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Energy-optimized approaches: a challenge from the perspectives of pilots and air traffic controllers

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Abstract

Carrying out an approach that is as economical and safe as possible remains a challenge for flight crews, with a multitude of requirements to meet simultaneously. For an aircraft to descend from cruise altitude to touchdown with the lowest possible fuel consumption and noise signature, an approach is required that is both at idle thrust in the ideal speed and follows an ideal vertical profile without using speed brakes, extending the landing gear too early, or flying unnecessary horizontal segments with high thrust settings. In September 2019, a total of 90 test approaches were carried out at Zurich Airport on DLR's Airbus A320 Advanced Technology Research Aircraft (ATRA) using the low noise augmentation system (LNAS) pilot assistance system for the most economical and quiet approaches possible. The aim of this paper is to present the challenges from the pilots' and controllers' point of view for an idle approach and its execution by means of LNAS, to show the potential for fuel savings and noise reduction on the basis of flight test data and to discuss the next development steps. The assistance system reduces the crew's workload and provides support for all these tasks during an approach. The key information needed to perform optimum approaches is the expected distance from the actual aircraft position to the runway. The approaches carried out with the assistance system were significantly more economical and quieter on average than the approaches performed by a pilot group tasked with conducting minimum-fuel and low-noise approaches without the assistance system.

Keywords Aircraft energy management · Fuel saving · Noise abatement operational procedures · Pilot assistance system · Continuous descent approach · Flight testing

List of symbols

L_{AE}	A-weighted sound exposure level

Abbreviations

AGL	Above ground level
AMSL	Above mean sea level
ATC	Air traffic control
ATRA	Advanced Technology Research Aircraft
CDA	Continuous descend approach
DLR	German aerospace center
DTG	Distance to go
FAF	Final approach fix
FL	Flight level
HMI	Human–machine interface
IAS	Indicated airspeed
ILS	Instrument landing system
LDLP	Low-drag low-power approach technique
LNAS	Low noise augmentation system
ND	Navigation display
OLDLP	Optimized LDLP
PFD	Primary flight display
RNAV	Area navigation
RNP	Required navigation performance
SCDA	Segmented CDA
TMA	Terminal manoeuvring area
ToD	Top of descent

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1 Introduction

The descent and approach phase of an airline flight has significant potential for reducing fuel consumption [1–3]. Unlike the cruise phase, where additional fuel consumption

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results primarily from lateral detours and vertical deviations from the optimum altitude, the causes for suboptimal fuel usage during descent are more complex. Just as anticipatory driving can save fuel by avoiding excessive braking and acceleration, anticipatory flying can also increase fuel efficiency. However, to fly with anticipation, an exchange of information between air traffic control and pilots is a prerequisite.

1.1 Approaches today

1.1.1 Vertical profiles

An analysis [4] of 4643 approaches with the aircraft Boeing 737 of an airline to runway 25 L in Frankfurt shows that in the terminal area over the last 30 nautical miles (NM) before touchdown, the vertical profiles differ significantly (Fig. 1). Despite an airspace structure that allows a continuous descent profile, the vast majority of approaches (80%) are characterized by horizontal flight segments that are longer than necessary and feature engine thrust levels above idle. The difference between the various profiles is ultimately a difference in the strategy of dissipation of kinetic and potential energy. This shows that even with existing airspace structures there is a great potential for fuel savings through improvements in flight operation.

1.1.2 Aircraft configuration changes

A similar picture emerges from a look at the landing gear extension point. For this purpose, 12,794 approaches to runway 14 at Zurich Airport for the Airbus A320 of a regular airline were evaluated. A very large spread of the landing gear extension points can be observed (Fig. 2). In 7% of all investigated approaches, the landing gear was extended before the final approach fix (FAF) of 8 NM before touchdown, i.e. the location where the glideslope is usually intercepted. An evaluation of the airspeeds at FAF shows three clusters at 240 knots (kt), 210 kt and 160–180 kt (see Fig. 2, bottom). In 10% of the approaches, the landing gear was extended at airspeeds above 190 kt. In these cases, the deployed landing gear serves as aerodynamic drag to dissipate excessive kinetic energy. The aircraft manufacturer recommends extending the landing gear after setting the first steps of the high-lift devices, which results in a typical airspeed of 150–180 kt. Extending the landing gear at higher airspeeds leads to high noise emissions and indicates a suboptimal energy dissipation strategy. This large observed variation in airspeed and distance of landing gear extension

