SIMULATION TOOLS FOR UAV/OPV AUTOROTATION PERFORMANCE METRICS EVALUATION

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Abstract

Under the framework of the US/France Project Agreement (PA) on Rotary Wing Aeromechanics and Human Factors Integration Research, ONERA and AED began to collaborate on helicopter autorotation capability in 2011. In 2017, a new joint task started, dedicated to improving control and guidance capability and defining requirements for implementation on rotary-wing UAV and OPV when operated in autorotation. This three-year program will investigate the enabling systems and technologies from an UAV automatic system to be used in an OPV for autorotation maneuver, thus taking the benefits of a full-automatic system to provide dedicated piloting aid functions. A modeling and simulation framework is proposed for designing, evaluating and testing flight control algorithms for helicopter autorotation flight. A common helicopter model and set of flight controllers have been developed and shared between ONERA and the US Army. Initial studies of the autorotation flare/landing metrics are presented and discussed, with a focus on using these metrics in the future to evaluate purpose-built automated autorotation controllers for UAV/OPV helicopters.

List of abbreviation

PA	Project Agreement
ONERA	Office National d'Études et de Recherche Aérospatiales / French Aerospace Lab
AED	Aviation Engineering Directorate
AMRDEC	Aviation & Missile Research Development & Engineering Center
UAV	Unmanned Aerial Vehicle
OPV	Optionally Piloted Vehicle
FCS	Flight Control System
PID	Proportional, Integral, Differential feedbacks
RCAH	Rate Command Attitude Hold
ACAH	Attitude Command Attitude Hold
ATT	Attitude (3 axis) target/hold
NATO	North Atlantic Treaty Organization
SEMA	Series Smart Electro Mechanical Actuators

List of symbols

XC	Collective position (0%-100%)
IAS	Indicated Airspeed (knots)
U	Forward speed (knots)
V	Lateral (m/s)
W	Vertical speed (ft/min)
TTc	Time to Contact (s)
ϕ, PHI	Roll Angle (deg)
θ, THETA	Pitch Angle (deg)
ψ	Heading (deg)
H	Height (ft)
HFlare	Height (ft) of initiation of the flare phase
HLanding	Height (ft) of initiation of the landing phase

1. INTRODUCTION

Unmanned Air Vehicles (UAV) and Optionally Piloted Vehicles (OPV) are in various stages of development, testing, production and fielding.

One limitation for rotary-wing UAV/OPV is the control, guidance and management of automatic or pilot-assisted autorotation. The current (NATO) requirement for UAVs is for safe controlled crash (no injury, no airspace violations) – but modern systems are costly, which provides motivation to improve survivability of the system. An OPV may

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be occupied and may or may not have a pilot – better management of autorotation emergency procedures is required.

The present research is focused on simulation tools and process development towards qualifying UAV and OPV rotorcraft systems to the qualification level 1 as defined in US Army Regulation 70-62 [1] and equivalent to a manned system.

In the framework of the US/France Project Agreement (PA) on Rotary Wing Aeromechanics and Human Factors Integration Research, ONERA and AED previously shared their experience through a task investigating the potentiality of improving the flight safety and performance of manned helicopters when operated in autorotation. In 2017, a new joint task started, dedicated to improve control and guidance capability and define requirements for implementation on rotary-wing UAV and OPV when operated in autorotation. This three-year program will investigate the enabling systems and technologies from an UAV automatic system to be used in an OPV for autorotation maneuver, thus taking the benefits of a full-automatic system to provide dedicated piloting aid functions.

The task can be divided into three main objectives:

- Develop automatic flight control system for UAV autorotation
- Analyze "Technology/knowledge" transfer from UAV to OPV
- Propose performance requirements for UAV/OPV landings

This paper will describe the works performed by AED and ONERA to realize an automatic flight control system for autorotation of a rotary wing UAV and the preliminary performance requirements for landings which have been proposed.

Autorotation is an emergency procedure that is both important and unique to helicopter systems. Pilots are trained in autorotation maneuver and landing techniques. The very nature of the emergency – unexpected power failure – requires the pilot to adapt to the specific circumstances at the time of the failure. The autorotation flight may begin at almost any altitude and airspeed, and may involve any conceivable type of terrain and ground obstacles. For this reason, the design and implementation of automated or higher order flight control laws and software packages for autorotation flight and landing is challenging.

An automated autorotation flight controller must:

- detect the failure immediately and switch from normal to emergency control modes
- adjust flight controls to enter autorotation flight (typically within 2 seconds of the failure)
- select a landing site or immediately present an operator or pilot with possible landing sites
- perform maneuvers to reach the landing site
- perform the complex flare and touchdown landing

These tasks may all be required of an unmanned helicopter that happens to be large enough for passengers, if it were to be qualified to operate in a “normal” airspace or flight envelope alongside manned aircraft. These tasks would also be required for any future “optionally piloted” helicopter system that could carry passengers with or without a pilot.

