SAFE AND GREEN INTEGRATION OF TILTROTORS INTO THE FUTURE AIR TRANSPORT SYSTEM

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Abstract

Flightpath 2050[1] envisages revolutionary steps towards a future resource efficient Air Transport System (ATS) respectful of the environment. The European aeronautics is responding by implementing breakthrough technologies, like those of the Single European Sky ATM Research (SESAR)[2], which will radically change the operation and regulation scenario. Next-generation aircrafts, conceived in Clean Sky[3] and fully compatible with the future ATS, will strongly reduce noise and pollutant emissions, making full use of innovative Concepts of Operations (ConOps)[4], 4D trajectory management, new Communication, Navigation, Surveillance (CNS) technologies, and Remote Towers. Such radical innovations call for significant attention to human factors on both the aircrew and the air traffic control (ATC) sides. One of the goals of Clean Sky Green Rotorcraft 5 (GRC5), in conjunction with the partner project TRAVEL (Tilt Rotor ATM integrated Validation of Environmental Low noise procedures)[5], is the co-simulation of civil tiltrotor operations into Northern Italy airspace close to the city of Milano, using piloted real-time Tiltrotor models connected to a simulator of the envisioned air transport scenario. The purpose of this paper is to present the results of such co-simulated exercise as the final outcome of an incremental approach to study several aspects of introducing next-generation aircrafts (tiltrotor) flying new procedures in a medium-congested air transport scenario.

1. LIST OF ACRONYMS

   APHelion: Auto-Pilot for Helicopter Off-board Navigation;
   APP: Approach;
   ATC: Air Traffic Control;
   ATCo: Air Traffic Controller;
   ATM: Air Transport Management;
   ATS: Air Transport System;
   AWARE: Flight Mechanics Simulator facility;
   CNS: Communication, Navigation and Surveillance;
   Conditions;
   LPV: Localizer Performance with Vertical guidance;
   MAP: Missed Approach Point;
   PinS: point in space;
   Rwy: Runway;
   w noise procedures;
   ConOps: Concepts of Operations;
   CWP: Controller Working Position;
   eDEP: Early Demonstration and Evaluation Platform;
   FAF: Final Approach Fix;
   GND: Ground;
   GNSS: Global Navigation Satellite-based System;
   GRC5: Clean Sky Green Rotorcraft 5;
   GS: Glide Slope;
   HMI: Human-Machine Interface;
   IFR: Instrument Flight Rules;
   IMC: Instrument Meteorological Conditions;
   SEL: Sound Exposure Level;
   SESAR: Single European Sky ATM Research;
   SNI: Simultaneous-Non-Interfering;
   TRAVEL: Tilt Rotor ATM integrated Validation of Environmental Low noise procedures;
   VPN: Virtual Private Network;
2. INTRODUCTION
The success of the civil tiltrotor relays on the combination of the characteristics\(^{[6]}\) and performance\(^{[7]}\) of a helicopter and of a small turboprop, suitably harmonized with the future ATM capabilities. The effectiveness of tiltrotors will be measured by their contribution to a fast and flexible point-to-point mobility system\(^{[8]}\); the regional transport flight service will be complemented and enlarged using ground infrastructures inside congested and densely populated areas and exploiting the peculiar low-speed capabilities of rotorcraft. Tiltrotors will feature advanced satellite-based (GNSS) navigation capabilities to take-off from a helipad, enter the high altitude airspace under Instrument Flight Rules (IFR), cruise in Instrument Meteorological Conditions (IMC) and finally land onto another helipad, with minimum noise impact and, on the long term, the potential of operating in all-weather conditions. The methodology proposed in this paper to analyze and predict the safety and environmental impact of tiltrotors is divided in three stages, respectively based on off-line desktop simulations, pilot-in-the-loop tiltrotor virtual experiments and finally real-time co-simulation of the vehicle and the ATS. In all cases, IFR routes and departure/approach procedures are virtually flown by means of comprehensive models implemented using commercial software tools (e.g. FlightLab and Simulink).

