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LNAS – A PILOT ASSISTANCE SYSTEM FOR ENERGY-OPTIMAL APPROACHES USING EXISTING AIRCRAFT-INFRASTRUCTURE

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ABSTRACT:

In order to assist pilots to realize low-noise and more efficient approaches, the German Aerospace Center (DLR) has developed the assistance system LNAS (Low Noise Augmentation System). It is a software solution using flight data provided by a common interface aboard a passenger aircraft. Recommendations are visualized on the "Electronic Flight Bag" (EFB) in the cockpit by an intuitive energy-based "Vertical Situation Display" (VSD) which also indicates the optimal points in time to perform the different actions like setting of speeds, flaps, landing gear and if necessary speed brakes. During approach a continuous correction is carried out to provide the energy-optimal profile at any time, even if the predicted approach changes e.g. due to a variation of ground wind conditions.

NOTATION:

E_{tot}	Total Aircraft Energy
g	Gravitational Acceleration
H	Aircraft Height
$H_{E_{tot}}$	Total Energy Height
m	Aircraft Mass
V_K	Flight Path Velocity
ΔE_{kin}	Kinetic Energy Deviation
$\Delta H_{E_{kin}}$	Kinetic Energy Height Deviation
AGL	Above Ground Level
ATC	Air Traffic Control
ATRA	Advanced Technology Research Aircraft
AVES	Air Vehicle Simulator
CDA	Continuous Descent Approach
DLR	German Aerospace Center
EDDF	ICAO Code for Frankfurt Airport
EFB	Electronic Flight Bag
IAC	Instrument Approach Chart
ILS	Instrument Landing System
LDLP	Low Drag Low Power
LNAS	Low Noise Augmentation System
ND	Navigation Display
PFD	Primary Flight Display
UNH	Umwelt- und Nachbarschaftshaus
VSD	Vertical Situation Display

1. INTRODUCTION

1.1. Motivation

A goal of the European Commission for the aviation sector is a door-to-door time within 4 hours for 90 % of all travelers within Europe until 2050 [1]. In addition, a 45 % rise of aircraft movements until 2035 is expected, what results in more carbon dioxide and nitrogen oxide emissions in the same time. Furthermore, the amount of local residents near major European airports and consequently the people most affected by the emissions are expected to increase by 15 % [2]. This leads to a higher possibility of conflicts between aviation industry and residents and also decreases the acceptance for growth of airports and aircraft movements. Due to this trend the topics of environmental protection and noise reduction will play an important role for the aircraft industry in the future. In this regard, the European Commission also declares a reduction of carbon dioxide emission per passenger kilometer of 75 % and a reduction of 90 % in nitrogen oxide emissions compared to a typical new aircraft from 2000 as a goal to be reached until 2050. Also the aircraft noise emission should be reduced by 65 % [1]. The noise is not only annoying but has also a health impact to the affected people, especially during sleep [3]. In summary, the challenge is to decrease the emissions of aviation while a constant growth is happening in the same time.

Despite the fact that quieter engines and more efficient aircraft configurations are in development to reduce the source of noise as well as fuel consumption, the developments need many years to market maturity and even longer to renew the global fleets. Due to high costs of physical optimizations on current aircraft and also the long time for integration in a majority of the fleets, this approach is not a short-term solution and cannot speed up the required reductions. A mid-term alternative to reduce aircraft emissions is to improve the currently applied operational procedures, especially those related to start and approach, including configuration changes for the high-lift devices, gear, speed and altitude for the following reasons:

- The variety of configuration changes during approach gives wide possibilities for optimization.
- The emission of noise and exhaust directly affect the residents around airports due to a lower mean flight altitude and thus a short distance between aircraft and ground.
- The high accumulation of aircraft near airports where these procedures are used.

The continuous decent approach (CDA) in Frankfurt at night time since 2005 and the approaches with an increased glide slope of 3.2 ° as standard since 2014 are examples which show that procedure changes can be implemented at least in medium term. However, an effective possibility to improve the situation in short-term is an optimization of currently applied procedures without changing itself. In practice, to fly an approach in an optimal way related to noise and fuel consumption means to perform all necessary actions precise in time, which is difficult without further assistance to the pilots.

1.2. Problem Definition

In a simulator study related to the STENA ("Steiler Endanflug") project, a standard approach was carried out with 16 professional pilots at the Airbus A330 full flight simulator at the former ZFB (Center of Flight Simulation Berlin) in Berlin [4]. The task in the experiment was to fly with autopilot until 1000 feet above ground level (AGL) and perform all settings according the specification of the pilots' airline. All other conditions were similar for all test candidates and no speed or altitude restrictions were given. The study results show, that fan speed (which is directly correlated to engine thrust) deviates significantly from the optimal profile during the approaches (see Fig. 2). This means additional energy is fed into the system despite the fact that kinetic and potential energy should be reduced during the approach. Also the flap setting is widely scattered along the approaches.