There are technology solutions that could add reliability to newer systems, perhaps reducing the inherent complexity of the emergency flight control system. Power boosting or back-up electric motors can reduce or eliminate the need for autorotation flight. New platforms may be designed with multiple, distributed lifting rotors and flight controls that adapt to an individual rotor failure. Terrain databases, artificial “vision” systems, and surrogate models of aircraft performance can all enhance the performance of the flight control system. These systems can also, of course, introduce added weight and complexity to the helicopter, and may or may not be feasible or cost effective to add to existing aircraft. And there still remains the overall problem of qualifying a software package designed to detect and adapt to emergency situations as well as determine the “best” control strategy for a helicopter that may or may not carry passengers and may or may not be operating around people on the ground and other aircraft.

The present paper focuses on the construction of a modeling and simulation framework that enables testing different controllers during various portions of the autorotation flight spectrum, from monitoring and detection, through entry and maneuvering phases, to the complex flare and landing. During this initial part of the overall research program, the focus is on basic in-house controllers and developing methods for assessing the performance of controllers. Future efforts are planned to test specific, purpose-built controllers for each phase of the autorotation maneuver.

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2. METHODOLOGY

2.1. Flight mechanics code, control and guidance algorithms for automatic autorotation maneuver

In order to facilitate the exchanges in this cooperation, ONERA and AED decided to use the same flight mechanics code (FLIGHTLAB®) and the same helicopter model. The helicopter model chosen is the OH-6A model [2]. The main reasons are that the data and all required information for integration in the code were available in the public domain and that an unmanned variant (Little Bird H-6U) of the AH-6i manned scout helicopter, relatively close to the model chosen in this study, has been flying for over a decade.

2.1.1. **AED controller**

AED previously coupled the FLIGHTLAB® simulation tool with a developed and correlated VirtualPilot software to conduct various studies on autorotation flight. For this study, this VirtualPilot controller has been integrated and adapted to the OH-6A helicopter model and a real-time model was implemented within the AED simulator. In addition, the Georgia Institute of Technology provided to AED specific controller algorithms [3] which will also be integrated and adapted to the FLIGHTLAB® OH-6A model as an external model during the next phase of the research. AED and ONERA shared the various controllers, enabling ONERA to integrate these algorithms on its own desktop and real-time simulation environment. AED has also worked to integrate drivetrain monitoring algorithms that can detect engine or drivetrain failures and trigger the autorotation algorithms. The current approach is based on the work in Reference [4], and the integration effort is ongoing.

This section of the paper describes the modifications brought to the VirtualPilot controller and the common helicopter model. These changes allow for testing of autorotation control algorithms and evaluation of flare entry criteria such as flare attitude, flare height above ground, and collective pull timing/height. Model validation against limited US Army flight test data is planned.

The AED VirtualPilot software has been previously developed and used for autorotation analyses of OH-58 and UH-60 US Army aircraft [5]. The current approach has implemented this software as an available “controller” in the OH-6A FLIGHTLAB® model. The VirtualPilot provides a user-selectable set of control strategies for each axis (longitudinal, lateral, yaw, collective). As such, it must be programmed to use certain control strategies in each phase of a maneuver. For example, during the steady autorotation descent phase, the collective axis manages RPM while the longitudinal axis can manage either pitch attitude or airspeed. The VirtualPilot is not an autonomous controller; however, it is useful for parametric studies as well as for “matching” a specific flight maneuver.

The OH-6A model has been modified for this present study. A clutch model and “simple engine” were added in order to provide a way to induce drive train failure by disengaging the clutch. Landing gear (skids) have been added to allow for FLIGHTLAB® to automatically detect ground contact. The baseline control system model has been modified to have a second input added to each of the pilot stick inputs. This second input is for the VirtualPilot model and also provides inputs for coupling other external controllers. The VirtualPilot control gains have also been manually tuned to the OH-6A model dynamics. A more thorough controller tuning is planned for future work.

An example of an autorotation maneuver flown by the VirtualPilot is shown in Figure 1.

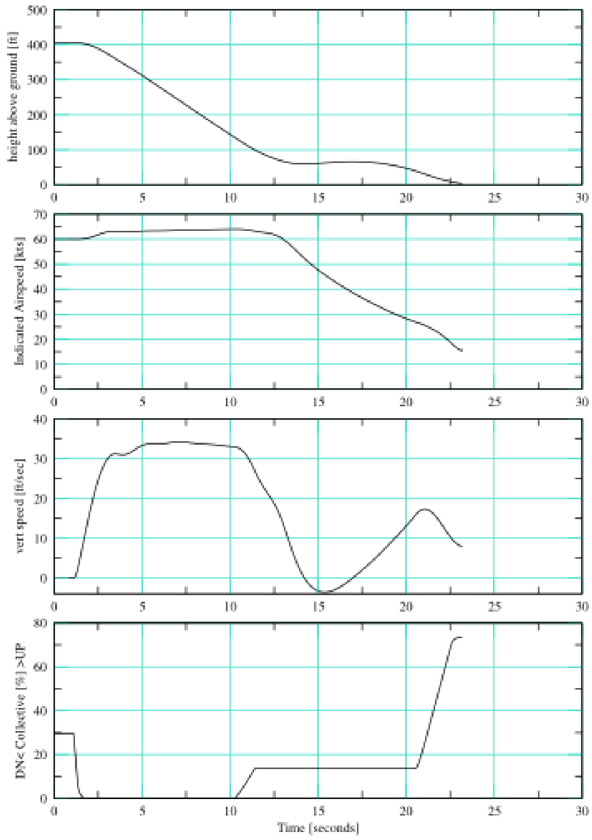

Figure 1 Autorotation example for AED VirtualPilot controller with the OH-6A model