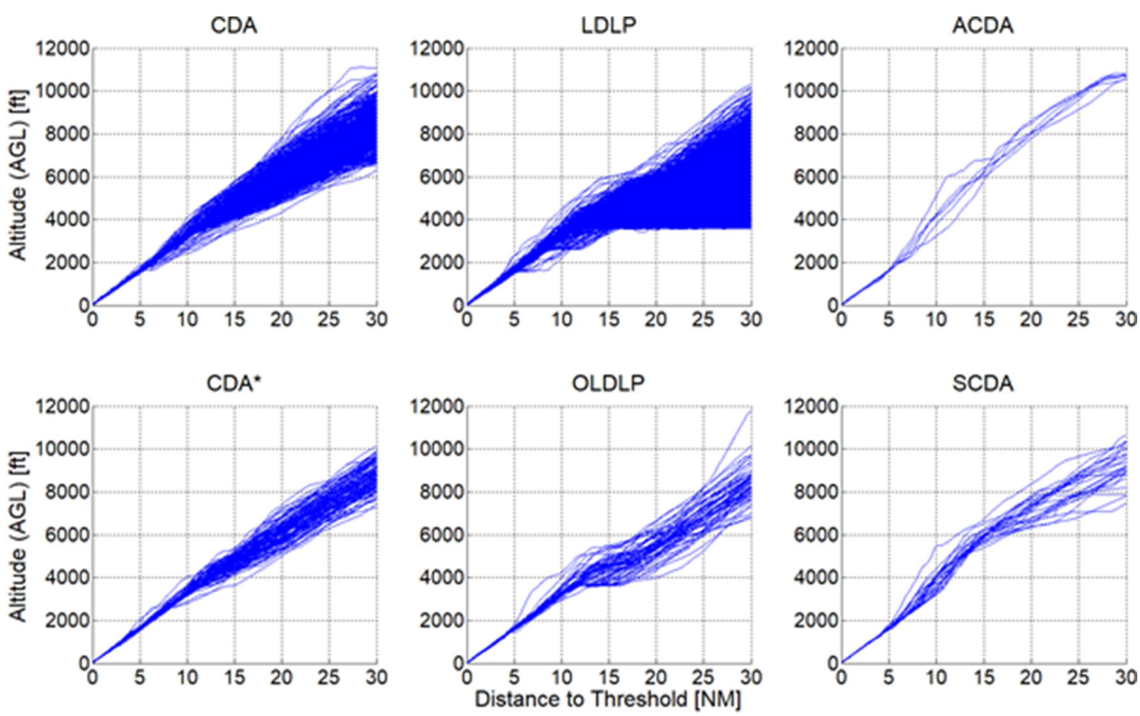

Fig. 1 The figure shows vertical profiles of 4643 approaches on runway 25 L in Frankfurt. Low drag low power (LDLP): 3713 (80%), optimized LDLP (OLDLP which is an LDLP in idle thrust): 68 (1.5%), continuous descent approach (CDA): 831 (17.9%), advanced CDA (ACDA): 6 (0.1%), segmented CDA (SCDA): 25 (0.5%), 15% of CDA represent CDA* category (approaches with idle thrust)

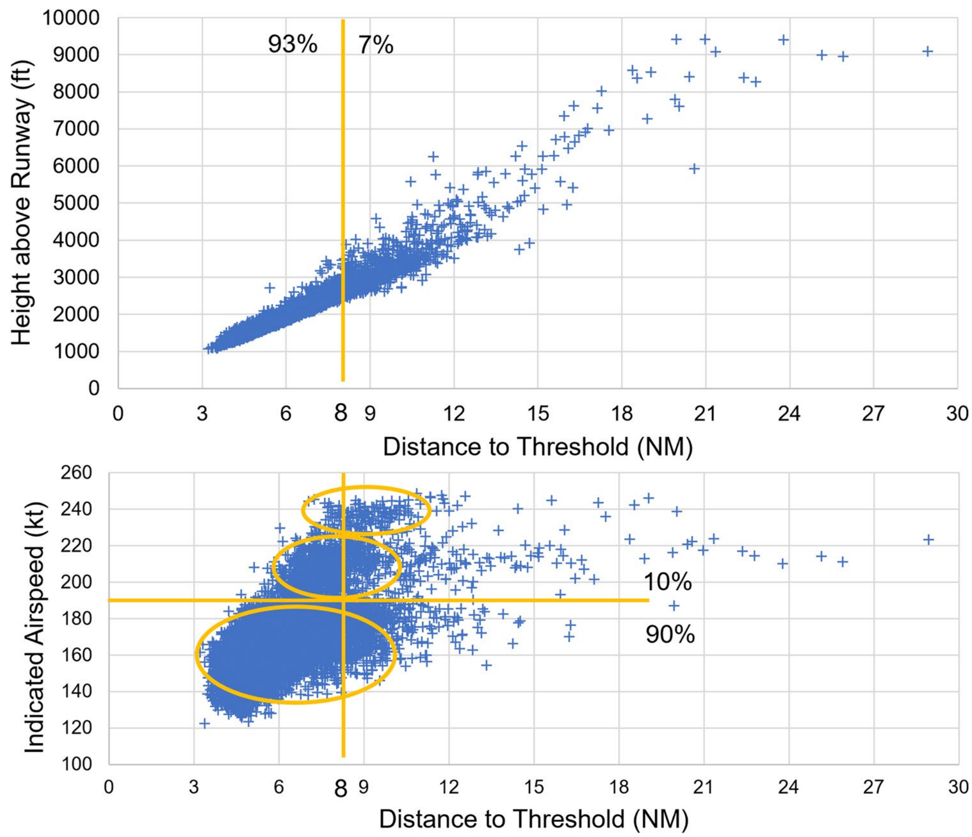

Fig. 2 Landing gear extension points from 12,794 approaches to runway 14 in LSZH for the Airbus A320 in relation to flight height (top) and airspeed (bottom)

points suggests various reasons for deviations from the optimal approach.

1.2 Aircraft energy management

During descent, the objective of the pilot is to bring the aircraft from cruising altitude to the runway in the most fuel-efficient and noise-reducing manner possible. In this context, aircraft energy management describes the dissipation of kinetic and potential energy by the flight crew (automatically or manually) and by air traffic control. Kinetic and potential energy are equivalent. To illustrate this equivalence, two approaches to Zurich Airport with an Airbus A320 in regular airline operation recorded during the same timeframe in 2019 as the later flight test campaign (see Sect. 4.1) are analysed. The first example in Fig. 3 shows a near-optimum approach. From 60 NM from the runway threshold until shortly before stabilization altitude, the entire approach was performed at engine idle thrust. Between 60 and 30 NM, the aircraft configuration does not change and the speed brakes are not used. At 50 NM, 40 NM and 30 NM, further descent is delayed each time due to altitude constraints. Instead of maintaining constant indicated airspeed at the constraint altitude, which would result in an increase in thrust, the crew reduces airspeed each time, thereby keeping the engine at idle without adding more energy to the aircraft's energy state. As a result, the energy dissipation rate e_{tot}/dt remains constant over the entire approach distance between 60 and 30 NM (lower right Fig. 3). With clever descent management and an anticipatory flight strategy, fuel can thus be saved.

In contrast, a flight is shown in Fig. 4 where the current airspeed and thrust level was maintained from 60 to 40 NM with an altitude restriction until 40 NM instead of reducing airspeed to continuously reduce the aircraft's energy state. This significantly reduces the energy dissipation rate and leads to an excess energy situation which consequently requires the use of speed brakes.

2 Problem description

Many studies on the continuous descent approach focus on aspects of airspace structures and procedure design [3, 5]. However, it has been shown that even with ideal airspace structures, an optimum approach is often far from being achieved, as expressed in the European CDO/CCO Action Plan [2]. In the following sections, the ideal standard approach is explained and the reasons for deviations from it are investigated.

