THE STEPLESS PROJECT - A NOVEL APPROACH TO AN AUTOMATIC HIGH-LIFT SYSTEM

D. Vechtel[1], B. Böing[2], R. Sáez[3], M. Gerber[4], J.-M. Wunderli[5]

[1] German Aerospace Center (DLR), Institute of Flight Systems, Braunschweig, Germany
[2] Royal Netherlands Aerospace Centre (NLR), Amsterdam, Netherlands
[3] Technical University of Catalonia (UPC), Department of Physics-Aerospace Division, Castelldefels, Spain
[4] Swiss Skylab Foundation (Skylab), Dübendorf, Switzerland
[5] Empa, Dübendorf, Switzerland

Abstract

Today's high-lift systems are designed to allow most efficient approaches with continuous deceleration on a 3° glideslope. For the approach they typicall posess a limited number of intermediate high-lift settings so that the aircraft is able to decelerate to landing speed. However, under current operations at most major airports pilots cannot choose their speed freely and can decelerate continuously but have to follow speed instructions given by ATC for the sake of a better sequencing and separation between aircraft in the intermediate and final approach segment. Also, an increase of the glideslope angle is currently under investigation and at some airports even already applied in order to reduce the noise impact on ground. In both cases today's high-lift systems cannot provide constantly optimal high-lift configurations, which increases fuel consumption (due to the higher drag) and noise. In the framework of the STEPLESS project an automatic and stepless high-lift system was developed and validated. The aim of the STEPLESS autoflaps system is to dynamically optimise continuous intermediate settings of the high-lift system in order to (i) enhance the aircraft's capability to follow speed restrictions from ATC, and to (ii) enable the increase of the glideslope angles to reduce the noise perception on ground, while optimising fuel consumption and minimizing noise emissions by optimising the high-lift configurations. The developed solution demonstrated to provide greater fuel efficiency together with a further reduced noise perception on ground without negatively affecting capacity or traffic predictability for ATC, both for approaches with conventional 3° glideslopes and approaches with increased glideslopes.

1. INTRODUCTION

The concept of free, stepless positioning of high-lift devices (flaps and slats) and their continuous actuation throughout the descent and approach phase represents a new concept for civil aviation. Currently, airliners deploy flaps and slats in fixed increments, moving between predetermined positions only after the aircraft's speed has dropped below the maximum allowable speed for the next configuration step, known as Maximum Flap Extended Speed (VFE). In typical operations, these high-lift devices are fully or nearly fully extended for landing, providing two primary benefits: the generation of a large lift coefficient, which helps to achieve a low touchdown speed, and the creation of aerodynamic drag, which allows the aircraft to descent and decelerate. While the increased drag during landing is accepted, and even desired, to facilitate the necessary deceleration and descent rate, the existing fixed configurations limit the flexibility to follow a precise flight path in terms of vertical profile (i.e. altitude) and speed with minimum thrust. This forces the flight crew to fly with either a higher thrust than idle thrust or to use additional means for deceleration, such as speed brakes or early landing gear extension. Both, the use of drag devices and the increase of thrust causes increased emissions and noise impact especially during descent, final approach and go-around.

In the framework of the SESAR 3 exploratory research project named STEPLESS, lead by DLR, a European team of research and industry experts developed an automatic, stepless high-lift system, called the STEPLESS solution with the aim to minimise the flight environmental footprint during final approach under operations with conventional and non-conventional (increased or decreased) glideslope angles, while at least not negatively affecting (or even improving) the flow of arriving traffic within the Terminal Manoeuvring Area (TMA). The project consortium consists of the seven European partners DLR, Empa, L-Up, NLR, Skylab, Thales AVS and the Technical University of Catalonia UPC. The project started in September 2024 and ends in February 2027. The project aims at a final TRL of the developed solution of 2.

The introduction of stepless, continuously actuated high-lift devices represents a significant opportunity to improve the aircraft performance across various flight phases. By enabling continuous and dynamic adjustments to flap and slat settings, the STEPLESS solution offers greater control over the aircraft's aerodynamic configuration. This is particularly advantageous in optimising the glide

©2026

doi: 10.25967/680032

performance during descent, where subtle adjustments to high-lift devices can help to maintain optimal energy management while adhering to ATC speed restrictions and achieving noise and fuel efficiency objectives. Especially, during descent with increased glideslopes (IGS) – such as in the context of noise abatement procedures – current fixed-setting high-lift systems may require premature configuration to ensure sufficient deceleration. This can lead to unnecessary noise and fuel consumption due to increased drag earlier in the approach than ideal. In contrast, a stepless high-lift system could continuously adapt to real-time conditions, allowing to fine-tune the aircraft's descent profile and energy state without compromising on performance or efficiency.

