RIA to support future rulemaking on single engine helicopters with increased pilot intervention times following power failure

Final Report

Client: European Aviation Safety Agency

Rotterdam, August 2013

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Executive Summary

This Report describes the Regulatory Impact Assessment (RIA) to support future rulemaking on single-engine helicopters with increased pilot intervention times following power failure. It is developed to support EASA in its rulemaking task RMT.0246 (MDM.050). The specific objective is: *"the establishment of the case for/against enhancing certification requirements in the area of pilot intervention time following power failure in single-engine helicopters"*.

The study on which the RIA is based started with a literature search. This had the twin objectives of:

1. Establishing an optimum or range of pilot response times for single-engine helicopter loss of power events that was commensurate with known human performance; and
2. Identifying existing or emerging technologies that could reduce or delay the loss of rotor speed following engine failure to increase the allowable response time to the pilot to successfully enter autorotation.

From the literature search it can be concluded that the allowable response time depends on the type of aircraft and its characteristics (weight, rotor inertia, etc.) but even more on the phase of flight. In hover or climbing flight the allowable response time is at its lowest, around 0.3 seconds, and in forward flight is increased to in general 3 to 5 seconds. The actual response times found in the literature search indicate that the actual pilot response time to enter autorotation can be up to 3 seconds (90^{th}-percentile value for twin-engine helicopters). As no actual response times were found for single-engine helicopters, this value has been used as an indication for possible actual response times for single-engine helicopters. It is however recommended to continue research in this field with a focus on single-engine helicopters.

The allowable response time can be increased by active systems such as tip jets, a flywheel, an auxiliary turbine or an electric motor. Also passive systems in the form of added tip weights or increased rotor speed can increase the allowable response time. The actual response time can be decreased by visual or other warning cues provided in advance as well as active systems that detect low rotor speed and automatically perform the corrective action.

Based on the outcomes of the literature search it appears that the currently applied normal certification practice to assume a 1 second time delay for the cruise phase and 0.3 seconds for other flight phases may not be sufficient to adequately embody normal pilot performance. Increasing the corrective action time delay for power failure in the certification specification to reflect the ability of the 90-percentile pilot would be desirable.

Next an analysis of the <u>safety impact</u> was made in order to quantify the maximum safety benefit that could be achieved if safe entry into autorotation following engine failure in a single-engine helicopter was assured. For this all accidents[1] with single engine helicopters that occurred in an EASA member state during 2000-2011 were collected. Analysis of this data determined that the maximum safety benefit that could be expected would be that 20% of all engine failure related accidents with single-engine helicopters, in which an autorotation is possible, could be avoided. The maximum safety benefit attainable therefore equates to an estimated reduction of approximately 22

[1] According to ICAO Annex 13 definition.

accidents during the period of 2000-2011 (2 accidents per year), saving the lives of about 13 people (1 person per year).

The study then attempted to determine the impacts on helicopter design and operation as a result of increasing allowable response times to accommodate the range of pilot response times established from the literature search. This was determined by performing a (parametric) study using a combination of analysis, simulation and engineering judgment. Technologies identified in the literature search have then been incorporated in the helicopter design so as to sufficiently increase the time available to the pilot to successfully enter autorotation following a (complete) power failure.

Several technological solutions that can increase the allowable response time have been investigated (adding an emergency power source, increasing the rotating system inertia and automatic lowering of collective control). From the simulations that have been performed, it is apparent that these solutions are capable of increasing the time available, but they come with a mass and/or cost increase. Increasing the allowable response time to more than 2 seconds is not deemed realistic.

From a strictly safety point of view it is advised to adapt the relevant certification requirements to bring them closer to actual pilot response times. E.g. by going from 1 second for the cruise phase and 0.3 seconds for other flight phases to 2 seconds for all flight phases. However, such an increase in the allowable response time will not assure that all accidents caused by a “late response to start autorotation” will not happen again as this increase is still less than demonstrated actual pilot response times.

Against the background of the safety impact analysis, it is assumed that an increase in time available to 2 seconds for all flight phases will achieve 80% of the maximum safety benefit available. This assumption is based on the fact that on the one hand there remains a shortfall between allowable response time and the demonstrated actual response times, and on the other hand the types of helicopters under investigation are for a large part flown in an active, hands-on way, providing the lower range of actual response times. The maximum achievable safety gain would therefore drop from the prevention of 22 accidents in the time period between 2000 – 2011 to 18 (1.5 accidents per year) and from the prevention of 13 fatalities to 10 (<1 person per year).

Given these results, three main policy options were identified:

- Option 0 – “Do nothing scenario”;
- Option 1 – Mandatory certification of new single-engine helicopter models – Increase the allowable response time for pilot intervention following engine power failure, from 1 second for the cruise phase and 0.3 seconds for other flight phases to 2 seconds for all flight phases; This option is split further to variants 1A and 1B representing the complexity of the technological solutions that can be applied to achieve this target:
  - Option 1A – Increasing rotating system inertia by placing tip weights on rotor blades;
  - Option 1B – Application of auxiliary systems (emergency power supply, automatic lowering of collective control).
- Option 2: - Mandatory certification of new single-engine helicopter models – Increase of the allowable response time from 1 second for the cruise phase and 0.3 seconds for all other flight phases to above 2 seconds for all flight phases;
- Option 3: Additional non-mandatory information provided to manufacturers regarding the safety benefit gains by increased allowable response times.

Option 2: - Mandatory certification – Increase of the allowable response time from 1 second for the cruise phase and 0.3 seconds for all other flight phases to above 2 seconds for all flight phases has been excluded from further analysis as this option is not deemed realistic from a technological point of view.

The regulatory impact assessment indicates that the policy options to impose mandatory requirements to manufacturers to increase the allowable response time following engine power failure to 2 seconds for all flight phases do not show a positive case if the safety impacts are compared with the economic, environmental and social impacts. The option to provide non-mandatory information however does provide a positive case.

It is therefore recommended:

- Not to implement Options 1A/1B in the nearest future;
- To issue a recommendation to the manufacturers of helicopters to increase the allowable response time following engine power failure, to 2 seconds for all flight phases, as suggested by Option 3;
- To continue research in close cooperation with the industry in this area in order to try and materialise the significant safety benefits that are there, while trying to avoid the negative impacts as addressed in this study. EASA could for example open a Research Program to encourage European companies to stay on top of global innovation in this area.

Abbreviations and Definitions

Abbreviations

CBA	Cost Benefit Analysis
CS	Certification Specifications
EASA	European Aviation Safety Agency
EMPRESS	Energy Method for Power Required EStimateS
EUROPA	EUropean ROtorcraft Performance Analysis
MCA	Multi-criteria Analysis
MTOM	Maximum Take-Off Mass
RIA	Regulatory Impact Assessment
RMT	Rule Making Task
SME	Small and Medium size Enterprises
SPEAR	SPEcification Analysis of Rotorcraft
VLR	Very Light Rotorcraft

Definitions

Allowable response time (response time available)	The period between the failure occurring and the pilot having to make an input in order that the rotor speed does not fall below its minimum transient limit.
Actual (pilot) response time	The combination of the decision time plus the reaction time.
Decision time	The time needed by the pilot to recognise and interpret cues and warnings to identify the problem and to decide on the appropriate corrective action.
Reaction time	The time taken by the pilot after the decision on the appropriate corrective action until commencement of the recovery action.

1 Introduction

This Report describes the Regulatory Impact Assessment (RIA) to support future rulemaking on single-engine helicopters with increased pilot intervention times following power failure. It is developed to support EASA in its rulemaking task RMT.0246 (MDM.050). The specific objective is *“the establishment of the case for/against enhancing certification requirements in the area of pilot intervention time following power failure in single-engine helicopters”*.

1.1 Outline of the report

The outline of this report follows as close as possible the Regulatory Impact Assessment template of EASA. Therefore, in chapter 2, the report starts with describing the process followed. In chapter 3, the preliminary issue analysis as specified in the terms of reference is provided, as this forms the background for the study underlying this RIA. Attention is paid to the current regulatory framework, who is affected and what the preliminary safety risks are. In chapter 4, the objective of the study is defined. Before continuing with the identification of the different options, the results of the different tasks which were executed to identify different options are described first. These results also provide a more in-depth analysis of the issue under consideration and of the safety risks involved. In chapter 5, “literature search”, attention is paid to the identification of an optimum or range of pilot response times for single-engine helicopter loss of power events and existing or emerging technologies that could increase the time available to the pilot to successfully enter autorotation following engine failure. In chapter 6, “safety impact”, the maximum safety benefit is quantified that could be achieved if safe entry into autorotation following engine failure in a single-engine helicopter was assured. In chapter 7, analytical helicopter models for use in the analysis and comparison phase of the study are defined together with typical operational (mission) profiles. The analysis and comparison is done by means of a parametric study. The results of this parametric study are described in chapter 8. In chapter 9 then different options are identified, followed by a description of the applied methodology for the RIA including the data requirements (chapter 10), the analysis of the impacts (chapter 11) and the conclusions and preferred option in chapter 12.

2 Process and Consultation

The Regulatory Impact Assessment (RIA) to support future rulemaking on single-engine helicopters with increased pilot intervention times following power failure is based on a study which consisted of the following tasks:

Task 1: Literature search

From previous research and published papers an optimum or range of pilot response times for single-engine helicopter loss of power events is identified (task 1a). The cruise condition (hands-off, passive) and other flight conditions (hands-on, active) are addressed in this identification. Existing or emerging technologies that could increase the time available to the pilot to successfully enter autorotation following engine failure are identified as well (task 1b). The results of the literature search are used as input for the analysis and comparison in task 4.

Task 2 Safety impact

Through analysis of historic accident statistics and accident reports the maximum safety benefit is quantified that could be achieved if safe entry into autorotation following engine failure in a single-engine helicopter was assured. Individual categories of helicopters are addressed separately, and factors which may influence safe entry into autorotation are identified.

Task 3 Models and missions

In this task analytical helicopter models for use in task 4 (Analysis and comparison) have been defined and typical operational (mission) profiles have been identified. To capture the complete range of single-engine helicopters, the following four helicopter types are chosen:

- HeliSport CH-7 Kompress (piston engine, MTOM 450 kg; estimated t/k 0.2s);
- Robinson R44 Raven I (piston engine, MTOM 1089 kg; estimated t/k 1.35s);
- Bell 206B-3 JetRanger III (turbine engine, MTOM 1452 kg; estimated t/k 1.4s);
- Aerospatiale AS350B2 Ecureuil (turbine engine, MTOM 2250 kg; estimated t/k 1.3s).

With this choice an adequate distribution of MTOMs is realised, and both piston driven and turbine driven single-engine helicopter models are included. For each of these 4 helicopter types sufficiently detailed input data files have been prepared for the various simulation tools used (EMPRESS, EUROPA and SPEAR).

Task 4 Analysis and comparison

A parametric study is performed using a combination of analysis, simulation and engineering judgement to determine the impacts on rotorcraft design and operation throughout the range of pilot response times from what is currently applied in certification to the (optimum) values determined in task 1a. Technologies identified in Task 1b will be incorporated in the helicopter design so as to sufficiently increase the time available to the pilot to successfully enter autorotation following engine failure. Impacts primarily focus on safety, performance and economic considerations.

Task 5 RIA

With completion of the previous 4 tasks, the analysis-part of the study and with that a large part of the RIA is complete. In task 5, possible regulatory options and related impacts are drafted.

Task 6 Recommendations

Any changes to CS-VLR/27/29.143 and associated advisory material are recommended, providing a balance between enhanced safety and impact on stakeholders.

For this study and corresponding RIA, no preliminary RIA was available. Mr. David Haddon represented the rulemaking group on behalf of EASA.

3 Issue Analysis and Risk Assessment

3.1 What is the preliminary analysis of the issue, the current regulatory framework and the safety risks?

The entry into autorotative flight following loss of power in a single-engine helicopter is a time-critical event. It requires immediate recognition and response by the pilot to avoid the rotor speed decaying to a point where the rotor enters an unrecoverable stalled condition. Safe entry into autorotative flight is therefore dependent on the allowable response time (response time available) matching or exceeding the actual (pilot) response time.

The allowable response time is primarily a function of rotor design and the amount of inertia built-in to the rotor system. Existing or emerging technologies, for instance automatic pitch reduction or electrical/mechanic energy storage systems, could enhance the allowable response time. Modern helicopter design trends, however, are for low inertia rotor systems with high disc loadings aimed at reducing cost and weight and maximising payload.

The relevant design requirement that dictates the rotor design to enable entry into autorotation have not substantially changed since prior to JAA in 1993 (or FAA prior to 1963). CS VLR.143(d)[2] states that:

> "The rotorcraft, after complete engine failure, must be controllable over the range of speeds and altitudes for which certification is requested when such power failure occurs with maximum continuous power and critical weight. No corrective action time delay for any condition following power failure may be less than-
> (1) For the cruise condition, one second, or normal pilot reaction time (whichever is greater); and
> (2) For any other condition, normal pilot reaction time."

Similar requirements are defined for the larger rotorcraft (CS 27.143(e) and CS 29.143(e)). Up to now normal certification practice has been to assume a 1 second time delay in cruise, with 0.3 seconds typically used for other flight phases.

Earlier studies, being referred to in the Terms of Reference of this RIA, indicate that failure to enter autorotation has been a causal factor in many helicopter accidents, especially in relation to helicopters with low inertia rotor systems. This has brought into question whether the existing rules and certification practices are truly representative of normal pilot response in such situations, or even whether it is still appropriate to consider only normal pilot response. In this RIA, the focus will be on answering these questions. Therefore, in chapter 5 up to and including 8, first of all a more detailed description and analysis of the issue and of its safety impact – based on European accident data – is provided. Next, in chapters 9 up to and including 11, different policy options are identified and impacts of these options assessed.

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[2] Decision N° 2008/011/R of the Executive Director of the European Aviation Safety Agency of 10 November 2008 amending Decision No 2003/17/RM of the Executive Director of the Agency of 14 November 2003 on Certification Specifications, Including Airworthiness Code and Acceptable Means of Compliance, for very light rotorcraft " CS-VLR" http://easa.europa.eu/agency-measures/docs/certification-specifications/CS-VLR/MERGED_v2.pdf.

3.2 Who is affected?

The occupants of (light) single-engine helicopters, pilots and passengers, are primarily affected. They bear the safety risk. When it comes to possible changes in the current certification specifications, helicopter manufacturers and their clients (private operators, commercial operators using single engine helicopters including helicopter flight schools) are affected as well. Types of helicopters affected are single engine helicopters, both piston and turbine engine driven. In the 27 EU Member States together with Switzerland, Norway, Iceland and Lichtenstein a total of 2975 single-engine piston helicopters and 2239 single-engine turbine helicopters are operated (2010).

4 Objectives

The overall objectives of the Agency are defined in Article 2 of Regulation (EC) No 216/2008 (the Basic Regulation). This proposal will contribute to the overall objectives by addressing the issue outlined in chapter 3. The specific objective for this proposal is therefore: *"the establishment of the case for/against enhancing certification requirements in the area of pilot intervention time following power failure in single-engine helicopters"*.

5 Literature Search

5.1 Introduction

The first task of the study supporting this RIA deals with the execution of a literature search. The objectives of the literature search are:

1. Identify, from previous research and published papers, an optimum or range of pilot response times for single-engine helicopter loss of power events. The cruise condition (hands-off, passive) and other flight conditions (Hands-on, active) should be addressed;
2. Identify, from previous research and published papers, existing or emerging technologies that could increase the response time available to the pilot to successfully enter autorotation following engine failure.

To meet these objectives research and published papers from various sources are used, e.g. from the American Helicopter Society (AHS) and the European Rotorcraft Forum (ERF), research work undertaken by the UK-CAA, the information collection of the NLR library as well as external libraries to which NLR has access including patents. Information from the European Helicopter Safety Team (EHEST) has also been consulted.

The pilot response times and existing or emerging technologies are treated separately in the following paragraphs. The results of this search are listed in paragraph 5.4 *conclusions* and will be used as input in the further analysis and comparisons performed in this RIA.

5.2 Pilot response time

The objective of this section is to identify an optimum or range of pilot response times for single-engine helicopter loss of power events, thereby addressing cruise condition and other flight conditions.

A division is made between <u>allowable response time</u> and the <u>actual (pilot) response time</u>. The allowable response time, or response time available is according to [ref. 1] considered to be “the period between the failure occurring and the pilot *having to make an input* in order that the rotor speed does not fall below its minimum transient limit”. The actual (pilot) response time is in accordance with [ref. 2] considered to be the combination of the decision time plus the reaction time. The decision time is the time needed by the pilot to recognise and interpret cues and warnings to identify the problem and to decide on the appropriate corrective action. This time is dependent on the pilot’s attentiveness, the perceived strength of the cue and the training and experience of the pilot [ref. 3]. The reaction time is the time taken by the pilot after the decision on the appropriate corrective action *until commencement* of the recovery action. It should be noted that in both definitions, the time taken to execute the recovery action (lowering the collective) is not taken into account.

In this RIA the terms allowable response time and actual (pilot) response time are used because their definitions are in compliance with the terminology currently being used in European (and corresponding FAA) regulations. In CS-VLR 143(d), CS 27.143(e) and CS 29.143(e) reference is being made to <u>corrective action time delay</u>, what is equivalent to the period between failure onset and the *first movement* of the appropriate control [ref. 15], in other words equivalent to what in this RIA is called actual (pilot) response time.

5.2.1 *Allowable response time (response time available)*

To know what the dependencies of the allowable response time are it is of importance to elaborate more on the changes needed to enter an autorotative state from normal flight. This is described in [ref. 4]: “A power failure immediately results in a dissipation of rotor RPM while the airflow through the rotor system is changing from the downward flow present in powered flight to the upward flow occurring during autorotative flight. Rotor RPM decreases at a rapid rate if immediate action is not taken to decrease the pitch angle of the rotor blades. This decrease continues (even after the upward flow of air has stabilized) to the point that controlled flight may not even be possible depending upon the pitch angle at the time of power failure. After the pitch angle is lessened and the upward flow of air stabilizes, the rate of descent will not stabilize at its minimum until the rotor RPM builds back up to its maximum for that particular pitch angle setting and helicopter gross weight.

The successful entry from powered flight to autorotation consists of the following transitions:

1. Changing of airflow from a downward flow to an upward flow;
2. Lowering collective pitch to maintain a tolerable angle of attack which would otherwise increase because of the descent;
3. Regaining rotor RPM and stabilizing rate of descent.

The magnitude of these transitions depends on the mode of flight. If power failure occurs in a descent, there is very little transition. A vertical climb requires large transitions because of the helicopter's upward inertia and the high rotor blade pitch angle required for the vertical climb.”

The allowable response time can be described as in [ref. 5], being “the length of time the controls can remain fixed during a transition is equal to the time required for divergence of one or more characteristics as follows:

1. Minimum tolerable rotor speed;
2. Attitude or angular rate or combination of attitude and angular rate which does not afford 100% probability for a successful recovery;
3. Conditions that do not allow the pilot to move the flight controls as rapidly as required without producing acceleration or blade flapping exceeding structural limits.”

As these matters are highly dependent on the rotor design and the amount of inertia built-in to the rotor system the allowable response time differs from type to type.

Early testing on a UH-1C helicopter by the US army [ref. 6] showed that the aircraft response, pilot cues, and allowable delay time varied significantly with the nature of the power reduction. In hover rapid directional changes occur requiring a fast response in the order of 0.3 second[3]. At low airspeeds the aircraft response was considerably less and a response could be safely delayed to 3 seconds. At intermediate airspeeds the aircraft response was even less and a response could be safely delayed to more than 5 seconds. At high airspeed the maximum allowable delay time was found to be 4.5 seconds. Similar tests for Mi-8 and Mi-17 helicopters as reported in [ref. 8] showed “available times” of 2.5 to 3.5 seconds and states that the “time available to the pilot to initiate actions in demand under emergency conditions is affected by: flight altitude, helicopter’s take-off weight, air density, level of pilot’s skill, and the way of warning against failure/emergency.” For the Chinook flying at average 115 knots and Sikorsky S-61 helicopter flying at average 85 knots it was found in [ref. 9] that it took respectively 3.8 and 10 seconds before the rotor RPM dropped below an unrecoverable level.

[3] An accident report from 1948 [7] states that during a hover flight an engine failure occurred and within about 0.5 seconds the rotor RPM dropped below the minimum allowable value.