The paper will: (1) enlighten challenges and practical solutions for inserting the tiltrotor into the conventional fixed-wing airspace of Milan Malpensa, complying with ICAO regulations in an eco-friendly manner. Particular evidence is given to noise pollution; (2) focus on tiltrotor peculiar capabilities and their effect on the implementation in APHeliON and AWARE in GRC5, as well as their impact on flight procedure design and execution and the solutions identified in TRAVEL; (3) present the results of the final co-simulation test campaign, in terms of pilot and ATCo qualitative and quantitative evaluations and feedbacks, and the final outcomes and lessons learnt of the activity.

3. FIRST STAGE: OFF-LINE SIMULATION
The first, off-line simulation stage aims at (1) the verification of the flight dynamic (stability, control, navigation) characteristics and performance of the designed low-noise trajectories and maneuvers, and (2) the validation of the noise benefit feeding specialized acoustic software packages. To translate the synthetic description of departure and approach procedures (flight speeds, glide angles, heights) in command inputs to the rotorcraft model, a virtual pilot model named APHeliON has been evolved from previous internal efforts in the field\(^{[9]}\), achieving quasi-real-time simulation capability on a standard desktop pc. On the other side from the acoustics point of view to set up the aero-acoustic computational chain.

3.1 Aphelion
APHeliON consists in a suite of pilot modes which controls the rotation of the vehicle (bare or SAS-augmented aircraft) about the three body axes, plus the translation along the vertical one: each pilot mode is composed by four pilot logics implemented in FlightLab, one per input channel, generating the associated control input to follow a target signal which is provided by the user using only high-level information. In practice a flight procedure is divided in phases separated by events (i.e. a certain time, the achievement of a given altitude or speed): the specialist can program APHeliON to use the desired sequence of pilot modes to suitably follow the target signals in each phase (see Figure 1). The software creates target time histories and switches between pilot modes when the logical conditions associated to the events are satisfied. As the software tool is programmed in a generic and segregated form, its use is intrinsically flexible (covers both conventional helicopters and tiltrotors), its results are fully deterministic (same inputs produce the same results), and it does not require piloting or programming skills, paving the way to massive and automatic batch simulations.

3.2 Task Description
Scope of this task is to evaluate AW609 maneuvers at different configurations and in nacelle conversion. This task can be subdivided in the following steps:

- APHeliON adaptation and gains tuning at different configurations (helicopter, aircraft, conversion mode).
- For this purpose we have selected a set of maneuvers involving all input channels:
  - Gains scheduling: to deal with a rotorcraft that changes its dynamics characteristics during flight an update of APHeliON code has been needed.
  - Then approaching maneuvers were taken into account at the glide slopes 3 and 9 deg. The flight envelope considered included the nacelle angle from 50 deg to 90 deg and the speed range [20, 120] kts.

3.2.1 Aero-acoustic computational chain
The evaluation of the noise footprint of the several flown trajectories has been evaluated following the state-of-the-art methodology currently used within Leonardo Helicopters\(^{[10]}\). The Figure 2 reported depicts the main steps taken to complete the work. The typical Leonardo Helicopters aero-acoustic computational chain has been split in two parts: the first one is the creation of a database of acoustic hemispheres for different flight speeds, rates of climb (or descent) and thrust levels; while the second part is the on ground propagation starting from the database and the flown trajectories data.

ADPANEL is a Full-Unstructured Panel code coupled with a Time-Stepping Full Span Free Wake Vortex model. This tool implements the most advanced aerodynamic features in the field of potential methods, especially for the possibility to represent the aerodynamic surfaces into unstructured-hybrid meshes (this code can handle with both quadrilateral and triangular cells), for a Constant Vorticity Contour (CVC) modeling of both rotary and fixed wing wakes, and for its Multi-Processor implementation. Thanks to the previous features ADPANEL is able to analyze in short computational times and with detailed prediction entire helicopters and advanced tiltrotor configurations.

