flight distances and CI regimes with particular focus set to the effects on cruise speed and vertical profiles. Based on the development of cost scenarios a realistic range of speeds as well as climb and descent distances are discussed and assessed regarding the impact onto the ATM system. The paper concludes with an outlook concerning further research and development in the field of CI based flight planning.

II. Background and Basics

A. Airline Operating Costs

For a comprehensive understanding of the cost index concept it is essential to have a closer look on all operating costs with effects on the in-flight performance of an aircraft. In the following, a short overview on the entire cost structure of a typical airline operator is provided in order to identify all relevant costs related to a certain flight operation and in particular those costs directly related to in-flight performance.

Basically, operating costs of an airline consist of direct and indirect costs illustrated in Figure 1 [2], [3]. Direct operating costs (DOC) cover all costs related to the flight operation of an aircraft. On the contrary indirect operating costs are independent and not connected to the operation of an aircraft mainly including expenditures for administration and distribution. Direct operating costs can be subdivided into a fixed and a variable part. Fixed direct costs are related to the operation of the aircraft but cannot be influenced by the flight event itself. These are costs for depreciation, insurance and the fixed part of maintenance and crew costs. On the contrary all variable direct operating costs are directly addressable to the flight event. Hence, a higher share of variable DOC regarding all operating costs enables an increased cost control in the frame of the flight planning process. Items that can be classified as variable DOC are listed in Table I with their associated cost drivers[1].

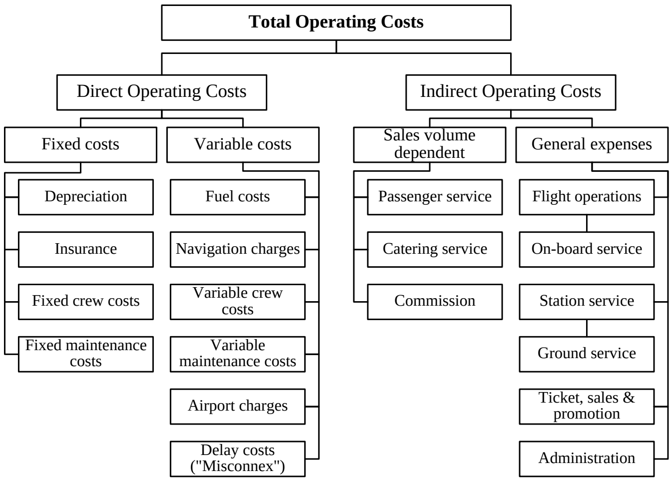

Figure 1. Airline operating costs [2], [3]

Table I
VARIABLE DIRECT OPERATING COSTS AND RELATED COST DRIVERS

Cost item	Cost driver
Fuel costs	Fuel burn
ATC charges	Airspace, distance, MTOM
Time-related maintenance costs	Flight duration
Time-related crew costs	Flight duration
Delay (Misconnex) costs	Length of delay (non-linear)

B. The Cost Index

Despite the fact that more than one-third of all airline operating expenditures are spent on fuel [4] it is obvious that optimizing a flight profile only by minimizing fuel costs is not sufficient. Economic flight planning rather takes into account all costs that are influenced by the flown trajectory and in-flight performance. To reach the most economic flight trajectory the outcome of flight track, flight profile and in-flight performance has to minimize the sum of all cost positions shown in Table I. Therefore, modern flight planning tools like Lido/Flight use algorithm for both lateral and vertical trajectory optimization. Whilst a cost function for lateral optimization has to consider all cost items listed in Table I, the cost function for vertical optimization takes into account all costs except Air Traffic Control (ATC) charges as they are neither time- nor fuel-related. Generally, ATC charges depend on the airspace charging system of the Regional Enroute Agency, the unit rate of the Air Navigation Service Provider and the flown distance as well as the Maximum Take-off Mass (MTOM) [5]. Consequently, the most economic in-flight performance and resulting vertical trajectory is only based on fuel costs and the costs of time (time-related maintenance costs, time-related crew costs and delay costs).

