

CITYAIRBUS, A SAFE ENTRY INTO REMOTE PILOTED FLIGHT TEST WORLD

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Abstract

Airbus took the opportunity to bring its expertise to the Urban Air Mobility adventure and launched CityAirbus in 2017. This twin-quadcopter of 2.3 tons was designed as a demonstrator to explore the challenges of a full scale remotely piloted electric vehicle. After a short technical description, this article focuses on the main aspects of the safety process followed throughout the project and points out the main lessons learnt regarding the remotely piloted flight test campaign.



The roots of what we call "Urban Air Mobility" today go back to the 2010's when first ideas around flying passengers with electrical multirotors emerged. But only from about 2014 on, concrete studies and concepts started to materialize, whereas the term "Urban Air Mobility" was only introduced in 2016. If the concept evolved a bit during the mid-2010's, we can nowadays consider that the ultimate goal of UAM is to provide a vehicle robust enough to run air transportation at scale, safe enough to fly over congested cities, able of vertical take off and landing to minimize infrastructure impacts, simple enough to be accessible to a large public, autonomous enough to proceed without any onboard crew and clean enough to emit absolutely no harmful gases. Harmful for human beings or for the environment.

Because of the incredible challenges that this ultimate goal presents, it was obvious, from the beginning that designing such a serial air taxi will not be solved in a single week ! Which architecture ? which technology ? which energy ? Between safety, CO₂ emission, noise and performances, what is the best compromise ?

As hundreds of other companies, Airbus took the

opportunity to bring its expertise to the challenge. Starting with VOOM to explore urban air mobility, Airbus has been assessing how recent technology advancements – from battery capacity and autonomy to electric propulsion – can help drive the development of new kinds of aerial vehicles. It gave birth to Vahana in the US silicon valley in 2016 and to CityAirbus in 2017 in European Bavaria. If Vahana was more oriented toward tilt rotor/propeller technologies and speed exploration, CityAirbus was designed to explore a full scale electric vehicle. Moreover, opportunity was taken to get in touch with topics such as unmanned flight testing, mobile ground control station and engine redundancies for multicopters.

After having checked what kind of impacts those objectives had on the CityAirbus architecture, we will focus on the unmanned aspect and particularly on the approach we followed on safety and on the consequences brought onto the flight test crew.

1. SHORT TECHNICAL DESCRIPTION

CityAirbus (CiA) was designed in partnership with

several Airbus divisions as well as with external partners as Rolls Royce for the electrical engines, Euroavionics for avionics system and ground control station software and Aviotech for flight control system.

CiA is a twin-quadcopter. Eight propellers, each driven by one motor are mounted on four symmetrical arms. Propeller pitch is fixed and thrust is obtained by increasing the rotational speed of each 3 blade-propeller. Roll, pitch and yaw are produced applying different rpm on the propellers.

Each electrical Power Unit is able to provide a mechanical power per engine of 68kW in all engines operative mode. An one minute One Engine Inoperative mode as well as an emergency 10 seconds regime are also available.

A classical EC135 skids landing gear supports the complete vehicle, which weighs almost 2300 kg. And as no fuel is burned and gas is emitted, weight and center of gravity are constant for the complete duration of the flight!

High voltage batteries are located between the front and rear arms, hanging under the ceiling of the fuselage. With 39 Ah capacity each battery is able to deliver a current from 850 down to 550 V. Based on Li-ion cells technologies, the total battery weight is almost 720 Kg.

Vehicle electronic systems are situated on the floor of the rear part of the fuselage. The mission avionic system gathers sensor data and monitors the vehicle's health in order to provide a computed situation to the ground control station. Automatic reconfiguration and sensor redundancy are the

main drivers of the system which also uses a dual datalink with the ground control station. Flight control system uses directly the sensor data to compute stabilization and automatic flight path control. Orders coming from the Ground control station consist of longitudinal and lateral velocity and heading and vertical velocity commands. Advanced algorithms are enabled to include fully automatic hover hold, takeoff and landing capabilities.