FAST - Farassat1A Acoustic Solver Tool - is an helicopter acoustic analysis tool developed to enable fast, multiple analysis, on multi-core CPUs. FAST was also developed to simplify the interface with the current tools in the
Leonardo Helicopters aero-acoustic chain, resulting in faster analysis and fewer sources of errors. Another important feature present in FAST is the ability to perform full helicopter unsteady noise analysis in relatively short times which will enable realist manoeuvre analysis, something not possible/practical with the current tools. Finally, the possibility of using porous data surfaces to include the non-linear sources around the blades enables the analysis of HSI noise whenever CFD data is available.

3.3 First Stage Results
Hereinafter we summarize some outcomes of the desktop analysis.

3.3.1 APHelioN simulations
For the sake of brevity hereinafter we show simulation of the 3 deg of glide slope approach only. The maneuver was subdivided in the five phases:

1) the first phase is a trim in level flight at 100kts of IAS and 3000 ft of altitude;
2) the second phase consists in an deceleration to 90 kts at constant altitude;
3) the third phase is an altitude variation with glide = -3 deg at constant speed;
4) the fourth phase is a deceleration to 50 kts with altitude variation and glide = -3 deg;
5) the fifth phase is an altitude variation to 300 ft with null final vertical speed.

The results reported in Figure 3-Figure 5 show that analyzed approaching maneuvers are adequately performed by flight mechanics model implemented in AWARE framework and steered by APHelioN synthetic pilot. The procedure considered as well as the steepest one are then compatible with the tiltrotor peculiar capabilities. Time histories of the proper outputs of the simulated approaching maneuvers were used to validate the acoustic software.

3.3.2 Acoustics reference maneuver
Since giving absolute numbers in terms of noise effects from analytical tools could be misleading due to all the effects not taken into account (i.e. background noise, engine noise, etc.) in numerical simulations, the choice is to refer the acoustic results with respect to a reference maneuver. For the this region the certification rules and guidelines have been used in order to produce a reference trajectory; more in detail the approach condition is the interesting one and it is characterized by the parameters reported in Table 1.

4. SECOND STAGE: PILOT-IN-THE-LOOP EXPERIMENTS
As a second stage, the validated procedures are implemented in compliance with ARINC424 coding rules on a software model of the rotorcraft flight management system and virtually flown at the piloted engineering simulator AWARE, to verify the acceptability in terms of pilot workload and human factors of the proposed operations and guidance. The transparent adoption of the same software models as in the previous stage guarantees maximum compatibility of off-line and real-time simulations and the repeatability of the experiments.

4.1 Aware
AWARE is the flight mechanics simulator facility at the Helicopter System Design Dept. of Finmeccanica-Leonardo site in Cascina Costa (see Figure 6). It consists by: a mock-up cockpit with two pilot seats, one programmable inceptor, four generic cockpit displays; a curved screen for out-of-the-window representation and four projectors; a desk with three computer stations for managing and monitoring the simulations. From a software point of view AWARE is composed by a variable number of modules that implement simulation functional components (e.g. flight mechanics, engine, AFCS, visual, control loading, etc.). It is a distributed system in which communication between components is implemented following a publisher/subscriber scheme. Modularity and flexibility characteristics allowed to easily connect to a third part (SICTA ATS simulator) and interact with it without modify the software architecture.

4.2 SICTA ATS simulator
The ground platform is the eDEP tool. It is an ATC simulator which offers broad yet simplified functionality (Figure 7-Figure 8). The CWP is a building block that can provide a complete function in an autonomous manner and is configurable and sizeable. The purpose of the CWP subsystem is to simulate an air traffic controller working position during the execution of an exercise. It is the key element of the Human-Machine-Interface (HMI) in the ATC operational environment, and meets the operational requirements of a Sector Suite as well as those of a single position. The CWP is used for executive as well as planning functions, and meets the requirements of a strip-less system. It is basically intended to be manned by one controller; for this purpose, it is characterized by a unique set of input devices, which interacts with the graphics display.

