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DESCENT TRAJECTORY MODELLING FOR THE LANDING SYSTEM PROTOTYPE

Henrich GLASER-OPITZ[1*], Ján LABUN[2], Kristína BUDAJOVÁ[3], Leonard GLASER-OPITZ[4]

[1, 2, 3]*Faculty of Aeronautics, Technical University of Košice, Slovakia*
[4]*Slovak Republic Air Traffic Services SR (LPS SR š. p.), Bratislava, Slovakia*

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Abstract. This paper gives another view on a method used for aircraft approach and landing phase of flight that enables replacement of standard glideslope. Proposed Landing System is based on Terrain Reference Navigation (TRN) using own created terrain elevation database, based on Radar Altimeter (RA) measurements compared to the overflown terrain. Simulations were performed on a chosen airport (KSC – Košice Airport) and aircraft (Boeing 737-800), where descend procedures was designed based on real airline data in compliance with Initial 4D Trajectory (i4D). Descend trajectory was modelled with EUROCONTROL Base of Aircraft DAta (BADA) performance model as a Continuous Descent Approach (CDA) from proposed merging point to the KSC RunWaY (RWY) threshold. This method was proposed to enhance pilot situational awareness in situations when standard Instrument Landing System (ILS) information could be lost or misleading and without the need of any ground station for successful navigation and guidance to the RWY threshold. Landing System prototype flight test were performed on full mission flight simulator.

Keywords: terrain relative navigation (TRN), landing system, base of aircraft data (BADA), continuous descent approach (CDA), initial 4D trajectory (i4D), full mission flight simulator.

Notations

ACMass – aircraft mass;
AGL – above ground level;
AMSL – above the mean see level;
ARPM – airline procedure model;
ATCo – air traffic controller;
BA – barometric altimeter;
BADA – base of aircraft data;
CAS – calibrated aircraft speed;
CDA – continuous descent approach;
CFIT – controlled flight into terrain;
CFMU – central flow management unit;
DEM – digital elevation model;
DLCSim – datalink communication simulator;
ECAC – European civil aviation conference;
ESF – energy share factor;
EUROCONTROL – European organisation for the safety of air navigation;
FL – flight level;
FSX – Microsoft flight simulator;
GPS – global positioning system;
GRAD – gradient angle of descent (or climb trajectory);
GUI – graphical user interface;
i4D – initial 4D trajectory;
ICAO – International civil aviation organization
ILS – instrument landing system;
INS – inertial navigation system;
KSC – Košice airport;
MAD – mean absolute difference;
MTOW – maximum take-off weight;
RA – radar altimeter;
RNAV – area navigation;
RNP – required navigation performance;
ROCD – rate of climb or descent;
RWY – runway;
TAS – true aircraft speed;
TCP/IP – transmission control protocol/internet protocol;
TEM – terrain elevation matching;
TEMo – total energy model;
TERCOM – terrain contour matching;
TRN – terrain reference navigation.

*Corresponding author. E-mail: *henrich.glaser-opitz@eurocontrol.int*

Introduction

The continuing growth of aviation increases demands on airspace capacity therefore emphasizing the need for optimum utilization of available airspace. It is expected that all future RNAV/RNP applications will identify the navigation requirements through the use of performance specifications rather than defining equipage of specific navigation sensors (ICAO 2013).

This paper describes a work where the final phase of flight – descent and approach to the destination airport could be done more efficiently and safe using performance based navigation principles. The flight safety is one of the most important features in aviation. In recent years several times occurred accidents or incidents that took place due to not mechanical failure or maintenance malfunction, but due to pilot CFIT, caused by the loss of pilots situational awareness. CFIT includes among the collision with the ground at low altitudes, also aircraft impacting hillside and mountainsides while at higher altitudes, even thousands of feet above mean see level. The current initiative is to improve aviation safety, with a primary focus on reducing CFIT. This can be achieved with integration of digital terrain database into TRN and other on-board navigation data (Meduna 2011). The output of this paper is directly applicable on the CFIT accidents reduction by vertical position uncertainty reduction increasing the pilot situational awareness. TRN together with digital terrain database has the potential for vertical channel accuracy improvements during the approach and landing procedure for both civil and military applications. Terrain profile knowledge enables integration of RA into the navigation solution. The TRN implementation is completed with simulations using created digital terrain database. Descent trajectory used in developed Landing System is modelled using EUROCONTROL BADA performance model. This trajectory is designed for a specific airport (KSC) in compliance with i4D trajectory and then modelled and implemented into the Landing System. The Landing System was designed to be able to interact with FSX/Prepar3D flight simulator and to communicate with developed DLCSim (Glaser-Opitz, H., Glaser-Opitz, L. 2015b; Glaser-Opitz *et al.* 2015). It increases mutual interaction between pilot and ATCo and improves procedures for pilot and controller testing (e.g. workload) and training.

1. TRN

The main goal of the TEM algorithm is to fuse the information from RA, terrain database, INS and BA measurements. The data output fusion should represent the estimation of the aircraft position together with an estimation error. There exist many ways how to approach this fusion problem. We have chosen the batch correlation TRN concept. The idea is that by collecting a large enough number of measurements, the TRN likelihood surface will collapse to a near-unimodal distribution. This allows position to be uniquely determined from the measurements (ICAO 2013).

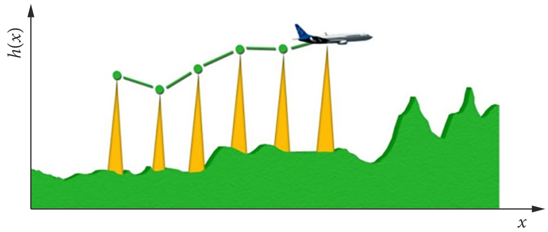

Figure 1. Batch correlation TRN concept (TERCOM)

Figure 1 depicts the process of an aircraft collecting a series of RA measurements along its path, and correlates this resulting measured profile to generate a position estimate. A technique used for position determination is called TERCOM. Several simulations were made using MATLAB® (*https://www.mathworks.com*) implementing TERCOM algorithm and using own created terrain elevation database. Because during take-off or landing phase we expect the curved flight trajectory, the example simulation is concentrated on this case. This flight path consists from 30 samples of elevation data with resolution same as the DEM grid, meaning 900 m long flight path in a rough environment (with higher elevation gradient). Elevation samples are in this case noiseless. Such situation is illustrated in Figure 2.

