Active Noise Abatement Using the Newly Developed Pilot Assistance System LNAS

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ABSTRACT
Reducing aircraft noise becomes more and more important due to an increased number of flights and population in the vicinity of airports. An important opportunity to reduce noise during the approach phase is to increase the chronological precision of each task conducted by the pilots. In order to improve the situation the pilot assistance system LNAS is developed. It provides a vertical approach profile with optimal points in time to set flaps, gear and speed. A correction algorithm continuously compensates the actual wind situation and possible deviations from the optimal points as well as speed restrictions which are given by air traffic control. If the pilots follow the LNAS suggestions, the approach can be executed with minimum thrust from cruise altitude to stabilization height. For demonstration and evaluation of the developed system under operational conditions, seventy-four approaches were performed with the DLR research aircraft A320 ATRA during three days in September 2016. The flight trials had been conducted by seventeen type-rated airline pilots in order to assess the benefits of LNAS during approaches at Frankfurt Airport. The evaluation of the measurement data from ten ground-based noise monitoring stations shows that there is a need for flight procedure optimization and a potential for aircraft noise reduction.

Keywords: noise abatement, vertical approach profile, assistance system

1. INTRODUCTION

1.1 Motivation
After the economic crisis in 2009, the forecasts for growing traffic in the aviation sector were revised downwards. However, further growth is expected in the coming years. The expansion of airports, particularly in the vicinity of densely populated regions, is accompanied by an increasing number of aircraft movements. This increases the possibility of conflicts between residents and airport operators. In order to increase the acceptance by local residents and to avoid conflicts, the topics of environmental and noise protection will play an important role in the future among other themes like safety and will continue to be a key driver for the aviation industry as a whole. The challenge with respect to the environment is to reduce continuously the environmental impact in the face of continuing expansion in aviation. The Advisory Council for Aviation Research and Innovation in Europe ACARE presents a summary of the objectives for future air transport: In 2050 technologies and procedures available allow a 75% reduction in CO2 emissions per passenger kilometer and a 90% reduction in NOx emissions. The perceived noise emission of flying aircraft is reduced by 65% (1). These are relative to the capabilities of typical new aircraft in 2000. These ambitious aims will drive the need to deliver revolutionary technology solutions at an increasing rate.

The most consistent way to reduce aircraft noise would be the optimization of the noise source itself. However, the development times of new aircraft and also the service life of current models are very large. Therefore it is useful to deal with other aeronautical aspects in addition to the technical characteristics of aircraft. For example, arrival and departure procedures are particularly interesting.

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Because the requirements for flight safety are very high, optimizing and modifying already existing procedures is only possible within the scope of existing regulations. The following examples show that such changes can be implemented, at least in the medium term. At Frankfurt Airport a continuous descent approach (CDA) has been flown at night time since 2005. Furthermore, approaches with an increased glide path angle of 3.2° are flown as standard since 2014.

A further potential to reduce noise is the optimization of the approach procedure. This is only possible if such an approach procedure is realized precisely. In most cases pilots are not able to achieve this precision without further support.

1.2 Problem Definition

In the simulator study STENA (2), standard approaches with different glide path angles and wind conditions were carried out by 16 professional pilots of one airline in an Airbus A330 full-flight simulator of the Center for Flight Simulation in Berlin (ZFB). The result of operational investigations shows that there is a need for a pilot assistance system. For one approach scenario with 8 kts headwind and 6 kts crosswind the recorded data for the fan speed $N_1$, the indicated airspeed $V_{IAS}$, the altitude as well as the flap setting for all approaches are displayed in Figure 1.

The approaches were flown with autopilot and at an altitude of 1000 feet above ground level the pilots switched to manual flight. Speed, flap and landing gear setting should be executed in accordance with the airline-specific procedures. It can be seen in Figure 1 that the thrust, speed and configuration sequence of the approaches varies significantly until reaching the stabilization height (red line). That indicates an individual procedure by each pilot. The theoretically optimal sequence of the fan speed is shown by the green line. Initially, the engine is at a constant power level to maintain speed. Then it is retarded to idle so that the aircraft can decelerate at constant altitude. In this aircraft model, the idle power of the engine increases automatically from the flap configuration 2 in order to reduce the ramp-up time of the engines in the case of a go-around. When the stabilization height is reached, the thrust setting is raised again to maintain the approach target speed and flight path angle.