The results on testing on the UH-1C helicopter would meet the normal certification practice to assume a 1 second time delay in cruise, with 0.3 seconds typically used for other flight phases (for instance hover). It is interesting to note that for instance the United Kingdom military design and airworthiness requirements state that, for *all flight conditions*, "the aim shall be to allow two seconds to elapse from the occurrence of an engine failure to the point where collective pitch is sharply reduced to establish autorotation, this being an allowance to provide reaction time for an average pilot to identify under favourable conditions that a failure has occurred and then to respond correctly by reducing collective pitch to the minimum".

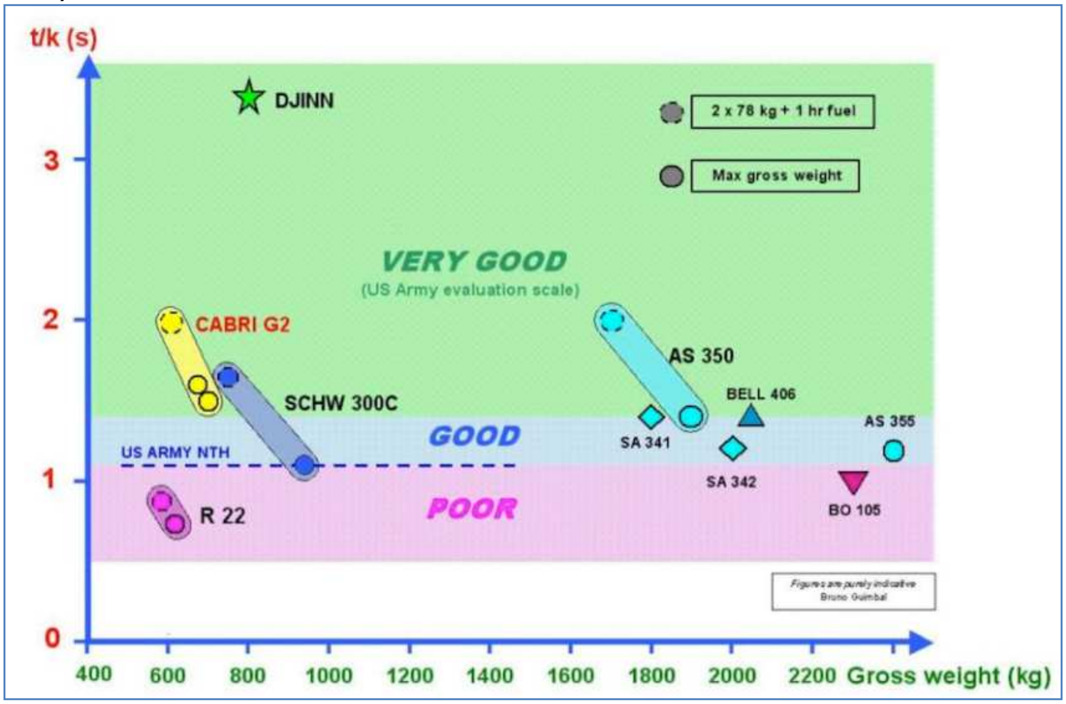
During the 70-ies and 80-ies Bell and Sikorsky in their design process used autorotation indices [ref. 37], with slightly different definitions:

- Bell's Autorotation Index: $AI = (I_R * \Omega^2) / (2 * M)$;
- Sikorsky's Autorotative Flare Index: $AI = (I_R * \Omega^2) / (2 * M * DL)$.

in which I_R is the polar moment of inertia, Ω the rotor rotational speed, M the helicopter gross mass and DL the rotor disk loading. Note that the absolute values of these indices are of no significance by themselves (much unlike the t/k values, for which see next section), but their relative values provide a means of comparing the autorotative performance of a new helicopter design against another helicopter with already acceptable autorotative characteristics. The current usage of these indices is unclear.

More recently the parameter t/k came into use, which was also mentioned in the early version of the JAR-VLR [ref. 38] (the forerunner of the CS-VLR). This parameter was adopted at Bell as a useful criterion to appreciate the main rotor rotational decay occurring in case of a sudden engine failure. The parameter t/k is [ref. 10] "the criterion used worldwide to qualify the helicopter autorotation ability. It is calculated by dividing the useable rotor inertia (to rotor stall) by the hovering power (giving the number of seconds of stored energy). The value of t/k gives an idea of the time to land (in a hover) or time to enter autorotation (in cruise) after an engine failure at full power". Figure 5.15.1 contains the t/k parameter for some small single-engine helicopters given in standard atmosphere at sea level. For the NTH (New Training Helicopter) the US Army requested a minimum value for t/k of 1.0. In 1993 the contract was won by the Bell TH-67 Creek, a derivative of the Bell 206B-3.

Figure 5.1 t/k criterion for various single engine helicopters [10] (the Bell 406 being the military OH-58D model)



5.2.2 *Actual response time*

In the literature several types of information sources were found in which actual (pilot) response times were included. These can be divided in research or simulation projects that used assumed response times and those that included actual measured response times from piloted simulations.

Assumed times

In various research and simulation projects *assumed pilot response times* varied from 0.5 to multiple seconds [ref. 1 and ref. 11 to 13]. In [ref. 5] it is stated that "studies indicate that when all factors including initial aircraft responses (motion, aural warning, etc.) are considered, the minimum probable pilot reaction time to a sudden unexpected power loss is about one second". According to [ref. 14], pilot reaction time can be assumed to be 1.6 seconds when based on the automotive industry's Detect-Decide-React model. Note that both ref. 5 and ref. 14 use (minimum probable) pilot reaction time, not pilot response time.

Results from piloted simulations

Various piloted simulations have been performed to determine the actual (pilot) response time in case of an engine failure. All earlier performed simulations found where performed on twin-engine turbine helicopters (Chinook, S-61, Super Puma, Mi-8 and Mi-17) confronted with a double engine-failure. No piloted simulations performed on single-engine helicopters were found.

Piloted simulations performed by the Royal Air Force showed in [ref. 9] the following values for detection time, response time and total reaction time (Table 5.1):

Table 5.1 Summary of detection, response and total reaction time data [ref. 9]

Summary of detection time data (s)				
Aircraft type	Min	Max	Mean	90th percentile
Chinook	0.37	3.62	1.13	2.01
S61N	0.66	2.53	1.65	2.52
Summary of response time data (s)				
Chinook	0.54	2.93	1.15	2.17
S61N	1.21	7.37	2.58	7.02
Summary of total reaction time data (s)				
Chinook	1.00	4.72	2.28	4.15
S61N	2.20	8.58	4.23	8.29

In this study, the detection time was defined as the period between failure onset and the *first downward movement* of the collective. Response time was defined as the time from the first movement of the collective to the collective reaching its minimum position. Total reaction time was defined as the detection time plus the response time. As in this RIA the actual (pilot) response time is defined as the decision time (time needed by the pilot to recognise and interpret cues and warnings to identify the problem and to decide on the appropriate corrective action) plus the reaction time (time taken by the pilot after the decision on the appropriate corrective action until *commencement* of the recovery action), the detection time data should be read as actual (pilot) response times.

Trials as discussed in [ref. 8] showed "required times", defined as the minimum time that – at the moment an in-flight emergency occurs – gives the operator a capability to safety terminate the control process. It consists of time of non-responding and time of responding (time of performing all instruction- (manual-) recommended actions to prevent the critical parameter from exceeding the admissible value). Results of examining flight parameters recorded with SARPP-12 flight data recorders indicated – in the case two engines fail in the air – required times of 7.64 seconds for the Mi-8 and 3.50 seconds for the Mi-17. Results of analysing flight tests proved that the required time depends first and foremost on the level of both the pilot's skill and the helicopter weight. The results of computer simulation supported the conclusion that the greater the helicopter weight, the longer the required time. The results of flight-testing the required time indicate that the required time for the Mi-8 range between 1,49 to 10.09 seconds and for the Mi-17 helicopter between 3.89 to 4.78 seconds (Table 5.2):

Table 5.2 Results of flight-testing the required time (data in [ref. 8], calculation of mean and 90th percentile by NLR)

Kind of specific case	**Type of helicopter**	**Required times**			
		Min	**Max**	**Mean**	**90th percentile**
Shut-down of two engines	Mi-8	1.49	10.09	6,45	9,74
	Mi-17	3,89	4,78	4,32	4,73

In this study, the required time is compared to the available time, being the time that remains at the operator's disposal while he's performing his duties under some specific conditions. As long as the available time is longer than the required time, safe termination of the control process is provided. Hence, also in this study longer periods of time are used (the 'required time' and 'available time') than the actual (pilot) response time and allowable response time used in this RIA.

Finally, simulator trials performed for the CAA-UK indicated in [ref. 15] the following:

Table 5.3 Summary of detection, response and total reaction time data [ref. 15]

Summary of detection time data (s)				
Aircraft type	Min	Max	Mean	90th percentile
Chinook	0.37	3.62	1.07	2.07
S61N	0.66	3.09	1.67	2.53
Super Puma (undistracted)	1.02	3.14	2.22	2.95
Summary of response time data (s)				
Chinook	0.54	2.93	1.24	2.28
S61N	0.93	3.00	1.61	3.85
Super Puma undistracted)	1.11	2.44	1.82	1.95
Summary of total reaction time data (s)				
Chinook	1.00	4.72	2.30	4.42
S61N	1.86	6.18	3.33	5.72
Super Puma (undistracted)	2.74	5.08	4.13	4.73

It should be noted that a large part of this study is identical to the study described in [ref. 8], with only small differences in some of the data reported for the Chinook and S61N. Most probably this is the result of excluding some data points from the analysis. The Super Puma was added to the experiment. The definitions for detection time, response time and total reaction time are identical to [ref. 8]. For the actual pilot response time used in this RIA, reference should be made to the detection time again.

In the studies [ref. 8, 9 and 15] no information was provided related to active/attentive/passive and hands-on/off. In [ref. 15] it is stated that the objective measurement of the states 'active', 'attentive' and 'passive' is problematic and that only the distinction between 'hands on' and 'hands off' seems viable. Assuming the pilot is 'hands on', [ref. 15] recommends to deviate between failures immediately detectable because the deviating variable is within the pilot's primary focus of attention (e.g. AFCS runaways in the hover), and failures less immediately obvious and which may become evident through secondary effects (e.g. total power failure and tail rotor drive failure). In case of latter, based on the data provided above, [ref. 15] recommends that up to 3 seconds detection time should be allowed assuming that a failure to recover rate of 10% is acceptable, and that total reaction times of about 6 seconds should be expected assuming no distraction.

Next question is whether the results of piloted simulations discussed above, which were all performed on twin-engine helicopters, are applicable to single-engine helicopters as well. Given the fact that twin-engine helicopters are more complex, it could be that the actual (pilot) response times for single-engine helicopters are shorter. On the other hand, [ref. 15] for instance explicitly assumes 'hands on' flight conditions, which would also be the relevant case for single-engine helicopters. Moreover, the twin-engine helicopters being flown in the simulations are normally flown with a flight crew of two, professionally trained, pilots. Single-engine helicopters are normally flown by one pilot who is not always professionally trained, as these helicopters are frequently being used for leisure flights and ab-initio flight training. Therefore, it could also be that the actual (pilot) response times for single-engine helicopters are indeed comparable or even longer. It is recommended to continue research in this field and use single-engine helicopters in piloted simulations.

The fact that [ref. 15] recommends using the 90th percentile values instead of mean values is fully supported. Given the possible fatal consequences of actual (pilot) response times exceeding the allowable response times, it is necessary to assure that in case actual (pilot) response times are longer than average, without being abnormal, an autorotative flight can still be entered safely.

5.3 Technologies

The objective of this section is to identify existing or emerging technologies that could increase the time available to the pilot to successfully enter autorotation following engine failure.

When looking at technologies with the potential to increase the time available to the pilot to successfully enter autorotation following engine failure a subdivision is made between technologies that increase the allowable response time and those that decrease the (pilot) response time.

5.3.1 Increasing allowable response time

When looking at the technologies with the potential to increase the allowable response time two types of technologies can be identified. The first type includes those technologies that actively add power, for reasons of clarity these technologies are hereunder referred to as ‘active’ systems. The second type is referred to as ‘passive’ systems and uses the concept of storing energy in the main rotor (by increasing the blade inertia).

Active systems

A means to increase the allowable response time in case of an engine failure is by actively adding power. Although there are more concepts, in the literature three concepts are commonly mentioned, being tip jets, a flywheel and auxiliary turbines as [ref. 17] states “the autorotative characteristics of a single-engine scout helicopter can be substantially improved with the combination of a MIL-STD-1290 type landing gear and either a Tip Jet, Flywheel or Auxiliary Turbine system”.

The tip jet concept uses jet thrusters installed in the tip of each main rotor blade and provide emergency power to the main rotor for a set period of time (in the order of 30 seconds). A system described in [ref. 17] provides 0.34 pounds of thrust per blade and weighs around 44 pounds (including fuel system on the hub).

A flywheel is connected to the main rotor transmission and automatically ‘powers’ the main rotor when its RPM drops below a certain level. In [ref. 17] it was found that a 40 pound flywheel sufficed[4], for a single engine scout helicopter. On the one hand it should be noted that engine start requirements will be increased due to the inertia of the flywheel but on the other hand this system is considered to be simple in design and requires no pilot action.

Auxiliary turbines have also been explored. In this concept an additional turbine is used that drives into the main gearbox to provide power to the main and tail rotor in the event of an engine failure. For this concept the detection of loss of the primary power source and automatic start of the auxiliary turbine is needed as the auxiliary turbine is during normal operations isolated from the main drive system. In [ref. 17] a system is described that uses a gas generator/turbine that provides 30 seconds of emergency power. More recently, Eurocopter tested a hybrid concept in a helicopter

4 The article describes the case that with this system installed (estimated weight of the system is 40 lbs) and a forward speed of 20 knots, there is no minimum height required anymore for a safe autorotation.

combining the traditional combustion engine with an electric motor as auxiliary turbine [ref. 18]. A clear advantage of an electric motor over an auxiliary turbine is its quick start possibility.

Passive systems

Another way of increasing the allowable response time is by adding more energy into the rotor. Two possible ways of doing this have been found in the literature.

The first solution is to increase the rotor blade inertia by adding tip weights as described in various papers and reports [e.g. ref. 16 and 17]. In [ref. 19] the pros and cons of both high and low inertia systems are listed, being:

- High inertia:
  - Positives:
    - Smooth changes in rotor RPM as speed changes are resisted;
    - More kinetic energy stored in the rotor system, which helps in making flight manoeuvres that require a lot of energy, for example the execution of a flare while in autorotation.
  - Negatives:
    - It requires more engine power to accelerate to the desired rotor RPM. This is also an important reason why high inertia systems are not found in light helicopters with their less powerful combustion engines[5];
    - Due to the higher forces involved, the rotor head must be stronger and heavier.
- Low inertia:
  - Positives:
    - Easier to recover from low rotor RPM by applying engine power;
    - Tilting the rotor disc is easier (less resistance by inertia), which makes the helicopter more manoeuvrable;
    - Rotor head construction doesn't have to be as strong as in the high inertia counterpart, which makes a lighter build possible.
  - Negatives:
    - Less margin of error when it comes to maintaining rotor RPM;
    - Less stored kinetic energy which is needed in critical manoeuvres, for example, when executing a flare during autorotation.

Another possible solution was found in [ref. 20] which describes the principle of increasing rotor RPM to give a slight increase in performance and a more comfortable rotor speed margin in the event of a sudden engine failure. In this case an EC145 helicopter is equipped with an option to increase the rotor RPM to approximately 103.5%. This can be selected in the helicopter's control system and is intended for Category A operations, so during take-off and landing. Typical disadvantages are:

- An increase in noise level due to the higher tip speed;
- An increase in power required; the drag of the rotor blades increases almost linear with the rotor speed; the energy stored in the rotor system increases with the square of the rotor speed; so, in total, there is a benefit in case of a power failure;
- A negative impact on flight performance due to the increase in power required (less power margin).

5 Author's note: a doubling of the rotor inertia at constant engine torque will double the time to spin up the rotor.

5.3.2 *Decreasing actual response time*

Actual response time could be decreased by systems that warn the pilot or that provide improved cues in case of an engine failure, as well as by active systems that detect low rotor speed and automatically perform the corrective action.

In case of an engine failure the pilot is presented with various cues through the natural response of the helicopter possibly aided by additional warning systems. These can be divided in visual, audio and kinaesthetic (tactile/motion) cues.

Visual cues are provided by instrument indications. As the timeliness in which these are noted are highly dependent on the attentiveness of the pilot, visual warning systems, such as a Central Warning Panel, could be added. This is typically done in the larger and twin engine helicopters. If such central warning is not available the response time is larger. The principle of an autorotation flight director to provide the pilot with visual control cues during the autorotation manoeuvre is described in [ref. 21]. Although considered favourably during the manoeuvre no indications were found that this would reduce the pilot response time.

Powerful cues to indicate an engine failure are audio cues generated by a mechanical failure or change in rotor, transmission or engine noise. In addition to these 'natural' cues audio warnings are generated, typically in the form of a horn warning for low rotor RPM. Modulated tones which are a function of rotor RPM and rate of change of rotor RPM were found in [ref. 1] to be beneficial in maintaining rotor rpm during the manoeuvre. There were no indications that this warning reduces the response time.

The natural kinaesthetic cue after an engine failure is a yaw motion. An additional tactile cue in the form of a collective stick shaker was introduced in [ref. 1]. Initial evaluation of the concept showed poor results and the concept was not further developed.

One of the other possibilities mentioned in [ref. 1] is to provide an advance warning through improved state monitoring by identifying an engine failure at its root instead of its symptoms (such as low RPM). This is a complex system and a simpler derivative of this is the phase advance filter. This filter determines the rate of change of rotor RPM and assesses if the limit is expected to be exceeded. Offline simulations with this filter performed in [ref. 1] indicated a possible reduction in response time of 0.5 to 1.4 seconds.

An active system that detects low rotor speed and automatically performs the corrective action was found in Eurocopter's patent [ref. 22]. This patent describes "a device enabling the collective pitch of the blades of the main rotor of a single-engined rotorcraft to be reduced automatically in the event of an engine failure". In [ref. 1] a similar strategy, named Automatic Collective Stick Lowering Strategy, is mentioned and includes the remark that "integrity issues may make this system impractical/uneconomic for inclusion in existing helicopters, and it may only be commercially acceptable for new, high specification types".

5.4 Conclusions

The first conclusion which can be drawn from the discussion of the different studies provided above is that the usage of different terms and definitions both in research studies and regulatory requirements is not very helpful when there is a need to discuss the validity of the latter. It is therefore recommended to discuss, with the relevant stakeholders, the usage of a common set of terms and definitions, which should be – as already recommend by the UK CAA in 1999 [ref. 15] – operationally defined.

The allowable response time depends on the type of aircraft and its characteristics (weight, rotor inertia, etc.) but even more on the phase of flight. In hover the allowable response time is at its lowest, around 0.3 seconds, and in forward flight is increased to in general 3 to 5 seconds and for some twin-engine types even to 10 seconds.

The actual response times found were all related to twin-engine helicopters. For instance for the Chinook, the 90th percentile of the detection time, which is equivalent to actual (pilot) response time, is 2.07 seconds, for the S61N 2.53 seconds, and for the Super Puma 2.95 seconds [ref. 15]. It is recommended to use the 90th percentile instead of the average. Given the possible fatal consequences of actual (pilot) response times exceeding the allowable response times, it is necessary to assure that in case actual (pilot) response times are longer than average, without being abnormal, an autorotative flight can still be entered safely.

As there were no piloted simulations found which were performed on single-engine helicopters, it is hard to conclude – based on the results of the literature search – whether or not the current European regulations (CS VLR/27/29/.143) are sufficient for this type of helicopters. There are arguments based on which one could conclude that the actual response times for single-engine helicopters are shorter than the ones found for twin-engine helicopters, for instance complexity of the helicopter type. However, there are also arguments based on which one could conclude that the actual response times for single-engine helicopters are comparable or even longer, for instance single-pilot operation, type of flights executed (leisure flights, ab initio flight training), and the training & experience level of the pilot. Even *if* it is assumed that the actual (pilot) response times are shorter than the ones found for twin-engine helicopters, then still it appears that the currently applied normal practice to assume a 1 second time delay for the cruise phase and 0.3 seconds for other flight phases in certification may not be sufficient. This view is for instance supported by the United Kingdom military design and airworthiness requirements. These requirements state that, for *all flight conditions*, "the aim shall be to allow *two seconds* to elapse from the occurrence of an engine failure to the point where collective pitch is sharply reduced to establish autorotation, this being an allowance to provide reaction time for an average pilot to identify under favourable conditions that a failure has occurred and then to respond correctly by reducing collective pitch to the minimum".[6] This will be further substantiated by the remainder of this RIA. However, it is also recommended to continue research in this field with a focus on single-engine helicopters.

