Evaluation of the ESReDA Cube Method for the Aviation Sector

First analysis of the method's applicability by applying it on 3 aviation cases

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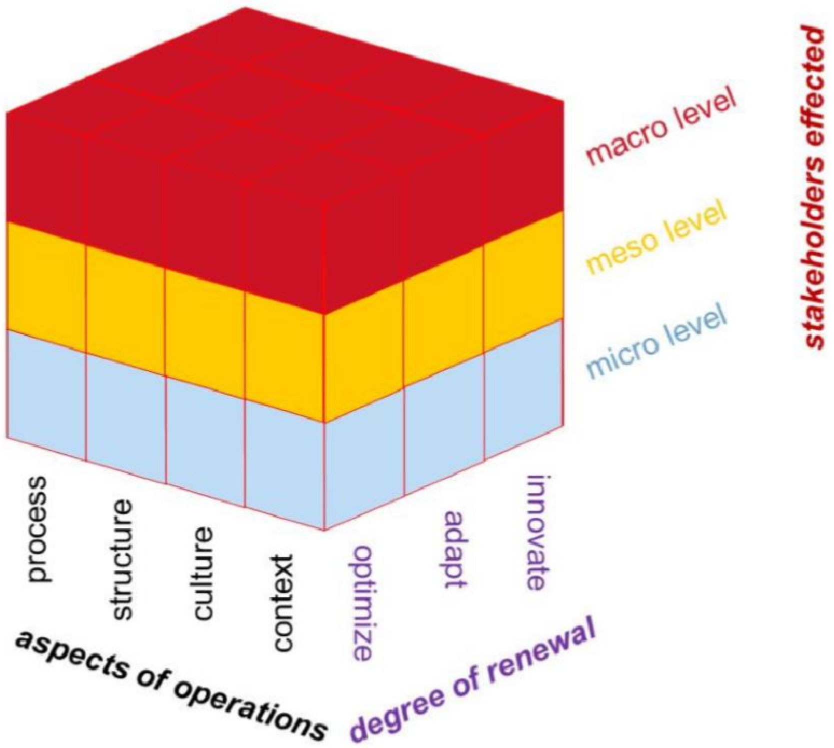

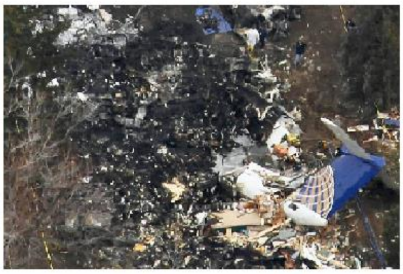

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EVALUATION OF THE ESReDA CUBE METHOD FOR THE AVIATION SECTOR

FIRST ANALYSIS OF THE METHOD'S APPLICABILITY BY APPLYING IT ON 3 AVIATION CASES

by

F.J.L.G. Martens

in partial fulfilment of the requirement for the degree of

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SYSTEM ENGINEERING AND AIRCRAFT DESIGN

The undersigned hereby certify that they have read and recommend to the Faculty of Aerospace Engineering for acceptance a thesis entitled "**Evaluation of the ESReDA Cube Method for the Aviation Sector"** by **F.J.LG. Martens** in partial fulfillment of the requirements for the degree of **Master of Science.**

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Summary

Nowadays accident analysis tools focus on finding the cause of an accident so that lessons can be learned. The ESReDA Cube method is designed to explore a new field in accident analyses. It focuses on the next step, namely analysing the lessons learned out of an accident. It is checked if they are sufficient and if they caused any change(s). With this project the ESReDA Cube method will be evaluated for the first time for the aviation sector.

The ESReDA Cube analysis is performed in several steps. First the accident is described. Next a three dimensional overview of the lessons learned is created. This overview, in the shape of a cube, is called the ESReDA Cube. The three dimensions the method explores are: operation level, system level and depth of learning level. To make the overview three questions are asked for every lesson learned. Every question is related to a specific dimension:

- Operation level: "What needs be learned?" (content, structure, culture, context)
- System level: "Who should learn?" (micro, meso, macro)
- Depth of learning level: "How to learn?" (optimize, adapt, innovate)

Behind every question, the available answers are presented between parentheses. The three answers represent a lesson learned as a set of three dimensional coordinates. In this way every lesson learned can be located in a specific part of the ESReDA Cube and an overview is created. Using this overview it can be analysed where exactly lessons are learned. By checking the spreading of the items over the cube it is checked if there is still learning potential somewhere. It is also possible to combine the results of several cases into one cube to analyse multiple cases together.

The next step is to describe the impact of the lessons learned to check if something changed or if any implementation problems are encountered.

With the results obtained conclusions can be drawn and if necessary new learning suggestions can be issued.

In this thesis the method is applied on three accident cases. The three analysed cases all have stall as a contributing factor, and due to that they are quite similar. The cases chosen are:

- Air France flight 447
- Colgan Air, Continental Connection flight 3407
- Turkish Airlines flight 1951

The cases are analysed both individually as well as together. The results show that the part of innovation on the depth of learning level is quite empty, which can indicate learning potential. Although new concepts to prevent stall accidents exist, they are not recommended. All lessons on the depth of learning level are learned in the part of adaptation and optimization. Stall accidents still occurred after these three accidents, which confirms that maybe other lessons should be learned instead of always optimizing and adapting. It can be concluded that more research should be done for new innovative concepts to prevent stall accidents.

By applying the method on three cases it is seen that in the current method's state and usage, problems are encountered which prevent a complete analysis. Only one level can be completely analysed, namely the depth of learning level. At the operation level no complete analysis is possible due to lack of input with only public sources and due to an insufficient lay-out. At the system level also no complete analysis is possible due to an insufficient lay-out of the meso and macro part.

These problems cause the method to almost always obtain the same results, namely an empty aspect of innovation. Due to this the method is in its current state and usage not applicable for the aviation sector.

It is recommended to change the lay-out of the operation and system level. Another recommendation is to change the target group of the method to investigators/instances with access to more than only public sources, like companies or safety agencies. To check if the new lay-out and target group make the method applicable for aviation further evaluation is recommended.

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Abbreviations

ACARS	Aircraft Communications Adressing and Reporting System
AD	Airworthines Directive
ADS-C	Automatic Dependent Surveillance–Contract
AEG	Aircraft Evaluation Group
AOA	Angle Of Attack
ASAP	Aviation Safety Action Program
ATOS	Air Transportation Oversight System
BEA	Bureau d'Enquêtes et d'Analyses
BRF	Basic Risk Factors
CPDLC	Controller-Pilot Data Link Communications
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
Desdemona	DESoriëntatie DEMONstrator Amst
DGAC	Direction Générale d'Aviation Civile
DSAC	Directions de la Sécurité de l'Aviation Civile
DGCA	Directorate General of Civil Aviation
EASA	European Aviation Safety Agency
ECP	Entraînements et Contrôles Périodiques
EDFCS	Enhanced Digital Flight Control System
EGPWC	Enhanced Ground Proximity Warning Computer
ELT	Emergency Locator Transmitter
ETOPS	Extended-range Twin-engine Operational Performance
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
FIM	Fault Isolation Manual
FOQA	Flight Operational Quality Assurance
HF	High Frequency
ICAO	International Civil Aviation Organization
ILT	Inspectie Leefomgeving en Transport
INCR	increase
IVW	Inspectie Verkeer en Waterstaat
LOSA	Line Operations Safety Audit
LRRA	Low Range Radio Altimeter
LVNL	LuchtVerkeersleiding Nederland
MMEL	Master Minimum Equipment List
MOQA	Maintenance Operation Quality Assurance
NASA	National Aeronautics and Space Administration

NM	nautical miles
NTSB	National Transportation Safety Board
QAR	Quick Access Recorder
RA	Radio Altimeter
SAR	Search And Rescue
SUPRA	Simulation of UPset Recovery in Aviation
ULB	Underwater Locator Beacon
VDV	Voorschriften Dienst Verkeersleiding
VVM	Verbalize, Verify and Monitor

Chapter 1

Introduction

As long as aviation exists accidents have happened. Every time again an accident is carefully investigated to find its causes. With these findings lessons can be learned to prevent the accident in the future. In this way aviation constantly keeps improving its safety. If however wrong or insufficient lessons are learned from accidents or if the lessons learned did not cause change, this safety gets endangered. To prevent this it is important to analyse and check the lessons learned from accidents and to verify their impact.

When analysing aviation accidents today the focus lays only on finding the cause of an accident and why it happened[103]. Using these findings lessons are learned out of which recommendations are issued and corrective actions are taken. Like this it is tried to prevent the accident from happening in the future. To perform such analysis, several tools are available today. The most used, relevant and state of the art methods and models to find the cause of the accident and to learn lessons are[103][2][50][9]:

- ACCIMAP[3][4][5]: an accident analysis model which was developed by Professor Rasmussen. It focuses on the sociotechnical context of an accident. An accident is seen as the result of "loss of control" over work processes. These work processes are controlled by the sociotechnical system. This sociotechnical system is divided into the government level, regulator level, company level, management level and the work level. With ACCIMAP a causal diagram is constructed which represents all the levels of the sociotechnical system and their contributing factors to the accident. More elaborate explanation can be found in appendix A.
- STAMP[6][7] (Systems-Theoretic Accident Model and Processes): an accident analysis model created by Professor Nancy Leveson. Three concepts are used in this model, namely constraints, hierarchical levels and process models. The model states that an accident can happen due to inadequate control or enforcement of safety-related constraints. These constraints are imposed by the hierarchical levels on the process. The process models help the hierarchical levels to have better coordination of their action(s). The hierarchical levels in this model are based on the sociotechnical system of ACCIMAP. Using these three concepts STAMP analyses how the system changed over time, causing the accident. More elaborate explanation can be found in appendix B.
- FRAM[8][9][10] (Functional Resonance Analysis Method): an accident analysis method designed by Erik Hollnagel. It can be used for accident investigation and for safety assessment. An accident or failure in FRAM does not show some malfunction of a system. It shows a conversion, with the necessary adjustments, of the processes to the current conditions. With the FRAM method an organization will be described as a system of functions. Performance variation of these functions can cause undesired consequences. More elaborate explanation can be found in appendix C.
- Tripod Beta[98][100][101][102]: an incident analysis method based on the Tripod Theory. This theory was developed by the university of Leiden, the university of Manchester and Shell. Later the method was made publicly available by Shell. This method can also be used to analyse accidents. The method states that accidents can happen if barriers fail to prevent actors from taking incomplete decisions which can lead to undesired consequences. With the method it is found which barriers are broken and why. In the method there is strong focus on human behaviour. More explanation can be found in appendix D.

These tools can be used for a first analysis of the accident to find the cause(s) and issue recommendations. They can also be used to redo an accident investigation to get a second opinion. In this way it is checked if all findings are correct and if all lessons are learned in the first investigation. By checking the NLR Safety

Methods Database[103] it can be concluded that this option was the only way in the past to check if all lessons are learned. In that database all safety assessment methods are described and the stages in which they are used. For the moment only 8 stages[103][104] are available for safety assessment, namely:

- Scope the assessment
- Learning the nominal operation
- Identify hazards
- Combine hazards into risk framework
- Evaluate risk
- Identify potential mitigating measure to reduce risk
- Safety monitoring and verification: confirm actual risk is tolerable or reducing. Continually monitoring overall safety performance.
- Learning from safety feedback: this safety feedback is obtained out of safety monitoring.

Analysing and checking lessons learned and their follow-up is not one of these stages, meaning no specific tool was available to perform such analysis.

The development of the ESReDA Cube method[1][2][50] changed this. With this method the lessons learned from an accident can be analysed. It is checked if these lessons learned are sufficient, and if necessary new learning suggestions can be made. The method also checks if any changes have happened due to the lessons learned and/or if there are problems encountered with their implementation. The ESReDA Cube method focuses on the next step in the learning process, right after where the analysis of the other tools stop. In this way a new field is explored in the area of accident analysis. Using this method it can be assured that analysing accidents and learning from it does not become a routine in which always the same lessons are learned.
The method is, as the name says, developed by ESReDA (European Safety, Reliability and Data Association). It is designed to be usable in all high risk sectors, such as construction, rail-road, aviation, chemistry, etc. The method can also be used to analyse incidents. Since in this evaluation the method will be used to analyse three aviation accidents, the term incident will not be further repeated in this thesis. If the method would be used for an incident, the modus operandi is exactly the same as for an accident.
The ESReDA Cube method is quite young and unknown. Until now it has only been used and tested for the aviation sector by its developers, never by an outsider. The next step in the method's development is an evaluation by someone outside the ESReDA group.

1.1 Research question and objective

Testing, analyzing and evaluating the ESReDA Cube method for the aviation sector by someone outside the ESReDA developers group is the main objective of this research project. By applying the method on three aviation cases a neutral view can check and evaluate the method's applicability. If necessary also recommendations can be made. In this way feed-back to the method's developers is provided.
To accomplish this objective the following research question will be answered in this thesis:

Is the ESReDA Cube method applicable to analyse aviation accidents?

To answer this research question several topics have to be addressed. That is why sub questions are defined.

- *Does the method work? Can useful results be obtained?*
- *What is the method's usefulness?*
- *Are there other possibilities for the method than the ones described?*
- *Does the method have limitations?*
- *Are there recommendations for further development?*

All these questions will be answered in this research project.
It has to be noted that this thesis is mainly based on the method's papers of beginning 2014[2] and April 2014[50], when this research project started. A next version appeared in November 2014[106] and in February 2015[105] the final version was published.

1.2 Thesis structure

The report consists of seven chapters. In the second chapter the ESReDA Cube method is explained. A description of how the cases for the applications are selected is provided in chapter 3. In chapter 4 the three selected cases are analysed individually with the ESReDA Cube method and conclusions about the lessons learned are drawn. The elaborate version of these analyses, using the ESReDA Cube method's template, can be found in the appendices E, F and G. In chapter 5 the results of all three individual analyses are put together and a general analysis of all cases together is performed. The chapter ends with a conclusion about the lessons learned in these three accidents. In chapter 6 an evaluation of the method is performed using the knowledge gained by applying the method. With this evaluation the research question can be answered. Chapter 7 states the conclusions and recommendations about this project. In the appendices A, B, C and D an elaborate explanation can be found of FRAM, Tripod, ACCIMAP and STAMP. These tools were shortly described in the introduction.