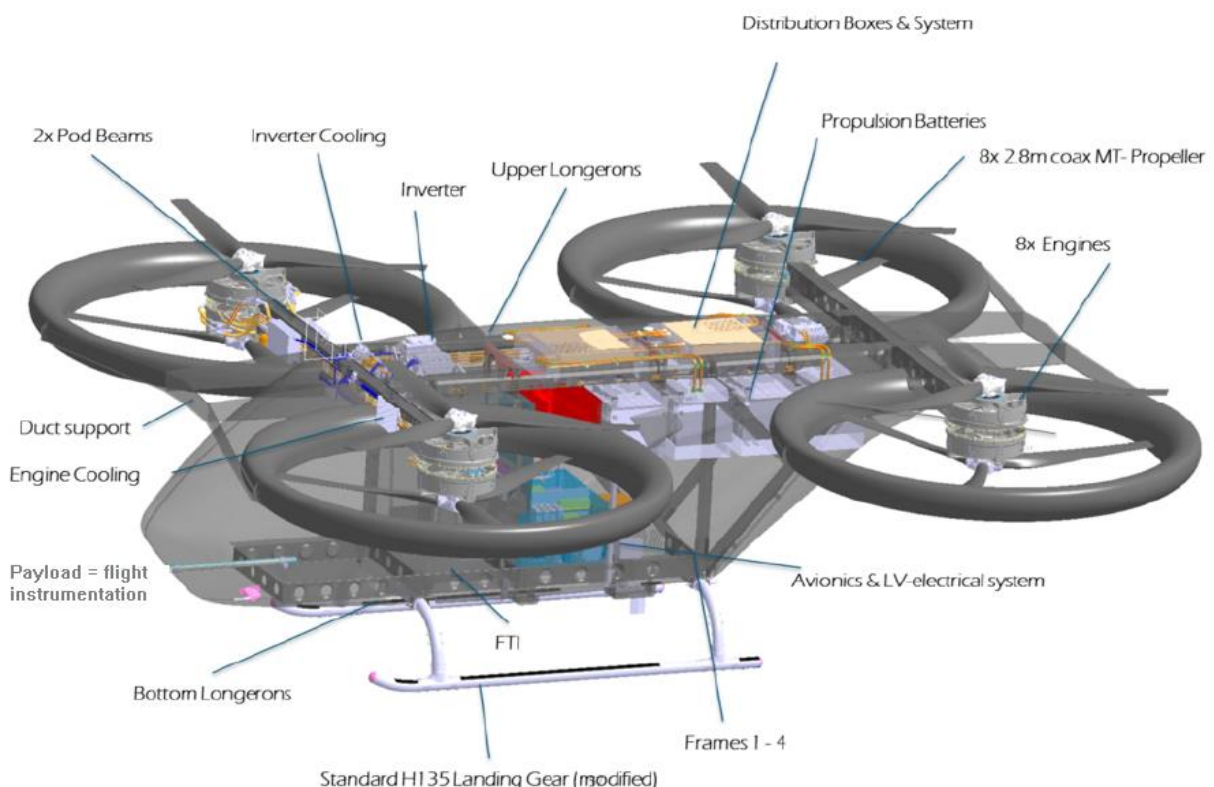
To cope with safety requirements, datalink loss algorithms have been implemented inside the flight control system. On top of that, a dedicated independent flight termination system has been added. Upon activation, it switches the engines high voltage current off, stopping instantly all propellers.

The front part of the cabin, which could be seen as the "passenger" compartment, is filled with flight test instrumentation systems. Data from the flight test instrumentation is shared between the ground control station (flight test engineer console) and the telemetry room. Parameters can be displayed upon demand, using an in-house developed software.

2. AN APPROACH TO UNMANNED FLIGHT SAFETY

2.1. Theoretical safety concept

Although being a demonstrator only, the CiA Demonstrator was treated from the beginning as any normal aircraft, following the usual quality and safety processes required for bringing an aircraft into the air for the first time. This approach is



founded on the belief that a powerful Safety Culture is the key for accident prevention and managing risks.

When speaking about unmanned aircraft and more precisely about drones, the SORA process comes usually on the table. This Specific Operation Risk Assessment is based on the document developed by JARUS (JARUS is a group of experts from the National Aviation Authorities (NAAs) and regional aviation safety organizations.), providing a vision on how to safely create, evaluate and conduct an unmanned aircraft system (UAS) operation. However, the Airbus Helicopters in-house Design Office approach was preferred to this approach, specifically oriented toward operations.