In this case, the OH-6A model is trimmed in level flight at 2600 lbm, 400 ft above ground, and 60 kts indicated airspeed. The clutch is disengaged after

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1 second and the collective is immediately reduced (pilot reaction time has been previously studied and is not a factor in the present study). Airspeed is managed through the longitudinal axis. A 15 degree nose up flare is executed by the controller beginning at 100 feet above the ground, and the collective is increased slightly to prevent rotor overspeed. At 40 feet above the ground the pitch attitude is returned to 0 degrees as the collective pull is made. In this case, the collective is increased 30% per second for 2 seconds. The figure shows the height above ground, forward airspeed, vertical speed, and collective control. This particular example shows a relatively "successful" flare and touchdown, with a forward speed of 16 kts and vertical speed of 8 ft/sec.

2.1.2. **ONERA controller**

ONERA developed its own controller, which has been shared with AED, dedicated to parametric studies. This controller has been developed in SIMULINK®, the helicopter flight mechanic code FLIGHTLAB® has been integrated though a S-function.

While mainly dedicated to UAV and full automatic maneuver from the clutch disengagement to the touchdown, some additional features have been integrated for future evaluations on the real-time simulation with pilots. These developments are up to now a RCAH law and a rotor RPM control through collective. Used for OPV configuration, these types of controls could be also used by UAV automatic controller.

The following figure (Figure 2) shows an example of control of the rotor RPM during the stabilized autorotation phase.

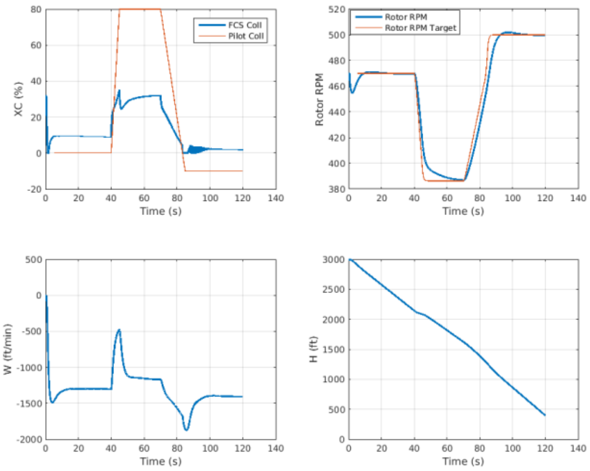

Figure 2: Rotor RPM control through collective

At the engine failure (Time=0.5s), the level of required collective to recover the rotor RPM is automatically set by a controller. This level of collective is then considered as the reference (corresponding to the nominal/autorotational rotor speed). The collective lever is then calibrated as a function of rotor RPM: 0% corresponding to 500 rpm, 100% to 375 rpm. The red curves show the pilot commanded collective and the corresponding targeted rotor RPM. Thus, the logic remains the same as the current situation where, when the pilot increase the collective, the blade pitch is increased leading to a reduction of the rotor RPM and vice versa.

While the forward speed is kept constant at 60kts, the impact of the variation of the controlled rotor RPM can be seen on the vertical speed, thus on the loss of altitude, and potentially adding a new degree of freedom on the control of the trajectory. In a previous study [5], this function was partially tested in flight with a visual indicator. The next step will consist in evaluating this function in ONERA's simulator.

A specific UAV controller has been developed, enabling a full automated autorotation maneuver. The main objective was to develop a very modular controller, allowing a large number of computation options as this will be explain after. It is composed of a maneuver phase estimator, detecting the different phases of the maneuver (entry, steady state, flare and landing). The logics and related algorithms switch from one to another in function of the estimated phase.

An ATT controller has been adapted from previous studies, enabling to hold current pitch, roll and heading angles or to reach (and hold) targeted values. Nevertheless, it's not an ACAH law, which will be integrated in the next steps.

Series Smart Electro Mechanical Actuators (SEMA) dynamics are taken into account. Their maximum allowable speed of actuation is a variable parameter, set by default to 40%command/s but which can be modified. In addition, electro-hydraulic actuator dynamics have been integrated through a transfer function.

The controller has been split into different modules, managing the different phases of the maneuver.