Defined as the ratio between time-related costs and costs of fuel the cost index estimates the worth of time in relation to the price that has to be paid for fuel. Basically, the cost index expresses the time costs with the fuel unit being the currency. The CI is defined by the following formula [6]:

$$CI = \frac{C_t}{C_f} \qquad (1)$$

with

CI	cost index	$[\mathrm{kg/min}]_{\mathrm{Airbus}}$ $[\mathrm{100lb/h}]_{\mathrm{Boeing}}$
C_t	specific time costs	
C_f	fuel price	

Since a large number of Flight Management System (FMS) vendors have been established in the market, two different units for the CI are generally used depending on the specific aircraft type. Airbus uses CI values with unit kg/min whilst Boeing defines the CI with 100lb/h (corresponding to 0.756 kg/min). Looking into detail at the CI equation the range of feasible cost indices can be identified. In case of nonexistent time costs the minimum CI of 0 is applied. If, in contrast, time costs are extremely high and/or the price of fuel negligible, very high values can be achieved. For instance, assuming time costs of 15 EUR/min for the A320 and a fuel price of about 0.45 EUR/kg a CI of 33 kg/min represents the optimum. The upper limitation of the CI range depends on the particular FMS. Maximum limitations are 999 kg/min for most Airbus aircrafts and 9999 100lh/h in case of the Boeing 747.

The CI is the key input value for the calculation of the speed and the vertical trajectory based on the most economical in-flight performance. Generally it is given to the pilot within the briefing package provided by the dispatch and entered into the FMS as part of the flight preparation. The flight profile calculation is done by the aircrafts integrated FMS. The calculation process is performed immediately before block-off time and, if required, during the flight in order to adapt the in-flight performance when conditions are changing. Consequently, a trajectory is calculated that balances the costs of time and fuel in order to minimize the sum of all direct operational costs.

C. ECON Speed

The crucial parameter when balancing time-related and fuel costs is the speed. Depending on the entered CI the Flight Management Computer (FMC) calculates the most economic (ECON) speed for every phase of the flight. For the minimum CI boundary of 0 time costs are neglected and fuel costs are reduced to minimum. In this case the ECON speed will equal Maximum Range Cruise (MRC) speed. For a high CI the ECON speed increases in order to reduce time costs and a speed up to the operational limitation of the aircraft is possible.

[1]Service charges for ground handling processes are also part of variable direct operating costs but cannot be optimized within the flight planning process.

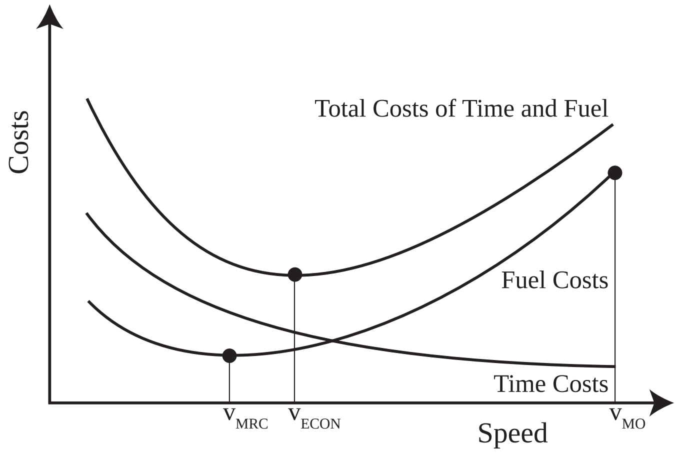

Figure 2. Impact of speed on operating costs

Figure 2 presents both fuel and time-related costs depending on the speed.

According to this figure flying with speed below or above to the ECON speed corresponding to the optimum CI will cause an increase of total costs. For low speed the fuel savings will not compensate the inevitable higher time costs and vice versa for higher speed. It must be stated that on closer examination the relation between speed and operating costs is more complex because the ECON speed varies significantly in dependence on the flight conditions. Fuel cost curve is dependent on the gross weight of the aircraft, assigned flight level (FL), the air temperature as well as the wind conditions. Time cost curve is dependent on ground speed and with it strongly influenced by the wind. This leads to shifting curves in dependence of the mentioned parameters and with it variations of the ECON speed. However, since during the flight planning process as well as the communication between the pilots and air traffic controllers normally indicated air speed (IAS) or Mach number is used, the upcoming results in Section IV refer to these speeds as well (by default with no wind and no deviation from ISA conditions).

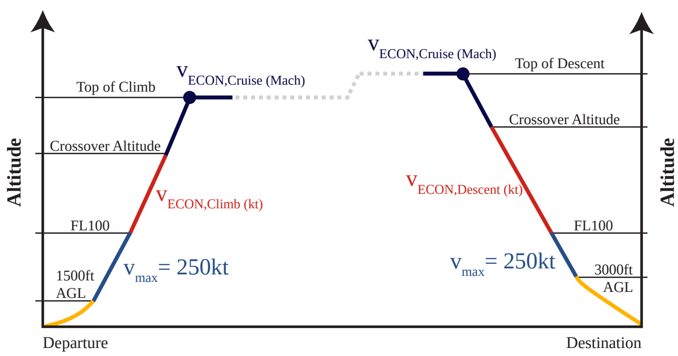

Figure 3. Speed during climb, cruise and descent, based on Lido/Flight specification for ECON Climb/Descent [7]

As depicted in Figure 3 three different speed regimes can be identified for each flight. The speed below FL100 is restricted to 250 kt IAS according to ATC rules. As the ECON speed of most aircraft types is equal or higher for this altitude IAS is 250 kt below FL100 for almost every flight. Between FL100 and the crossover altitude ECON climb speed is measured in knots (IAS), above crossover altitude ECON Mach is applied during the remaining climb and cruise. The ECON speed is corrected during cruise phase with every step climb and when mass reduces due to fuel consumption. When reaching the top of descent same procedures are applied vice versa.