![Figure 1: Simulator trials A330 (ZFB) (2)](image)

As the figure shows, in most cases there is a considerable difference between the actual and the optimal $N_1$. In the areas where the engine would optimally be in idle, the deviations are particularly large and thus lead to an avoidable increase in noise immission and fuel consumption during the approach. Obviously there is a very individual behavior regarding the speed management, since all pilots followed the same operational requirements. It can be assumed that a significant amount of noise in the vicinity of airports is based on the pilots' individual settings regarding configuration and speed.

In Figure 2 flight track data of the aircraft type A320 from the airport operator Fraport at Frankfurt Airport (EDDF) are shown in the form of ground speed over distance to threshold. The data reflect approaches to the former runway 25R (now 25C) during 33 days in autumn 2012 (maximum tailwind 6 kts; maximum headwind 12 kts). Only data in the area of the glide path are shown to ensure comparability of all approaches. The ideal ground speed profiles for different wind situations and gross weights are also shown in Figure 2. Obviously the real ground speeds deviate from the optimal
speed profile. There is a trend towards a higher speed than necessary in the optimum case. Thereby the noise immission could be higher.

At this point, it should be noted that this problem is not a result of a poor qualification of the pilots. The precise execution of an approach procedure is highly complex. This includes the settings of configurations, landing gear as well as speeds at the optimal time, taking into account the dynamic wind conditions, the variable gross weight and possible requirements of air traffic control. Finally, years of experience also do not lead to optimal results, so that there is a need for a pilot assistance system.

2. THE PILOT ASSISTANCE SYSTEM LNAS

The assistance system LNAS (Low Noise Augmentation System) has been developed to improve the above described situation. It is based on the so-called Vertical Situation Display (VSD), which, in addition to the Navigation Display (ND), maps the vertical flight plan, i.e. the altitude above the distance to the touchdown point. This display is now regarded as state of the art.

The assistance system LNAS includes three parts: preliminary trajectory planning, correction algorithm and human-machine interface in a novel display. The preliminary trajectory planning is based on performance data of the Airbus A320. This planning should ideally take place before the start of the actual approach. In doing so, optimal points in time for setting speed, high lift devices and landing gear are determined in such a way that the approach can be carried out with minimum engine thrust and if possible without using speed brakes. The optimization algorithm is designed for the approach phase until an altitude of 1000 ft above ground level (AGL). It also accounts for the stabilization criteria at 1000 ft AGL, i.e. the optimal profile terminates with a stabilized flight condition at 1000 ft AGL such that there will be no problems completing the landing. The optimal points in time depend on the wind conditions at the current altitude and at the airport, which are already known at this time. In order to assess this information in the current situation (aircraft mass, wind conditions, flight safety regulations), in particular the prospect of a timely stabilization of the approach, the additional graphical representation of the current speed error and its expected progression is necessary. These quantities can be obtained via a suitable simplified simulation model. For a low-noise approach, it is a prerequisite that the required speed reduction can be carried out to the next configuration point under the current boundary conditions without using speed brakes. In order to enable a common representation of the height profile and the speed error in one and the same display despite the different units, a representation in the form of an energy height is preferred here. For this purpose, the sum of kinetic and potential energy is formed and divided by the force of gravity, see Eq. (1). Clearly, the energy height $H_E$ is the height that can be reached by converting the current kinetic energy completely and without loss.
\[ H_E = H + \frac{V^2}{2g} \] 

The vertical profile, the points in time and the trend of the speed in terms of the energy height are provided to the pilot in a symbolic way. The display of the assistance system LNAS can be seen in Figure 3. With its intuitive structure, it provides a basis for planning the entire approach (6).

During the approach the current wind situation is entered automatically, as well as possible imprecise pilot actions are taken into account, so that at each time the optimal vertical approach profile is shown on the display. An imprecise pilot action could be for example an early or a delayed setting of a certain flap configuration. In addition, speed constraints required by air traffic control can be entered by the pilot in order to optimize the approach under the new boundary conditions. Figure 4 illustrates the basic principle of LNAS to ensure an optimized vertical approach profile at any time.

