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Evaluating the Effect of Marker Balls as Means of Avoiding Wire Crossings:

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Evaluating the Effect of Marker Balls as Means of Avoiding Wire Crossings

for

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Executive summary:

Wire crossings can represent an aviation risk when flying low in un-controlled air space. Norwegian terrain is characterised by numerous valleys and fjords with wire crossings. Wire strikes are therefore a safety challenge in Norway. Although this safety challenge is known within Norwegian aviation, little documentation exists of this problem. This evaluation may therefore contribute to improved aviation safety.

The objective of the present study was to evaluate and establish an independent documentation of the *as is* situation with respect to the effect that existing marker balls may have on pilots' possibility of avoiding coming too close to wire crossings. Coming too close is defined as closer than 200-500 feet vertically and 5-10 seconds horizontally. Planned operations inside this area or below the wire crossing, such as construction work or power line maintenance, are outside the scope of this study.

In addition to a literature review, a mix of methods was used: Interviews and workshops with relevant stakeholders as inputs to a risk evaluation in the form of a Failure Mode Effect and Criticality Analysis (FMECA). This was supported by test flights and a final workshop for validation (quality check) purposes.

It was considered that marker balls can be beneficial for safety in many situations. It became clear, however, that these effects to a large extent were random. Marker balls were considered to have a systematic (significant) effect in two scenarios only. These scenarios were considered best case scenarios, i.e. the pilots could have managed almost as well without marker balls. The analysis did not identify any negative effects of marker balls.

Marker balls were, because of these limited effects, considered insufficient as a safety system.

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1.0 Introduction

In connection with a prospective revision of the ”Bestemmelser for sivil luftfart”, BSL E 2-2 (01), which includes regulations for marking of wire crossings, Obstacle Collision Avoidance System AS (OCAS) has asked DNV for an independent evaluation of markers’ suitability to alert pilots about the presence of wire spans. DNV has conducted this evaluation and the methods and results are presented in this report.

Wire crossings constitute a significant and well known risk to aviation. At the same time, the general development within the theoretical and practical field of aviation safety puts this specific risk in a different perspective today than two or three decades ago. Back then, it was a widespread belief that technology and procedures alone could guarantee aviation safety, and that the biggest threat was the inherent unreliability of humans.

This perspective on safety is prominent in accident reports from the 60’s and 70’s, where the conclusion typically is “the cause of the accident was human error”. Today, it is well accepted that most accidents should be seen as a result of organisational processes, where the so called “human error” is only the last in a chain of events. These organisational accidents have multiple causes and involve people on different levels within and outside of the organisation (34,38).

In line with this development, the perspective on human error has changed accordingly. From a situation where errors were considered as a sign of weakness and lack of professionalism, it is today accepted that errors and mistakes are a natural part of human behaviour. This must be managed like any other risk. One of the consequences of this perspective is that the aviation system must be able to tolerate human error. Barriers, safeguards, alarms or defences must be installed in order to prevent a human error from turning into an accident.

With regard to the wire crossings, human errors could typically lead to situations where the pilot comes so close to the wire crossing that avoidance is difficult or even impossible. The result can be a serious, potentially lethal, accident. Given today’s perspective on aviation safety, and given the fact that wire crossings are a well known aviation risk, it is probably not acceptable to rely only on the pilots in order to avoid such catastrophes.

The As Low As Reasonable Practicable (ALARP) principle has become widely accepted as a means to distinguish between acceptable and non-acceptable safety risks. For a risk to be ALARP it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained. It should be noted that with this type of acceptance criterion, the acceptance is actually allowed to change with time as new mitigation means become available and/or cheaper. This evaluation can contribute to such an update.

In this semi-quantitative analysis the wording 'significance' is used to distinguish a minor effect, which is considered random, from remaining significant effects of marker balls. This type of distinction between significant and not significant safety barriers is not uncommon[1].

[1] Safety barriers may, for example, be divided into marginal and major: Well-accepted standards like ESARR 4 (39) or IEC 61508 (40) introduce a subdivision between safety-function reliability of a factor 10. This means that additional functions which do not improve the safety by a factor 10 are considered marginal and are not officially considered as safety barriers.

The company funding this study, OCAS AS, is a commercial supplier of warning systems for power lines. Given the commercial interests involved, DNV has taken several steps in order to maintain the independence and integrity of this study:

- The objective is to evaluate and document the *as is* situation with respect to the effect that existing marker balls may have on pilots' possibility of avoid coming to close of wire crossings. Thus, the objective of this evaluation is not to evaluate the OCAS System nor to compare alternative systems with marker balls.
- DNV has utilised method triangulation, i.e. using multiple methods, to evaluate the potential effect of marker balls.
- DNV has consulted all stakeholder categories: Operative pilots, regulators, power line owners as well as subject matter experts from the field of aviation medicine and cognitive psychology.
- The results of the study are thoroughly validated (quality checked), both through test flights and through a workshop.
- In addition, the study has been subject to DNV's internal approval procedure.

2.0 Literature Review

As the first step of the study, a literature review was conducted. The review served two purposes:

1. To present a description of the extent and seriousness of wire strikes as an aviation safety issue.
2. To provide input to the analysis evaluating the effect of marker balls.

The search for literature has focused on Norway, the United States, Canada, Australia and New Zealand. These geographical areas represent some of the similar challenges related to wire crossings. The review included accident investigations of wire strikes, reports and articles on the subject, legislation and demands for marking of wire crossings. A general internet search with search terms "wire strikes", "wire strike", "wire strike accidents", "wire strike incidents", "wire strike investigations" etc. produced numerous hits, mostly from aviation industry reports and magazine articles. Finally, a search was conducted in academic databases such as Science Direct using the same search terms. This produced only a few, low relevance, hits.

Wire strikes have been identified as the most serious threat for low-flying aircraft (02). Wire crossings are difficult to see even under ideal conditions if one is not prepared and knows where to look (03,04). Others have described wires as a "hidden menace" virtually invisible from the air (05). That wires are extremely hard to spot seems to be a fact generally acknowledged by pilots with experience from flying in areas with wire crossings. Still, wire strikes have been a frequent cause of accidents within the aviation industry for several decades. This includes both private, commercial (such as agriculture and construction work) and military aviation.

2.1 Wire strike statistics in Norway

In Norway 16 accidents involving wire strikes have been investigated by the Accident Investigation Board from 1980 until today (03,6-19). Nine of these accidents involved rotary wing aircraft and seven fixed wing aircraft. 29 people have been killed in these accidents. The accidents occurred with non-scheduled general aviation or helicopters on occupational flying

(such as chartered trips or construction work). In addition, The Civil Aviation Authority in Norway has registered four non-lethal accidents and incidents involving wire strikes from 2003 until today (two helicopters, one fixed wing and one glider).

The Royal Norwegian Air Force has reported a total of 15 wire strike accidents or incidents from 1970 to 1999 (20). Nine of these involved fixed wing aircraft including five high performance fighters. The remaining six wire strikes occurred with rotary wing aircraft. In three of the accidents one or more people were killed. According to the Royal Norwegian Air force there is also reason to believe that a lot of near miss incidents involving wire crossings have been unreported (20).

The wire strike accidents account for a relatively small part of the total number of accidents involving VFR (Visual Flight Rules) flying (air taxi, aerial work, instruction, GA private and GA club) registered by the Norwegian CAA since 1980 (21). However, the statistics suggest that wire strikes more often tend to be lethal compared to other types of accidents.

2.2 Wire strike statistics in comparable countries

Wire strikes appear to be an even larger problem for aviation safety in other countries. In the United States, wire strike accidents or incidents are reported more than once a week to the National Transport Safety board (22). In Australia, 119 wire strike accidents, of which 34 fatal, were reported from 1994 to 2004 (23). Also in New Zealand and Canada wire strike accidents has been a challenge for the aviation industry. Between 1974 and 2006, there were 95 wire strike accidents in New Zealand, mostly involving helicopters, which resulted in 41 deaths and many serious injuries (24). The majority of these wire strikes have occurred in agricultural operations, forced landings and takeoffs and landings (25). In Canada a total of 190 wire strike accidents and incidents have been registered from 1989 till today (26).

Statistics on these issues are fragmented and not directly comparable. Still, the literature review indicates that wire strikes constitute a major aviation safety challenge, especially in areas with fjords and valleys.

2.3 Physiological aspects

According to the Federal Aviation Administration (FAA) of the United States, a typical response time in an emergency situation is around four seconds from a pilot detects a danger until he/she initiates an action (36).

The ease with which an object can be seen depends on various factors such as speed, distance between object and viewer, illumination, colour and contrast, position of target within the visual field, length of time viewing the object and atmospheric clarity (28). Each of these factors can either decrease or increase the visibility of an object.

A wire crossing is typically greyish with low contrast to the background. It occupies a relatively small part of the visual field and is often poorly illuminated, if not directly hit by sunshine. A wire can be clearly visible or disappear completely depending on the sun's angle.

In an article published by the Civil Aviation Authority in New Zealand it is concluded that the human eye is ill-equipped for seeing wires:

- *"The eye starts to lose its visual acuity at 3 degrees off-centre. At 10 degrees off-centre, you are legally blind. Unless you are looking straight at a wire, you are unlikely to see it."*(29)

Several quotations from accident investigation reports following wire strikes illustrate how wires can be difficult to see:

- *"The power line was invisible unless viewed at close range with knowledge it was there (…). The pilot did not see the power line before the aircraft struck it."* (30, p. 5).

- *"The wires were oxidized, and the background to the wires was dull terrain and trees. When viewing the film which was taken during the flight, the wires were not distinguishable from the background prior to the impact."* (31, p. 2).

- *"The chief pilot has simulated the approach pattern under identical weather- and lighting conditions. This particular wire span was totally invisible because of the angle of the sun and the glittering water surface background."* (18, p. 2)

- *"Such wire spans are difficult to see even under ideal conditions unless one is prepared and knows where to look"* (03, p. 11).

2.4 Evaluation of marker balls

A systematic trial was conducted in the US to compare different physical markers (32). The results showed that single coloured marker balls were visible at 1281 meters (4200 feet) under daytime conditions. The observations were conducted by people actively looking for the markers. The observers were located in the rear seat of the helicopter and were able to devote their full attention to the wires. How representative these findings are for real life operative scenarios is not known.

More recently, the CAA in New Zealand asked pilots to give feedback on the visibility of wires following the introduction of new markers (33). The feedback from the pilots was not uniform, but the wires were reported to be more visible with the markers than without them. Several of the pilots could also see the markers from their cars when driving. However, many needed a bit of time from spotting them to actually identifying them as marked wires. The reports from the pilots indicate that the larger markers were clearly visible under certain conditions and from specific angles. It seems that marked wires are most visible from positions above ore below the wire spans and less visible when the aircraft is flying directly towards the wires.

These are the qualified opinions from a handful of pilots concerning one specific wire span. It is important to note that these pilots knew were the wires were and searched actively for the markers in order to evaluate them.

2.5 Conclusions from the literature review

Differences in traffic volume are not adjusted for and the statistics can therefore not be directly compared between the countries. However, the accident statistics illustrate that wire crossings present a significant safety challenge for low flying aircraft in several countries.