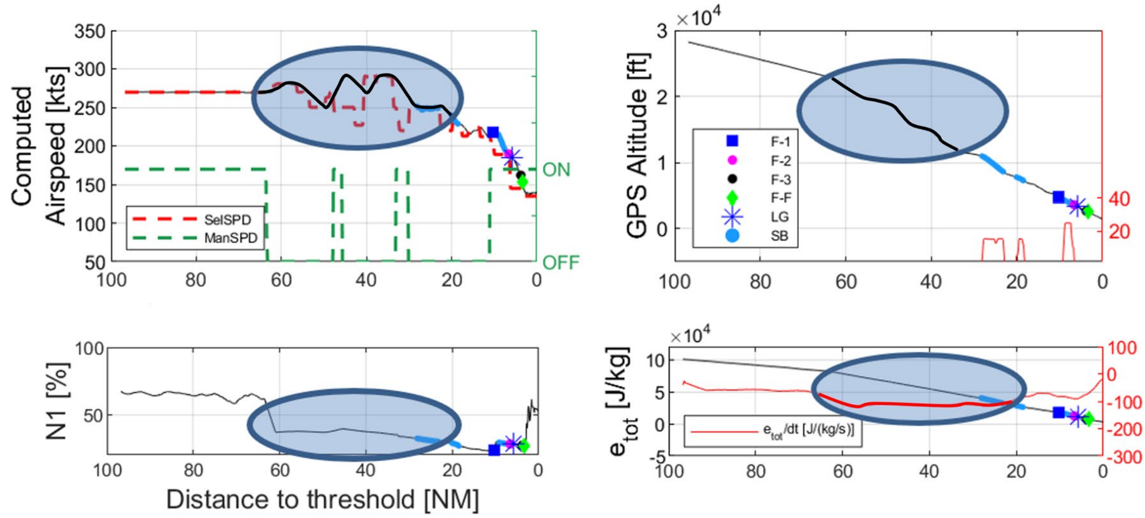

Fig. 3 An approach with altitude constraints but with continuous energy dissipation rate between 60 and 30 NM due to trading between kinetic and potential energy with an Airbus A320 at engine idle

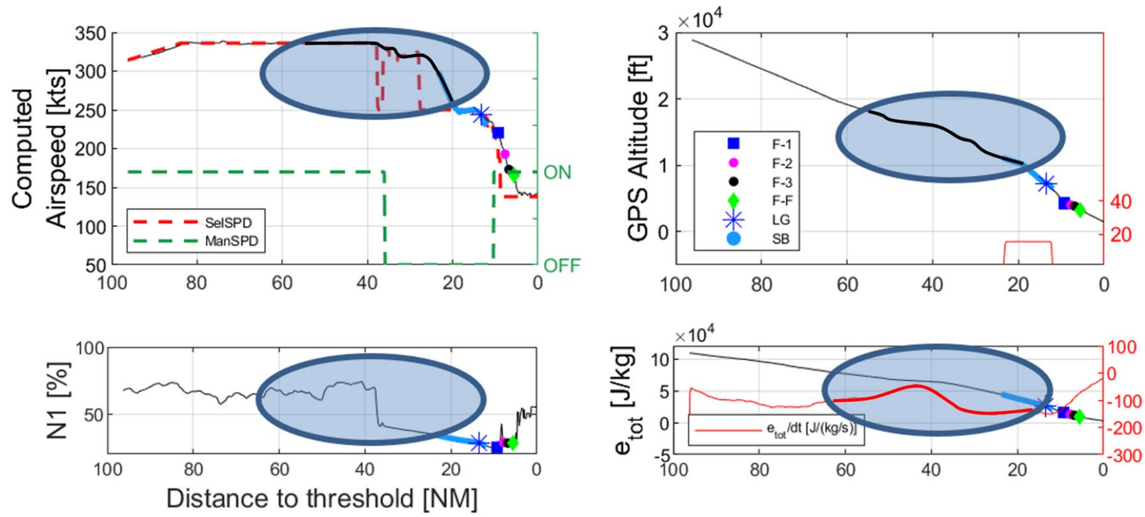

Fig. 4 An approach with an altitude constraint at 40 NM but with thrust levels maintained until 40 NM which results in an over-energy situation that requires energy dissipation with speed brakes. The reduction of the energy dissipation rate e_{tot}/dt can be observed in the lower right illustration with a peak at 40 NM

2.1 Pilot's perspective

2.1.1 The ideal standard approach

The standard approach without ATC restrictions starts at cruising altitude at the time of top of descent (ToD), see Fig. 5. As a rule of thumb, distance to go (DTG) = flight level divided by 3, e.g. flying at FL360 with a runway at sea level, the descent should be initiated at approximately 120 NM before touchdown. From there, the ideal approach is performed completely in engine idle thrust down to the stabilization altitude of 1000 ft AGL (under certain circumstances and depending on the airline, this can also be lowered to 500 ft AGL, e.g. in visual meteorological conditions). The airspeed at the time of descent initiation is defined by the so-called Cost Index (CI), i.e. the ratio of time-related costs divided by fuel costs. A CI of zero corresponds to a flight with minimized fuel cost or fuel burn. As another rule of thumb, reducing the descent speed by 1 kt saves 1 kg of fuel and adds 3 s of flight time [2]. The first part of the descent takes place with constant Mach number, below the crossover altitude with constant indicated airspeed (IAS). Shortly before reaching 10,000 ft above mean sea level (AMSL) (FL 100), the reduction to 250 kt IAS is initiated. This speed is

