Flight Testing of an Unmanned Aircraft System – A Research Perspective

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Abstract

This contribution outlines the lessons learned from ten years of flight test experience with ARTIS, a family of unmanned helicopters of the German Aerospace Center (DLR). The project started as a small team in research environment where hardly any flight test planning was necessary. Nowadays, ARTIS is part of a larger experimentation fleet including unmanned fixed-wing aircraft of different sizes and quad-rotors. Both, the team grew and complexity of the vehicles and missions increased, such that a standardization of flight test planning and procedures became necessary. We present a procedure for flight test planning and realization that has proven successful. This process includes risk assessment and mitigation as well as personnel-wise organization during flight test. As an example, we show details about flight test campaigns for automatic navigation in obstacle rich environments.

Notation

ARTIS	Autonomous Rotorcraft Testbed for Intelligent Systems
COTS	Commercial Off-the-Shelf
DLR	German Aerospace Center
GCS	Ground Control Station
GNSS	Global Navigation Satellite System
HIL	Hardware in the Loop
HMI	Human Machine Interface
MiPlEx	Mission Planning and Execution Framework
MTOW	Maximum take-off Weight

1 Introduction

The effort of planning, performing and documenting flights of unmanned aircraft varies with the scale of the aircraft, its velocity, the distance covered and impact of possible hazard. Complementary to approved methods of flight testing manned aircraft as outlined in [1, 2], the methods applied to unmanned aircraft are influenced by the following aspects:

1. **Level of automation:** The degree of automation influences the procedures in flight test. At the current state of the art the usable flight envelope for automated flight is significantly reduced compared to the ability of the aircraft itself. However, the more soft- and hardware modules are needed to achieve the desired automation, the higher the system complexity. This complexity imposes more a priori test effort to maintain a low level of risk and increases the workload of the test engineers to maintain awareness of the full system security.
2. **Integration of the ground control station:** A flight test of an unmanned aircraft does not only test the aircraft itself, but also includes aspects of the HMI of a ground control station and data links to the aircraft. The ground control station itself is also under development. The concurrent development state implies additional risks that have to be considered during the flight planning phase.
3. **Integration in the development circle:** Especially for small scale aircraft, flight tests are affordable. It is thus possible to perform tests more frequently and link the results closer to the system's development circle. The advantage is enabling early and granular validation; however, the disadvantage is additional risks due to the concurrent development state.
4. **Variety of configurations:** The absence of a pilot onboard allows the aircraft itself to be developed more freely resulting in a broad spectrum of variations. These variations include scale, weight and payload setup but also aerodynamic configurations. As a consequence, flight testing procedures may vary between different aircraft significantly.

In general, the flight testing of unmanned aircraft has unique aspects caused by the absence of a pilot onboard and reduced reliability of the system, as also confirmed in [3–5]. However, deriving general methods for flight tests of unmanned aircraft is hindered by the diversity of possible configurations and test setups, especially caused by aspects 1 and 4.

In this contribution, we present the experiences and lessons learned from 10 years of flight tests of the ARTIS (Autonomous Research Testbed for Intelligent Systems) as one realization of unmanned aircraft system. ARTIS is a family of unmanned helicopters operated by the DLR in Braunschweig, Germany. In this paper, we focus on variants with MTOW of 10-25 kg. Figure 1 shows the mid-scale variant with MTOW of 14 kg. We flight tested our rotorcraft in campaigns with single automated functions up to higher levels of automation, e.g. navigation in obstacle rich environments. Focus of this contribution is the general procedure undertaken for planning and performing a flight test in the ARTIS context. As will be evident later on, risk mitigation plays and important role in this flight test planning process.

Some aspects of the paper are illustrated using flight tests performed in an obstacle occupied environment and tools involved in reducing risks for these missions will be discussed in more detail. Two automation aspects are addressed for navigation in low altitudes through a priori unknown terrain and for difficult sensor data gathering used for real-time terrain mapping.

The paper is structured as follows: First we present categories of flight tests that have been performed with ARTIS in the recent years. The challenges of these categories and the differences from flight testing perspective are discussed. The example of a complex flight test scenario is also introduced that serves as illustration throughout the paper. Subsequently, the planning process is outlined and possibilities of risk mitigation are outlined. Using the example mentioned above we illustrate the aspects of flight test planning focusing on specific tools for risk mitigation. These tools include simulation environments, pretests and flight test decomposition. Finally, some striking lessons learned are presented.

Figure 1: midiARTIS rotorcraft with onboard obstacle detection: Stereo camera (left) or a composite sensor configuration with laser scanner and camera (right).

2 Types of flight experiments performed with ARTIS

Flight experiments with ARTIS are related to at least one of four mission aspects:

(1) **Validation flights** focus on one specific aspect or component of flight. They target a requirement, hypothesis, algorithm or system concept and aim to validate the aspect under test. Often these flights involve new system components and algorithms.