Chapter 2

ESReDA Cube Method[1][2][50]

As mentioned earlier, the ESReDA Cube Method is used to analyse the lessons learned from an accident. It is checked if all necessary lessons are learned to prevent look-a-like accidents. If not, new learning suggestions can be made. It is also checked if the lessons learned caused any changes or if implementation problems occurred.
The inputs for this method are the lessons learned, which can be found as recommendations/actions issued/taken to prevent the accident. Also information about the origin and the circumstances of the accident is collected and analysed to get a whole picture of the learning process. All this input information can be found in accident investigation reports, articles, company reports, etc.
In the method three main themes are discussed:

- origin of the accident/incident
- analysis of the lessons learned
- comments and conclusions

All these themes are investigated using a template (see paragraph 2.4) which contains questions to get more insight in the case and to analyse it.

2.1 First theme: origin of the accident

The first theme is divided in four parts. In the first part the causes and circumstances of the accident are described, including historical events which can be important for the analysis. In the second part the environment of the accident is described. The magnitude of the damage caused by the accident is focused on in the third part. The last part describes the investigations which have been performed.

2.2 Second theme: analysis of the lessons learned

The second theme concerns the main purpose of the ESReDA Cube, namely analysing the lessons learned (recommendations/actions) from the accident. For this three questions are asked:

- What needs to be learned?
- Who should learn?
- How to learn?

These three questions represent the three dimensions of the ESReDA Cube: aspect of operations (operation level), stakeholders effected (system level) and degree of renewal (depth of learning level). For every recommendation/action these questions have to be answered using the template (see paragraph 2.4). At the end of this theme the impact of the lessons learned is checked.

2.2.1 What needs to be learned/Operation level

The first question and dimension focus on the operations affected by the lessons learned. The operation level exists out of four aspects: content, structure, culture and context.
Content concerns the process of the accident, to check how the primary activity can be improved to increase safety.
The aspect of structure is about (re)design of the organizational structure (organization, processes) and the technological structure (technology, hardware) after the accident.
The aspect of culture concerns change in organizational culture, learning culture and behavior of stakeholders involved in the accident.
Context concerns the operational environment. This aspect is about change in supporting conditions (politics, safety boards, management) and the development of knowledge which is done because of the accident.
By asking "what needs to be learned" for every recommendation/action it can be checked precisely in which of the four aspects of the operation level lessons are learned.

2.2.2 Who should learn/System level

The second question and dimension focus on the stakeholders affected by the lessons learned. The stakeholders can be divided in three groups: the macro level (the highest level which contains society and the European Union), the meso level (the holding branch of the industry and the safety authorities) and the micro level (the lowest level, this can be an individual or the entire company or organization) (see figure 2-1). Every recommendation/action can be addressed to one of these three stakeholders. This dimension represents the system level in the ESReDA Cube.

Figure 2-1: Stakeholders of a process

The sociotechnical system of ACCIMAP (see chapter 1 and appendix A) and the hierarchical level of STAMP (see chapter 1 and appendix B) can be compared with the system level of the ESReDA Cube method.

2.2.3 How to learn/Depth of learning level

The last question and third dimension focus on the degree of renewal caused by the lessons learned. Lessons can be learned in one of the three levels of the learning process. These levels are the triple, double or single loop. The depth of learning or degree of renewal depends on the level of the learning process where lessons are learned. When learning happens in the triple loop the principle is changed which means the whole concept of operations is innovated beyond the state of the art. When the lesson is learned in the second loop the insights are changed/renewed which causes an adaptation of the existing operations. At last, when the single loop is touched it means the rules/routines are changed/improved to optimize the operations. This can all be seen in figure 2-2 and 2-3.

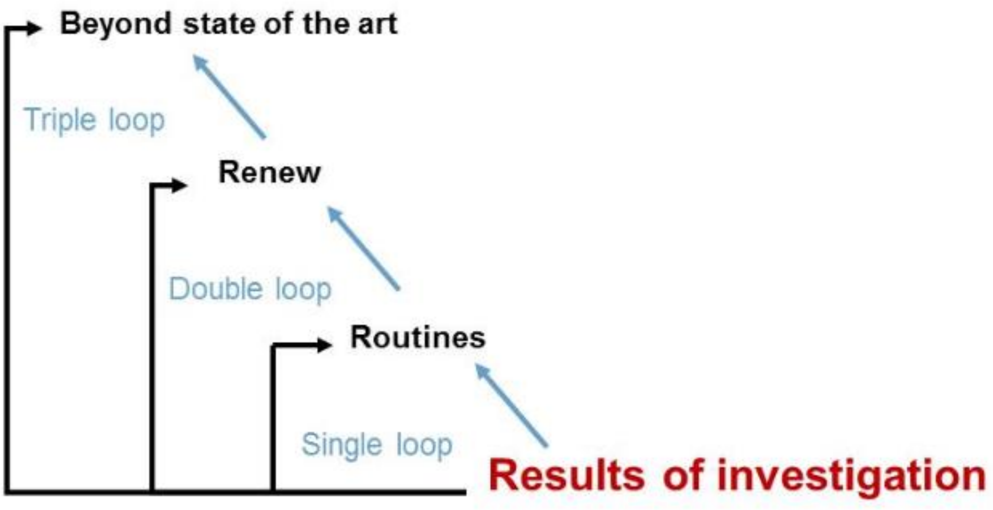

Figure 2-2: Levels of the learning process

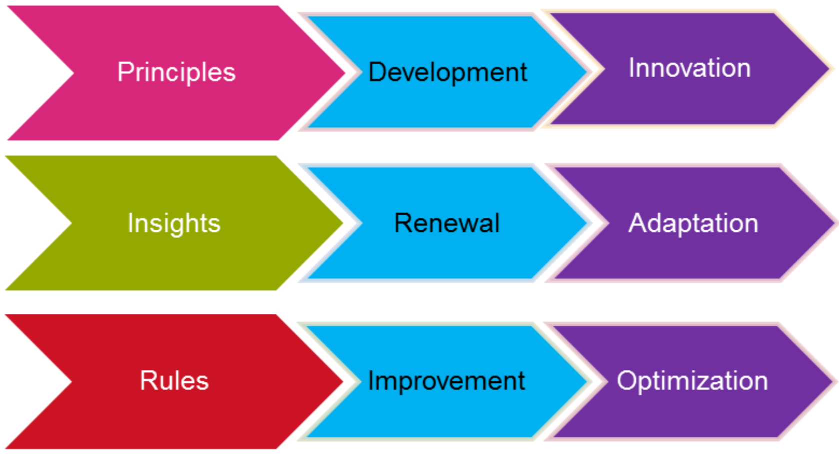

Figure 2-3: Depth of learning

Every recommendation/action can be addressed to one of the three aspects: optimization, adaptation or innovation. This dimension represents the depth of learning level in the ESReDA Cube.

2.2.4 ESReDA Cube

As mentioned, these three questions represent the three dimensions which form the ESReDA Cube (see figure 2-4). This cube is a Cartesian coordinate system. On the X axis of this system "aspects of operations" (operation level) can be found, on the Y axis "stakeholders effected" (system level) and on the Z axis "degree of renewal" (depth of learning level).

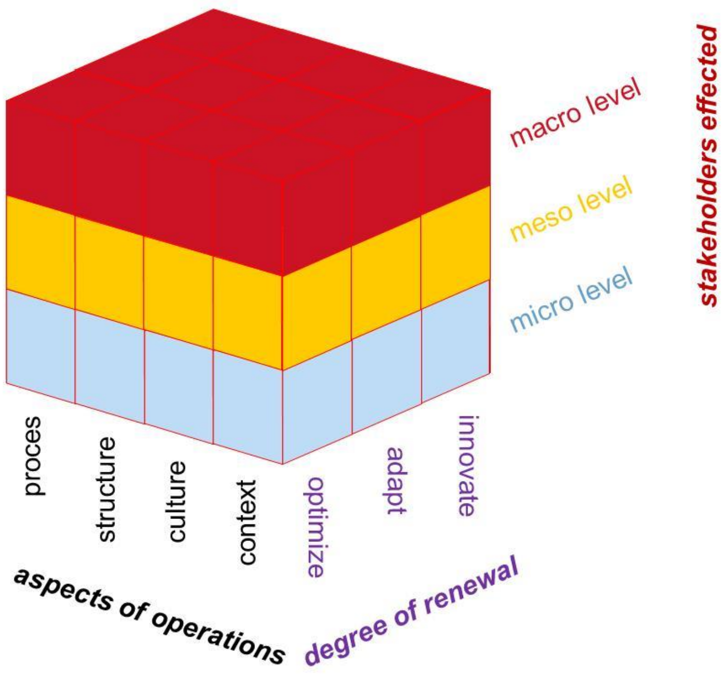

Figure 2-4: Visual display of the ESReDA Cube

By answering the three questions and so categorizing all recommendations/actions in the template, every lesson learned is transformed into a set of three dimensional coordinates.
With these coordinates all items from the template can be plotted in the ESReDA Cube. In this way it can be clearly checked how, what and where lessons are learned (see figure 2-5).

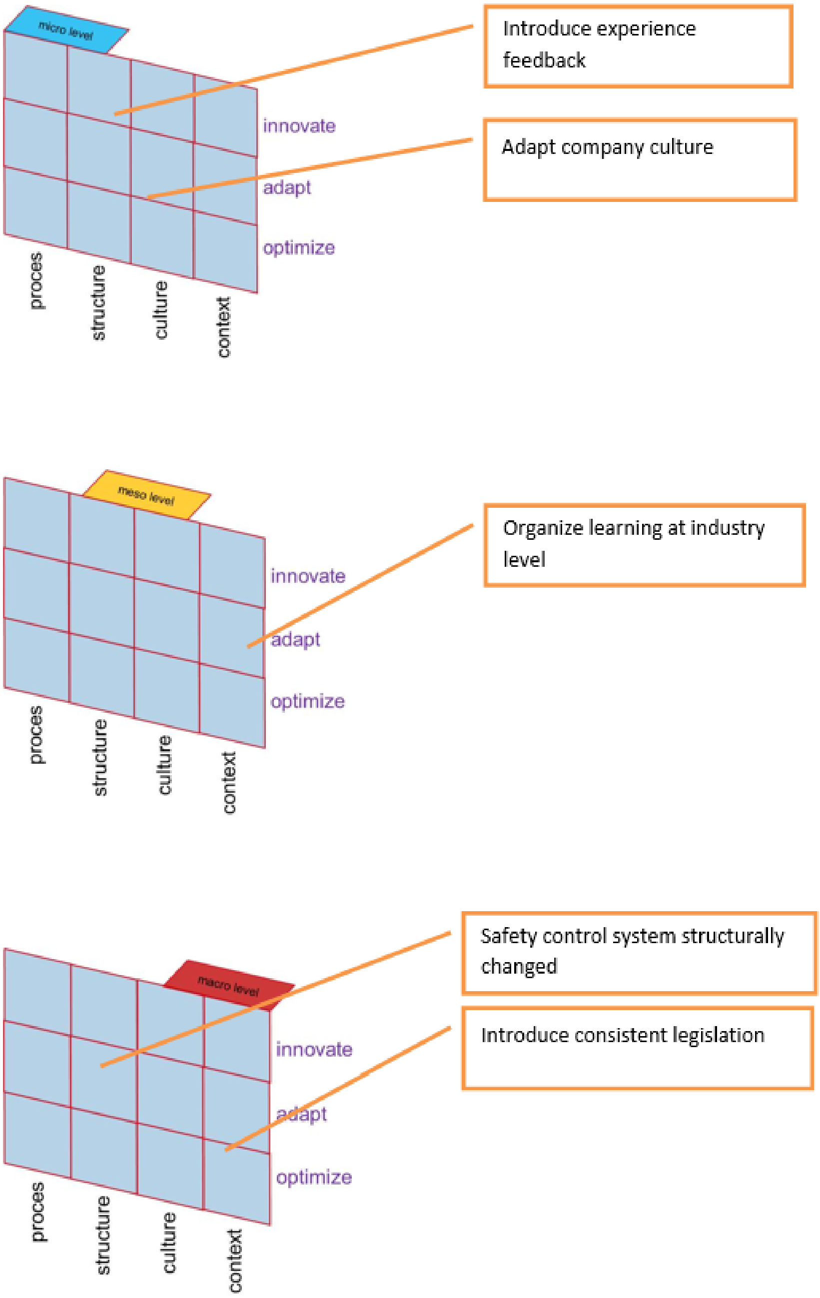

Figure 2-5: Example of recommendations/actions plotted in the cube

2.2.5 Impact

The recommendations will, after they are issued, be checked by the stakeholders and they will decide if these recommendations will be implemented or not. Since it are only recommendations, implementation is not mandatory. To analyse the impact of the lessons learned the template provides questions about their follow-up and about the changes they caused. With this section it can be checked if something is learned or if problems were encountered in the follow-up or implementation of the lessons learned. Also the impact of the accident on the investigation process or structure is analysed in this section.

2.3 Third theme: comments and conclusion

An ESReDA Cube analysis can be performed for an individual case but also for multiple cases together.

Comments and conclusion individual case
With all recommendations/actions categorized in the cube it can be checked how, where and what lessons are learned. If some parts of the cube are left open or are quite empty, it can be a sign that learning potential is present. New learning opportunities, where other investigators did not think of and which could prevent the accident, can then be suggested by the ESReDA investigator(s). In this way it is possible to issue recommendations which are less evident but can prevent the accident. It is also possible that the information of the cube and the template will confirm that all learning potential has been used. In this way with all the information obtained from the analysis, a conclusion can be drawn. Remarks about the investigation itself or about the impact of the accident can also be stated in the conclusion. Other comments about the learning process can always be mentioned.

Comments and conclusion multiple cases
It is possible to put the results of several cases together in one cube to compare them and to check for possible patterns. This can be done for accidents which don't have a mutual cause. Then it can be checked if recommendations/actions are spread across the cube or that they are always found in the same aspects/levels. In other words to see if investigators always try to prevent accidents in the same way or not. Also results of accidents with a mutual cause can be put together in a cube. Then an analysis can be made for a specific type of accident. In such analysis it can be checked if for similar accidents always the same lessons are learned to prevent them. Crucial information which cannot be found when the cases are checked individually, can be provided by analysing them together with the ESReDA Cube.
Again, as with the analysis of individual cases, the results of this analysis of multiple cases can be used to identify learning potential. In this way new recommendations can be suggested or it can be confirmed that all learning potential has been used. Same as with the analysis of individual case, with all the information obtained from the analysis a conclusion can be drawn. Remarks about the investigation itself or about the impact of the accident can also be stated in the conclusion. Other comments about the learning process can always be mentioned.