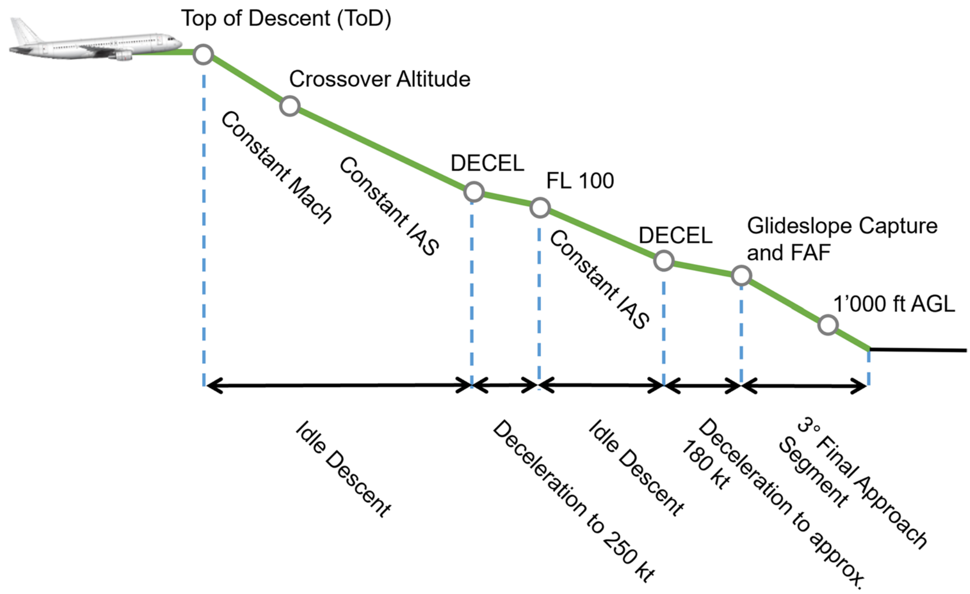

Fig. 5 The standard textbook descent without ATC restrictions

maintained, still at engine idle, until further speed reduction to intercept the glideslope with an IAS of around 180 kt. This speed is aimed at so that when reaching the glideslope, the flaps and slats are already extended to decelerate below minimum clean speed. If the glideslope is intercepted in clean configuration, for normal weights, deceleration is only possible with additional use of speed brakes or landing gear extension, leading to higher noise emissions. This speed reduction to approximately 180 kt can occur either in a continuous descent approach (CDA) segment, or in a shorter horizontal segment, latter denoted as optimized low drag low-power (OLDLP) approach (see Fig. 8). If the altitude of the final approach fix is reached too early, engine power must again be applied, which also increases noise emissions and generates additional fuel consumption. When passing the stabilization altitude at 1000 ft AGL, the aircraft must be in an unaccelerated steady-state condition with the engines at the thrust value for the respective final approach speed and fully configured.

To conduct this ideal standard approach, the aerodynamic performance data of the aircraft, the wind conditions and especially the distance to go between the aircraft and the runway must be known. With this information, an ideal approach can be performed under the assumption of no further restrictions.

Therefore, the crucial decision points for the flight crews consist in selecting ToD, continuously estimating the DTG and the deviation to the optimum profile, deciding about corrective measures, choosing an approach strategy for the intermediate approach segment (e.g. OLDLP or CDA), and achieving the perfect timing for the initiation of deceleration to the glideslope intercept speed, while keeping the engines at idle at all times, if possible. Aside from this optimization, it must be ensured that the approach is stabilized at 1000 ft AGL. Optimum fuel efficiency and a more conservative approach strategy to reduce pilot workload and ensure a stable approach are therefore sometimes in conflict.

2.2 ATC's perspective

Besides providing a safe and orderly air traffic flow, the main tasks of an approach controller is to ensure minimum separation between the aircraft to enable the maximum number of approaches per hour. At the same time, the different wake turbulence categories and, in some cases, different airline approach philosophies must be taken into account. This task is further complicated by environmental factors such as changing wind conditions or areas with weather phenomena that must be avoided. The approach controller defines the aircraft's airspeed and the time of the next speed reduction such that the distances between the aircraft are minimal at times when the highest approach capacity is required. During phases with less dense approach traffic, more freedom can be given to pilots to determine airspeeds or time airspeed changes themselves. Maximum approach capacity and aircraft-specific optimal speed profiles are thus in conflict.

For ATC, it is simplest to consider the aircraft as a point mass with freely assignable speed to achieve the minimum separations. This naturally conflicts with a free choice of approach speeds by the approaching aircraft itself and a complete idle thrust profile. This means that the more the aircraft choose the speed profiles themselves, the more the lateral separations are compromised. However, this can be mitigated by first using a pilot assistance system to render the speed profiles very similar (e.g. no noisy high-speed approaches or excessively slow approaches, both of which can often be observed in situations of free speed selection in daily operation) and second by specifying a speed restriction with which the final approach fix FAF should be flown over. Already today, speed restrictions are often defined on the approach charts. The variation of the speed profiles is thus reduced to a small variation in the time and location of the beginning of the reduction from the initial speed to the FAF speed restriction due to different weights or different aerodynamic profiles (in the case of different aircraft types). How much separation or time loss in aircraft scheduling results from a moderate individualisation of the speed profiles should be investigated in future research.

2.3 Reasons for the deviation from the standard approach

Almost every approach consumes more fuel than necessary. There are many reasons for this. The crucial information for calculating the optimum time of descent initiation and the optimum vertical profile is the DTG. Many airports define RNAV arrival transitions, which, in practice, are seldom followed entirely. The vast majority of approaches take place under radar vectors, whereby the remaining DTG can often change at short notice, for example, in the case of changes in the approach sequence. If the approach is planned in the flight management system with a longer DTG than the actual path eventually flown, the descent will be initiated too late and the aircraft will have to dissipate the excess energy with additional aerodynamic drag. On the other hand, it may be that the flight crew, due to lack of information, expects a direct approach and thus descends early, but then the approach takes considerably longer and the aircraft must fly horizontally at a low altitude for an extended time, resulting in increased fuel burn.

Another important factor for the calculation of the ideal approach is the wind data at different altitudes. Omitting wind information in the calculation can lead to a significant deviation from the optimal vertical and speed profile. If the optimum profile is calculated using DTG, this sometimes still cannot be flown due to other air traffic (e.g. departure traffic blocking further descent), unfavourable airspace structures or terrain.

When flying without ATC speed assignment, a single aircraft unexpectedly reducing speed early on intermediate or final approach can result in a domino effect on the aircraft behind. For this reason, at London Heathrow, for example, it is mandatory to maintain 160 kt to 4 NM, regardless of aircraft type or aircraft mass. However, this fixed speed is not the physically optimal speed of a single aircraft.

3 Development of CDA function for LNAS

Enhanced pilot support is necessary to further exploit the potential for fuel optimization and noise reduction. For this reason, DLR has developed the low noise augmentation system (LNAS). LNAS runs as a demonstration technology on an electronic flight bag (EFB) and is directly connected to the avionics data in real time. The LNAS pilot assistance system allows optimization for approaches in continuous descent in terms of specifying the time of transition to idle and the time of configuration changes in order to be stabilized at 1000 ft AGL. LNAS makes it possible to increase the pilot's situational awareness by calculating and visualizing the excessive kinetic and potential energy. This gives the pilot an overview of the aircraft's energy state during the entire approach. Thanks to the high-frequency optimization algorithm, LNAS reacts immediately to any changes in flight trajectory, wind or airspeed. The optimization aims at the quality criterion to fly the entire approach in idle thrust and to maintain a standard configuration sequence (example on A320: flaps 2 before landing gear down). Deviations, e.g. due to wind changes, are compensated by shifting the configuration points in real-time. If, for example, the intercept of glideslope is slightly faster than expected due to a wind change, the landing gear is extended a slightly earlier (Fig. 6).