Consequently, this leads to the assumption that current standard approaches with an individual aircraft configuration are often unnecessarily noisier and less fuel efficient than possible from a technical point of view. As a proof for the data recorded in the simulator study real flight track data from daily operation of one runway in Frankfurt (EDDF) were analyzed and compared with the calculated optimal approach [5]. Also in this case the results show a large deviation from the optimal profiles, already considering the influence of different weather conditions. The reason for these results is the highly complex situation during the approach phase with multiple influencing parameters. Such influences are variations in e.g. the gross weight, wind conditions, lateral flight path or restrictions given by Air Traffic Control (ATC). Also for pilots with a high amount of flight experience and high qualification it is very difficult to perform an optimal approach without additional support. With respect to possible steeper approaches and more complex approach procedures in future e.g. in order to increase the airports' capacities, there is a strong need for pilot assistance in these flight phases. If the approaches should be additionally implemented with low fuel consumption and low noise by the pilots, the demand is even higher.

1.3. Method of Resolution

To meet the demand for pilot assistance during approach, the following solution for LNAS was developed. An assistance system calculates the energy optimal approach profile depending on different influence parameters (see section 2.1). Energy optimal means to spread potential and kinetic energy of the aircraft in such a way that no or only minimal additional thrust is needed and the aerodynamic drag is kept low as long as possible.

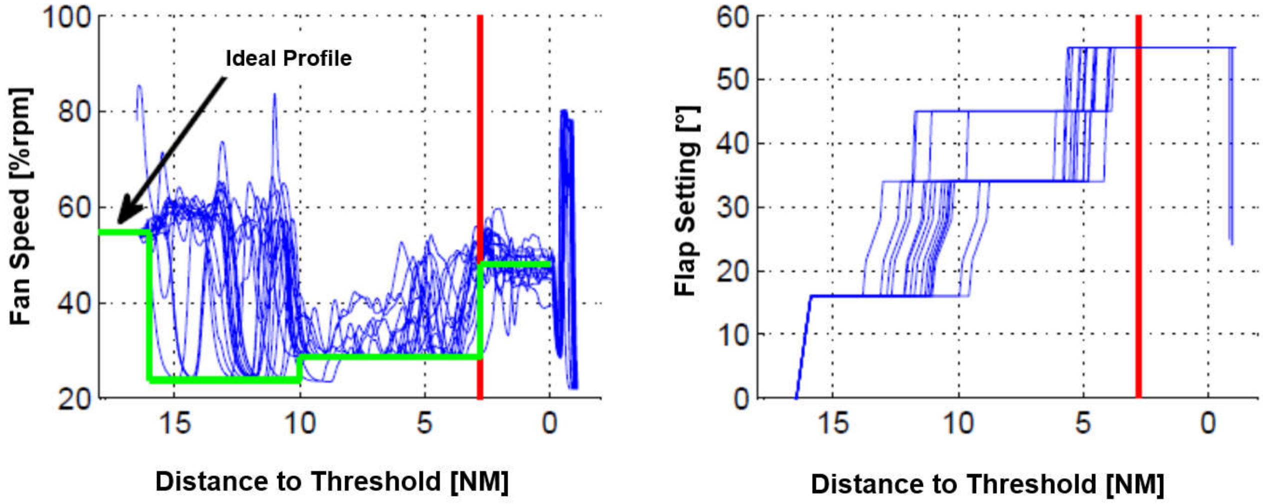

Figure 1: Simulator study: Individual pilots behavior during a standard approach with same conditions; Red mark: stabilization height (1000 feet gate above ground level); from [5]

This leads directly to minimal noise emission at the engines and the aircrafts structure. The overall view of the approach profile until the stabilization height (1000 feet AGL) is displayed for the pilots in an intuitive way and already indicates in an early approach phase whether the stabilization criteria can be fulfilled. This should reduce the probability of a go-around which has to be implemented if the aircraft is not stabilized at the already mentioned stabilization height. The system calculates precisely the optimal points in time to set speeds for the autopilot, gear, flaps and speed brakes if needed and indicate these to the pilot. These points and their visualization are updated continuously considering the current flight state and changing external conditions. If these recommendations are carried out by the pilots, the approach can be performed in an energy optimal way within the limits of external conditions. If the best possible conditions can be assumed, e.g. no speed restrictions from ATC, the whole approach can be carried out in idle thrust. Considering that the noise generated by high-lift devices, landing gear and speed brakes as well as the engine noise are the main sources of noise during approach, this optimization has a great potential to reduce noise immission in the approach phase.