III. Methodology

In order to analyze all effects of the cost index concept and corresponding ECON speeds a simulation was undertaken using the state-of-the-art flight planning tool Lido/Flight. More than 4,000 operational flight plans have been calculated considering different aircraft types and realistic boundary conditions. In the following a short overview of the simulations setup is provided. Furthermore, in order to enable an assessment of flight profiles based on realistic cost indices, the development of appropriated cost scenarios is presented.

A. Simulation Setup

1) Aircraft Types: Every type of aircraft has its own characteristics and is therefore individual in size, in-flight performance, flight efficiency and popularity. For a representative but also feasible survey a limited sample with three different aircraft types was chosen covering national short-haul flights as well as international long-haul flights.

With the Airbus 320, Airbus 330 and the Boeing 747 three aircraft types were selected that are each among the top ten of the popularity ranking in Europe [8]. It can be assumed that with regard to size and in-flight performance, aircrafts of the same family or aircrafts of competing manufacturer will show similar results. For a validation of this assumption it is strongly recommended to continue with further studies using the same approach.

Table II
Aircraft Types of the Sample

Aircraft	Airbus 320-214	Airbus 330-323	Boeing 747-438ER
Engine (#)	CFM56-5B4/P (2)	PW4168B (2)	CF6-80C2B5F (4)
DOM [t]	44	122	185
MZFM [t]	61	173	252
MLM [t]	65	185	296
MTOM [t]	77	230	413
Fuel capacity [l]	23859	97530	241140
Passenger capacity [PAX]	150	295-335	416-524
Payload[2] [kg]	11764	39167	55018
Max altitude [FL]	398	410	450
Max ECON speed	340 kt/M0.80	330 kt/M0.86	364 kt/M0.92
Cost index range	0–999 kg/min	0–999 kg/min	0–9999 100lb/h
Range [NM]	3000	5650	7670

[2]The payload was defined by taking the average load factor of the relevant distance classes of the database from the Association of European Airlines (A320: 69.2%, A330: 77.1%, B747: 81.9%) [9]

2) City Pairs: For a sample of applicable city pairs the study was focused on connections with an assumed high potential for delay costs. Especially flights to airports with many interconnecting flights (Hubs) can be seen as very critical regarding probable missed connections (Misconnex). If additionally the turnaround processes are planned with a very tight schedule a modification of the CI likely happens in order to reduce flight time and thus delay costs.

The airport of Frankfurt/Main (EDDF) is the third biggest airport of Europe after London-Heathrow and Charles de Gaulle in Paris. The remarkable rate of transfer passengers with over 50% makes Frankfurt to Europeans airport with the highest interconnection rate (London 35%, Paris 32%)[3]. Located in a central area of Europe it is the main hub of Lufthansa. Consequently, it was chosen as the destination airport for all city pairs of the sample in this study.

The selection of the departure airports was based on the 2009 flight schedule of Lufthansa. Due to the limited scope of the study only a feasible number of departure airports were used. They were selected in such a way that a homogenous distribution in geographical location (great circle distance to Frankfurt) and frequency could be achieved. Finally 30 city pairs were defined, each for the Airbus 320 and the Airbus 330. In case of the Boeing 747 two additional city pairs were added due to the extended range capability. In total 80 different departure airports with a distance range from 162 NM (EDDL) to 6449 NM (SAEZ) were applied (12 of these served by both the A330 and the B747).

3) Flight track: For each city pair an identical routing was applied for the entire cost index range. The routing was optimized using a Minimum Cost Track with the default value for time costs and the actual fuel price of the Lido/Flight database.

4) Fuel Policy: The fuel policy was based on the Commission Regulation (EC) No 859/2008 (EU-OPS) 1.255[4]. Alternate fuel was simulated with a fixed amount of fuel to reach safely the alternate airport Frankfurt Hahn (EDFH).

5) Weather: To ensure a high degree of comparability all flights have been calculated under ISA conditions without any wind component.