(2) **Documentation flights** are reoccurring flights that are meant to generate performance data to capture and document the state of development of the system. These flights often focus on flight and handling performance as well as integration tests.

(3) **Payload directed flights** rather focus on the payload than the helicopter. The helicopter only serves as a carrier and the experiment is performed using the payload under test.

(4) **Mission focused flights** are experiments where procedures and feasibility of sorties are assessed.

Examples of experiments are shown in Figure 2. Figures 2a shows a validation flight (1), specifically a mapping experiment performed with a stereo camera. The goal is to evaluate algorithms for extracting 3D maps based on stereo camera imagery [6]. Figure 2b shows the performance of path following as described in [7]. This flight is also a validation flight if performed for the purpose of validating the controller design. However, this test is performed on a regular basis to evaluate whether changes made to other system components influence the closed-loop performance. The achieved accuracy and environmental conditions like wind are documented at each time. By doing so, changes to the system performance are traceable and these experiments are assigned to category (2). A payload based test (3) is shown in Figure 2c. In a process called mosaicing, a certain area is overflown and images of a downwards oriented camera are stitched together forming a texture of the complete flight. Finally, a mission focused flight (4) is presented in Figure 2d. Here, the unmanned helicopter is operated out of a manned helicopter to evaluate possible landing sites [8]. The focus of this experiment was the procedure of teaming manned and unmanned helicopters in a shared airspace.

The flight tests gain in complexity implying increased risks if several of these mission aspects are combined. The example used later in this paper, the automated flight through a partially known obstacle occupied environment illustrate this combination: The helicopter flies through an urban environment with an incomplete 3D map of the existing buildings and obstacles. It is evident that a flight test campaign of this scale

(a) Mapping (b) Controller Performance

(c) Mosaicing (d) Teaming

Figure 2: Four examples of the test categories using the ARTIS research helicopters.

involves at least three of the above mentioned aspects. For this kind of missions ARTIS is equipped with additional payload for environmental sensing and mapping that is not standard equipment of the system. Integration test flights are thus necessary to ensure safe operation of the system. The flight objective is eventually the validation of the complete system including the helicopter itself, flight control, sensor fusion modules as well as path and motion planning and mapping modules.

Over the past years a prominent set of guidance algorithms and their evolution have been developed by our and many unmanned air vehicle groups (cf. surveys by [9]). These guidance approaches often aim at the closed-loop navigation capability of unmanned aircraft in fully or partially unknown terrain, i.e. safe flight in complicated terrains without the need of human intervention.

Although an early set of flight tested guidance algorithms exists, their performance potential remains still high. Examples of active fields of research are operational safety considerations like uncertainties in GNSS availability or state estimation supported by environmental sensing. To achieve acceptable flight duration from ”A to B” while flying smoothly along an arbitrarily shaped given trajectory, mission performance aspects in realistic scenarios with real sensors are still an area of active research.

To account for most of these aspects, a set of test scenarios was designed. A large set of scenarios were developed using a desktop simulation of the closed-loop system. For rotorcraft a set of benchmark scenarios have been developed that are now shared among their early adopters [10]. One aim of the benchmarking activity is to bring as many aspects of these scenarios into flight test. However, the vast combinatorial set of possible performance aspects over each scenario requires a drastic test case reduction. Thus, as a first step, cases are based on manual parameter inspection and test case selection. A more objective way of characterizing trajectories or scenarios with respect to their performance, safety, difficulty and scalability remains active research.

ARTIS' guidance algorithms are implemented in the Mission Planning and Execution framework (MiPlEx). Its automated rotorcraft guidance has been evaluated in flight tests with respect to the closed-loop motion planning. The framework is based on a decoupled approach for path planning, trajectory generation, trajectory following and inner loop flight control [11]. Since 2006 the MiPlEx framework was implemented and repeatedly validated with the testbed shown in Figure 1.

3 The flight test process

3.1 Flight test planning

In general, the first steps of flight test planning with unmanned aircraft do not differ from planning manned flights. The objectives and goals are documented and constraints for the flights are collected. Some constraints are permanent which are imposed by the official regulations of the country where the test is performed, the test team, the vehicle itself, its avionics and software:

- The flight tests have to be performed at suitable test sites. In many countries the site selection depends on take-off weight and varies between dedicated model flight areas or test sites have restricted ground and air space.
- In many cases, the flight may only be performed within sight of a safety pilot that can take over control at all times.
- The maximum height above ground is fixed by the official flight permit, height of the restricted airspace or line of sight of the safety pilot.
- Technical constraints are generated by the development state of the system. These constraints include endurance of the vehicle, usable flight envelope due to limitations of the flight control system, precision limitations due to the sensor fusion and so on.
- The flight test crew underlies regular fluctuations. A very small minority participates in most or all of the flight tests. Most researcher participate only in those tests of his particular concern causing different levels of experience and education in flight test procedures.