2.4 The template

First theme: origin of the accident
Description of the event (sequence and system involved)

1. short description
2. what has happened, what agent (description, pictures etc.)
3. how has it happened, what where the circumstances
4. why did it happen, direct causes, root causes other root causes
5. when: timeline, historical events
6. where: place, context of event and system (general, environment, topography, weather)
7. sector(s) involved

Type of event:
1. content aspects: primary activity, operational aspect involved
2. process aspects: general/macro and local/micro description of what business process was involved, what activity was going on?
3. structural aspects: what structure was involved?
4. cultural aspects: was any culture aspect of importance?
5. contextual aspects: are specific items or influence of interest?
6. area and stakes vulnerability to the system

Magnitude of damage to system involved:
1. kind of property damage
2. victims
3. scale (magnitude) of damage, financial, environmental

4. down time business process and connected logics chain, infrastructure involved
5. after the event, aftermath actions to restore, repair, compensate
6. speed/pace of recovery to get completely back into business

Investigations known:
1. by safety board/special commissions
2. by public authorities
3. by companies involved

Second theme: analysis of the lessons learned
Dimensions lessons learned: operations
Recommendations/actions developed
1. content process (what goes on in primary process):
   how can the work be done safer?
2. structure (system architecture and functionality): lessons on aspect structure: what structural improvements are sought: organizational, technological?
3. culture: what behaviour or even cultural changes are sought or have been developing as a result of the accident?
   Organizational culture, learning culture, behavioural change.
4. context (operation environment)
   Business/change management organized (learning agent) political, social changes needed, supporting organization (e.g. safety board), development of knowledge

Dimensions lessons learned: system levels involved.
System level with on each level groups of stakeholders:
1. recommendations/actions at micro: individuals, teams, company and holding level; timeline of implementation
2. recommendations/actions at meso: industry and industry branch level; timeline of implementation
3. recommendations/actions at macro: government and society level; timeline of implementation

Dimensions lessons learned: depth of learning
Depth of learning refers to type(s) of learning identified:
1. optimize: restore and repair (cf. first loop/order learning (change of rules)
2. adapt: improving (cf. second loop/order learning (change of insight, norms and values)
3. innovate: renewing (third order learning (learn to learn), technological (new principles, breakthrough) knowledge development.

Impact
1. changes identified: what changes in safety climate are observed?
2. change/learning agent
   a. who/what takes care for follow-up
   b. who/what keeps memory/knowledge alive
   c. who/what keeps monitors effectiveness
3. change timeline
4. change of investigation process
   did the accident and following investigations lead to any changes in the way investigations are structured (investigation board), done?

Third theme: comments and conclusions
Evaluation of accident and follow-up
1. conclusion/discussion by ESReDA group
2. are changes sustained?

References to resources knowledge used

1. communication of findings, recommendations (government, safety board, investigation commission, third party, company reports)
2. other transfer of knowledge by parties involved, professional organizations (articles, courses, training relevant links)

Chapter 3

Case Selection

This chapter concerns the selection of the three cases that will be used to evaluate the ESReDA Cube method. To select the cases first some conditions are set up and next the cases' choice will be explained.

3.1 Case conditions

To be able to answer the research question of this thesis good cases have to be chosen:

- The cases should allow to test the method intensively for every individual case. This means enough input information about the cases have to be found. This is necessary for the ESReDA Cube method to create a good output.
- To test the method for analysing multiple cases it is chosen in this thesis that all cases should have some mutual contributing factor. In this way it can be seen, using the ESReDA Cube method, if similar cases always lead to the same recommendations or actions. Like this patterns can be identified. It can also be checked if the ESReDA Cube method provides more insights when analysing similar cases together.

With these two points the cases will be selected.

3.2 Case choice

In this thesis the phenomena of stall is chosen as the factor which links all the cases. Stall is chosen because it is one of the most basic problems of aviation. It has already caused a lot of accidents and incidents in the past and this will probably continue in the future.
At the start of this project it was the purpose to choose cases from both general and commercial aviation. In this way not only a comparison between the recommendations/actions of each case could be made, but also between the different kinds of aviation.
To make a selection several databases (Dutch Veiligheidsraad's database, Belgian Directoriaat Luchtvaart's database, French Bureau D'Enquêtes et d'Analyses' database and the British Air Accidents Investigation Branch's database) were checked for stall accident cases. Both general and commercial aviation cases were checked. It was seen that general aviation accidents could not be used to evaluate the ESReDA Cube method. As already mentioned before, as an input for the ESReDA Cube method recommendations/actions found in accident investigation reports or other sources are required. It was seen that in general aviation accident investigation reports not many recommendations/actions, or even often non, are mentioned. General aviation accidents reports are most of the time not very elaborate. Other sources also did not provide enough information to test the ESReDA Cube method for an individual case. This does not mean that general aviation accidents are not suited to be analysed by the ESReDA Cube method. It only means that enough input has to be available and accessible. For this thesis report, where only use is made of public sources, it is not possible to collect enough input. Commercial accident investigation reports on the other hand are almost always very elaborate and often other sources can be found as well. Due to this enough input for an ESReDA Cube analysis is available. For this reason the evaluation of the ESReDA Cube method will be done in this thesis

using commercial aviation accidents only. With this a limitation of the ESReDA Cube method is shown, namely that it can only investigate cases if enough input is found.

The three cases chosen are:

- Air France flight 447
- Colgan Air, Continental Connection flight 3407
- Turkish Airlines flight 1951

All three cases will be analysed using the ESReDA Cube method. First every case will be analysed individually (using the template), this can be found in chapter 4. Next in chapter 5 the results of all cases are put together. In this way the method can also be tested for multiple cases together, specifically for stall cases. Not all conclusions are mentioned in every individual analysis. The conclusions which are valid for all three cases are stated in chapter 5.

Chapter 4

Individual Case Analysis

This chapter will show a short version of every individual analysis done with the ESReDA Cube method.
A remark about all analyses is that the aspect of content at the operation level is left empty every time on purpose. During the analyses some problems were encountered with this aspect. Further explanation can be found in 6.2.2.

4.1 Air France flight 447

The first case analysed is the crash of Air France flight 447. More details and the elaborate template of this case can be found in appendix E.

4.1.1 First theme: origin of the accident

On June 1st 2009 the Air France Airbus A330-200 was flying from Rio De Janeiro to Paris. During cruise over the Atlantic Ocean the pitot tubes got blocked by ice crystals. Because of that improper speed information was given to the pilots and the systems. This caused the automatic systems to disconnect, reconfiguring the aircraft to alternate control law. In this control law the high angle of attack protection is lost but the stall warning still works. The captain was not in the cockpit when the automatic systems disconnected. The pilot flying took over control and a nose-up input was given while the speed of the aircraft was decreasing. This was probably done because he thought the aircraft was in an overspeed situation and because the flight director instructed a nose-up input. This nose-up input was given without informing the pilot not flying. Later the pilot not flying took over control without communicating clearly with the pilot flying. These miscommunications probably happened because the captain, before he left, did not specify who the relief captain was.
The pilots did not know what the problem and reason was why the automatic systems disconnected so they did not know how to react. Since they did not know this error, the procedures were not followed. It was assumed that the stall protection was still active. Because of this they thought the stall warning triggered was invalid. Due to this nose-up and decreased speed the aircraft was undeliberate brought into a stall from which it did not recover and crashed.
There had already been problems in the past with inconsistent speed measuring. Due to that Air France was about to replace the pitot tubes on its entire A330/A340 long-haul fleet[21].

4.1.2 Second theme: analysis of the lessons learned

In the next table a summary is given of the lessons learned.

Total					
Innovate	1	**Micro**	19	**Content**	0
Adapt	19	**Meso**	11	**Structure**	41
Optimize	33	**Macro**	23	**Culture**	5
				Context	7

Table 4-1: Summary of every level Air France 447

If we put all data found with the template in a cube, the recommendations/actions are located as follows (with the number showing how many recommendations/actions on each level).

MICRO	innovate	adapt	optimize
content	0	0	0
structure	0	7	8
culture	0	1	3
context	0	0	0

Table 4-2: Micro level Air France 447

MESO	innovate	adapt	optimize
content	0	0	0
structure	0	2	8
culture	0	0	0
context	0	0	1

Table 4-3: Meso level Air France 447

MACRO	innovate	adapt	optimize
content	0	0	0
structure	0	7	9
culture	0	1	0
context	1	1	4

Table 4-4: Macro level Air France 447

The most important recommendations that were issued to prevent this problem concerned:

- improving the pilot training[21]
- improved working of the pitot tubes[21]
- improved safety at Air France by changing culture, adding safety programs, changing processes, changing organization[16][17][18][21]
- evaluating a direct angle of attack indicator[21]
- improving the flight director[21]
- improving warnings, including better low speed and stall warning[21]
- improving crew monitoring[21]
- ensuring better fidelity of the simulators[21]

4.1.3 Third theme: comments and conclusion

Also recommendations about improving the SAR services, the flight recorder and the presence of drifting buoys on the place of the accident were issued in this report[21]. The ESReDA Cube analysis here focuses on recommendations and actions which could help to prevent this accident from happening in the future. The recommendations about improving SAR services, flight recorders and the presence of drifting buoys do not concern preventing the accident. That is why they are not taken into the ESReDA Cube analysis. Otherwise a wrong image of the results would be provided.

In the recommendation review reports of EASA[60][61][62] it is mentioned that some recommendations are agreed on and closed. This creates the expectation that action will be taken to implement these recommendations. Agreed on, however, does not necessarily mean the recommendation will also be implemented. It was found that some recommendations were agreed on and closed, while they were still under consideration. Closing the recommendation while considering it causes difficulties to check if action is taken or not. To have a more clear view of what is happening with a recommendation it is recommended that different terms would be used to prevent confusion.
In this recommendation review report 2013[62] it was stated that the direct angle of attack indicator will not be implemented. The reason was that it will require extra training and increase the pilot's workload. It is not mentioned if this concept was tested or not. This looks like a drastic decision since a direct angle of attack indicator really could have helped the pilots in this case. According to the report EASA agrees that it could help in the proximity of stall situations. They state, however, that the information provided by such an indicator is only of small benefit.
It is seen that there is an unbalance in the spreading at the depth of learning level. The quite empty aspect of innovation will be discussed in chapter 5. Between adapt and optimize there is also an unbalance. This unbalance is however too small to indicate learning potential.
Other comments and conclusions, which are valid for all three cases, can be found in chapter 5.

4.2 Colgan Air, Continental Connection flight 3407

The second case analysed is the crash of Colgan Air flight 3407. More details and the elaborate template of this case can be found in appendix F.

4.2.1 First theme: origin of the accident

On February 12th 2009 a Bombardier Dash 8 of Colgan Air, performing a flight for Continental Connection, was flying from Newark to Buffalo. Because the aircraft had to fly in icing conditions the ref speeds switch was set on INCR (increase). With this switch on INCR the stick shaker is activated earlier, at a lower AOA and above normal stall speed. This is done to anticipate with the icing conditions, which can cause aircrafts to stall earlier (at a lower AOA and higher speed). The fact that the stick shaker would be activated earlier was not described in the procedures of Colgan Air. During approach, when the aircraft was slowing down, the pilots did not see the visual low speed warnings. The aircraft was still above stall speed when suddenly the stick shaker was activated. The captain was surprised and reacted by pulling the stick, even overpowering the stick pusher when it activated. This caused the aircraft to stall and crash. The AOA at which the stick pusher is activated is not influenced by the position of the ref speeds switch. Only the stick shaker is activated earlier with this switch on.
The pilots talked the entire flight about non-flight related subjects and so they did not hold the sterile cockpit procedure. The pilots also did not have a lot of sleep before the flight. Their fatigue probably impaired their flying performance[45].

4.2.2 Second theme: analysis of the lessons learned

Below a summary of the lessons learned is given.

Total					
Innovate	1	**Micro**	21	**Content**	0
Adapt	31	**Meso**	0	**Structure**	41
Optimize	17	**Macro**	28	**Culture**	6
				Context	2

Table 4-5: Summary of every level Colgan Air 3407

If we put all data found with the template in a cube, the recommendations/actions are located as follows (with the number showing how many recommendations/actions on each level).

MICRO	innovate	adapt	optimize
content	0	0	0
structure	0	9	8
culture	0	1	3
context	0	0	0

Table 4-6: Micro level Colgan Air 3407

MESO	innovate	adapt	optimize
content	0	0	0
structure	0	0	0
culture	0	0	0
context	0	0	0

Table 4-7: Meso level Colgan Air 3407

MACRO	innovate	adapt	optimize
content	0	0	0
structure	0	18	6
culture	0	2	0
context	1	1	0

Table 4-8: Macro level Colgan Air 3407

The most important recommendations that were issued to prevent this problem concerned[45]:

- improving the pilot training
- improvement in the use of the ref speeds switch
- improved safety at Colgan by changing culture, adding safety programs, changing processes, changing organization
- implementing safety programs in airline companies
- improvement of the weather information for pilots
- better low speed warnings
- addressing the topic of fatigue
- improving crew monitoring
- regulating pilot records
- improving communication of information to crew
- defining minimum fidelity requirements for the simulator

4.2.3 Third theme: comments and conclusion

This accident report[45] differs from the reports of Turkish Airlines 1951[49][107] and Air France 447[21] because one specific probable cause for the crash is stated. This is remarkable since a lot of factors led to this accident and not only one specific factor. It is probably done because of legal issues. In the other two cases' reports the conclusions state all factors contributing to the accident. One single cause is, however, not specified.
It is odd that some recommendations were already issued in the past and are now repeated to the FAA in this report because they are not implemented yet. All three reiterated recommendations had the status "open-acceptable alternate response" before the crash happened. Some of them were left open by the FAA without any action taken for three years. It raises the question if this accident could have been prevented if these recommendations would have been implemented. That's a question which will never be answered, but for sure it is not good that recommendations have to be repeated. Next to the three reiterated recommendations, three other old open recommendations were closed and new recommendations superseded them. Information about these reiterated or superseded recommendations can be found in the analysis in appendix F.

Another strange fact is that no recommendation is made regarding an improvement of the stick pusher system, specifically its activation. In this aircraft the stick shaker is activated at a lower angle of attack and at a higher speed when the ref speeds switch is on INCR. The angle of attack to activate the stick pusher, however, does not depend on the position of the ref speeds switch. It was expected that a recommendation would have been made regarding the earlier activation of the stick pusher when the ref speeds switch is on INCR. Although no recommendation is made, it should be investigated if is not opportune to link the activation of the stick pusher to the ref speeds switch position.
The FAA was recommended to address fatigue risks to all operators. However, no sufficient action was taken by the FAA and the recommendation was closed[71]. Looking at the seriousness of the problem, this is a strange decision of the FAA.
It is seen that there is an unbalance in the spreading at the depth of learning level. The quite empty aspect of innovation will be discussed in chapter 5. Between adapt and optimize there is also an unbalance. This unbalance is however too small to indicate learning potential.
Other comments and conclusions, which are valid for all three cases, can be found in chapter 5.