Figure 3: Display of the assistance system LNAS

Figure 4: Basic principle of LNAS

LNAS needs certain input values for calculating the optimal vertical approach profile, which are
graphically summarized in Figure 5. These are subdivided into information, which must be configured by the pilot, are provided directly by on-board systems of the aircraft as well as read out from a database stored in the LNAS application.

Figure 5: System interfaces and signal inputs

As already indicated, the software provides a graphical user interface. By this interface certain values (e.g. tower wind, speed constraints) need to be inserted by the pilot. Simultaneously all relevant information for executing the optimized approach is provided in an intuitive way. The display consists of soft keys for configuration, symbols for current states and constraints as well as a schematic representation of the vertical approach profile. The LNAS application is installed on both electronic flight bags and is available for the captain as well as for the first officer. Figure 6 shows the LNAS display during a flight trial.

Figure 6: LNAS onboard DLR's ATRA A320

3. RESULTS OF THE LNAS TEST FLIGHTS

3.1 Flight Trials

The LNAS flight trials took place from 26 to 28 September 2016 and comprised a total of 25 flight hours using DLR's A320 aircraft ATRA at Frankfurt Airport. The flight hours were divided into a total of 3 days, so that five test flights were planned. The aim of the campaign was to test LNAS under real conditions of a highly-frequented airport. During the test flights at Frankfurt Airport, the flights were carried out without special treatment by air traffic control. During the entire period, ATRA was treated like any other aircraft for the approach to the north-west runway.

During each test flight the DLR crew and four external professional pilots were on board. After each approach the external pilot changed in order to avoid a possible learning process. Another reason for this was that in general the pilots only perform one landing before a subsequent flight. Furthermore, this provided the greatest possible time interval until the next approach had to be performed by the same pilot in order to obtain varying weather conditions. After the next pilot took place in the cockpit, the information was given whether the following approach had to be flown without or with the LNAS display. Finally 74 approaches were performed on the north-west runway at Frankfurt Airport. The
runways 07L and 25R were operated with a glide path angle of 3.0° (runway 07LZ/25RZ) as well as 3.2° (runway 07LY/25RY).

Figure 7 shows the flight tracks of the first test flight on the runway 25RZ. After each go-around the downwind segment was passed for the next approach until air traffic control provided the next vectors to intercept the extended runway center line. That was reached at different distances so that every approach had to be carried out under other boundary conditions. After each go-around the aircraft climbed to flight level 80 and performed the next approach.

As already mentioned, ATRA did not get any special treatment from air traffic control during the test flights. This leads to restrictions on climb and descent clearances as well as on speed constraints. In total, about one third of all approaches could be carried out without speed constraints. The percentage distribution of the approaches without speed constraints for approaches with and without LNAS is almost identical.

Figure 7: Flight tracks EDDF 25R

In addition to the influence of air traffic control, real test flights are influenced by environmental conditions. Figure 8 shows the wind profiles for three test flights. Tailwind components between 7 kts and 12 kts were measured at 3000 ft, while this wind component decreased down to a range from 0 kts to 8 kts at the first flight trial. During the second flight trial even a wind shear in 1800 ft can be seen. At the last one turbulent headwind components were measured up to 22 kts. The approaches with and without LNAS have the same wind conditions for each flight trial and are thus comparable. Through the different environmental conditions the flexibility of LNAS could be shown.

Figure 8: Wind profiles in flight direction; pos./neg. values: tail-/headwind
3.2 Noise Measurement

At Frankfurt Airport several noise monitoring stations are operated by the airport operator Fraport and the Umwelt- und Nachbarschaftshaus (UNH). The approaches were performed with and without the support of the LNAS display so that the noise measurements provided by UNH and Fraport need to be grouped. In addition invalid records are neglected, which occur e.g. through the following environmental influences: street/rail/neighbourhood/industrial noise or parallel events (two aircraft are approaching on parallel runways).