Other constraints are mission specific and will be different for each experiment. Examples might be attitude limitations of the vehicle imposed by a sensor payload, velocity limitations to ensure overlap in image series from overflights or flight path restrictions due to obstacles.

When both, goals and constraints are determined, the flight concept is assessed that satisfy both aspects. A risk assessment is performed based on this concept.

3.2 Risk assessment

In the case of manned flight tests, a test hazard analysis is performed [12]. Here, each risk is classified using probability and impact of the hazard. Applying this hazard analysis to unmanned aircraft comes with two challenges. First, in manned operation there is a distinction between on-board and on-ground personnel. This distinction is due to the intrinsically increased risk of flight operation. However, for unmanned operation this differentiation is unnecessary, thus the impact classification has to be modified. The second aspect is a lack of experience concerning the probability of occurrence, which is especially true for flight tests in the research field. Quantitative assessment of a hazard is thus often not feasible and a verbal declaration is used.

These two aspects lead to a hazard assessment similar to the one proposed in [5]. The hazard assessment is documented in form of a table that summarizes all hazards, their impact (catastrophic, critical, minor, neglectable) and probability (frequent, probable, occasional, remote, improbable). The combination of the impact and probability is then categorized into a risk index. Different scales for this index have been used in different contexts. Often a four class system is used. The identified categories define the effort necessary to reduce the probability and impact until the remaining risk is deemed acceptable.

Nevertheless, a complete hazard assessment is performed only if the flight test involves a high degree of system or mission innovation. For ARTIS these risks are documented and are either reduced by procedures or alternatively technical measures like safety features within the flight software. The remaining risks are discussed within a pre-flight briefing and especially important aspects are trained in a hardware in the loop simulation.

Many risks are reoccurring and always involved in flight tests of the ARTIS family. These risks have been initially determined and the corresponding list is extended every time a new aspect has been discovered during flight testing. Ultimately, the ARTIS helicopters are equipped with a safety switch which operates completely separate from the remaining avionics. This switch enables the safety pilot to take over manual control at all times. Thus the risk can be considered that of a model helicopter which is deemed satisfactory and impact is minimized by maintaining sufficient distance between the vehicle and safety pilot as well as the vehicle and the border of flight test site.

3.3 Risk mitigation

The possibilities to reduce the risks involved in flight tests are manifold. The following starts discussing dedicated test tool development. In the proceeding section, we consider certain inspections and hardware in the loop simulations performed directly before flight test. Afterwards, dedicated roles during flight test and a communication flow helping to reduce the probability of hazards are discussed. In case of an event this role standardization ensures fast and correct reactions. Finally, possibilities to decompose the flight test in multiple tests of lower risk are motivated.

Test-tool development

Determining the risks as discussed in the previous sections allows dedicated tool development for testing purposes. These tools help maximizing the probability that the algorithms under flight test work as expected. For the example of obstacle field navigation, a software component for mapping of virtual obstacles was developed that enhances our closed-loop simulation. It is based on a set of a priori acquired high precision terrain databases of 1 m horizontal resolution and 10 cm vertical resolution. Moreover, simplified sensor field of view emulation allows for real time collision checking against the high resolution terrain. This function enables a comparably low computational requirement for a virtual, sensor-based terrain mapping function. The terrain features are condensed into enclosing volumes (e.g. 3D prisms or axis aligned bounding boxes) and fed into the guidance algorithm. Figure 3 shows an example terrain map of our test site acquired by overflights in sub-meter resolution. Indications mark the area of test operation with an unobstructed tower as test obstacle.

Developing automated guidance algorithms using such virtual sensor functions serves as an important tool during the transition from desktop development into flight test. Its set of virtual obstacle sensors allows assisting in predicting and evaluating the motion planning behavior during all flight test phases:

1. In the flight planning phase, the combination of a precise terrain map and a virtual map building sensor allows to tune the experiment with respect to procedures and parameter sets on a desktop computer.