The LNAS HMI (see Fig. 7) shows the pilots two vertical profiles: the vertical reference profile which is calculated backwards from the stabilisation altitude of 1000 ft AGL to the beginning of the approach and the actual vertical predicted trajectory which is calculated from the actual aircraft position by means of a complete aerodynamic and flight-mechanical 6-degree-of-freedom model in small time steps (forward simulation). In the forward simulation, the

Fig. 6 LNAS displays the optimum vertical profile and the optimum timing of the aircraft configuration changes to the pilots on an electronic flight bag

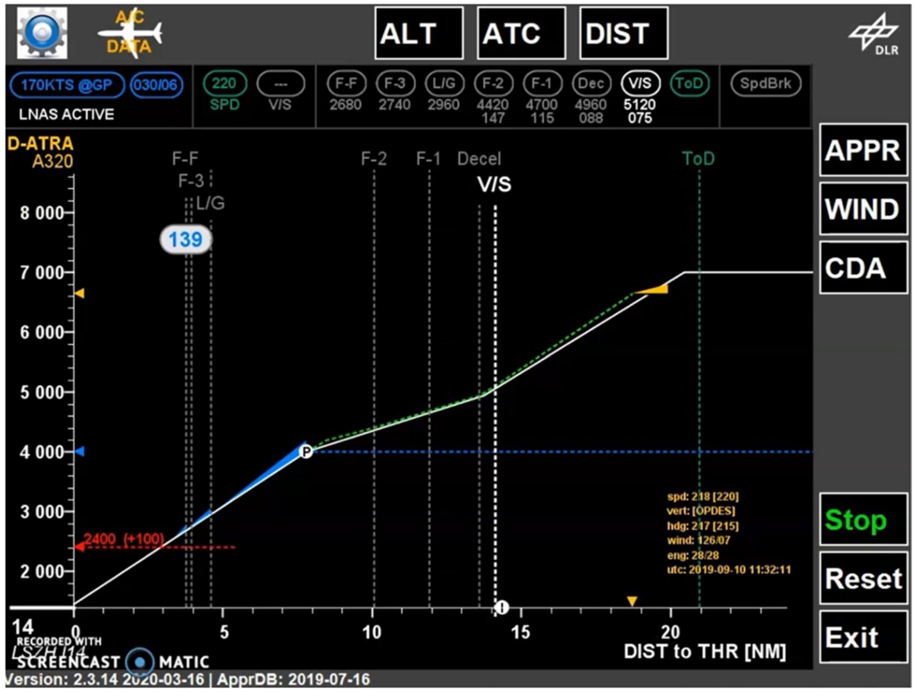

Fig. 7 Display of the vertical profile in LNAS by means of the reference profile (white line) and the forward simulation (green dashed line), as well as the configuration points

locations of the configuration changes are determined and shown on the display by means of distance information. Blue trapezoids indicate the development of the aircraft energy state.

3.1 From OLDLP to CDA

A first flight test campaign to demonstrate LNAS was conducted in Frankfurt in 2016. In this campaign, LNAS supported the so-called optimized low drag low-power (OLDLP) procedure, whereby the speed reduction to reach the configuration speed for setting the high-lift devices takes place in a horizontal idle segment at the final approach altitude. Within the scope of the project presented in this paper, LNAS was further developed between 2018 and 2020 by the consortium of DLR, Skylab and Empa to implement a CDA segment for the speed reduction below FL 100 (see Fig. 8).

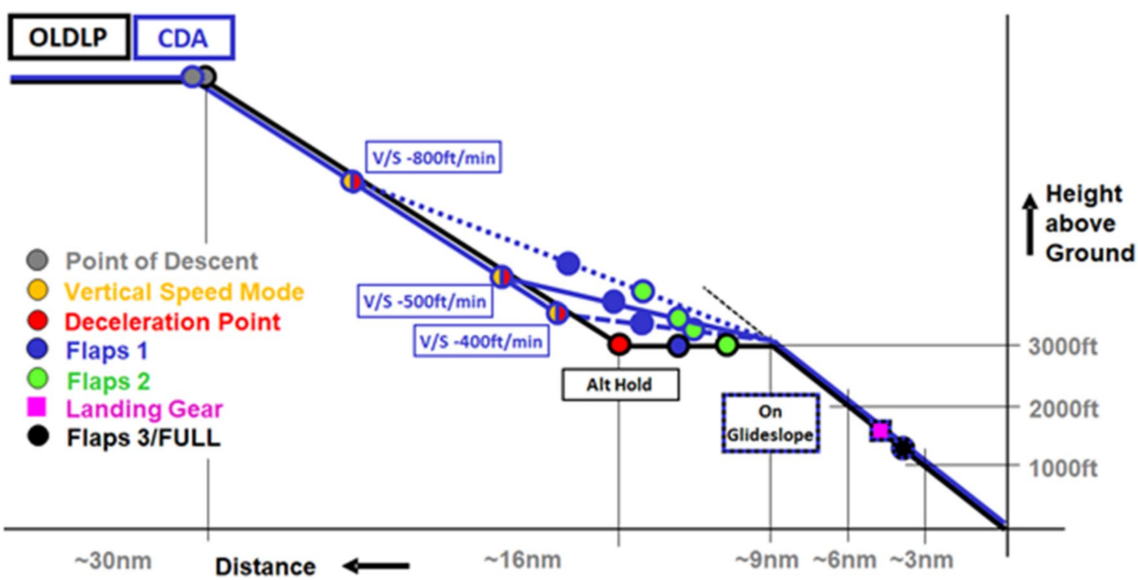

Fig. 8 Different deceleration strategies between optimized low drag low power (OLDLP) and continuous descent approach (CDA)

The slope of this segment increases the distance between initiation of the speed reduction and the glideslope intercept point, but the terrain is overflown slightly higher which leads to noise reduction. During investigations for this project, a segment with a vertical speed of 500 ft/min was found to be a good compromise between minimum fuel consumption in OLDLP (thanks to shorter flight time. which is, however, quickly sacrificed if the procedure is not flown perfectly) and only slightly higher fuel consumption in CDA due to slightly longer flight time, which is, however, compensated for by the greater robustness of the procedure. Maintaining constant airspeed for a short time in an inclined segment consumes less fuel than doing so in a horizontal segment.