The majority of the accidents appear to involve known, unmarked wire crossings which the pilots for some reason, for instance navigational errors, were not expecting. Based on the accident investigation reports it is difficult to conclude about the effectiveness of markers on wire crossing as an accident preventing measure. However, their theoretical functionality as an alarm seems limited.

To expect a wire crossing at an exact location appears to be an important determinant for the pilot's chance of detection in time to avoid a wire strike. Physical marking also appear to be most visible for pilots who know the exact location of the wire crossing.

These elaborations regarding how pilot expectations may be a main factor for the sufficient detection of wire crossings will serve as one hypothesis to be further explored in the interviews.

2.6 Pilot Situation Awareness (SA): Marker balls as alarm function

The aim of the Norwegian regulations for marking of wires is to "reduce the risk of aviation accidents or incidents" (01). Marker balls may contribute to reduced risk by making wire crossings generally more visible for pilots. Given that marker balls should reduce risk, then the concept of visibility must also include the time needed to avoid the wire crossing. However, such an effect can be random and it is therefore necessary to evaluate this potential effect systematically.

Situation awareness (SA) is the pilots' ability to see and understand the relevant elements in the situation. Pilot Situation Awareness (37) can be generally described in terms of both *noticing* the wire crossing, as well as *understanding* what this means for the safety of the flight. Understanding implies an element of time, i.e. predicting how the situation develops, allowing the pilot to act on what he/she sees in order to avoid a near miss. In this study, safety is conceptually defined in terms of pilot SA.

Specifically, for marker balls to be considered an SA enhancing safety system, it must be demonstrated that marker balls function as alarms, giving pilots enough time to avoid coming too close of wire crossings. Such alarms can be random or significant (3.3.4). A random alarm effect does not mean that the marker balls can not be of help. Given a number of conditions (light, angles, speed etc.) there is always a potential for the marker ball to help pilots notice a wire crossing.

The evaluation in this study addresses marker balls as an SA enhancing alarm system, contributing to aviation safety. This means that the marker balls must systematically warn pilots about the presence of wire crossings in due time to avoid coming too close. One definition of the concept of an alarm function is given by the Norwegian Petroleum Directorate (27):

"Alarms shall always be presented at a rate that makes it possible for the operators to recognize and understand the alarms, and there must be sufficient time for the operators to make the necessary responses (p. 5)*."* Further it says that *"any demand for responsive action from the operator to an alarm shall be based on realistic ideas about what the operator can be expected to do in the given situation* (p. 5)*."*

For markers to function as alarms, they should present pilots with a warning when the distance to the wire crossing is sufficient for the pilots to make evasive action. This warning must be given every time the pilot is about to violate a defined box of air around a wire crossing, i.e. in due time before coming too close. Thus, for marker balls to contribute to safety by functioning as an alarm, they must be visible for pilots with sufficient time to avoid a near miss with wire crossings.

The basis for this evaluation of marker ball effects is that, in order to contribute to aviation safety, the marker ball must function as an alarm. This means that it is not enough simply to notice the wire crossing (due to a marker ball). It is also required that the pilots' notice the wire crossing early enough to be able to avoid coming too close. Further more, this marker ball effect must not be random, but an effect that can be considered to occur in all defined scenarios of a given type.

3.0 Methods

The objective of the present study is to evaluate and document the *as is* situation with respect to the effect that existing marker balls may have on pilots' possibility of avoiding coming too close to wire crossings.

A familiarisation flight was conducted as preparation prior to the analyses. The purpose of this flight was for DNV to get a better understanding of the subject matter of the analysis and to generate initial hypotheses. The flight included wire crossings with and without marker balls.

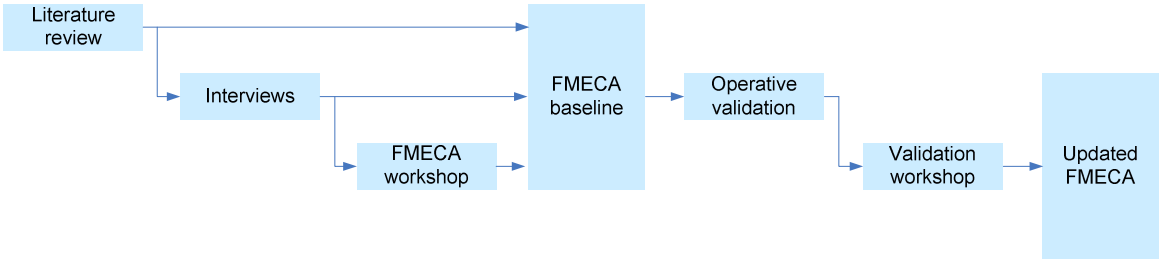

Figure 1: The steps in the analysis.

This figure illustrates the outline of the overall approach. All methods are eventually inputs to a risk analysis, using a Failure Mode Effect and Criticality Analysis (FMECA) as framework. Each step builds on the ones before and leads to the next as described below. The FMECA is conducted with and without marker balls, for a baseline version and an updated, validated version.

To evaluate and document the effect of marker balls we conducted an FMECA risk analysis (35). FMECA is traditionally used for the analysis of technical systems and components (37). In this study FMECA was used as a framework methodology for risk evaluation of the effect of marker balls. FMECA can be based on inputs from various quantitative and qualitative techniques. The FMECA is, in the present case, used to analyse the overall system.

3.1 Definition of the system to be analysed

The overall system to be analysed consists of the following elements (figure 2):

- The wires (phases and earth)
- Marker balls on the wires (when present)
- Peripheral infrastructure, specifically end towers (or cleared right of way)
- Pilot in the aircraft (single pilot operation)

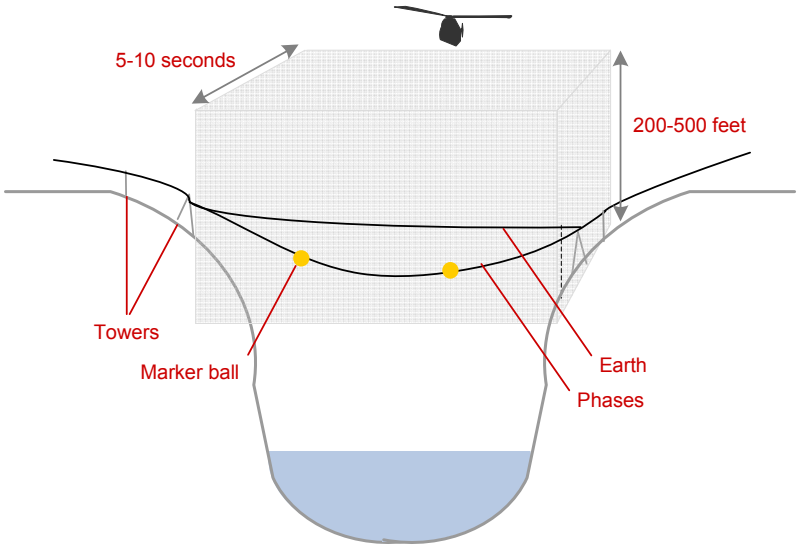

Figure 2: The defined area to be avoided around the wire crossing.

This figure illustrates the defined box of air around the wire crossing to be avoided. I.e. aircraft inside the box are by definition too close (near miss). Operations inside the defined box of air and directly under the wire crossing are not part of the scope.

Coming closer to the wire crossing (phases and earth) than 200-500 feet vertically and 5-10 seconds horizontally is in the FMECA analysis defined as a near miss. This is a definition of a box of air based on a rough evaluation of pilot reaction time of approximately four seconds (36) plus a minimum buffer of approximately three seconds (near miss; i.e. coming too close to the wire crossing). Violating this box of air does not necessarily lead to a wire strike (with possible fatal consequences) but is assumed to be too close for safely avoiding the wire crossing. Thus, violating this airspace is considered critical in the analysis (i.e. the worst consequence).

Sometimes pilots need to operate closer to the wire crossing, i.e. inside the defined box of air. However, the present report addresses marker balls alarm functionality, i.e. warning pilots with respect to avoiding coming too close of the defined area. In close maneuverings such as construction work or line maintenance the marker balls may serve a different purpose. Scenarios where pilots intentionally operate within the defined area of a near miss, or below the wire crossing, are not included in the analysis. The potential effects of marker balls for such conditions are therefore not evaluated.

Marker balls can, by definition, not have effects in conditions where it is impossible to see anything. Weather conditions with close to zero visibility, e.g. heavy fog, lies outside the scope of this evaluation. The scope of the study is VFR flying under varying daylight conditions.

Norwegian Medi Vac (air ambulance) pilots fly approximately 20 % of their flights at night (in 2007 1315 flights at night of a total of 6611 flights). The BSL E 2-2 (01, § 6) states that marker

balls should be reflecting or fluorescing to the extent possible, but we have not looked at the effect that marker balls may have on pilots' possibility of avoiding coming too close to wire crossings at night. Flying at night using night-vision goggles were also defined as out of scope.

Generally we assume that when the effects of marker balls are evaluated for a number of scenarios with VFR daylight conditions, it is unlikely that marker balls have more effect when visibility is poorer.

3.2 Interviews

A total of 11 subject matter experts were interviewed in order to establish a breakdown structure for the FMECA and to generate hypotheses. Subjects from the following categories were interviewed:

- Accident Investigation Board Norway (AIBN)
- Military pilots (rotary and fixed wing)
- General Aviation pilots (fixed wing)
- Helicopter pilots (not offshore)
- Medi Vac pilots (airborne ambulance)
- Power line owner
- New Zealand CAA
- Norwegian Air Navigation Service Provider
- Aviation medicine
- Royal Norwegian Air Force (RNoAF) (Inspector of flight safety, "flytryggingsinspektoratet")

The Norwegian CAA did not want to participate in the project due to integrity issues.

The semi-structured interview guide was developed based on the results from the literature review and the general impression the project team got during the initial familiarisation flight.

The purpose of the interviews was to get an understanding of how pilots look for wire crossings when flying in areas with wire crossings.

In the interviews, pilots were asked three main types of questions (see appendix section for the complete interview guide):

1. What do you actually see when you become aware of a wire crossing?
2. What makes wire crossings difficult to see?
3. What makes wire crossings easy to see?

On each of these questions we asked them to prioritise (what parts of the wire spans do they see first and under what conditions).

According to some of the interviewed pilots, the correct way to look for wire crossings is to systematically scan for the towers. To what extent such a scan pattern is applied is determined by a number of factors. The most important of these is the pilot expectation, i.e. whether or not the pilot is expecting a wire crossing to be present at an exact location. This expectation may be a function of factors such as local knowledge, training, experience, preparations before the flight and whether maps are updated.

The most important external/physical factor, as opposed to psychological factors, determinant for the visibility of the wire crossing is contrast, i.e. the degree to which the wires/markers and the peripheral infrastructure stand out from the background.

Interviews resulted in a suggested breakdown structure, i.e. the scenarios, used as starting point for the risk analysis. Further more, the interviews resulted in a set of hypotheses regarding the effect of marker balls.

The following main hypothesis was generated based on the interviews: Marker balls may help to locate the exact position of the wire crossing if

A. Visibility is sufficient[2] for both peripheral infrastructure/towers and wires.
B. The pilot expects the wire crossing to be at that location.
C. The pilot has first seen the towers.