However, the true potential of a stepless high-lift system lies in its ability to be coupled with automated actuation. Automated flap actuation is rarely used in aviation today. Only some protection functions have been implemented today at some airliners (e.g. A350), that retract the flaps in case of a violation of the maximum flap extended speed (VFE) [1]. The STEPLESS solution maximises this capacity to its fullest extent by connecting the automatic high-lift functions with the aircraft's Flight Management System (FMS), Flight Guidance (FG) and Flight Control System (FCS). This way, the STEPLESS autoflaps system continuously provides an optimal high-lift configuration for airspeeds and vertical flight path angles provided either by the FMS or selected by the pilot through the Flight Control Unit (FCU), always based on the currently active Flight Guidance mode. By also considering the current aircraft weight and the prevailing wind conditions, the developed autoflaps system always provides the optimal high-lift configuration for the current flight condition, allowing flight with minimum thrust and minimum noise. The STEPLESS solution also comprises adaptations in the cockpit HMI and procedures in order to ensure intuitive handling and indication for the pilots.

To ensure broad acceptance and operational viability, the proposed solution must adhere to a straightforward and practical design philosophy. It must be certifiable, meet stringent safety standards, and be intuitive to operate. Minimising training effort is essential to ease the integration into current operations, and the overall implementation and retrofit costs on adequate aircraft architectures must remain low to support scalable deployment across diverse aircraft fleet configurations (depending on the baseline platform selected).

In the STEPLESS project an autoflaps system is developed for the A320neo as a representative state-of-the-art single-aisle aircraft. However, most of the development strategies can also be applied to other aircraft types.

At the beginning of the design phase, all potentially affected systems were considered (referring to Airbus terminology):

- Cockpit interface devices such as Flight Control Unit (FCU), flaps and speed brake lever
- Cockpit Display Systems (e.g., Engine/Warning Display E/WD)
- Slat Flap Control Computer (SFCC)
- Flight Management System (FMS)

Given the limited time and resources of an exploratory research project, the STEPLESS project concentrates on the development of the mandatory system functions. Hence, the project was only able to develop an initial prototype of the STEPLESS solution, providing a first implementation of the core functionality and enabling an initial operational and technical assessment.

As the high-lift system must be operative under all possible flight conditions (even in fully manual flight and not only when following an FMS-calculated, in Airbus-terminology so-called "managed" approach), the flight control aspect is of higher priority than the flight management aspects. For this reason, the flight control functions of the high-lift system were ingestigated first.

In subsequent development steps, if necessary, the solution can be matured incrementally by extending the integration with additional avionics systems, refining the operational use cases, and progressively increasing the level of automation, performances and system authority.

Such an incremental development approach allows the concept to be introduced with limited complexity at an early stage, while preserving a clear evolution path towards more advanced implementations. The future development of STEPLESS may therefore be structured in successive capability steps, for example as follows:

- Step 1 (this project):
  - Independent STEPLESS feature calculating the optimal flap and slat deflection angle using Flight Control Unit (FCU) and possibly flap lever and speed brake lever inputs.
  - The Slat/Flap Control Computer (SFCC) commanding the flap and slat actuation.
  - Pilot HMI to monitor the stepless high-lift device configuration and manage the high-lift configuration.
  - Flight crew procedures and training for operating an aircraft with stepless high-lift devices.
- Step 2 (future research):
  Incorporation of FMS trajectory computation to dynamically update the predicted vertical profile with actual STEPLESS slat and flap deflection angle
- Step 3 (future research):
  Automatic optimized stepless configuration management using FMS inputs (flight path

and guidance targets), pilot input, or a combination depending on the flight mode.

For the project-specific implementation and development of the solution, the STEPLESS autoflaps system could only be implemented at flight controls level, not at FMS-level (consistent with step 1 increment described above). For this reason, a fundamental fraction of the full set of all functions of the full STEPLESS solution was already developed and validated. The functional description of the solution considers the actual implementation. Specific, FMS-related functions and requirements need to be subject to future research. However, when the STEPLESS solution is referred to as such, the full implementation including FMS is meant.

The intention of this paper is to provide a general overview on the work performed in the project, its aims and scope. As for various exercises described here, more detailed publications are planned. Where applicable the paper will give reference to planned publications, so that the reader is aware of an upcoming detailed publication on the respective topic.

Further project documentation [2-4] can be found on cordis [5].

2. PROJECT EXERCISES

The STEPLESS solution has been validated through various studies clustered into four exercises directly addressing the different parts of the concept [6]. All exercises target the same set of use-cases and provide relevant information for a solution wide analysis.

The use cases applied for the evaluation of the solution are

- Fly without FMS Profile, with and without Autopilot
- Fly along FMS Profile
- Adjust to ATCO Speed Intervention
- Manage Vertical Deviation from High-Energy
- Manage Vertical Deviation from Low-Energy
- Perform Go-Around

Figure 1 shows the four exercises in which all evaluation activities are clustered together with the related project partner.

As can be seen in Figure 1 the four validation exercises overlap each other. These overlaps form the interfaces between the exercises. Nevertheless, each exercise can be regarded as an individual contribution to the complete validation of the developed STEPLESS solution. The depiction of the partner logos in Figure 1 shows the respective validation exercise to which each partner mainly contributes.