The allowable response time can be increased by active systems such as tip jets, a flywheel, an auxiliary turbine or an electric motor. Also passive systems in the form of added tip weights or increased rotor speed can increase the allowable response time. The actual response time can be decreased by visual or other warning cues provided in advance as well as active systems that detect low rotor speed and automatically perform the corrective action.

[6] Def Stan 00-970 Volume 2 Chapter 907, paragraph 6.2.

6 Safety Impact Analysis

This chapter deals with the quantification of the maximum safety benefit that could be achieved if safe entry into autorotation following engine failure in a single-engine helicopter was assured. In paragraph 6.1 the approach is discussed, in paragraph 6.2 the results are given.

6.1 Approach

For the quantification an analysis of historical accidents with single-engine helicopters was conducted. Accidents[7] with single-engine helicopters were collected that occurred in an EASA member state during 2000-2011. The accidents were obtained from the NLR-ATSI Air safety database supplemented with data from the EASA safety database. All information in the database was based on official investigations conducted by Accident Investigation Boards of the different EASA member states as much as possible. In a few cases supplemental information was obtained from insurance companies.

The final data sample encompassed a total of 886 accidents with single-engine helicopters of which 151 (17%) were related to an engine failure (including significant power loss). These engine failures or power losses were caused by mechanical failures, fuel exhaustion or fuel starvation. The data sample includes both piston as well as turbine engine helicopters. Excluded were occurrences related to military operations and sabotage.

In all cases, a successful emergency landing depends on the helicopter's height and velocity at the commencement of autorotation. The so-called height-velocity diagram of a helicopter shows those combinations of airspeed and height above the ground where either a fully developed autorotation can be entered or a safe landing carried out after a single-engine helicopter suffers an engine power loss. For each accident considered in the data sample it was determined if an autorotation and safe landing was possible based on the airspeed and height at the time of the engine failure and the height-velocity diagram[8] of the involved helicopter. If an autorotation was deemed possible the reasons for the emergency landing not being successful were determined for each case in the data sample. Several reasons were considered:

- Incorrect autorotation technique applied (e.g. pilot deviated from an initially successful autorotation to an uncontrolled descent);
- Improper landing flare[9];
- Hostile landing environment (an environment in which the landing site is such that there is a very high likelihood of injuries/fatalities and/or damage to the helicopter);
- Late response to start the autorotation;
- Unknown.

In only a few cases multiple factors were identified. However, for this study only the most dominant factor was coded.

7 According to ICAO Annex 13 definition.

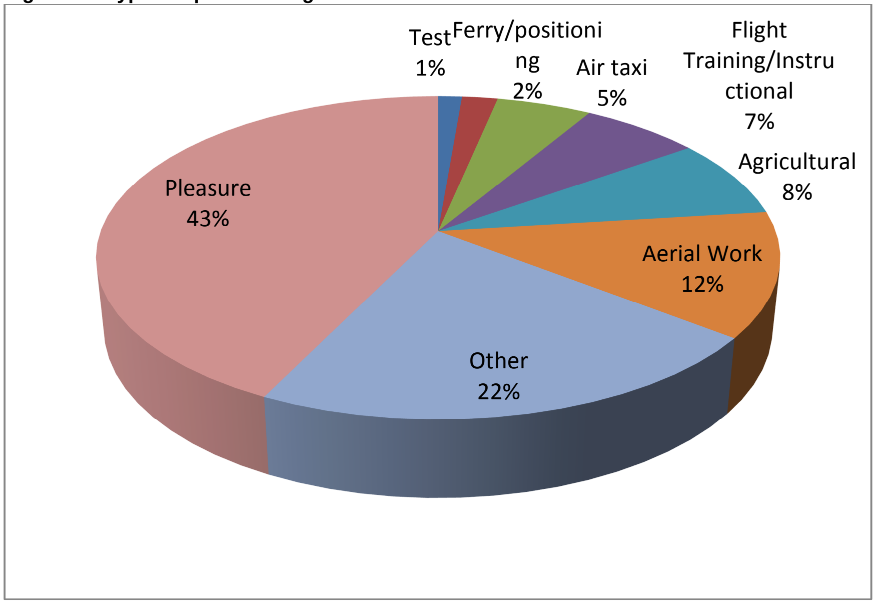
8 These height-velocity diagrams were obtained from approved flight/operating manuals of the helicopter involved.

9 The "proper" landing flare technique can be influenced by gross weight, density altitude, wind, and airspeed of the helicopter.

6.2 Results

Figure 6.1 shows the distribution of the operation type of the 151 accidents that are related to an engine failure. The vast majority of the accidents occurred with so-called pleasure flights conducted by general aviation helicopter pilots. To some extend this share is reflected by the overall number of pleasure flights conducted with single-engine helicopters. A similar distribution was also found in the overall accident data sample of single-engine helicopters.

Figure 6.1 Type of operation engine failure occurrences



Of the 151 accidents, 69% involved piston engine helicopters and 31% turbine engine helicopters. NLR maintains a large database with information on the utilisation of aircraft and helicopters. From this database it was determined that the share of single-engine piston helicopters in the total number of flight hours was around 35% for the period 2000-2011 in EASA member states. This means that the probability of an accident related to an engine failure with a single-engine piston helicopter is four times higher than with a single-engine turbine helicopter[10]. It is often argued that modern piston engines are now far more reliable and that it can be expected to achieve similar reliability to turbine engines[11]. Despite this improvement in piston engine reliability the present data indicates a lower probability for a successful landing after an engine failure with a piston engine helicopter than with a single-engine turbine helicopter. Other studies tend to confirm these findings[12].

Table 6.1 provides an overview of the basic results of the coded 151 accidents of which 14 accidents were fatal. Of the 151 accidents there were 39 (26%) for which the height and speed of the helicopter at start of the engine failure were such that a successful autorotation was considered unlikely. For piston engine helicopters there were twice as many of these cases. No good explanation could be found for this difference between piston and turbine helicopters. In 99 accidents (66%) it was determined that a successful autorotation was possible. For 13 accidents (8%) it was not possible to determine if a successful autorotation was possible or not. Of these 112 accidents (99 + 13), 9 accidents were fatal (1 during the departure phase of the flight, 5 during the

[10] =(69/35)/(31/65)=4.1.

[11] Furthermore new piston helicopters have a much lower weight and are aerodynamically improved so that piston engines can run at lower RPMs. This de-rating of the engine also improves engine reliability.

[12] See e.g. Fox, R. G., Measuring Risk in Single- and Twin-Engine Helicopters, AHS 2nd Asian Vertiflite Seminar, Singapore, February 24, 1992. And Fox, R.G., The History of Helicopter Safety", Bell helicopters, 2005.

en-route phase of the flight, 1 during descent, 1 during the approach and 1 was related to aerial work – not further specified).

Several reasons for an unsuccessful emergency landing after an engine failure were coded. For the present study the late response of the pilot to start the autorotation is the most interesting factor. The analysed data showed that this is not the most frequent reason for an unsuccessful emergency landing (see Table 6.1 6.1). A hostile landing environment and improper landing flare are more dominant factors. Of all accidents with ***known reasons*** for an unsuccessful emergency landing, 30 (46%) were related to a hostile landing environment, 17 (26%) to an improper landing flare, 13 (20%) to a late response of the pilot to start the autorotation (with 4 accidents fatal), and 5 (8%) to an incorrect autorotation technique. It can be assumed that those accidents, for which the reason for the unsuccessful emergency landing could not be determined, have a similar frequency distribution of factors as for those accidents with known reasons.

With this assumption the maximum safety impact related to a late response of the pilot to start the autorotation would be that 20% of all engine failure related accidents with single engine helicopters, in which an autorotation is possible, could be avoided. The average probability of a fatal accident after a late response to start autorotation with a single-engine helicopter is estimated to be around 30% using the data sample (as mentioned, 4 out of 13 accidents were fatal), with an average number of fatalities of 2. As shown earlier there were 99 accidents for which it was determined that a successful autorotation was possible during the period 2000-2011. Including the estimated share of unknowns for which a successful autorotation could be possible (13*99/138=9) the total becomes 108 accidents. The maximum safety impact is that approximately 22 accidents (20% * 108 accidents) can be avoided during the period of 2000-2011 (2 accidents per year), saving the lives of about 13 people (1 person per year). From the available data it is not possible to account for the changing fleet.

Table 6.1 Overview of coding of single-engine helicopter engine related accidents

Propulsion type	Autorotation possible	Reason for unsuccessful emergency landing	Count
Piston	Unlikely	n/a	26
Piston	Possible	Hostile environment	22
Piston	Possible	Improper landing flare	12
Piston	Possible	Incorrect autorotation technique	3
Piston	Possible	Late response to start autorotation	9
Piston	Possible	Unknown	26
Piston	Unknown	n/a	9
Turbine	Unlikely	n/a	13
Turbine	Possible	Hostile environment	8
Turbine	Possible	Improper landing flare	5
Turbine	Possible	Incorrect autorotation technique	2
Turbine	Possible	Late response to start autorotation	4
Turbine	Possible	Unknown	8
Turbine	Unknown	n/a	4

7 Models and Missions

In this chapter analytical helicopter models for use in the analysis and comparison phase of the study will be defined and typical operational (mission) profiles identified.

7.1 Selection of helicopter types

During the project's kick-off meeting the suggestion was made that the selected helicopter models should represent the Guimbal Cabri G2, the Robinson R22, and the Eurocopter AS350 or McDonnell-Douglas Helicopter MD600 helicopters. During the initial phase of this task NLR has carried out a market study on single engine helicopters with a Maximum Take-Off Mass (MTOM) of up to 3175 kg (being the upper boundary for CS-27 rotorcraft). The results are summarized in Table 7.1.

Table 7.1 Various single engine helicopter types below 3175 kg MTOM

Helicopter type	Maximum Take-Off Mass (kg)	Engine type (P = Piston / T = Turbine)	Main rotor blade number	Disk loading (kg/m2)
HeliSport CH-7 Kompress	450	P	2	14.57
Robinson 22	621	P	2	13.44
Rotorway A600	680	P	2	14.99
Guimbal Cabri G2	700	P	3	17.19
Schweizer 300	930	P	3	17.70
Enstrom F-28	975	P	3	13.05
Robinson 44	1090	P	2	13.71
Robinson 44 II	1135	P	2	14.28
Enstrom 280	1179	P	3	15.76
Hiller UH-12E	1270	P	2	13.89
Bell 47G-3B	1340	P	2	13.31
Schweizer 330/333	1156	T	3	20.96
Robinson 66	1225	T	2	15.42
Enstrom 480	1350	T	3	17.90
MD Helicopters 369D	1361	T	5	26.74
Bell 206B-3 JetRanger III	1452	T	2	17.95
MD Helicopters 520N	1520	T	5	28.09
Sud-Aviation 313 Alouette II	1600	T	3	19.58
Eurocopter 120B	1715	T	3	21.83
Sud-Aviation 341 Gazelle	1800	T	3	20.79
MD Helicopters 600	1860	T	6	33.56
Bell 206L LongRanger	1882	T	2	18.83
Sud-Aviation 342 Gazelle	2000	T	3	23.10
Sud-Aviation 316 Alouette III	2100	T	3	22.10
Bell 407	2268	T	4	25.22
Aerospatiale 350B Ecureuil	2250	T	3	25.07
Eurocopter 130B4	2500	T	3	27.85
Agusta 119 Koala	2720	T	4	28.62
Sud-Aviation 360 Dauphin	3000	T	4	28.88

To better capture the complete range of single-engine helicopters, the following four helicopter types have been chosen for the underlying study (helicopters marked in blue in Table 7.1):

- HeliSport CH-7 Kompress (piston engine, MTOM 450 kg; estimated t/k 0.2s);
- Robinson R44 Raven I (piston engine, MTOM 1089 kg; estimated t/k 1.35s);
- Bell 206B-3 JetRanger III (turbine engine, MTOM 1452 kg; estimated t/k 1.4s);
- Aerospatiale AS350B2 Ecureuil (turbine engine, MTOM 2250 kg; estimated t/k 1.3s).

With these choices an adequate distribution of MTOMs and t/k values is realised, and both piston driven and turbine driven single-engine helicopter models are included. It is to be noted that of the above the Bell 206B-3 meets the t/k criterion as requested by the US Army for their New Training Helicopter (NTH) program in the early 90-ies (t/k to be at least 1.0), which contract was won by a B206B-3 derivative.

For each of these 4 helicopter types sufficiently detailed input data files have been prepared for the various simulation tools to be used for this study. Sources that have been consulted are Rotorcraft Flight Manuals and the like [refs. 23-27], Jane's All the World's Aircraft [refs. 28-31], Type Certificate Data Sheets [refs. 32-34], manufacturer brochures [a.o. ref. 35], plus various web sites and public domain documents. Also existing NLR input data files for other (comparable) helicopter types have been consulted.

7.2 Description of selected helicopter types

The selected helicopter types are described in more detail below. A summary of their main characteristics is provided in Table 7.2.

CH-7 Kompress

The HeliSport CH-7 Kompress (see Figure 7.1) is a 2-seat ultra light kit built helicopter, based on a single-seat Argentinian design from the late 1980s. It continues in production and some 215 had been built by January 2012. The Kompress features a two-bladed semi-rigid (teetering) main rotor, a two-bladed tail rotor, and a pod-and-boom fuselage. It is mainly used for private flying.

R44 Raven I

The Robinson R44 Raven I (see Figure 7.2) is a 4-seat helicopter, based on the proven 2-seat Robinson 22 design. It continues in production and some 900 examples of this Raven I sub-model had been built by the end of 2012 (out of a total of about 5400 R44 helicopters). The Raven I features a two-bladed semi-articulated main rotor with tri-hinged under slung rotor head to reduce blade flexing, rotor vibration and control force feedback, a two-bladed tail rotor, a pod-and-boom fuselage, and is standard equipped with a hydraulic main rotor flight control system. It is mainly used for training and passenger transport.

B206B-3 JetRanger III

The Bell 206B-3 JetRanger III (see Figure 7.3) is a 5-seat helicopter, initially developed for the military. Production has ended with about 2700 examples (including licenses) having been built of this JetRanger III sub-model (out of a total of more than 8000 civil and military Bell 206 helicopters). The JetRanger features a two-bladed teetering main rotor with preconed and under slung blades, a two-bladed tail rotor, and a pod-and-boom fuselage. The main rotor controls are fully hydraulic powered. It is mainly used for passenger transport and utility work.

AS350B2 Ecureuil

The Aerospatiale AS350B2 Ecureuil (see Figure 7.4) is a 6-seat helicopter. It continues in production and more than 1000 examples of this AS350B2 sub-model had been built by the end of 2012 (out of a total of about 4500 AS350 helicopters). The Ecureuil features a three-bladed Starflex bearingless main rotor, and a two-bladed tail rotor. The rotor controls are fully hydraulic powered. It is mainly used for passenger transport and utility work.

Table 7.2 Main characteristics for selected helicopter types

		HeliSport CH-7 Kompress	Robinson R44 Raven I	Bell 206B-III	Aerospatiale AS350B2
General data	MTOM (kg)	450	1089	1452	2250
	empty mass (kg)	280	662	777	1224
	number of seats	2	4	5	6
Main rotor	no. of blades	2	2	2	3
	diameter (m)	6.27	10.06	10.16	10.69
	chord (m)	0.18	0.254	0.33	0.35
	airfoil section	NACA 8-H-12	NACA 63015	NACA 0012 mod.	OA212, OA209, OA207
	normal rpm (100%)	500	400	394	390
	omega (rad/s)	52.36	41.89	41.26	40.84
	twist (deg)	-6.0	-7.0 (?)	-11.1	-12.3
	hinge offset (%)	0.0	0.0	0.0	3.8
	rpm, maximum power off	550	432	422	430
	rpm, minimum power off	450	360	355	320
	polar moment of inertia (kg.m2)	59	264	715	995
Tail rotor	no. of blades	2	2	2	2
	diameter (m)	1.02	1.473	1.65	1.86
	chord (m)	0.097	0.13	0.13	0.205
	normal rpm (100%)	2700	2379	2553	2046
	distance to main rotor (m)	3.55	5.68	5.96	6.2
Fin	area (m2)	0.17 (estimated)	0.7 (estimated)	1	1
Stabilizer	area (m2)	0.1 (estimated)	0.45 (estimated)	1.14	1.2
Fuel	usable fuel (kg)	30	133	275	426
Engine	type	piston	piston	turbine	turbine
	name	ROTAX 914 UL Turbo	Lycoming O-540-F1B5	Allison 250-C20J	TM Arriel 1D1
	power	TOP 84.5 kW, MCP 73.5 kW	175 kW	TOP 313 kW, MCP 236 kW	TOP 546 kW, MCP 466 kW
	SFC (kg/kW/hr)	0.276 (at 73.5 kW)	---	0.393 (at 313 kW)	0.359 (at 466 kW)
	fuel flow (kg/hr)	---	38 (at cruise speed)	---	---
Transmission	MCP rating (kW)	75 (at 5500 rpm)	153 (at 2718 rpm, 102%)	201	466
	TOP rating (kW)	85 (at 5800 rpm)	168 (at 2718 rpm, 102%)	236	531
Performance	cruise speed (kts)	86	113	113	133
	max. range (km)	320	644	682	667
	max. endurance (hrs)	2	3	4.6	4.4

7.3 Helicopter input data files and operational profiles

For each of the selected helicopter types input data files have been prepared for three computer codes that will be used for the analysis and comparison phase. These data files include geometric data (like rotor diameter, number of blades, rotor rpm and mass), engine data (power output and fuel consumption), and aerodynamic data for rotor and fuselage. Typical operational profiles (altitude, temperature, speed, weight and the like) have been established as well. For all analytical models the calculated results have been compared with manufacturer's data and where required the input data have been adapted to get improved results. The three computer codes are as follows:

- Energy Method for Power Required EStimateS (EMPRESS), to be used to assess the impact on the steady state flight performance, including power required and fuel consumption; all input data per helicopter type are contained in a single file, an example of which is provided in Fig. 7.5 for the AS350B2 helicopter; to illustrate the quality of the analytical models, Fig. 7.6 shows the B206B-3 calculated fuel flow vs. manufacturer's data;
- EUropean ROtorcraft Performance Analysis (EUROPA), to be used to assess the impact of the pilot response times and the technologies on the rotor speed decay after power failure during various operational conditions; this tool requires more elaborate input data per helicopter type, with a range of individual files for various helicopter components, examples of which are

provided in Fig. 7.7 for the AS350B2 helicopter (it is to be noted that not all input files are shown here);
- SPEcification Analysis of Rotorcraft (SPEAR), to be used to assess the impact of selected technologies on the helicopter design, including weight penalties; the tool establishes feasible helicopter dimensions (expressed in size and mass) based on a set of flight performance requirements and a set of operational (mission) profiles.

To be able to (re)size a helicopter with the inclusion of the new technologies three representative operational (mission) profiles have been defined for use by the SPEAR code, being a Private Flying profile to be used for the Kompress, a Training profile to be used for the Raven I, and a Passenger Transport profile to be used for the JetRanger III and Ecureuil. It is to be noted that for the engine failure simulations representative flight conditions will be selected from these profiles.

A typical Private Flying profile comprises the following segments:
1. Start engine;
2. Idle for 2 minutes;
3. Hover (incl. hover taxi);
4. Climb to 1500 ft AGL at 1000 fpm;
5. Fly locally at cruise speed (incl. manoeuvring);
6. Descend to 0 ft AGL at 750 fpm;
7. Hover (incl. hover taxi);
8. Idle for 2 minutes;
9. Shut down engine.

A typical Training profile comprises the following segments:
1. Start engine;
2. Idle for 2 minutes;
3. Hover (incl. hover taxi);
4. Climb to 1500 ft AGL at 1000 fpm;
5. Fly locally at cruise speed (incl. manoeuvring);
6. Descend to 0 ft AGL at 750 fpm;
7. Hover;
8. Climb to 1000 ft AGL at 1000 fpm;
9. Fly circuit;
10. Descend to 0 ft AGL at 750 fpm;
11. Repeat segments #7 - #10 for number of circuits to be flown;
12. Hover (incl. hover taxi);
13. Idle for 2 minutes;
14. Shut down engine.