The blue cross in Figure 3 indicates the estimated position counted by TRN. From comparison with straight flight path simulation one can see, that we better eliminated the uncertainty of estimated position. This happened because the elevation profile of simulated flight path (Figure 4) is even more variable, what leads to smaller amount of possible positions of the aircraft according to the DEM data.

Uncertainty of estimated position due to the smooth terrain under the aircraft can be eliminated by acquiring more data from RA, using DEM with greater resolution (10 m) and using INS or GPS and filtering techniques for better estimation.

2. Descent trajectory modelling with BADA

All simulations to validate the proposed model for trajectory simulations were performed using a specifically chosen type of aircraft. According to EUROCONTROL (2014) data shows that Boeing 737-800 (B738 – BADA designator) represents the most used aircraft in the ECAC area, based on the CFMU traffic statistics over the last 12 months, representing 15.871% off overall traffic. Based on this data B738 was chosen as a suitable representative of European fleet for model validation process, as we are mainly focused on the aircraft with MTOW > 5700 kg, usually used for commercial flights. After the analysis of sustainability, actuality, aircraft models coverage, performance, future development options and accessibility of different models, BADA family 3 was chosen as an appropriate model. BADA 3 model was used for trajectory modelling within the Landing System to model the glideslope and aircraft descent, and approach trajectory.

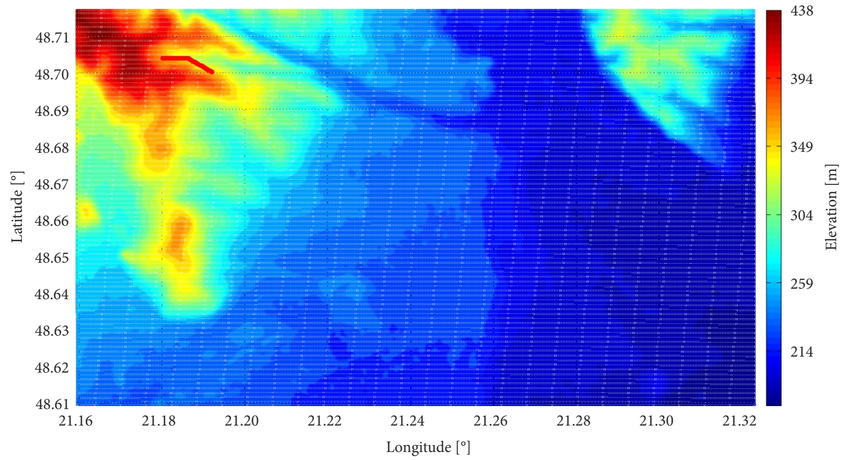

Figure 2. KSC elevation map (30 m resolution) with simulated flight trajectory (curved)

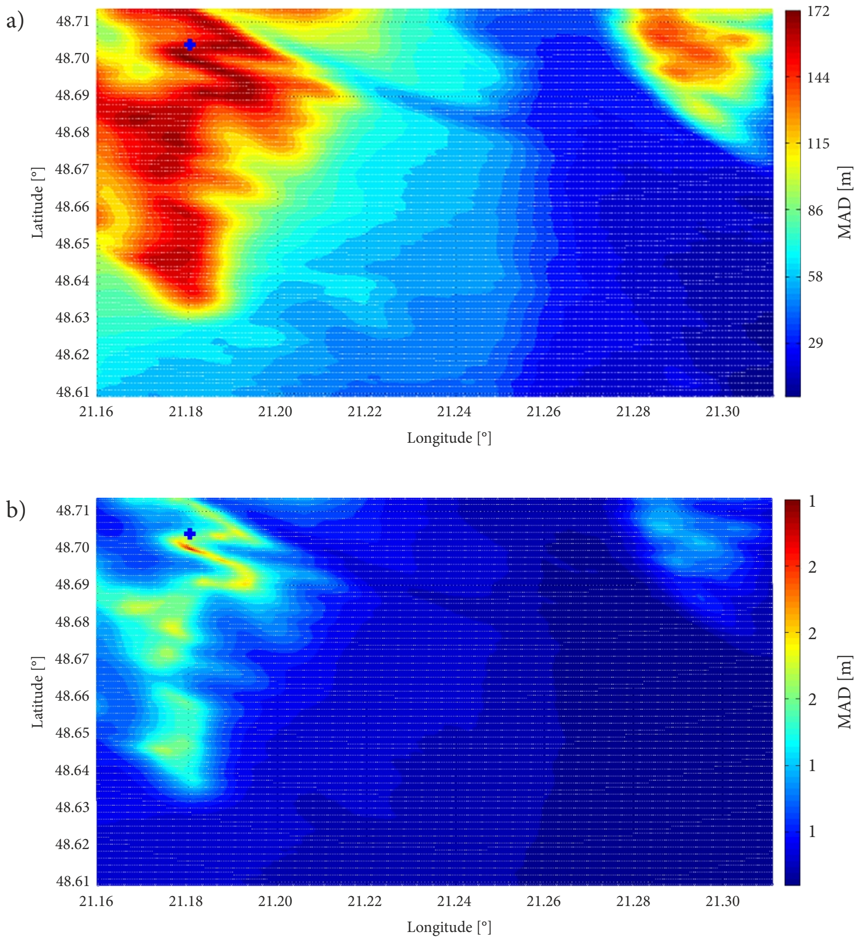

Figure 3. KSC TERCOM MAD map with calculated estimation of current position from simulated flight trajectory (curved – without noise): a – normal scale; b – logarithmic scale

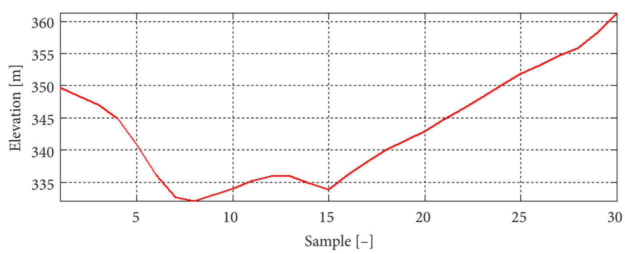

Figure 4. Elevation profile of a simulated flight trajectory (curved trajectory)

2.1. BADA model overview

BADA is based on the so-called TEMo that can be considered as being a reduced point-mass model. TEMo equates the rate of work done by forces (Figure 5) acting in the aircraft to the rate of increase in potential and kinetic energy (EUROCONTROL 2015).