The flight physics modelling and avionics validation is mainly performed by DLR, advised by Thales AVS concerning all aspects of the FMS integration. This work mainly comprises the development of the core optimisation algorithms of the autoflaps system and its validation in the AVES full-flight research simulator operated by DLR. Although the integration into the FMS is not performed in the STEPLESS project, all development work had to consider future aspects of the FMS integration. The cockpit HMI development was performed by NLR together with the evaluation of safety and certification related aspects. The developed cockpit HMI was validated in the APERO simulator environment operated by NLR. The ATM assessment was performed by UPC using NLR's ATM fast-time simulation tool Traffic Manager TMX. Empa developed a dedicated noise model to evaluate the noise benefit from the STEPLESS solution for the conducted simulator trials in the AVES flight simulator and the ATM simulations. SkyLab acts as the connection between all exercises, bringing expertise from the cockpit into the development and validation exercises, and mainly developed the adapted cockpit procedures and participated in the result evaluation of the simulator trials.

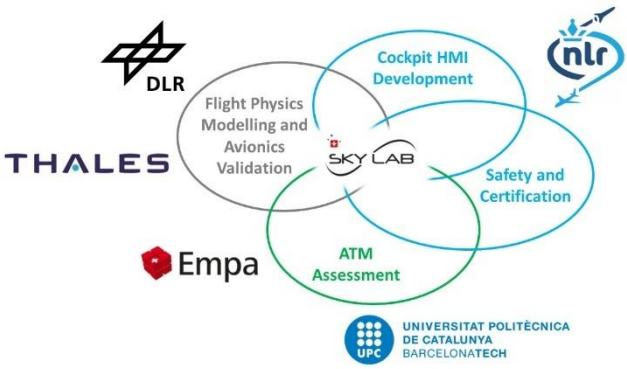


Figure 1: Overview on the various project exercises [6].

In order to validate the developed STEPLESS autoflaps system, different validation objectives have been defined, that should cover the current validation work.

- Objective #01: "Understand and implement the principles of stepless aircraft configurations on the aircraft's capability to capture and fly steeper glidepath angles in an energy-efficient way".
- Objective #02: "Provide evidence of the environmental benefits, namely CO_2 emission and noise reduction".
- Objective #03: "Assess the impact of stepless high-lift aircraft operations on ATM".
- Objective #04: "Assess the impact of operations with stepless high-lift configurations on the human performance of pilots and required interfaces".
- Objective #05: "Assess the impact of operations with stepless high-lift configurations on aircraft airworthiness".

©2026

- Objective #06: “Assess the impact of operations with stepless high-lift configurations on go-around flight phases”.

The work performed in the different exercises is described in the following subsections.

2.1 Development of the STEPLESS Core Functions

The development of the core functions of the STEPLESS solution was performed in the exercise “Flight Physics Modelling and Avionics Validation”. Here, the main optimisation algorithms of the autoflaps system were developed.

The developed concept is based on pre-calculated lookup tables of optimal high-lift configurations for various flight states. The major input parameters for these tables are the target calibrated airspeed, the target vertical flight path angle, the current aircraft mass, the current altitude and the current wind. As can be see in Figure 2 the only inputs from the pilots are the selected speed and selected vertical speed as inserted on the FCU. For these input parameters optimum high-lift configurations were determined by flight mechanical calculations for various flight states, that allow flight (i) with idle (or at least minimum) thrust and (ii) at constant speed.

The commanded high-lift configuration also depends on the chosen flight guidance mode. In the current development step of the STEPLESS solution there is no integration with the FMS yet and therefore the STEPLESS solution doesn’t yet support specific managed flight guidance modes or energy management along the flight path. For all selected flight modes that use a geometric path angle (e.g. FPA mode, V/S mode and G/S mode), the lookup tables provide a high-lift configuration considering the targeted vertical flight path angle. For all other selected flight modes (e.g. ALT mode, OPEN DES) a configuration is commanded that provides best lift-to-drag-ratio (L/D), which practically is the value from the lookup tables for FPA = 0°.

For the future, full implementation of the STEPLESS solution, in case that managed flight guidance modes are used, the target values for calibrated airspeed and flight path angle would likely be provided by the FMS. In the project this was only applied in a first simple connection with the experimental FMS of NLR’s APERO (Avionics Prototyping Environment for Research and Operations) simulator. For the simulator campaign conducted in the AVES simulator, where a real Thales FMS was operated, the connection to the FMS was not implemented. Therefore, the integration into a real operational FMS in order to also use managed flight guidance modes with the STEPLESS solution must be subject to future work.

Regardless from the chosen flight guidance mode the STEPLESS autoflaps system incorporates a special VLS/VFE protection. With stepless movement of the flaps and slats the related limit speeds also change continuously. In order not to violate these limit speeds, the STEPLESS system limits the extension or retraction of flaps and slats in a way that the VFE or VLS for the current flap/slat deflection is not violated. This way, it is guaranteed that the aircraft is always operated within a safe speed regime.