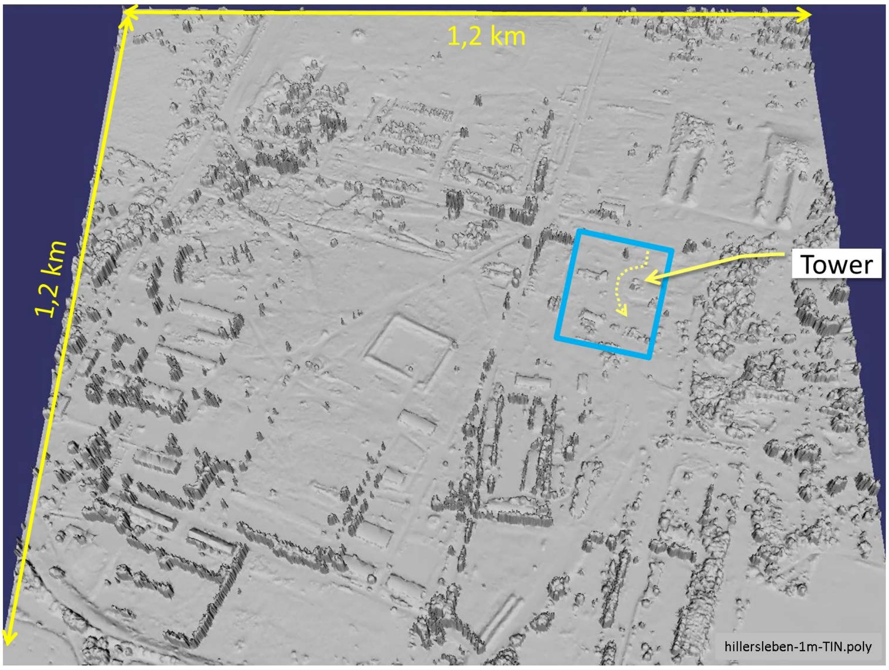


Figure 3: High precision terrain elevation map for the virtual obstacle sensor models.

This way, important aspects can be validated before flight, including appropriate initial conditions for a given obstacle set to ensure visibility of the system by the safety pilot while exploring the area.

2. During the flight test, the terrain database can be used to emulate sensors without changing the flight hardware. For example, one can instantly switch between various sensor types (e.g. an active, rotated LIDAR scanner or a passive stereo camera), or change sensor parameters of its instantaneous field of regards (e.g. detection range or angle of beam spread). Running the virtual obstacle detection onboard the control computer instead of the ground control station allows to safe valuable data link bandwidth. Nevertheless, it may be required to send detected obstacles to the ground control station for better situation awareness. This transfer can occur using a lossy compression in real-time.

3. After a set of test runs and for deeper analysis of obstacle avoidance maneuvers, the same software component can be used to replay flown log data. This replaying supports the test team to identify which subsystem contributed to the observed maneuver to what extent. Moreover, the detailed replay of recorded data allows observing the internal processes that otherwise remain hidden and can be used to adapt the flight experiment by the flight test crew.

Tests before automatic flight

The tests directly before automatic flight are subdivided into three different categories: the HIL simulation, checklist-based on ground inspection and manual test flights.

The HIL simulation contains as many components of the flight test hardware and vehicle as possible. However, it is important to note that the components included in the simulation underlay the stress of operation during simulation; thus maintenance and replacement circles are shortened. The benefit of the HIL simulation is, however, that proper functionality of integrated software and avionics components can already be ensured before the flight test. For ARTIS it has been found beneficial that there are no particular simulation states within the on-board software. If there were, the software of the simulation would differ from that of the flight testing, which would need to be considered in the remaining test procedures.

In the case of the ARTIS helicopters, the HIL simulation includes all avionic components except the hardware of the sensors and the mechanical response of the actuators. A real-time computer simulates flight mechanical responses based on measured actuator commands and emulates sensor errors. The resulting sensor signals are wrapped within the sensor protocols and transmitted to the avionics system. Thus, all software components, the flight computers, the signal side of the actuation and the safety switch are included in the simulation. The ground control station operates the vehicle identically to real flight test during simulation. By this means it is also possible to do a training of the mission and brief the flight test crew on the expected outcome. This training includes the safety pilot who can fly the helicopter manually in a 3D visualization of the simulation environment.

Inspections are performed both in-lab and on-site. Checklists are reused and extended if new experiences are gained. These inspections include component tests of the vehicle and avionics, wiring, data links, actuation, propulsion and mechanical integrity. All tests are performed with the two-man rule and are recorded on the checklist documents. The checklists ensure that no aspect is overlooked in situations of stress and the two-man rule increases the chance of fault detection and enforces conscious decision when seemingly irrelevant irregularities are identified. These inspections also include software components which are dependent on the hardware configuration. A particular important aspect is consistency checks of the sensor fusion as well as calibration checks.

Finally, some aspects of the system can neither be handled by HIL simulation nor by inspection. These aspects are tested with **manual pre-flights** performed by the safety pilot to ensure that the flight performance is as expected. After this manual flight, the logs of the onboard software are evaluated. It is important to note that the test coverage of the HIL simulation and this pre-flight have to engage with one another in a safely manner. As mentioned before, the sensors are excluded from simulation for ARTIS, as is the mechanical reaction of the actuators. These aspects have to be covered by this pre-flight and the proceeding data analysis.