This hypothesis was considered interesting because the basic assumption regarding pilot expectation was identified already in the literature review. Efforts were therefore made during interviews to falsify this hypothesis, i.e. specifically asking if marker balls could have effects independent of point B and C above (point A/sufficient visibility is by definition required).

Specifically, point C (above) states that the towers must be seen first. There were disagreements between subject matter experts on this point and it was not possible to determine this from interviews. It was therefore assumed, for the baseline risk analysis, that it would be possible to make good use of marker balls even when towers were difficult to see/if pilots were not looking specifically for towers. Alternative visual cues, like terrain characteristics and characteristic buildings/infrastructure, were hypothesised to function as substitutes for the towers. This particular issue was later addressed during validation (test flights and workshop).

3.3 General principles for the FMECA risk analysis

The FMECA evaluates and prioritises risks relative to each other in a number of scenarios involving flying in areas with wire crossings. The scenarios, given by the breakdown structure identified through interviews, ensure the completeness of the evaluation. In the scenarios, we assume that a pilot is surprised by a wire crossing due to a mistake (for instance navigation error). Such a mistake is termed a failure mode in the analysis.

The consequences of a failure mode are specifically related to how early or late the pilot will see the wire crossing under different conditions. Probabilities address how often an average pilot might find him/herself in the given situation during a career. Both consequences and probabilities are divided in four classes (described in 3.3.4).

The risks are first evaluates for wire crossings without marker balls, then for wire crossings with marker balls. This complete set of ranked risks is first conducted as a baseline analysis. This

[2] Sufficient visibility means that contrast is good and visibility is not reduced by fog, clouds, snow etc. When visibility is termed insufficient it means that it is reduced by such factors.

baseline analysis is then up-dated to a validated version based on test flights and a validation workshop.

No acceptance criterion is defined. The evaluation of risk represents a relative prioritising between the scenarios. Thus, all scenarios may represent a potential hazard in that wire crossings are present. The specific risk associated with flying in areas with wire crossings is not compared with flying in areas without wire crossings.

The main interest is to evaluate the possible safety effect, i.e. as alarm function, marker balls may have on the risk evaluated for each scenario:

- Marker balls can have effects considered to be random, i.e. without moving a consequence class (as described in section 3.3.4).
- Marker balls have a significant effect if they can be considered to always change the consequence class (one or several classes) for a given scenario.

Based on the results from the literature review and interviews with the subject matter experts the following breakdown structure, i.e. the scenarios, for the risk analysis was suggested:

- Aircraft performance: Speed, manoeuvrability and view from cockpit.
    - Visibility: Combination of visible infrastructure (sufficient contrast) and visible wire/marker ball (sufficient contrast).
        - Expectation: Active, systematic vs. passive, not systematic search.

The scenarios are defined at a relatively high level of abstraction in order to cover all situations with hazards due to wire crossings. As described above, the analysis aims to determine when marker balls have significant effects and when marker balls have random effects.

The following categories of subject matter experts participated in the initial FMECA analysis at the risk workshop:

- Helicopter pilots (including Medi Vac).
- Military fixed wing.
- Pilot instructors.
- Aviation Medicine.

The participants gave feedback on the breakdown structure, i.e. the defined scenarios. Further more, feedback was given on the failure modes and the associated initial risk evaluation (probability/consequence) of failure modes and the effect of marker balls. The FMECA workshop was followed by further discussions and analyses, resulting in the FMECA baseline.

3.3.1 Aircraft performance

The performance of the aircraft may be of importance when flying in an area with wire crossings. We identified the most important performance factors as speed, manoeuvrability

and view from the cockpit. For practical purposes aircraft performance was categorised as three types of aircraft:

1. Military fixed wing (high speed jet fighters)
2. Helicopter.
3. Light aircraft.

A helicopter has the possibility to reduce speed, stop completely or land. Helicopters also have better view from the cockpit, which may help to increase the pilot's situational awareness. Pilots in light aircraft or a fighter does not have the opportunity to stop or land and will typically have less good outside view. A military fighter jet is more agile and is able to climb or dive much faster than a light aircraft or a helicopter in an emergency.

3.3.2 Visibility

According to the subject matter experts, the best way to become aware of a wire crossing is to actively look for the towers first. The wire itself, with or without marker balls, is typically seen after the towers are detected by following/searching the direction from a tower/between towers.

In the present analysis the visibility of the wire crossing is a combination of the visibility of the peripheral infrastructure and the wire/marker. The peripheral infrastructure may include a number of elements: The most important is the end towers[3]. These may be partly hidden by trees or vegetation or painted to blend in with the surrounding terrain, or covered in clouds. Contrast is largely depending on the background and light conditions.

3.3.3 Expectation

The literature review indicated that expecting a wire crossing at an exact location was an important determinant for whether the pilot sees it or not. The interviews with the subject matter experts confirmed this and suggested that expectation is important for how pilots look for wire crossings. Typically, a pilot who is expecting a wire crossing at an exact position will perform a different search than a pilot who is not expecting it or not aware of its exact location. Whether he/she has this expectation is a function of a number of elements such as local knowledge, flight preparations and the pilot's experience and skill level.

In the present risk analysis the degree of expectation is operationalised as two different search strategies for wire crossings:

1. Systematic search for wire crossings.
    a. Pilot expects wire crossings to be present at exact locations and directs sharp-sight systematically outside towards cues for wire crossings (mainly towers).
    b. Is attentive, not easily disturbed and top-down driven. Uses available information actively to support search for wire crossings:
        i. Uses electronic maps, GPS or other technical equipment in cockpit.
        ii. Uses paper maps for low flying aircraft.

[3] The term "towers" refer to all the different kinds of anchor points that are used on wire crossings in Norway.

2. No systematic search for wire crossings.
    a. Is not expecting specific wire crossings. It is random whether sharp-sight is directed towards specific cues for wire crossings or if such are seen as relative movements.
    b. Is less attentive and probably more easily disturbed than a pilot performing a systematic search for wire crossings.

3.3.4 Failure modes

The scenarios are constructed in the following way: A pilot is flying a military fixed wing aircraft, a helicopter or a light aircraft in an area with wire crossings. He/she may have sufficient or insufficient visibility of a wire crossing (i.e. the wires and the peripheral infrastructure) which may be expected or unexpected.

In all scenarios included in the risk analysis it is assumed that something goes wrong which causes the pilot to be surprised by an unexpected wire crossing (reduced SA). When something goes wrong a failure mode has occurred. Based on discussions with subject matter experts, literature and interviews, the following two failure modes were systematically addressed in the FMECA:

Erroneous scanning technique
The pilot is not performing a systematic search for wire crossings as described in chapter 3.3.3, i.e. not systematically directing fovea (sharp-sight) towards cues (towers) of wire crossings. This is a sensory-related failure mode caused by the pilot not looking for what he/she should be looking for.

Correct scanning technique, but misjudgement
When this failure mode occurs the pilot is performing a systematic search for wire crossings using a correct scanning technique. However, he/she is making a misjudgement, i.e. a cognitive error. The pilot can be mistaken about which wire crossing it is or about his/her own position in relation to the wire crossing.

The failure modes can occur for a number of reasons. Some of the main contributing causes identified in the literature review and interviews are listed below:

- Training and experience (relevant for erroneous scanning technique).
    - Knowledge about scanning techniques.
    - Experience in use of such techniques.
- Local knowledge – relevant for misjudgement.
    - Exact position or power line.
    - Exact knowledge of topography.
- Preparations/navigation error – relevant for misjudgement.
    - Map.

  - GPS (no id of obstacles in map database, relying too much on GPS).
  - Weather.
- Technical failures – relevant for both erroneous scanning technique and misjudgement.
- Workload or performance shaping factors influencing workload. Relevant for both erroneous scanning technique and misjudgement,

Consequences of failure modes
Consequences are related to whether a defined area of 200-500 ft vertically and 5-10 seconds horizontally around the wire crossings is violated (**Figure 2**). This is a definition of a box of air based on a rough evaluation of pilot reaction time of approximately four seconds plus a minimum buffer of approximately three seconds (near miss; i.e. coming to close to the wire span). Violating this box of air does not necessarily lead to a wire strike but is assumed to be too close for an average pilot to safely avoid the wire crossing.

Rating the scenarios
The scenarios were rated in terms of frequency, consequence and effect of marker balls. The word 'significance' is used to distinguish random effects from systematic effects of marker balls. Specifically, significant means that marker balls affect consequence with one or more classes every time the defined scenario occurs.

The following categories were used:

Frequency categories:

1	Incredible:	May occur for very few pilots
2	Unlikely:	Once in a pilot's career
3	Moderate:	More than once in a pilot's career
4	Often:	Several times in a pilot's career

Consequence categories:

1	None:	Noticing with sufficient time to avoid.
2	Minor:	Noticing somewhat late. Normally avoidable for most pilots.
3	Major:	Noticing late. Not avoidable for majority of pilots.
4	Critical:	Noticing too late or not at all. Not avoidable.

Moderators (effect of marker balls on consequence class):

1	Negative:	Negative effect (minimum 1 class up)
2	Minor:	Minor effect but no consequence class change
3	Medium:	Consequence improvement by one class (down)
4	Major:	Consequence improvement by more than 1 class (down)

In order to ensure a systematic approach to the risk evaluations, a number of basic principles were applied:

- It is assumed that pilots more often expect than not expect wire crossings when flying in areas with wire crossings.
- We assume – for the baseline evaluation - that the primary means for pilots to detect wire crossings is to look for the towers and/or other topographic cues.
- We assume that, for marker balls to affect the consequence classes, pilots must know the exact position of the wire crossing and contrast must be sufficient.
- We assume that light aircraft may have cockpit outside view and manoeuvrability that differs from helicopter. This may affect the consequence classes.
- In order for a marker ball to have a significant effect it must move the consequence classes every time the conditions in the relevant scenario are present.

The output from this analysis is referred to as the FMECA baseline, later to be validated.

3.4 Operative validation

In order to do an operative validation of the baseline conclusions from the risk analysis a validation/testflight was conducted. The purpose of this was to do a quality check of the baseline evaluation. In the flight a Robinson R44 helicopter was used (pilot flying was not part of the test). Subjects were two experienced pilots, one helicopter pilot and one GA pilot.

None of the pilots had specific local knowledge. Both subjects were seated in the back of the helicopter and given a score sheet to complete for each scenario. The pilots in the back seat were only concentrating on the task of detecting wire crossings. Wirre crossings were with and without marker balls. The view from the backseat was considered satisfactory. Four scenarios were flown (Table 1).

	Without marker ball	With marker ball
With map and brief of exact position of wire crossing	A	B
Without map and brief of exact position of wire crossing	C	D

Table 1: Scenarios in the test flight (operative validation/quality check)

The scenarios were video taped. Immediately after the flight, a debrief was performed. Both pilots commented on the video and elaborated on the consequence ratings they made during flight (auto confrontation). They were also asked (after the flight) to rate the frequency for each scenario, i.e. the likelihood of an average pilot experiencing this type of situation during his or her career.

Finally an interview was conducted with both pilots. In this they were asked to prioritise the risks in relation to each other and discuss deviation from the baseline results and recommend adjustments.

The data output from the operative validation:

- The pilot's score sheets that was completed in flight
- Video taped scenarios with the pilots' comments (inclusive evaluation of frequencies)
- Experimenters log
- Interview data

3.5 Validation workshop

Finally a validation workshop was arranged. The conducted work was presented and adjustments following the validation flight were addressed.