TEMo can be expressed by the Equation (1) as follows (EUROCONTROL 2015):

$$(T-D)\cdot V_{TAS} = m\cdot g_0\cdot\frac{dh}{dt} + m\cdot V_{TAS}\cdot\frac{dV_{TAS}}{dt}, \quad (1)$$

where: T is temperature; D is drag; V_{TAS} is actual TAS speed; m is the aircraft weight; g_0 is gravitational constant; $\frac{dh}{dt}$ is the change in altitude during the time sample of dt.

Calculation the ROCD, where the speed and the throttle are controlled, is the most common situation. Such situation can be calculated using TEMo Equation (1), what can be rearranged in a way of expressing the ROCD calculation as follows:

$$ROCD = \frac{T-\Delta T}{T}\cdot\frac{(THR-D)\cdot V_{TAS}}{m\cdot g_0}\times \frac{1}{1+\left(\frac{V_{TAS}}{g_0}\right)\cdot\left(\frac{dV_{TAS}}{dh}\right)}, \quad (2)$$

where: ΔT is temperature deviation; THR is thrust; D is drag.

As shown in EUROCONTROL (1987) and Gillet *et al.* (2010), equation (1) can be rewritten by introducing an ESF as a function of a Mach number – $f(M)$:

$$ESF = f(M) = \frac{1}{1+\left(\frac{V_{TAS}}{g_0}\right)\cdot\left(\frac{dV_{TAS}}{dh}\right)}, \quad (3)$$

where: M is Mach number.

This leads to:

$$ROCD = \frac{dh}{dt} = \frac{T-\Delta T}{T}\times \left(\frac{(THR-D)\cdot V_{TAS}}{m\cdot g_0}\right)\cdot f(M). \quad (4)$$

As stated in EUROCONTROL (2015), the ESF specifies how much of the available power is allocated to climb or descent as opposed to an acceleration/deceleration while following speed profile during climb or descent. Difference between descent and climb is that the available power is negative for descent.

The change in speed in descent or climb phase can be derived from (3) as follows:

$$dV_{TAS} = \left(\frac{1}{ESF}-1\right)\cdot\frac{g_0}{V_{TAS}}, \quad (5)$$

where: dV_{TAS} is the change in TAS speed with chosen ESF value, which will be used for calculation of speed update for next iteration of simulation algorithm as follows:

$$TAS_{new} = V_{TAS} + dV_{TAS}. \quad (6)$$

Graphical representation of calculated ROCD in descend phase of flight is illustrated in Figure 6, where we are simulating descent with B738 from FL350 to FL100 with constant speed 290 kt.

2.2. KSC ARPM descent design

The way an aircraft is operated differs in function of specific airspace procedures and operating policies of every airline. That is the reason why we have designed and simulated a specific procedure for aircraft descend and approach to KSC. Proposed ARPM for KSC descent and approach is shown in Figure 7.

Figure 8 depicts proposed descent procedure design based on an i4D trajectory concept. We have created a merging point for approach to both runways RWY01/19 at a distance of 29 NM and altitude of 10000 ft. The approach follows standard approach procedures from the 5.5 NM distance at 2500 ft for both RWY with airport elevation of 750 ft AMSL.

This concept allows cabin crew to follow approach route regardless to runway orientation by simply following the same designed paths for both runways. In the figure (Figure 8) could be seen three different colours. Red line is for optimized i4D trajectory concept with continuous descent from altitude 10000 ft to airport's elevation based on BADA model. Alongside routes at each fix are displayed

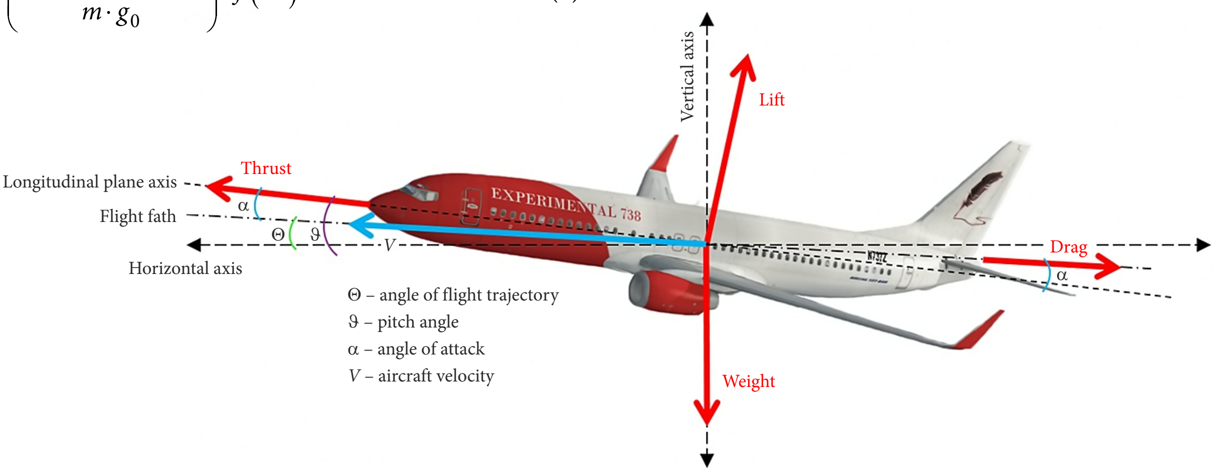

Figure 5. Aerodynamic forces acting on the aircraft (Gričová 2016)

altitudes and distances from runway threshold for each route. Blue line indicates an option for direct entry for approach at each runway with indication of necessary altitude for continuous descent. Black line indicates original route designed for approach at KSC.