Roles in flight test

The research environment changes procedures compared to routine operation. The roles of the staff during flight tests are defined by particular scenarios. During the past years, the following roles and responsibilities have proven efficient. These six roles are documented within the team to avoid inefficiencies or even misunderstanding. Due to the frequently changing flight test crew, these roles are clearly presented on cards, such that every participant can quickly check his responsibility in each situation.

The **flight test lead** coordinates the flight test. He is responsible that the flight test runs smoothly and takes care that every other position receives the information required. He also assigns the other positions. He is responsible for safety of the crew and observers. It is his responsibility to initiate the experiment and he also may abort it at all times. He synchronizes the remaining positions and takes care that every station is manned when necessary. The flight test lead is required and is occupied by an experienced researcher who has participated in flight tests for years.

The **ground control station operator** is in charge of mission planning of the vehicle. He supervises the state of the system and sends the mission commands to the vehicle. In contrast to many manned flight experiments, the GCS operator is actively involved in the flight test, which increases workload compared to a solely observing role. He informs the flight test lead about problems, delays and readiness of the overall system. He also communicates with the person in charge of the vehicle about tests, inspections and final adjustments of the vehicle's hardware. Furthermore, he communicates with the payload operator about state and synchronization of the payload to the flight experiment.

The **payload operator** is responsible that the payload is working during flight-experiment. He operates the payload, synchronizes its operation with the flight test and gathers the information needed for the goal of the experiment. In case of a critical failure he directly informs the flight test lead.

The avionics and **system responsible** ensures the nominal operation of the vehicle and avionics. He maintains the interfaces with the payload and performs inspections of the system. It is his responsibility that the system remains operational and that the flight test lead is informed about any delays or possible risks. During flight test he constantly observes the airspace and the behavior of the helicopter.

The **safety pilot** is responsible for safe flight. He observes the automated flight of the vehicle and is ready to take over manual control at all times. He also inspects the vehicle from a mechanical point of view. He is the only person that might abort a mission without confirmation of the flight test lead. However, he may never start one without been instructed. It is his responsibility that no other person except him is within the vicinity of the vehicle. If an unexpected event occurs, either caused by the vehicle, the environment or flight test crew he immediately takes over control and returns the vehicle to a defined safety position. The safety pilot also carries the legal responsibility of the aircraft and damage done by the aircraft.

The **ground assisting crew** includes camera operators who record the whole experiments, provides aid for complex tests and improves smoothness of the test itself. These ground crew stays in contact with the flight test lead and the safety pilot who have to be informed about their position and possible safety measures at all times. For example, a statistical analysis of near incidents of the past showed that camera operators are subject to higher risks than other ground crew. The reason is that they are often positioned such that their field of view covers the most important and thus most risky part of the experiment. These risks have to be explicitly addressed in the flight planning phase and during mission briefing.

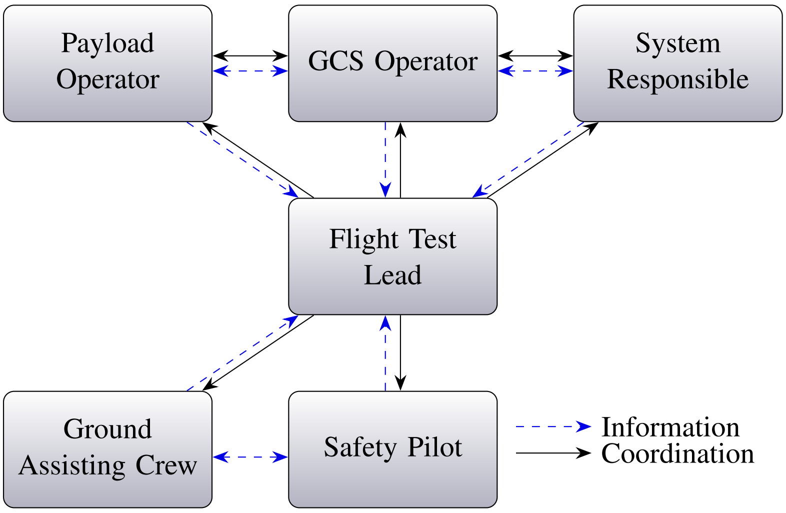


Figure 4: The roles in flight test with coordination and information flow.

Figure 4 shows the six roles and their nominal communication flow during flight tests. In complex scenarios, especially if multiple vehicles are involved, a direct communication link is added between the GCS operator and safety pilot. The indirect communication including the flight test lead can causes delays if he is too occupied by the experiment complexity. The decision of direct communication links is based on a balance between coordinating the radio communication and avoiding information delay. During simple experiments some of these roles might be occupied by one person. However, it is the authors' experience that all positions should be manned separately as often as possible to decrease workload and thus the probability of errors.