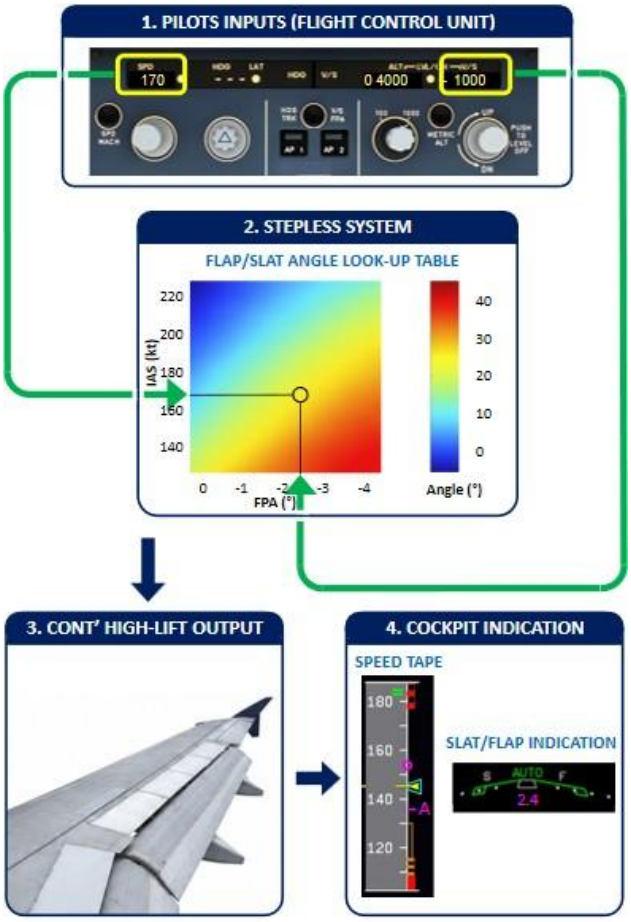


Figure 2: Generalised functionality of the STEPLESS system (with randomised flap angle lookup table) [4].

A detailed scientific journal publication on the functions of the STEPLESS autoflaps system and its validation in the AVES full-flight simulator is planned to be submitted in the near future.

2.2 Cockpit HMI Development and APERO Simulator Campaign

Various HMI concepts were developed and analysed regarding their applicability. This mainly concerns changes in the cockpit displays, especially indications on the speed tape in the Primary Flight Display (PFD) and indications related to the high-lift system in the Engine and Warning Display (E/WD). The aim of the additional indications is to assure that the pilot remains informed and has enhanced situational awareness of the automatic flap system's status. Apart from necessary changes in the cockpit displays,

©2026

changes in the cockpit hardware, such as a changed use of the flap lever was also analysed.

These different HMI concepts were tested at the NLR test facility APERO (Avionics Prototyping Environment for Research and Operations) in Amsterdam (see Figure 3) with airline pilots acting as experimental pilot.

The piloted trials focused on the validation of the HMI concepts by assessing the pilots' capability of dealing with information (situational awareness and workload) and operating the system (handling quality and system usability). Both, questionnaires and semi-structured interviews are used to collect data for this validation.

The test scenarios used in the APERO simulator campaign were approaches to Zurich airport (ZRH) runway 34.

The use cases covered by the NLR trials were:

- Fly along FMS profile
- Adjust to an ATCO speed intervention
- Manage a vertical deviation from high-energy
- Manage a vertical deviation from low-energy
- Perform a go-around

These use cases were selected to address all the common modes of operation of the flaps in the actual operation environment.



Figure 3: Piloted test campaign in the APERO simulator (photo credits: NLR).

The APERO simulator campaign showed that the presented cockpit controls and displays functioned as expected. The adaptivity of the APERO test environment allowed for extensive testing of the concepts for the relevant flight phases, which enabled a comprehensive evaluation. In combination with the STEPLESS system, the scenarios demonstrated sufficient realism. The airline pilots involved confirmed the operational relevance of the research and described the solution to be an improvement over current operations. The operational use of the STEPLESS system requires specific procedures to be developed by the manufacturer and airline, and corresponding training. From a technical standpoint, the primary limitation was the currently limited integration between the STEPLESS system and the FMS, which requires further technical developments. However, one of the main findings of the APERO campaign was that the potential of the STEPLESS auto-flaps system lies in the ease of functioning and intuitive usage of the solution.

The campaign led to several HMI-related recommendations for future research. Overall, the current STEPLESS system was found to be an intuitive system, which provided participants with the necessary information and controllability to fly approaches safely.

A detailed scientific publication on the cockpit HMI development and the APERO simulator campaign is planned to be submitted in the near future.

2.3 Cockpit Procedures and AVES Simulator Campaign

Based on the findings from the APERO simulator campaign the STEPLESS autoflaps system was revised and cockpit procedures were developed for a STEPLESS solution without a flap lever.

The fully automatic STEPLESS autoflaps system was then tested with airline pilots in the AVES A320neo full-flight research simulator [7], operated by DLR in Braunschweig (see Figure 4). In this flight simulator piloted trials were conducted to validate the operational and cockpit procedures and to generate high-fidelity data for the assessment of benefits of the STEPLESS solution on fuel consumption and noise.