<u>The entry phase</u> is managed from the engine failure to the estimated steady phase. The detection of the engine failure has not been introduced here, with AED working in parallel on that specific issue. The clutch can be disengaged at a specified time

The collective is automatically decreased down to 0 then a PID feedback is used to recover a given

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rotor RPM value (nominal or different). It is possible to introduce a delay between the clutch disengagement and the collective action. The speed of decrease corresponds to the SEMA dynamics.

The following figure (Figure 3) shows the ability of the controller to reach and maintain different rotor RPM after the engine failure. A module is used to maintain the initial Indicated Airspeed at its current value while the lateral speed is hold to zero. But both velocities can be hold to their current values or set to other values. If the airspeed is not controlled, Roll, Pitch and Heading can also be hold at their current values or set to different ones.

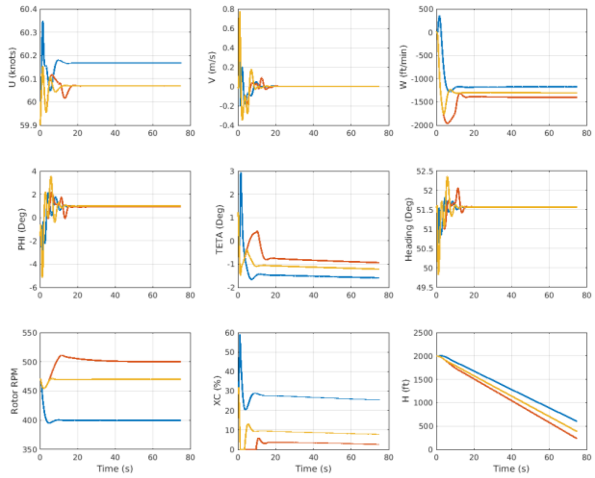

Figure 3: Rotor RPM hold to different values at autorotation entry

The following figure (Figure 4) shows the ability of the controller to reach and maintain different indicated airspeed (IAS) after the engine failure.

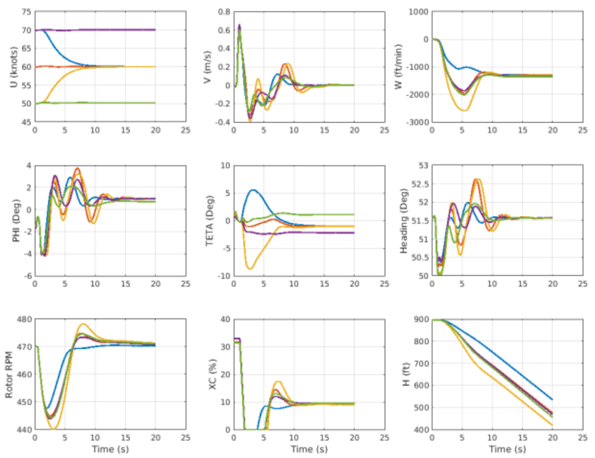

Figure 4: Indicated Airspeed set to different value at autorotation entry

<u>The steady phase</u> is not covered yet by the ONERA's controller in terms of guidance and navigation features. But the speed controller and rotor RPM controller previously mentioned could be used during this phase. It is planned to use the Georgia Tech and AED controllers for that specific phase, or to develop specific ones in the future. The steady phase estimation is based on the dynamic of the rotor RPM. Variations of the rotor RPM have to be ±1 rpm around the nominal value, while its derivative $\frac{dNR}{dt} < 0{,}05$.

<u>Flare phase:</u> An altitude set by the user determines the beginning of the flare phase (Hflare). The following figure (Figure 5) shows the ability of the controller to initiate the flare maneuver at different altitudes, and to reach and maintain different pitch attitudes.

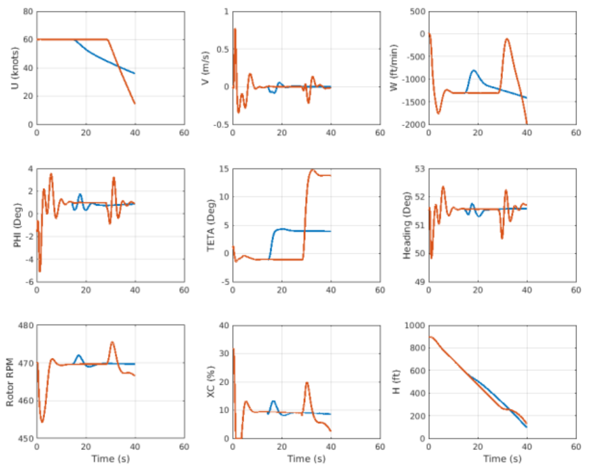

Figure 5: Initiation of the flare phase at different altitudes and pitch angles

The blue curve shows the beginning of the flare at Hflare = 600ft and a pitch angle θ = 5°, the red curve shows a start altitude of Hflare = 300ft and θ = 15°. These values are given here as an example, and could be modified to perform parametric studies.

During the flare, the collective can be controlled by:

- a PID feedback maintaining a given rotor RPM value (nominal or different)
- a direct prescribed command (amplitude of the collective increase).
- a targeted vertical speed during flare.