2. LNAS

2.1. Optimization Philosophy

The optimization of the approach profile and related recommendations are based on an aircraft model simulation and currently supports the Airbus A320 family. For this, know-how obtained with the DLR A320 “Advanced Technology Research Aircraft” (ATRA) and the A320 “Air Vehicle Simulator” (AVES) was adapted to create a simplified aircraft model which meets the processing capabilities of commercial EFB hardware. The system currently optimizes the commonly used “Low Drag Low Power” (LDLP) approach procedure. The optimization performed by LNAS is divided into two parts. Before the aircraft enters the approach phase, the pre-planning algorithm determines a detailed optimization of the current approach with the distinct points in time for all necessary actions within the operating parameters of the related aircraft type like the speed ranges of the individual flaps settings. Thereby high-lift devices and landing gear are deployed as close to the runway as possible in order to minimize drag during the approach. Furthermore speed brakes are only used if unavoidable to perform a stabilized approach. If they have to be used, they are set as soon and thus as high as possible to minimize related noise impact due to a maximized distance to the ground. Also, both actions lead to a minimized demand of engine thrust.

Until the stabilization height in 1000 feet AGL a closed-loop real-time correction of all actions is carried out, taking into account all varying parameters like changing wind conditions, new speed restrictions from ATC or delayed pilot actions. This ensures a stabilized flight state at the stabilization height, with respect to flight physics and regulations (e.g. the aircrafts’ speed limits or approach procedure boundaries), even under changing conditions and provides the best possible results at any time. The latest optimization results are shown to the pilots by an intuitive display, which is described in section 2.3 in detail. As mentioned above, the optimization algorithm considers the wind condition at any time. Therefore a linear regression over the following data is carried out. First, the current and previous wind data at the aircraft determined by the aircrafts’ system, and second the ground wind entered by the pilots via the display on the captains and first officers’ EFB (see section 2.3). In case of a go-around the complete recorded wind profile is considered during the next approach and should therefore decrease the go-around probability caused by unexpected wind effects.

2.2. Data Flow

In order to calculate an optimized approach with regard to noise and pollutant emission, LNAS needs certain input values which can be split in three categories:

- real-time inputs from the aircraft,
- static data from several databases integrated in the software,
- inputs from the pilot entered via the display

A scheme of the system architecture including the data-flow is given in Fig. 2.