A typical Passenger Transport profile comprises the following segments:
1. Start engine;
2. Idle for 2 minutes;
3. Hover (incl. hover taxi);
4. Climb to 2000 ft AGL at 1000 fpm;
5. Transit to destination at cruise speed (incl. manoeuvring);
6. Descend to 0 ft AGL at 750 fpm;
7. Hover (incl. hover taxi);
8. Idle for 2 minutes;
9. Shut down engine.

Specific details for each operational profile per helicopter type are provided in Table 4.3. For the Raven, JetRanger and Ecureuil the passenger average mass has been taken from Table 3 in JAR-OPS 3.620 [ref. 36].

Table 7.3 Details for selected operational profiles

	Kompress	Raven I	JetRanger III	Ecureuil
Private flying				
Climb / descent flight speed (kts)	43	---	---	---
Cruise speed (kts)	86	---	---	---
Time to cruise (hr)	2	---	---	---
Number of passengers (75 kg average weight)	1	---	---	---
Training				
Climb / descent flight speed (kts)	---	60	---	---
Cruise speed (kts)	---	110	---	---
Time to cruise (hr)	---	1	---	---
Circuit speed (kts)	---	80	---	---
Time per circuit (min)	---	10	---	---
Number of circuits	---	6	---	---
Number of passengers (90 kg average weight, incl. luggage)	---	3	---	---
Passenger transport				
Number of passengers (90 kg average weight, incl. luggage)	---	---	4	5
Climb / descent flight speed (kts)	---	---	52	55
Cruise speed (kts)	---	---	110	130
Transit distance (km)	---	---	665	660

Figure 7.1 HeliSport CH-7 Kompress

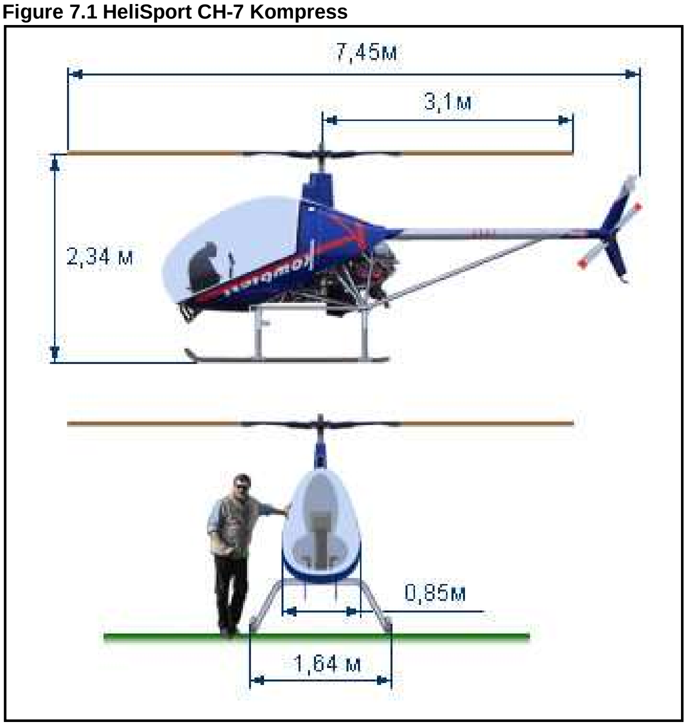


Figure 7.2 Robinson R44 Raven I

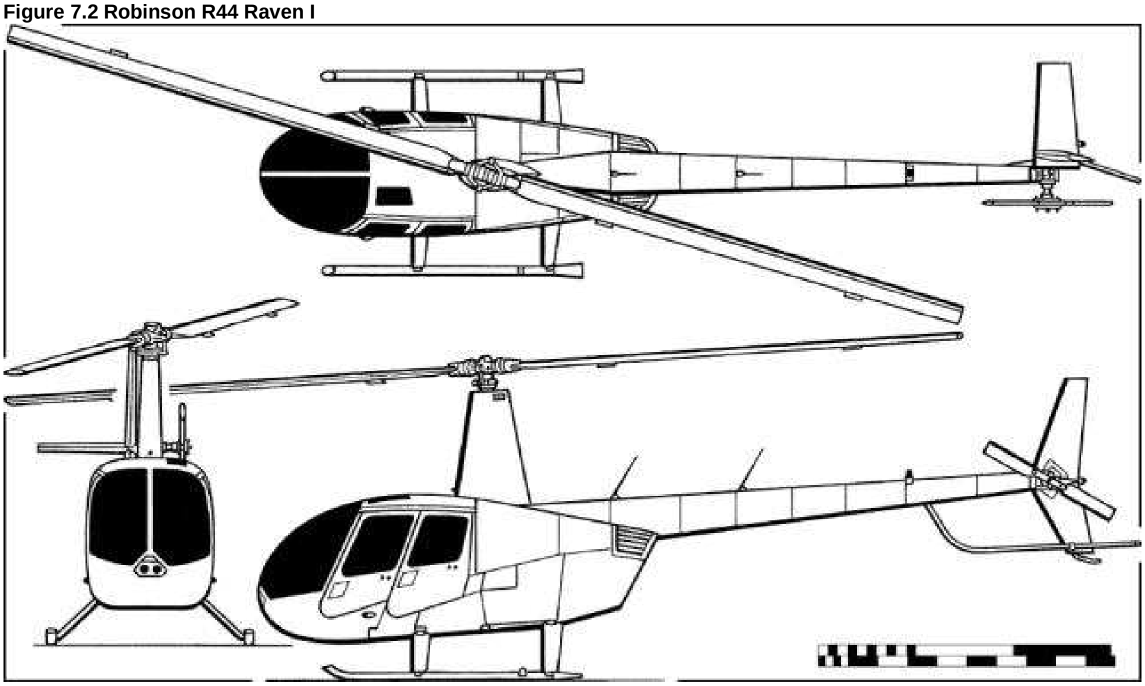


Figure 7.3 Bell 206B-3 JetRanger III

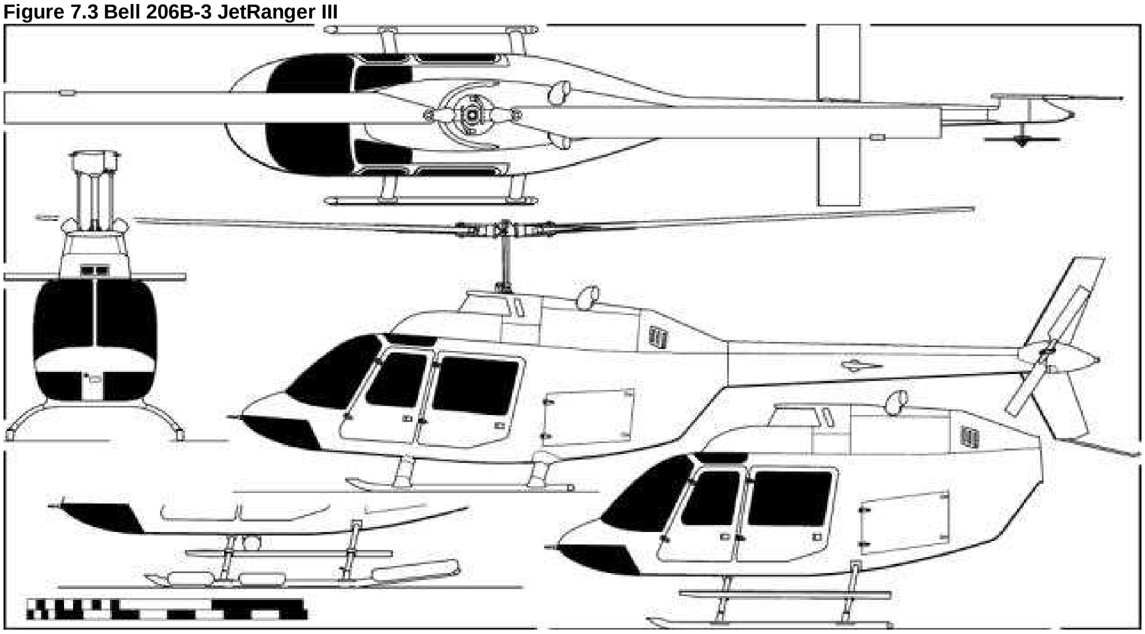


Figure 7.4 Aerospatiale AS350B2 Ecureuil

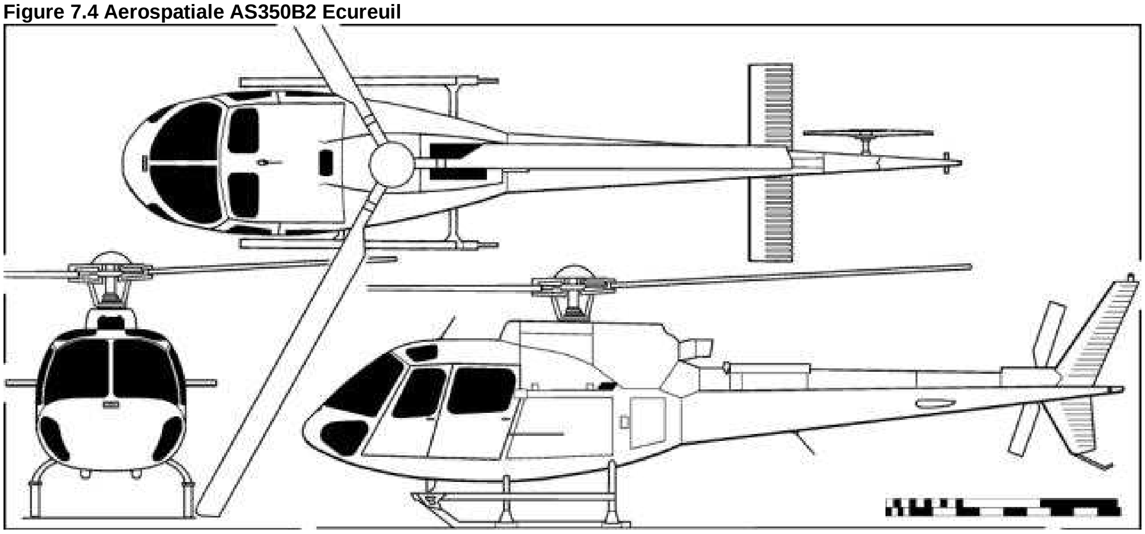


Figure 7.5 Example input file for AS350B2 Ecureuil for use by the EMPRESS tool

Rotorcraft input data for AS350B2

General

Configuration:	Main/tail rotor		
Max. gross mass [kg]:	2250		
Empty mass [kg]:	1224	Usable fuel mass [kg]:	426

Main rotor

Number of blades:	3	Clockwise rotation [T/F]:	True
Chord [m]:	0.350	Induced factor (hover):	1.075
Diameter [m]:	10.69	Induced factor (mu regime):	1.050
(Rotor solidity:	0.0625)	Airfoil aerodynamic data	
Rotor speed [rpm]:	390.0		
(Tip speed [m/s]:	218.29)		
Blade taper ratio:	1.00		
Blade roughness	1.00		

Airfoil aerodynamic data:

D1: 0.009	D6: 0.86	D10: 0.105
D2: -0.0241	D7: 2.46	D11: 9
D3: 0.459	D8: 0.2	
	D9: 0.0085	D12: 0.12

Tail rotor & fin

Number of blades:	2	Induced factor (hover):	1.17
Chord [m]:	0.20	Induced factor (mu regime):	1.17
Diameter [m]:	1.86	Blockage factor (hover):	1.05
Ratio TR/MR rpm:	5.25	Blockage factor (mu regime):	1.05
(Rotor speed [rpm]:	2048)	Fin lift coefficient:	0
Blade drag coefficient:	0.012	Fin area [m²]:	1

Engine & transmission

Number and type of engine:	1 X Turbomeca Arriel 1D1		
MCP (MSL/ISA/uninst.) [kW]:	466.0	Installation losses [%]:	4
SFC at MCP [kg/kW/h]:	0.359	Gearbox MCP limit [kW]:	466
k1_SFC:	0.265	Gearbox TOP limit [kW]:	531
k2_SFC:	0.658	Accessories power [kW]:	15
k3_SFC:	0.076	Mechanical efficiency [0-1]:	0.95

Airframe

Horizontal drag area [m²]:	0.95	MR height with rotorcraft "light on wheels" [m]:	3.10
Download factor (hover):	1.05	Climb efficiency [0-1]:	0.9
Horiz. distance rotors [m]:	6.20	Mu regime:	0.1

Figure 7.6 Fuel flow for the B206B-3 as calculated with EMPRESS vs. manufacturer's data (reference)

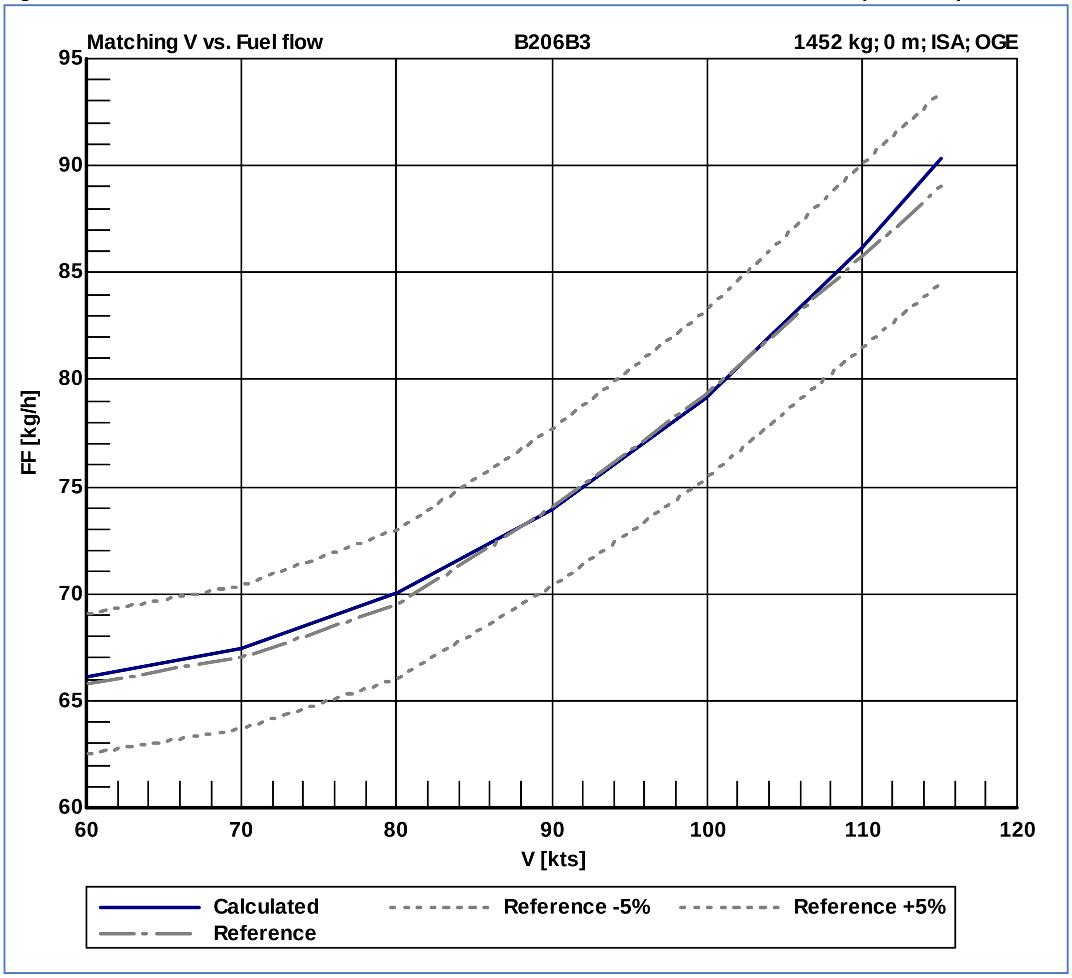


Figure 7.7 Example input files for AS350B2 Ecureuil for use by the EUROPA tool

```
MAIN ROTOR MODEL: AS350B2
VERSION: AS350B2, DATED: 14/12/2012
  1 -1  0                MAIN ROTOR: Type, Direction, Model (0=Padfield)
  0.0 0.0 -1.99          XHUB, YHUB, ZHUB
  0.0 0.0                SHAFT TILT: AFT, STBD (DEG)
  3 5.35 0.35            NUMBER OF BLADES, RADIUS, CHORD
 -12.3 6.8               TWIST (DEG), LIFT CURVE SLOPE
  158.0 8260.0 0.0       IBETA, KBETA, KBETA0
  0.97 0.009 38.66       TIP LOSS FACTOR, CD0, CD2
  1.39 1.19 3.0          BLADE STALL COEFFS: CDSN1 CDSN2 CDSN3
  0.0                    PHASE ANGLE
  1.0 1.0 1.0            PILOT CONTROL POWER FACTORS: CPFACC,CPFACF,CPFACL
INTERLINK LOGIC
  3.6  19.6              G01, G02
-10.5  15.5  0.0  0.0    G1S0, G1S1, GSC0, GSC1 (pitch)
  6.0 -10.0  0.0  0.0    G1C0, G1C1, GCC0, GCC1 (roll)
```

```
TAIL ROTOR MODEL: AS350B2
VERSION: AS350B2, DATED: 14/12/2012
  2                   Rotor Type: Agusta (mod. disk model)
 -6.19  0.41 -0.56    XHUB, YHUB, ZHUB
  0.0 0.0             SHAFT TILT (CLOCKWISE AROUND Z AND X AXES) DEG
  2  0.93  0.205      NUMBER OF BLADES, RADIUS, CHORD
  5.25                TAIL ROTOR : MAIN ROTOR GEAR RATIO
  -45.0    5.8        DELTA3, LIFT CURVE SLOPE
  0.35     0.0        IBETA, KBETA
  0.012    9.5        DRAG FACTORS: DELTA0, DELTA2
  30.0    -10.0       TH0MAX, TH0MIN
  0.0                 TRTHTTW linear blade twist (deg)
  0.95                FIN BLOCKAGE FACTOR
 10.0                 ENDVTR velocity for end blockage effect (kts)
  1.0                 MAIN ROTOR VELOCITY FACTOR
  1.0                 PILOT CONTROL POWER FACTOR: CPFACR
INTERLINK LOGIC
  1.0                 YAW COLLECTIVE INTERLINK RATIO (1 = none, 0 = full)
```

```
VERTICAL FIN: AS350B2
VERSION: AS350B2, DATED: 14/12/2012
  0                    FIN MODEL: Model (0=Padfield;1=AGUSTA)
 -6.60   0.0  -0.825   Fin location (X,Y,Z) rel to aircraft datum (m)
 1.0                   Fin area (m2)
 0.0                   Fin setting angle (deg)
 1.5                   Fin maximum lift coefficient
 1.0 1.0               MR wake and dynamic pressure correction factors
 1.0                   Tail rotor wake contraction factor at fin
 1.856                 Fin lift curve slope (/rad)
```

8 Analysis and Comparison

8.1 Introduction

To determine the impacts on helicopter design and operation throughout the range of pilot response times identified in Task 1a a (parametric) study using a combination of analysis, simulation and engineering judgment has been performed. The currently applied response times in certification assume a time delay of 1 second for the cruise phase and 0.3 seconds for other flight phases. However, actual pilot response times – in case of twin-engine helicopters – were shown to be nearer to 3 seconds. Technologies identified in Task 1b have then been incorporated in the helicopter design so as to sufficiently increase the time available to the pilot to successfully enter autorotation following a (complete) power failure. The implementation of the technologies has an impact on the helicopter design (in terms of mass, dimensions and installed engine power). In Task 3 described in the previous chapter four generic single-engine helicopter types (in the classes of the AS350B2, B206B3, R44 Raven I and CH7 Kompress) have been identified and for each one sufficiently detailed input data files have been prepared for the various tools to be used for the study.

Simulations of complete power failures have been performed. The EUROPA helicopter flight dynamics simulation tool is used to determine the rotor rpm drop before pilot interception. The EUROPA software tool is a European-wide helicopter flight mechanics code that has been developed by rotorcraft manufacturers and research institutes within the European RESPECT project. The code includes models for the complete vehicle, the atmosphere and the pilot. EUROPA can model steady state performance (trim) as well as dynamic (manoeuvre) performance. The code is ideally suited to calculate Flight Manual performance charts, to determine (optimized) take-off and landing flight paths and to determine flight performance after power failures.