Flight test decomposition

One of the most important aspects of risk mitigation is the flight test decomposition. Here the overall test is subdivided into different flight tests where each flight is limited to one mission aspect of Section 2. The decomposition is performed in such a way, that complexity of the experiments increase as trust in the system and its properties grows. In the example of the navigation in obstacle occupied environments, a possible decomposition separates four dedicated experiments. The first flight would be in obstacle free environment using virtual sensor data including virtual obstacles. This flight is free of the danger of in air collision while the path and motion planning modules are already in the loop.

The second test is flown in obstacle occupied environment, but using virtual sensor readings based on the exact knowledge of the terrain. The third test is a manual flight through the obstacle occupied environment with integrated environment sensing hardware and post flight sensor analysis. It is only the last flight, where the complete exploration of an unknown environment is performed completely automatically. The following paragraphs provide exemplary results of the second and third experiments.

Flight with virtual obstacles: Figure 5 shows the top view of the second flight experiment. The test site for which the terrain validation and sensor emulation database has been acquired is shown. Two safety distance observers were placed with cameras around the reference obstacle. One additional chase UAV was placed above the reference obstacle as flying camera. The tower is the test obstacle the helicopter is supposed to avoid. The GPS position was determined and the tower represented in the high precision map of Figure 3 by a wall of cylinders.

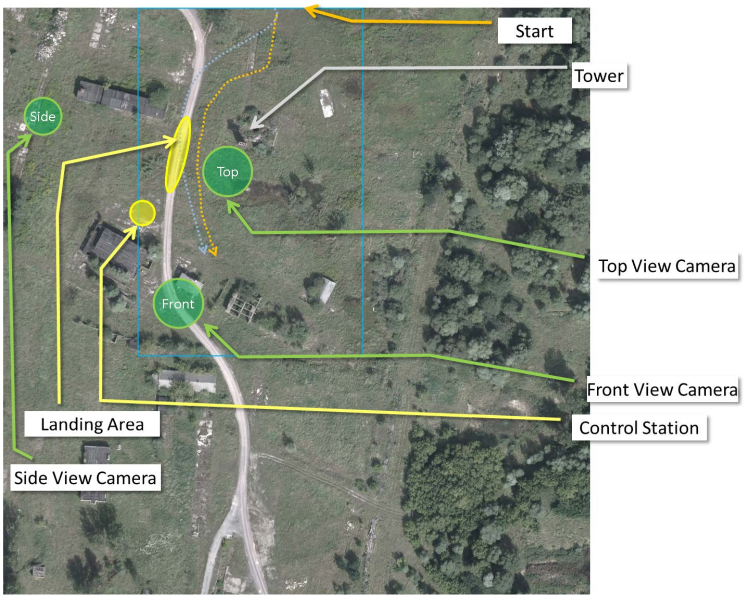
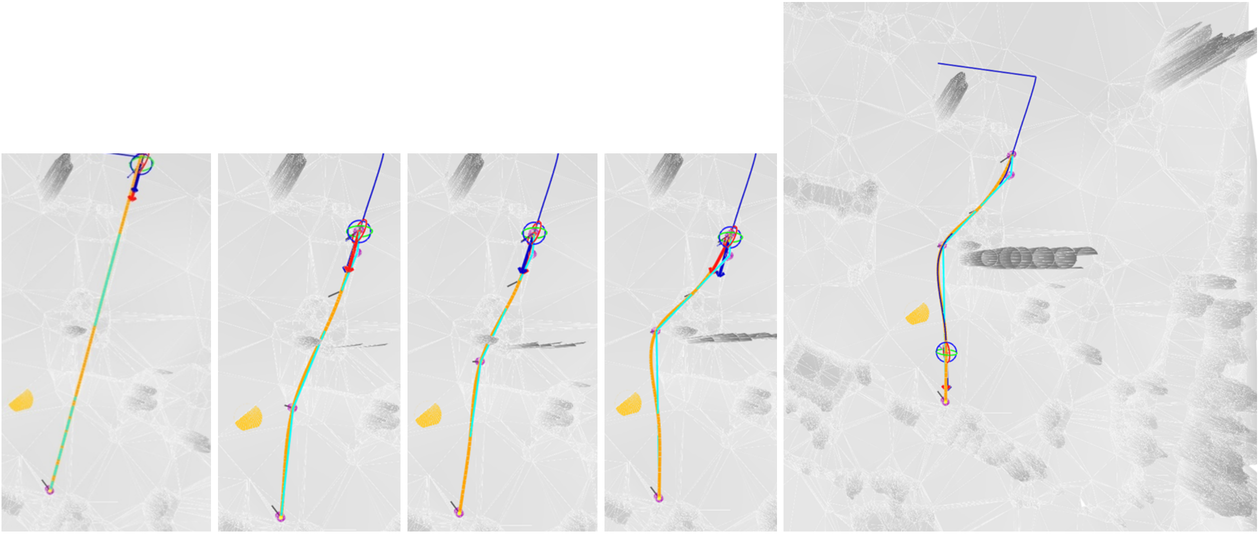


Figure 5: Top view of the flight test setup for obstacle avoidance maneuvers.