Although the validation means of using piloted trials in a flight simulator is typically used for validations at higher TRL, the envisaged TRL in this validation exercise is 2. This does not contradict the use of a flight simulator, as the TRL of the developed system is not expected to be higher than TRL 2. Apart from the system development, one important item to be validated in the exercise have been the operational cockpit procedures. This can only be validated by piloted trials.

Same as in the APERO simulator campaign the test scenarios used in the AVES simulator campaign were approaches to Zurich airport (ZRH) runway 34.

The use cases covered by the DLR trials were:

- Fly without FMS profile
- Adjust to an ATCO speed intervention
- Intercept the glideslope from above
- Perform a go-around

The current cockpit implementation in the AVES simulator trials completely omitted the flap lever and the cockpit procedures have been adapted accordingly. The STEPLESS autoflaps system was always engaged and became active when the current airspeed fell below green dot speed. In the auto-mode the high-lift configuration was chosen based upon the lookup tables and the chosen flight guidance modes as described above. The final landing configuration was triggered by the deployment of the landing gear

©2026

(STEPLESS LAND mode). After the LAND mode was activated, the flaps automatically extend to landing configurationand are then fixed, so that the flaps are fixed for the very final approach after lowering the landing gear.



Figure 4: The AVES A320neo full-flight research simulator (photo credits: DLR).

The developed concept and the current implementation in the AVES simulator framework were successfully demonstrated in the AVES flight simulator test campaign. The exercise was able to demonstrate that the concept and its implementation is operationally feasible.

The pilot feedback given in the AVES flight simulator campaign generally showed that the pilots were very positive on the concept and its operational application.

2.4 ATM Evaluation

In order to validate the effect of the introduction of the STEPLESS solution not only on aircraft level but also on ATM level, simulations were conducted by using the Traffic Manager (TMX) fast-time simulator, developed by NLR [8]. For this, a dedicated aircraft performance model representing the specific behaviour of an aircraft equipped with the STEPLESS solution was developed by DLR for the Airbus A320neo, and was integrated into TMX.

An Interval Management (IM) algorithm was implemented within TMX to regulate the arrival sequence. The algorithm continuously calculates the required aircraft speeds to achieve a target spacing interval of 90 seconds at the Final Approach Fix (FAF) between successive aircraft on the arrival. When the difference between the current speed and the calculated required speed exceeds a certain threshold an ATCO speed instruction is generated. This speed instruction is acknowledged by the virtual pilot and the aircraft will adjust its speed accordingly.

This validation exercise performed by UPC [9] follows an iterative, scenario-based testing approach designed to assess the STEPLESS solution under a wide range of operating conditions, including variations in airport, approach procedures, weather conditions (e.g., wind), traffic density, aircraft energy state, mass, and glideslope. The scenario establishes the airport location, the sub-scenario defines environmental and operational variables not directly related to ATM, and the case study introduces ATM-specific variables to represent particular traffic management conditions within a given scenario and sub-scenario. This framework enables the evaluation of the STEPLESS solution from an ATM perspective across a broad range of operational environments.

Furthermore, each experiment is evaluated under two conditions: a baseline configuration (without the STEPLESS solution) and a solution configuration (with the STEPLESS solution), allowing the benefits of the STEPLESS solution to be quantified.

Same as in the two aforementioned piloted simulator campaigns and in order to assure the comparibilty of the results, the test scenarios used for the ATM simulations were approaches to Zurich airport (ZRH) runway 34. Apart from Zurich airport the ATM simulation study also assessed approaches to Brussels airport as well.

The use cases covered by the ATM fast-time simulations are as follows:

- Adjust to an ATCO speed intervention
- Manage a vertical deviation from a high-energy state
- Manage a vertical deviation from a low-energy state

While not all ATCO actions are explicitly modelled, the Interval Management (IM) algorithm implemented in TMX remained continuously active throughout the simulations, performing the sequencing and spacing functions normally associated with ATC arrival management by issuing speed instructions to aircraft.

The use of an Interval Management (IM) algorithm allowed the representation of realistic sequencing and spacing operations throughout the simulations. The performed experiments demonstrated stable operation of the simulation environment across a wide range of operational conditions, including different

©2026

airports, traffic levels, weather conditions, glide slope angles, aircraft masses, and energy states.

Although certain simplifications were introduced in the fast-time environment, such as the absence of explicit pilot modelling and the use of a lower-fidelity aircraft performance model compared to e.g. flight simulator exercises in the AVES simulator. These limitations did not prevent the successful evaluation of the targeted ATM-related indicators.

The validation exercise demonstrated that the STEPLESS concept can be integrated within realistic arrival operations without introducing adverse effects on ATM-specific performance indicators. The simulations showed that aircraft equipped with the STEPLESS autoflaps system can operate within standard sequencing and spacing constraints while remaining compatible with representative TMA arrival procedures and Interval Management (IM)-based traffic regulation.

Furthermore, the simulations indicate that the additional flexibility introduced by STEPLESS high-lift configurations can be accommodated within existing arrival management processes without negatively affecting arrival throughput or temporal predictability, as well as leading to fuel consumption benefits.

Overall, the exercise confirms that the STEPLESS concept is operationally compatible with representative European TMA arrival environments and supports further maturation of the concept.