4.3 Turkish Airlines flight 1951

The last case analysed is the crash of Turkish Airlines flight 1951. More details and the elaborate template of this case can be found in appendix G.

4.3.1 First theme: origin of the accident

On February 9th 2009 a Boeing 737-800 of Turkish Airlines, flying from Istanbul to Amsterdam, crashed upon approach. The left radio altimeter of the aircraft was broken and showed an altitude of -8 feet. This was known by the crew, but it was not known that the information of this radio altimeter was provided to the autothrottle. During approach the autothrottle went from vertical speed modus into retard flare modus which is normally used right before touch down. This could happen since all conditions to activate this modus were fulfilled. These conditions are: being below 27 feet (the radio altimeter showed -8 feet), flaps more than 12.5°, an autothrottle mode active and the aircraft cannot climb or descend to a set altitude. Because of this modus the autothrottle was pushed backwards to idle approach, causing the speed to decrease. Next to this thrust change, the nose moved up. This nose-up was caused by the autopilot, which received correct altitude information of the right altimeter, to follow the glide path as long as possible. Several visual indications on the instrument panel showed what was happening. These visual indications consisted of a visual warning on the primary display, a retard flare modus message on the primary display and a much to high nose-up on the artificial horizon. Although all these indications, the pilots did not notice anything. The reason is probably because in the beginning the actions of the aircraft corresponded to the crew's inputs of descending and decreasing speed. Suddenly, the stick shaker activated and the first officer, who was the pilot in command, immediately pushed the throttle and steer column forward. He stopped doing this after a second since the captain called out "I have". Due to this and the fact that the autothrottle was still on, the thrust decreased back to idle. Next the autothrottle was switched off, but it still took seven seconds before full thrust was selected. Unfortunately it was too late and the aircraft crashed.
Normally an aircraft has to fly horizontally during the final approach track before intercepting the glide path and intercept the glide path from below. In this case the line-up of the aircraft happened in a distance of 5-8 NM from the runway threshold. There was no command given to descend, what resulted in a glide path interception from above. Because of that the aircraft had to descend and decrease speed to intercept the glide path. This masked the autothrottle change into retard flare modus. This late descend kept the crew of finishing their landing checklist before they reached 1000 feet. If it is not finished by 1000 feet, pilots should abort the landing according to Turkish Airlines procedures (with bad visibility all actions should be finished before passing 1000 feet, with good visibility this changes to 500 feet). The workload was enormous for a flight phase where the crew should normally only monitor.
Approaching the runway between 5 and 8 NM of the threshold is allowed if two conditions are fulfilled. It has to be offered to the pilots. Second condition, they have to get instructions to descend below 2000 feet so that the glide path is intercepted from below. These two conditions were not fulfilled.

This aircraft had, in the 48 hours before the crash, already two similar problems with the radio altimeter. The pilots of these flights did not report these incidents. Also several other similar incidents with other Boeing 737s are known[49][107].

4.3.2 Second theme: analysis of the lessons learned

Below a summary of the lessons learned is given.

Total					
Innovate	0	**Micro**	33	**Content**	0
Adapt	13	**Meso**	5	**Structure**	39
Optimize	29	**Macro**	4	**Culture**	0
				Context	3

Table 4-9: Summary of every level Turkish Airlines 1951

If we put all data found with the template in a cube, the recommendations/actions are located as follows (with the number showing how many recommendations/actions on each level).

MICRO	innovate	adapt	optimize
content	0	0	0
structure	0	7	24
culture	0	0	0
context	0	2	0

Table 4-10: Micro level Turkish Airlines 1951

MESO	innovate	adapt	optimize
content	0	0	0
structure	0	2	3
culture	0	0	0
context	0	0	0

Table 4-11: Meso level Turkish Airlines 1951

MACRO	innovate	adapt	optimize
content	0	0	0
structure	0	1	2
culture	0	0	0
context	0	1	0

Table 4-12: Macro level Turkish Airlines 1951

The most important recommendations/actions that were issued/taken to prevent this problem concerned:

- improving the pilot training [49][107]
- increasing awareness about the importance of reporting[49][107]
- improving the radio altimeter's reliability and improving aircraft maintenance[49][107]
- autothrottle and flight management computer improvement[49][107]
- developing software to compare left and right radio altimeter[49][107]
- harmonizing air traffic procedures for lining up[49][107]
- implementing an aural low speed warning[49][107]
- improving the communication of information to crew[49][107]
- improving safety at Turkish Airlines by improving processes, improving safety programs, and performing organizational changes[49][107][95]

4.3.3 Third theme: comments and conclusion

Boeing will equip its new Boeing 737's with a new low speed aural alert system. Old aircraft can be modified but this is not mandatory[94]. The recommendation of better warnings for stall returns also in the Air France 447 and Colgan Air 1951 case. The question can be asked then if this system should not be made mandatory for every aircraft.
ICAO was also advised to include in their regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs[49][107]. According to ICAO this is already described in the regulations under a different chapter. The only action that will be taken by ICAO is the development of guidance material[97]. FAA on the other hand received the same recommendation and they agreed, issuing a notice of proposed rulemaking change[96]. The recommendation was also addressed to EASA and they are considering it[62]. This recommendation also returned in the other investigated cases, which shows the importance. It is bizarre that ICAO did not agree.
The micro level is much more filled than the other two levels. This does not imply there is still learning potential on the two other levels. It is just because a lot of small corrective actions were taken by Turkish Airlines and Boeing immediately after the crash. Some actions are all small steps to achieve one goal. There are also items at the micro level overlapping each other, they belong to different stakeholders but have the same goal.
It is seen that there is an unbalance in the spreading at the depth of learning level. The empty aspect of innovation will be discussed in chapter 5. Between adapt and optimize there is also an unbalance. This unbalance is however too small in this case to indicate learning potential. At the micro level this can again be explained by the big number of small corrective actions taken by Boeing and Turkish Airlines.
Other comments and conclusions, which are valid for all three cases, can be found in chapter 5.

Chapter 5

Multiple Case Analysis

In the previous chapter the three cases are analysed individually. In this chapter an analysis will be performed for all cases together to have a better idea where lessons are learned for stall accidents. In this way it can be seen how accident investigation agencies will try to prevent stall accidents in the future.
To perform this analysis the results of the three individual analyses are put together in one set of cubes, which gives the following results.

MICRO	innovate	adapt	optimize
content	0	0	0
structure	0	23	40
culture	0	2	6
context	0	2	0

Table 5-1: Micro level of all cases

MESO	innovate	adapt	optimize
content	0	0	0
structure	0	4	11
culture	0	0	0
context	0	0	1

Table 5-2: Meso level of all cases

MACRO	innovate	adapt	optimize
content	0	0	0
structure	0	26	17
culture	0	3	0
context	2	3	4

Table 5-3: Macro level of all cases

The total summary of every level of all cases is given below.

Total					
Innovate	2	**Micro**	73	**Content**	0
Adapt	63	**Meso**	16	**Structure**	121
Optimize	79	**Macro**	55	**Culture**	11
				Context	12

Table 5-4: Summary of every level of all cases

In this thesis only three cases are checked which is quite a small sample size. That is why these data cannot be used to make a general conclusion for all stall accidents. They can, however, give a good indication of how recommendations for stall accidents are spread over all the different levels.

It can be seen that implementing a recommendation takes a lot of time. Six years after the crashes a big part of the recommendations still have the status “open” or are still considered (see appendices).

5.1 Operation level

If the tables with the results are checked several observations can be made. It can be seen in the operation level that the aspect of culture is quite empty in comparison with the aspect of structure. This can give the impression that no so much is done to change the safety culture. There is, however, another explanation. The section of culture could not be completely filled in since most information about this is confidential. Both for the Air France as for the Colgan Air case a report was made about the company culture for internal use only. For Turkish Airlines an audit was performed. This report was also not found publicly available so it is not known if company culture was looked into. The review of company culture by the official accident investigation agencies is minimal. Since not all information is available the level stayed quite empty. Due to that it is not possible to identify new learning potential. Checking for learning potential with only the results available is kind of useless. It is possible that the new lessons which would be suggested are already learned in those internal reports.
The aspect of context, which consists of development of knowledge and supporting conditions, is also much more empty than the aspect of structure. The part of supporting conditions only contains one item. Supporting conditions issues are, however, also covered by the aspect of structure. This means there is no indication for learning potential. The exact rules used to set the difference between structure and supporting conditions can be found in section 6.2.2. At development of knowledge there is still learning potential, not so much research is done for new concepts. A way to use this potential is suggested in paragraph 5.4.

5.2 System level

If the system level is checked it stands out that the meso level is quite empty. This can be explained by the fact that the meso level is partly hollowed out by the macro level. This has two reasons. First of all, in European aviation the ability to take action has moved for the biggest part from the countries’ local safety authorities (meso) to EASA (macro). Secondly, the choice to make the FAA part of the macro level also hollows out the meso level. The reason for this choice is explained in paragraph 6.2.2. This hollowing out has to be kept in mind when analyzing aviation accidents. It implies that an empty meso level not necessarily equals learning potential. The hollowing out is the only explanation for an empty meso level in this case, there is no indication of learning potential. Small remark, when an accident involves a non-EASA country and not the USA the ability to take action also still lays at the meso level. This can be seen in the Turkish Airlines case, where some identical recommendations are made for EASA/FAA (macro) and for the local Turkish safety authority (meso). This is done since FAA and EASA don’t have jurisdiction in Turkey. In such case the hollowing out is less strong, since the local safety authority can also take action.

It is strange that for all these stall accidents only two recommendations were issued for ICAO. For EASA and the FAA, on the other hand, 27 and 33 recommendations are issued respectively. A recommendation which was found back in all three cases was that stall and low speed warnings in cockpits should be improved. This recommendation was only addressed to the FAA, EASA and Boeing. There are, however, also manufacturers outside FAA and EASA territory. The aircraft they produce and which fly around outside FAA and EASA territory don’t fall under this recommendation. It is strange then that such recommendation is not suggested to ICAO to make sure it counts for all aircrafts flying around worldwide. It is of course also still possible that when a recommendation gets approved by FAA and EASA it will automatically be taken into account by ICAO.

5.3 Depth of learning level

The quite empty aspect of innovation implies that there is learning potential for this aspect. The circumstances are every time different but all these three aircrafts crashed due to stall. These three accidents show that stall is still a very important problem in today's commercial aviation. The same recommendations keep coming back to prevent stall in all these cases, namely:

- recommendations to improve pilot training
- recommendations to improve the stall and low speed warnings

In the case of Colgan and Air France is was also recommended to improve the fidelity requirements of flight simulators and to improve crew monitoring.
In these three cases only one new concept to prevent stall was recommended, namely a direct accessible angle of attack indicator. It is already decided that even this concept will not be used, as already mentioned in section 4.1.3. Maybe it is useful to look for new concepts which can prevent these kind of stall accidents, instead of only adapting and optimizing. There are new concepts known today for commercial passenger aircrafts to prevent stall accidents. They were found by consulting literature and are shortly described in the next overview.

Desdemona simulator for upset recovery training[51][52][53]
The Desdemona (DESoriëntatie DEMONstrator Amst) simulator (see figure 5-1) is part of a European project called SUPRA (Simulation UPset Recovery in Aviation). During flight it is possible that a loss of control situation happens due to which an aircraft can get into an upset situation like stall. An adequate and quick reaction of the pilots is very important in such situation to ensure recovery and flight's safety. For this it is important that pilots are able to train on upset situations and on handling corresponding G-forces. One of the project's purposes is to develop new simulator concepts to prepare pilots better for these kind of situations. Current simulators have a limited motion envelope because they make use of a hexapod (six legs) platform. These platforms suffice for most aircraft maneuvers which have to be performed by commercial aircraft but not for upset situations and the corresponding G-forces. That is why the Dedemona simulator is developed. The Desdemona simulator combines the possibilities of a hexapod platform with a centrifuge. In this way complex situations which can happen during flight can be simulated, including their G-forces. The cabin of the Desdemona simulator can rotate around any conceivable axis and can generate up to 3G. With this simulator pilots can be better prepared for upset situations.

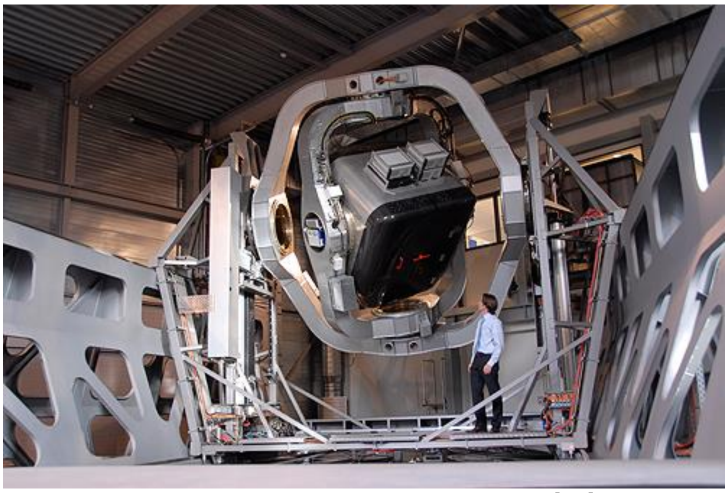

Figure 5-1: Desdemona simulator[108]

Stall shield device[54]
Stall shield devices (see figure 5-2) are a new innovative concept to prevent stall accidents in the future. It can be used in both general and commercial aviation to prevent an aircraft from stalling or if necessary, to improve its recovery. It is still being researched for the moment. It was suggested in a paper written by J.A. Stoop and J.L. de Kroes.
A stall shield device is based on the principles of dynamic flight control over the forces exercised on an aircraft. These principles are:

- New aerodynamic forces have to be used instead of changing the classic existing forces.

- These new aerodynamic forces have to be used in an uncorrupted air flow.
- High pitching moments have to be generated by using long arms with small forces.
- Correcting forces can only be used in case of emergency.