Different types of CWP were represented:

- 1 Ground Position, it was manned by the controller allocated the Ground role;
- 1 Tower Position, it was manned by the controller allocated the Tower role for the RWY 35L, 35R and FATO;
- 1 Approach Position (Executive), it was manned by the controller allocated the Approach role;
- 4 Pilot Working Positions, Pseudo-pilots were responsible for ensuring the realistic performance of the aircraft of the simulated environment by the timely input of controller instructions received over R/T.

In particular, 3 Pseudo-pilots piloting all aircraft under the control of the three controller positions and 1 Pseudo-pilot for Clearance Delivery Position (Hybrid).

4.3 Task Description
During this phase the test pilot took confidence with the simulator facility and assessed the approaching procedure on one side and the flight mechanics model on the other side. To reach the scope the pilot started with some real-time sessions and then some of the prescribed procedures were taken into account. In particular some critical parts of the procedure like strong decelerations or
final descending paths were repeated several times to find out the best vehicle configurations (nacelle angle, speeds) and transition legs to be compliant with the procedure constraints. On the other hand specialists considered the robustness of the overall system and prepared the final test session in such a way to minimize risk of crashes and implement a sequence of operation to reset the system reducing waste of time. Moreover connections with the counterpart of the co-simulation were tested both voice and data. Some effort was done to synchronize the two geographical databases to be completely aligned in terms of position and altitude.

4.4 Second Stage Results
The great experience of the test pilot allowed to overcome some limitations of the facility regarding piloting feelings and simulation fidelity both in terms of field of view and vehicle reaction in some points of the flight envelope. In any case the pilot considered the overall system suitable to the simulation scope. Moreover the pilot decided how to perform the descending paths at all glide slopes prescribed by the procedures. During the preparatory exercises all subsystems were tested and all connection issues were eliminated.

5. THIRD STAGE: FINAL CO-SIMULATED EXPERIMENT
At the third stage, the final demonstration is performed by co-simulation using two remote simulation facilities: the engineering simulator AWARE in connection (data and voice) with the ATC virtual platform by SICTA, allowing a team of air traffic controllers (ATCo) and pseudo-pilots to realistically operate on the simulated air traffic around Milano Malpensa airport in which the virtual tiltrotor is inserted in real-time. This complex simulation approach is aimed to assess the impact of further operative factors from the pilot point of view (communication and coordination with ATCo and associated workload), as well as the effect of tiltrotor simultaneous operations on the conventional fixed-wing activity of the airport.

5.1 Task Description
The tiltrotors are supposed to fly at the same flight level as turboprops (i.e. around 25000 ft or 8000 meters) and at congested airports operate as much segregated as possible from other conventional flights. The very substantial difference from the aircraft is concerning both approach/landing and takeoff operations. The operational environment in which this validation exercise was conducted was Milan Malpensa airport. In particular departure and landing procedure refer to the hypothetical FATO AG on the west side of airport (see Figure 9). The procedures that were simulated are the following:

- Departure procedures:
  - Malpensa SID North from FATO;
- Landing procedures:
  - PinS to Malpensa FATO with a GS of 3°, 6°, 9° (see Figure 10-Figure 12).

Three scenarios of simulation have been designed to perform the validation activities of simulation within the project TRAVEL (Table 2). The scenarios have been chosen combining the greatest possible number of designed procedures in a realistic way able to stress the workload for ATCo and pilot. The scheduling of the exercise covered an entire work week as shown in .