3.2 Implementation of distance to Go (DTG)

Another central functionality that was integrated into LNAS as part of this project is the distance to go (DTG). The optimal vertical profile can be calculated by entering the distance to the threshold from the actual aircraft position, which is communicated by ATC before the approach is initiated. Instead of a manual input of DTG, the FMS distance could be used. However, as mentioned earlier, the lateral flight plan in the FMS (e.g. full RNAV transition) usually does not correspond to the effective lateral flight track flown. With future FMS functions such as the permanent resume trajectory (PRT), this problem could be solved. The PRT allows to have at any time a closed lateral flight plan in the FMS for the vertical profile calculation corresponding to the actual expected lateral flight path and also available when the aircraft is guided under radar vectors instead of following an RNAV transition. With PRT, the expected flight route to be flown would then be used as a reference lateral trajectory in the FMS instead of the published complete RNAV transition.

4 Flight test results

4.1 The flight test campaign

In September 2019, the DLR Airbus A320 ATRA performed 90 approaches to Zurich's Runway 14. 20 approaches were excluded from the evaluation mainly because icing conditions were present on the first 2 flight test days, causing the anti-ice system to change the thrust profiles of the engines. Of the remaining 70 approaches, 43 were flown with LNAS assistance and 27 without. The approaches were flown by regular airline pilots from Swiss International Air Lines, Lufthansa, Edelweiss and Condor under the supervision of the DLR test pilots. The approaches were coordinated and guided by Skyguide. The pilots flying without assistance systems were also informed by ATC about the DTG and given the task of flying as quietly and economically as possible using the standard sequence of configuration changes. This resulted in a direct comparison between human and machine. Of the 27 approaches flown without LNAS, 6 featured horizontal flight segments (see Fig. 9). The present analysis is

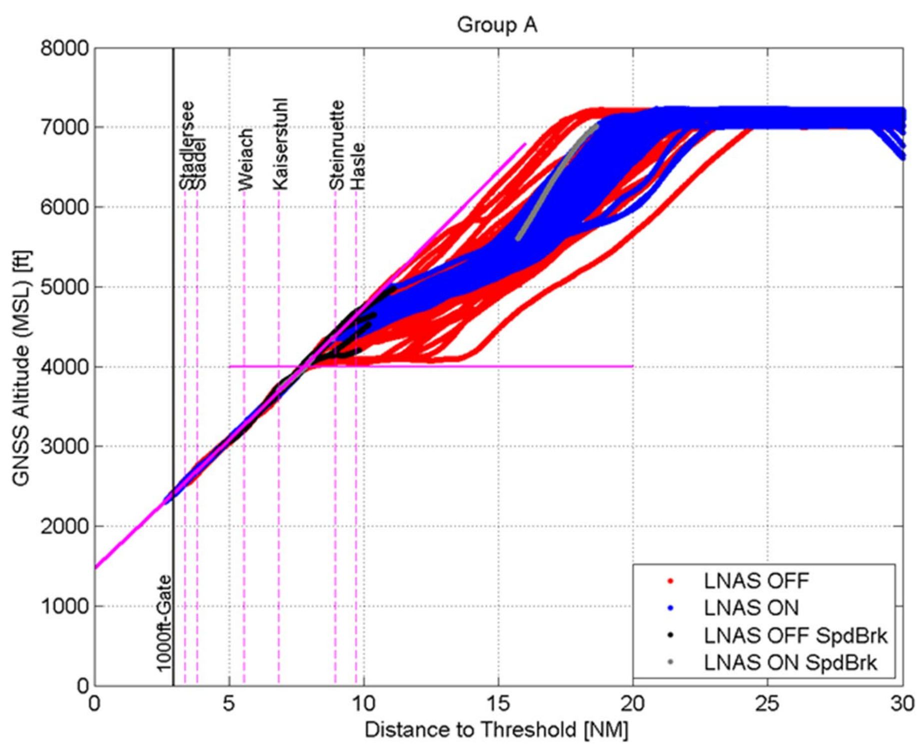

Fig. 9 Vertical profiles of the flight tests on runway 14 in Zürich with LNAS (blue) versus without LNAS (red). The vertical magenta lines signify the positions of the six acoustical measurement stations

focused on the comparison of real-world approaches with and without LNAS and is not limited to comparison of CDAs. Therefore, these non-CDAs with a short horizontal segment were not excluded from the analysis, as they occurred naturally within the given approach conditions. The approaches began at 7000 ft AMSL in a downwind leg at 220 kt. The test flights focused on the idle descent phase below FL100 down to stabilization altitude. All approaches were acoustically measured by Empa and subsequently simulated with the sonAIR aircraft noise model to calculate the noise footprints using the recorded flight data.

4.2 Results

The results from the flight tests are significant. Regarding the vertical profile (see Fig. 8), the approaches with LNAS all took place within a narrow vertical corridor. The horizontal variation in the location of the initiation of the descent with LNAS is significantly lower. Likewise, all horizontal flight segments could be avoided with LNAS assistance.

Regarding the speed profiles, a clear picture emerges as well (Fig. 10). With LNAS, the speed reduction from 220 kt was initiated at almost the same distance to the runway during each flight. The variation of airspeed at the interceptions of the glideslope results from the fact that the optimum speed in the 3° final approach is weight-dependent and lies between 170 and 185 kt and from minor deviations from the calculated wind profile to the effective wind profile.

The comparison between the approaches with LNAS and without LNAS results in a fuel reduction of 6% on the last 26 NM. For illustration: extrapolated to the overall number of flights of Swiss International Air Lines on the A320 for the year 2017, this results in a saving potential of 500 tons/year for the same 26 NM flight distance.

An evaluation of the noise reduction for the approaches with LNAS based on noise measurements and post-measurement simulations with the noise simulation tool sonAIR by Empa also shows clear results. Measurements revealed reductions of up to 1.8 dB in A-weighted noise exposure levels (L_{AE}) in the final approach area, where the landing gears are typically extended (between 5 and 7 NM before touchdown). In the area between 7 and 10 NM from touchdown, a reduction in noise exposure levels of up to 1 dB was observed. sonAIR simulations confirmed this reduction potential and showed that the noise reductions measured directly underneath the glide path can also be transferred to laterally adjacent areas (see Fig. 11). Additionally, the simulations revealed reductions in the noise exposure of up to 3 dB in an area north of the measurement point 'Hasle'.