The stall shield device consists of several adjustable control surfaces which are mounted on the aircraft's fuselage at the nose and tail section. Because they are positioned near the nose and tail the moment arm is quite long which makes it possible to minimize the size of these surfaces. These surfaces have two positions. The neutral one where they are incorporated in the fuselage structure and the operating position where they are deployed into the fuselage's free air flow. They are deployed in case of a (near) stall situation and during a 1G unstable flight. The size and angle of attack of these surfaces is adjustable. It can be adjusted automatically or manually to meet the required aerodynamic forces necessary to control the dynamic behavior of the aircraft during (near) stall. Several working modes for these shields are available: nose and tail separately or combined. The mode depends on the flight phase, the stall situation, the operating conditions and the aircraft configuration. The control system of the stall shield device is integrated in the flight management system. The control system should also make use of GPS data like speed, positioning and altitude. In this way redundant data (next to the pitot static data) is available. Also a direct angle of attack indicator will be used.

Control surfaces for dynamic vehicle control are already used in the maritime sector to improve ship's sea behavior.

Figure 5-2: Nose stall shield devices deployed[54]

The Dedesmona simulator and stall shield devices may be very effective to prevent stall accidents in the future. They are, however, not recommended in any of the reports. In all these cases only two recommendations are made in the aspect of innovation. Of these two only one concerns a new concept to prevent stall, which even will not be implemented. In comparison, adaptation has 63 and optimization 79 recommendations and actions. Even when new concepts exist much more recommendations are found in the aspects of adaptation and optimization. This is caused by the fact that a recommendation in an official accident investigation report differs from a solution. Solutions can solve the problem while a recommendation is something which can solve the problem, but is also plausible and realistic to execute. Probably a completely new concept belongs more at the side of solutions than at the side of recommendations. Several reasons can be named for this:

First of all a completely new concept can financially be very difficult to implement. The benefit of this investment will not weigh up against the costs.

Secondly it is also possible that some concepts are not recommended because next to their positive effects they can also have negative effects. These negative effects makes them inapplicable. A canard is a good example of that. The Piaggio 180 is equipped with canards. According to the manufacturer of the P180, the pitch angle of this canard is set in such way that it will stall before the main wing. Because of that a nose-down moment is created, preventing the aircraft from stalling[109]. However, next to this advantage concerning stall, canards have a negative effect on other flight characteristics, causing it to give more disadvantages than advantages.

Thirdly it is possible that some of these concepts are known by the investigators but that it is too early to make a recommendation about it. The phases of development of a concept can be expressed in levels of technology readiness. The several levels can be seen in figure 5-3.

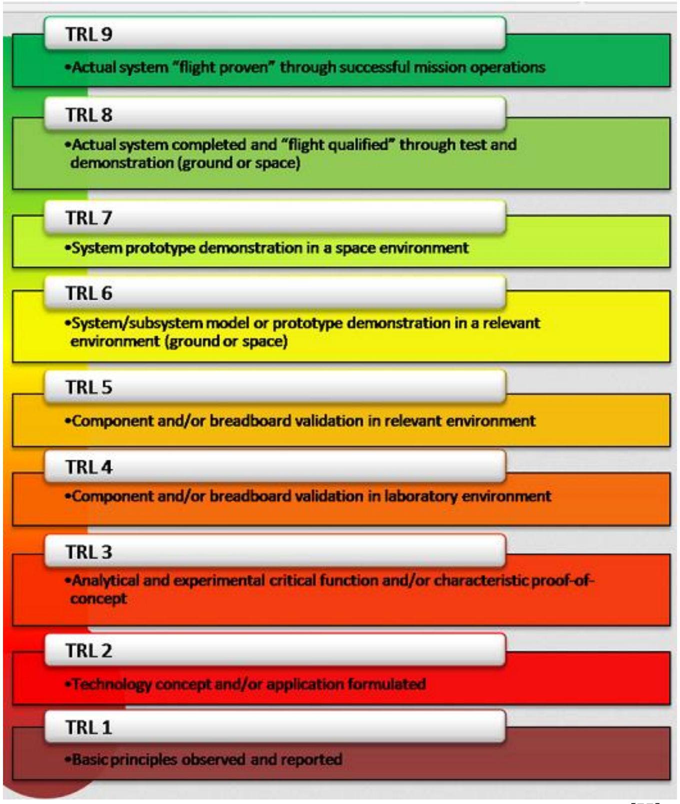

Figure 5-3: Technology readiness levels of NASA[55]

As can be seen, a lot of levels have to be passed before the technology is ready to be used in actual operations (level 9). As mentioned, in the analysed reports only two innovative recommendations were suggested. These were the evaluation of the use of a direct accessible angle of attack indicator and the development of multimedia guidance material for pilots. These concepts were ready for evaluation or development, which means that they are certainly higher than level 3 in its technological readiness. If a concept is known but still in a too early level, like the stall shield devices, probably no recommendation is made about it. The reason is that in an early level not enough information is known yet about the usefulness of the concept to recommend it.

It is also possible that a new concept is not known by the investigators, which excludes it from being recommended.

All this causes that new concepts are very difficult to recommend. It is easier to prevent an accident by changing existing concepts, so by recommending optimizations and adaptations.

5.4 Conclusion

Since the three analysed accidents happened two other aircrafts crashed due to stall. A Boeing 777 of Asiana Airlines crashed on July 6th 2013 in San Francisco[56][58]. An A320 of AirAsia crashed on December 28th 2014 (according to the limited information available for the moment it crashed due to stall[57]).

In the analysis performed in the previous section, it was seen that on the operation level the distribution of the lessons learned is not very even. Most recommendations are found in the aspects of adaptation and optimization. Almost none were found in the aspect of innovation. The fact that stall accidents keep happening can be an indication to stop with only optimizing and adapting existing concepts. It shows that it for sure can be useful to explore innovative concepts. To do this it can be useful if investigation reports would provide recommendations, not only for manufacturers, operators and safety agencies, but also for research centers. In this way the development of new knowledge and concepts for specific problems is pushed. This research can be done under the supervision of the safety authorities. In this way the safety authorities are kept up to date of the concepts available today. They can also provide the research centers with information necessary to develop a new concept. By developing and researching new concepts the learning potential of the aspect of context is also used.

It has to be said that a zero chance on accidents, including stall accidents, is impossible. The development of new concepts is not a magic potion. There will always be a chance of accidents happening. The smaller the chance, however, the better. By learning all possible lessons, including new concepts, this chance can probably be made smaller.

It can be concluded that it is certainly worth and necessary to investigate innovative concepts which can help to prevent stall accidents.

Chapter 6

Evaluation of the ESReDA Cube Method

With the information of the applications an evaluation of the method is made in this chapter. With this evaluation it will be possible to answer the research question and sub questions of this thesis.

6.1 Usefulness

Although some problems were encountered, the analysis performed could provide useful and valid results about accidents individual and stall accidents in general. In this section it is explained how these results were obtained and what the method can do. One thing is sure when analysing the lessons learned with this method, the template is a really important tool. It makes sure the categorizing of the recommendations and actions happens in an orderly fashion so that nothing is missed or forgotten in the analysis.
In the last paragraph of this section the method will also be compared with other models/methods.

6.1.1 Individual case analysis

As seen in the applications performed in this thesis, the method can be used as a control tool to check the lessons learned out of an accident. A complete description of the accident and an overview of the lessons learned and their follow-up is made using the template and the cube. Using the template and the cube an analysis can be performed so that irregularities in the lessons learned can be identified. It has to be noted that the analysis can be updated all time. If new information becomes available it can be added to the template and then later to the cube. Like this the method can be used dynamically.
Identifying irregularities in the lessons learned can be done in several ways.
The first one is by filling in the template. In this template the investigator starts with filling in the information concerning the accident's origin and circumstances. Next the aspect of content has to be filled in. In this aspect the investigator has to describe measures to prevent the accident. These measures are not found in any input source, they are formulated by the investigator him/herself. The measures are based on the information gained about the accident's origin and circumstances. In this way the investigator builds up expectations about the lessons learned. These expectations can, when the template is completely filled in, be compared with the recommendations/actions found in the input sources to check if they correspond. If not or if something is missing, learning suggestions can be made.
A second way to find irregularities in the lessons learned or in the investigation process is by using the hard results in the cube. If levels are not evenly filled, this can imply learning potential and it should be looked into. Like this learning suggestions can be made depending on the results of the analysis. In these learning suggestions it can be recommended to look more into a specific level. Also literature can be checked to see if there are specific solutions available to cover the learning gap.
With the template it is also possible to check the impact to see what really changed or where there is a problem with implementing lessons learned. By updating the part of impact all the time a follow-up of the accident

can be performed. In this way it can be checked what happened with the recommendations issued after the accident. If it would reveal later that not all recommendations are implemented, it can be identified which instance or company is responsible for it.

In this way a complete analysis of the lessons learned is made. This analysis of individual cases can always be performed, independent of the cause of the accident, everything stays the same as in this thesis.
A small remark has to be made. An individual ESReDA Cube analysis of a case can also conclude that all lessons have been learned already or that no impact problems occurred. The results are always dependent on the case analysed.

6.1.2 Multiple case analysis

The ESReDA Cube method can always be used to make an overview of how, where and what lessons are learned for multiple cases together. This is done by putting the results of several analyses in one set of cubes. In this way it is possible to check if lessons are always learned in the same way or not. As mentioned in chapter 3, it was chosen that the cases should have a mutual contributing factor. With the applications performed in this thesis it is seen that the selected cases had more than one mutual contributing factor. Not only stall was a mutual factor, but also the fact that the stall was every time caused by a pilot error. Due to this the accident scenario was for all three cases even more similar. It is not surprising then that similar recommendations and actions were issued/taken, namely improve pilot training and improve the stall and low speed warnings. Because of the similarity a really specific conclusion concerning learning potential could be made, namely that more research should be done for new stall concepts. Also literature can be consulted to check for new specific solutions to solve the problem. The similarity between the cases was really important when making conclusions concerning the learning potential. If one of the cases would not have stall as a contributing factor, everything would have changed. This would have caused no similarity. In this way it would not be possible to make the conclusion (more research should be done for new concepts to prevent stall accidents) which counts for all cases. The more similar the cases are, the stronger the analysis can be. If in one of the cases stall would have happened due to a design error, no similar recommendations/actions would be issued/taken to prevent stall. Lessons learned out of stall due to design error are completely different from lessons learned out of stall due to pilot error. The suggestion of the Desdemona simulator would also not be useful.
Similarity between cases is important to draw specific conclusions if they are analysed together. This does not mean the method cannot be used to analyse the lessons learned of non-similar cases together. The conclusions drawn will, however, be more general since the cases are completely different.

If similar accidents are analysed together, the specific similar contributing factors are focused on. Although accidents always happen because of several contributing factors together, it can be useful to focus on one aspect of an accident. Certainly if this aspect returns in a lot of accidents. If similar cases are analysed together with this method it is possible to see the bigger picture and background of the mutual problem(s). When accidents are analysed individually recommendations/actions are most of the time issued/recommended as a reaction on a specific finding. This causes some sort of one on one way of thinking. Due to this it is possible that less attention is paid to problems which keep returning and causing accidents. It was seen in this analysis that stall in every individual case was just seen as one of the contributing factors. This is also correct, but by analysing these cases together it can be seen that stall is a big problem which keeps causing accidents. By analysing similar cases together a stronger analysis with more insights and arguments is built since all knowledge is combined. This can give a better idea of the scale of such a problem in aviation. By analysing similar accidents together with this method possible gaps in lessons learned and/or possible patterns can be identified which can help to find new learning potential. It can be that, like in this thesis, the analysis results in identifying new learning potential. It is also possible that an analysis will learn us that all learning potential has been used. In that case accidents are well investigated and proper actions or recommendations have been taken/issued. It is of course possible that the learning potential would already be identified when the cases were analysed individually. However, by analysing them together it can, as mentioned before, help in building a stronger case since the sample consists of more data. The results of the analysis of multiple cases is of course dependent of the input, so of the cases analysed.

6.1.3 Usefulness in comparison with other method/models

As mentioned earlier, the ESReDA Cube method covers a new field in safety analysis. Today the only way to analyse and check the lessons learned from accidents is by redoing the investigation. This can be done using the methods/models suggested in the introduction, namely ACCIMAP, FRAM, STAMP and Tripod Beta. No method specific method was available to check and analyse the lessons learned. Then the question can be asked if it is necessary to analyse and check the lessons learned. Aviation is the safest way of transportation for the moment. Is it possible to improve safety even more then? It is not because something is working properly that things cannot be done better. Constant improvement is key to aviation. Since safety is of huge importance for aviation, it means that also in this field constant improvement needs to happen. The ESReDA Cube Method does not change anything to the current investigation or learning process. Nothing of the positive results build up until today will be lost. The method will just add an extra control barrier to the learning process.
It has to be noted that the method is focused on analysing and checking the lessons learned. This means the method has no use in finding the cause of an accident. For this ACCIMAP, FRAM, Tripod Beta and STAMP are suited. To get information concerning the cause the method uses input sources.

6.2 Problems encountered

By applying the method some difficulties and issues were encountered. The assignment of this project was to evaluate the method exactly like it was designed. That's why only for problems which would prevent a correct analysis a solution was immediately developed and implemented.

6.2.1 Finding enough input

As was stated in chapter 3, a condition to apply the method is that enough input has to be available.
This can be difficult if only public sources can be used. Due to that it is not possible to analyse every individual case with the method. It was seen with this thesis that for the analysis of individual general aviation accidents not enough input is available. It was also seen that sometimes parts of the cube cannot be analysed because of lack of input. This was the case for the aspect of culture in the operation level. It was found, with the applications performed in this thesis, that information about culture is often described in reports for internal use only.
The question can be asked why this condition of having enough input was not fulfilled for the applications performed. During the case selection for these applications, it was seen that in the investigation reports of these three cases the aspect of culture was looked into. Because of that it was assumed that the information of these reports would be sufficient. It was only when the method's applications were performed that it was seen that this information was not enough to analyse the aspect of culture completely. Upon this observation the necessary information was sought in other sources. However, it was not available. Only fragments could be retrieved.

6.2.2 Correct categorizing of the recommendations and actions

Another difficulty encountered was the correct categorizing of the recommendations and actions in the template and cube. The line between some levels is very thin, which can cause confusion or difficulties when categorizing items. Sometimes it was also seen that what is written in the template does not correspond to what can be found in the theory of the method. It is very important to make sure that the analysis of the several cases is performed in a consistent way to obtain valid and comparable results. To make sure the three applications performed in this thesis happened in a consistent way, specific rules were set up and used. Most rules set specific differences between levels. In this way it became more clear which item has to go where so that misconceptions and wrong categorizing was avoided.
The difficulties encountered when categorizing recommendations/actions are stated below. If a specific rule was set to solve the problem it is also mentioned.