In Figure 6, the flare is initiated at 170ft, with a pitch attitude of +15° (from 34s to 42s). The blue and red curves correspond to the first option, where the rotor RPM is respectively maintained to its nominal value (470rpm) or set to another value (490 rpm). The possibility of a precise

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management of the rotor RPM during the flare will be further investigated, providing higher kinetic energy at the landing and as a result, reduced vertical speed at touchdown.

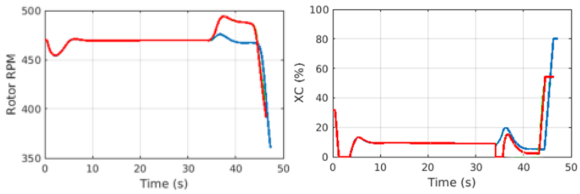

Figure 6: Rotor RPM control during flare

Finally, the deceleration is controlled by a targeted IAS or a direct pitch angle prescribed value. The lateral speed being maintained to zero. The attitude angles can be also directly controlled.

<u>The landing phase</u> is defined by altitudes or it can be based on the estimation of the time to contact. Time to Contact (TTc) is defined as:

$$TTc = \frac{h}{\dot{h}}$$

where h is the current height, $\dot{h}$ the vertical speed.

TTc is limited to the higher bound of 120s and the lower bound of 0s. Its value is kept to the last minimal value reached. Thus, in case of increase of the altitude (due to a collective action, a pitch attitude, etc.), TTc is held to the previous value and decreased once the altitude decreases again.

The helicopter attitudes are controlled (reduced from their flare values to a targeted value, generally equal to zero) once the helicopter is lower than a given altitude (HLandingATT). The yaw axis is managed by holding the heading or the sideslip to 0.

The collective is managed once the helicopter is below a prescribed altitude (HLandingColl) or if TTc is lower than a prescribed value (TTc_L). Then, a direct collective increase can be set to a prescribed amplitude, or it can be managed by a PID feedback to reach a prescribed vertical speed. The PID gains are dependent on the HLandingColl value.

<u>Complete autorotation maneuver</u>

The main purpose of this controller is to propose a large number of logics and options to investigate the impact of the different "decision" parameters such as Flare altitude, Pitch angle at flare, Landing altitudes (for Pitch and collective), etc. The controller is clearly not autonomous or even an "automatic pilot"; however, some of the algorithms could be adapted for that purpose.

Figure *7* shows the complete maneuver, starting at level flight at 900 ft and IAS 60 kts. The engine failure occurs at T=0,5s. The collective is automatically set to reduce the rotor rpm drop and then maintain it at 470 rpm. Pitch, roll and yaw attitudes are computed to hold IAS, lateral speed and heading to their initial values.

Figure 8 represents the phase estimator. It can be seen that the steady phase is established at around T=7.95s. The phase state takes the following values for the different phases:

- Phase state=0: Powered flight
- Phase state=1: autorotation entry (T=0.5 s)
- Phase state=2: steady phase (T=7.95s)
- Phase state=3: flare phase (at T=34.1s)
- Phase state=4: landing phase (at T=43.2s)

The steady phase consists here in maintaining the flight speeds (IAS and lateral), the heading and the rotor RPM.

At HFlare = 170ft, the flare is initiated. A prescribed +15° for pitch attitude is ordered while holding the lateral speed to 0, the heading and the rotor RPM. The pitch target follows a second order dynamic given by a transfer function. This function can be adapted. A rate limiter can be selected or not.

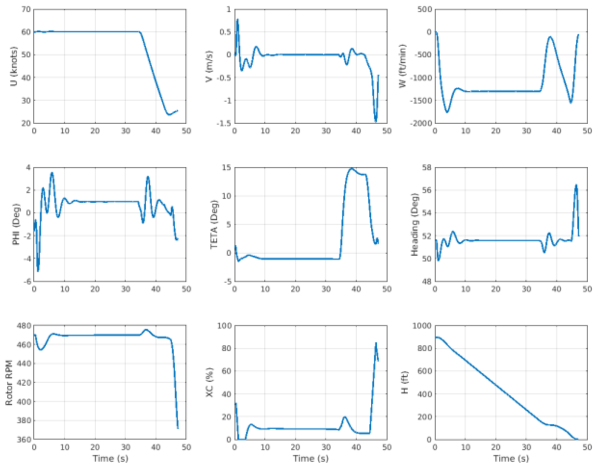

Figure 7: Complete autorotation maneuver

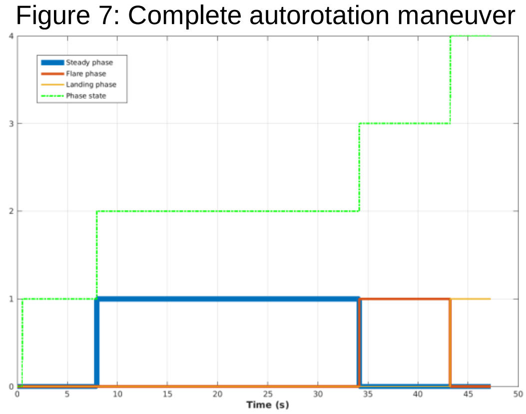

Figure 8: Maneuver phase estimator

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Here, θ reached the value in around 7s. This induces a large decrease of the vertical speed and a deceleration of the IAS from 60 kts to 21.5kts. The pitch motion tends to accelerate the rotor speed, which is managed by the collective controller (between 34,1s and 40s).