B. Realistic ranges of cost indices

In order to enable the assessment of realistic ranges of speed and vertical profiles, first realistic ranges of future cost indices are presented based on cost scenarios. Costs caused by a flight are hard to predict as they are directly connected to the specific flight event. Whereas fuel cost can comparatively easily be assessed, especially the quantification of time cost is more difficult. This is mainly due to delay costs, which can have a significant impact on the total operating costs of the flight. Delay costs are affected by the length of delay, the number and status of all involved passengers and "network effects" on other connected flights. Basically, a flight delay can cause "hard" costs for compensation such as meal or drink vouchers, the rebooking of passengers or, if a rebooking is impossible the same day, a hotel accommodation. "Soft" costs are the result of a loss in revenue due to unsatisfied passengers who abandon the airline service in future as a result of the delayed flight [10]. The amount of compensation payments is regulated by law. In Europe it is based on the Regulation (EC) No 261/2004 of the EU Parliament[5].

A comprehensive approach of estimating delay costs was undertaken by the Westminster University of London, commissioned by the Eurocontrol Performance Review Unit. Since this study proved the consideration of an extended amount of cost factors compared to previous studies (e. g. undertaken by the Institut du Transport Aérien, published in November 2000) the current paper completely refers to the results of the Westminster study. For passenger delay costs a low, base and high scenario was defined taking into account a rise of compensation costs with increasing delay minutes. The resulting average costs per passenger and delay minute for all three scenarios are listed in Table III.

Table III
COMPENSATION COSTS PER PASSENGER AND MINUTE [10]

Delay [min]	1–15	16–30	31–45	46–60	61–75	76–90	91–119	120–179	180–239	240–299	> 300
Low	0.06	0.17	0.26	0.35	0.42	0.47	0.58	0.75	0.89	0.92	1.15
Base	0.13	0.36	0.63	0.89	1.11	1.24	1.47	1.75	1.98	2.03	2.40
High	0.15	0.43	0.72	1.03	1.27	1.42	1.69	2.03	2.31	2.38	2.82

Values in EUR/min

Considering the passenger capacity and average payload of the aircraft, the costs of Table III can be transformed into costs per flight and delay minute. This approach is depicted in Table IV for all three types of the study (base scenario, load factor 0.75). The coefficient for payload and passenger conversion was derived from the Westminster University approach. It has to be clarified that this calculation is not taking into account the "network effect" and higher crew and maintenance costs.

Table IV
COMPENSATION COSTS PER FLIGHT AND MINUTE BASED ON WESTMINSTER UNIVERSITY APPROACH [10]

Delay [min]	1–15	16–30	31–45	46–60	61–75	76–90	91–119	120–179	180–239	240–299	> 300
A320	15	42	73	103	128	143	170	202	228	234	277
A330	29	80	141	199	248	277	328	390	442	453	535
B747	41	114	199	281	350	391	464	552	624	640	757

Values in EUR/min

It becomes clear that time costs per minute increase significantly with every delay minute, in particular caused by the

[3]http://www.ausbau.fraport.com/cms/default/rubrik/6/6963.basic_facts.htm (25/04/2009)

[4]http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:254:0001:0238:EN:PDF (13/05/2009)

[5]http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:046:0001:0007:EN:PDF (31/01/2010)

increased probability of rebooking or even hotel accommodations. If the individual flight is early compared to schedule, time costs often appear to be very small due to the possibility to use up the strategic buffer typically foreseen by the network planning of the airlines. The amount of time costs is then strongly influenced by the way the crew salaries are calculated by the airlines. Since previous studies (e. g. [11]) mainly focus on delay costs only, further research is needed concerning the calculation of true time costs for early flights. Hence, within this study a minimum of 0 EUR per minute is assumed. However, true time costs even for early flights are expected to be higher. Current fuel price is estimated by the IATA[6] to 0.45 EUR per kg. Since increasing prices are rather expected for the coming years the range of fuel costs is assumed between 0.30 EUR per kg (fuel price in 2004) and 1.50 EUR per kg (peak value so far in 2008 plus an allowance of 50%). Based on the presented values Table V presents the appropriate range of cost indices that are supposed to be realistic in the future.

Table V
COST INDEX RANGE FOR A320 [KG/MIN]

	0 EUR/min (no delay)	15 EUR/min (<15 min delay)	277 EUR/min (>300 min delay)
0.30 EUR/kg (low scenario)	CI = 0	CI = 50	CI ≈ 900 (max)
0.45 EUR/kg (base scenario)	CI = 0	CI = 33	CI ≈ 600
1.50 EUR/kg (high scenario)	CI = 0	CI = 10	CI ≈ 180

The range of cost indices to be expected for the A320 includes values between 0 and 900 kg/min and as such covers almost the complete CI range of the FMS. Same analysis performed for the A330 even leads to a maximum CI of approx. 1800 kg/min that even exceeds the possible FMS range. Maximum CI for Boeing 747 accounts for 3300 given in 100lb/h (corresponding to 2500 kg/min). The following section presents the respective flight profile ranges, again with particular focus on the A320 example.