It starts with an aircraft functional hazard assessment. This process allows the identification and evaluation of potential hazards related to the aircraft regardless of the details of its design. Failure conditions are analyzed for their effect on the aircraft, crew and occupants to determine the associated severity classification. Flight phase, environmental and operational conditions can be considered in the assessment as an aggravating event within the functional scenarios. The method used is compliant to Aerospace Recommended Practice ARP 4754A from SAE International.

Top level aircraft functions typically are decomposed to lower level functions. This allows the analyst to determine if the functions and failure conditions under consideration are correct and complete, and if the top level function statement requires clarification. The detailed functional breakdown is performed in dedicated system functional hazard assessments (FHA). The severity classification is based on five failure condition categories, based on the worst case foreseeable condition.

Hazard characterization	Severity
Failure Conditions which would result in multiple fatalities to occupants, fatalities or incapacitation to the flight crew, or result in loss of aircraft	CATASTROPHIC
Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be: (A) A large reduction in safety margins or functional capabilities; (B) Physical distress or excessive workload such that the flight crew's ability is impaired to where they could not be relied	HAZARDOUS

on to perform their tasks accurately or completely; or, (C) Possible serious or fatal injury to a passenger or a cabin crew member, excluding the flight crew.	
Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew work load or in conditions impairing crew efficiency, physical distress to occupants, possibly including injuries, or physical discomfort to the flight crew.	MAJOR
Failure conditions which would not significantly reduce aircraft safety, and which would involve crew actions that are well within their capabilities. Minor failure conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some physical discomfort to occupants.	MINOR
Failure Conditions that would have no effect on safety; for example, Failure Conditions that would not affect the operational capability of the aircraft or increase crew workload, however, could result in an inconvenience to the occupants, excluding the flight crew.	No safety effect

The severity classification summary table is detailed according to Advisory Circular for Certification of Normal Category Rotorcraft AC27-1B chg 6 - §1309.

However, this severity classification is not completely accurate for unmanned aircraft because neither crew nor occupants can be impacted. Consequently, this classification was adapted to take into account the third parties instead of the crew. The loss of the aircraft was considered as industrial risk and then rated as "Major" in the severity classification. "Hazardous" was then used when a risk to third parties might occur (typically a controlled flight over unsecured area) and "catastrophic" for third parties fatalities. That means that we have to take care of the loss of datalink of course, but also of the runaway of an engine, or the runaway of all engines induced by a faulty flight control system, and the ejection of aircraft parts after crash. As no crew flies the aircraft, termination of the flight may be voluntary (in case of loss of control for example) and consequently done at the right time. When a manned aircraft crashes, it is accepted that the crew did not crash voluntarily, but

when an unmanned aircraft crashes, inquiry will inevitably show that additional safety means would have been possible: the guilty guy will be the one who did not want to pay or wait for the installation of a third or a fourth safety level. This is not straightforward and lots of environmental constraints have to be taken into account, with test location being one of the most sensitive ones.

The permit to fly process was launched with the German aviation authority approximately 1,5 year before the first flight was scheduled. The main philosophy was always the prevention of injury to third parties.

2.2. Simulation validation means

Because final assembly of the aircraft was performed at the Airbus Helicopters facility in Donauwörth, this location was also scheduled for first test phases. Then, some safety means were necessary to not endanger the nearby Donauwörth city inhabitants or the users of the regional road running alongside the facility, 100 m from the runway.

At first, it was necessary to find a mean to calibrate the developed simulation software. To this purpose, a thrust measurement kit was designed and manufactured. It is made up of a steel chassis that can be anchored to specific rails already fitted inside the apron concrete and on which the CiA can be fixed through the landing gear brackets. Skids are no more in contact with the ground so that vertical forces can be measured through flight test instrumentation at each of the attachment points by load cells. This set-up allowed to test, verify and tune our models (aerodynamic, flight mechanics, propulsion, flight controls) without requiring any dedicated test rig.