At HLandingATT = 70ft, the landing phase begins, at least for attitudes. The pitch attitude is reduced and targets 0. At HLandingColl = 42ft, the collective is managed through a PID controller to reach a vertical speed of -0.5m/s (-98.4 ft/min). This sudden increase of the collective has an impact on the attitudes and on the rotor RPM which decrease from 470 to 370 rpm.

The touchdown vertical speed is -0.39 m/s (-78 ft/min), θ =1.19°, ϕ=-2.4°, U= 22.6kts

The collective increase for landing phase was based on an altitude, but it could have been based on the TTc. The following figure (Figure 9) shows the TTc during the entire maneuver.

Once the helicopter has touched the ground the simulation is stopped. The management after touchdown is not performed.

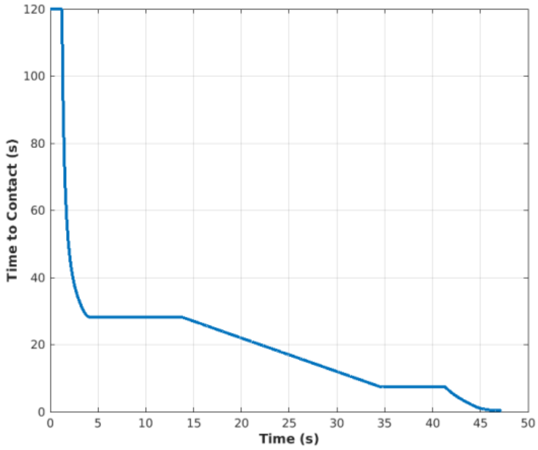

Figure 9: Time to Contact (TTc) computation

3. RESULTS-PERFORMANCE METRICS

The AED model and Virtual Pilot controller have been used for a preliminary study of the flare phase. In this study, the model flight conditions are all taken to be the same as in Figure 1, but the height above ground for both the flare entry and the collective pull are varied. The effect of these height variations on the vertical and horizontal speeds at touchdown is shown in Figure 10. Recall that the "baseline" case shown in Figure 1 has a flare entry height of 100 feet and a collective pull height of 40 feet. All other flight parameters from the baseline case are held constant.

For this specific combination of flight conditions and control strategy, the baseline heights provide the "best" performance, and would be acceptable for a piloted or optionally piloted helicopter. The vertical landing speed is less than 10 ft/sec and the horizontal speed is relatively low. It can be seen from the results in Figure 10 that there is very little margin to change these heights. A slightly earlier or later collective pull or a slightly later flare may be acceptable for an unmanned aircraft; however, an earlier flare results in unacceptably high vertical landing speed. Note that "height above ground" should not be taken as a control strategy, but rather as one of many parameters that can be studied for different controller strategies.

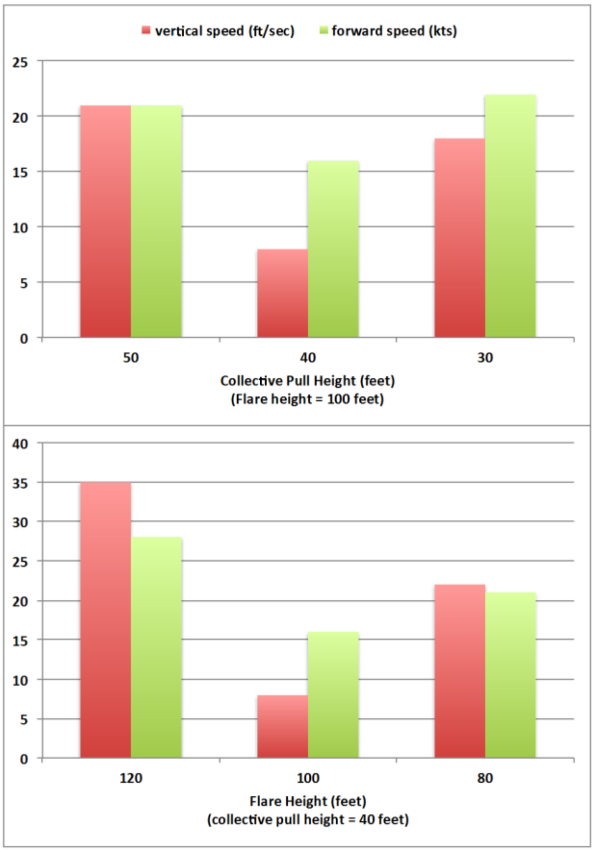

Figure 10 AED Virtual Pilot Flare/Touchdown: effect of flare and collective pull heights on vertial and horizontal speed at touchdown

The ONERA controller, with the multiple settable parameters or logics, is well adapted to parametric studies. It allows a large number of combinations and helps to determined most influent parameters in different phases. In this study, we mainly concentrated on the final parts of the maneuver, performing parametric studies on the actuator speed, and the strategy on the collective (based on height or TTc).