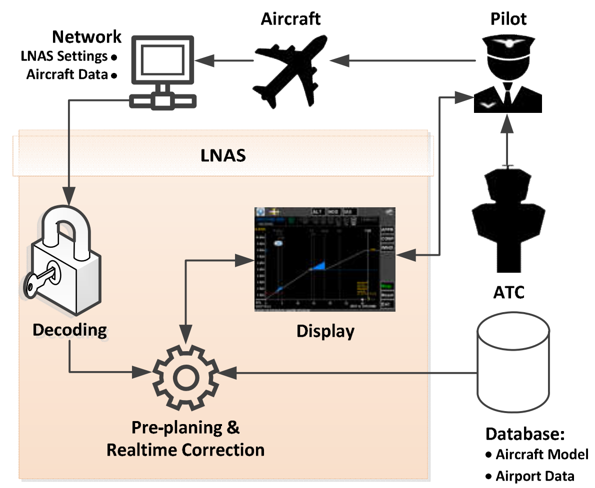

Figure 2: LNAS system integration scheme

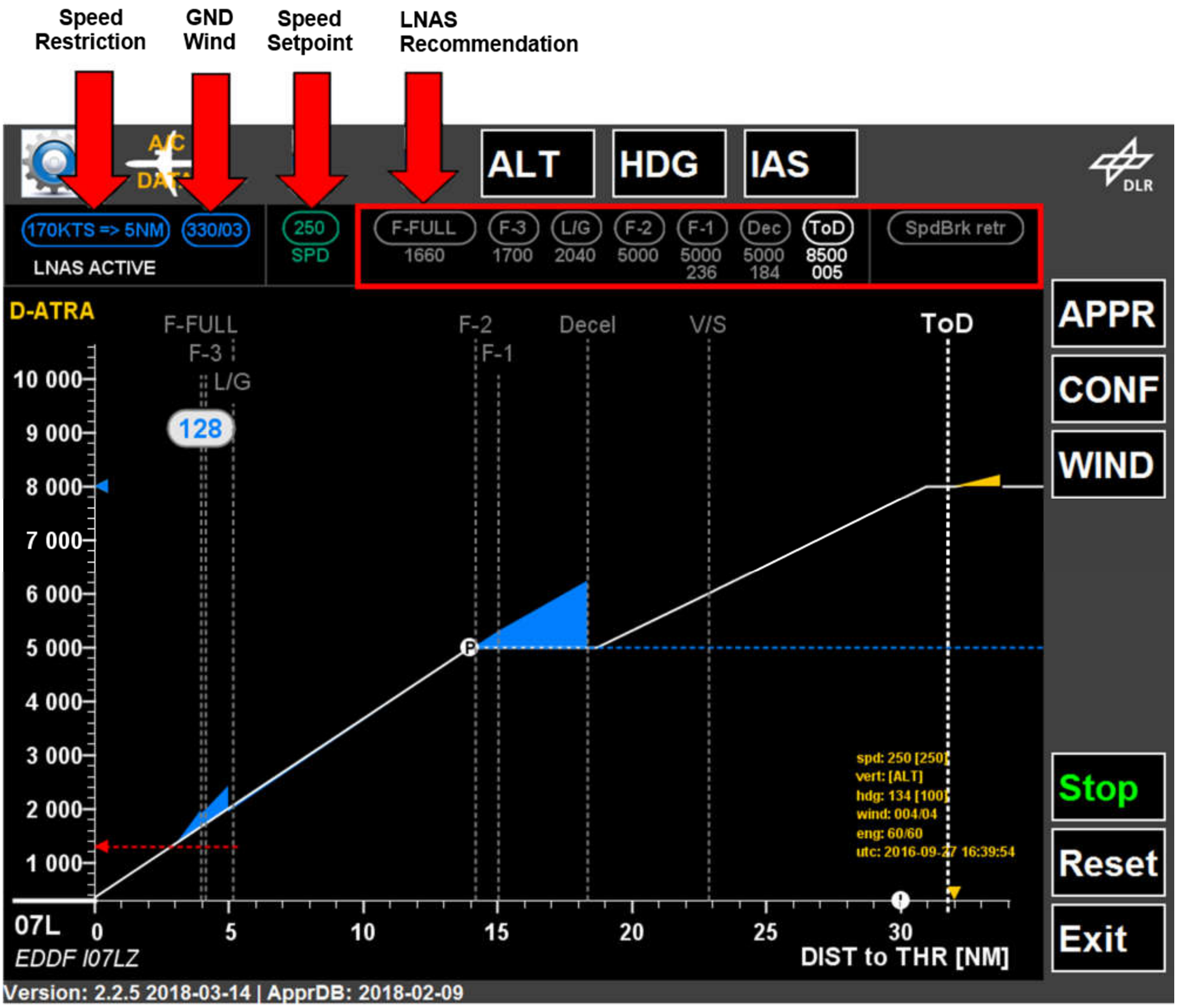

Figure 3: LNAS display at the top of decent; first officer side

The real-time inputs from the aircraft include all available data from the EFB interface. These are, for example altitude, speed, heading, horizontal wind conditions (at the aircraft), landing gear state and the high-lift devices configuration. On one hand, these data act as one part of the input values for the calculations but on the other hand as feedback channel to determine if given recommendations are carried out, delayed or ignored by the pilots. The static data are divided into two databases. The first one contains information regarding the already mentioned aircraft model which describes the specific characteristics of aerodynamics and engines. The second database provides information about airports, runways and details of local approach procedures. These are for example the runway heading and threshold position, instrument landing system (ILS) frequency and glide path angle. Additionally the pilot has to enter ground wind and restrictions given by ATC. Finally, the pilot defined inputs are synchronized automatically between EFBs on both sides via network, so that only one crewman (pilot monitoring is suggested) has to input the necessary values.

2.3. Display

The display is available on the captains and first officers' EFB. The orientation is always in the direction of flight, thus both displays are mirrored. In Fig. 3, as an example for the first officers' side, the upper and right side provide soft keys for program controls and user inputs. The "Start/Stop", "Reset" and "Exit" buttons in the lower right corner allow switching between pre-planning and continuous correction (Start/Stop), to reset the optimization (Reset) and exit the application (Exit). The most important other soft keys are "WIND" (to enter the horizontal wind conditions on ground) and "IAS" to enter the speed restrictions given by ATC. The upper horizontal panel below the soft-keys as indicated in Fig. 3 is called the action bar. On the left side, the entered values for speed restrictions and ground-wind are displayed in blue color. In Fig. 3 a speed restriction of 170 kts until 5 NM before runway threshold and ground wind conditions with 3 kts from 330 degrees are active. Additionally, LNAS is marked as active, which means the pre-planning is completed and the real-time correction is active. The rest of the panel