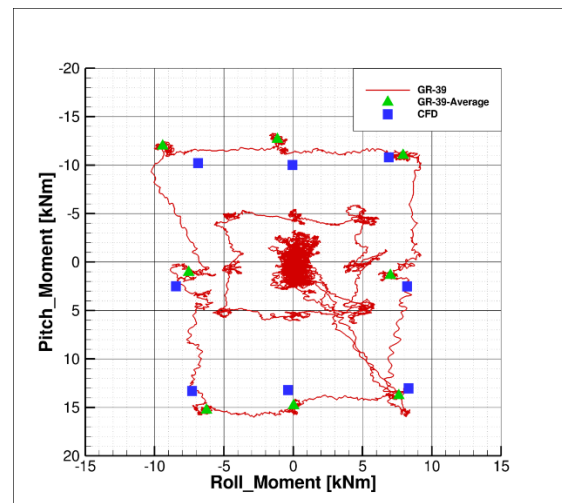


Several ground runs were performed with the help of the thrust measuring kit. It allowed to record the

thrust, rolling and pitching moments acting on the vehicle. Four force sensors were also fitted to over-constrain the static system therefore a tuning in Nastran® was carried out and linear transformations were devised in order to reconstruct the two moments acting along the lateral and longitudinal axes of the aircraft.

The ground runs with the thrust measuring kit allowed not only to validate the thrust/power curve from the simulations but also the control margins in ground effect. Initial confidence gained from the comparison enabled to confirm the required power and RPM levels for a Hover Out of Ground Effect.

The control margin test, in which the pilot deflected the stick up to specified positions commanding a dedicated moment, was compared with the simulations and confirmed the validity of the predictions. Having a high confidence in the calculated values it was possible to extend the results into different wind scenarios and define the maximum wind envelope allowed for a safe take-off. In addition, the initial stick authority was increased to counteract the adverse moments that were seen during predictions with a side wind.



Comparison between measured and predicted commanded moment on the ground

Overall, the ground tests with the thrust measuring kit increased the confidence in the simulation results and confirmed the predicted behaviour. This opened the way to use the CFD simulation to devise a take-off strategy and also define a safe wind envelope in and out of ground effect.

2.3. Resonance tests

The architecture of CiA shows four arms fitted with heavy contra-rotating propulsion units on its extremities. A dream if we want to create resonance problems !

Goal was an automatic take off, but how to identify automatically the resonance range before the first trial ? As we were building a demonstrator, we aimed at understanding all phases the aircraft would have to go through and therefore did not circumnavigate the potential problem by going quickly through the “light on skid” range. Decision was then taken, early during the design phase to fit the aircraft with a thrust lever. This enabled to perform those tests already in early 2019, just 2 years after the official launch of the project. As the resonance range ends in hover, it led to the first CityAirbus take off: several short “jumps” to check that the aircraft configurations were safe with regard to resonance.



2.4. First hover

For the first hover, constraint was to find out a mean to avoid any crash or roll over. From the beginning, the goal was not only to contain any possible crash, but to avoid it. A long line attached to a single point on the aircraft seemed not suitable for an aircraft of which the aerodynamical behavior was not perfectly known and which never flew before. A single point attached line would have restrained the vehicle from running away but would have worked against the flight control system in case of significant drift. And once again, first hover was planned to take place at Airbus Helicopters Donauwörth facility, surrounded by buildings and bordered by a frequently used road.

The solution was found by using a safety cable laid across the aircraft skids and attached to the ground on both ends, which provided a quite stable safety mean: any trend in the longitudinal axis would be recovered by the transversal cable. By drifting forward, the cable would be trapped “behind” the center of gravity of the aircraft, physically forcing the aircraft to pitch up, which would yield a reduction of the forward speed.



However, the tension of this cable needed to be quite high to work. This would result in flying close to the ground inside the ground effect of eight propellers sustaining 2,3 tons!

Once again, to be sure to completely master the whole flight envelope it was decided to fit the aircraft with a remotely piloted “manual mode”. This was the condition required to really gather all the flight characteristics of this phase and later, open the way towards smooth take off and kiss landings. Nevertheless, as the pilot does not sit inside the aircraft, he has no clue concerning the accelerations; that means no way to anticipate the movements of the aircraft. Even with a direct view on the vehicle, the remote pilot must visually detect the movements before thinking about how to react. This considerably increases the pilot processing time! The process to go into flight and perform the first maneuvers was therefore significantly increased. But it was the price to pay in order to go smoothly into hover and understand the aerodynamic reactions of the aircraft inside the ground effect.

Once completed, the tethered phase paved the way to the free flight phase. It may seem extensive, but following this process was also a way to show the German aviation authority that our processes were safe.

2.5. First free flight

Thanks to the confidence gained during the initial manual flight phase, it was possible to plan the first free flight at Airbus Helicopters facility in Donauwörth.