The simulations have been performed for various pilot response times as identified in Task 1a, and for various flight conditions and technologies as identified in Task 1b. For the simulations an instantaneous power failure is used (worst case situation). From the moment of complete power failure to the moment of recovery the rotor speed will drop, and the helicopter will roll, pitch and yaw to various degrees. In the simulations the pilot responds by lowering the collective, for which the time required varies with the initial collective stick position (a movement from full up to full down would take 1.67 seconds). The simulations are halted when rpm is increasing again after having passed the minimum allowable rpm value. The Rotorcraft Flight Manuals for the 4 helicopter types under consideration provide values for the minimum power-off rotor speed. However, it is to be noted that none of these Flight Manuals provides a value for a transient minimum power-off rotor speed. Therefore it is not clear whether the rotor rpm is allowed to drop below the stated minimum value. For the analysis of impacts, it is assumed that it is not allowed.

The rate of rotor speed decay varies with the level of the power required before failure, and therefore will be highest in conditions of high power demands (like hover or high speed at high mass). In the simulations several parameters have been varied (maximum take-off mass has been used throughout):

- pilot response time for all controls;
- air speed;
- level flight / climbing flight;
- emergency power supply;
- rotating system inertia;

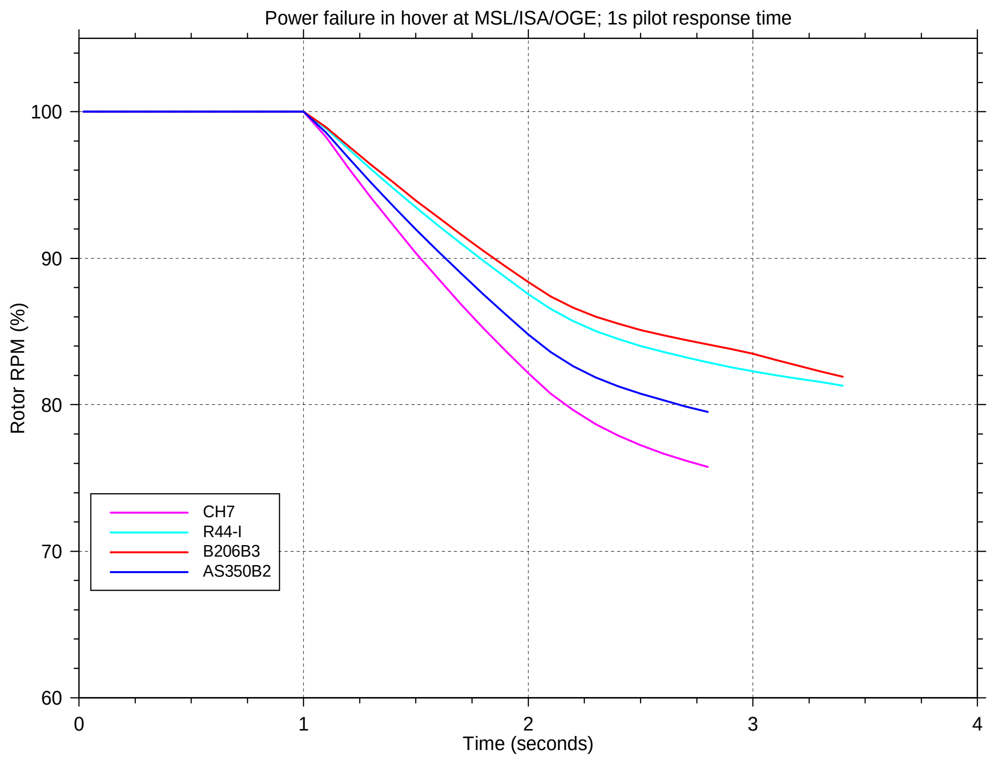
- automatic collective drop at various response times.

Simulated power failure time histories will be shown and elucidated in the following paragraphs. In certain cases the simulation was halted prematurely, e.g. when the fuselage attitudes are more than 70 degrees in pitch or roll, or when the normal g loading is nearly zero or negative.

8.2 Variation of pilot response times and flight conditions

Simulations have been performed with various pilot response times after power failure, ranging from 0.5 to 4 seconds. As an example Figure 8.1 shows the rotor rpm time histories for all 4 helicopter types, after a power failure in hover Out of Ground Effect (OGE) and a 1 second pilot response time. The engine failure takes places 1 second into the simulation, with the pilot responding 1 second later (so 2 seconds into the simulation).

Figure 8.1 All helicopter types, rotor rpm time histories after power failure in hover and 1s pilot response time



For the AS350B2 the minimum allowable rotor rpm is given in the Rotorcraft Flight Manual as 82%, for the other three helicopter types (being equipped with a teetering rotor system) it is 90%. After the power failure this minimum value is reached:

- for the AS350B2 after 1.2 seconds (t/k estimated to be 1.3 seconds);
- for the B206B3 after 0.8 seconds (t/k estimated to be 1.4 seconds);
- for the R44-I after 0.75 seconds (t/k estimated to be 1.35 seconds);
- for the CH7 after 0.5 seconds (t/k estimated to be 0.2 seconds).

For the latter three helicopters the time to reach the minimum rpm is much shorter due to the higher value of the minimum allowable rotor rpm, which is inherent to their teetering rotor system. In all of those 3 hover cases with a 1s pilot response time the actual rotor rpm after the power failure decreases to a level (well) below the allowable minimum level. Also the pitch and/or roll attitudes or the normal g-level within 1 second after the power failure may be such that recovery is deemed to be impossible.

It seems strange that the simulated results show a time to minimum allowable rotor rpm which in most cases is clearly distinct from the t/k value. The t/k equation is as follows [ref. 38]:

$$\frac{t}{k} = \frac{0.5\ J\ \Omega^2}{Preq, OGE} * \left(1 - \frac{Ctw/\sigma}{0.8\ (Ctw/\sigma)stall}\right)$$

In which J is the rotor inertia, Ω the rotor speed, Preq, OGE the power required in hover, Ctw the rotor thrust coefficient, and σ the rotor solidity. For (Ctw/σ)stall a value of 0.166 is advised in [Ref. 38].

This equation assumes that the rotational energy stored in the dynamic system (rotors, transmission, drive shafts) can be dissipated down to a rotor rpm close to rotor stall. However, this does not take into account that rotor controllability already may be at stake at a higher rotor rpm, especially for those helicopters equipped with a 2-bladed teetering rotor system. This is apparent from the minimum allowable rotor rpm levels found in the respective Rotorcraft Flight Manuals, which, as has been stated before, for the helicopters with teetering rotors are higher than the one for the AS350B2. Therefore less energy can be dissipated and so the actual times to minimum allowable rotor rpm for the B206B3 and for the R44-I are lower than one would expect on the basis of the t/k value alone.

For the CH7 the difference is expected to have a different cause. This helicopter uses a low-drag, asymmetrical rotor airfoil section, which is specifically aimed at helicopter usage (the R44 and B206B3 have symmetrical airfoil sections). Therefore the CH7 will have a higher value for (Ctw/σ)stall (higher than the advised value of 0.166) and thus a higher t/k than one would expect. Increasing (Ctw/σ)stall to 0.19 will bring t/k close to the calculated time of 0.5 seconds.

Apparently the aforementioned t/k equation is not sufficiently suited for a wide range of (modern) helicopter characteristics and therefore should be used with care.

Variations in air speed, in level flight and climbing flight, have also been considered. Comparable results are found for simulations during level flight at cruise speed (the respective values of the cruise speed are provided in Table 7.3) and during climbs at best rate of climb speed, conditions for which the power required more or less resembles the one found in hover. When the power failure occurs when flying at the bucket speed (this is the air speed for minimum power required) and the pilot response time is 1 second, all four helicopter types are recoverable. Rotor rpm stays within allowable limits for 3 of the 4 helicopter types, but momentarily drops to 85% for the CH7. Table 8.1 summarizes the simulation results for various flight speeds and pilot response times for the 4 helicopter types. The following definitions are used:

- 'Likely' denotes a situation in which recovery is possible with rotor rpm staying within limits or temporarily dropping slightly below the limit;
- 'Probable' denotes a situation in which recovery seems to be possible, but in which the rotor rpm drops below the minimum allowable value by 5-10%;
- 'Unlikely' denotes a situation in which rotor rpm drops far below the minimum allowable rpm, or the fuselage pitch/roll attitudes exceed limitations.

Table 8.1 Likelihood of recovery after a complete power failure at various flight speeds and pilot response times

		AS350B2	B206B3	R44-I	CH7
Recovery after 0.5s pilot response time	hover OGE	likely	probable	probable	probable
	bucket speed	likely	likely	likely	likely
	cruise speed	likely	probable	probable	probable
Recovery after 1s pilot response time	hover OGE	probable	unlikely	unlikely	unlikely
	bucket speed	likely	likely	likely	probable
	cruise speed	likely	probable	likely	unlikely
	climb VBROC	probable	unlikely	unlikely	unlikely
Recovery after 2s pilot response time	hover OGE	unlikely	unlikely	unlikely	unlikely
	bucket speed	likely	unlikely	probable	probable
	cruise speed	unlikely	unlikely	unlikely	unlikely
	climb VBROC	unlikely	unlikely	unlikely	unlikely
Recovery after 3s pilot response time (or beyond)	hover OGE	unlikely	unlikely	unlikely	unlikely
	bucket speed	unlikely	unlikely	unlikely	unlikely
	cruise speed	unlikely	unlikely	unlikely	unlikely
	climb VBROC	unlikely	unlikely	unlikely	unlikely

Summarizing the simulation results it is concluded that the following values of pilot response times will potentially lead to a safe recovery after a complete power failure (cells labelled 'likely' and 'probable' in Table 8.1):

- up to 0.5 seconds in hover for all 4 helicopter types;
- up to 2 seconds at bucket speed for all types but the B206B3;
- up to 1 second at cruise speed for all types but the CH7.

These values are in line with the certification requirements (1 second for cruise phase and 0.3 seconds for other flight phases). It is to be noted that the CH7, being a homebuilt helicopter, does not come under EASA regulation. From the simulations it has become clear that for pilot response times of 2 seconds or more an unrecoverable flight condition will likely be entered after the power failure. For pilot response times between 1 and 2 seconds this will happen for certain flight conditions, esp. during high power demands (like in hover or climbing flight). Therefore technological solutions will be required to bridge the gap between allowable response times and actual response times.

8.3 Influence of technological solutions

With the previous conclusions from the simulation results several technological solutions from Task 1b have been investigated. The options considered in Task 1b can be grouped in three systems:

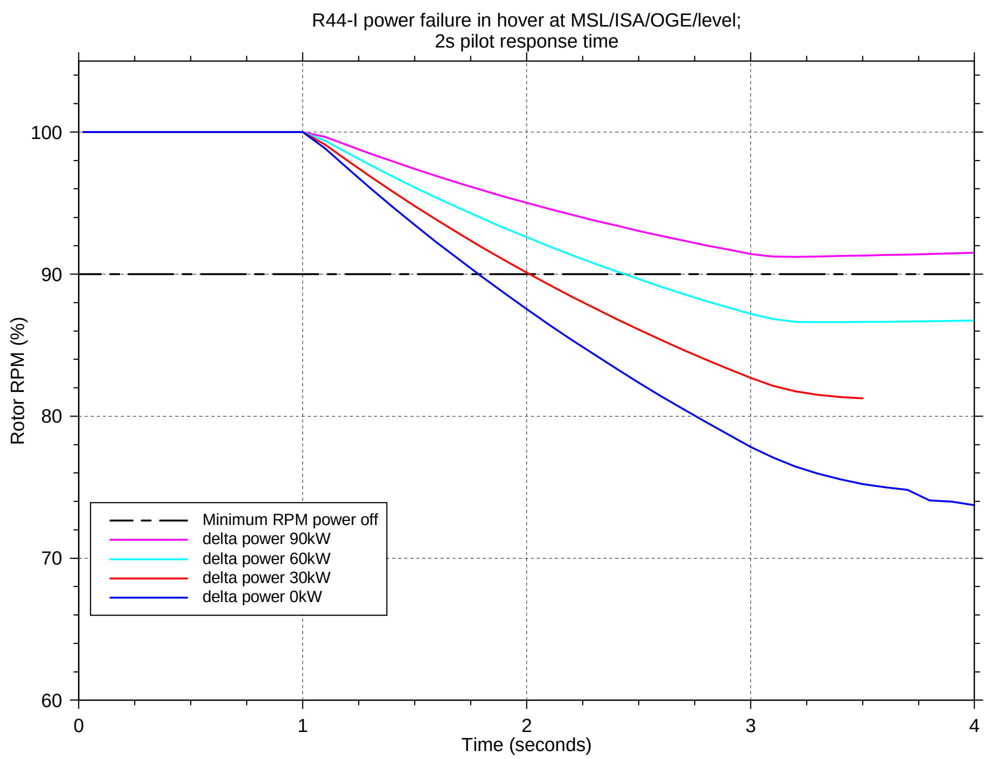
- adding emergency power source;
- increasing rotating system inertia;
- automatic lowering of collective control.

The objective of implementing these systems is to increase the time available to the pilot to successfully enter autorotation following a complete power failure. Simulations have been made for various pilot response times and mainly for the hover OGE case (being the most critical flight phase). From the simulation results it has become clear that catering for pilot response times up to 3 seconds already requires rather heavy systems (leading to a mass increase of far more than 100 kg for the R44-I). On the other hand a pilot response time of 1 second seems rather short if one wants to cover all possible conditions including hover. Def Stan 00-970 stipulates 2s delay from any flight condition, as did BCAR Section G. Solutions that will raise the available pilot response time to 2 seconds are deemed feasible and therefore the following paragraphs concentrate on that case. Hence, in the following paragraphs, the engine failure takes places 1 second into the simulation, with the pilot responding 2 second later (so 3 seconds into the simulation).

8.3.1 Adding emergency power source

The first technology is an emergency power source that will kick in automatically when a (complete) power failure has occurred. Task 1b results showed various alternatives to add emergency power. Here, only the electric motor is considered because of its quick start possibility, thereby providing an immediate response. It is not foreseen that the normal battery can be used to supply power to this electric motor given the particular needs of such a system. Hence, an additional battery to supply power for a short duration will be necessary. As an example Figure 8.2 for the R44-I shows the impact of various emergency power levels ranging from 0 to 90 kW (as a comparison: the installed Maximum Continuous Power for the R44-I is 175 kW).

Figure 8.2 R44-I, effect of adding emergency power on rotor rpm after power failure in hover and 2s pilot response time



From the Figure it becomes clear that an electric motor of about 90 kW will be required to keep rotor rpm above the minimum allowable level. If a temporary drop below that level is allowed, an electric motor of about 60 kW will suffice. Note that the assumption has been that power was available instantly. Table 8.2 summarizes the simulation results for the 4 helicopter types. In addition, a comparable calculation has been made for a pilot response time of 3 seconds.

Table 8.2 Additional power required after a complete power failure in hover

	AS350B2	B206B3	R44-I	CH7
Installed MCP	466 kW	236 kW	175 kW	73.5 kW
2s pilot response time				
Additional power required if rotor rpm must remain above minimum allowable	120 kW	120 kW	90 kW	39 kW
Additional power required if rotor rpm is allowed to temporarily drop below minimum allowable	80 kW	80 kW	60 kW	26 kW
3s pilot response time				
Additional power required if rotor rpm must remain above minimum allowable	180 kW	140 kW	100 kW	46 kW

Note: as has been stated before, none of the 4 Flight Manuals provides a value for a transient minimum rotor rpm under power off conditions; therefore it is not clear whether the rotor rpm is allowed to (temporarily) drop below the minimum allowable value.

Table 8.3 shows the total mass impact of adding an emergency power source that will deliver power during a short period of time after the failure of the regular power source. It is anticipated that the solution will be included into a new helicopter design with the same payload-range capability. The total mass impact takes into account all associated aspects, like the mass of the electric motor, the battery, the installation mass, the fuel load, etc. The mass of the electric motor and battery are average values based on various internet sources [Refs. 39-43]. The delta masses (empty, fuel and total) have been calculated with the SPEAR computer code, described in section 7.3. Again a comparable calculation has also been made for a pilot response time of 3 seconds.

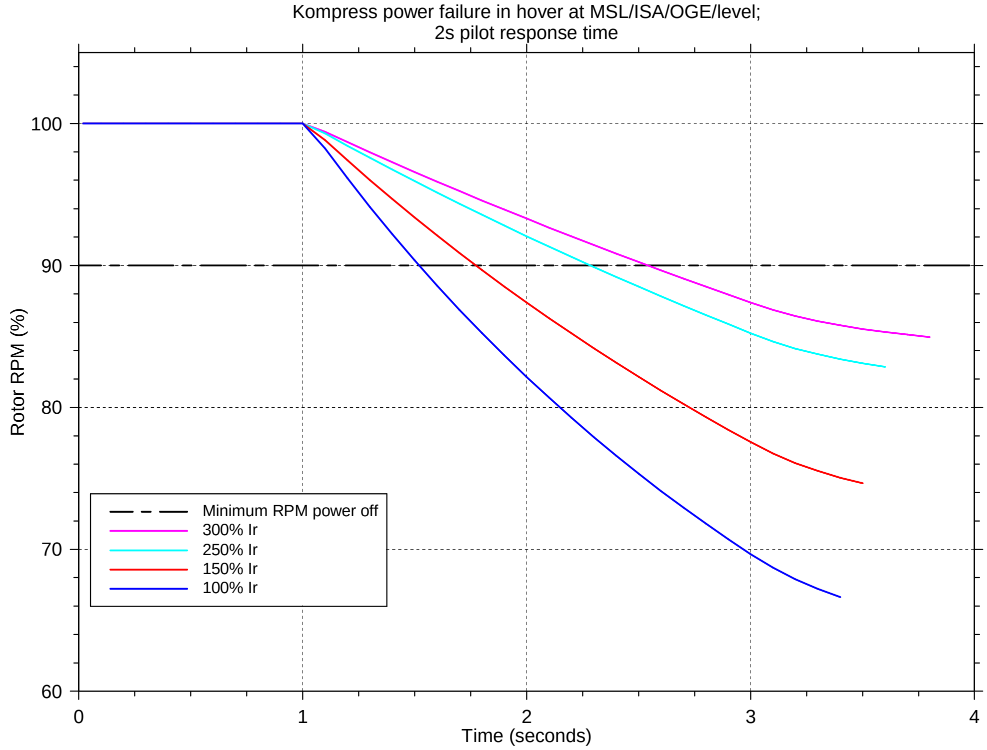
Table 8.3 Mass impact of installing an emergency power source

	AS350B2	B206B3	R44-I	CH7
Helicopter empty mass (kg)	1224	777	662	280
Fuel mass (kg)	426(?)	275	133	30
Maximum take-off mass (kg)	2250	1452	1089	450
2s pilot response time				
Electric motor mass (kg)	25	25	20	15
Additional battery mass (kg)	20	20	15	10
Delta empty mass (kg)	85	92	71	48
Delta fuel mass (kg)	10	18	10	2
Total delta mass (kg), at equal payload and range	95	110	81	50
3s pilot response time				
Electric motor mass (kg)	40	30	22	16
Additional battery mass (kg)	35	24	17	11
Delta empty mass (kg)	140	110	79	52
Delta fuel mass (kg)	18	22	11	2
Total delta mass (kg), at equal payload and range	158	132	90	54

8.3.2 *Increasing rotating system inertia*

A second technology that can be adopted is an increase of the inertia of the rotating system. As an example Figure 8.3 for the CH7 shows the impact of varying the inertia from 100% to 300% of the standard value.

Figure 8.3 CH7, effect of rotating system inertias on rotor rpm after power failure in hover and 2s pilot response time



From the Figure it becomes clear that an increase of the inertia to more than 300% of the standard value will be needed to keep rotor rpm above the minimum allowable level. If a temporary drop below that level is allowed, an increase to about 250% will suffice. Table 8.4 summarizes the simulation results for the 4 helicopter types.

Table 8.4 Increased rotating system inertia after a complete power failure in hover with a 2s pilot response time

	AS350B2	B206B3	R44-I	CH7
Minimum value of inertia if rotor rpm must remain above minimum allowable	200%	250%	250%	> 300%
Minimum value of inertia if rotor rpm is allowed to temporarily drop below minimum allowable	150%	150%	150%	250%

The rotating system inertia will be increased by adding tip weights to the main rotor blades. Adding tip weights will not only increase the rotor inertia, but will also have other effects. A higher rotor inertia makes the rotor less prone to variations in rpm, but it will require more engine power to accelerate to the desired rotor RPM. Due to the higher centrifugal forces the rotor head must be stronger and therefore will be heavier. An increase in rotor inertia also leads to an increase in other rotating system parts inertia due to the higher torque demands. Table 8.5 shows the total mass impact of adding these tip weights. The delta masses (empty, fuel and total) have been calculated with the SPEAR computer code, described in section 7.3. It is anticipated that the solution will be included into a new helicopter design with the same payload-range capability. The total mass impact takes into account all associated aspects, like increased mass for the blades, the rotor hub, the drive train, the fuel load, etc.