4.0 Results

In the following chapter the results are presented. First the baseline results (5.1.1) and then the final results adjusted after the validation activities (test flights and workshop) (5.1.2). For complete results see the appendix section.

4.1 FMECA Baseline

Often				
Moderate		10,14,50	1,12,16,54	52,56
Unlikely			11,15,51	13,53,55
Incredible				17,57
	None	**Minor**	**Major**	**Critical**

Table 2. Baseline FMECA; before validation flight. Without marker balls.

Table 2 shows the risk matrix rating the different scenarios without marker balls. Table 3 shows the evaluations of the same scenarios with marker balls.

Often				
Moderate	10,50	14,12	1,16,52,54	56
Unlikely			11,15,51	13,53,55
Incredible				17,57
	None	**Minor**	**Major**	**Critical**

Table 3: Baseline FMECA; before validation flight. With marker balls.

The FMECA breakdown structure, based on interviews and a workshop, defines the scenarios. All combinations of aircraft performance, VFR daylight visibility, pilot expectations and failure modes that were considered relevant are covered in 17 scenarios. The numbers in the matrix is referring to the associated 17 uniquely numbered failure modes. The colours represent a relative priority of risk, but no acceptance criterion is defined. The main interest is to see which failure modes that are affected by the presence of marker balls.

Scenarios 10, 50, 12 and 52 changed consequence class following the introduction of marker balls in the baseline analysis. All scenarios in the matrix are described in detail below.

Military fixed wing (Scenario 1)
One pilot is flying a military fixed wing aircraft in an area with wire crossings. Visibility of the wire crossing's peripheral infrastructure is sufficient and the contrast to the wire itself is sufficient. The pilot is expecting a wire crossing at an exact location, is performing a correct scan for wire crossings, but makes a misjudgement. The misjudgement may be caused by navigation errors due to deviation from planned route, navigation equipment errors or non-updated maps or GPS.

When the pilot is surprised by an unexpected wire crossing under these conditions, time to avoid will be very limited due to the high speed of the aircraft. The subject matter experts considered that when flying at more than 400 knots the pilot will need to see the wire crossing on at least 1 nautical mile distance. This is very difficult, if not impossible, even with the best possible visibility conditions. Hence the consequence is set to "Major: Noticing late, not avoidable for most pilots." This means that most pilots would be likely to violate the defined area of 200-500 ft. and 5-10 seconds around the wire crossing (near miss). The likelihood of a pilot experiencing such a scenario during his or her career is set to "Moderate, i.e. more than once in a pilot's career."

Marker balls have a minor effect on the consequence in this scenario. This means that marking may help the pilot to see the wire crossing earlier, but that it is random when it actually does. Thus, the effect of marker balls is not considered to change the consequence class.

Because the wire crossing will be very hard, if not impossible, to see in time with the best possible visibility conditions, less favourable conditions were not evaluated. Hence scenario 1 was the only one involving a military fixed wing aircraft in the present analysis.

Helicopter (Scenario 10)
In this scenario a helicopter pilot is flying in an area with wire crossings. The visibility conditions are sufficient, the pilot is expecting a wire crossing and uses a correct scanning technique, but makes a misjudgement and is surprised by an unexpected wire crossing. In this situation the consequence class is set to "Minor"; pilots will typically notice the wire crossing somewhat late but normally have time to avoid the critical area. The frequency class is set to "Moderate", meaning that most pilots are likely to experience this more than once in their career.

In this scenario marker balls are evaluated to have a medium effect. If this wire crossing had been marked with marker balls, the consequence would, according to our analysis, be reduced to "None, noticing with sufficient time to avoid." In our analysis, scenario 10 is judged as the best case scenario to be in as a pilot. Therefore scenario 10 is used as a baseline for evaluating the other scenarios.

Helicopter (Scenario 11)
The scenario is identical to scenario 10, except that the pilot is not expecting a wire crossing and is using an erroneous scanning technique (i.e. he/she is not systematically searching for towers). This may be because of insufficient training or experience, technical errors or increased workload dragging the pilot's attention away from wire crossings. The pilot in scenario 11 will typically see the wire crossing later than the pilot in scenario 10. Hence the consequence class is increased to "Major". This means that most helicopter pilots would be likely to violate the critical area around the wire crossing under these circumstances. However, according to our first principle for rating the risks, pilots are more often expecting than not

expecting a wire crossing when flying in areas where wire crossings are known to be present. Therefore, scenario 11 is rated as “Unlikely, once in a pilot’s career”.

Marker balls may have an effect occasionally, but this effect is rated as minor and not strong enough to reduce the consequence class from “Major” to “Minor”.

Helicopter (Scenario 12)
In this scenario, still flying a helicopter, the visibility of the wire crossing’s peripheral infrastructure is insufficient. The contrast to the wire is still sufficient. Typically, this is a situation where clouds or fog covers the upper parts of the wire crossing. The pilot is expecting a wire crossing and performing a correct search. Due to a misjudgement the pilot is surprised by a wire crossing. In this situation the error mode may in part be caused by the reduced visibility of the towers. When towers are difficult to see, these cannot be used as primary means to locate the wire crossing.

The consequence in scenario 12 is set to “Major” because most pilots are unlikely to notice the wire crossing in time to avoid violating the defined area surrounding the wire crossing. The subject matter experts rated this as a fairly common situation to be in for a Norwegian pilot who flies in an area with wire crossings. Hence the frequency is set to “Moderate”, indicating that most pilots are likely to experience this more than once in their career.

In the baseline analysis, marker balls were given a medium effect in scenario 12, meaning that they reduce the consequence class to “Minor; normally avoidable for most pilots”.

Helicopter (Scenario 13)
The type of aircraft and visibility conditions are similar as to scenario 12. However, in scenario 13 the pilot is not expecting a wire crossing and is using an erroneous scanning technique. When the towers are difficult to see the pilot needs to see the wires (or the marker balls if present). Since the pilot is not expecting a wire crossing this is likely to happen very late.

The consequence class is set to “Critical” because it would be practically impossible for a pilot to see the wire crossing before violating the defined area around the wire crossing. Many pilots would not see the wire crossing at all in this scenario. The frequency class is set to “Unlikely”, which is once in an average pilot’s career.

In scenario 13, marker balls may only have a minor, random effect. This is due to the general principle used, i.e. that for marker balls to affect the consequence classes, pilots must know the exact position of the wire crossing.

Helicopter (Scenario 14)
In this scenario the towers are sufficiently visible, but the contrast to the wire itself is insufficient. The pilot is expecting a wire crossing and performing a correct scan. Still, a failure mode occurs and the pilot makes a misjudgement and faces an unexpected wire crossing. The reason may be insufficient local knowledge or preparation, navigation errors or workload. However, the pilot is expecting a wire crossing and can use the towers as primary means of detection. Therefore the consequence is set to “Minor, noticing somewhat late, normally avoidable for most pilots.” The frequency is set to “Moderate” because this is a scenario an average pilot is expected to experience more than once during his or her career.

Marker balls may only have a minor, random effect because the contrast to the wire is poor.

Helicopter (Scenario 15)
A helicopter pilot is flying in an area with wire crossings. Visibility of the peripheral infrastructure is sufficient but contrast to the wire is insufficient. Not expecting a wire crossing he/she uses an erroneous scanning technique and will typically detect the periphery (towers) by coincidence. The consequence is set to “Major” indicating that most pilots would be unable to avoid the defined area around the wire crossing in such a scenario. The frequency is set to “Unlikely” due to our analysis principle, that that pilots more often expect than not expect wire crossings when flying in areas with wire crossings.

Like for scenario 14, marker balls may only have a minor, random effect because the contrast to the wire is poor.

Helicopter (Scenario 16)
In scenario 16 the visibility conditions are generally insufficient, both when it comes to infrastructure and the contrast of the wire. However, the helicopter pilot is expecting a wire crossing and is, to the extent possible given the visibility conditions, performing a correct scan for wire crossings. Due to reduced visibility other cues than the peripheral infrastructure is needed in order to locate the wire crossing (such as rivers, churches, bridges or other landmarks). When a failure mode occurs and the pilot makes a misjudgement and faces an unexpected wire crossing., he/she is likely to be rather close to it and most pilots will not be able to avoid the defined area.

Therefore the consequence is set to “Major” for this scenario. The frequency is set to “Moderate”, because this is a situation that is quite normal. Weather conditions shift fast and suddenly a pilot may find himself in a situation like in scenario 16.

Marker balls are unlikely to help the pilot noticing the wire crossing in this scenario, if they do this will be totally random.

Helicopter (Scenario 17)
The visibility conditions are the same as in scenario 16, but now the pilot is not expecting a wire crossing. Therefore he/she is not performing a correct scan and will detect a wire crossing completely by surprise, if detected at all. The consequence is “Critical”, a pilot will not be able to escape the defined area around the wire crossing. The frequency in this scenario is set to “Incredible; may occur for very few pilots”.

Marker balls are unlikely to be helpful in any systematic way because the visibility conditions are poor and the pilot is not expecting a wire crossing.

Light aircraft (Scenario 50 to 57)
Scenarios 50 to 57 are identical to scenarios 10 to 17, respectively. The only difference is that type of aircraft is changed from helicopter to light aircraft. Because the manoeuvrability is poorer the pilot may need to see the wire crossing earlier in order to avoid the defined area when flying a light aircraft. At the same time, visibility from cockpit is not as good as in a

helicopter which may contribute to late detection. Therefore the consequences were rated as more serious in a light aircraft compared to a helicopter.

Like for the helicopter scenarios, marker balls were judged to move the consequence classes in two scenarios (number 50 and 52). In scenario 50 a pilot is flying with good visibility conditions in a light aircraft, is expecting a wire crossing and performing a correct scan. Marker balls reduce the consequence from “Minor” to “None”. In scenario 52 a light aircraft pilot is flying with insufficient visibility of the infrastructure but with good contrast to the wires. Marker balls reduce the consequence from “Critical” to “Major”.

4.2 Validated FMECA, results from operative validation

The breakdown structure and main conclusions from the risk analysis were approved by the pilots following the test flight. It was not called for any revisions on either of these elements. A summary of the results from the validation flight is presented in the bullet points below:

- Both pilots agreed that to be briefed in advance and to have the map available had major effect on how early the wire crossings were detected. This confirms the importance of expecting the exact location of wire crossings in order to see them.
- Whether the wire crossings had marker balls or not was less important for what was rated the most and least dangerous crossings.
- Both pilots were somewhat surprised about how difficult it was to detect the marker balls on the marked wire crossings. Immediately after the flight they were unsure whether marker balls actually can have a significant consequence reducing effect at all. This does not mean that they can not be of help, only that their effect was perceived as random.
- The “best case” scenario was confirmed (scenario 10, helicopter with best possible visibility conditions and where pilot is expecting wire crossings and searching systematically for them).
- One of the pilots questioned the low frequency set for scenarios 17 and 57. He felt that these scenarios may occur more often for pilots following navigation errors. When a pilot is suddenly in an unfamiliar environment and visibility is poor, workload will increase and focus will be drawn towards flying the aircraft and regain control of position. To search for wire crossings may simply be forgotten under such circumstances. Since navigational errors are fairly common and weather conditions shift fast, scenario 17 and 57 is more frequent than incredible according to the pilot (later discussed in the final workshop).
- In all scenarios but one pilots noticed the towers before any other parts of the wire crossings. The exception was the wire crossing with white marker balls (scenario D) in which one of the pilots noticed the wires together with the marker balls before he saw the towers.
- Our assumption about differences between helicopter and light aircraft due to reduced manoeuvrability of the latter, were confirmed.