IV. RESULTS

The speed is the main control variable when changing the cost index setting. It plays the key role in terms of balancing flight time and fuel consumption. However, as described above, a different speed can have significant effects on many other flight parameters of the entire flight profile, such as the optimum altitude or the optimum point for the top of climb and top of descent. In this paper the focus is set to speed and the top of descent since these values are considered to have the strongest impact on the Air Traffic Management and Control system.

A. *Range of speeds*

Figure 4 gives an overview of the typical ECON speeds for the A320 during the cruise phase. The ECON speed depends primarily on the actual altitude and mass (ISA deviation and wind components were disregarded, see Section III-A for details) of the aircraft. It will alter with the increasing flight time due to performed step climbs and the reduction of the remaining fuel amount which reduces the aircraft mass. The depicted values represent the respective average speed that was calculated by taking into account the minimum and maximum speeds between top of climb and top of descent. Thus, the average values imply the speed variation of all factors mentioned above. Each grayscaled bar represents the speed average of a distance range.

The chart of Figure 4 shows a minimum cruise speed of Mach 0.59 for a selected CI of 0 and a maximum speed of Mach 0.80 for CI 130 which results in a total deviation up to 0.21 between both CI settings. However, on closer examination the ECON cruise speed is influenced by the flown distance, strongly below 250 NM. Flights inside this distance range show a cruise speed far below than all other distance ranges. This is due to the lower cruise altitude (see Figure 5). Considering all flights with a distance of more than 500 NM a minimum speed of 0.72 is applied for a CI of 0. An ECON speed of Mach 0.80 is achieved for cost indices 100 and 130. This is equal to the defined maximum operating speed within the ECON speed range.

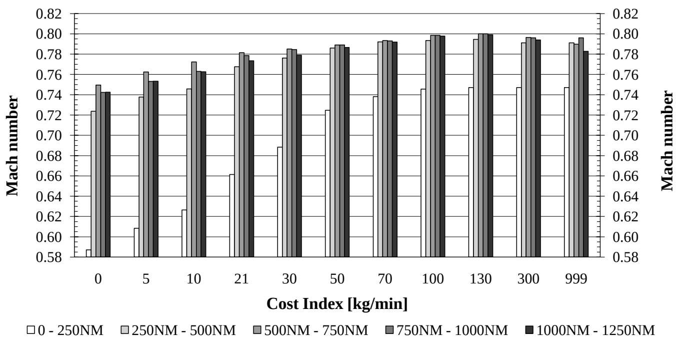

Figure 4. ECON Cruise Speed A320

It becomes obvious that the maximum speed of Mach 0.8 is reached far below the cost index limitation of 999 kg/min. Furthermore for higher CI than 130 only a very slight reduction of air speed can be noticed. This behaviour becomes clear with the analysis of the corresponding altitudes. Figure 5 illustrates the optimum flight level for each cost index of the study. Starting from a cost index around 100 the flight level decreases with higher cost indices finally ending between FL240 and FL280 for the CI limitation of 999 kg/min. This is due to the fact that ECON speed is geared to the ground speed. Because the sound of speed decreases in lower altitude the aircraft can obtain a higher ground speed if a mach number close to the maximum value of Mach 0.8 is applied in a lower flight level.

Moreover the low altitude for flights with less than 250 NM depicted in Figure 5 causes the low air speed for short distance flights that has been explained above. The altitude level of around FL260 in average is applied for this distance range.

[6]http://www.iata.org/whatwedo/economics/fuel_monitor/price_analysis.htm (31/01/2010)