Table 8.5 Mass impact of increasing the rotating system inertia

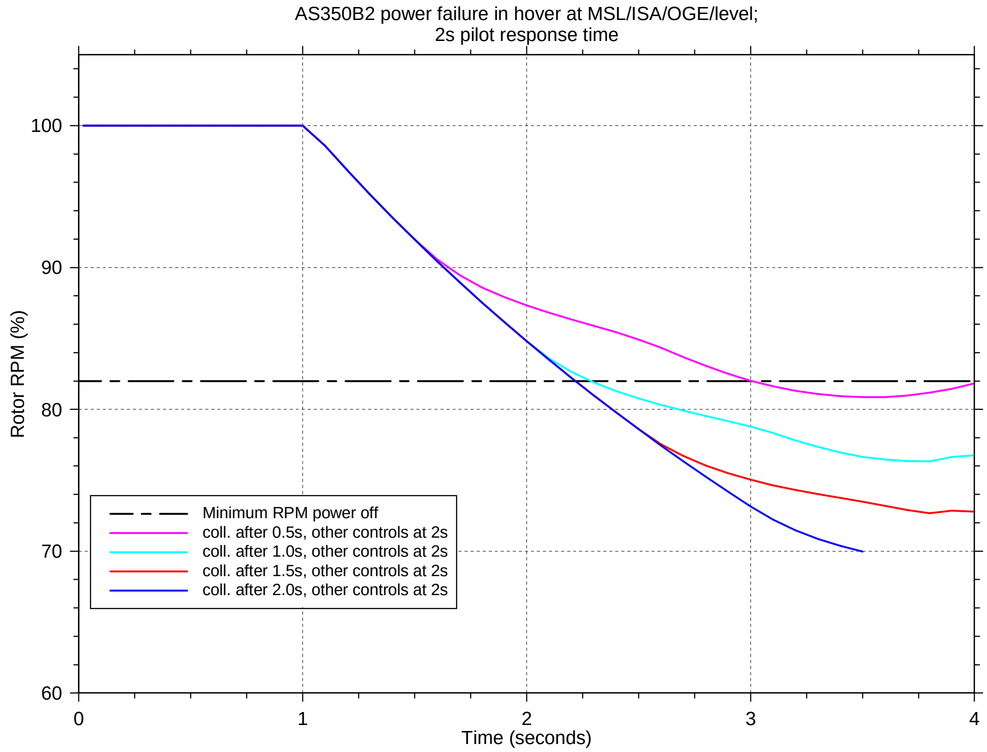
	AS350B2	B206B3	R44-I	CH7
Helicopter empty mass (kg)	1224	777	662	280
Fuel mass (kg)	426	275	133	30
Maximum take-off mass (kg)	2250	1452	1089	450
No. of main rotor blades	3	2	2	2
Individual blade mass (kg)	35 (est.)	42 (est.)	26	9
Increase in inertia (%)	100 (200 - 100%)	150 (250 – 100%)	150 (250 – 100%)	200 (300 - 100%)
Total tip mass needed (kg)	34.8	41.6	26.0	15.1
Delta empty mass (kg)	84	100	62	39
Delta fuel mass (kg)	10	20	8	2
Total delta mass (kg), at equal payload and range (kg)	94	120	70	41

It is apparent that increasing the rotor inertia has almost the same mass effect as adding the emergency power source.

8.3.3 Automatic lowering of collective control

A third technology is the automatic lowering of the collective lever when a power failure has been detected. For the simulations the time at which the collective is lowered has been varied from 0.5 to 2 seconds after the power failure. In all cases the other controls are kept fixed for 2 seconds. As an example Figure 8.4 for the AS350B2 shows the impact of varying the time at which the collective is automatically lowered.

Figure 8.4 AS350B2, effect of time at which collective is automatically lowered on rotor rpm after power failure in hover and 2s pilot response time



From the Figure it becomes clear that automatically lowering the collective 0.5 seconds after the power failure will significantly ease the recovery, even with the delayed pilot response time of 2 seconds (after power failure). Table 8.6 summarizes the simulation results for the 4 helicopter types.

Table 8.6 Variation in time at which collective is automatically lowered after a complete power failure in hover with a 2s pilot response time

	AS350B2	B206B3	R44-I	CH7
Time at which to automatically lower the collective if rotor rpm must remain above minimum allowable value	0.5s	< 0.5s	< 0.5s	<< 0.5s
Time at which to automatically lower the collective if rotor rpm is allowed to temporarily drop below minimum allowable value	1s	0.5s	0.5s	< 0.5s

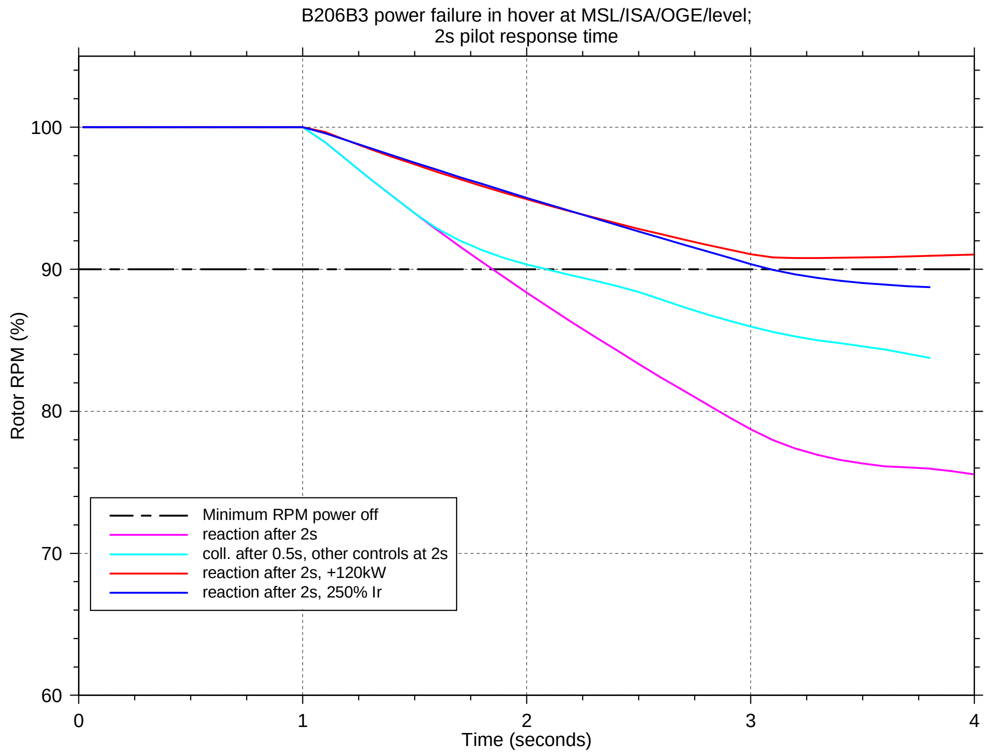
It is estimated that the introduction of such a system will only have a minor mass impact (a few kg's).

8.3.4 Summary of technological solutions

The simulations for various technological solutions have shown that it is possible to safely raise the available response time to 2 seconds. As an example Figure 8.5 for the B206B3 shows the impact of a 2s pilot response time, without and with adding technological solutions. Only with the addition of the technological solutions can the rotor rpm be kept above or near the minimum allowable level when the pilot response time is 2 seconds. But these solutions come with a mass and cost penalty.

To increase the allowable response time to match the demonstrated pilot response time of 4 seconds is not feasible.

Figure 8.5 B206B3, effect of pilot reaction time and technological solutions on rotor rpm after power failure in hover



8.4 Conclusions

After a (complete) power failure the time available to recover the situation and enter into an autorotative flight is very limited. High power settings immediately before the failure will reduce the available response time. Helicopter types with a 2-bladed teetering rotor system inherently have a high value for the allowable minimum rotor rpm under power off conditions, making them even more vulnerable to slow pilot responses after a complete power failure. For three of the four single-engine helicopter types under investigation (AS350B2, B206B3 and R44-I) the available response times are in line with current certification requirements (1 second for cruise phase and 0.3 seconds for other flight phases). The CH7 does not fully meet the requirements, nor does it have to, because it is a homebuilt helicopter and therefore does not come under EASA regulation. From the simulations for the four helicopter types it has become apparent that for pilot response times of 2 seconds or more an unrecoverable flight condition will be met. For response times between 1 and 2 seconds this will only happen for certain flight conditions (like hover OGE or climbing flight).

Several technological solutions that can increase the time available have been investigated. From the simulations that have been performed it is apparent that these solutions are capable of increasing the time available, but they come with a mass and/or cost penalty. Increasing the time available to more than 2 seconds is not deemed realistic.

From a strictly safety point of view it is advised to adapt the relevant certification requirements to bring them closer to actual pilot response times. E.g. by going from 1 second for the cruise phase and 0.3 seconds for other flight phases to 2 seconds for all flight phases. However, such an increase in time available will not assure that all accidents caused by a “Late response to start autorotation” will not happen again as this increase is still less than demonstrated actual pilot response times – under the assumption that these actual response times, which were demonstrated on twin-engine helicopters only, at least provide an *indication* of actual response times which could be expected on single-engine helicopters –.

Against the background of the safety impact analysis described in chapter 6, it is assumed that an increase in time available to 2 seconds for all flight phases will avoid, as a maximum, 80% of the accidents caused by a “Late response to start autorotation”. This assumption is based on the fact that on the one hand there still is a difference between time available and demonstrated response times, and on the other hand the types of helicopters under investigation are for a large part flown in an active, hands-on way.

9 Identification of options

Following the assessment of technological improvements and the safety performance of different single-engine helicopters, four options have been considered for the RIA. These are as follows:

- Option 0 – "Do nothing scenario";
- Option 1 – Mandatory certification of new single-engine helicopter models – Increase the allowable response time following engine power failure, to 2 seconds for all flight phases; This option is split further to variants 1A and 1B representing the complexity of the technological solutions that can be applied to achieve this target:
  - Option 1A – Increasing rotating system inertia by placing tip weights on rotor blades;
  - Option 1B – Application of auxiliary systems (emergency power supply, automatic lowering of collective control).
- Option 2: - Mandatory certification of new single-engine helicopter models – Increase the allowable response time following engine power failure, to above 2 seconds for all flight phases;
- Option 3: Additional non-mandatory information provided to manufacturers regarding the safety benefit gains by increased allowable response times.

The added value of Option 2 compared to Option 1 is that it is expected that a larger part of the maximum potential safety benefit will be realised. However, as concluded in the previous chapter, the expected safety impact of Option 1 would already capture as much as 80% of the maximum available safety benefit. Option 2 is therefore expected to have only a marginal additional safety gain. From a technical point of view increasing the allowable response time to more than 2 seconds is not deemed realistic given the even larger weight increase. Therefore option 2 is excluded from the analysis.

Option 3 examines the case where manufacturers voluntarily apply the increased standard with respect to the allowable response time to models developed targeting the market segments that would be willing to pay extra for the additional safety gain. Interviews with industry experts revealed that the vast majority of the single-engine helicopter market is usually price sensitive and would most probably not be willing to pay extra for this. However, it was suggested that an exception to this general trend would be the higher end of the private and corporate helicopter sub-market as well as the training helicopter niche market segment to which additional safety features seem to be appealing. All in all, the penetration of this option could raise up to a 9-15% of the total fleet. Thus Option 3 will be considering an average take-up of 12%.

The success of the Guimbal Cabri G2

The market success of the Guimbal Cabri G2 model can be considered as validating the existence of two market segments willing to pay higher unit prices for additional safety on single-engine helicopters[13]. Up to some extend the market penetration of the Cabri G2 model can be attributed to the increased safety elements[14] that are highly valued by these two market segments. This case is strengthened by the fact that despite it's significantly higher price[15] compared to other helicopters of the "under 500kg" category (like the Robinson R-22 and Schweizer 300), the Cabri G2 model has achieved to secure an increasing market share. The clientele of this model confirms the statement regarding it's primary target markets as the first unit sold was to iXAir[16], a French business jet operator, while among the first orders placed, that of

13 http://www.ainonline.com/aviation-news/aviation-international-news/2008-02-27/french-company-targets-training-market-cabri.

14 http://www.cabri.co.nz/the-cabri-difference/.

15 http://helicopterwise.com/the-all-new-cabri-g2/.

16 http://www.shephardmedia.com/news/rotorhub/hlicoptres-guimbal-delivers-first-produc/.

Eurocopter[17], aimed at using the Cabri G2 for training pilots. Among other orders placed for the Cabris G2 for private or training use[18] also the Polish military has trusted this model for training it's pilots[19]. All said, it can be concluded that, beyond being a modern-design helicopter, with emphasis in comfort, that naturally gains market share in the category of very small single engine helicopters, the Guimbal Cabri G2 model success clearly illustrates that some market segments value increased safety elements adequately to undertake the additional expenses.

Creating options to apply different requirements on the various sub-segments of the single-engine helicopter market according to divisions made on matters of take-off-mass or engine type could provide added value to this analysis, however, this is not possible as the recording of accidents per type of cause is made on the basis of broader categories and finding specific accident data per helicopter type requires additional in-depth research and potentially the cooperation of helicopter manufacturers who might maintain a detailed recording of such data.

Retrofit

One of the issues analysed in this RIA was a potential requirement of mandatory retrofitting of helicopters currently in-use. This was assessed as not feasible to implement. Our interview program with industry specialists and manufacturers representatives has led to the conclusion that it would be unrealistic to retrofit existing in-use models. This is specifically valid for the smaller single-engine helicopter models. Retrofitting of the existing models would be followed by a chain of changes, starting from a selected technology aimed at increasing the allowable response time to the pilot, through adjusting other systems on board of the helicopter ensuring the overall integrity of systems, finally leading to the decrease of the available payload. Some manufacturers argued that retrofitting of the existing helicopter models would lead to a payload decrease of 20 to 25% dependent on the model. This could be equal to decreasing the payload by one passenger. This is expected to have significant effects on the market and the sales of – especially – small single-engine helicopters.

For some larger single-engine helicopter models, retrofitting would be most probably possible from a technical point of view. However, the manufacturers assessed that it could most likely prove to be unrealistic from an economic point of view. That is because any of the researched technical solutions cannot come as a stand-alone addition to the existing models. An increase in the mass of the helicopter for instance due to the addition of an auxiliary electrical power supply, would impact the function of other helicopter systems triggering a spiral of necessary changes. Therefore, a more powerful engine could be required to be able to maintain the same payload. At the same time, this could impact the supporting helicopter frame structure and so on. All in all, it is assessed that the amount of necessary equipment replacements is such that the whole venture would not be feasible from an economic point of view.

To conclude, all of the manufacturers stated that retrofitting of the existing fleet is not a feasible option, which the study team subscribes. For some helicopters it would not be possible from the technical point of view as a change of the motor inertia would require a change of other systems and equipment installed on board of the helicopters. For other models, however, retrofitting could be technically possible, however, the manufacturers' assessment was that retrofitting of the existing fleet would have a significant impact on the price of the helicopters and would be extremely difficult and expensive to implement. Retrofit is not considered as a viable option.

[17] http://www.shephardmedia.com/news/rotorhub/first-cabri-g2-delivered-to-eurocopter/.
[18] http://helihub.com/2013/06/06/three-more-cabris-sold-to-uk-market/.
[19] http://helihub.com/2013/03/12/polish-military-order-guimbal-cabri/.

The implication of this for all of the policy options above is that, the application of the measures is envisaged only for the new models that are going to come in the market. This decision is based on the fact that redesigning existing models to accommodate the new safety requirements will have an effect on most of the helicopter's operating systems, requiring the launch of full research projects to redesign the existing helicopter units. This can prove to be equally or even more expensive than developing new models from scratch. Taking also into account, the fact that the redesign and certification of adjusted helicopter models and equipment is a process that might take many years to complete. Therefore the impact assessment assumes that only new models be subject to the proposed regulation.

10 Methodology and data requirements

10.1 Methodology

10.1.1 General Assumptions

Regulatory Impact Assessment (RIA)

A Regulatory Impact Assessment (RIA) is a tool used by decision-makers. The aim of a RIA is to establish which option would be able to achieve the objective of a rulemaking activity the best while minimising potential negative impacts at the same time. Five steps[20] are followed:

1. Problem identification;
2. Objective definition;
3. Option development;
4. Impact analysis;
5. Option comparison.

A RIA provides a transparent and evidence-based analysis of the advantages and disadvantages of the options. This is done in line with the defined objectives. Finally, the decision-makers and various stakeholders involved are provided with a reference framework for discussion and can make informed decisions on the new rules. It is an integral part of the rule development process of EASA.

The scope and depth of the impact analysis can vary pending on the expected size of the impact of the new policy. The analysis should be proportional to the expected impact: the so-called principle of proportional analysis. Areas that are not yet regulated or which affect a lot of people need to be analysed in detail. The analysis of areas which are already regulated or which do not affect many stakeholders can be more limited in scope. The impacts shall be analysed from different perspectives. This RIA, therefore, affecting the single-engine helicopter sector, considers in particular the following items for the impact assessment:

- Safety;
- Social;
- Environment;
- Economic;
- Proportionality issues; and
- Regulatory harmonisation.

Time horizon of the impacts and take-up period

The impacts assessed and which were possible to quantify have been presented as impacts per year. However, taking into account the long life-circle of helicopters (some 30 to 40 years), the impacts were assessed with the view on this time horizon.

The take-up period refers to the time period necessary for the full materialisation of costs and benefits as a result of the implementation of Option 1. Costs and benefits would reach their full extend only when the whole European fleet is fully replaced. This means that most of the costs and benefits are smaller initially and increase in time. Currently the European single-engine helicopter fleet has an average age of 16,5 years, while the median has an age of 12 years[21]. At the same

20 http://easa.europa.eu/rulemaking/docs/procedures-and-work-instructions/WI.RPRO.00046%20%20Regulatory%20Impact%20Assessment%20(RIA)%20Methodology.pdf.

21 Data from analysis conducted on the helicopter database in the possession of NLR.

time as much as 10% of the fleet is older than 40 years. It can be expected that in order to realise the full safety, economic and environmental impacts of Option 1, up to 40 years would be needed.

10.1.2 Assessment methodology: multi-criteria analysis

The analysis of the impacts of the options as described in Chapter 9 should be done in line with the scale of the issue considered as well as based on the availability of data. Different methodologies exist for the execution of a RIA, e.g. a Cost-Benefit Analysis, a Cost-Effectiveness Analysis or a Multi-Criteria Analysis. Taking into account the limited data available for the single-engine helicopter market as well as the fact that the existing data is a mix of quantitative and qualitative information, the multi-criteria analysis (MCA) was selected for the assessment of the proposed options.

Multi-criteria analysis recognises the various dimensions of the available data and the fact that economic, social and environmental impacts are hard to compare. MCA brings together the views of different stakeholders. It is well suited for managing and evaluating programmes in which opinions of different stakeholders can be expressed jointly without losing any of their specificity or making too many concessions regarding their value scales. Furthermore, the analysis can be used with contradictory judgment criteria (for example, comparing jobs with the environment) or when a choice between the criteria is difficult. The text below describes a general stepwise approach to MCAs.

Steps followed in the Multi-Criteria Analysis

Assessment criteria for the options

In this step the criteria are arranged in groups and an effects table is constructed in which each criterion is scored according to different scales (e.g. €, ratio, ordinal, nominal, --/++). Problem analysis is done in Chapter 3.Options are described in Chapter 9. The options are assessed against a wide range of criteria derived from the objectives of Regulation (EC) No 216/2008[22] and following the requirements of the RIA as described in Table 10.1.

Table 10.1 Assessment criteria for the options

Assessment criteria	Objectives
Safety	Maintain or improve the level of safety.
Economic	Ensure cost-effectiveness. Ensure 'level playing field'.
Social	Avoid negative effects on employment in the industry and ATC. Promote high-quality jobs.
Environmental	Avoid negative effects on the environment.
Proportionality	Ensure proportionate rules for Small and Medium-sized Enterprises (SMEs), General Aviation, Business Aviation, public clients.
Regulatory harmonisation	Ensure full consistency with EU laws and regulations. Ensure compliance with ICAO Standards (if appropriate). Achieve the maximum appropriate degree of harmonisation within Europe.