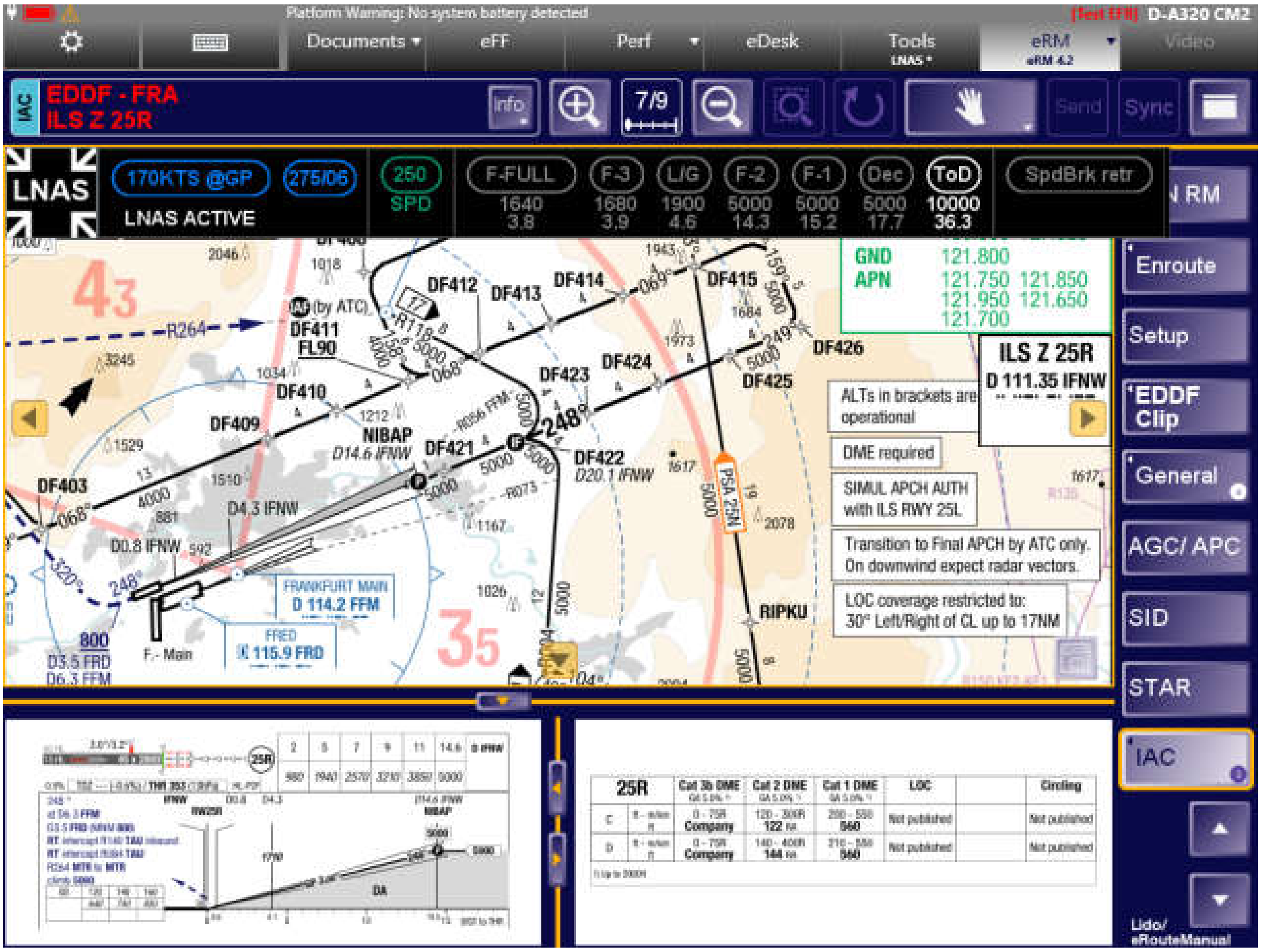

Figure 4: Screenshot of the Lufthansa EFB: LNAS action bar as overlay on the instrument approach chart (IAC)

contains the resulting recommendations, which are from left to right: The speed setpoints which must be reached to execute the next action or to meet the given speed restrictions. It will be updated 10 seconds before the next action has to be executed, so that the pilot has enough time to adjust the new setpoint. This is followed by the typical actions during an approach, shown in a symbolic format. This includes setting flap configuration ("F-1" to "F-Full"), speed brakes ("SpdBrk"), top of decent ("ToD") and landing gear ("L/G"). The symbols are arranged in the typical order for an approach. Additionally the related altitude and distance or a countdown is displayed under each symbol. The primary colour is grey, but the colour of the next action which has to be executed changes to white. If the action was implemented in time, the colour changes to green. If the action is delayed or missed for any reason, the colour changes to yellow. This helps the pilots to identify the next upcoming or currently active action at first glance. As an optional function it is possible to show a transparent version of the action bar, if LNAS is in background. This enables the possibility to show e.g. the instrument approach chart (IAC) on the EFB which is prescribed by some airlines during approach and simultaneously the most important data from LNAS for an optimized approach as an overlay (see Fig. 4). It can be minimized and moved individually over the screen. The rest of the screen shows a VSD as altitude over distance to the runway threshold. In particular, the vertical approach profile is represented schematically by the thick white line (see Fig. 3). The currently selected approach is shown in the lower left corner (e.g. EDDF I07LZ for Frankfurt runway 07L) and the current aircraft position is represented by the yellow triangle and its projections to the both scales. Furthermore, the stabilization height is visualized as red dotted horizontal arrow. Equivalent to the already mentioned action bar with its numerical representation, all actions to be implemented are shown as vertical dotted lines, representing their actual position relative to the approach profile and current aircraft position. Fig. 5 shows the timespan in which the speed brakes are recommended are highlighted with light red background. Beside the potential energy of the aircraft which needs to be reduced during approach and is represented by the aircraft altitude, also the kinetic energy needs to be reduced e.g. to reach the speed range for each high-lift device configuration. While the deviation of potential energy can be easily seen in the VSD, also the excess of kinetic energy is visualized to provide a complete overview of the current energy state relative to the optimal approach path.