The overview of the co-simulation platform is given in Figure 13. In the briefing before starting the simulation activity the scenario was selected and discussed. At the beginning of the session the two systems were switched on separately and the activity synchronization was guaranteed by the project coordinators on both sides connected by phone. During the flight simulation the co-pilot inserted the flight plan of the prescribed scenario while the SICTA interface operator (see Figure 6) activated the data transfer by VPN connection. On the other side the ATS simulation ran normally waiting that the tiltrotor flight appeared on the radar screens in the proximity of agreed entry point (i.e. MC415). Then the pilot was contacted by voice (through VPN connection) by ATCo which from such moment on followed and directed the flight. Pilot heard any ATCo communications on the selected radio frequency. During the first scenario (the more complex one), for example, pilot had to contact the ATC at the MAP and made a request of missed approach while the ATCo had the possibility to leave in a holding circuit or request an altitude change in case of interference with air traffic. At the end of any session a debriefing was held to discuss about issues, pilot and ATCo impressions. Then a questionnaire was proposed to the pilot on one side and to ATCo on the other side do assess the procedures and workloads. Any scenario had three repetitions in order to minimize possible spurious results and improve the quality of the data analysis.

5.2 Third Stage Results
In this paragraph we present some results of the simulation campaign.

5.2.1 Pilot perspective
With the aim to assess the procedure suitability the pilot has been asked to provide a rating for each phase of the scenario. The rating is representative of the workload experienced during the flight due to the design of the procedure legs. The rating scale of the procedure phase workload has been defined as in Table 3. Results regarding scenario 1 are reported in Figure 14. It is possible to note how some phases of the considered procedure require more effort. This evaluation led to suggest some correction in the profile of the procedure. For example the transition from missed approach with altitude recovering up to TL011 and the shortness of the subsequent leg between TL011 and TL013 were considered a little bit challenging.

With the aim to assess the handling qualities of the tiltrotor model, the pilot has been asked to provide a rating for each phase of the scenario. The rating is representative of the handling qualities experienced during the flight of the scenarios legs. An important aspect to take into account speculating about the handling qualities assessment is that, commonly IFR procedure are design considering two pilot in the crew especially for a Tilt-Rotor. And PINs LPV are supposed to use a FMS that provides lateral and vertical guidance, fully coupled with an
advanced digital Automatic Flight Control System 4-axis autopilot. These characteristics enable the helicopter to perform any LPV procedure in a fully automatic manner, especially even with extremely steep approach angles. In the TRAVEL campaign the pilot has been relieved from the MCDU managing to simulate the second pilot contribution. No AFCS system was available. The rating scale of the scenario phase has been defined following the Cooper-Harper (Table 4). Results regarding scenario 1 are reported in Figure 15. Even in this case the pilot gave important suggestions and found some improvable areas.

5.2.2 ACTo perspective
Situation awareness assessment has been performed with the application of a set of methods that are all based on having evaluators rating their situational awareness with the introduction of the integrated concepts. Situational awareness is defined as “the continuous extraction of environmental information, the integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events” (Dominguez et al., 1994).

In this regard, situational awareness can be considered a mental state consisting of three phases:

- perception of the situation (perception of important elements in the environment);
- comprehension of the situation (integration of different pieces of data in order to determine their relevance);
- anticipation of future states of the current situation.

Cognitive workload assessment has been performed with the application of a set of methods that are all based on having evaluators rating their workload with the introduction of the integrated concepts under evaluation. There are two main parts in perceived workload: physical workload and cognitive workload.

In ATM, the objective is to keep operators (ATCCos and pilots) global workload in a range where they are kept (at least mentally) stimulated without going to the point where they become overloaded and start to postpone tasks. Automation is a mean to reduce operators’ workload by providing automated tools to help them identifying / solving some operations. Workload can be increased by the lack of usability of a tool – adding more physical workload or more cognitive workload to the operator. The main problem is to help the operator while keeping him in the decision making loop. In Figure 16 and Figure 17 a part of the questionnaire results are shown. In general ATCo did not find difficulties in managing a vehicle like the tiltrotor inside the air traffic context of Milano Malpensa.