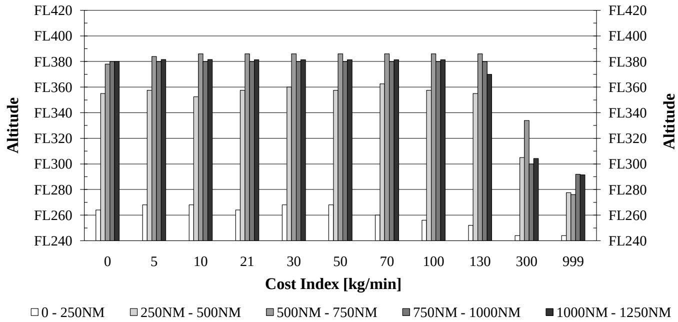

Figure 5. Average Flight Level A320

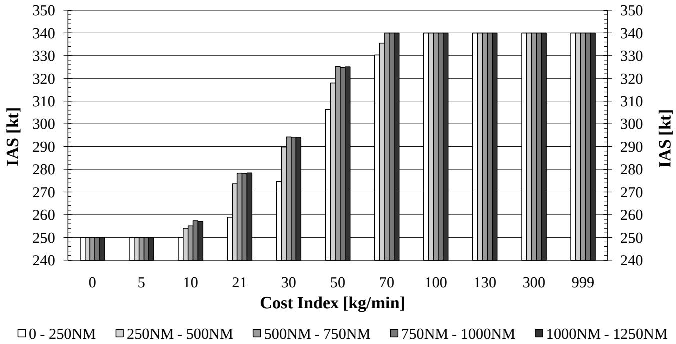

Figure 7. ECON Descent Speed A320

However, the identical behaviour appears for high cost indices with a reduction of the optimum altitude to FL240.

During the climb and descent phase the ECON speed above the crossover altitude (see Section II-C) is based on the speed (Mach) at the top of climb and the top of descent respectively. However, the speed below the crossover altitude seems to be the crucial parameter of both with a considerable impact on the aircraft guidance by the Air Traffic Control close to or inside the Terminal Manoeuvring Area (TMA).

According to Figure 6, the ECON climb speed for the A320 shows a similar behaviour as already presented for the cruise speed. The climb speed increases from 279 kt for the cost index of 0 up to the speed of 340 kt for cost indices higher than 130. The speed of 340 kt represents the maximum operating speed within the ECON speed range. The deviation leads to a range of 61 kt between aircrafts operating with the two mentioned cost index settings.

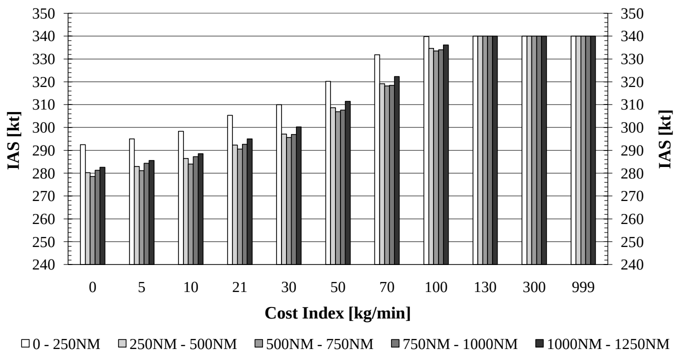

Figure 6. ECON Climb Speed A320

On closer examination of the ECON descent speeds shown in Figure 7 the speed deviation between minimum and maximum speed is considerably higher. The maximum speed of 340 kt is already applied for a CI of 100 and in case of a flight distance of more than 500 NM even for a CI of 70. Furthermore a CI of 5 and less generates an ECON speed of 250 kt. The measured descent speed range of 90 kt between a CI setting of 5 to 100 is remarkable and emphasizes the issues addressed by the current investigation.

ECON climb and descent speed is only slightly affected by the flight distance. The ECON speed of flights with a distance above 250 NM doesn't vary more than ± 5 kt for both the ECON climb and descent speed. It is noticeable that the ECON speed of the distance range between 0 and 250 NM is high in climb phase and lower in descent phase compared with the speed for flights with more than 250 NM. This is due to the reduced optimum flight level described above and the fact that the indicated air speed decreases relative to the ground speed for a higher altitude.

In Table VI an overview of the respective speeds of all three aircraft types is provided. Since Section III-B proved that realistic cost indices can cover almost the complete CI range supported by the FMS, speed range is presented between CI 0 and CI 999 [kg/min]. Due to impact of the reduced flight level of the A320 profile below 250 NM the speed values of this distance range are excluded. If compared to the ECON speeds of the A320, the A330 and the B747 show a similar characteristic. However, whilst the speed range between minimum and maximum speeds in climb and cruise differ less significantly the speed range in the descent phase is up to 96 kt for the B747. This is remarkable since it is equal to a variation of 30% and more than two times higher than in climb phase.