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 by geometrical spreading. The farther away an aircraft is from the threshold, the higher it flies with exception of the intermediate approach altitude. In most cases a higher altitude results in a lower aircraft noise level, so that the more distant noise monitoring stations could not measure the desired aircraft noise due to the higher ambient noise or an indefinable mixture of both. 100% of the measurements of noise monitoring station MP44 can be used, which is stationed at a distance of 6.16 NM to the runway threshold. In comparison, only 54% of the measurements of noise monitoring station MP268 (distance to threshold: 13.36 NM) are usable. Ten noise monitoring stations were available for the evaluation, for runway 25R and 07L 5 stations each.

For the noise evaluation the A-weighted maximum noise levels $L_{AS,\text{max}}$ and the A-weighted single event noise exposure levels $L_{AX}$ are provided by UNH and Fraport. The disturbance effect of a noise event is probably best represented by the maximum sound level $L_{\text{max}}$, since this level determines how strongly the noise event differs from the background noise which is always present. Additionally, the duration of a noise event has to be considered. This is justified by the fact that a flyover with a very low noise event time and a high maximum sound level can be less disturbing than a flyover with a larger noise event time and a low maximum sound level (7).

The duration of the noise event is taken into account by the A-weighted single event noise exposure level $L_{AX}$. According to ISO 3891 (8), this corresponds to the energetically converted sound pressure level averaged over the noise event duration and referred to $t_{ref} = 1$ sec. The A-weighted single event noise exposure level is defined by

$$L_{AX} = L_{AS,\text{max}} + 10 \cdot \log \left( \frac{t_e}{t_{ref}} \right). \quad (2)$$

The effective noise event duration $t_e$ can be replaced by the time-interval $t_{10}$, which indicates how long the noise level is less than 10 dB below the maximum sound level. Approximately it corresponds to the relation

$$t_e = \frac{1}{2} \cdot t_{10}. \quad (3)$$

Consequently, the A-weighted single event noise exposure level can be calculated as follow

$$L_{AX} = L_{AS,\text{max}} + 10 \cdot \log \left( \frac{t_{10}}{t_{ref}} \right) - 3 \text{dB(A)}. \quad (4)$$

3.3 Results of the Noise Measurements

For the evaluation, data sets are available for 17 approaches on runway 07L and 57 approaches on runway 25R. Therefore, the focus of the results is on approaches on runway 25R, where approaches with glide path angles of 3.0° and 3.2° were performed. Figure 9 to Figure 12 show the valid results of the noise measurements for the sound pressure levels $L_{AS,\text{max}}$ and $L_{AX}$ versus aircraft altitude, true airspeed as well as gross weight. The blue crosses encode the noise measurements of approaches with support of LNAS, while the red crosses represent the noise measurements without LNAS. Figure 9 shows the measurements of the noise monitoring station MP268, which is 13.36 NM away from the runway threshold. It is the farthest noise monitoring station for approaching the runway 25R.

The A-weighted maximum noise level and the A-weighted single event noise exposure level of the approaches with LNAS as shown in Figure 9 have a tendency towards lower noise levels relative to the measurements of the approaches without LNAS.
The maximum of 64.4 dB(A) of the maximum noise levels is reached by two flyovers without using LNAS. The two flyovers are nearly at the same altitude as well as in idle thrust. The difference in gross weight is only 1.2 tons. The true airspeed shows a difference of 30 kts. Both flyovers were carried out with extended speed brakes, but different flap settings. The flyover with a true airspeed of 227 kts and flap configuration 1 required a speed constraint of “170 kts at glidepath intercept” and later “reduce and maintain 160 kts until 6 NM”. The other flyover with a true airspeed of 200 kts and flap configuration 2 was carried out without any speed restriction. The single event noise exposure levels are 76.5 dB(A) and 77.7 dB(A) for the speeds of 227 kts and 200 kts. The lowest measured maximum noise level of 58.9 dB(A) is reached with the support of LNAS at the noise monitoring station MP268. True airspeed, altitude and gross weight were 205 kts, 4900 ft and 53.1 tons. A speed constraint of “170 kts or more until 5 NM” was required by air traffic control. The engines were in idle and the speed brakes were retracted. These circumstances led to the lowest maximum noise level and lowest single event noise exposure level of 71.3 dB(A).

The noise measurements from the noise monitoring station MP203 (10.18 NM from the runway threshold) are shown in Figure 10. There are no trends in noise levels between flyovers with and without LNAS.