From an ATM perspective, the simulations showed that throughput and predictability remained comparable to the baseline configuration under all tested conditions. No significant degradation in arrival capacity or temporal variability was observed, indicating that the introduction of STEPLESS does not negatively affect the sequencing and spacing performance of arrival operations.

A more detailed description of the ATM assessment in the STEPLESS project and its outcome can be found in [10].

2.5 Trajectory Backwards-Simulations

Besides the piloted simulator trials and the fast-time ATM simulation a further fast-time simulation study was conducted using a backwards simulation model for the descent and approach flight phase. This backwards simulation model is used for the analysis of flight performance using the STEPLESS solution for the calculation of reference vertical trajectories similar to the way an FMS calculates the flight's vertical profile.

The purpose of the backwards simulations study was to investigate the potential benefits to update the FMS and use the STEPLESS solution outputs for the calculation of the reference vertical trajectory in the FMS. For this, the same simulations were conducted using the STEPLESS solution and the classical high-lift system as a reference. The backwards simulations are intended to give a first indication for the future development of the STEPLESS solution covering the implementation into the classical FMS and the further improvement of the FMS trajectory optimisation using the STEPLESS solution. For representing an integration into a classical FMS approach, the current schedule of target speeds for the current high-lift configurations was applied to the backwards simulations. In order to demonstrate the potential for further improvements in the trajectory optimisation, also different speed schedules were applied, so that the different high-lift configurations commanded by the STEPLESS solution led to different trajectories.

A detailed scientific publication on the backwards simulation and the findings, which are relevant for the future FMS integration of the STEPLESS system is planned to be submitted in near future.

2.6 Survey on Certification Related Aspects

The project exercise "Safety and Certification" analysed the concept of automatic, stepless flaps in relation to certification aspects and compiled this into a separate report [11]. The outcome provides a roadmap to safely integrate the concept into the current rules and regulations. Therefore, the CS-25 was analysed with respect to requirements, which need to be updated to take into account an automatic, stepless flap concept. Furthermore, relevant requirements are identified for the concept development in other tasks in order to provide a safe and certifiable STEPLESS solution.

The current certification specifications for large aeroplanes, the CS-25, are designed based on the actual technology level. New technology might require adaptations, since the technology was not foreseen at the time of the formulation of the certification specifications. Nevertheless, the certification specifications establish a safety standard that any new aircraft design must fulfil. With an impact analysis, the STEPLESS autoflaps system has been analysed and its influence on the certification specifications has been evaluated. This analysis provides integration possibilities of stepless flaps in the current rules, but also architectural and design limitations have been indicated. Further, an adaptation of particular paragraphs of the CS-25 is proposed to provide a basis for the development of an aircraft design with stepless flaps.

In case new regulations or adaptations should be implemented in the certification specifications, a rule-making process has to be followed. This process comprises the consultation of relevant legislation and international standards.

The Certification Review Item (CRI) provides a possibility for certification of designs, which are not fully covered by the certification specifications. During the certification process, an Equivalent Safety Finding can be requested. This allows to develop alternative

©2026

requirements, where non-compliance to the certification specifications can be shown, provided that an equivalent level of safety can be achieved.

The comprehensive analysis of all parts of the CS-25 certification has been compiled into a report [11] that was reviewed by EASA. The relevant paragraphs of the CS-25 that pertain to the implementation of automatic, stepless high-lift devices have been identified and highlighted, with indications of potential modifications or other critical aspects that require attention. This examination provides an understanding of the existing regulatory framework and its implications for the design and certification of aircraft featuring stepless flaps.

The list of requirements provides boundaries and technical information for the concept. Taking the limits of the CS-25 into account and providing equivalent safety findings for automatic, stepless high-lift devices, where original regulations cannot be applied, will enable safe operations.

From a certification point of view, there are no major concerns for the feasibility of the STEPLESS solution, as long as safety standards are taken into account. The requirements provided in comprehensive report of this validation exercise [11] have to be used for the further development of STEPLESS solution in order to provide a safe and certifiable system.

Currently, an analysis of the applicable requirements and a first roadmap to certification are available, fitting to the general TRL 2 of the project. With further development of the system and reaching a higher TRL, the certification and safety analysis must be further developed towards an actual Certification Review Item and development of Equivalent Safety Finding. These steps have to be in close collaboration with the certifying authority and to be pursued when an actual operation with the system is foreseen. Further rulemaking to address automatic, stepless high-lift devices are only relevant when it is foreseen that a significant amount of new aircraft developments apply this system.

3. DEMONSTRATION RESULTS

It could be demonstrated that the STEPLESS solution brings measurable benefits to the European ATM system by reducing fuel consumption and noise emissions during the descent phase, in particular during flight phases where high-lift devices are deployed. One such critical flight phase is the capture of the glideslope segment, which typically coincides with a phase of speed deceleration and change in vertical flight path, e.g., from a shallow deceleration segment to the glideslope segment.