5 Discussion

The approaches supported by the pilot assistance system LNAS show significant reductions in both fuel consumption and noise emission, as well as very good predictability in terms of vertical and speed profiles. The tests were carried

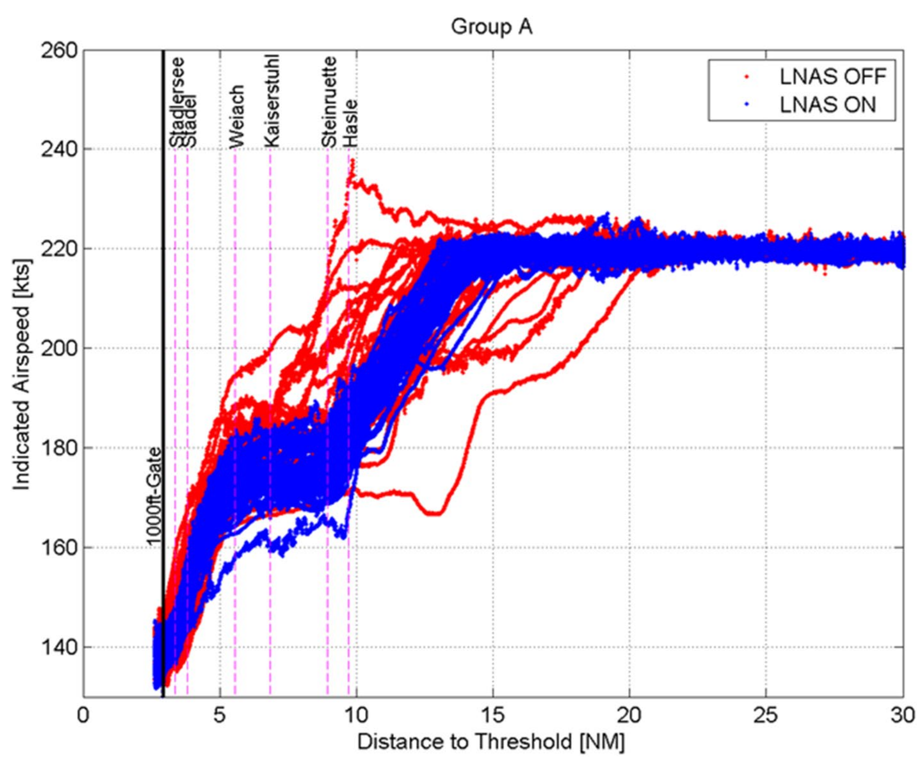

Fig. 10 Speed profiles of the flight tests on runway 14 in Zürich with LNAS (blue) versus without LNAS (red). The vertical magenta lines signify the positions of the six acoustical measurement stations

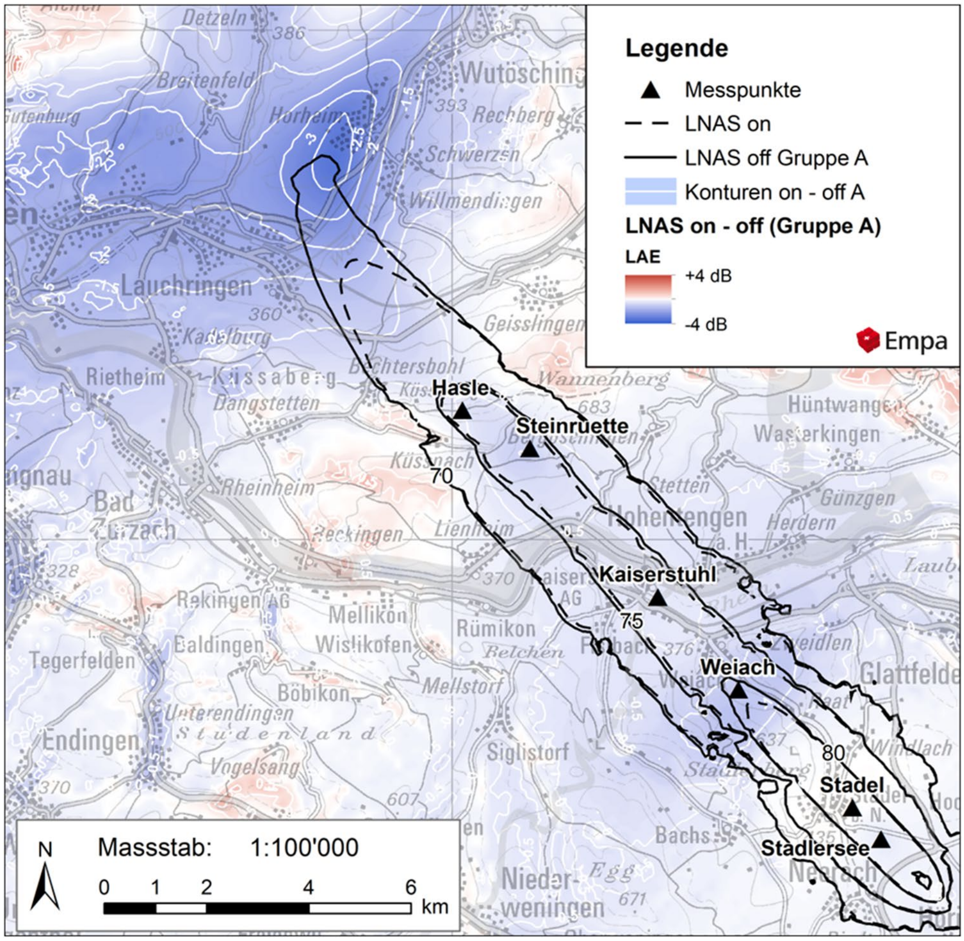

Fig. 11 Footprint differences between LNAS on versus LNAS off based on the weighted sound exposure level L_{AE} footprints for the ATRA flights. Relevant with respect to Swiss noise legislation are the differences within the absolute L_{AE} contours for LNAS on (dashed) and LNAS off (solid). The differences are additionally marked with white contour lines in 0.5 dB steps

out during flight operating hours outside the peak hours of Zurich Airport. Nevertheless, the approaches took place during regular operating hours, and in the year 2019, which saw the highest amount of air traffic ever. The flight-mechanical characteristics of approach optimization can also be transferred to other aircraft types. At Zurich Airport, the early morning arrivals of long-haul aircraft at sensitive times of the day in particular offer a considerable potential for noise optimization. As far as fuel savings are concerned, the optimization potential can also be transferred to larger aircraft.