With the exception of the speed, the aircraft almost always flew above this station with the same flap configuration. However, it is apparent that the minimum and maximum of both noise levels are achieved with the use of LNAS. Both flyovers were made in flap configuration 2 and retracted speed brakes. The true airspeed of the quieter flyover is 165 kts due to the given speed constraint of 160 kts at a distance of 16.5 NM. The louder approach needed to adhere to a speed constraint of 170 kts, which had been reached before the maximum noise level was measured. However, the aircraft accelerated on
the glide path so that the speed increased by about 10 kts. There was no additional thrust and no further configuration changes were made. At present, no further flight mechanical explanation could be found, which explains the difference of circa 7 dB(A).

In Figure 11 measurements from the noise monitoring station MP303 are shown. This station is positioned 6.93 NM away from the runway threshold. Particularly conspicuous is a flyover without assistance from LNAS, which reaches a maximum noise level of 72.6 dB(A). At this approach there was no speed restriction by air traffic control. Unlike the other approaches, an intermediate approach altitude of 4000 ft was required instead of the usual 5000 ft. At the time of measurement the aircraft was 64.4 tons heavy and 198 kts fast. The glide path was intercepted in flap configuration 1, which results in an increasing true airspeed on the glide path. To prevent this, speed brakes were extended in the range between 10.2 NM and 7.8 NM. In addition, the landing gear was already extended at 7.87 NM, in order to decelerate the aircraft. Once the speed was reduced by using landing gear and speed brakes, the flap configuration 2 could be extended at 6.93 NM. Most probably the noise level was increased through the extended landing gear and the high true airspeed.

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The measurement results of the last noise monitoring station MP44 (6.16 NM from the runway threshold) are shown for approaches on runway 25R in Figure 12. Two approaches without LNAS reach the maximum noise levels of 73 dB(A) and 72.3 dB(A), respectively the single event noise exposure level of 84.1 dB(A) and 82.9 dB(A). The first one is part of the same approach, which is already described in connection with Figure 11. For the further speed reduction, the speed brakes were extended again, which explains the increased noise levels. During the other approach the speed restriction “170 kts until 5 NM” was required. The pilot decided to extend the landing gear at 6.69 NM and it was locked at 6.01 NM, so that the noise measurement is influenced by the gear.
The differences between the approaches with LNAS and the approaches without LNAS could be even more pronounced if the noise monitoring station MP44 would be moved about 0.5 NM towards the runway threshold. This expectation can be explained by the distribution of the gear down position.

Figure 13 shows the position where all landing gear components are locked (Gear Down all green status). This occurs between 4.16 NM and 5.63 NM with LNAS and between 3.99 NM and 7.87 NM without LNAS, with the exception of the one approach at which the landing gear was extended at 15.66 NM. Despite the variable wind conditions, the range of the landing gear extension with LNAS is only about half as large as the gear extension range without LNAS support.

In general, the noise levels increase with decreasing distance. Unfortunately the noise monitoring stations are not based on the entire final approach so that not all advantages of the pilot assistance system LNAS, especially the later landing gear extension, can be shown by the noise monitoring station measurements. This circumstance only allows noise reduction prognoses in specific areas, which are shown in Figure 14. At the intermediate altitude before the glideslope interception, the 1st and 2nd configuration can be done more efficiently with the aid of LNAS, so that the optimal energy balance is better achieved in order to avoid an unnecessary increase in the thrust or a later speed brake use. Depending on the current traffic volume, at high traffic densities the aircrafts will probably have to follow the speed restrictions of air traffic control from a distance of approx. 15 NM until approx. 5 NM. These restrictions limit the freedom 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), as can be seen in Figure 12. It is important to emphasize here that an average value of the noise level is not sufficiently informative, because the outliers, which generate a lot of noise, need to be reduced.

**Figure 13:** “Gear Down all green” positions

**Figure 14:** Noise reduction areas RWY25R
4. CONCLUSIONS

The interpretation of low-noise flight procedures is a complex process, because even under ideal conditions (no wind, no restrictions due to other traffic or flight safety regulations) it must be taken into account that the noise generation at the various main sound sources of the aircraft cannot be influenced independently. Even though the aerodynamic noise basically scales to a high degree with the airspeed, a slow flying aircraft is not necessarily quieter because of the necessary configuration changes, which are accompanied by increased aerodynamic drag and consequently by higher noise levels. Flying higher with otherwise unchanged parameters obviously provides a lower noise immission directly below the flight track, but from a certain lateral distance, the noise level increases due to the lower ground attenuation. In addition, it should be remembered that an approach with a higher approach angle to the same touchdown point must be designed differently and not necessarily be quieter.