The subject matter experts agreed that, based on these results, it is a premise for marker balls to have an effect, that pilots first see the towers. See discussion in the chapter Interviews (3.2).

Table 4 and Table 5 show the revised results following the operative validation with and without marker balls, respectively.

Often				
Moderate		10,14,50	1,12,16,54	52,56
Unlikely			11,15,51	13,17,53,55,57
Incredible				
	None	**Minor**	**Major**	**Critical**

Table 4: Validated FMECA. Without marker balls.

Often				
Moderate	10,50	14	1,12,16,54	52,56
Unlikely			11,15,51	13,17,53,55,57
Incredible				
	None	**Minor**	**Major**	**Critical**

Table 5: Validated FMECA. With marker balls.

The following results are changed from the baseline described in chapter 4.1:

1. Because it is necessary to first see the towers, the effect of marker balls in scenarios 12 and 52 are reduced from “Medium” to “Minor”. This means that the marker balls go from having a significant effect on the consequence class to having no significant effect on the consequence class. The marker balls may still have random effects, but not enough to move the consequence class.
2. Furthermore, subject matter experts agreed (also discussed in the final workshop) that the frequency categories in scenarios 17 and 57 are increased from “Incredible” to “unlikely”.

These results were further validated in a final workshop.

4.3 Validation workshop

As a final activity in the project a validation workshop was arranged. All stakeholders were invited to participate. The objective of the workshop was to present the conducted work and get feedback on necessary adjustments, the following personnel categories participated:

- Helicopter pilots
- Light aircraft pilots
- Representatives from OCAS AS
- DNV

The most important conclusion from this workshop was that the subject matter experts approved, although uncertainty was expressed on some points (addressed below), that the adjusted analysis takes as a premise that towers must be seen first in order for marker balls to have a significant effect. It was emphasised by the stakeholders that marker balls may still have an effect in terms of alarm functionality, but that this effect was considered random. Following the workshop it was decided to keep the conclusions drawn after the validation flight.

5.0 Discussion

As described in chapter 2.5 marker balls need to meet certain criteria in order to have alarm functionality that enhances the pilots' Situation Awareness. If marker balls make a pilot aware of a wire crossing in due time to avoid coming too close, then they function as an alarm in that situation. This means that the marker balls made it possible for the pilot to avoid the defined box of air earlier than he/she would have without the marker balls, i.e. it moves the consequence classes as described in chapter 3.3.4, consequences of failure modes.

This alarm effect can be either random or significant:

- If the effect is random it means that the effect of the marker balls may not be the same the next time the pilot flies the same route (given similar flying conditions) or that the marker balls did not alarm the pilot's colleague who flew with the same conditions earlier the same day. In the FMECA field "marker ball effect" a random effect is termed "minor", implying that marker balls may have an effect, but not enough to move the consequence class.
- A significant alarm effect is present when the marker balls move the consequence classes every time the same conditions occur. In the FMECA field "marker ball effect" a significant effect is termed "medium" or "major" depending on whether it moves the consequence class one or more than one classes.

A random alarm effect does not mean that the marker balls can not help. Given a number of conditions (light, angles, speed etc.) there is always a potential for the marker ball to help pilots noticing a wire crossing. This possibility is never ruled out of the present analysis. However, if the alarm effect is random then it can not be considered a safety system (as defined).

For marker balls to be considered a safety system, they need to have a significant alarm effect. It means that, under VFR conditions, marker balls always alarm pilots about the presence of wire crossings in due time to avoid coming too close. The present analysis concludes that

marker balls in most scenarios (15 out of 17) have a random alarm effect and that they therefore can not be considered a safety system[4].
The effect of marker balls depends on a complex set of interacting variables, such as:

- Type of aircraft: Related to e.g. speed / view from the cockpit / manoeuvrability / typical flight pattern.
- Visibility: VFR conditions will vary with respect to the visibility of the various parts of the wire crossings. It is possible to have sufficient visibility of parts of the wire crossing only (for example when towers are covered in clouds). The lowest common denominator is the degree of contrast. Contrast depends on numerous variables such as light conditions, the angle of pilot's line of gaze, relative position of point of view versus the marker ball, type of background, colour, relative movements, and qualities of the markers (colour, size, shape and spacing of markers). The weather is a main variable contributing to visibility.
- Pilot expectation of exact location of wire crossings (depends on e.g. local knowledge, pre-flight planning, the use of up-dated maps and GPS). This expectation is a premise for a top-down active type of search versus a bottom-up and less active type of search
- Correct scanning technique, i.e. systematically directing fovea toward exact locations of selected indicators of wire crossing such as towers (dependent on theoretical knowledge of scanning techniques, training and experience)

These main variables can, as a result of complex interactions, produce conditions where wire crossings are more visible (and therefore avoidable) with marker balls than without marker balls. The exact number of seconds with extra response time will vary with the interaction of these variables and is therefore difficult, if not impossible, to predict with any degree of accuracy. For all scenarios but two, the possible beneficial effects of marker balls must therefore be considered random.

Marker balls are considered to have a significant effect in two scenarios (id 10 and 50): In these two scenarios subject matter experts consider that marker balls function as a warning that significantly increases the available time for responses.

Scenario 10 (helicopter) and 50 (light aircraft) are identical except for the type of aircraft. The main difference is considered to be better manoeuvrability and view from the cockpit in helicopters than in light aircraft. This can affect the evaluation of consequence classes in that light aircraft can be rated slightly higher in consequence. The probability of helicopter versus light aircraft pilots experiencing the situation is considered equal for the two types of aircraft (given the premise for the analysis, i.e. that both are flying in areas with wire crossings).

Scenario 10 and 50 represent best case scenarios for helicopters and light aircraft: The visibility is considered sufficient for all parts of the wire crossing, pilots' expect the wire crossing at an exact location and the pilot is using a correct scanning technique for the identification of the towers. Still, a misjudgement occurs in these two scenarios. Even though the visibility conditions make it possible to see the wire crossing, the pilot may misunderstand what he/she sees in several ways. The pilot could be wrong about his/her own position in relation to the wire

[4] It should be noted that this evaluation is not a comparison of different types of alarm systems. Nor is it a comparison of marker balls against any alternative system. It is therefore not possible to conclude anything regarding the superiority of one system versus another. This is an evaluation of the effect that current marker balls may have on pilots' possibility of noticing wire crossings in due time to of coming too close.

crossing (e.g. erroneous judgements of distance) or a navigation error could have occurred making it the wrong wire crossing (possibly with different associated hazards than the expected wire crossing).

Based on the validation flight, it is considered a premise that pilots have sufficient visibility of towers in order for marker balls to have a significant consequence reducing effect. Thus, for marker balls to have a significant effect, the pilot must know the exact location of the wire crossing, there must be sufficient contrast of the wire and the marker ball, and the pilot must also have visibility (with sufficient contrast) of towers. The scenarios 12 and 52 will therefore not represent situations where marker balls have a significant effect.

Throughout the analysis there were discussions regarding the necessity of seeing towers before seeing marker balls. The baseline analysis assumed that it would be possible to see marker balls, without seeing the towers, i.e. based on other cues. The validated analysis (after validation flight and validation workshop) concluded that it was a premise for seeing marker balls that pilots had first seen the towers. Thus, scenario 12 and 52 were changed so that marker balls went from having a significant to having a random effect on the consequence classes. This was discussed during the validation workshop. Although the conclusion was to regard seeing the towers as a premise for seeing the marker balls, there is still uncertainty related to this. It would not, however, change the overall conclusions if significant effects were to be found in four scenarios instead of only two scenarios (from a total of 17 scenarios).

It is only in scenario 10 and 50 that it will be significantly easier for the pilot to detect the wire crossing, specifically the exact path of the wires, with marker balls than without marker balls. However, the baseline analysis shows that even with a misjudgement, the conditions in these two scenarios are so good that the defined box of air surrounding the wire is avoidable for most pilots. Thus, the marker balls further increase the avoidability so that all pilots can avoid the wire crossing (the consequence class is moved form minor to none).

Although identified as a significant effect in scenario 10 and 50, this can be considered a fairly modest safety effect. This is because the effect was random in the majority of scenarios (15 out of 17) and significantly effective only in two scenarios where most pilots would not need them.

6.0 Conclusions

The conclusion was that marker balls have a limited effect on pilots' possibility to avoid coming too close to wire crossings, as specified below:

- Marker balls may have alarm functionality, but this effect was considered random for most scenarios.
- There were two scenarios identified (id. 10 & 50, see appendix section) where marker balls were considered to have a significant alarm functionality in terms of pilots' possibility to avoid coming too close (as defined).
- No negative effects of marker balls were identified.

Scenario 10 and 50 represent “best case” scenarios in terms of maximum visibility and pilot expectation of position of wire crossing. Thus, most pilots would (according to defined consequence classes) not be needing marker balls in these two scenarios.

However, in these two scenarios, marker balls will ensure an even better safety margin than would be the case without marker balls.

Although marker balls can contribute to safety, marker balls can not be considered a sufficient safety system in terms of systematically warning pilots about the presence of wire crossings in due time to avoid coming too close to them.

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33	Civil Aviation Authority of New Zealand (2002). Wire Marking Trial, *CAA News*
34	Reason J. (1997). *Managing the Risk of Organizational Accidents*. Aldershot: Ashgate
35	IEC 60812 Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA). Ed. 2.0. 2006-01
36	FAA-H-8083-3A, Airplane Flying Handbook. http://www.faa.gov/library/manuals/aircraft/airplane_handbook/media/faa-h-8083-3a-7of7.pdf
37	Hauland, G. and Eisinger, S. (2007): A case of man – technology – organisation system relations in helicopter operations offshore as subject matter in a failure mode effect and criticality analysis. In: Terje Aven and Jan Erik Vinnem (Eds.), *proceedings of the European Safety and Reliability conference*, Stavanger, Norway. Taylor and Francis.
38	Pidgeon, N., O'Leary, M. (2000). Man-made disasters: why technology and organizations (sometimes) fail. *Safety Science 34*, pp 15-30

39	ESARR 4. Risk Assessment and Mitigation in ATM. Version 1.0. 05.04.2001. EuroControl.
40	IEC 61508. Functional safety of electrical/electronic/programmable electronic safety-related systems, ed. 1, 20.01.2005.

8.0 Appendix

Appendix I - Interview guide

Note that these are keywords, i.e. not representing exact wording or sequence of questions.

DNV Interview guide ”evaluation of marking of wire crossings”

1. Introduction

DNV is conducting an independent evaluation in order to:

Document the degree to which marker balls are suitable to warn about the presence of wire crossings: seen vs not seen.