Yet, it was expected that the main essential equipment to prevent a fly away was the flight termination system. However, to ensure that the aircraft is really kept within a dedicated safe area without direct view to the aircraft, monitoring of the flight path or aircraft position came into the loop. That means navigation systems. Just remember that for conventional aircraft, flight navigation is

never an issue for first flights! Lessons learnt on that topic came when assessing all those failure cases and checking if the equipment involved were able to fulfill their role. In fact, several non-compliances were found. For instance, the digital map implemented was not meeting the required safety level and the flight termination system had no full substantiation of the level of safety. Dedicated corrective actions were required to increase the data redundancy and then limit the impact of any failure.

In summary, the safety/failure impact analysis initially performed during the early design phase, clearly underestimated the importance of position monitoring for the early flight test phase, because of applying the experience obtained from conventional aircraft testing. On that topic, thanks to the permit to fly process and a strong safety culture among Airbus Helicopters teams, it was eventually possible to identify this and to timely adapt the chosen direction. The safety process was then validated...but it cost time!

3. THE FLIGHT TEST CREW

3.1. Initial thoughts

The flight test crew is classically considered as the crew who operates the aircraft, inside the aircraft itself. Consequently, as we planned to test the unmanned field we started to consider the crew as the team steering CiA from the ground control station (GCS). We chose to implement two consoles inside the shelter that would become the GCS. In terms of redundancy, it was also planned to be able to take control from one or the other console using a master/slave switch. One seat would be occupied by the pilot, the second one by the flight test engineer. As the flight control system was tasked to control the aircraft, including take-off and landing phases, the pilot could also be enabled to monitor some parameters. A work share was defined to allow the flight test engineer some time to take notes and properly direct each test.



One additional independent console was mounted to gather and monitor the data coming from the flight test instrumentation. One crew member could work on this console: the Flight Test Instrumentation Operator however was not deemed mandatory at the beginning of the test phase.



Finally, the Ground Station Engineer (GSE) in charge of driving the GCS to the test location and set it up properly, also received a seat, as provision.

3.2. Ground run phase

The first full power-up of the vehicle, including connection of the high voltage supply sources was driven with a complete GCS and telemetry room set in order to check all functions and to adjust the setting of each station for the first ground run. No-one was underemployed during that test, even though everything went perfectly! We thought that this would only be the case for the first part of the ground-run phase and would be relaxed later.

We then started the ground run phase with a full set-up inside the GCS as well as in the telemetry room. Of course, this phase did not run without any problem and we encountered several technical facts, as in any test campaign. Even if we knew the aircraft perfectly, it was surprising that each technical fact took an incredibly long time to be solved, even if it was only a small fact, not even

safety related. A sensor for example, that was experiencing drop outs, or a movement on the camera that seemed doubtful..... all those not significant facts completely disturbed the tests. After some ground-runs, the crew dug into the problem to try to find out why the tests were going so slow. It was often not possible to complete the whole test order (without speaking of the back-up test points in case of enough time...!). We never had enough time!

Eventually, we found out, that the reason was coming from the remotely piloted aspect. The crew was monitoring the main technical parameters, but without any real contact with the aircraft: feeling nothing, hearing nothing, smelling nothing. That means that when a needle shakes or shook, when the video showed a spurious abnormal movement, you could not rely on your other senses and “passively” monitor the normal behavior of the aircraft when focusing on the detected “unusual” thing. On the contrary, you have to continue your overall scanning before coming, sometimes, back to the doubtful parameter. And it is incredibly time consuming. During dynamic maneuvers (thrust increase, controls inputs, etc...), it was even worse, often forcing us to come back to the previous position to double-check if the phenomenon was just a “parasite” or the first sign of a dormant failure. We were even rapidly forced to “define” a new vocabulary among the teams (telemetry room and GCS), using “stop” during dynamic maneuvers to ask the pilot not to go any further and “abort” if a step back was necessary (means when a real problem is detected). Introducing this “stop” finally helped us a lot in not losing more time.