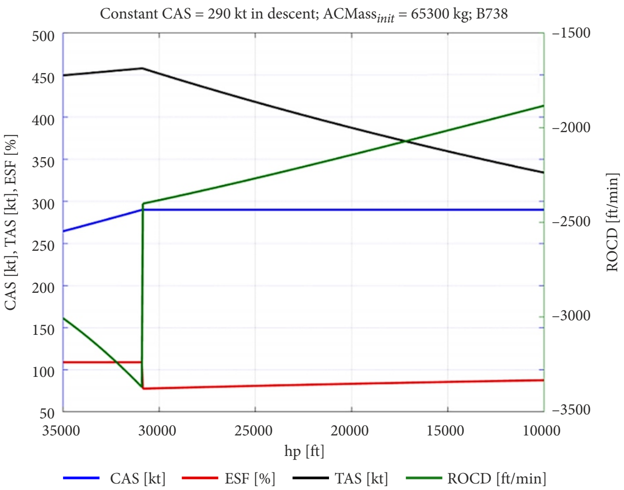

Figure 6. Descending with constant CAS for B738

When we compare blue numbers to black ones, which indicates the original requested altitudes for airplanes approach, lower values could be seen, what leads to lower speed, higher required engine thrust and higher fuel consumption, caused by maintaining lower altitudes.

Proposed descent procedure for KSC descent trajectory (Figure 8) was designed using BADA model for later use in developed Landing System. Figure 9 illustrates a top view descent trajectory initiating from proposed merging point to RWY01 KSC. The whole procedure is designed as a CDA with 3° angle, what means approximately 29 NM long path.

The advantage of such modelling is that we now have the great amount of information for modelled trajectory to be used in developed Landing System for better aircraft position and movement prediction. Data available (Figure 10) includes not only GPS coordinates and altitude, but also other important information, e.g., desired aircraft speed corresponding to defined ARPM and many more.

In depth analysis included descent procedure simulations while changing ESF values together with ACMass. Figure 11 depicts just an example of the different ESF values impact on descent procedure.