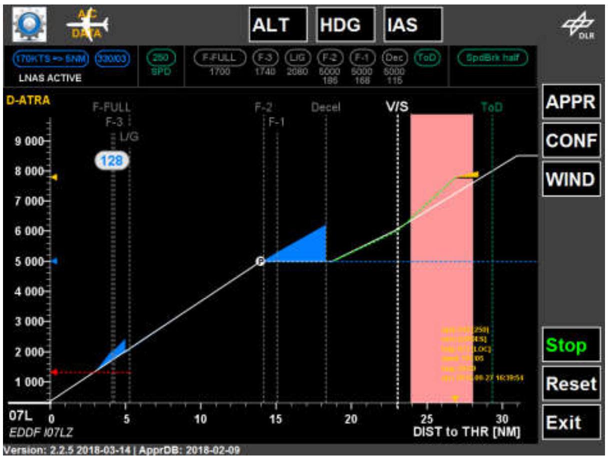

Figure 5: LNAS display with active speed brake recommendation

For this, the total aircraft energy, neglecting the rotational energy, is considered as shown in Eq.1 by adding potential and kinetic energy as purposed in [5]:

$$E_{tot} = m \cdot g \cdot H + \frac{1}{2} \cdot m \cdot V_K^2 \qquad \text{(Eq.1)}$$

Dividing this by the weight, results in an energy-height which is a measure of the total energy state (Eq.2).

$$H_{E_{tot}} = \frac{E_{tot}}{m \cdot g} = H + \frac{V_K^2}{2 \cdot g} \qquad \text{(Eq.2)}$$

Assuming that the entire kinetic energy would be converted into potential energy instantly without losses, the aircraft would reach this height. By calculating the deviation of the kinetic energy, related to the optimal speed setpoint (Eq.3) and converting it to an energy-height (Eq.4), it can be added to the optimal approach profile and displayed as seen in Fig. 3 as blue triangular areas.

$$\Delta E_{kin} = m \cdot \frac{V_{K,current}^2 - V_{K,target}^2}{2} \qquad \text{(Eq.3)}$$

$$\Delta H_{E_{kin}} = \frac{V_{K,current}^2 - V_{K,target}^2}{2 \cdot g} \qquad \text{(Eq.4)}$$

After an executed action by the pilot, the speed must be reduced to implement the next action. Therefor a speed setpoint is calculated and the excess kinetic energy is displayed as energy-height in the blue area. While the aircraft is decelerating, this area gets smaller until the speed matches the setpoint, thus the excess kinetic energy is zero and the next action can be carried out. In general, the approach procedure can be implemented within regulations if speed and height reaches the related setpoints at the stabilization height. Thus, the aircraft moves on the optimal approach profile and no blue area is left at this point.

2.4. Software

LNAS is a software solution and can be installed on EFB which exist on most current commercial aircraft. This way pilots can handle LNAS as a normal EFB tool (like e.g. IAC charts) with the possibility to start, close or switch to another application at any time. Due to the overlay functionality as described in section 2.3, the pilot can also use LNAS simultaneously with other applications (see Fig. 4). For development, test and validation, the EFB as platform offers proper system access possibilities compared with e.g. the Primary Flight Display (PFD) or Navigation Display (ND). It also enables an easier admission of the responsible aviation authority due to a lower claim on software security and reliability on this platform. As implied before, LNAS is installed as an application on the underlying operation system beside the other applications of the related airline like e.g. airspace charts or handbooks. It has access to all needed system resources like memory, processing power, network and display to fulfil the given tasks (see Fig. 2). Currently, the software is compatible with Rockwell Collins EFB Class 2 hardware but in general also adaptable to every other EFB-system with access to aircraft data in flight.
Beside the optimization, the software provides several other automated features to reduce the pilots' workload and increase the reliability of the system. As already mentioned in 2.2, the related aircraft model and the current approach data like glide path angle, intermediate altitude and runway position is selected and loaded automatically from the database. Therefore the selected ILS frequency or the GLS channel from the flight management system and the current aircraft position is used. Additionally the change between the pre-planning algorithm and the real-time correction is carried out automatically.