Meso versus macro, system level
The system level consists, as already mentioned, of the micro, meso and macro level. The difference between the meso and macro level is unclear. The definition of these levels in the template differs from the one found in the theory of the ESReDA Cube method's paper[2][50]. In the method's paper it is explained that the meso level includes the holding branch of the industry and the macro level includes the government and safety boards. In the template on the other hand, the meso level includes the safety authorities. Since a safety authority is a government agency or safety board this should be put on the macro level, according to the theory of the paper. On the macro level in the template it is asked what actions happened on the EU-level. To ensure consistent results of all three cases in this analysis the next rule, concerning this matter, was set up:
Every item which is addressed to a local safety authority of a country should be categorized on the meso level. Every item which is addressed to EASA/FAA and to ICAO should be categorized on the macro level. Although the FAA is the safety authority of a country, it can regulate every aspect of the American civil aviation. That is why it is chosen to give it an equal status as EASA and why it is put under macro and not under meso.

Micro versus meso versus macro, system level
Next to the difficulty described above, another categorizing problem can be found in the system level. Categorizing a recommendation or action on the system level means checking where the effect of this item will happen. This can cause misconceptions since some recommendations and/or actions can cause, in several steps, effects on different levels. Then the question is asked what specific effect is checked and used for categorizing the recommendation or action. The following rule was set up for that:
A recommendation has to be categorized on the level where it will first have effect on.
A small example is given for clarification. If a recommendation concerns implementing a regulation, advisory circular or procedure, it first has an effect on the safety authority which needs to implement it. Only when it is implemented it will affect the operators, manufacturers or the industry. This means that such a recommendation should be categorized on the macro level (for FAA and EASA) or on the meso level (if its needs to be implemented by a local safety authority). An already implemented regulation, procedure or advisory circular has to be categorized on the level it will affect.

Adapt versus optimize versus innovate, depth of learning level
The aspects of the depth of learning level adapting, optimizing and innovating lay very close to each other. This caused difficulties when categorizing the recommendations and actions in the applications. In combination with the description of these aspects in the method's paper[2][50], the rules set up provided a clear distinction between these three aspects. The rules set up were:
Changing an existing concept, without adding anything, to improve its working is defined as optimization. Changing an existing concept by adding something new and/or extra without changing the basic working method of the system is defined as adaptation. Using a complete new concept which was not in use before is defined as innovation.

Structure-organization versus context-supporting conditions, operation level
The operation level consists of four aspects, namely content, structure, culture and context. The aspect of structure is divided into two parts. These are organizational structure and technological structure. Organizational structure concerns (re)design of organization and processes. The aspect of context is also divided into two parts, namely the supporting conditions and the development of knowledge. Supporting conditions concerns change in politics, safety boards, management. Between the aspect of structure-organization and context-supporting conditions there is a lot of overlapping. There can be organizational change in the supporting conditions. To prevent difficulties in the applications, following rule was set:
Everything which changes or renews an organization or process is put under structure-organization (including implementing a new process or political changes). When a recommendation or action implies that still a solution has to be found for a specific organizational or process problem, it is categorized under context-supporting conditions.

Change of behavior versus change of culture, aspect of culture, operation level
The aspect of culture in the operation level consists of two parts, namely change of behavior and change of culture. These two terms can overlap each other due to which a clear distinction was necessary to perform the applications. The rule used is as follows:
Items which are categorized under change in behavior are specifically about personal and/or individual behavior, including the behavior of an individual towards another individual. Behavior of one group towards another group is part of change of culture.

Structure organization versus culture, operation level
A third difficulty at the operation level was the difference between the aspect of structure, specifically organizational structure, and the aspect of culture. Some parts of these two aspects overlap due to which it is not very clear where to categorize some recommendations or actions. Implementing a new safety program for example improves safety culture but it will also cause organizational structure changes. The following rule was set to provide a clear distinction:
Human factors and organizational safety policy changes are put under safety culture, because these will cause a change in behavior and in culture. An exception are the changes concerning the pilot technical flying training. These are also dealing with human factors sometimes but they are categorized under organizational structure because they more concern process change. Changing or implementing a safety program or changing an organization to improve the safety culture is also put under organizational structure. If there is, despite this rule, still overlapping, the main consequence should be checked.
In case of the example of the new safety program set earlier. This will be categorized under organizational structure since it implements a new process to improve safety.

Content, operation level
In the aspect of content, at the operation level, the measures which could prevent the accident from happening or delete/improve the weak parts of the system are suggested. These suggested measures cannot be found in any input source. They are formulated by the investigator based on the template's information about the origin of the accident. This does not correspond to the cube's focus of categorizing lessons learned found in input sources. It is even quite possible that these suggested measures can later be found back in the aspect of structure, culture or context as an official recommendation or action. If these items in content would be made part of the results shown in the cube, they will be seen as official recommendations/actions what is not correct. Also, if the aspect of content is part of the cube this can cause sometimes items to be counted double. Ones as an official recommendation/action in the aspect of structure, culture or context and ones as a possible measure suggested in the aspect of content.
It can be useful to suggest measures as an investigator with knowledge about the origin of the accident before checking the official recommendations and actions. This was already explained in paragraph 6.1.1.
That is why in this thesis content is filled in with possible measures, like it was designed in the template. However, when transforming the results of the template into the cube, the aspect of content is left open to prevent that a non-correct image would be given. In this way double counting and drawing wrong conclusions is avoided.

Lessons learned versus changes in section of impact
In the cube the lessons learned are analysed. In the template at the end of the second theme of the analysis, the impact of the lessons learned is described. With this description it is possible to see what changed because of the accident. It is important that a difference is set between an action taken as a lesson learned and an action taken because of a lesson learned. For this the next rule is used in this thesis:
If some action is a reaction on a recommendation, the recommendation is seen as the lesson learned and the action following the recommendation is seen as impact. By keeping this rule in mind, it was prevented that wrong items were taken into the cube's analysis.

Note:
With the rules set it is tried to cover every possibility which can cause misconceptions when using the method. However, it has to be said that these rules are not completely watertight. The line between some levels stays very thin. Because of this it was sometimes still difficult to decide where a recommendation has to go. If some problems were encountered with these rules it was tried to keep the categorizing consistently for the three analyses. Still, a lot of confusion was prevented by using these rules.

6.2.3 Other problems encountered

Other difficulties or issues encountered when applying the method on the three cases did not influence the end results. They were however confusing and/or prevented a good analysis.

Impact
According to the theory of the template, only the changes identified should be stated in the section of impact. As already mentioned before, the implementation of recommendations takes time. It was chosen in the applications performed to state all information about the implementation of the lessons learned, not only if a change is identified. In this way a more elaborate analysis was provided.

ICAO vs FAA and EASA, system level
When analysing the results of the cube difficulties were encountered when checking the recommendations/actions for ICAO. Since aviation is a worldwide business, it was checked how many recommendations/actions were found for ICAO in comparison with FAA/EASA. In this way it could be seen how many lessons are learned worldwide and how many lessons stay local. This information could, however, not be obtained from the cube. In the cube the FAA, ICAO and EASA are all together on the macro level. To see how many recommendations/actions were issued/taken specifically for ICAO the filled in template of every individual case had to be used. With these templates the items for ICAO could be counted manually. When it was counted, it could be seen that only two recommendations were made to ICAO to prevent the accident. For EASA 27 and for the FAA 33 items could be found. This shows that locally 60 lessons are learned and worldwide 2, which implies there is still learning potential. This potential could, however, not be retrieved from the cube. That is why this potential was not part of the conclusion in chapter 5. The assignment was to apply the method exactly as it was designed.
One of the reasons why ICAO is at the same level of EASA/FAA is because this template focuses on Europe and on several sectors. In Europe and for most sectors (except aviation) the highest instance is the European Union, at the macro level.

Operation level
It was seen during the applications that the operation level has in fact only two valuable aspects, namely the aspect of culture and the aspect of structure.
As was said in section 6.2.2, the aspect of content is not added to the cube since otherwise no correct analysis could be made.
The aspect of context does not add anything to the operation level which can help in identifying learning potential. The aspect of context exists of supporting conditions and development of knowledge. These will both next be discussed separately.
In the ESReDA Cube method's paper[2][50] it was written that supporting conditions concern changes in politics, safety board or management. These changes are, however, already covered by the aspect of structure in the level of operations. Every item which can be found under supporting conditions could be categorized under structure, specifically under organizational structure. This was also seen in the results of the applications in section 5.1. Only one item could be found for supporting conditions because this field was also covered by the aspect structure. This implied that much more items were found at the aspect of structure. There was a rule set for supporting conditions in section 6.2.2: "only recommendations or actions implying that still a solution has to be found for a specific problem regarding an organization or process are put under context-supporting conditions". This rule was, however, only set to make sure if items would be put in the supporting conditions part, that it would happen in a consistent way. Items for which a solution is still pending, as the rule states, can also be covered by the aspect of structure. It was, however, not an option to completely ignore the part of supporting conditions and categorize everything immediately under structure. With this rule an analysis could be performed like the method was designed originally. It can be concluded that supporting conditions does not contribute an extra necessary aspect to the level of operations
For development of knowledge it was seen in the template that the complete description is: "development of knowledge: managerial, scientific and technological research and innovative practice aimed at finding solutions or allow solution for safer system". This is however already covered by the aspect of culture and the aspect of structure. Every recommendation/action issued/taken in the aspect of structure or culture results out of lessons learned. To learn lessons, first knowledge has to be gained and developed. Development of knowledge is the stage before an action or recommendation is taken or issued. It can be seen in the applications that there is only one difference between the items under structure/culture and the items under

development of knowledge. The items under development of knowledge are still under development or study. The items under the aspect of culture and structure, on the other hand, are already developed and ready for implementation. When knowledge development on itself is an aspect its learning potential indicates, if it is empty, that more knowledge should be developed. This can, however, be connected to every level and position of/in the cube where research is necessary. It is not specified where or what knowledge development is required. This was seen in the results of the applications. The aspect of context-knowledge development was quite empty. This emptiness showed that there is learning potential. The only way, however, to use the information about this learning potential, was by connecting it to an empty innovation level. Then it could be stated that research is necessary for innovative concepts. However, this could already be concluded out of the results of the depth of learning level. The learning potential found in the aspect of context-knowledge development was of no use. Knowledge development on its own has no use. It happens on every level already and in the operation level it is covered by structure and culture.

These issues with the aspect of context and content result in only two useful aspects on the operation level, due to which the analysing possibilities are limited.

6.3 **Validity**

A question which should be asked is if the results which are obtained with the method are valid. This depends on a few factors.

6.3.1 **Input**

First of all the method is a function, so the output of the method depends on the input given. The input for this method, as mentioned in the introduction, are recommendations and actions which have been issued/taken to prevent the accident. Other input is information about the origin and the circumstances of the accident. Recommendations and actions are based on the findings and conclusions done concerning the cause of the accident. The same counts for the information about the origin and the circumstances. If these conclusions and/or findings are not correct or only partly correct, the input for the method is based on wrong information. This implies that also the output of the method is invalid and that possible new learning potential, based on incorrect findings and conclusions, will be suggested. The most perfect solution to obtain valid information would be if the user of the ESReDA Cube method also stands very close to the accident investigation performed. In this way he/she can double-check the findings and conclusions and their consequential recommendations/actions. This would ensure the input used for the analysis is correct. When an analysis has to be performed with only public sources there is, however, no option to double-check information. Using more sources to check the accident investigation report's findings is not possible. Almost every source available is based on the official accident investigation report's findings. The findings and conclusions found have to be relied on. It is, as for every research project, really important to make use of reliable sources and to be critical. Most of the time the information found in these input sources, if they are reliable (like official accident reports), is also valid and correct.

6.3.2 **Method**

As mentioned earlier in section 6.2.2, sometimes problems may arise with the correct categorizing of the recommendations and actions. The categorizing of recommendations/actions is vulnerable to interpretation. It is possible that actions and recommendations are categorized in different ways, dependent on the investigator. This can cause problems when analyses, performed by different investigators, are compared. If only the results of the cubes are compared, only the numbers, it is possible that wrong conclusions are drawn because these are based on inconsistent results. It is important if analyses are compared that everything is compared. Not only the results of the cube, but also how these were obtained. This can be checked in the template. In this way it can be seen if there is a different way in categorizing recommendations/actions. If necessary this can be taken into account when drawing conclusions.

It also has to be noted that the ESReDA Cube method only categorizes the recommendations and actions found in input sources. It does not change anything.

6.4 Critical reflection and general conclusion

With it all this information a critical reflection and a general conclusion concerning the method can be made so that the research question of this thesis can be answered. At the end of this section some recommendations are issued.

6.4.1 Critical reflection

The ESReDA Cube method is a very young method and has only been tested and used by its developers for the aviation sector. As was said before the concept and purpose of the method are new in comparison with the other method/models available. By analysing and checking the lessons learned, the ESReDA Cube method provides a next step in the learning process. As mentioned in the introduction the ESReDA Cube method can also be used to analyse incidents.

It was stated before (section 6.1.1) that the template's overview can be used to analyse the impact of an accident. Another possibility of the method is to create expectations as an investigator about the lessons learned when filling in the template. These expectations can later be compared with the actual recommendations/actions to check if they correspond and if more lessons need to be learned (see section 6.1.1). Analysing the impact and creating/checking expectations can be done using the template since it provides a clear schematic overview. However, the template, and so the method, is not a necessary tool to do this. Impact analysis and creating/checking expectations can just be performed/done by analysing literature. It can be said that these two possibilities on their own do not provide something new to analyse accidents. They should be seen more in the complete picture of the method to analyse the lessons learned, using all possibilities.

The new contribution of the method to accident and incident analysis is the usage of a cube. This cube provides an overview of how, where and what lessons are learned. By comparing the numbers of recommendations and actions on every level of the cube, patterns and flaws in the learning process can be identified. With this information new learning potential can be found. It is of course impossible that all levels will have the same amount of items. If, however, some unbalanced spreading is found it should be looked into closer to check if it implies learning potential or if there is another explanation. In this way a conclusion about the lessons learned and learning suggestions can be made. In these learning suggestions it can be recommended to look more into a specific level. Also literature can be consulted to check for new specific solutions available which can fill the learning gap. This cube analysis can both be done for individual cases as for multiple similar cases together. By analysing multiple cases together the knowledge is combined which provides more insights. It was seen with the cases analysed here that the method can provide useful and valid results for both individual and multiple case(s) analysis. With these results it could be concluded that not enough is done for the aspect of innovation and that more lessons should be learned in this area. That the aspect of innovation would be empty was already expected before the analysis was performed. In aviation not a lot of innovative recommendations/actions are issued/taken after an accident. This raises the question if not always the same result will be obtained when applying the method on aviation accidents. In the ESReDA Cube method's paper some method applications are performed on example cases by the developers. One of these cases is the Bijlmer crash. At the depth of learning level it was seen that the recommendations and actions taken are quite evenly spread for this case. This means that a different result would be obtained. Although for aviation this can be seen as an exception. Most of the times the innovative aspect will be found to be quite empty. This implies that the outcome will frequently indicate that new innovative concepts should be more looked into to prevent the accident. If every time the same outcome is obtained, the method does not add anything meaningful to accident or incident analysis. Then it is easier to check every case specifically for the aspect of innovation, instead of analysing the case with the whole template. The cube, however, exists out of three dimensions. The depth of learning level, which contains the aspect of innovation, is only one of

them. If it is possible to also find learning potential on the two other levels then the empty aspect of innovation is only a part of the outcome.
The results found on every level are first of all case dependent. The fact that only on the depth of learning level results were obtained can mean that on the other two levels all learning potential is used. There are, however, other explanations why in these applications no results were found on the other two levels.