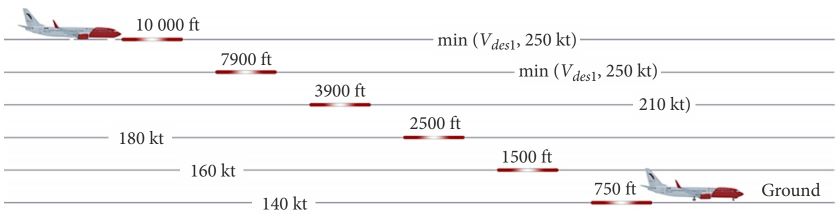

Figure 7. Descent ARPM design for Jet aircraft for KSC

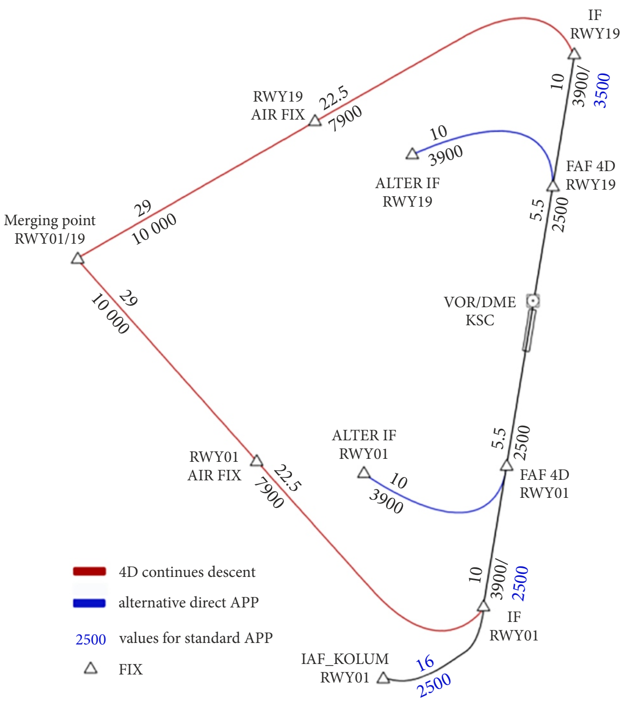

Figure 8. KSC 4D trajectory descent procedure design

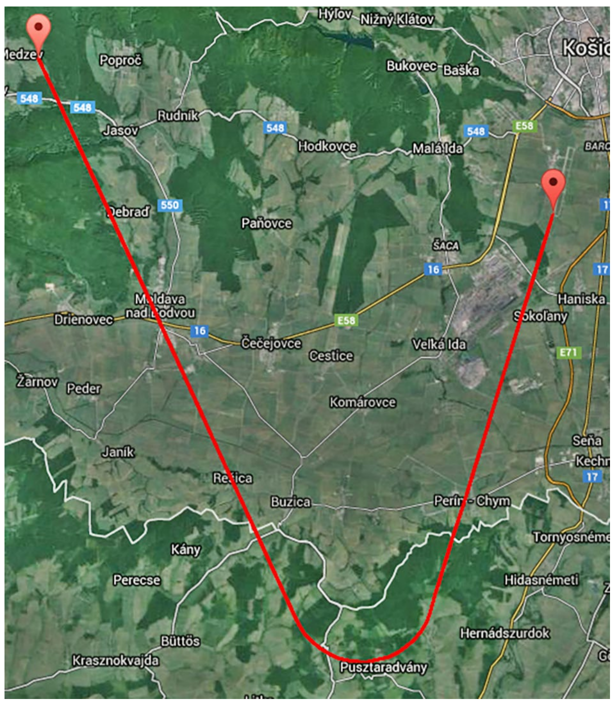

Figure 9. Proposed KSC descent trajectory modelled using BADA

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Hp[ft]	ACMass[kg]	CAS[kt]	TAS[kt]	M[-]	ROCD[ft/min]	Grad[deg]	FuelFlow[kg/s]	Fuel[kg]	Time[s]	Distance[NM]	Thr[N]	D[N]	fM[-]	bankAngle[°]	bearing[°]	LAT[°]	LON[°]
2	10000	65300	250	288.7023134	0.452275114	-1532.218816	-3	1.196718817	1.1967188	0	0	80683.95419	43463.68775	0.9016752	0	155.3397492	48.7118	20.92515
3	9974.46302	65298.80328	250	288.5934003	0.4520618779	-1531.640786	-3	1.196572139	2.3932909	1	0.08019508706	80680.54136	43464.20175	0.9017538	0	155.3403838	48.71058613	20.92599456
4	9948.935673	65297.60671	250	288.4845838	0.4518488534	-1531.063268	-3	1.196425604	3.5897165	2	0.1603599205	80677.13193	43464.71458	0.9018323	0	155.3410182	48.70937271	20.92683877
5	9923.417952	65296.41028	250	288.3758637	0.45163604	-1530.486262	-3	1.196279213	4.7859957	3	0.2404945271	80673.72591	43465.22623	0.9019107	0	155.3416522	48.70815974	20.92768261
6	9897.909848	65295.214	250	288.2672399	0.4514234375	-1529.909767	-3	1.196132965	5.9821287	4	0.3205989337	80670.32328	43465.73671	0.9019891	0	155.342286	48.70694723	20.9285261
7	9872.411352	65294.01787	250	288.1587122	0.4512110455	-1529.333782	-3	1.195986861	7.1781155	5	0.400673167	80666.92405	43466.24603	0.9020673	0	155.3429194	48.70573516	20.92936923
8	9846.922455	65292.82188	250	288.0502806	0.4509988639	-1528.758307	-3	1.195840899	8.3739564	6	0.4807172537	80663.5282	43466.75418	0.9021455	0	155.3435526	48.70452355	20.930212
9	9821.44315	65291.62604	250	287.9419448	0.4507868921	-1528.183341	-3	1.19569508	9.5696515	7	0.5607312205	80660.13574	43467.26116	0.9022235	0	155.3441855	48.70331238	20.93105441
10	9795.973428	65290.43035	250	287.8337049	0.45057513	-1527.608883	-3	1.195549404	10.765200	8	0.6407150941	80656.74665	43467.76698	0.9023015	0	155.3448182	48.70210167	20.93189647
11	9770.51328	65289.2348	250	287.7255606	0.4503635773	-1527.034933	-3	1.195403869	11.960604	9	0.720668901	80653.36092	43468.27164	0.9023794	0	155.3454505	48.7008914	20.93273817
12	9745.062698	65288.0394	250	287.6175118	0.4501522336	-1526.46149	-3	1.195258477	13.155863	10	0.8005926678	80649.97856	43468.77515	0.9024572	0	155.3460826	48.69968158	20.93357951
13	9719.621673	65286.84414	250	287.5095584	0.4499410985	-1525.888553	-3	1.195113227	14.350976	11	0.8804864211	80646.59956	43469.2775	0.9025349	0	155.3467144	48.69847221	20.9344205
14	9694.190197	65285.64902	250	287.4017003	0.4497301719	-1525.316121	-3	1.194968118	15.545944	12	0.9603501873	80643.2239	43469.77869	0.9026125	0	155.3473459	48.69726329	20.93526113
15	9668.768262	65284.45406	250	287.2939373	0.4495194534	-1524.744195	-3	1.194823151	16.740767	13	1.040183993	80639.85159	43470.27873	0.9026900	0	155.3479771	48.69605481	20.9361014
16	9643.355858	65283.25923	250	287.1862693	0.4493089427	-1524.172773	-3	1.194678325	17.935446	14	1.119987864	80636.48263	43470.77762	0.9027674	0	155.3486081	48.69484679	20.93694132

Figure 10. An example of descent trajectory data modelled with BADA

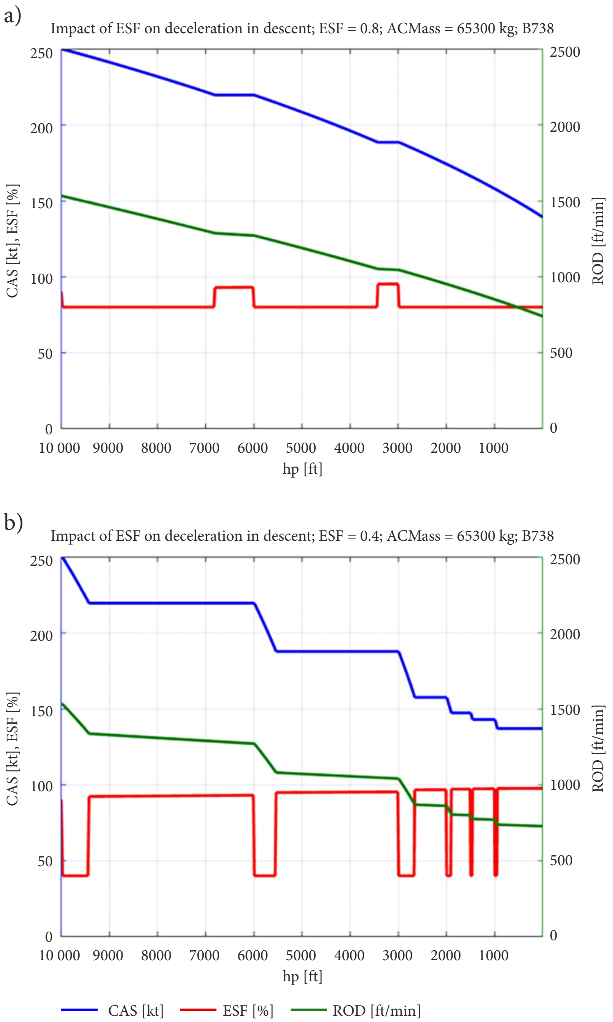

Figure 11. Impact of ESF on deceleration for ESF (ACMass = 65300 kg): a – ESF = 0.8; b – ESF = 0.4

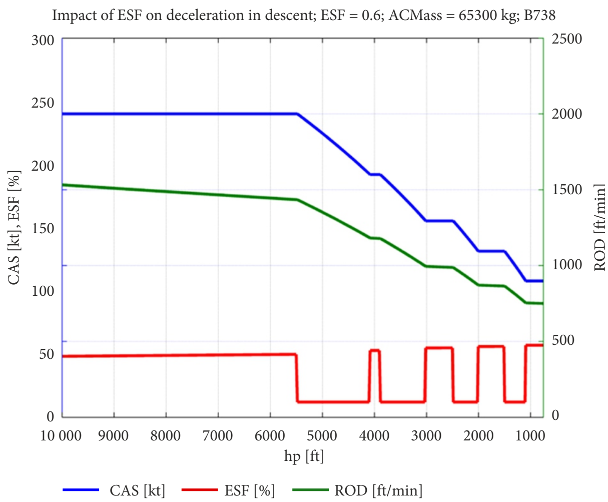

Figure 12. Deceleration in descent on KSC based on designed procedure from the merging point