The exercises demonstrated a clear benefit in fuel consumption and noise. This benefit depends of course on the test scenario and varies with the chosen schedule of speed interventions from ATC and the glideslope angle. The highest fuel benefit was demonstrated with speed interventions similar to today's typical operations at Zurich airport. In this case the fuel benefit of the STEPLESS solution was at 9.8 kg (4 %) for the last 45 NM of the approach. The noise benefit for this scenario is a 13 % reduction of the area with LAE ≥ 65 dB and a 7 % reduction of awakenings. For the increased glideslope angle (IGS) scenario with a glideslope angle of 4.2° the fuel benefit is low, which could be expected as in this case also the reference flight with the classic high-lift system was performed with engines mostly in idle on the glideslope. However, even in this scenario the STEPLESS solution saved 2 kg of fuel (1 %) over the last 45 NM of the approach. The noise benefit is the more relevant benefit in the IGS case with a reduction of the noise contour of LAE ≥ 65 dB of about 15 % and a reduction of awakenings by about 10 %.

The results obtained in the ATM assessment indicate that STEPLESS can provide environmental benefits while preserving ATM performance. From an ATM perspective, the simulations showed that throughput and predictability remained comparable to the baseline configuration under all tested conditions. No significant degradation in arrival capacity or temporal variability was observed, indicating that the introduction of STEPLESS does not negatively affect the sequencing and spacing performance of arrival operations.

The results therefore suggest that STEPLESS can improve operational efficiency while maintaining stable ATM performance indicators.

Further details of the result evaluation can be found in the related scientific publications that will be published in the near future.

4. CONCLUSIONS

A concept for the optimisation of high-lift configurations was developed and applied in the framework of the STEPLESS project. The developed concept is based on pre-calculated lookup tables of optimal high-lift configurations for various flight states. The major input parameters for these tables are the selected calibrated airspeed, the selected vertical flight path angle, the current aircraft mass, the current altitude and the current wind. For these input parameters optimum high-lift configurations were determined that allow flight (i) with idle (or at least minimum) thrust and (ii) at constant speed.

The exercise executed in the APERO simulator showed the potential of the different HMI concepts that were developed for the STEPLESS solution. Although no single HMI concept emerged as the optimal solution, several components were found to be convenient, while others were deemed essential. The main finding, showing the potential of the STEPLESS solution, lies in the ease of functioning and intuitive usage. Without excessive training all participants were capable of flying the approaches safely and

©2026

manage their energy profile effectively. Pairing the LAND mode to the gear extension is considered of added value as well, and eliminates the necessity to have a flap lever in the cockpit during normal operations. Other aircraft states which allow for extension of flaps to their landing position, besides operating the gear down selector, could be an altitude or height limitation (e.g. below 2,000 feet radar altitude) and an airspeed reaching approach speed. As a result, this would prevent flap extension to landing configuration during gear extension in an emergency descent or during early gear extension on an approach. The ability to use speed brakes is considered necessary and must operate separate to the STEPLESS system.

A flap back-up mode should be available for non-normal procedures to enable basic operations of the flaps and slats in the event of STEPLESS system failure. Actuation of the back-up mode could be via, for example, a simple switch or button for flaps movement up and down.

For the assessment of safety and certification related issues a list of relevant certification requirements was compiled and reviewed by EASA. The list of requirements provides boundaries and technical information for the concept. Taking the limits of the CS-25 into account and providing Equivalent Safety Findings for stepless high-lift devices, where original regulations cannot be applied, will enable safe operations.

The developed concept was successfully demonstrated in the AVES flight simulator test campaign. The exercise was able to demonstrate that the concept and its implementation is operationally feasible and brings benefits in terms of fuel consumption and noise.

The ATM Assessment demonstrated that the STEPLESS concept can be integrated within realistic arrival operations without introducing adverse effects on ATM-specific performance indicators. The simulations showed that aircraft equipped with STEPLESS can operate within standard sequencing and spacing constraints while remaining compatible with representative TMA arrival procedures and Interval Management (IM)-based traffic regulation.

Furthermore, the simulations indicate that the additional flexibility introduced by STEPLESS high-lift configurations can be accommodated within existing arrival management processes without negatively affecting arrival throughput or temporal predictability, as well as leading to fuel consumption gains.

Based on the findings of the exercises conducted in the STEPLESS project, various technical and operational recommendations have been derived.

The simulator campaigns conducted in the AVES simulator and the APERO simulator proved the implemented STEPLESS solution is a suitable and functioning system that provides benefits in terms of fuel savings, noise reduction and reduction of pilot workload. The simulator trials also revealed some possible first steps towards a fully automated, stepless high-lift system, which could already gain some of the operational benefits.

The simulator campaign in the APERO simulator led to several HMI-related recommendations for future research. To improve guidance, the FMS and STEPLESS modes should be integrated, enabling managed descent mode with automatic flap extension. Establishing standardised flying procedures and training is essential, including ECAM indications and procedures for system failures.

In section 1 three steps of the development of the STEPLESS solution are introduced, with the present project being step 1. Consequently, it is required to further develop the STEPLESS solution concerning these next steps:

- step 2: incorporation of STEPLESS into the FMS trajectory computation in order to dynamically update the vertical profile with the actual STEPLESS slat and flap deflection angle.
- step 3: automatic optimised stepless configuration management using FMS inputs (flight path and guidance targets), pilot input, or a combination depending on the flight mode.