- In this lies an evaluation of situation awareness: seen/not seen + understood what this means for own aircraft + in due time to avoid coming too close when the wire crossing is known (actively searching for wire crossings) and when it is not known (not actively searching)
- The job is conducted for OCAS A/S. DNV’s independency is secured through broad stakeholder involvement in all the phases of the project
- We are interested in your evaluations based on your experience.
- We’ll make notes and record the conversation. This material stays with DNV and all information is treated as confidential. No single person can be identified in the final report.
- We assume that the conversation will last for about 1,5 hours.
- Questions?

2. Background

Name and contact information

Relationship to OCAS or similar systems

Cat. I; Operative

Military (fixed wing/ helicopter), GA, Helicopter (medi vac, transport / pax), commercial fixed wing.

Cat. I; Non- operative

Civil Aviation Authorities, aviation medicine, accident investigators etc.

Experience

How long, where (geographically), experience with low flying, typical operations, how often

3. Story

Your job – typical ”modes of operation”

- Typical tasks, normal day:
  - Normal conditions
  - Maintenance tasks
  - Unnormal conditions (emergencies etc.)

Tell us about a time…

Surprised by marked wire crossings

Surprised by unmarked wire crossings

Was “saved” by marking

It (almost) went wrong

4. Risk Scenarios – (check out for FMECA)

Breakdown structure / conditions
What failure modes are most important
Situation awareness (see+understand+plan)

What do you see when you see a wire crossing – prioritise

Hypotheses relating to expectation

What makes wire crossings easy to see? – prioritise

What makes wire crossings difficult to see? – prioritise

5. Non-operative factors

Problem size – for whom

Functionality of marker balls (BSL)

What is good enough

- active versus passive
- cost - benefit
- alarm functionality – time to react

Rationale for the definition of marking

Baseline for normal attention

6. Miracle--- If you could choose?

7. Closing

Our summary, did we understand you correctly?

Other sources (statistics, references, persons)?

Further work

Our contact information

Appendix II – METAR and NOTAM from operative validation

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-----------------------------------------------------------------------
AIS NORWAY -    PREFLIGHT INFORMATION BULLETIN: 081112/0805
                GENERAL BULLETIN
                INCLUDES NOTAM VALID FROM: 120810    FOR: 24 HOUR(S)
                FIRS: ENOR
                AERODROMES: ENBR
                HEIGHT: 000/999
                PERM NOTAM CUTOFF: 365 DAY(S)
                TRAFFIC: IV          PURPOSE: NBO     SCOPE: AEW
                SNOWTAM: NO          MET: METAR/TAF/SIGMET/ICE
-----------------------------------------------------------------------

>>> FIR: ENOR (NORWAY FIR) <<<

ENBD ICE MESSAGE 02 VALID 120530/120900 ENVN-
NORWAY FIR LOC MOD ICE FCST N OF N6500 AND W OF E02500 BLW FL120.
0-ISOTHERM BTN SFC AND 3000FT. WKN.

NEW TODAY WEF 0811120900
SCHEDULE: DAILY 0900-1030 AND 1200-1330
FRNG AREA 'SETERMOEN EXPANDED' 6844N01712E 6832N01808E 6835N01826E
6836N01849E 6852N01849E 6859N01747E
LOWER LIMIT: GND UPPER LIMIT: FL300                  : NOTAM ENWN/0364/08

SCHEDULE: 10-14 DAILY 1245-1500 AND 1645-1900
TRIGGER NOTAM - AIP SUP 13/08 WEF 3NOV2008
MIL EXERCISE 'FIGHTER WEAPON INSTRUCTOR TRAINING 2008'
WILL TAKE PLACE WITHIN BODOE AND OSLO AOR
AIP SUP AVBL ON WEBSITE WWW.IPPC.NO
LOWER LIMIT: GND UPPER LIMIT: FL500                  : NOTAM ENAV/0410/08

REF AIC N 37/06, DATED 18 SEP 2006.
OCAS FOR RDO AND LGT MARKING OF POWERSPAND HAS BEEN INSTALLED OVER
INNER-TYSFJORDEN BTN BRENNESET AND BAATTOVIKA PSN 6808N01627E. IF
RISK OF COLLISION, AUDIO WARNING WILL BE TRANSMITTED ON THE VHF RDO
ON THE FLW FREQ: 123.250MHZ 122.500MHZ 123.45MHZ 123.500MHZ
123.650MHZ 130,750MHZ
LOWER LIMIT: GND UPPER LIMIT: 2000FT AMSL            : NOTAM ENCA/0109/08

SCHEDULE: 05 11 12 19 20 25 26 AND 27 0600-1800
DANGER AREA EN D354 LEKSDALEN ACTIVATED
LOWER LIMIT: GND UPPER LIMIT: 4000FT AMSL            : NOTAM ENWN/0361/08

AERONAUTICAL CHART NORWAY 1:250000 M517AIR - SHEET 2 BERGEN EDITION
3.
ADD: TOWERS, MULTIPLE, UNLIT, 602359N0061533E, 204 FT AMSL.
ADD: POWESPAN (SHORTSPAN SYMBOL), 602402N0061540E, 204 FT AMSL.
AMEND: MAST, UNLIT, 602249N0054630E, 965 FT AMSL, 99 FT AGL. TO READ:
1231 FT AMSL.                                        : NOTAM ENCB/0029/08

SCHEDULE: SR-SS
TEMPO DANGER AREA ESTABLISHED RAMFJORDEN - BREIVIKEIDET TROMS
6941N01939E 6938N01940E 6935N01914E 6937N01914E. UAV ACTIVITY SR-SS
LOWER LIMIT: GND UPPER LIMIT: 1500FT                 : NOTAM ENWN/0366/08

REF AIP ENR 6.2-3 6.2-5 6.2-11 6.2-13 4.4-10 SIG POINT 'RIGNA' AND
'KUXUB' COMPLETELY WITHDRAWN                         : NOTAM ENAV/0390/08

REF AIP ENR 2.2-3 SOERKJOSEN E TIA AND SOERKJOSEN W TIA.
UNIT PROVIDING SERVICE CHG TO SOERKJOSEN AFIS. IDENT CHG TO
SOERKJOSEN INFORMATION                               : NOTAM ENAV/0387/08

SCHEDULE: TUE WED AND THU 0800-1500
DANGER AREA EN D155 FJELLHAUG ACTIVATED              : NOTAM ENWN/0230/08

TACAN VIA CH71X U/S                                  : NOTAM ENAL/0127/08

REF AIP AIRAC AMDT 06/08 WEF 23 OCT 2008, ENR 3.5-4/5/6. STANDARD
ROUTES TO READ

FROM    TO      ROUTE

ENGM    ENVA    TOMBO RBU
ENGM    ENBO    TOMBO U/L996 RBU U/Z103 BNN U/Z200 STM
ENTO    ENVA    TRF U/M609 TOGAT TGA
ENCN    ENVA    DCT SVA U/M604 TOBIT AGNON  ELLER/OR  OSLOX U/M609
TOGAT TGA
ENBR    ENVA    ROXET U/Z11 LASAG
ENBO    ENGM    STM U/Z200 BNN U/Z103 MERAK U/Z101 TGA U/M609 MES
ENTC    ENGM    ROSKO U/M609 EVD U/Z101 TGA U/M609 MES
                                                     : NOTAM ENAV/0335/08

REF AIP GEN 3.1 AND AD 1.3, THE FOLLOWING INTL AERODROMES UPGRADED TO
BE DISTRIBUTED IN SERIES ALPHA: ALTA, FAGERNES/LEIRIN,
HARSTAD/NARVIK/EVENES, HAUGESUND/KARMOY, KIRKENES/HOYBUKTMOEN,
KRISTIANSAND/KJEVIK, MOLDE/ARO, NARVIK/FRAMNES, ROROS, ALESUND/VIGRA
                                                     : NOTAM ENAV/0355/08

OCAS AND OWS OVERVIEW:
IF RISK OF COLLISION, AUDIO WARNING WILL BE TRANSMITTED ON VHF RDO ON
THE FOLLOWING FREQ: 123.250MHZ 122.500MHZ 123.450 MHZ 123.500MHZ
123.650MHZ 130.750MHZ/OWS
LOCATION                PSN            HGT AMSL       ORIGINALNOTAM
SOERFJORDEN HERLAND   6025N00532E      2000FT : NOTAM ENCA/0103/08
VIKAFJORDEN           603930N0054724E  1500FT : NOTAM ENCA/0100/08
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MOFJORDEN              604636N0054500E 1500FT : NOTAM ENCA/0097/08
TYSSESUNDET            603800N0055324E 1500FT : NOTAM ENCA/0099/08
GAMMELSETERVATNET      624640N0075220E 1500FT : NOTAM ENCA/0096/08
SAMANGERFJORDEN        6021N00539E     2000FT : NOTAM ENCA/0095/08
OLAVSVERN              6932N01902E     2000FT : NOTAM ENCA/0094/08
VEAFJORDEN             6034N00543E     2000FT : NOTAM ENCA/0093/08
KVALSUNDET BRIDGE      703037N0235612E 1000FT : NOTAM ENCA/0092/08
HELLEMOFJORDEN         6801N01611E     2000FT : NOTAM ENCA/0090/08
FRIERFJORDEN/OWS       590316N093848E  1000FT : NOTAM ENCA/0089/08
BAGNSFJORDEN           6030N00654E     2000FT : NOTAM ENCA/0088/08
KJOEPSVIKSUNDET        6806N01619E     2000FT : NOTAM ENCA/0087/08
OSAFJORDEN             6031N00656E     2000FT : NOTAM ENCA/0086/08
HARDANGERFJORDEN       6015N00611E     2000FT : NOTAM ENCA/0085/08
OSTERFJORDEN           6039N00536E     2000FT : NOTAM ENCA/0084/08
SOERFJ/VEAFJORDEN      6026N00535E     2000FT : NOTAM ENCA/0083/08
ROMBAKSBOTN            682608N0174420E 1200FT : NOTAM ENCA/0082/08
HOLANDSFJORDEN         6642N01335E     2000FT : NOTAM ENCA/0081/08
KAAFJORDDALEN          692742N0205454E 2500FT : NOTAM ENCA/0080/08
SALTDALSFJORDEN        670648N0152706E 2000FT : NOTAM ENCA/0079/08
SVEFJ/SALTSTRAUMEN     6713N01440E     1000FT : NOTAM ENCA/0078/08
KAAFJORDEN             6933N02036E     2000FT : NOTAM ENCA/0077/08
BOLSTADFJORDEN         6037N00550E     2000FT : NOTAM ENCA/0076/08
FOR FULL INFO FOLLOW THE LINK TO THE ORIGINAL NOTAM
                                                : NOTAM ENEX/0229/08

REDUCED COVERAGE UHF SOUTHERN PART HELGELAND TMA BLW FL100 FREQ
278.700MHZ                                      : NOTAM ENBD/0041/08

NO UHF COVERAGE ENBD SECTOR EAST FREQ 278.585 MHZ.
                                                : NOTAM ENBD/0042/08

PARA GLIDING WITHIN ENOL CTR/TMA AND ENVA TMA, IN AREA BOTN
6336N00955E 6338N01002E 6334N01008E 6330N00958E AT THE COAST
(6336N00955E). ACT WILL TAKE PLACE DURING DAYTIME IN VMC.
INFO ON ACT WILL BE GIVEN BY ENOL TWR/APP AND ENVA TWR.
LOWER LIMIT: GND UPPER LIMIT: 3000FT AMSL       : NOTAM ENWN/0235/08