After detailed analysis partially published in paper by Gričová (2016) and Glaser-Opitz *et al.* (2016), it was found out that according to designed descent trajectory and descent ARPM for KSC, the most suitable value for ESF will be 0.6 (Figure 12). This value for deceleration simulates the most similar procedure to the real one. In the end, it represents the optimal amount of fuel burned during descent phase in comparison with smaller ESF values. Greater ESF values cause the violation of designed speed schedule. Also more rapid deceleration caused by smaller ESF values increases time to descend to the RWY threshold. Figure 12 depicts simulation of descent with constant 3° gradient angle, designed based on latest requirement on descent trajectory.

2.3. BADA model validation tool

Implementation of BADA model into the Landing System algorithms requires validation, to see if the aircraft is behaving as it is supposed to. The validation tool (Figure 13) was used to validate all output parameters including aircraft weight or fuel flow and other important parameters in all phases of flight and under various conditions we can encounter designing the Landing System using BADA model. BADA model validation tool is depicted on Figure 13.

Real time simulation is based on time integration method with step frequency set to 1 Hz. Figure 13 is showing only 6 graphs for BADA output parameters, with an option to choose more of them, specifically: Hp (geopotential altitude); ROCD; CAS/TAS; GRAD; FFlow (aircraft fuel flow); FWeight (weight of fuel burned from the start of the simulation); ACMass (changed due to fuel burned during the flight); Distance (travelled by aircraft from the start of simulation); Air temperature (time change of air temperature from the simulation start); Air pressure (time change of air pressure from the simulation start); Air density (time change of air density from the simulation start); Thrust (actual engine thrust); Drag (actual aircraft drag); Mach (hach speed); actual ESF.

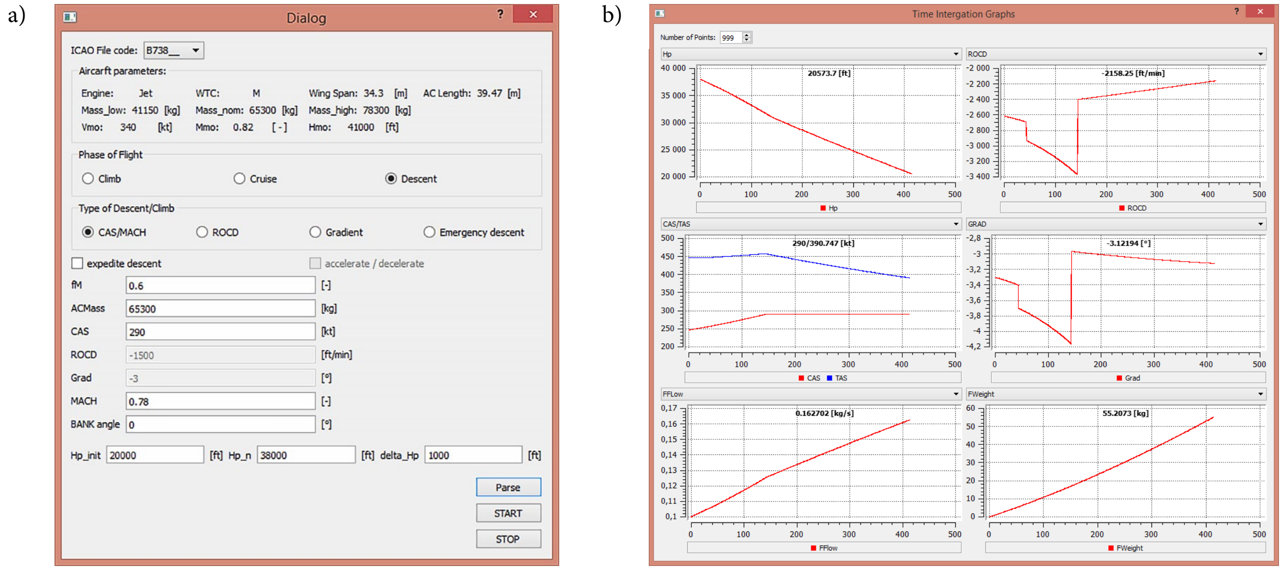

Figure 13. BADA model validation tool (a) with time integration output (b)

3. Landing System prototype implementation

The primary reason of CFIT is a lack of situational awareness of surrounding terrain in combination with poor visibility or other additional factors. Today pilots must rely mostly on paper, or electronic charts to understand the relationship between terrain and the own ship, estimate their position by finding their location to nearby radio navigation aids, and after all mentally project the relative location onto the charts. This increases the pilots overall workload especially during climb, descent and landing phase of flight. Moving maps in combination with glass cockpit brings an improvement thanks to the simpler representation of aircraft position. On the other hand, also require additional attention diverted from primary flight instruments. Synthetic vision system that combines a terrain database, position sensor information, computing platform and display, allows pilot very natural and intuitive view of terrain features ahead. Addition of such system could dramatically reduce the number of CFIT accidents by increasing the pilot situational awareness (Wenger 2007).

The Prediction Landing System was developed using Qt programming environment (Qt 2016). Throughout the development process it was tested using FSX flight simulator as a source of all data to test the Landing System functionality. The whole simulation and development process was focused on KSC and its surroundings. This airport was chosen due to its vicinity and simplicity for pointing out the main advantages of such system. To successful design of descend and landing procedure, we needed more information than is usually publicly available. Thanks to project participants familiarity with its design and data availability for KSC, we were able to gather sufficient information. Descend procedure for this airport was designed in cooperation with professional pilots, taking advantage of his experience with such procedures. We used the data to design airline descend speed profile and procedure. Data sent to Landing System for calculation are updated every 1 s.