Below, the feasibility of the LNAS-CDA concept is discussed with a focus on what can be achieved immediately and the upcoming industrialization of this concept.

5.1 Pilot's perspective

In European airline traffic, most approaches take place at airports which are not constantly limited by the maximum possible approach capacity. The predictability of the lateral flight path for the flight crews is often highly dependent on the respective airport. It has been shown that the most important information for approach optimization is the remaining distance to go. If the DTG and wind is known, then each approach can be perfectly optimized from ToD down to the runway. This can be achieved, for example, by ATC communicating the expected waypoints in an RNAV transition as early as possible or by transmitting an accurate DTG under radar vector guidance and updating the DTG should it change. Closed RNP to ILS procedures offer exactly this advantage of a known DTG. However, since numerous influence factors are not known at the time of descent initiation, the calculation of an exact timing for the flyover at FAF remains a major challenge. For this reason, LNAS-CDA cannot yet be used with minimal separation between aircraft. However, it can be clearly stated that the energy management for the pilots will be significantly simplified if air traffic control makes use of possible tolerances depending on the traffic density with instructions such as “descent when ready”, “reduce 180 kt or less”, "intercept glideslope with 160 kt or more”, etc. For ultimate fuel efficiency and noise reduction on the 3° final approach segment, it is necessary that the aerodynamically optimal, weight-dependent airspeed can be flown.

Even though it is often not possible to perform the entire descent from ToD to touchdown in an energy-optimized manner, LNAS nevertheless already enables local optimization, as was shown in the flight tests over the last 30 NM. In case of low approach traffic intensity, fuel optimization can also be achieved by asking the approach controller for an 'own line-up' specifying the requested lateral track of the approach transition and thus flying a closed-path procedure with a predefined DTG. Future developments within SESAR such as the permanent resume trajectory (PRT) provide the same benefit of a more reliable DTG.

From the point of view of a human factor analysis, the feedback from the pilots who took part in the flight tests was positive. In the debriefings of the flight tests, questionnaires with 32 questions were filled out by the pilots to assess the system. The pilots who flew with LNAS were asked different questions than the reference group who flew without LNAS. For the evaluation of the questions, the pilots were given a rating scale from 1 (completely agree) to 5 (not at all agree). The display of the altitude profile received particularly good ratings. In terms of pilot workload, however, it is necessary for future applications that the information displayed is integrated into the primary field of view so that the focus remains on the primary flight instruments during the work-intensive phase of the approach.

In general, a pilot assistance system enables better awareness of the aircraft's energy state, which in turn helps to reduce the number of approaches that are unstable at 1000 ft AGL. In addition to reducing fuel and aircraft noise, this also makes an important contribution to flight safety. In any case, it is better to correct an unfavourable energy situation early in the approach than to realize at 1000 ft above ground that the approach is unstable and a go-around must be initiated.

5.2 ATC's perspective

The approaches of the flight tests were carried out in Zurich, one of the most complex airports in Europe. At times when maximum approach capacity must be ensured, individual flight profiles (altitude and speed) conflict with minimum separation requirements. At the same time, however, it could be observed that the speeds flown by approaches with LNAS assistance fit very well into today's standard speed profiles (within TMA 220 kt, about 180 kt at FAF, thereafter about 160 kt up to 4–5 NM). Thus, in any case, an approach conducted with LNAS is more predictable than simply giving a crew ‘free speed’ for the entire approach. At FAF, even with a weight-dependent airspeed variation between 170 and 185 kt, this variation was smaller than that of a pilot group without assistance assigned with the task of conducting energy-optimized approaches with a standard configuration sequence.

To overcome the problem of capacity limitation in mixed operation with/without LNAS (or an industrialized solution of LNAS) during times of medium and high approach, various challenges must be solved. This includes the communication of the DTG from ATC to the aircraft, and the optimum approach speed from the aircraft to ATC via data link. Trajectory-based operation (TBO), for example, goes in this direction. However, to ensure minimum separation, it would be necessary to adhere to a required time over (RTO) at the FAF point almost to the second. Today’s FMS with required time of arrival (RTA) function adhere to a time constraint with ± 30 s, latest generation 4D FMS with a precision of ± 10 s [2] which is not yet sufficient for maximum approach capacity. A further suggestion is the implementation of variable arrival transitions (predefined flight paths to the final approach point with different DTGs that can be assigned before commencing the approach).

In a shorter time frame, by training air traffic controllers and pilots on the presented aspects of aircraft energy management, as offered, for example, with online courses by Eurocontrol, a certain potential for improved energy management can be realized today.

6 Conclusion and outlook

The low noise augmentation system (LNAS) is an assistance system that supports pilots in performing energy-optimized approaches. This significantly saves fuel, reduces aircraft noise in the vicinity of airports, and increases flight safety thanks to stabilized approaches. The further development within the project presented through the implementation of the CDA procedure and the use of DTG information has been successfully demonstrated in flight tests with regular airline pilots. The close cooperation between air traffic control and flight crews in the further development of a pilot assistance system for energy management is essential, so that an industrialized solution can be developed, which considers all aspects and works successful in congested airspace. Concepts for data exchange between air traffic control and aircraft must be further developed to this end (TBO with precise RTO). In any case, as has been demonstrated in the flight tests, anticipatory flying with constant awareness of the current aircraft energy status saves fuel and reduces aircraft noise.

In two ongoing SESAR projects, LNAS-CDA is now brought to the next level of implementation. In the SESAR Very Large Scale Demonstration (VLD 2 ALBATROSS), LNAS is going to be demonstrated in scheduled flight operations at Swiss International Air Lines for the potential of fuel savings. At the same time, an FMS prototype is being developed in the SESAR Exploratory Research Project DYNCAT together with Thales Avionics, which translates the LNAS concept into an integrated avionics environment. These latest developments of LNAS and its integration into an avionics environment focus on the development of human–machine interface aspects for the display of relevant information on the primary flight display (PFD) and navigation display (ND), on using lateral flight plan information from the FMS as a basis for determining the vertical profile, on the integration of measured wind profiles of preceding aircraft instead of interpolations of measured wind at aircraft position and ground wind, as well as on the development of concepts for data exchange between aircraft and air traffic control.

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