5.2.3 Aero-acoustic results
A series of sensitivity study has been carried out with the aim of identifying the differences between the various flown trajectories. First of all the reference system has been changed in order to have more suitable set of ordinates to input in the aero-acoustic chain; this has not any impact on the resulting noise. In the Figure 18 the new reference system has been reported.

Subsequently the flown trajectories have been grouped based on their nominal glide slope (i.e. 3 deg, 6 deg and 9 deg); for each group a sensitivity study has been performed in order to evaluate the difference in terms of noise footprint due to the existing difference of flight conditions and parameters. The most visible difference is the nacelle setting angle, the Figure 19 is showing differences for the 9 deg group.

From the run analysis it has been resulted negligible the difference in terms of noise footprint mainly due to the fact that differences are present but only in the level flight portion of the trajectory. Those differences would be more visible if carried over the descent path.

Each group then has been analyzed based on three noise parameters hereafter reported:

- Peak of SEL noise measured in dBA;
- Certification like procedure based on three microphones and noise measured as SEL dBA at the following ordinates:
  o X = 0, Y = -150 m,
  o X = 0, Y = 0 m,
  o X = 0, Y = 150 m;
- Ground area extension on which noise greater than a certain level is seen (noise levels have been established as SEL: 74, 77, 80, 83, 86, 89 dBA).

The plots in Figure 20-Figure 22 report the obtained results. As expected the higher descend slope is giving a slightly increment of noise peak and noise on “certification” microphones while an important reduction of the noisy area for the levels 80, 83 and 86 dBA is present.

6. CONCLUSIONS
In this section we summarize the outcomes covering the all aspects covered by the experiment.

6.1 Air Traffic Controllers Evaluation and Recommendations
Generally, the tiltrotor integration in the air traffic was positively accepted by the Air Traffic Controllers. The management of this type of aircraft and its specific performances did not constitute an obstacle for the management of airport operations. The Controllers affirmed that their situational awareness and cognitive workload during tiltrotor operations was always maintained at a good level, as:

- Traffic evolution prediction;
- Traffic situation understanding;
- Traffic unexpected behavior;
- Situation understanding during tilt-rotor operations.

Regarding the Point-in-Space (PinS) type of procedures and SNI concept, they sustained and confirmed the benefits deriving from their development and implementation. Furthermore, all three experimented glide slope angles (3°, 6°, 9°), linked to the PinS, were accepted.
without particular problems as they had the same impact on their working methods and they affirmed that there was no risk to misunderstand the specific glide slope flown by a tiltrotor, because the related rates of descent are different and immediately recognizable. ATCo considered also FATO position acceptable because it allowed to monitor the tiltrotor during the visual portion of the IFR procedure.

In particular, they clarified that the approach and departure procedures should be further adapted to the Milan Malpensa airport. Sometimes an increase occurred in controllers’ attention demand during tilt-rotor operations due to the interference of tilt-rotor procedures with conventional traffic (missed approach) procedures. Controllers asserted that the tuning of tiltrotor procedures should be aimed to harmonizing them with noise constraints related to Milano Malpensa operational environment, constraints related to departures from Milano Malpensa runway and constrains related to other aviation surfaces. Particular attention should be given to the facilities used for the tiltrotor operations inside the airports in order to operate safely.

6.2 Pilot Evaluation and Recommendations

From the pilot perspective the simulation exercise allowed to confirm the acceptability of pilot workload and operational suitability in the case of tiltrotor low-noise IFR procedures. In particular, this assessment refers to the feasibility of operating with the AW609 tiltrotor in the Milano Malpensa environment using Point-in-Space approach and departure procedures on an independent FATO helipad inside the airport perimeter in Simultaneous-Non-Interfering mode.

Indications for improvement were also provided by the pilot, in order to tuning the design of procedures taking into account both current tiltrotor performance and average pilot capabilities, in order to minimize pilot overload.