In the context of this navigation objective, the performance of a motion planner was assessed, i.e. a drastically compressed free-space representation is supposed to achieve comparable planning performance compared to more computationally demanding approaches. An example of flight tests with this planner can be seen in Figure 6 where a smooth trajectory help the rotorcraft to avoid unforeseen obstacles although no exact free space map is available. From left to right, the time-wise evolution of the near top view is shown. Initially a linear path was planned as the obstacle was not yet known (Figure 6a). While the unmanned



(a) 0 s (b) 11.1 s (c) 11.5 s (d) 12.3 s (e) 15 s

Figure 6: Path planning experiment replay from flight test data (timeline is left to right).

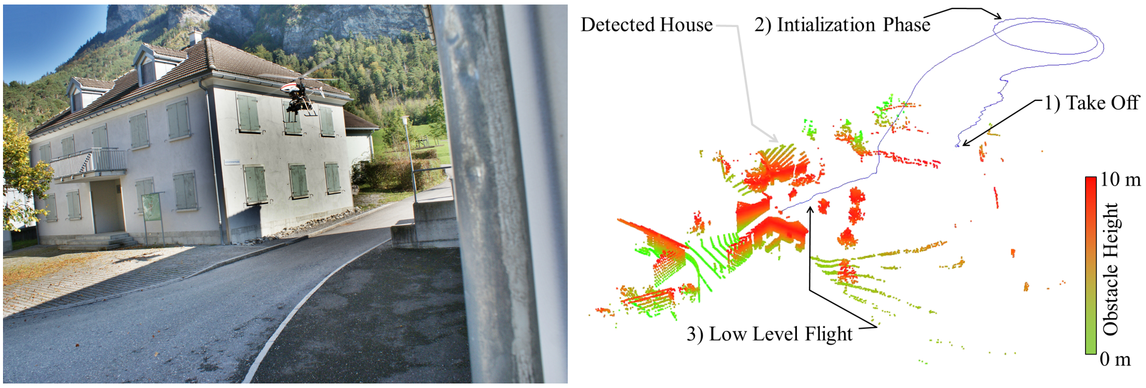
rotorcraft approaches the virtual obstacle, more and more of the cylinder wall is revealed by the virtual dynamic sensor model. It can be seen that the path is re-planed by the MiPlEx planning component under test. Sometimes small changes in the free space yield path changes for which this planning component must ensure that no ”stop and go” or other jerky flight maneuvers are performed, i.e. the transition phase form an obsolete path to a valid path must be performed smoothly and in real time (e.g. Figure 6c to Figure 6d)).

Performance metrics are based on refined pass-fail criteria (i.e. smoothness, safety, performance) and enhanced benchmark evaluations as proposed in [10]. This category of path planning algorithm has its advantages in a drastic reduction of the computational complexity inherent to all overall 3D path planning problems where many obstacle details need to be expected. However its uncertain representation of free space has critical implications with respect to determinism of the experiment, especially during flight tests.

One problem of automated planners is the possibility to yield paths not suitable for flight test dedicated to prove of concepts. Initial conditions might results in paths that are not completely visible by the safety pilot—e.g. the tower might hinder the view of the helicopter if a path is planned avoiding the tower to the east. While these paths are completely valid from the perspective of algorithm development, they pose a threat during flight tests. Situations like these have to be determined during the test planning phase and corrective actions have to be taken—in this case, the tower has been represented by a wall extending eastwards that ensures a replanning in a desired direction.

Terrain Perception Validation Another important building block for automated navigation are our real-time terrain mapping components [13, 14]. The latest evolution of the sensor suite comprises a set of COTS laser scanner available to the automotive industry. These sensors are integrated into a composite sensor suite with which flight tests were conducted to assess the field of view performances and avionic performance. The mission profile was set to very close flights in populated terrain structures. Flight tests were conducted on a military training site in Switzerland.

Figure 7 implies the challenges the safety pilot had to cope with during the flight test. Figure 7a shows the manual flight through an obstacle field while Figure 7b shows the reconstructed flight path in blue and the recorded mapping data. This flight corresponds to the third test of the decomposition and mitigates risks involved with automatic flight through the obstacle field. By this decomposition procedure the impact of e.g. brown out on the feature-based computer vision algorithm can be assessed. These results form important risk assessment aspects for the final stage of automatic flight through the obstacle field. Furthermore, it also provides valuable input data to be accounted for in the algorithms increasing the probability of the final experiment's success.