3. FLIGHT TEST RESULTS

After LNAS had been successfully tested in the flight simulator and also in subsequent first research flights conducted by DLR test pilots, it had to pass the test in regular operation at Frankfurt airport. For three days, the DLR's research aircraft A320 ATRA flew various approaches to Germany's largest commercial airport. The LNAS flight trials took place from 26th to 28th September 2016 and included a total of 25 test flight hours. In addition to the DLR crew, 17 professional pilots from four different airlines were available for the test flight program, so that the acceptance of LNAS could be evaluated by a group of possible future users. The aim of the LNAS experiments was to test the system under real limitations of a busy traffic airport. The test approaches were carried out without special treatment by ATC. After each approach a go-around was initiated in 800 ft above ground level. Afterwards a pilot change took place in the cockpit. This guaranteed to avoid a learning process for one pilot as much as possible due to a longer time between flights. Afterwards, the pilot received the information whether the following approach should be flown with or without LNAS display. During the flight trials the runways 07L and 25R were operated, both with a glide path angle of 3.0 degrees (runway 07LZ / 25RZ) and with 3.2 degrees (runway 07LY / 25RY). Fig. 6 shows the flight tracks on the runway 25R.

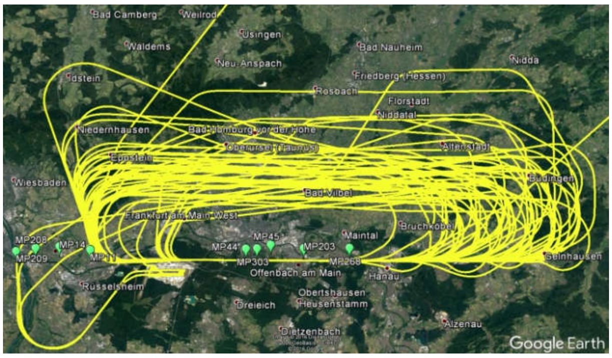

Figure 6: Flight tracks EDDF 25R of the LNAS flight trials in September 2016

After each go-around manoeuvre, the aircraft climbed to flight level 70 or 80 and was available for the next approach until ATC requested the next vectors for entry into the approach baseline. As mentioned before, during the trials ATC treated ATRA the same as all other approaching aircraft. Of course, this leads to restrictions during each approach with respect to climb and descent clearance as well as to speed restrictions. In total, 36 % of all approaches were made without ATC speed requirements. Thereof the proportion of approaches with and without LNAS is almost identical. It was found that "reduce and maintain 170 kts until 5 NM" and "170 kts at glidepath" were the most frequently speed restrictions given from ATC during the flight trials. In addition to the restrictions from ATC the influence of environmental conditions is very important in real flight. The approaches with and without LNAS took place each with similar wind conditions and are therefore comparable. In general LNAS was able to demonstrate its functionality in different horizontal wind conditions as following summarized:

- tailwind component between 7 kts and 12 kts at a height of 3000 ft, decreasing to 0 kts at stabilization height,
- relatively calm atmosphere down to 2500 ft. Wind shear below this altitude: headwind component increased in magnitude only to 11 kts and changed again to 0 kts below 1800 ft,
- more than 22 kts headwind and gusty conditions.

At Frankfurt airport several noise monitoring stations are operated by “Fraport” and the “Umwelt- und Nachbarschaftshaus”[1] (UNH). The proportion of usable measurements decreases with increasing distance to the threshold. This effect can be explained by the flown altitude and the sound attenuation caused by geometrical spreading. Unfortunately the noise monitoring stations are not based on the entire final approach so that not all advantages of the system, especially the later landing gear extension, can be seen by the noise monitoring station measurements. For this reason only allows noise reduction prognoses in specific areas can be made which are shown in Fig. 7. At the intermediate altitude before the glideslope interception the first and second flap configuration can be implemented more precisely with the aid of LNAS, so that the optimal energy balance is better achieved in order to avoid an unnecessary increase in thrust at this point or a later speed brake use e.g. on the glide path. At high air traffic densities the aircraft will probably have to follow the speed restrictions of ATC from a distance between approximately 15 NM and 5 NM. These restrictions limit the capabilities of the system to optimize the actions and reduce the expectations for noise reduction in this area. The later extension of the landing gear and the landing configuration on the final approach segment can result in a noise reduction of up to 5 dB(A) in the area of landing gear extension, as can be seen in the measurements [6].

Figure 7: Noise reduction areas EDDF/RWY25R

In addition to the aim of aircraft noise reduction, lower fuel consumption was achieved. The graph in Fig. 8 shows the average fuel savings achieved when LNAS is used at a certain distance relative to the distance to the stabilization height. For example, 10 % fuel can be saved when LNAS is

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[1] UNH is a non-profit organization funded by the federal state of Hesse. It’s a center of information, dialog and monitoring related to the region and the Frankfurt airport.

used from a distance of 25 NM to the stabilization height. In the same segment an Airbus A320 with a landing weight of 62 t requires about 300 kg of kerosene which was also determined during the flight trials. Therefore up to 30 kg of kerosene can be saved in one approach with the use of LNAS for this aircraft type.