6.3 Best Trajectory

The 9 deg descend trajectory resulted as the most promising in terms of reduction of the noisy area. In the plots of Figure 23-Figure 24 the obtained noise footprint has been reported; this noise footprint has been compared with the one of the reference maneuver and on the last plot the difference of the two has highlighted. It is clearly visible in the comparison plot the area (in blue and green) where the noise reduction is present. Very important is the central region with a 4 dBA reduction. On the other hand an increment is present near the landing area; this is consistent with the integral results obtained, in fact the peak and the “certification” microphones are on the red area.

6.4 Conclusions and Future Work

The objective of inserting the Tiltrotor in a medium-congested and complex air traffic scenario, considering the overall space inherent to the vehicle performance characteristics ranging between helicopter and turboprop, was successfully achieved.

The validation platform proposed in this paper received the positive appraise of ATCo and Pilot and endow us an effective tool to improve the procedures design.

All the three scenarios take into account was considered suitable and accepted by all the principle stakeholders. Nevertheless in the first scenario some improvement area appeared and yielded to the following recommendations to improve the IFR approach and departure procedures:

1. Flight paths emanating from waypoint MC415 are not coherent with conventional traffic when Malpensa runways are operated in direction 35 (north-bound), which is the most typical case; procedure design should consider to direct at first the tiltrotor East-bound (e.g. towards Saronno) or West-bound (towards Biella or Novara) and then approach the FATO in SNI;
2. The final leg of all the approach profiles is almost perpendicular to the runway, causing a reduced separation between the missed approach path of the tiltrotor and that from runway 35 left, the latter making a left turn to avoid obstacles and mountains north of Malpensa: this factor can be typically addressed by adapting the design of the procedure, reducing the angle between the two approach paths, or requiring the airplanes to execute the left turn of the missed approach from runway 35L not before the runway final threshold;
3. Altitude on waypoints MC415 and TL011 shall be reduced, to keep the rate of descent into a more comfortable range and avoiding interference with departure and approach paths from runway (35 left in particular);
4. The intermediate leg between TL011 and TL013 is short and shall be flown preferably at constant altitude;
5. The angle between the missed approach course and the intermediate leg TL011/TL013 course is small: when a new approach is initiated, it requires to make one loiter turn exploiting the designed holding; this design aspect can be improved and harmonized with points (1) and (2) above.

The simulation activity has been extremely fruitful in making all these aspects emerged: further piloted simulations are strongly encouraged to make procedure design limitations evident as early as possible in the development and validation process.

ACKNOWLEDGEMENT

The research leading to these results has received funding from Project TRAVEL in conjunction with GRC5 programme, financed by European Community’s Clean Sky Joint Undertaking Programme.

REFERENCES

[3] Clean Sky Green Rotorcraft (GRC) 5 website,
Table 1: reference maneuver parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glide slope</td>
<td>6 deg</td>
<td></td>
</tr>
<tr>
<td>Entry altitude</td>
<td>3000 ft</td>
<td>Chosen to be comparable with flown trajectories (not specified by the rules)</td>
</tr>
<tr>
<td>Flight speed</td>
<td>80 kts</td>
<td>Constant for the entire path</td>
</tr>
<tr>
<td>Flight mode</td>
<td>Helicopter only</td>
<td>Nacelle 95 deg</td>
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</table>
Table 2: Scenarios taken into account during the campaign.