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The purpose of the analysis presented hereafter was to see the impact on the final vertical speed (= at touchdown) of the maximum allowable speed of the actuators (i.e. collective increase dynamic at touchdown), the final amount of collective increase and the time before impact at which this collective increase is performed.

A complete autorotation maneuver is performed (as shown in Figure *7*) from level flight at 60kts, 900 ft height and weight of 2600 lbf. The final helicopter attitudes being < - + 5 deg.

- 4 different actuator speeds have been considered: 20%/S, 40%/s, 60%/s, 80%/s
- 4 different amount of collective: +25%, +50%, +75%, +95%
- And collective increase before "impact" from -1s to -3s

The baseline controller is used initially to maintain airspeed (U), heading, roll attitude, and rotor RPM. The controller then begins the flare (pitch up) maneuver to reduce airspeed and begin to reduce vertical speed (W). Finally, the controller executes the collective pull just prior to touchdown, reducing vertical speed to the final landing value.

The example of the final collective pull (Figure 11) illustrates the time prior to touchdown at which the collective pull begins (Tcoll), and the amount of collective that is commanded by the controller (CollIncrease). The collective increase dynamics being equal to the actuator speed.

For example: considering an actuator speed of 40%/s and a maximum landing vertical velocity of -3m/s (600ft/min) for a manned helicopter (Figure 12). The simulation results show that it is impossible to reach this final speed if your collective increase is below +45%, or if this collective increase happens too late (below 1,5s before impact) or too early (over 2s).

While for an UAV, still considering an actuator speed of 40%/s but a maximum final vertical speed of -6m/s (1181ft/min), the ranges of