The operation level consists out of four aspects, namely: content, structure, culture and context. At the operation level it was seen with the applications performed that no complete analysis of this level was possible.
The aspect of culture could not be completely analysed due to lack of information. The accident investigation reports did almost not look into individual or company culture. As already mentioned, for two out of three cases analysed an internal safety culture investigation in the airline company was performed. The reports, however, were for internal use only. For the third case, Turkish Airlines, it is not known if an investigation was performed concerning this topic. Culture is often a very important factor concerning accidents. With the template both individual as company culture is looked into. It is possible, if all information is available, that with the ESReDA Cube method more lessons could be learned for this aspect. This could help in a more clear view of the aspect of culture.
The lay-out of the operation level also prevented a complete analysis. Both the level of content as the level of context did not add anything to the analysis. As mentioned in section 6.2.2, the aspect of content has to be left open since otherwise a non-correct image of the lessons learned is given.
The aspect of context is divided into two parts, namely supporting conditions and knowledge development. These parts, however, are, as mentioned in section 6.2.3, already covered by other aspects of the operation level. Supporting conditions is already covered by the aspect of structure in the operation level. Because of this overlap, this part was almost completely empty in the applications performed. The part of knowledge development is covered by the aspect of structure and culture. Knowledge development on its down did not add anything to the analysis.
This operation's level lay-out resulted in only two valuable aspects available for the operation level, namely culture and structure. Since not enough input was available for the aspect of culture, only one aspect could be analysed accurately. This means that if all information is available and the lay-out is changed more lessons could be learned on the operation level.

The system level consists of three levels, namely: micro, meso and macro. At the system level it was seen that for aviation accidents concerning EASA countries or the USA the meso level is largely hollowed out by the macro level. This resulted in only two valuable fields for this level, which limited the analysis possibilities. It was also seen during the analyses that the number of recommendations/actions for ICAO could not be found directly in the cube. Due to that the learning potential available for ICAO could not be derived from the cube. This means that the method did not help to identify this learning potential. If this problem could be solved, there is another possibility for the method to identify learning potential.

A few last remarks. It has to be noted that the limitation of having enough input is not specific to this method. This limitation is a quality specific to analysing the lessons learned. For this always input will have to be used. The other limitation, namely that with only public sources the input has to be taken as the truth is also not specific for this method. If only public sources are used to analyse the lessons learned from accidents then the input sources will always have to be taken as granted. The method does not add anything to solve these issues.

6.4.2 General conclusion

Aviation is the safest way of transportation since the industry is always questioning itself to keep improving. The purpose of this method, analysing and checking the lessons learned out of an accident, fits well into that way of thinking. It adds a new way for critical reflection in the aviation sector which was not explored before. The purpose of the method itself can be useful for the aviation industry. The question remains then, if the ESReDA Cube method is suited for this purpose. The results of course always depend from case to case. However, as the method was used in this thesis there is a big chance that always the same results will be obtained, namely an empty innovative aspect. The reason is that problems encountered during the method's application prevent a complete analysis. In this way, only one of the three levels of the cube provide useful results. This questions the applicability of the method. It can be said that if the results always indicate an empty innovative aspect, the method shows something is wrong with how lessons are learned today. However, the method is not necessary in that case to prove something might be wrong. It is easier then to just check the accident reports for innovative concepts than to completely apply the method. If always the same results are obtained, the method does not add anything meaningful to accident or incident analysis.

It can be concluded that in the current state and usage the method is not applicable for the aviation sector. The problems encountered, however, are not unsolvable and recommendations are suggested in the next section.

It has to be remembered that the purpose of the method on itself is very useful. Since the method is really young, it is normal that problems are still encountered. It is hoped that with the evaluation performed and the recommendations issued in the next section, this thesis could help in the further development of the method.

6.4.3 Recommendations

To get a complete analysis and to make the method applicable for the aviation sector, recommendations are suggested to solve the problems encountered. At the end of the section also recommendations for further evaluation of the method are issued.

Recommendations for further improvement
First of all it is not recommendable to use the method with only access to public sources. As it was seen no complete analysis of the lessons learned was possible in this thesis. This was because not all input for the operation level, and then specifically for the aspect of culture, could be found with only public sources. If of course all needed input is available with only public sources there is no problem. With the experience from these analyses, however, this is not considered realistic. This method is suited for investigators/instances with access to more than only public information like companies or safety boards connected to the accident. If the method is used by this target group all necessary input is available. In this way a complete analysis to check if all learning potential is used is possible. This target group also has possibilities to double check information to ensure valid input data, as was mentioned in section 6.3.1.

A second recommendation is to change the lay-out of the system level so that more learning potential can be identified. It is recommended to move the FAA and EASA from the macro level, where they are now, to the meso level. This would imply that the macro level only contains ICAO. The meso level would like this contain the FAA, EASA, the aviation industry and the local safety authorities. This change would provide three valuable levels again instead of one, so no hollowing out anymore. FAA also goes back to where it belongs, namely to the local safety authority level. The fact that there is no difference in level between EASA and the local European countries' safety authorities in the new lay-out will not cause difficulties. The local safety authorities' ability to take action is limited. EASA also belongs more on the meso level, since it is the local European safety authority. The new lay-out also adapts the method more to the aviation sector which is a worldwide connected industry. In a worldwide connected industry, the upper system should be the worldwide responsible organization and for aviation that is ICAO.
In the applications performed, this lay-out change would already have resulted in identifying new learning potential (see section 6.2.3). This shows the recommendation is useful.

A third recommendation it to change the lay-out of the operation level so that more learning potential can be identified. If like now only two valuable aspects are present (structure and culture), it is almost impossible to find learning potential. That is why it is suggested to make the operation level consist of the aspects of culture, organization and technology. For the aspect of culture everything would stay the same as it is now. The aspect of organization would concern organizational changes. It would, in the template, be divided in supporting organizations (e.g. politics, safety boards, safety organizations, aviation authority) and companies (e.g. aircraft manufacturers, airliners, maintenance companies). The aspect of technology would check if technical aspects are (re)designed or changed after the crash. This can be processes, hardware or regulations. An overview is made in table 5.1.

Culture	Change of behaviour Change of culture
Organization	Supporting organizations Companies
Technology	

Table 6-1: New lay-out operation level

This new layout represents every aspect of operations in a sector. It is in fact just a reorganization of the old layout. In the old lay-out the aspect of structure consisted of organizational structure and technological structure. In the new lay-out these two parts are split up into full aspects.
The supporting conditions from the old lay-out are added to the organizational aspect. Knowledge development of the old lay-out is deleted, since it is covered by all three other aspects. In this way the operation level consists of three valuable aspects.
If this new layout is applied on the three cases analysed in this thesis the aspect of culture would contain 11 items, the aspect of organization 97 and technology 36. Culture could not be investigated, which clarifies the low number. For the rest, it could indeed be seen in the analyses that most effort goes to safety programs, pilot training and non-technical regulations, so to organizational changes. It is easier to change an organization than an aircraft. The results of the applications also showed that still some lessons were missing in the technology aspect, namely new technical concepts to prevent stall. The lower number for the aspect of technology is a combination of these two reasons.
With this new lay-out the operation level will exist out of three aspects and not four, as in the past. As seen in figure 2-4, the cube exists out of small cubes. Every small cube is a location where a recommendation/action can be categorized. With the new lay-out, every level's axis will exist out of three small cubes. This means that the ESReDA Cube will become a regular cube. Since there is one row deleted, the total number of locations where a recommendation or action can be categorized in the cube is reduced from 36 to 27. This means if a location is empty, it has a much bigger impact then in the previous lay-out of the cube because of the reduced total number. One empty location in the old lay-out meant one cube on 36 is empty. Now it means one on 27 is empty. In this way conclusions and new learning suggestions made concerning one empty location become more strong. For the cases analysed here the ratio does not change. The whole aspect of innovation is empty for the analysed cases, meaning 12 out of 36 locations are empty. In the new lay-out this is 9 out of 27, so also one third.

Recommendations for further evaluation

The next suggested step is further evaluation of the method. Further evaluation is required to check if these recommendations add something to make the method applicable for the aviation sector. It is advised to apply the method again on three to four cases. The focus in these new analyses should mostly be on the operation level. This has two reasons. First of all it should be checked, with all necessary information available, if the method can provide new insights for the aspect of culture. Secondly it should be checked if the new lay-out of the operation level is well applicable to be used for analysis. This includes examining if all overlapping and categorizing problems are solved. Since the suggested lay-out change of the system level is already seen to be useful, the focus on this is less important during new analyses.
The three or four cases chosen should, just like in this thesis, have a mutual common factor. In this way it is possible again to test the method individually and for multiple cases together. The mutual factor chosen should be very closely connected to company and behavioral culture, for example maintenance mistakes or fatigue. It is important, as mentioned before, that all necessary input is available. With these cases it should be possible to the check if the aspect of culture can provide new insights and to check the use of the new operation level.

Chapter 7

Conclusions and Recommendations

In this section the conclusions which can be drawn from this research project will be formulated.

7.1 Conclusions

Does the method work? Can useful results be obtained?
For both the individual analysis of cases as for the analysis of multiple cases together the method worked and provided useful results. The results showed an empty aspect of innovation, implying that more research should be done for innovative stall concepts.

What is the method's usefulness?

- The method starts with analysing the origin of the accident. In this way the investigator creates expectations concerning the lessons learned. At the end of the ESReDA analysis it can be checked if the lessons the investigator expected, based on the information of the origin, are learned or not. If not they can be suggested in the conclusions.
- The method provides a clear overview of all the lessons learned out of an accident. With this overview it can be exactly checked what, where and how lessons are learned. This overview is provided in two ways. In the method's template an overview is given in text form. In the cube the overview is created by showing the amount of lessons learned on every level. By checking the distribution of the lessons learned in the several levels of the cube, learning potential can be identified. In this way conclusions about the lessons learned can be drawn. This can be done for both individual as for multiple cases together. By analysing similar cases together more insights into a specific problem are provided since all knowledge of the several cases is combined.
- The ESReDA Cube method is the only tool available to analyse the lessons learned.
- The impact of the lessons learned is checked to see if they caused any changes. It is also checked if implementation problems are encountered.
- The whole learning process of the accident is analysed to check for irregularities.

Are there other possibilities for the method than the ones described?
With this research project, none were found.

Does the method have limitations?

- Enough input has to be available. If not, no complete analysis can be performed.
- The line between some levels is very thin, due to which the categorizing of the lessons learned is vulnerable to interpretation. This can cause inconsistencies in the analyses.
- The operation level only consists of two valuable aspects: structure and culture. The aspect of context and content do not add anything necessary to the operation level to identify learning potential. This limits the analysis' possibilities.

- The lessons learned for ICAO cannot be obtained from the cube.
- The validity of the method's output dependents on the validity of the method's input.

Is the ESReDA Cube method applicable to analyse aviation accidents?
In the current state and usage the method is not applicable for the aviation sector. However, the problems and limitations encountered are not unsolvable and recommendations are suggested in the next section.

7.2 Recommendations

By applying and evaluating the ESReDA Cube method recommendations, as are asked in one of the sub questions, can be formulated to improve the method for future use.

- This method should be used by investigators/instances with access to more than only public information, like companies or safety boards connected to the accident. In this way input for a complete analysis is available and input information can be double-checked.

- Since the method is a function, the validity of the results depend on the quality of the input sources. That is why it is really important when performing an analysis to use reliable sources and if possible to double-check information.

- The lay-out of the operation level should be changed. The new operation level should consist of the aspects of culture, organization and technology. In the template the aspect of culture is divided into change of culture and change of behaviour. The aspect of organization is divided in supporting organizations and companies. The aspect of technology is not divided into parts.

- The aspect of content was used in these three applications to create expectations for the investigator. These expectations could be checked at the end of the analysis to see if no lessons were forgotten. As mentioned the aspect of content does not add anything to the operation level, but creating and checking expectations can be useful in another part of the analysis. That is why it is recommended to add two sections to the method's template. One section should be added to the first theme of the template, in which the investigator suggests measures to prevent the accident. A second section should be added to the third theme of the template to compare the suggested measures and the ones found to check nothing is missing. Like this an extra control tool to check the lessons learned is added to the method.

- The lay-out of the system level should be changed. EASA and FAA should move from the macro level to the meso level. In this way the macro level only contains ICAO and the meso level consists out of FAA, EASA, local safety authorities and the aviation industry.

- It is recommended for the section of impact to state all information available about the implementation of the lessons learned, not only if a change is identified.

- To ensure the ESReDA Cube analyses are performed in a consistent way, it is recommended to add the rules used in thesis to the ESReDA Cube method's paper. Not all rules used in this thesis are still valid, because of the recommendations above. The rules set in this section are already adapted to the new lay-out. With these rules it is easier to categorize lessons learned in a correct way. The following rules should be added (sometimes it is clarified first for what aspects or levels they count):
  - <u>Adapt versus optimize versus innovate, depth of learning level</u>. Changing an existing concept, without adding anything, to improve its working is defined as optimization. Changing an existing concept by adding something new and/or extra without changing the basic working method of the system is defined as adaptation. Using a complete new concept which was not in use before is defined as innovation.
  - <u>Change of behavior versus change of culture, aspect of culture, operation level.</u> Items which are categorized under change in behavior concern personal, individual behavior. This includes the behavior of an individual towards another individual. Behavior of one group towards another group is part of change of culture.

- Organization versus culture, operation level. Under culture human factors and organizational safety policy changes are categorized. An exception are the changes concerning the pilot training. These are also dealing with human factors sometimes but they are categorized in the aspect of organization. Changing or implementing a safety program or changing an organization to improve the safety culture is also put under organization. If there is, despite this rule, still overlapping, the main consequence should be checked.
- Micro versus meso versus macro, system level. A recommendation has to be categorized on the level where it will first have effect on.
- If an action performed is a reaction on a recommendation, it has to be put under "Impact-what really changed" in the template.