Table VI
ECON SPEED RANGE

Aircraft	A320	A330	B747
ECON cruise speed min	Mach 0.72	Mach 0.79	Mach 0.79
ECON cruise speed max	Mach 0.80	Mach 0.84	Mach 0.88
ECON cruise speed range	Mach 0.08	Mach 0.05	Mach 0.09
ECON climb speed min	279 kt	293 kt	323 kt
ECON climb speed max	340 kt	320 kt	362 kt
ECON climb speed range	61 kt	27 kt	39 kt
ECON descent speed min	250 kt	270 kt	260 kt
ECON descent speed max	340 kt	320 kt	356 kt
ECON descent speed range	90 kt	50 kt	96 kt

B. *Top of descent*

In addition to the speed, a crucial parameter regarding aircraft guiding and control can be identified with the top of climb and descent. Especially the optimum top of descent (TOD) is very hardly to maintain. Restrictions in speed and altitude given by the local Air Traffic Control make a continuous idle descent difficult to achieve. In most cases this leads to an early start of descent far away from optimum and will finally result in higher fuel consumption. The TOD is optimal if the destination airport is reached by performing an idle descent with the respective ECON descent speed. Consequently, the optimum TODs for different cost indices will differ due to the wide range of ECON speeds presented in last section. For the A320 a selection of TODs associated to different cost indices are depicted in Figure 8 with the related distance to destination airport EDDF. The shown values are based on the CI specific average TOD of all flights of the sample.

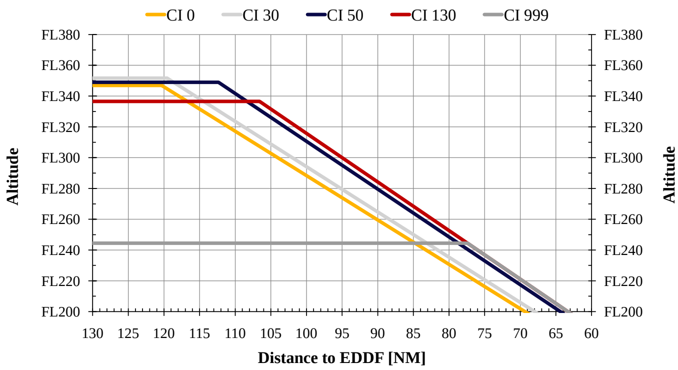

Figure 8. Top of Descent A320

With increasing cost indices and higher ECON speed the TOD "moves" towards the destination airport. If the TODs are compared around FL350 a deviation of ca. 11 NM can be stated between the minimum and maximum remaining distance to the destination airport EDDF. According to Table VII the deviation can rise to 14 NM and 18 NM in case of the B747 and the A330.

Table VII
TOP OF DESCENT RANGE

Aircraft	A320	A330	B747
Typical Altitude	FL350	FL400	FL360
Max descent length	120 NM	159 NM	138 NM
Min descent length	109 NM	141 NM	124 NM
Deviation of descent length	11 NM	18 NM	14 NM

V. IMPACT ONTO THE AIR TRAFFIC MANAGEMENT SYSTEM

Both the identified range of speeds and vertical flight profiles implies additional work for air traffic controllers due to the increasing amount of heterogeneous traffic. Although CI based flight planning has long time been a feature of airline operations, the increasing impact onto the ATM system is nowadays caused by the rising number of flights reverting to this functionality. Especially short haul flight operators consider the use of CI more and more as beneficial in view of increasing fuel prices. The widespread use of CI based flight planning software (e. g. "Lido/Flight" [12]) as well as the ongoing developments for regional aircraft (e. g. "Pacelab™ CI OPS" [13]), stress out the appropriate changes in the flight planning processes and aircraft operations. Contrary to the past, when variations in forward and vertical speeds were mainly caused by different flight performances between the aircraft types, controllers are consequently experiencing an increasing range of speeds of the same aircraft type [1]. Two main challenges have to be stressed out in this context.

First challenge is caused by the reduced predictability of flight profiles. Prediction depending on the aircraft type is well possible based on the controller experiences, whereas the variations based on the chosen CI are dynamically influenced by the airlines and barely predictable today. Though the current ICAO flight plan includes information concerning the cruising speed and as such provides particular information, only speed changes of more than 5% have to be reported to ATC [14]. Hence, a cruising speed of Mach 0.78 indicated in the flight plan can theoretically lead to a range between Mach 0.81 and 0.75, which is adequate to a difference of approx. 40 knots in the upper airspace. Additionally, significant variations in the vertical speeds in dependence on the CI lead to uncertainties. The Single European Sky ATM Research Programme (SESAR) meets this challenge by the envisaged change of the current flight plan into a more detailed 4D Trajectory including a more detailed and precise flight profile data shared through a System Wide Information Management (SWIM) [15].