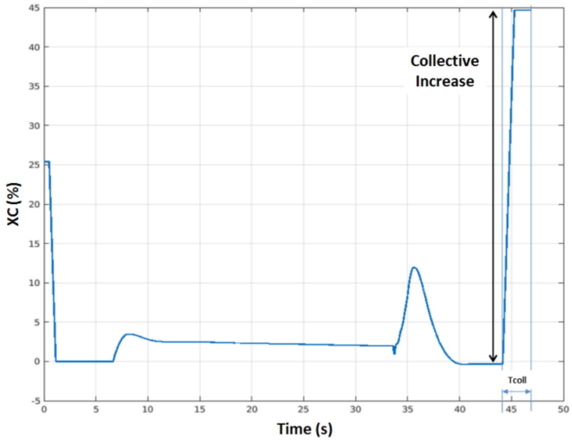

Figure 11: final collective pull at landing

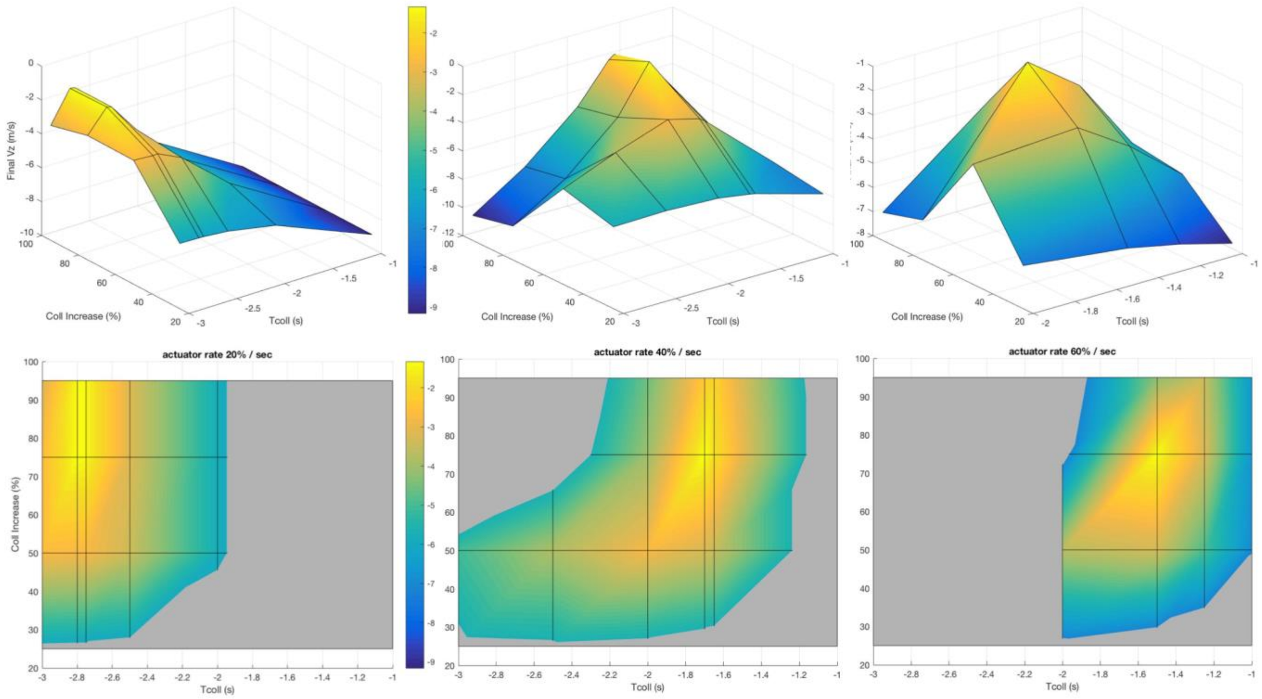

Figure 12: Vertical landing velocity function of speed of the actuators, final amount of collective increase and the time of actuation before contact

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allowable collective amount and collective increase delay before "impact" are larger. The yellow shades indicate approximately the maximum acceptable vertical landing velocity for manned aircraft, while the green shades indicate approximately the maximum acceptable velocity for unmanned aircraft.

These results apply to a specific initial condition (60 kts, 900 ft, 2600 lbm). The flare initiation was performed at 170ft and landing at 70ft (landing attitudes).

For all actuator speeds, the minimal final vertical speed is obtained for collective increase of around 75% while the time of actuation is dependent on the actuator speed. An actuator rate of 60%/s allows a collective increase at -1,5s before touchdown where an actuator rate of 20%/s needs -2,8s.

The results apply to a specific control strategy regarding the timing of the flare and the collective pull. It is true that another control strategy would give different results.

4. CONCLUSIONS

In the framework of the US/France Memorandum of Agreement for Cooperative Research on Helicopter Aeromechanics, ONERA and AED started a new study dedicated to improve control and guidance capability and define requirements for implementation on rotary-wing UAV and OPV when operated in autorotation. It was decided to use the same flight mechanics code (FLIGHTLAB®) and the same helicopter model (OH-6A) [2] for which all the data and required information for integration in the code is available in the public domain to develop an automatic flight control system for a rotary wing UAV.

A demonstration of the emergency autorotation procedure has been constructed using the common simulation model. Desktop simulation tools were developed, as well as real-time/piloted simulation capabilities. These simulation tools, based on validated flight mechanics codes, offer the possibility to reproduce or to perform simulated autorotation maneuvers in very different situations. This should allow the possibility to develop and to test piloting aid functions to help the pilots to perform this difficult maneuver in safer conditions.

Preliminary performance requirements for landings have been proposed. The entry criteria for the flare maneuver (height, attitude, airspeed) are key parameters that affect the touchdown vertical and horizontal speeds. For a particular aircraft configuration, these flare entry parameters will form targets or limits for steady descent controller phase. Similarly, the timing, magnitude, and rate of the final collective pull can dramatically affect touchdown velocities. These values depend on both aircraft configuration and controller strategies.

5. NEXT STEPS

Autorotation is a current topic within the US/FR Rotorcraft Project Agreement.

ONERA will continue to develop the described controller and in parallel, based on shared guidance modules with AED, automatic flight control systems for UAV autorotation will be developed. An analysis of "Technology/knowledge" transfer from UAV to OPV will be performed; the resulting piloting aid functions will be implemented on the ONERA's prototyping bench "PycsHel" for piloted evaluations (tactile cueing, visual aids, auto-pilot modes, etc.).

AED intends to continue to work to implement the purpose-built drive train monitoring algorithms and the ONERA and Georgia Tech autorotation controllers in the current framework. This approach will provide an end-to-end simulation tool for evaluating different controllers through different phases of the autorotation maneuver.

The overall goal is to develop simulation tools and performance metrics to aid in design, testing, and qualification of flight control algorithms/software for UAV and OPV helicopter emergency autorotation.

6. REFERENCES

[1] Army Regulation 70-62, “Airworthiness of Aircraft Systems”, May 2016

[2] Ouellette, G., “Modeling the OH-6A Using Flightlab and Helicopter Simulator Considerations”, PhD Dissertation, Naval Postgraduate School, March 2002

[3] Rogers, J., Jump, M., et al., “Handling Qualities Assessment of a Pilot Cueing System for Autorotation,” Proceedings of the 73rd Annual Forum of AHS International, May 2017.

[4] Martin, J., “A Predictive Autorotation Entry Analysis Using Bayesian Multi-Model Estimation Detection”, PhD Dissertation, Auburn University, December 2017.

[5] Binet, L., Martin, J. N., and Brackbill, C., “Autorotation Maneuver Analysis of Main Rotor And Aircraft Flight From Engine Failure to Ground Contact”, Proceedings of the 42nd European Rotorcraft Forum, September 2016.

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