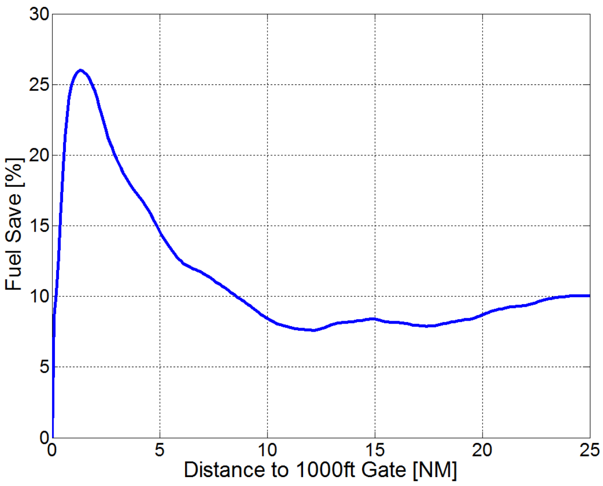

Figure 8: Fuel savings due to the usage of LNAS measured during flight test: averaged savings (compared with flights without LNAS) when using the system from a certain distance to the stabilization height.

In the distance range between 1 NM and 3 NM up to the stabilization height, maximum fuel savings of more than 25 % are possible. This is based on the relationship between the extension of the landing gear and the final high-lift device configuration as well as the subsequent necessary increase of thrust to stabilize the aircrafts' final approach speed. The savings of more than 25 % reflect the use of optimal setpoints for all configurations and the latest possible setting of the stabilization thrust when approaching with LNAS. In addition, a significantly higher fuel saving can be reached between 10 NM and 25 NM due to less restrictions of ATC. These restrictions must be taken into account by LNAS, so that the best possible solution cannot be provided in these cases. Consequently, this leads to higher thrust level [7]. Beside the objective investigation of the flight trials, the subjective impressions of the pilots regarding LNAS were recorded by answering questionnaires after each test flight. Questions about display, labeling, scaling, integration, safety, acceptance and experimental procedure were generally assessed positive. Finally, the pilots were convinced by the LNAS application whereby they would prefer the LNAS display in the primary field of view.

4. CONCLUSION

4.1. Summary & Potential

The developed assistance system LNAS generates recommendations based on the aircraft properties, aircraft state and environmental conditions. It optimizes the approach procedure related to noise immission and fuel efficiency within all given regulations, so that no additional approvals e.g. for a new procedure are necessary. The software is compatible with common aircraft hardware and can be integrated in short term. Furthermore it does not conflict with other common software installed on the EFB. The display is the interface to the pilots and shows the recommendations in an intuitive way, both as numerical representation and in the vertical profile. During approach, the system automatically takes care of the most of its own configurations to keep the workload as low as possible and provide the pilots always with the latest solution. The test series under operational conditions show a noise reduction of up to 5 dB(A) on the ground and a fuel saving of maximum 25 % within the last 3 NM before the stabilization height. In general, the first and second hight-lift device configuration can be done more precisely with the aid of LNAS compared to the approaches without LNAS. The huge amount of approaches to an airport by commercial aircraft and the expected growth of this number in the next decades is a huge challenge for aircraft industry, airport provider and local governments. LNAS with its reduction of fuel consumption and noise immission has a big potential to improve the situation around the airports immediately or at least to reduce the environmental impact of the growing number of aircraft movements. The fact that LNAS was finalist at the Innovation Award of German Aviation (IDL) in 2018 in the category "Reduction of emission" confirms the importance of this solution and its goals to aviation industry and government even now.

4.2. Outlook

A more detailed proof of the LNAS potential is expected in 2019 with data generated by new flight-tests with several cooperation partners. Lufthansa currently equips up to 86 aircraft of the Airbus A320 family with the LNAS assistance system and will test it over a period of one year in daily operation. Additionally to the aircraft data, UNH and the Fraport will provide noise measurement data from along the approach ground track at the Frankfurt airport. With this data a precise analysis of the effects of LNAS related to fuel consumption and noise immission under varying environmental conditions is possible. Also possible effects to the daily operations and workload will be determined by questioning the pilots.
Currently LNAS optimizes the LDLP approach procedure, as mentioned in section 2.1.

Nevertheless also other procedures are practically used and could be optimized in a similar way. An extension of the functionality related to the support of other common approach procedures and also to start procedures would increase the benefit of the system to the environment and the airlines as well. If the system will be considered as fit for use after research and validation phases, the integration into the PFD and ND with a suitable graphical representation would be the next step for the following reasons; first the usual field of view of the pilots, especially in the approach phase, is in direction of flight. Hence the information for the optimal approach settings should also be displayed at this position. Additionally all other important information during the approach are displayed in this area, e.g. speed, speed limits, altitude or lateral navigation. Nevertheless the integration in these displays would be a deep intervention in the aircraft system and thus this is a task for aircraft and system manufacturers. In general the widespread use of this system in combination with a data exchange with ATC could enable an even higher efficiency by optimizing the approaches and adjusting the graduation of all aircraft approaching a certain airport.

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