[22] REGULATION (EC) No 216/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC.

Some of the assessment criteria are expressed in monetary values while others, due to limited amount of data, are assessed in a qualitative manner. The overview of the areas assessed in a quantitative and qualitative manner is presented in Table 10.2.

Table 10.2 Quantitative and qualitative assessment of different areas

Assessment areas	Quantitative assessment	Qualitative assessment
Safety	√	
Social		√
Environment	√	
Economic	√	√
Proportionality issues		√
Regulatory harmonisation		√

Each of these areas is analysed and assessed in Chapter 11. For the purposes of assessing various criteria, literature research was conducted. Additionally, it was complemented by interviews with leading helicopter manufacturers. These are listed in Annex B.

The data and information obtained is used for the calculation of the effects on the European level (European based). The market shares are estimated for European and non-European sales of helicopters per year.

Standardisation of effects

The effects are standardised on a scale. This can for example be done on the basis of a linear value function between the lowest and highest score (range standardization) or by standardizing at the highest score (maximum standardization). For the purposes of this RIA, the linear value function was selected to be able to assess also small differences between the different effects of the options. An indication of the meaning of the values with which effects are ranked is presented in Table 10.3.

Table 10.3 Standardised scale for assessment of effects

Effect	Value
very negative	-5
medium negative	-3
slightly negative	-1
neutral	0
slightly positive	1
medium positive	3
very positive	5

After the calculations and assessment done in the previous step, the effects are expressed in quantitative and qualitative terms. The standardized scale is then used for all of the effects in order to ensure a standardized way of assessing them.

Construction of weights

Usually the weighting is done by a group of experts on the subject under investigation, or by those who ultimately must make a decision. For the purposes of the RIA, the helicopter operations, safety and IA experts have assigned the weights to the different assessment criteria. Weight 3 has been assigned to safety; weight 2 has been assigned to economic, social and environmental impacts as well as proportionality issues; weight 1 has been assigned to the regulatory coordination and harmonisation. This is presented in Table 10.4.

Table 10.4 Weights assigned to different assessment criteria

Assessment criteria	Weight
Safety impact	3
Environmental impact	2
Social impact	2
Economic impact	2
Proportionality issues	2
Regulatory coordination and harmonisation	1

Ranking of the options

This is the final step in the MCA. The weights are multiplied by the standardized scores and then summed for each alternative. Options are compared by combining their respective weighted scores and the alternatives are ranked according to their total score. After all impacts for each main issue and each related policy option have been identified, in relation to the specific objectives, the results are presented in summary in an impact matrix. Conclusions are drawn from the MCA.

10.2 Data requirements

The helicopter data analysed originated from one of the databases of NLR. The data include an overview of the helicopter fleet operated in Europe for non-military purposes. It includes the number of helicopters in use per year per type. For the purpose of this analysis, the helicopters have been grouped into four main categories according to their Maximum Take-Off Mass and Engine type. The criteria for the categorisation used in the next steps of the study are presented in Table 10.5. The four helicopter types used in the safety analysis (interim report) are each considered to be the typical representative of a respective category. The specific helicopter types that fall under each category according to their characteristics can be found in Table 7-1.

Table 10.5 Main single-engine helicopter types and the categorisation used

Category	Representative helicopter model	Maximum Take-Off Mass range (kg)	Engine type	Units in the current fleet[23]
Category 1	HeliSport CH-7 Kompress	400 - 800	Piston	35
Category 2	Robinson 44	800 - 1400	Piston	1380
Category 3	Bell 206B-3 JetRanger III	1000 - 1800	Turbine	585
Category 4	Aerospatiale 350B Ecureuil	1800 - 3000	Turbine	1095
Total				3095

Additionally, a literature review was done for the impact assessment purposes. It mainly covered information of the helicopter market sector, focusing on the single-engine helicopters in Europe, the data on the performance of the helicopters, fuel usage, CO2 emissions, employment in the sector, status of the regulatory issues, structure of the market, etc. The data and information collected was further supported by the information received through interviews with the key industry representatives.

[23] Data from analysis conducted on the helicopter database in the possession of NLR.

11 Analysis of Impacts

This chapter provides an analysis of the expected impacts of options described in Chapter 9. The impacts analysed and described are:

- safety impacts;
- economic impacts;
- social impacts;
- environmental impacts;
- impacts on proportionality issues;
- impacts on regulatory harmonisation.

The summary of the impacts and the conclusions are presented in Chapter 12.

11.1 Safety impact

Following the safety analysis, it can be concluded that the maximum safety impact of all examined Options, as compared with the “do nothing” scenario is that approximately 22 accidents could have been avoided during the period of 2000-2011 (2 accidents per year), saving the lives of about 13 people (1.2 person per year). The full extent of these safety gains would not be realised in the first year after implementation of the examined Options but only after 30 to 40 years when all the single engine helicopters meet the new safety standards.

Option 1A/1B

The allowable response time requirement is set at the same level for both sub-options. Thus the safety impact of options 1A and 1B is expected to be the same and is therefore not calculated separately.

Options 1A/1B have a significant potential to bring the majority of these safety gains. It has been estimated that Options 1A/1B could bring a maximum safety gain at a level of 80%. This means that in total, a maximum of 80% of the 22 accidents that happened over the period 2000-2011 and which were related to a “late response to start autorotation” would have been avoided with Options 1A/1B in place at that time. The maximum safety gain of Options 1A/1B is 17.6 accidents and 10.5 fatalities prevented in total in that period. This means that Options 1A/1B would lead to safety gains of 1.6 accidents, 0.95 fatalities prevented per annum.

In order to estimate the number of injured persons, the accidents that happened in the past years were analysed from the point of view of how many people passed away while being on board of a piston helicopter and how many were on board of a turbine helicopter when the pilot did not manage to enter a autorotation successfully. Then, an average number of crew and passengers was estimated for both types of helicopters. In order to do that, a review of the main types of helicopters was done and the average number of seats was reviewed. For the purposes of the analysis, it was assumed that on average there are 2 persons on board including an average of 1 crew member. The average number of injuries prevented per year was estimated by multiplying the number of accidents prevented per year by the average number of persons on board of the helicopters minus the number of fatalities prevented.

In order to express the safety gains of Options 1A/1B, the value of prevented fatalities, injuries and equipment loss were calculated. For the purposes of calculating the value of prevented fatalities, the average value of statistical life was used[24]. Additionally, the compensation for the crew that passed away was estimated[25]. As presented in Table 11-1, the annual safety benefits of preventing fatalities of crew and passengers as a result of Options 1A/1B are estimated at the level of €1.80 million.

For the purposes of calculating the value of prevented injuries, based on the average value of statistical life[26], an estimation of average value of preventing injuries was calculated[27]. Additionally, the compensation for the crew that passed away was estimated[28]. As presented in Table 11-1, the annual safety benefits of preventing injuries of crew and passengers as a result of adopting Options 1 are estimated at the level of €0.90 million.

Finally, an estimate of the equipment loss was calculated. In order to do that, the average price of each of the helicopter categories (1 to 4 as presented in Data requirements section of Chapter 10) was estimated for all of the age categories currently in use. This led to the estimation of the average price of a single-engine helicopter in Europe. It was assumed that an accident of a single-engine helicopter leads to a 100% loss of equipment. As presented in Table 11-1, the annual safety benefits of preventing equipment loss as a result of Option 1 are estimated at the level of € 1.23 million.

Table 11.1 Safety benefits of Option 1A/1B

Item	Value
Number of accidents prevented per year	1.6
Cost of loss of machine	€ 767,000
Equipment loss costs prevented	**€ 1,227,000**
Number of fatalities prevented per year	0.95
Value of statistical life	€ 1,824,500
Fatalities costs prevented	€ 1,725,000
Compensation for crew fatalities	€ 71,000
Fatalities prevented	**€ 1,796,000**
Number of injuries prevented per year	2.25
Average cost of injury	€ 374,000
Injuries costs prevented	€ 843,000
Compensation for injured crew	€ 56,000
Injuries prevented	**€ 900,000**
Total safety benefit per year	**€ 3,923,000**

To conclude, the total maximum safety benefits resulting from the full implementation of Option 1 are expected to prevent 1.6 accidents, 0.95 fatalities, 2.25 injuries per year. The total expected benefits of Option 1 are at the level of € 3.92 million per year. Compared to an overall average of

24 Eurocontrol, Standard inputs for CBA, 2009.
25 Expert judgment.
26 Eurocontrol, Standard inputs for CBA, 2009.
27 Revised Department Guidance: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analysis, February 2008.
28 Expert judgment.

around 80 accidents with single-engine helicopters per year in Europe, the safety benefit is thus relatively small.

Option 3

Due to the limited take-up potential of Option 3, it is assessed to have a limited capacity to bring safety benefits. Since the requirements related to the allowable response time are the same as those in Options 1A/1B, Option 3 could bring a maximum safety gain at a level of 80%. However, the take-up potential of Option 3 is considered to be around 12% of the market (see chapter 9). Thus, the overall potential safety benefit of Option 3 can be estimated to be: 80%*12%=9.6%.

This means that in total, a maximum of 9.6% of the 22 accidents and 13 fatalities that occurred over the period 2000-2011 and which were related to a "late response to start autorotation" would have been avoided with Option 3 in place at that time. The maximum safety gain of Option 3 is 2.11 accidents and 1.25 fatalities prevented in total in that period. This means that Options 1A/1B would lead to safety gains of 0.19 accidents, 0.11 fatalities prevented per annum. The safety benefit of Option 3 has been calculated in a similar way as that of Options 1A/1B, and the results can be seen in the following table.

Table 11.2 Safety benefits of Option 3

Item	Value
Number of accidents prevented per year	0.192
Cost of loss of machine	€ 767,000
Equipment loss costs prevented	**€ 147,000**
Number of fatalities prevented per year	0.11
Value of statistical life	€ 1,824,500
Fatalities costs prevented	€ 207,000
Compensation for crew fatalities	€ 9,000
Fatalities prevented	**€ 216,000**
Number of injuries prevented per year	0.27
Average cost of injury	€ 374,000
Injuries costs prevented	€ 101,000
Compensation for injured crew	€ 7,000
Injuries prevented	**€ 108,000**
Total safety benefit per year	**€ 471,000**

As presented in Table 11.2, the annual safety benefits of preventing fatalities of crew and passengers as a result of Option 3 are estimated to be at the level of € 0.22 million, the annual safety benefits of preventing injuries of crew and passengers as a result of adopting Options 3 are estimated at the level of € 0.11 million. Finally the estimation of the equipment loss is at the level of € 0.15 million. All together, the total safety benefit of adopting Option 3 is estimated to be € 0.47 million. As expected this is a portion of the safety benefit that can be obtained by Options 1A/1B.

Table 11.3 Summary of safety impacts

Option	Total safety benefit per year	Assessment of effects	Weight	Weighted score
Option 1A/1B	**€ 3.9 million**	2	3	6
Option 3	**€ 0.47 million**	1	3	3

On top of the safety benefits presented above in a quantitative manner, additional benefits could be expected. These include prevented costs of:

- Site contamination;
- Search and Rescue incl. emergency services;
- Accident investigation;
- Third party damage including material damage (buildings) and costs of business interruptions.

The above-mentioned cost categories are difficult to calculate for single-engine helicopters. It is expected, however, that they would increase safety benefits of the examined options only to a small extent and proportionally to the calculated safety benefit components.

11.2 Economic impacts

Within the economic impact assessment an attempt was made by the study team to identify all cost elements that contribute to the overall cost of introduction of the options that have been assessed. The cost assessment was done based on the information provided by the manufacturers and desk research conducted by the study team.

The following costs were assessed:

One-off costs:
The one-off costs that are examined below, are costs that are induced at full extent, regardless of the take-up rate of the intervention and the replenishment rate of the existing helicopter fleet. These are distinct from the recurring costs (addressed later) that reach full extent only when the current single-engine helicopter fleet is fully replenished with models complying with the future regulation.

Development for a model and its derivatives
Some of the manufacturers have already conducted research projects on possible technological solutions to increase the allowable response time. Other companies are conducting such research at present. Some of the manufacturers have not focused their research much on this subject. The research projects conducted and technologies considered by the industry were part of the analysis described in chapter 8:

- Adding emergency power source;
- Increasing rotating system inertia;
- Automatic lowering of collective control.

Some of these solutions are relatively simple to develop while others are very complex including all sorts of issues with respect to the overall integrity of the used systems, Human-Machine Interface (HMI) challenges, changes in the scope and complexity of certification, etc. The manufacturers provided very different figures for the expected development costs associated with the developed options. These varied from € 1 million to as much as € 20 million dependant on the scope of the changes.

In case these solutions are developed in parallel to the design of a new model, then the design cost for the other helicopter systems will not be significantly higher than normal. Then the only additional costs induced would be those of the relevant research programme to develop the technological option. The European manufacturers indicated during our interview programme, that the average duration of a research programme to explore the full potential of technological changes needed to the existing types of helicopters would last a minimum of 2 to 3 years and would involve an additional minimum of 2 to 3 full time employees summing up to a minimum of 4 to 9 man years plus additional efforts from the existing staff in different departments as well as any other costs related to the physical components or systems alterations. Average annual salary costs of high skilled labour in Europe were estimated at the level of € 55,500 per year per full time employee[29]. The total salary costs as part of the development costs are thus estimated at the level of approximately € 220,000 to € 500,000. However, other cost elements like overhead and non-salary costs of research projects should not be neglected as they might be even higher than the labour costs and can vary depending on the structure of each company. For the purpose of this study the assumption that adding those cost elements doubles the total costs of a research programme is made. Thus, the final costs for developing the suggested technological solutions is calculated to be between € 440,000 and € 1,000,000 to be borne by industry.

Certification impact

New technological improvements introduced as for example indicated by Option 1 may require new certification standards applicable to not only the new technological systems but also to the systems on board of the helicopter that might be related to it. In the case of more complex solutions (examined by Option 1B) that require more significant changes to other systems on board of the single-engine helicopter, the certification tests needed might change. For example the automated collective lowering system and the auxiliary electrically-driven power source solutions would both involve the addition of auxiliary systems. Designing these new systems and ensuring their overall integrity would require additional efforts and possible new or changes in the existing standards for their operation. This could also have an impact on the duration of the certification programme while the costs of certification could increase.

It is expected, therefore, that the implementation of the new technological solutions aimed at increasing the safety of the helicopters under the examined options could effect small changes to the existing certification programme and their related costs. As indicated by some manufacturers, certification costs should be added on top of this amount and are estimated to represent some 10% of the total development costs.

All in all, Option 1A could be seen as a relatively small technological change, and thus would inflict little additional costs in the development phase of a new model. One could argue that adding tip weight is not something that would need a big research effort, as in the past, helicopters were equipped with heavier rotor systems. On the other hand, just adding weight without any research and additional development effort, and how that would affect a new helicopter model, is also not considered realistic. Therefore, we will apply a conservative estimate and take into account the lower bound of the bandwidth indicated above. Option 1B, which involves the development of new auxiliary systems that might have a more significant impact on the other model systems, would most probably be neared the higher end of the development cost margin given. Finally, Option 3 is considered to have the same costs as option 1A. Although it is not a mandatory option, manufacturers would still need to make costs in order to offer the safety features for their helicopters for the market segments for which they consider this a unique selling point. Table 11.4 summarises the development costs per examined option.

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[29] Ecorys, 2009, Competitiveness of the EU Aerospace Industry with focus on: Aeronautics Industry.

Table 11.4 Development cost per option

Option	Development cost
Option 1A	**€500,000**
Option 1B	**€ 2,500,000**
Option 3	**€ 500,000**

Production

It is expected that the implementation of either option would require new production tools and processes. This, however, would not differ from the "Do nothing" Option 0 where normal developments of new helicopters are expected to take place. It is expected that the implementation of either Options 1A/1B or Option 3 would not have a significant additional impact on the production costs.

Recurring costs

Operating costs, including fuel consumption, training and maintenance

Following the assessment of the technical solutions for the selected four types of helicopters, it is expected that the helicopters mass would increase. Therefore, in order to fly the same distance, additional fuel would be required. Table 11.5 presents an overview of the additional fuel mass needed per type of helicopter under each category (selected models) and the additional cost of that fuel.

Table 11.5 Additional fuel needed per helicopter category (all policy options)

	Range (km)	Additional fuel needed (kg)	Additional consumption (kg/h)	Average unit operating hours/year	Annual additional consumption per unit (kg/year)	Additional fuel estimation per helicopter unit (litres/year)	Additional fuel cost per helicopter unit per year (Euros)
Cat 1	320	2	1.000	50	50	69.348	€ 105.29
Cat 2	644	10	3.333	550	1,833	2,542.765	€ 3,860.60
Cat 3	682	18	3.913	480	1,878	2,362.592	€ 1,348.27
Cat 4	667	10	2.273	370	841	1,057.747	€ 603.63

With an indicative average of around € 130 per hour for direct operating costs[30], the actual increase of the total direct annual operating costs would be between 1% and 5%. Pending on the implemented technology that could increase the allowable response time to the pilot, additional training could be necessary. It is however not expected that it would be significant. Also, additional maintenance would most likely be needed but is not expected to be significant. If the additional fuel costs per unit per year from the above table are applied to the current single-engine helicopter fleet, an overall value of € 6.7 million additional recurring costs results. This outweighs the annual safety benefits of € 4 million, as presented in the previous section.

The calculation of the additional fuel needed and the relevant costs per helicopter stands for all examined policy options. What would vary between policy Options 1A/1B and Option 3 is the penetration level of these additional costs. Whilst for Options 1A/1B, at full replenishment of the fleet, additional costs would apply to the whole of the fleet, for Option 3, additional costs would apply only to 12% of the fleet, meaning that the additional operating costs of Option 3 would be 12% of the additional costs of Options 1A/1B.

30 http://helicopterwise.com/the-all-new-cabri-g2/.

Continued airworthiness

The continued airworthiness in the EU is covered by the Commission Regulation (EC) No 2042/2003 of 20 November 2003 (as amended) on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks. The European Aviation Safety Agency has applied fees for its certification activities since 1 June 2005. The current fees are detailed in the Fees & Charges Regulation (EC) N0 593/2007 which was adopted by the European Commission on 31 May 2007 and published in the EU Official Journal on June 1 2007. It is expected that the possible implementation of Option 1 and 3 would not have a significant impacts on the continued airworthiness.

Other economic impacts

Impact on the helicopter selling price

Some manufacturers argued that the price of a helicopter would increase significantly as a result of applying the examined policy options. Other manufacturers indicated a moderate price increase. One stated that a broadly adopted rule-of-thumb applied in the single-engine helicopter manufacturing industry states that for every kilogram added to the helicopter mass approximately € 2,000 should be added to the production cost and therefore, also to the sales price of the single engine helicopter. This rule-of-thumb refers to additions of weight without changing significantly the current helicopter design, such as in Option 1A. In case the additions require auxiliary systems (Option 1B) this indicative price might be even higher, depending on the cost of the specific materials used. All of the manufacturers indicated that the final impact on price would depend on the exact type of the helicopter, the way it is currently designed and the extent of changes it would require. The ranges they have given were between 10% up to even 50% increase in the selling price.

In order to sense-check this value of € 2,000 per kilogramme, some key figures of current mass of helicopters and their sales price were examined. This is presented in the following table.

	Base price (€)	Empty weight	€ / kg
Helecopteres Guimbal Cabri G2	249000	430	579
Schweizer 300 CBi	208741	500	417
Robinson R22 Beta II	167832	387	434
Robinson R44 Raven I	230769	656	352
Robinson R44 Raven II	279720	685	408
Average			438

Looking at difference between the Robinson R44 Raven I and its derivative the Raven II, there is a value of approximately €1,700 per kg added. However, the table indicates that on average for these five helicopter types including new types, the average is about € 438 per kilogram. However, the base price difference between these types is not only caused by a mass increase, but also by different specifications of these helicopters. As such, the average of € 438 per kg is therefore also not the optimal proxy indicator. Therefore, the study team takes the average of the two proxies (€ 438 and € 2,000) as input for sales price estimate of the options, i.e. € 1,200 per kg.

Taking this average, the impacts on the selling price of new helicopters are estimated to be as follows:

Table 11.6 Estimated impact on price of single engine helicopters

	Cat 1	Cat 2	Cat 3	Cat 4
Sales prices in 2013	€ 237,000	€ 375,000	€ 1,395,000	€ 1,820,000
Average additional mass*	45.5	75.5	115	94.5
Additional price	€ 55,000	€ 91,000	€ 138,000	€ 113,000
New price	€ 292,000	€ 466,000	€ 1,533,000	€ 1,933,000
Price impact %	23%	24%	10%	6%

* The average additional mass was calculated based on the results of the simulations conducted by NLR for increasing rotating system inertia and for installing an emergency power source. The values presented include the weight of additional fuel needed.