Already after the completion of step 2 the STEPLESS solution would be operational for all existing flight guidance modes (including managed modes). Step 3 would further exploit the full potential possible with the application of the STEPLESS solution in the FMS.

Apart from these necessary future development and research actions, it is also recommended to investigate in specific actuator-related issues. Generally, the existing slat and flap actuators of the A320neo are capable to cope with stepless high-lift configurations [12]. The current steps of the existing high-lift system are not discrete due to any mechanical hardware limitation, but because of fixed commands programmed in the control computers. Disregarding certification aspects, these commanded high-lift configurations could be changed easily in the software and without any limitation from the actuators. However, it was shown in the validation exercises that the movement cycles of the actuators are much longer and more frequent with the STEPLESS solution than with the classical high-lift configurations. As the existing flap and slat actuators might not be designed for such a continuous movement, it is recommended to investigate actuator wear and maintenance aspects related to the continuous actuator movement as commanded by the STEPLESS solution.

ACKNOWLEDGMENTS

This work was performed in the SESAR 3 Joint Undertaking project “STEPLESS” (Grant Agreement No.

101166837). The Swiss participants have received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) under grant contract No. 24.00505. The fruitful cooperation and instructive discussions with the participating project partners Thales AVS and L-Up are greatly acknowledged. The project was funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the SESAR 3 Joint Undertaking. Neither the European Union nor the SESAR 3 Joint Undertaking can be held responsible for them.

NOMENCLATURE

ALT	Altitude Hold (Mode)
APERO	Avionics Prototyping Environment for Research and Operations
ATC	Air Traffic Control
ATCO	Air Traffic Controller
AVES	Air Vehicle Simulator
CRI	Certification Review Item
CS	Certification Specification
DLR	German Aerospace Center
EASA	European Union Aviation Safety Agency
ECAM	Electronic Centralized Aircraft Monitoring
E/WD	Engine and Warning Display
FCS	Flight Control System
FCU	Flight Control Unit
FG	Flight Guidance
FMS	Flight Management System
FPA	(vertical) Flight Path Angle
G/S	Glideslope
HMI	Human-Machine Interface
IAS	Indicated Airspeed
IGS	Increased Glideslope Angle
IM	Interval Management
LAE	Sound Exposure Level
L/D	Lift-to-Drag Ratio
NLR	Netherlands Aerospace Centre
OPEN DES	Open Descent (Mode)
PFD	Primary Flight Display
SERI	Swiss State Secretariat for Education, Research and Innovation
SESAR	Single European Sky ATM-Research
SFCC	Slat/Flap Control Computer
TMA	Terminal Manoevering Area
TMX	Traffic Manager (simulation tool)
TRL	Technology Redainess Level
UPC	Technical University of Catalonia
VFE	Maximum Flap Extension Speed
VLS	Lowest Selectable Speed
V/S	Vertical Speed

REFERENCES

[1] Lulla, C. Functional Flexibility of the A350XWB High Lift System, German Aerospace Congress 2011, 27-29 September 2011, Bremen, Germany.

[2] SESAR 3 ER 2, “SESAR 3 ER 2 STEPLESS D2.1 Final Operational Service and Environment Definition (OSED)”, Deliverable D2.1, 2026.

[3] SESAR 3 ER 2, “SESAR 3 ER 2 STEPLESS D2.3 Final Functional Requirements Document (FRD)”, Deliverable D2.3, 2026.

[4] SESAR 3 ER 2, “SESAR 3 ER 2 STEPLESS D2.5 Exploratory Research Report (ERR)”, Deliverable D2.5, 2026.

[5] https://cordis.europa.eu/project/id/101166837

[6] SESAR 3 ER 2, “SESAR 3 ER 2 STEPLESS D2.2 Final Exploratory Research Plan (ERP)”, Deliverable D2.2, 2026.

[7] Duda, Holger and Gerlach, Torsten and Advani, Sunjoo and Potter, Mario (2013) “Design of the DLR AVES Research Flight Simulator”. AIAA MST 2013, 19.-22. Aug. 2013, Boston, USA.

[8] F. Bussink, J. Hoekstra and B. Heesbeen, "Traffic manager: a flexible desktop simulation tool enabling future ATM research," *24th Digital Avionics Systems Conference*, Washington, DC, USA, 2005, pp. 3.B.4-31, doi: 10.1109/DASC.2005.1563344.

[9] SESAR 3 ER 2 STEPLESS - D3.2 - ATM Validation Report, version 1.0, 19/06/2026.

[10] Sáez, R. et al., Next-Gen Flap Systems: Validation Results and Implications for Air Traffic Management, ICAS 2026 Conference 13-17 September 2026, Sydney, Australia.

[11] SESAR 3 ER 2 STEPLESS - High-Lift Devices with Stepless Operation: Certification Requirements, edition 2.0, 2026.

[12] Airbus A320 Aircraft Maintenance Manual, DG. AMM AEF, 1-May-2009.

©2026