<table>
<thead>
<tr>
<th>ID</th>
<th>Scenario description</th>
<th>Simulation details</th>
</tr>
</thead>
</table>
| Scenario 1 | 3 PinS Approach 3°, 6°, 9° on Fato AG:  
With this scenario the approaches from north with entrance from MC415 waypoint are tested. Approaches with glideslope 3°, 6° and 9° are performed sequentially. After the 3° and 6° approaches reached the MAP a missed approach will be carried out. After the 9° final leg a landing into FATO AG will be performed. | Procedure FATO APP NORTH (from MC415)  
MC415  
TL011  
TL013  
TL014  
Slope 3°  
TL015 (MAP)  
TL011  
TL013  
TL017  
Slope 6°  
TL015 (MAP)  
TL011  
TL013  
TL018  
Slope 9°  
FATO AG |
| Scenario 2 | SID toward north and following north approach through MC415 waypoint:  
Take off from FATOAG, all the waypoints of COMM1 transition foreseen in the procedure SID NORTH (BLA - FARAK - SRN)” are flown. Afterwards the approaches 6° from north it is carried out before landing on FATO AG. | Procedure SID NORTH (BLA - FARAK - SRN)  
FATO AG  
TL010  
TL007  
TL008  
-------------------  
Procedure FATO APP NORTH (from MC415)  
MC415  
TL011  
TL013  
TL017  
Slope 6°  
FATO AG |
| Scenario 3 | South Approach (VERCE):  
In this scenario the approach procedure “FATO APP SOUTH (from Verce)” is tested. After the 9° approach, reached the MAP a missed approach will be carried out. After the 3° final leg a landing on FATO AG will be performed. | Procedure FATO APP SOUTH (from Verce):  
VERCE  
TL012  
TL013  
TL018  
Slope 9°  
TL015 (MAP)  
TL011  
TL013  
TL014  
Slope 3°  
FATO AG |
Table 3: Procedure workload rating scale.

<table>
<thead>
<tr>
<th>Procedure Workload</th>
<th>Low</th>
<th>Moderate</th>
<th>Considerable</th>
<th>Extensive</th>
<th>Intolerable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 4: Cooper-Harper rating scale.

![Diagram of Cooper-Harper rating scale]

Figure 1: sketch of flight procedure description using high-level information as implemented in APHelioN.

Figure 2: Leonardo Helicopters aero-acoustic computational chain.
Figure 3: Shallow approach maneuver: nacelle angle (above), altitude (bottom) vs. distance.

Figure 4: Shallow approach maneuver: glide slope variation vs. time. Blue dashed line represents the target signal.

Figure 5: Shallow approach maneuver: IAS vs. time. Blue dashed line represents the target signal.

Figure 6: AWARE facility layout.

Figure 7: SICTA ATS simulator layout.

Figure 8: SICTA ATS simulator computer stations.

Figure 9: Aerial photo of Malpensa airport with FATOs marked.
Figure 10: Descent path (3, 6, and 9 deg glide slope) with corresponding waypoints.

Figure 11: Tiltrotor APP procedures at Milano Malpensa airport: Northern entry from MC415.

Figure 12: Tiltrotor APP procedures at Milano Malpensa airport: Southern entry from VERCE.

Figure 13: Overview of co-simulation platform.

Figure 14: Pilot perspective: Scenario 1 – Procedure workload for each phase
Figure 15: Pilot perspective: Scenario 1 Handling Qualities assessment for each phase

1=bad 2=poor 3=fair 4=good 5=excellent

Figure 16: ACTo perspective: Overall situational awareness.

1=Never 2=Rarely 3=Sometimes 4=Often

Figure 17: Attention demand during tilt-rotor operations.

Figure 18: Aero-acoustic simulations reference system definition. Top view of simulated procedures. Different colors represent different flight path sections, while blue dots are waypoints.

Figure 19: Nacelle conversion time histories for the 9 deg flown trajectories. Different colors represent different flight path sections coherently with Figure 18.
Figure 20: SEL noise peak values for the various descend slopes.

Figure 21: SEL noise measured following the "certification procedure" for the various descend slopes.

Figure 22: Ratio of the ground area characterized of a SEL noise greater that the given level w.r.t. the certification approach condition.

Figure 23: SEL noise footprint for the 9 deg flown trajectories.

Figure 24: SEL noise footprint difference of the 9 deg flown trajectories w.r.t. certification approach condition.

Figure 25: Clean Sky GRC5 team during final demonstration of TRAVEL low-noise tiltrotor procedures.