For simplicity reasons, it was estimated that implementing either Option 1A or Option 1B would result in the helicopter unit price increase by around 15% (weighted average) as compared to the "do nothing scenario". However the price rise would probably be a bit higher for Option 1B than for Option 1A. Option 3 would lead to the same price increases for the new models that would comply with the directive in a voluntary base (earlier estimated to be 12% of the fleet).

Other economic impacts: Impact on the market

Option 1A/1B

A weighted average of 15% increase in the selling price of the single-engine helicopters is obviously expected to impact the market. The extent to which this indeed leads to an overall loss of revenues for manufacturers and whether European manufacturers' competitive position is affected negatively is difficult to quantify in this study.

Most of the interviewed manufacturers argue that the price impact is expected to be significantly negative or could lead to a significant shrinking of the single-engine helicopter market in Europe or even beyond. Of course the impact on the market would be more significant for larger price increases. This would imply that a slightly lower price increase, as expected by Option 1A, would have a lower negative impact on the market than that of Option 1B. The manufacturers indicate that only a very small share of the European clients is not very price sensitive and would be willing to accept the mentioned price increase with the guarantee of the increase in safety (as shown by the Guimbal Cabris G2 case earlier). Therefore, in their view only a very small share of the European helicopter users is expected to be willing to pay more for the additional safety. This share is expected not to exceed a small percentage of the overall users of single-engine helicopters (private, corporate and training helicopter use). Some other operators may just reluctantly accept the price increase as using small helicopters is a part of their business they can not somehow substitute. Industry experts expressed the view that the remaining vast majority of the sales is extremely price sensitive and it is expected that the remaining clients would not be willing to accept a sharp price increase as assessed before. Most of them would prolong the usage of their current fleet, as much as possible before deciding to replace their helicopters.

It should be taken into account that the significant market decrease indicated by manufacturers is obviously a biased view. The price elasticity of demand for single-engine helicopters could not be found in open source literature and the manufacturers' statements could unfortunately not be quantitatively verified. A counter argument would for example be that the price increase might not so much lead to an overall demand decrease, but to demand shifts, e.g. between categories in the single-engine helicopter market or between single-engine helicopters and twin-engine helicopters. Additionally, the price increase would be valid for all manufacturers, hence the overall competitive position between them does not seem to alter. Finally, the average age of the current single-engine helicopter fleet in Europe is about 17 years. Assume thus an economic lifetime of at least15 years, then the maximum price increase foreseen (€ 138,000 for cat 3 helicopters) leads to an annual increase of depreciation costs for operators of € 9,200 which seems relatively limited in such capital-intensive industries.

On a balance it is expected that the impact on the market is negative, probably slightly more for Option 1B than for Option 1A. As a consequence, it is expected that the revenues from sales of single-engine helicopters in total would decrease for both Options 1A/1B. This may be offset though by increased sales of twin-engine helicopters and increased MRO activities for helicopters that operators may tend to keep operational for a longer period.

Additionally, it is important to mention the issue of harmonisation between Europe and other parts of the world. If Options 1A/1B are implemented in Europe, it is expected that EASA will cooperate with the FAA in order to harmonise the certification standards. If this takes place, the impacts on the market will be wider than Europe and will extend to the USA and possible other parts of the world.

Option 3

Contrary to Options 1A/1B, the case for Option 3 here, is different. Since this Option is not a mandatory one, hardly any impact on the market is expected. Single-engine helicopter market is expected to largely remain the same, with the exception of the newly, voluntarily developed helicopter models. These will capture the market segments that are willing to accept higher unit prices for increased safety. In total, revenues from helicopter production would slightly increase, as the (limited) shift to the new models will come at a higher price. Thus the market will grow, not in matters of volume, but rather in turnover.

To conclude, the impacts of Option 1A/1B on the market are expected to be negative as compared with Option 0. Also Option 3 is expected to have a slightly negative impact. The economic impacts of the examined policy options are summarised in Table 11.7.

Table 11.7 Summary of the economic impacts

Option	Non-recurring costs	Recurring costs	Impact on final price	Impact on the market	Average impacts score	Weight	Weighted score
Option 1A	-1	-2	-2	-2	-1.75	2	-3.5
Option 1B	-3	-2	-2	-2	-2.25	2	-4.5
Option 3	-1	-2	-1	1	-0.75	2	-1.5

11.3 Social impact

Options 1A/1B

The total employment in Europe that can be associated with the direct manufacturing of single-engine helicopters market is approximately 3,900-4,200 full time employees, excluding employment at suppliers. As described in the previous section, the implementation of Options 1A/1B as compared to the “do nothing scenario” are expected to have a negative impact on the selling price with a possible implication for the demand for single engine helicopters. This could impact the jobs at the manufacturers to some extent. A positive impact however would be the need for additional research capacity to develop the technical solutions.

Option 3

On the other hand, adopting Option 3 has been assessed to probably have a slightly positive impact on the sales of single-engine helicopters. Since manufacturers would continue their activities normally, the overall effect to employment would be marginally positive representing the additional labour force applied to produce the higher-value helicopters that would comply with the new standards.

Social impacts of the examined policy options are summarised in Table 11.8.

Table 11.8 Summary of the social impacts

Option	Assessment of effects	Weight	Weighted score
Option 1A	-1	2	-2
Option 1B	-1	2	-2
Option 3	0.5	2	1

11.4 Environmental impact

Following the assessment of the various technological solutions that could be used in order to increase the available pilot intervention time in case of an engine failure on board of a single engine helicopter, it was concluded that new solutions would require additional weight. This additional weight of the helicopters means that in order to fly over the same distance, the helicopters would require additional fuel. And as a consequence, they are expected to burn more fuel and produce more CO_2 emissions. The additional CO_2 emissions per helicopter unit as a result of the implementation of the examined technological improvements to the helicopters are presented in Table 11.9.

Table 11.9 Impact on CO_2 emissions per helicopter unit due to change in fuel consumption

	Cat 1	Cat 2	Cat 3	Cat 4
Additional fuel (in kg)	2	10	18	10
Annual additional fuel consumption per unit (kg/year)	50	1,833	1,878	841
Additional fuel estimation * (litres/year)	69.35	2,542.76	2,362.59	1,057.75
Additional CO_2 emissions (kg/yr)	153.05	5,611.95	6,092.80	2,727.79

* Based on 2010 fleet figures.

As can be viewed in Table 11.9, the impact on CO_2 emissions of the examined technological solutions are moderate. For helicopter categories 2 and 3, the increase in emissions can be more than 5,000 kg of CO_2/year per helicopter unit and for category 4 more than 2,000 kg of CO_2/year per helicopter unit. The impact for category 1 is rather limited, less than 200 kg of CO_2/year per helicopter unit. When these values are put in the overall perspective of total CO_2 emissions from helicopters in Europe, the increase may be considered as relatively limited.

Option 1A/1B

This impact on CO_2 emissions due to the change in fuel consumption of the helicopters as a result of the increased weight of the helicopters reaches its full extent and is expected to be the same for Options 1A/1B.

Option 3

The impact on CO_2 emissions of adopting Option 3 is expected to be lower than that of Options 1A/1B, due to the low expected penetration of the technological improvements (around 12%). However, in this option, the market is not expected to shrink to partly compensate for the increase in emissions. All in all the environmental impact of Option 3 is expected to be slightly negative and also lower than that of Options 1A/1B.

Finally, it is expected that the increase in safety of the single-engine helicopters and a significant decrease in the number of accidents would lead to a less debris of helicopters that crash. Due to the number of accidents prevented per year, this impact is expected to be rather small for all examined options.

Table 11.10 Summary of the environmental impacts

Option	Assessment of effects	Weight	Weighted score
Option 1A	- 1	2	-2
Option 1B	- 1	2	-2
Option 3	-0.5	2	-1

Table 11.10 concludes the comparison with Option 0. It is expected that the implementation of Option 1A/1B would have a small to moderate negative environmental impact as a result of additional fuel burnt. Moreover, Option 3 is expected to have a very small negative environmental impact compared to the base case.

11.5 Proportionality issues

The helicopter market in Europe is dominated by a few large companies. There are, however, a few small and medium sized enterprises (SMEs) producing single-engine helicopters in Europe. Some of them produce helicopters that fall within the scope of EASA (Guimbal) while some others not (CH-7 Helisport). These are often family owned companies producing very light helicopters. As described in the sections above, it is expected that the implementation of Options 1A/1B will have a significant impact on the selling price of single-engine helicopters and especially the smaller models.

Looking especially into the helicopter models produced by SMEs, CH-7 Helisport falls out of the EASA scope and thus it is not expected to be influenced by the examined options. It might even gain market share, should the proposed regulation cause significant impact on their completion. The other SME that has helicopters in this category, Guimbal, produces one of the helicopter models, the Cabri G2, that is closer to achieving the proposed standards for allowable response time. In this case the market stance of Guimbal is not expected to be considerably deteriorated due to an increase in its market price, while it might even rise in case the competition is dealt with a significant impact. In any case, for all the examined options, the impact on proportionality issues is expected to be minimal if not zero as summarised in Table 11.11.

Table 11.11 Summary of the impacts on proportionality issues

Option	Assessment of effects	Weight	Weighted score
Option 1A	0	2	0
Option 1B	0	2	0
Option 3	0	2	0

11.6 Impact on regulatory coordination and harmonisation

It is expected that increasing the certification requirement for the allowable response time following a power failure would not cause a significant burden for regulators.

If either Options 1A/1B or Option 3 is implemented, there should be additional coordination and harmonisation with FAA and possibly other administrations. Just like in the case of Europe, it is expected that the possible harmonisation of standards with other administrations would not bring major additional costs. It is important to remember, however, that most of the countries in the world accept the current European certification standards while others have lower standards.

Table 11.12 Summary of the impacts on regulatory harmonisation

Option	Assessment of effects	Weight	Weighted score
Option 1A	0	1	0
Option 1B	0	1	0
Option 3	0	1	0

It is expected that the implementation of either Option would have a fairly limited impact on the regulatory coordination and harmonisation as compared to Option 0. The exception could be potentially applicable to certification procedures and standards for certifying the newly designed helicopter models. The summary of impacts is presented in Table 11.12.

12 Summary and Conclusions

This chapter provides a summary of the main impacts and the conclusions and recommendations.

12.1 Summary of the RIA

Following the Multi-Criteria Analysis methodology, as described in the previous chapters, a Regulatory Impact Assessment to support future rule making on single-engine helicopters with increase pilot intervention times following power failure was prepared. The summary of the impacts of Option 1A, Option 1B and Option 3 as compared with the “do nothing scenario” are provided in Table 12.1, Table 12.2 and Table 12.3.

Table 12.1 Summary of impacts of Option 1A

Impact assessment areas	Assessment of effects (standardised scale)	Weight	Weighted score
Safety impacts	2	3	6
Economic impacts	-1.75	2	-3.5
Social impacts	-1	2	-2
Environmental impacts	-1	2	-2
Impacts on proportionality issues	0	2	0
Impacts on regulatory harmonisation	0	1	0
Total impacts			**-1.5**

Option 1A yields a positive safety impact, however, the impacts on economic, social, and environmental elements examined are moderately negative. It can be concluded that despite the possible safety gain, the negative impact on most of the other impact areas produces an overall slightly negative impact for Option 1A. The weighted total score of all the assessed impacts equals -1.5 indicating that Option 1A consists a slightly negative policy case.

Table 12.2 Summary of impacts of Option 1B

Impact assessment areas	Assessment of effects (standardised scale)	Weight	Weighted score
Safety impacts	2	3	6
Economic impacts	-2.25	2	-4.5
Social impacts	-1	2	-2
Environmental impacts	-1	2	-2
Impacts on proportionality issues	0	2	0
Impacts on regulatory harmonisation	0	1	0
Total impacts			**-2.5**

Similarly to Option 1A; Option 1B yields positive safety benefits. However the economic, social and environmental impacts of adopting this policy option where found to be negative. Specifically regarding the case of economic impacts, Option 1B deals slightly negative impacts than Option 1A, this being the point where they differentiate, as the development and price costs have been assessed to be higher for the development of new auxiliary systems than the adaptation of the currently existing ones. Option 1B produces an overall negative case, with the weighted total score being -2.5, thus ranking worse than Option 1A.

Table 12.3 Summary of impacts of Option 3

Impact assessment areas	Assessment of effects (standardised scale)	Weight	Weighted score
Safety impacts	1	3	3
Economic impacts	-0.75	2	-1.5
Social impacts	0.5	2	1
Environmental impacts	-0.5	2	-1
Impacts on proportionality issues	0	2	0
Impacts on regulatory harmonisation	0	1	0
Total impacts			**1.5**

Finally Option 3, produces a marginal safety benefit, nevertheless, this option manages to turn in slightly positive impacts also in the social areas of impacts, which together offset a slightly negative economic and environmental impact. Managing a weighted score of 1.5 the option of providing the relevant information to helicopter manufacturers and creating a standard that they are non-mandatory requested to comply with, produces a positive case.

12.2 Sensitivity analysis

To deal with the uncertainties that come along with this analysis and produce a more robust assessment of the impacts dealt by the different options, a sensitivity analysis is performed. Two variables have been chosen to test the robustness of the results:

1. The maximum safety impact captured by the increase in time available for pilot intervention (currently estimated at 80%);
2. The rule-of-thumb used to estimate price increase in case of weight increase (currently considered € 1.200/kg).

All options are tested as follows:

- For the safety impact against a 25% per cent fluctuation of the variables plus and minus;
- For the sales price impact against the bandwidth as presented in section 11.2.

This is summarised in Table 12.4:

Table 12.4 Sensitivity scenarios

Variable	Low scenario	Initial Value	High scenario
Maximum safety impact captured	60%	80%	100%
Helicopter price increase per kg of weight increase	438 € /kg	1,200 € /kg	2,000 € /kg

The results of the sensitivity analysis for the variable of maximum safety impact are given in Table 12.5. It can be observed that the fluctuation of the variable can have a significant impact on the absolute value of the safety benefit captured by the examined options. However, relatively to the overall potential safety benefit from improving helicopter safety, the value is still relatively low, like in our main assessment. As such, the standardised safety effect remains unchanged, and likewise the overall option ranking.

Table 12.5 Sensitivity analysis on maximum captured safety impact

	Low scenario	Initial Value	High scenario
Maximum safety impact captured	**60%**	**80%**	**100%**
Option 1A			
Safety benefit captured	60%	80%	100%
Total annual safety benefit	€ 2,942,000	€ 3,923,000	€ 4,904,000
Standardised safety effect	2	2	2
Overall option ranking	**-1.5**	**-1.5**	**-1.5**
Option 1B			
Safety benefit captured	60%	80%	100%
Total annual safety benefit	€ 2,942,000	€ 3,923,000	€ 4,904,000
Standardised safety effect	2	2	2
Overall option ranking	**-2.5**	**-2.5**	**-2.5**
Option 3			
Safety benefit captured	7.2%	9.6%	12%
Total annual safety benefit	€ 353,000	€ 471,000	€ 588,000
Standardised safety effect	1	1	1
Overall option ranking	**1.5**	**1.5**	**1.5**

The results of the sensitivity analysis for the variable of average helicopter price increase per kg of weight increase are given in Table 12.6. It can be observed that the fluctuation of the variable does affect the economic impacts of the examined options. The overall ranking of Options 1A/1B and option 3 changes slightly. However, option 1A is still only slightly negative. The sensitivity analysis of all three options yields also a minor impact on the social effects, since they are related to the growth of the market. However the effects there are even more marginal and not able to change the score the Options achieve in that area.

Table 12.6 Sensitivity analysis on price increase per weight increase ratio

	Low scenario	Initial Value	High scenario
Helicopter price increase per kg of weight increase	438 € /kg	1,200 € /kg	2,000 € /kg
Average helicopter price increase	5%	15%	25%
Option 1A			
Impact on price effect	-1	-2	-3
Impact on the market	*-1*	*-2*	*-3*
Standardised economic impact	-1.25	-1.75	-2.25
Overall option ranking	**-0.5**	**-1.5**	**-2.5**
Option 1B			
Impact on price effect	-1	-2	-3
Impact on the market	-1	-2	-3
Standardised economic impact	-1.75	-2.25	-2.75
Overall option ranking	**-1.5**	**-2.5**	**-3.5**
Option 3			
Impact on price effect	-0.5	-1	-2
Impact on the market	-0.5	-1	-2
Standardised economic impact	-0.5	-0.75	-1
Overall option ranking	**2**	**1.5**	**1**

To conclude, the sensitivity analysis exercise results in reinforcing the position of Option 3 as the best performing option, by proving it to be also the most robust option, yielding a positive overall score at all examined scenarios. On the other hand, Options 1A/1B remain with a negative score for all scenarios developed, despite their performance fluctuating significantly in between the different scenarios. If option 1A would truly lead to a minor price increase, the option is only slightly negative.

12.3 Conclusions and recommendations

Safety is one of the factors helicopter operators take into account when deciding to invest in a single-engine helicopter. It is an important factor, however, it is not the only one. Safety measures are likely to influence the sales price and recurring costs of helicopter operation. In that sense, any regulation imposed should be very deliberate in addressing economic impacts it might cause.

The literature search undertaken in this study indicates that the actual pilot response time to enter autorotation can be up to 3 seconds (for twin-engine helicopters), while certification requirements take into account an allowable response time of 1 second for cruise and 0.3 second for other flight phases. This study has identified a number of technological options that could increase the allowable response time available to the pilot. However, the study also indicates that these technological solutions could bridge the gap between the actual response time and available response time only to some extent and not entirely. Moreover, demonstrated actual response times for single-engine helicopters are not available. Increasing the time available to more than 2 seconds is not deemed realistic. Nevertheless, against the background of the safety impact analysis it is assumed that an increase in allowable response time to 2 seconds for all flight phases will avoid, as a maximum, 80% of the accidents caused by a “late response to start autorotation”. This leads to annual safety benefits, which are around € 4 million per year for Europe. While this number is substantial in absolute terms, relative to the total potential safety benefits from addressing all helicopter safety issues, they are relatively modest.

All technological solutions examined will lead to weight increases with consequences on helicopter prices. This is likely to affect market demand, although this depends on several factors. There are counterarguments, in the sense that the additional depreciation costs associated with the price increase is relatively modest in the overall perspective of the inclusion of helicopters in a company's asset base. Additionally, there may be a shift between segments in the single-engine helicopter market, or twin-engine helicopters may become more attractive.

Economically speaking, the impact on the recurring costs for operators, stemming from increased fuel burn as a result from the option's weight increase, is also important. Again this increase is relatively low in terms of the overall operating costs (as the safety benefits are relatively low compared to the overall potential safety benefits from helicopter safety), the absolute increase in recurring costs from the options 1A/1B does seem to outweigh the annual safety benefits on an annual basis. Nevertheless, as successful examples of integrating increased safety standards may come along (just like the Guimbal Cabri G2 referring to niche market segments) and the supporting technologies are getting more fine-tuned, the case might be that, in the not too distant future, conditions may become mature to implement the suggested regulation change.

All together, the regulatory impact assessment indicates that the policy options to impose mandatory requirements to manufacturers to increase the allowable response time following engine power failure to 2 seconds for all flight phases do not show a positive case if the safety impacts are compared with the economic, environmental and social impacts. The option to provide non-mandatory information however does provide a positive case.

All the above said it is recommended:

- Not to implement Options 1A/1B in the nearest future;
- To issue a recommendation to the manufacturers of helicopters to increase the allowable response time following engine power failure, to 2 seconds for all flight phases, as suggested by Option 3;
- To continue research in close cooperation with the industry in this area in order to try and materialise the significant safety benefits that are there, while trying to avoid the negative impacts as addressed in this study. EASA could for example open a Research Program to encourage European companies to stay on top of global innovation in this area.

Annex A: References

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Annex B: List of interviewed single engine helicopter manufacturers

List of the interviewed single engine helicopter manufacturers:

1. Eurocopter Group, an EADS Company, largest European helicopter manufacturer;
2. AgustaWestland, the Anglo-Italian helicopter company owned by Italy's Finmeccanica;
3. Bell Helicopter, a Textron company (headquarters in Texas, USA);
4. Robinson Helicopter Company (headquarters in Southern California, USA).

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