Figure 14 illustrates used digital terrain database for developed Landing System and for its testing procedures. The red line depicts the RWY 01/19 in relation to surrounding terrain. Greater precision of Landing System with this approach could be achieved using terrain database with finer resolution. Green line illustrates the final part of modelled descent trajectory according to the terrain database. The system operates in two basic modes: (1) flight mode, (2) approach mode. Flight mode is active throughout the cruise phase of flight and when the aircraft is not within the terrain database in airport surrounding. In other words, all the time when approach mode is not available. An example of flight mode is shown in Figure 15.

When the Landing System is in flight mode, many of its features are not available because there are no data to be calculated from, like vertical speed, deviation from glideslope or relative bearing to the runway threshold. The trajectory displayed is based only on measurement from RA with 1 Hz frequency, displaying the height of the aircraft over the unknown terrain (AGL). Nevertheless, even such simple information can be very useful as you can foresee the terrain closure just by looking at the change in radar altitude in time to prevent the CFIT. More information about the aircraft attitude, trajectory, terrain and airport can be derived in approach mode. Approach mode is active during the descent and go-around phase of flight. That means, when the aircraft is within the terrain database in airport surrounding. This mode is activated automatically. An example of approach mode is shown in Figure 16.

Altitude displayed in approach mode is calculated and depicted as an altitude AMSL. The aircraft altitude is calculated from RA measurements and added to the terrain elevation from the terrain database. The knowledge of aircraft position, terrain in its vicinity and exact flight path for descent to the RWY enables the terrain prediction. This increases the pilot situational awareness and reduces the CFIT probability.

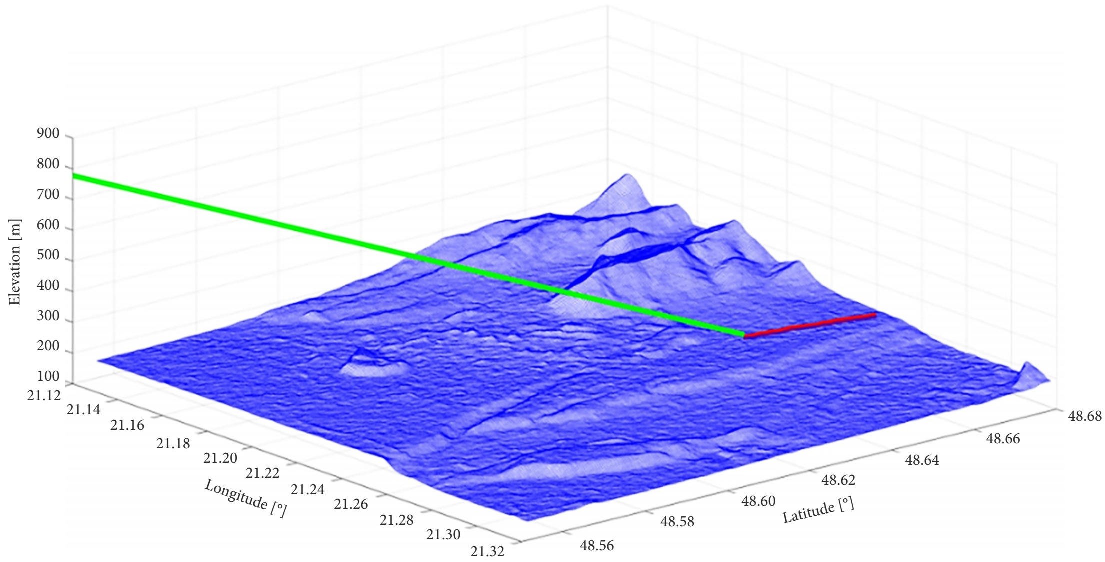

Figure 14. KSC digital terrain database

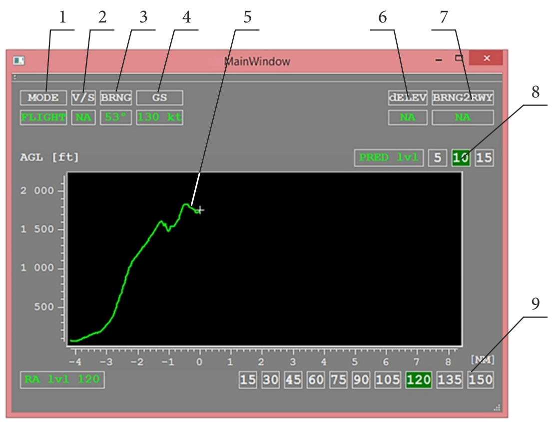

Figure 15. Landing System prototype (flight mode): 1 – active mode indication (currently is active flight mode); 2 – actual aircraft vertical speed (calculated based on last two position recorded); 3 – actual bearing (bearing calculated from last two aircraft positions); 4 – actual ground speed (calculated based on last two aircraft position and distance between these points on the ground using Vincenty formula (MTL 2016)); 5 – flown trajectory according to data received by Landing System from RA sensors; 6 – deviation from desired altitude according to designed descent trajectory; 7 – relative bearing to the runway threshold; 8 – level of trajectory prediction [seconds ahead]; 9 – level of displayed flown trajectory (in numbers of data received, 120 = 120 s in history)

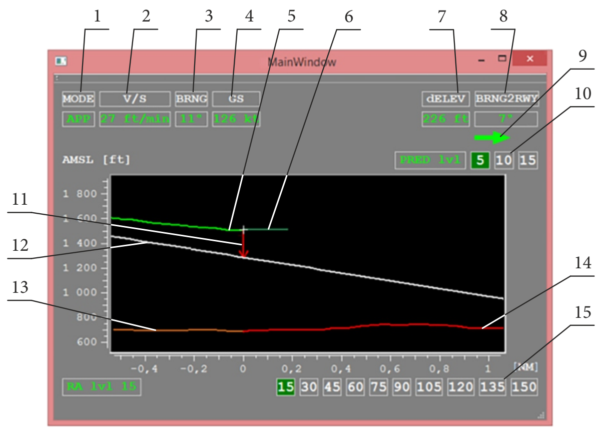

Figure 16. Landing System prototype (approach mode): 1 – active mode indication (currently is active approach mode); 2 – actual aircraft vertical speed (calculated based on last two position recorded); 3 – actual bearing (bearing calculated from last two aircraft positions); 4 – actual ground speed (calculated based on last two aircraft position and distance between these points on the ground using Vincenty formula (MTL 2016)); 5 – flown trajectory according to data received by Landing System from RA sensors; 6 – aircraft trajectory prediction based on BADA model; 7 – deviation from desired altitude according to designed descent trajectory; 8 – relative bearing to the runway threshold; 9 – arrow depicting direction in which the aircraft should move in horizontal plane according to relative bearing to runway threshold; 10 – level of trajectory prediction [seconds ahead]; 11 – graphical visualization of difference between actual and desired descent trajectory; 12 – designed descend trajectory used BADA model for descend trajectory modelling from merging point; 13 – terrain elevation that the aircraft flown over according to the terrain database; 14 – predicted terrain according to defined descent trajectory and terrain database; 15 – level of displayed flown trajectory (in numbers of data received, 15 = 15 s in history)