The aircraft-specific design of the approach profiles is thus of great importance. It presupposes a precise calculation or simulation of the flight path in order to determine in details operating conditions for the noise emission. This requires a series of aircraft-specific information (aerodynamic, engine), and modeling of dynamic effects (flaps and gear extension, simplified replication of the flight guidance and speed controller).

During the design phase of an approach profile, a number of constraints must be taken into account, such as the performance limits, the manageability of the workload by the pilots or the regulatory conditions imposed by the ICAO, which give priority to the safety and easiness of air traffic in contrast to environmental and especially noise issues. A change in these requirements must be internationally coordinated and is therefore conceivable as a long-term option at best. Short-term and medium-term processes must therefore be ICAO-compliant. In all this, it must be taken into consideration that inefficient procedures have no chance of practical implementation. A significant increase in flight time or fuel consumption should be considered as knockout criteria; a reduced predictability of the approach or a considerable deviation from the speed profiles of other flights and the associated capacity limitation at the airport are tolerated only in low-traffic time periods.

In order to achieve the optimum noise reduction, accurate procedures are necessary. These include adapting the procedures to the aircraft mass and the prevailing wind and weather conditions as well as the optimal aircraft configuration. However, today’s flight management systems (FMS, FCS) are not in a position to automatically fly a segmented continuous descent approach, which is recommended under noise and economic aspects (9). Even in standard procedures, the working load of the pilots during the approach phase is very high. Additional attention or action resources cannot therefore be requested; rather, support by improved assistance systems is urgently required.

A promising approach is the concept of an onboard assistance system, which helps the pilots to manage the energy budget, thus enabling a more precise implementation of the landing procedure. This is a display of the so-called energy level, summing potential and kinetic energy over the vertical profile of the flight path. Taking into account the tower wind and the mostly given speed restrictions, optimum points in time are determined for the extension of the flaps and the landing gear. The pilots are always informed about the energy balance during the entire approach as well as the necessary speed and height reductions. Impacts due to changes in wind conditions or new air traffic control instructions are immediately visualized. If the constantly updated forecast predicts a sufficient energy reduction to the stabilization height, the use of the noise-intensive speed brakes can be avoided. LNAS was able to prove its suitability in simulator tests and was tested under operational conditions in Frankfurt. It also appears as an indispensable component for implementing low-noise approach trajectories. The greater individualization of the vertical and speed profiles can also be seen as an opportunity to optimize the noise distribution along the approach path according to airport-specific aspects.

The very good cooperation of all partners enabled the conduction of the flight trials at Frankfurt Airport so that many aspects of the newly developed assistance system could be scientifically investigated. In summary, LNAS has a general tendency to improve aircraft noise, speed and configuration management as well as fuel consumption. With regard to fuel consumption, a reduction was demonstrated using LNAS during approaches, especially during the last 10 NM before reaching the stabilization height (6). A reduction in the influence of the air traffic control with regard to the specification of restrictive instructions would result in significantly higher fuel savings, as the evaluation of the flight data shows. Above all, the areas of setting the final landing configuration as well as the landing gear could be moved further towards the runway threshold. On closer inspection of the measurement values of the noise monitor station, it becomes clear that a noise reduction potential
is present in certain areas along the approach path, thus confirming the positive effects of the improvements described above.

Despite the successfully completed flight trials at Frankfurt Airport in September 2016, further developments of LNAS are desirable in order to further improve the system behavior and the interface between pilot and system. Currently, the low-drag-low-power approach procedure is implemented in LNAS, but that is not sufficient. At least the CDA approach procedure should also be implemented and tested.

In order to test LNAS in operational flights over a longer period of time and to identify more closely the noise and economic effects, cooperation between airlines, airport operators and authorities is essential. Such a project is necessary to further develop LNAS from the concept stage to a prototype assistance system.

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