PROC REGARDING OBST CLEARANCE AND CORRECTION FOR LOW TEMP EFFECT WERE
INTRODUCED IN NORWEGIAN TMA WEF 050929. THE NEW PROC STATES THAT THE
RADARCONTROLLER SHALL ISSUE CLEARANCES SUCH THAT THE PRESCRIBED OBST
CLEARANCE WILL EXIST AT ALL TIMES WHEN GIVING AN IFR FLIGHT A DCT
ROUTING WHICH TAKES THE ACFT OFF AN ATS-RTE. THE NEW PROC ALSO STATES
THAT THE RESPONSIBILITY FOR CORRECTION FOR LOW TEMP EFFECT WHEN
VECTORING AN IFR-FLT AND WHEN GIVING AN IFR-FLT A DCT ROUTING ARE
TRANSFERED TO THE RADARCONTROLLER. OSLO TMA AND FARRIS TMA ARE
TEMPORARILY EXEMPTED FM THE ABOVE MENTIONED PROC AND THE PILOT'S
RESPONSIBILITY IN THESE TMA WILL REMAIN UNALTERED
                                                : NOTAM ENAV/0233/08

LOW LEVEL RADIO COVERAGE ON 124,700MHZ IN THE NORTHERN PART OF SOGN
TIA MAY BE LIMITED. IF UNABLE TO ESTABLISH TWO-WAY CONTACT WITH
STAVANGER ATCC, CONTACT THE NEAREST AFIS UNIT.  : NOTAM ENSV/0017/08

HANG GLIDING AND PARA GLIDING WITHIN ENAL TMA AND ENOV TIZ. ACT WILL
TAKE PLACE DURING DAYTIME IN VMC. INFO ON ACT WILL BE GIVEN BY ENAL
TWR/APP AND ENOV AFIS.
AREA BONDALEN M: 621024N0060956E 620752N0061140E 621151N0063144E
621413N0062927E 621024N0060956E.
AREA BONDALEN N: 620752N0061140E 621750N0060449E 622235N0062052E
621151N0063144E 620752N0061140E.
AREA BONDALEN S: 621024N0060956E 620516N0061327E 620336N0062821E
620716N0063642E 621413N0062927E 621024N0060956E.
LOWER LIMIT: GND UPPER LIMIT: 5500FT AMSL       : NOTAM ENWN/0214/08

PARACHUTE JUMPING MAY TAKE PLACE, IN VMC, JARLSBERG AREA
592018N0102007E 592018N0102409E 591543N0102409E 591543N0102007E
LOWER LIMIT: GND UPPER LIMIT: FL150             : NOTAM ENWN/0209/08

ENSV ATCC HAS DELEGATED THE RESPONSIBILITY FOR ATS TO ENSG WITHIN
15NM FM SOG VOR/DME, FM 5500FT AMSL TO FL85. THIS AREA RESTS ENTIRELY
WITHIN THE EXISTING SOGN TIA AND COMPULSORY TWO-WAY COMMUNICATION
WITH ENSG APPLIES. AIRSPACE CLASS G             : NOTAM ENSV/0011/08

ENBD ATCC HAS DELEGATED THE RESPONSIBILITY FOR ATS TO ENKR WITHIN
LIMITS 7005N02800E 7110N02900E 7100N03000E 7022N03143E 6948N03049E
THEN WESTWARDS ALONG THE RUSSIAN AND FINNISH BDRIES TO 7005N02800E.
GND-FL105. AIRSPACE CLASS G AND E.              : NOTAM ENBD/0056/07

REF AIP NORWAY ENR 1.8-1/2 AND ENR 2.1-2
FOLLOWING UHF FREQ IN OSLO ATCC U/S:
SEC SKAGERAK/SOUTH 278.375, SEC NORTH 277.800, SEC WEST 340.075, SEC
EAST 279.000, FARRIS 278.225, INCLUDED FREQ 243.000
                                                : NOTAM ENOS/0032/07

>>> ENBR (BERGEN/FLESLAND) <<<

METAR 120750Z 03004KT 9999 FEW020 00/M01 Q1003 NOSIG RMK WIND 1200FT
      AMSL 35008KT

TAF 120500Z 1206/1306 06005KT CAVOK BECMG 1215/1218 9999 SCT030
          PROB30 TEMPO 1218/1306 15010KT SHRA FEW015CB BKN025


CAUTION. NEW TWY UNDER CONSTRUCTION BTN RWY AND TWY Y N OF TWY B. NOT
OPERATIONAL.                                    : NOTAM ENBR/0148/08

CL TWY Y S OF TWY G MOVED 6M W. NEW TWY WIDTH 18M.
                                                : NOTAM ENBR/0147/08

TWY E AND TWY Y S OF TWY G TEMP CLSD DUE WIP. CLOSURE PUBLISHED ON
ATIS.                                           : NOTAM ENBR/0146/08

TWY E AND TWY Y S OF TWY G CLSD FOR ACFT CODE LETTER D AND E DUE WIP.
                                                : NOTAM ENBR/0145/08

SALS RWY 35 COMPLETELY WITHDRAWN                : NOTAM ENBR/0076/08
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Appendix III – Documentation used for operative validation

Pilot's scorecard

- "Start" is heard through the intercom in due time before the wire crossing.
- You will be notified when you are about 10 seconds or 500 feet from the wire crossing. Not noticing before this point equals noticing too late or not at all (critical).
- In this situation/with you as pilot (after passing the wire crossing), please mark to what extent you would have had time to avoid a close encounter with the wire crossing:

Scenario/take number	Noticing with sufficient time to avoid (none) Noticing late: normally avoidable (minor) Noticing late: usually not avoidable (major) Noticing too late or not at all: Not avoidable (critical)

Comments:

Data log

Scenario/take number:

Visibility:

Infrastructure: Good [ ] Poor [ ]

Contrast: Good [ ] Poor [ ]

Video debrief:
Explain your consequence rating for this scenario:

At the end of each scenario, indicate how often will an average pilot experience this consequence?

Incredible [ ]

Unlikely [ ]

Moderate [ ]

Often [ ]

Interview after video debrief:
Rank order for scenarios (HK and light aircraft)?
Discuss deviation from baseline.

Appendix IV – FMECA, baseline results

Id	Aircraft performance	Visibility	Expectations	FailureMode	FailureCause	Freq	SA consequence	Cons	Marker Ball comment	Marker ball effect	Comments baseline
1	Military fixed wing	Sufficient v. of peripheral infrastructure and Sufficient contrast, best case scenario	Systematic search for Power Lines, best case	Correct scanning technique but misjudgement	Deviation from planned route. Navigation equipment error. Non-updated maps and GPS	Moderate	Time to avoid is very limited (time for reaction)	Major	May have a marginal effect to detect wire crossing	Minor	Must see at least on 1 nm distance. Very difficult if not impossible to see in best case scenario. Remaining three scenarios therefore not evaluated.
10	Helicopter	Sufficient v. of peripheral infrastructure and Sufficient contrast	Systematic search for Power Lines	Correct scanning technique but misjudgement	Insufficient local knowledge. Insufficient preparation. Navigation error. Technical faults. Workload.	Moderate	Loss of situation awareness. Late detection	Minor	Marker balls can help to detect the exact position of the wire. Good maintenance of marker balls will be an advantage	Medium	**Best case scenario**
11	Helicopter	Sufficient v. of peripheral infrastructure and Sufficient contrast	No systematic search for Power Lines	Erroneous scanning technique	Insufficient training/experience. Technical faults. Workload	Unlikely	Low situation awareness wrt. Power Lines. Random detection under good conditions.	Major		Minor	Consequence major: even when visibility is perfect, not expecting wire crossings will give less time to avoid compared to scenarios when pilot expects wires. All frequencies with no systematic search adjusted one frequency class down because it is generally more likely that pilots are expecting wire crossings when flying in areas with wire crossings

12	Helicopter	Insufficient v. of peripheral infrastructure and Sufficient contrast	Systematic search for Power Lines	Correct scanning technique but misjudgement	Not adapting search strategy to visibility. Insufficient local knowledge (topography) Insufficient preparation. Navigation error. Technical faults. Work load. Navigation error	Moderate	Reduced situation awareness. Can be surprised by power lines	Major	When towers are difficult to see, these cannot be used as primary means to locate wire crossing with marker balls. Hard to scan for marker balls even with good contrast. Marker balls may still mitigate consequenses of misjudgement.	Medium	Input from interviews: Marker ball effect medium because it can mitigate consequences of misjudgements even when peripheral infrastructure is difficult to detect
13	Helicopter	Insufficient v. of peripheral infrastructure and Sufficient contrast	No systematic search for Power Lines	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Reduced situation awareness. Can be surprised by power lines	Critical	When mast is not visible, these cannot be used to locate Power Line and markers will be visible rather late. Hard to see marker balls even with good contrast.	Minor	Marker balls will not influence the consequense because the pilot is not expecting a wire crossing
14	Helicopter	Sufficient v. of peripheral infrastructure and Insufficient contrast	Systematic search for Power Lines	Correct scanning technique but misjudgement	Insufficient local knowledge. Insufficient preparation. Navigation error. Technical faults. Workload.	Moderate	Reduced situation awareness. Can be surprised by power lines	Minor	Difficult to see in due time. Insufficient contrast can also be related to faded color of Marker Ball or light/background relations	Minor	Consequence reduced to minor because seeing the peripheral infrastructgure can give pilot more time to avoid than when seeing the wire
15	Helicopter	Sufficient v. of peripheral infrastructure and Insufficient contrast	No systematic search for Power Lines	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Detection of periphery only by coincidence (passive search strategy)	Major	Difficult to see in due time.Insufficient contrast can also be related to faded color of Marker Ball or light/background relations	Minor	
16	Helicopter	Insufficient v. of peripheral infrastructure and Insufficient contrast	Systematic search for Power Lines	Correct scanning technique but misjudgement	Insufficient local knowledge (topographic cues needed). Insufficient preparation (especially related to VFR) Technical faults. Workload.	Moderate	More complex judgement based on Local Knowledge of topography and technical means. Direct detection only through coincidence.	Major	Difficult to see in due time.	Minor	

17	Helicopter	Insufficient v. of peripheral infrastructure and Insufficient contrast	No systematic search for Power Lines	Erroneous scanning technique	Fundamental misjudgement error. Preparation error. Approaching non-VFR conditions combined with insufficient training/experience	Incredible	Detection of Power Line ony by coincidence	Critical	Difficult to see in due time.	Minor	
50	Light Aircraft (GA)	Sufficient v. of peripheral infrastructure and Sufficient contrast	Systematic search for Power Lines	Correct scanning technique but misjudgement	Insufficient local knowledge. Insufficient preparation. Navigation error. Technical faults. Workload.	Moderate	Loss of situation awareness. Decreased manoeverability ws. Helicopter, but due to correct search pattern, avoidable for most pilots.	Minor	Marker balls can help to detect the exact position of the wire. Good maintenance of marker balls will be an advantage	Medium	
51	Light Aircraft (GA)	Sufficient v. of peripheral infrastructure and Sufficient contrast	No systematic search for Power Lines	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Low situation awareness wrt. Power Lines. Random detection under good conditions.	Major	May have an effect to detect Power Line as secondary detection (mast has higher probability)	Minor	Marker balls will not influence the consequence because the pilot is not expecting a wire crossing
52	Light Aircraft (GA)	Insufficient v. of peripheral infrastructure and Sufficient contrast	Systematic search for Power Lines	Correct scanning technique but misjudgement	Not adapting search strategy to visibility. Insufficient local knowledge (topography) Insufficient preparation. Navigation error. Technical faults. Work load.	Moderate	Reduced situation awareness. Can be surprised by power lines. Reduced manoeverability with given visibility reduces response time.	Critical	When towers are difficult to see, these cannot be used as primary means to locate wire crossing with marker balls. Hard to scan for marker balls even with good contrast. Marker balls may still mitigate consequences of misjudgement.	Medium	Due to lower manuverability of light aircrafts compared to helicopters, consequence is increased to critical