(a) Manual Flight

(b) Recorded Sensor Data

Figure 7: Terrain data acquisition with a multi-sensor suite while flying close to obstacles: Mission altitude above ground after decent (a) and acquired sensor data (b).

4 Lessons learned and future work

The roles mentioned above have gradually been identified and established. Not using a role definition has proven to lead to misunderstandings due to unclear responsibilities and authority. It also causes uneven workload distribution causing a higher chance of errors due to overload of a few crew members. Therefore, it is desired to balance the work load for the participants optimally for these types of research experiments.

One aspect in a growing team is the question of real time documentation of flight tests. It has proven to be necessary to uniformly provide a flight test card for each flight. These cards are necessary at least to match log-files of the on-board software with camera logs. It is also beneficial to provide a a time stamp for each documentation component, including to present a watch to the camera to ease synchronization after the experiment. In general, the flight test card is the schedule of the flight test thoroughly prepared during the planning phase. However, it must be flexible enough to be adopted at the field without increasing workloads or risks.

As complexity increased and abilities of the ARTIS helicopters grew, performing regular training flights including documentation of the current state of performance became necessary. Performance extends on the term flight performance in the classical sense and rather refers to the overall systems performance. Handling of the ground control station is included as is the tracking performance of the flight controller, reliability of automated mission management and stability of the overall software. It is necessary to document the software revisions used in the flight tests which correspond to the software versioning system of the development. In fact, the list of maneuvers and missions used for performance documentation is under continuous development. Ideally, these missions have to be flown once before every experiment but have to cover sufficiently many aspects of the overall system thus demanding a rather big set of maneuvers. One of the challenges in this context is to maintain constant conditions and parameters to compare the maneuvers over a time frame of years. Defining the appropriate parameters is especially difficult, if not all influencing factors are known a priori.

Usually, safety pilots are neither flight test engineers nor research scientists. A suitable and special education for safety pilots of unmanned aircraft is not available at this time. For safety pilots it is therefore hard to fulfill the intended role w. r. t. the complexity and uniqueness of the unmanned system. The manual takeover of the control of the aircraft takes place in situations where the experiment does not evolve as expected. Thus, the safety pilot's workload increases suddenly. He has to determine if the system fails or not, has to take over the control to recover the vehicle and determine the options within seconds. Depending on the assistance functions of the vehicle this task is challenging and requires at the very least a thorough vehicle specific training.

An issue involved in the research environment is that basic support systems very often do not have scientific relevance. The researcher, by nature, is thus often more interested in the development of more complex and advanced functions. This circumstance leads to a lack of reliable and robust basic functionality relevant for everyday use. It is thus important, that projects leave sufficient resources for the development of this kind of support functionality.

Flight testing is a relatively time consuming evaluation of the researcher's implementations. A considerable amount of time has to be spent in preparation and pretesting. The time needed for the preparation in laboratory and on site is a multiple of the pure flight duration. A representative simulation environment and development tools thus help on this matter.

The smaller the unmanned system, the lower is the workload during flight test and impact of a critical situation. As a consequence using smaller systems, the motivation of researchers tends to be higher and testing progress can often be achieved faster due to more ambitious steps between test iterations. This aspect is in contrast to payload considerations. From our experience, available payload is always completely exploited, independent from planned reserves. As a consequence, many research projects can only be enabled by sufficient payload capabilities of the system.

During the recent years of development, we detected longer periods without flight tests. These long development circles produce a high degree of uncertainty and a lack of trust in the functionality of the vehicle. In retrospective, it is beneficial to test the performance and quality of the systems frequently, e. g. on a weekly basis and reduce the number and impact of changes between flight tests.

However, if the number of flight tests increase up to a regular basis, manual flight documentation and evaluation imposes significant effort. Hence, the process has to be automated as much as possible, including automatic problem detection based on the log files, preparation and intuitive presentation of the logged information. For example, if a certain hidden fault has been revealed in one flight test, the user should be informed about occurrences in future flight tests automatically. This framework of automatic log file evaluation has to be flexible enough to cover a vast variety of different maneuvers and provide the possibility to easily integrate lessons learned into the automatic detection. Such a framework is focus of future work.

Another future aspect is the training of the flight test team members. While expertise of the engineers grew together with the system and gained experience and flight test knowledge over time, it is difficult to train new crew members to the same degree. The knowledge of flight testing should be be transferred using standardized educational measures.

Acknowledgment

The authors gratefully acknowledge the help of the team members of the unmanned aircraft department, especially Jörg Rößner, Gordon Strickert, Andreas Voigt, and Stefan Krause who provided images, support and helpful discussions. Further thanks go to Joachim Götz who provided valuable discussions in respect to manned flight test operation and Anne Papenfuß for valuable feedback on flight test procedures.

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