Even with the door of the GCS opened it was not possible to hear the aircraft at 80 m (except for high power regimes). The only sense we were able to use in the GCS was vision, and it was only to see and then analyse parameters (or video images). We progressively found out that we were using the telemetry team as the “passive” monitoring of the

flying test crew. When something seemed strange to the GCS, it was immediately expressed by radio, and telemetry checked the related system while the GCS crew proceeded with the monitoring of its own other parameters. On the other side, each parasite or parameter drop out seen by the telemetry was shared with the GCS crew as a pre-warning with a severity quotation, using “proceed” when the problem/fact was not impacting the test.

The telemetry was not anymore analyzing the parameters in real time but was in fact acting as the “peripheral” sense for the crew.

3.3. Flight phase

Of course the flight phase in manual mode required an extra crew member as the pilot was standing at the door of the GCS in order to keep a direct line of sight on the vehicle. But we were confident that the automatic phase would enable us to relax a bit the GCS crew.



Once again, this was not the case! The pilot was provided with one digital map with the real time position of the aircraft, one field camera installed on the roof of the GCS and two onboard cameras, one looking forward, the other one looking vertically downward. Height, longitudinal and lateral speed, as well as heading were also displayed on the console. So, all necessary information to build a thorough situational awareness were provided.

What was underestimated, was the time necessary, when outside of the aircraft, to follow and completely understand the information displayed. Monitoring those eight parameters (map, 3 cameras, 2 speeds, heading and height) revealed to be quite a workload! No way to additionally monitor the technical parameters like the battery state of charge or the Li-ion cells temperature (you can imagine, it was like if a classical flight test crew was not able to monitor the fuel state). The ground station engineer had to take this task. And, as the automatic follow-up function of the field camera was not completely reliable, a fifth GCS crew member was required to monitor the technical parameters when the GSE was steering the field camera.

Finally, performing remotely piloted flight tests does not spare flight test personnel at all. During the whole test campaign of CityAirbus (including ground-run phase), we were never able to reduce the test crew under 9 souls (4 in the GCS and 5 in the telemetry room).

Conclusion

Stepping into a brand new flight test world is not an easy task. It requires thorough analysis and quite flexible mindset. CityAirbus was really that kind of project that requires you to think out of the box.

Eventually, designing an unmanned vehicle in order to reduce the constraint on the safety of the aircraft itself enables to explore unknown architectures ranges by going quickly on the test field. It enables also to gain experience on the actual technological bricks, to mature them and to steer the future projects in the right direction. It enables to quickly start the test phases.

Nevertheless, it is not magic enough to get free of drawbacks. As the aircraft itself is not of utmost importance, third parties become the focal point. Testing area and securing means then require maximum focus. How to proceed ? Up to which boundaries ? and how to monitor them ? These are the main questions to get worked on really early into the project. Then, when the test campaign starts, a numerous crew supported by a strong analysis team has to be available. Flight-testing an unmanned rotorcraft requires space and personnel. If the crew is spared in the operational life of the aircraft, it is exactly the contrary that happens for the development phase of it.

So aiming toward an unmanned or a manned flight test campaign, in terms of safety, is really a compromise to find between getting the first results quickly and getting all the results inside the pre-defined time and budget envelope. Any company,

that will be able to switch from one to the other solution will gain in agility and maximize its chance to meet its goals.

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Biographies

Lionel Arlen

Lionel is the project test pilot for CityAirbus from the very beginning of the project in 2017. He holds a master's degree of engineering, EASA ATPL(H) and PPL(A) licences and is also the NH90 program test pilot and Unmanned Aerial Systems representative at Airbus Helicopters Germany.

As a former French navy helicopter pilot, he mainly flew Alouette 3, Dolphin and Lynx during his operational tours overseas between 1998 and 2007. Specialized in naval warfare he became the head of the French Navy Tactical Helicopter Training Center in Hyeres. He attended EPNER's year long experimental flight test course in 2010-2011 and lead the Navy's NH90 operational evaluation team between 2014 and 2016.

He joined Airbus Helicopters Germany in 2016.

Henno Gemmink

Henno is the project flight test engineer (experimental FTE) for CityAirbus. He holds a master's degree of aerospace engineering, and is also the responsible FTE for German old range helicopters (CH-53, Mk41, Mk88).

As a former RNLAf helicopter FTE, he mainly flew the AH-64D Apache for OT&E purposes, between 2005 and 2010. After serving in the RNLAf as maintenance Officer for F-16 Falcon from 2000 - 2003, he attended ETPS rotary wing class of 2004.

He joined Airbus Helicopters Germany in 2010.