53	Light Aircraft (GA)	Insufficient v. of peripheral infrastructure and Sufficient contrast	No systematic search for Power Lines	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Reduced situation awareness. Can be surprised by power lines. Reduced manoeverability with given visibility reduces response time.	Critical	When mast is not visible, these cannot be used to locate Power Line and markers will be visible rather late. Hard to see marker balls even with good contrast.	Minor	Marker balls will not influence the consequence because the pilot is not expecting a wire crossing
54	Light Aircraft (GA)	Sufficient v. of peripheral infrastructure and Insufficient contrast	Systematic search for Power Lines	Correct scanning technique but misjudgement	Insufficient local knowledge. Insufficient preparation. Navigation error. Technical faults. Workload.	Moderate	Reduced situation awareness. Can be surprised by power lines	Major	Difficult to see in due time.	Minor	Insufficient contrast can be related to faded color of Marker Ball or light/background relations
55	Light Aircraft (GA)	Sufficient v. of peripheral infrastructure and Insufficient contrast	No systematic search for Power Lines	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Detection of periphery only by coincidence (passive search strategy). Reduced manoeverability with given visibility reduces response time.	Critical	Difficult to see in due time.	Minor	Insufficient contrast can be related to faded color of Marker Ball or light/background relations
56	Light Aircraft (GA)	Insufficient v. of peripheral infrastructure and Insufficient contrast	Systematic search for Power Lines	Correct scanning technique but misjudgement	Insufficient local knowledge (topographic cues needed). Insufficient preparation (especially related to VFR) Technical faults. Workload.	Moderate	More complex judgement based on Local Knowledge of topography and technical means. Direct detection only through coincidence.	Critical	Difficult to see in due time.	Minor	Due to lower manuverability, consequence is increased to critical.
57	Light Aircraft (GA)	Insufficient v. of peripheral infrastructure and Insufficient contrast	No systematic search for Power Lines	Erroneous scanning technique	Fundamental misjudgement error. Preparation error. Approaching non-VFR conditions combined with insufficient training/experience	Incredible	Detection of Power Line ony by coincidence	Critical	Difficult to see in due time.	Minor	

Appendix V – FMECA, adjusted after operative validation and validation workshop

Idx	Aircraft performance	Visibility	Expectations	FailureMode	Failuremode Cause (e.g.)	Freq	SA consequence	Cons	Marker Ball comment	Marker-ball effect	Comments baseline	Comments flight
1	Military fixed wing	Sufficient v. of peripheral infrastructure and Sufficient contrast, best case scenario	Systematic search for wire crossings, best case	Correct scanning technique but misjudgement	Deviation from planned route. Navigation equipment error. Non-updated maps and GPS	Moderate	Time to avoid is very limited (time for reaction)	Major	May have a minor effect to detect wire crossing	Minor	Must see at least on 1 nm distance. Very difficult if not impossible to see in best case scenario. Remaining three scenarios therefore not evaluated.	
10	Helicopter	Sufficient v. of peripheral infrastructure and Sufficient contrast	Systematic search for wire crossings	Correct scanning technique but misjudgement	Insufficient local knowledge. Insufficient preparation. Navigation error. Technical faults. Workload.	Moderate	Loss of situation awareness. Late detection	Minor	Marker balls can help to detect the exact position of the wire. Sufficient contrast is a premise.	Medium		
11	Helicopter	Sufficient v. of peripheral infrastructure and Sufficient contrast	No systematic search for wire crossings	Erroneous scanning technique	Insufficient training/experience. Technical faults. Workload	Unlikely	Low situation awareness wrt. wire crossings. Random detection under good conditions.	Major	Difficult to see in due time.	Minor	Consequence major: even when visibility is perfect, not expecting wire crossings will give less time to avoid compared to scenarios when pilot expects wires. All frequencies with no systematic search adjusted one frequency class down because it is generally more likely that pilots are expecting wire crossings when flying in areas with wire crossings	

12	Helicopter	Insufficient v. of peripheral infrastructure and Sufficient contrast	Systematic search for wire crossings	Correct scanning technique but misjudgement	Not adapting scanning technique to visibility. Insufficient local knowledge (topography) Insufficient preparation. Navigation error. Technical faults. Work load.	Moderate	Reduced situation awareness. Can be surprised by wire crossings	Major	When towers are difficult to see, these cannot be used as primary means to locate wire crossing with marker balls. Hard to scan for marker balls even with good contrast.	Minor	Input from interviews: Marker balls can mitigate consequences of misjudgements even when peripheral infrastructure is difficult to detect	Input from test flights: It is assumed that significant effects of marker balls on consequence classes depends on sufficient visibilty of peripheral infrastructure (towers).
13	Helicopter	Insufficient v. of peripheral infrastructure and Sufficient contrast	No systematic search for wire crossings	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Reduced situation awareness. Can be surprised by wire crossings	Critical	When towers are not visible, these cannot be used to locate wire crossing and markers will be visible rather late. Hard to see marker balls even with good contrast.	Minor	Marker balls will not influence the consequense because the pilot is not expecting a wire crossing and because visibility of peripheral is insufficient.	
14	Helicopter	Sufficient v. of peripheral infrastructure and Insufficient contrast	Systematic search for wire crossings	Correct scanning technique but misjudgement	Insufficient local knowledge. Insufficient preparation. Navigation error. Technical faults. Workload.	Moderate	Reduced situation awareness. Can be surprised by wire crossings	Minor	Difficult to see in due time. (Insufficient contrast can also be related to faded color of Marker Ball or light/background relations)	Minor	Consequence set to minor because seeing the peripheral infrastructure can give pilot more time to avoid than when seeing the wire	
15	Helicopter	Sufficient v. of peripheral infrastructure and Insufficient contrast	No systematic search for wire crossings	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Detection of periphery only by coincidence (passive search strategy)	Major	Difficult to see in due time.(Insufficient contrast can also be related to faded color of Marker Ball or light/background relations)	Minor		

16	Helicopter	Insufficient v. of peripheral infrastructure and Insufficient contrast	Systematic search for wire crossings	Correct scanning technique but misjudgement	Insufficient local knowledge (topographic cues needed). Insufficient preparation (especially related to VFR) Technical faults. Workload.	Moderate	More complex judgement based on Local Knowledge of topography and technical means.	Major	Difficult to see in due time.	Minor		
17	Helicopter	Insufficient v. of peripheral infrastructure and Insufficient contrast	No systematic search for wire crossings	Erroneous scanning technique	Fundamental misjudgement error: Preparation error. Approaching non-VFR conditions combined with insufficient training/experience	Unlikely	Detection of wire crossing ony by coincidence	Critical	Difficult to see in due time.	Minor		Input from test flights: This situation can occur for any pilot during his or her career.
50	Light Aircraft (GA)	Sufficient v. of peripheral infrastructure and Sufficient contrast	Systematic search for wire crossings	Correct scanning technique but misjudgement	Insufficient local knowledge. Insufficient preparation. Navigation error. Technical faults. Workload.	Moderate	Reduced situation awareness. Decreased manoeverability vs. Helicopter can influence consequence classes.	Minor	Marker balls can help to detect the exact position of the wire. Sufficient contrast is a premise.	Medium		
51	Light Aircraft (GA)	Sufficient v. of peripheral infrastructure and Sufficient contrast	No systematic search for wire crossings	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Reduced situation awareness. Decreased manoeverability vs. Helicopter can influence consequence classes.	Major	Difficult to see in due time.	Minor	Marker balls will not influence the consequence classes because the pilot is not expecting a wire crossing	

52	Light Aircraft (GA)	Insufficient v. of peripheral infrastructure and Sufficient contrast	Systematic search for wire crossings	Correct scanning technique but misjudgement	Not adapting search strategy to visibility. Insufficient local knowledge (topography) Insufficient preparation. Navigation error. Technical faults. Work load.	Moderate	Reduced situation awareness. Decreased manoeverability vs. Helicopter can influence consequence classes.	Critical	When towers are difficult to see, these cannot be used as primary means to locate wire crossing with marker balls. Hard to scan for marker balls even with good contrast.	Minor	Due to lower manuverability of light aircrafts compared to helicopters, consequence is set to critical	Input from test flights: It is assumed that significant effects of marker balls on consequence classes depends on sufficient visibilty of peripheral infrastructure (towers).
53	Light Aircraft (GA)	Insufficient v. of peripheral infrastructure and Sufficient contrast	No systematic search for wire crossings	Erroneous scanning technique	Insufficeint training/experience. Technical faults. Workload	Unlikely	Reduced situation awareness. Decreased manoeverability vs. Helicopter can influence consequence classes.	Critical	When towers are difficult to see, these cannot be used as primary means to locate wire crossing with marker balls. Hard to scan for marker balls even with good contrast.	Minor	Marker balls will not influence the consequence because the pilot is not expecting a wire crossing	
54	Light Aircraft (GA)	Sufficient v. of peripheral infrastructure and Insufficient contrast	Systematic search for wire crossings	Correct scanning technique but misjudgement	Insufficient local knowledge. Insufficient preparation. Navigation error. Technical faults. Workload.	Moderate	Reduced situation awareness. Decreased manoeverability vs. Helicopter can influence consequence classes.	Major	Difficult to see in due time.	Minor		
55	Light Aircraft (GA)	Sufficient v. of peripheral infrastructure and Insufficient contrast	No systematic search for wire crossings	Erroneous scanning technique	Insufficient training/experience. Technical faults. Workload	Unlikely	Reduced situation awareness. Decreased manoeverability vs. Helicopter can influence consequence classes.	Critical	Difficult to see in due time.	Minor		

56	Light Aircraft (GA)	Insufficient v. of peripheral infrastructure and Insufficient contrast	Systematic search for wire crossings	Correct scanning technique but misjudgement	Insufficient local knowledge (topographic cues needed). Insufficient preparation (especially related to VFR) Technical faults. Workload.	Moderate	Reduced situation awareness. Decreased manoeverability vs. Helicopter can influence consequence classes.	Critical	Difficult to see in due time.	Minor	Due to lower manuverability, consequense is set to critical.	
57	Light Aircraft (GA)	Insufficient v. of peripheral infrastructure and Insufficient contrast	No systematic search for wire crossings	Erroneous scanning technique	Fundamental misjudgement error: Preparation error. Approaching non-VFR conditions combined with insufficient training/experience	Unlikely	Reduced situation awareness. Decreased manoeverability vs. Helicopter can influence consequence classes.	Critical	Difficult to see in due time.	Minor		Input from test flights: This situation can occur for any pilot during his or her career.

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