However, even if predictability can be improved, second challenge arises from the operational difficulty to manage heterogeneous traffic. Both deviations in forward and in vertical speed seem in general to influence controller workload and hence reduce capacity. Looking more into detail, current research studies estimate the influence of speed variances between a pair of aircraft on the workload as minor important than the number of vertical movements [16]. Hence it is assumed, that the avoidance of speed variances during climb and descent should have higher priority than the avoidance of speed variances in cruise. As stated in [1] aircraft operators seem to be willing to accept general speed control during climb if it is considered necessary to maintain safe separation. However, during descent the pre-advice of ATC intentions regarding time constraints is preferred due to the wish to plan the optimum flight profile under consideration of such constraints. More research on appropriate procedures in order to maximize capacity and efficiency under maintenance of an adequate safety level is required.

Consequently, the increasing range of speed due to CI based operations must both be considered as a safety issue due to the decreased potential to separate aircraft within harmonized traffic flows as well as an operational requirement that Air Navigation Service Providers have to face. As such the appropriate controller training should be conducted with particular focus on safety awareness.

VI. CONCLUSION AND FURTHER RESEARCH

Although operational flight planning is under responsibility of the airspace users, these procedures are becoming more and more of high importance for the ATM system and the associated Air Traffic Control procedures. Hence, the understanding of the relevant principles in flight planning processes, including the CI based flight profile optimization, contributes both to the safe and efficient ATM system today as well as its convenient modernization during the next years.

The current paper proved that the variation of the cost indices with regard to the individual airline preferences lead to significantly increased ranges of flight profiles regarding speeds and vertical profiles. It is shown that in view of the expected range of time-related and fuel costs the aircraft speeds will capture almost the full range between maximum range cruise (with minimum fuel consumption per distance) and the maximum operating speed. Particular challenges arise during climb and descent where speed variations of up to 30% have to be expected without any predictability for air traffic controllers due to the missing of appropriate information given in the current ICAO flight plan format.

Situation may become more challenging in the future because the flight planning process is beginning to revert to ”dynamic cost indices”. While current flight plans are mainly based on an aircraft specific CI that is changed by the airlines very rarely, it is foreseen to dynamically adapt the CI to the individual conditions of each flight. This will in a first step include the cost index calculation for each individual flight during the flight planning. In a second step it will even lead to dynamic changes during the flight operations, mainly depending on changing wind conditions, weather predictions or network requirements (e. g. connecting flights) at the destination airport. This will increase the variation in speeds and vertical profiles for any particular flight independent of the aircraft operator. TU Dresden is currently developing a methodology to dynamically calculate the CI. Results will be used to assess the benefits for airlines in view of reduced fuel burn and increased punctuality as well as contributions to the environmental sustainability of air transport. With it, a more detailed understanding concerning flight profile variations to be expected in the future is aspired.

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Author Biographies

Wilhelm Rumler studies traffic engineering at Technische Universität Dresden. In his study he worked on different projects regarding ATM and flight efficiency. From 2008 to 2009 he performed research on the effects of the cost index on the ATM system supervised by TU Dresden and Lufthansa Systems. Currently he is continuing with a related research in his thesis that is undertaken in cooperation with Lufthansa German Airlines in the context of the dynamic cost index concept.

Thomas Günther works at Technische Universität Dresden, Chair of Air Transport Technology and Logistics as a scientific assistant. Within his PhD thesis he is currently working on the assessment of efficiency improvements under consideration of ATM network effects. The development and application of a proper methodology shall contribute to a better understanding of according potentials regarding lateral, vertical and speed profiles as well as queue management and surface movement aspects. Thomas studied traffic engineering at TU Dresden where he received his Diploma in 2004.

Hartmut Fricke (born in Berlin, Germany in 1967) studied Aeronautics and Astronautics at Technische Universität (TU) Berlin from 1985–1991. From 1991 to 1995 he was a research fellow in Flight Operations, Airport Planning, and ATM at TU Berlin, where he completed his doctor thesis in ATM (ATC-ATFM Interface). In 2001 he finished his Habilitation on ”Integrated Collision Risk Modeling for airborne and ground based systems”. This included HIL experiments with an A340 full flight simulator in co-operation with EUROCONTROL Experimental Centre (EEC). Since December 2001 he has been Head of the Institute of Logistics and Aviation, and Professor for Aviation Technologies and Logistics at TU Dresden. In 2006 he was appointed Member of the Scientific Advisory ”Board of Advisors” to the Federal Minister of Transport, Building and Urban Affairs in Germany.

Urban Weißhaar is currently team leader in the product development of Lufthansa Systems, division Airline Operations Solutions. He is responsible for planning and steering of strategic projects for the development of the flight planning software Lido/Flight. He represents Lufthansa Systems at international conferences and committees, dealing with ATM and environmental issues. Urban studied physics at the University of Freiburg where he received his Bachelor degree. After this he moved to the Institute of Meteorology and Climate at University of Karlsruhe where he finished his Diploma of Meteorology.