4. Flight simulator flight test

Landing System makes use of server application designed primary for DLCSim (Glaser-Opitz, H., Glaser-Opitz, L. 2015a). Therefore the data that are sent from flight simulator to server application were chosen accordingly. Either way, the Landing System can make use of most of them.

All selected data are transferred via client application (FSXtoDLCSim) directly from flight simulator in 1 s interval (subjected to change). These data are updated immediately when they are significantly changed. The FSXtoDLCSim GUI is depicted in Figure 17 together with console window displaying part of the information sent from flight simulator to make sure that data sent are valid. Parameter selection enables to test missing data and validate the Landing System functionality for various combinations of available/missing on-board navigation data. This also enables to test ATCo reaction when controlling the airspace while the pilot is flying the flight simulator. The whole communication between all client applications, including Landing System is based on server-client communication using TCP/IP protocol (Glaser-Opitz *et al.* 2015).

Flight simulator served as a testing device for the Landing System functionality. The Landing System worked as expected in both flight and approach modes as illustrated in Figure 18 respectively.

Test flight was performed as an approach procedure to KSC, following by a go-around procedure to test the Landing System behaviour in various cases. The test included approaching airport runway threshold from both sides to test switching between both operational modes.

Conclusions

This paper describes a method of flight safety enhancement as one of the most critical feature in aviation.

For flight safety and pilot situation awareness enhancement was chosen method based on TRN with focus on approach and landing phase of flight. This method was verified using MATLAB® with different types of test flight trajectories and created terrain elevation database. The main goal was to find a way to replace standard glideslope information (e.g. from ILS) requiring the airport ground infrastructure.

Within the development of the Landing System, the traditional glideslope was replaced with modelled descent trajectory modelled with EUROCONTROL BADA performance model. For the purpose of the modelling and simulations, BADA validation tool was developed.

All simulations were created for KSC as CDA procedures, based on real world airline data in compliance with i4D trajectory and proposed merging point. Based on mentioned models and simulations, Landing System prototype was developed, with BADA model based trajectory prediction capability. For testing and further research activities was developed server/client communication interface that enables developed Landing System prototype to communicate with flight simulator and with DLCSim.

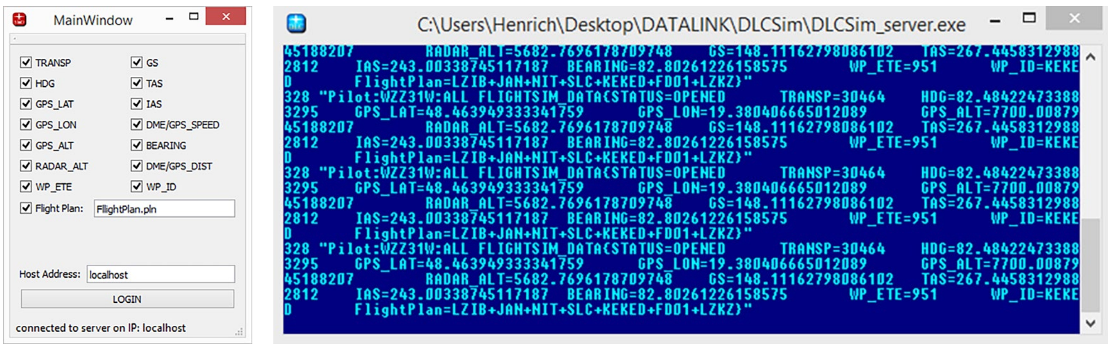

Figure 17. DLCSim data export interface (FSXtoDLCSim) (Glaser-Opitz *et al.* 2015)

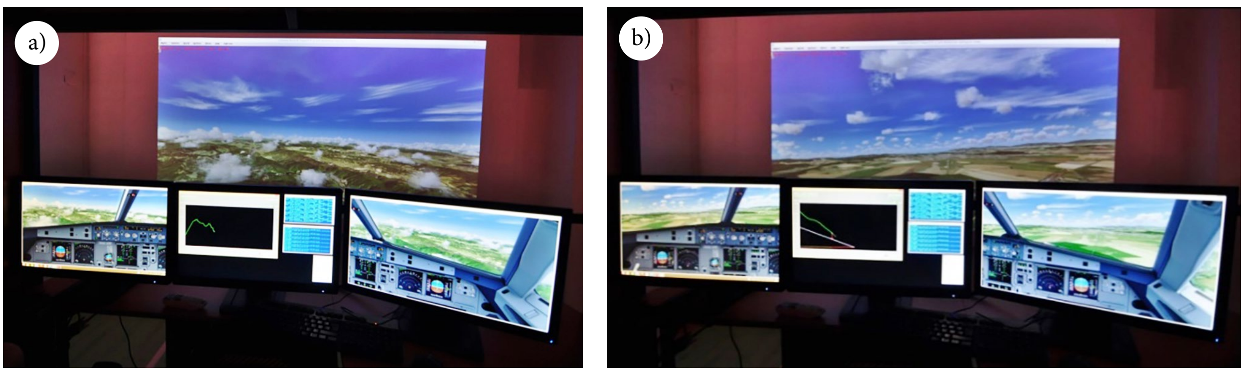

Figure 18. Landing System simulation on flight simulator: a – flight mode; b – approach mode

Enhanced interaction between flight simulator, Landing System and DLCSim enables future research to focus on pilot or ATCo workload during any phase of flight using future avionic systems already available on modern aircraft as well as in research stage.

Disclosure statement

Authors do not have any competing financial, professional or personal interests from other parties.

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