Although these rules are not completely watertight, they can prevent a lot of confusion. If some problems are encountered with these rules it is just important that the categorizing happens consistently.

- It is recommended, when comparing ESReDA Cube analyses, to not only compare the numerical results in the cube. The categorizing of recommendations/actions is, despite the rules set up earlier, still vulnerable to personal interpretation. When the complete analyses are compared, it can also be checked how the results are obtained and so no misconceptions can happen.

- For further evaluation the method should be applied on three to four cases, with focus on the operation level. The cases should all have a mutual contributing factor so that they can be analysed individually and together. The mutual factor chosen should be closely related to company culture and behavioural culture.

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Cube: [50]
Lower picture left: Brazil Air Force
Lower picture middle: No photographer found
Lower picture right: United Photos Toussaint Kluiters

Appendix A

ACCIMAP[3][4][5]

i. Description of the Model

ACCIMAP is an accident analysis tool. It is used to model the sociotechnical context of an accident to search for the combination of decisions and events which caused the accident. The designer, Professor Rasmussen, did not only want to use it as an accident analysis tool, he saw it as a part of a proactive risk management. In this proactive risk management the ACCIMAP analysis helps to set up risk management strategies. This model is not only used in the aviation domain but also in other sectors like railway, gas production and public health.

In this model accidents are seen as the result of the "loss of control" over work processes which can be hazardous. The definition of safety in this model is the "control of work processes so as to avoid accidental side effects causing harm to people, environment or investment". Systems which control the processes (sociotechnical system) can be divided into several levels:

- The government level which provides the laws and legislations to control the hazardous processes.
- The level of regulators and associations which converts these laws and legislations from the government into regulations and rules for the companies.
- The company level where the rules and regulations of the regulators are turned into company rules and policies.
- The management level which overlooks and checks the activities of the staff and personnel according to the company rules and policies which are implemented.
- The staff and work level which is in direct control of the hazardous processes.

These levels are connected. The upper level controls the lower level by making decisions. In the opposite direction these levels are connected by providing feedback of the actual system status of the staff and work level to the levels upward. This interaction is essential to keep control over the processes. The safety of the hazardous processes not only depends on the people who are in direct contact with it but on all the levels.

In this ACCIMAP model accidents happen because a lot of these hazardous processes can be found in really competitive environments. In such environments there is a lot of pressure to work as cost-effective as possible. Due to this cost effective way of working or cost-gradient, the hazardous process moves from the boundary of economic failure to the side of more efficiency. The workload or effort gradient also moves from unacceptable to more easy with less effort. The process balances itself between economic failure/unacceptable workload and the boundary of functionally acceptable performance. When the boundary of functionally acceptable performance is crossed an accident is possible (see figure A-1).

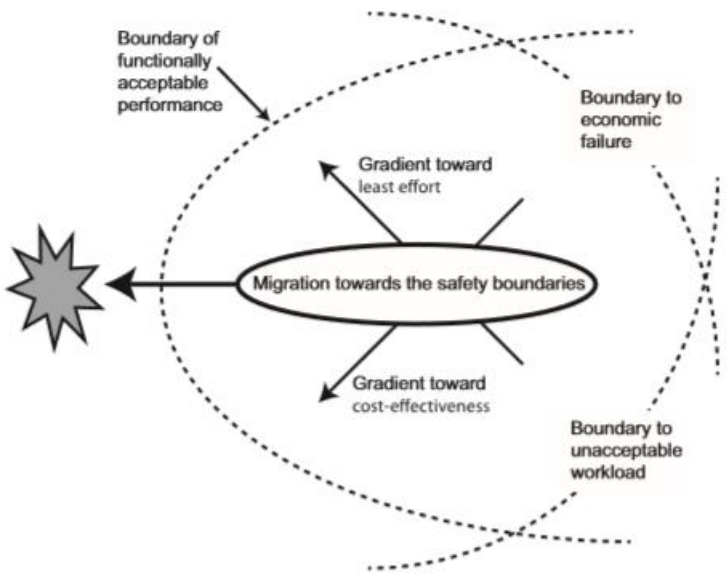

Figure A-1: Migration towards safety boundaries

In the total system, so on all the levels, decisions are taken individually to get to a more cost effective process. A problem which can occur is that an individual does not know or cannot judge where the safety boundaries of its personnel activity is located. A system is equipped with defenses which normally protect an individual. However, it is possible that these defenses become less effective due to a decision of an individual at another level. The boundaries in which the process can be performed safely only come out when it is too late, so when an accident has already occurred.
An accident does not just happen out of nowhere. Normally "the stage for an accidental course of events" has been developing for years, because each system's level wanted to work as cost-effective and efficient as possible. A "quite normal variation in somebody's behavior" can be enough to cause an accident then. In a lot of other accident analysis tools this difference in behavior will be seen as the primary cause of the accident. However, often it is very likely that if it was not this difference in behavior, something else would have caused an accident in the future. In this way ACCIMAP is not focused on the error which triggered the accident but on the sociotechnical system behind it which allowed it to cause an accident.

ii. How to use the Model

With this model a causal diagram is constructed which represents all the levels of the sociotechnical system and their contributing factors to the accident. Using this diagram the whole context and all the interactions between the several levels of the sociotechnical system can be described. In this way a clear image of the accident is illustrated. In figure A-2 an example is given of the model's use for the case of the Überlingen mid-air collision (in 2002 a Tupolev TU154M and a Boeing B757-200 collided in mid-air near the town of Überlingen in Germany).
In this scheme the outcomes can be found on the bottom of the diagram and the contributing factors are branched upwards. The contributing factors which are of practical significance (this means, the ones which could have been prevented) for the accident to happen can be found in the rectangles. The contributing factors in the ovals are the ones which were of no practical significance, but are necessary for the accident scenario to make sense (these are factors which contributed to the accident, but these factors could not been prevented or avoided). The contributing factors can be found in levels, just like the levels in the sociotechnical system of Rasmussen. Going up in the diagram from the outcome, first the primary cause of the accident is found. Next the organizational contributing factors is shown. Finally the external level (external to the organization involved) contributing factors are found.
Using a diagram to describe the bigger picture with all the contributions and interactions makes sure it is very clear. If this would be presented in text form it would take many pages and become more unclear. Using this model corrective actions can be taken so that such events will not happen again in the future.

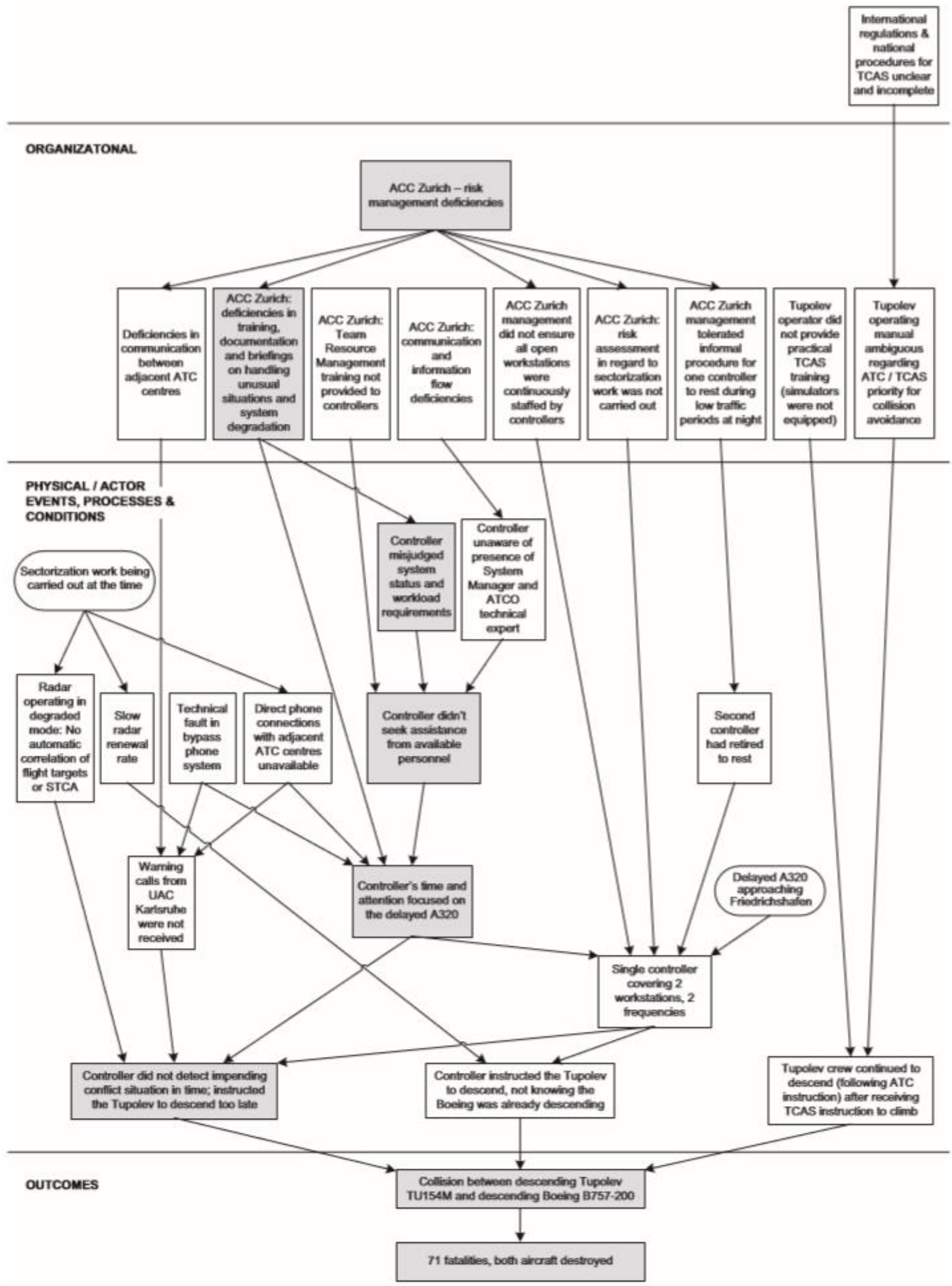

Figure A-2: ACCIMAP diagram for the Überlingen mid-air collision

Appendix B

STAMP[6][7]

i. Description of the model

STAMP (Systems- Theoretic Accident Model and Processes) is an accident analysis model created by Nancy Leveson, Professor Aeronautics and Astronautics at the university of MIT. It is partly based on the ACCIMAP model of Rasmussen.

It was developed to have more insight in the reason why accidents happen. Today most accident models are event chain models. The accident in these models is described as a chain of failure events or human errors leading up to the accident. These models have a lot of limitations which prevent it from finding the true cause of an accident. In this way it difficult to avoid the accident from happening again in the future. Event chain models have no specific rules which define at what event the investigation can be stopped. Some investigators stop when a direct cause is found or when someone can be blamed. Sometimes, however, another event can be found which provides an answer why the previous event happened. This means that without any specific rules of when to stop the investigation, event chain models can be seen as subjective. Every investigator can have a different result in the end.

The STAMP model was designed for complex socio-technical systems. Three concepts are used in this model, namely constraints, hierarchical levels of control (based on the sociotechnical system of ACCIMAP) and process models.
STAMP focuses on constraints and not on an event. Constraints are used to control the process in a complex socio-technical system. Accidents happen according to STAMP because of inadequate control or enforcement of safety-related constraints. In the hierarchical structure every controller or level imposes constraints on the level/controller below it. The system, which is a dynamic process changing all the time, always has to operate safely with the desired result. This means that if the process changes, constraints have to be adapted or be added to ensure a dynamic equilibrium. Between the hierarchical levels there are feedback loops of information and control to keep this dynamic equilibrium.
The concept of the hierarchical level (sociotechnical system) was already explained in appendix A.
The last concept of STAMP consists of process models. Every controller or level of the system (automated or human) must possess a process model. In this model the relation among the system variables, the current state (the current system variables) and the way(s) how the process can change state, can be found. In this way the controller knows how to react if there is any deviation in the normal process. A lot of accidents happen because the system controllers are not prepared for any change in the process which is not according to the theoretic process model. Process models help the controllers to have better coordination of their action(s). Certainly if there are multiple controllers for the same process or if a part of the process is controlled by a computer such models provide important information. Effective control of the hierarchical level is based on a correct, consistent and complete process model.

Using these three concepts, control flaws which cause an accident can be classified. In figure B-1 the classification of the control flaws according to Leveson is shown. This classification can help during analyses to identify all factors involved in the accident.

1. Inadequate Enforcement of Constraints (Control Actions)
- 1.1 Unidentified hazards
- 1.2 Inappropriate, ineffective, or missing control actions for identified hazards
  - 1.2.1 Design of control algorithm (process) does not enforce constraints
    - Flaw(s) in creation process
    - Process changes without appropriate change in control algorithm (asynchronous evolution)
    - Incorrect modification or adaptation
  - 1.2.2 Process models inconsistent, incomplete, or incorrect (lack of linkup)
    - Flaw(s) in creation process
    - Flaws(s) in updating process (asynchronous evolution)
    - Time lags and measurement inaccuracies not accounted for
  - 1.2.3 Inadequate coordination among controllers and decision makers (boundary and overlap areas)

2. Inadequate Execution of Control Action
- 2.1 Communication flaw
- 2.2 Inadequate actuator operation
- 2.3 Time lag

3. Inadequate or missing feedback
- 3.1 Not provided in system design
- 3.2 Communication flaw
- 3.3 Time lag
- 3.4 Inadequate sensor operation (incorrect or no information provided)

Figure B-1: Classification of control flaws

ii. How to use the model

In this section it is shown how the STAMP model can be used in practice. This will be done using an example model of a water contamination accident. This accident happened in Canada in May 2000, 7 people died and about 2300 people became ill.
As already mentioned, the STAMP model is lightly based on the ACCIMAP model of Rasmussen. For the ACCIMAP model, however, events are added to the organizational levels. This makes such analysis an event chain model.
The first step in applying STAMP is to look for the system hazards, the system constraints and the system's hierarchical control structure. This information is used in three views to explain the accident. In the first view it is checked how the safety in the hierarchical control structure changed over time. This is checked by making and describing two models. The first model (see figure B-2) shows how it was in the beginning and how it should be when all safety requirements and constraints are still in place. The lines entering the rectangles from the top or from the bottom show feedback, information or a physical flow. Lines coming in from the left are control lines.

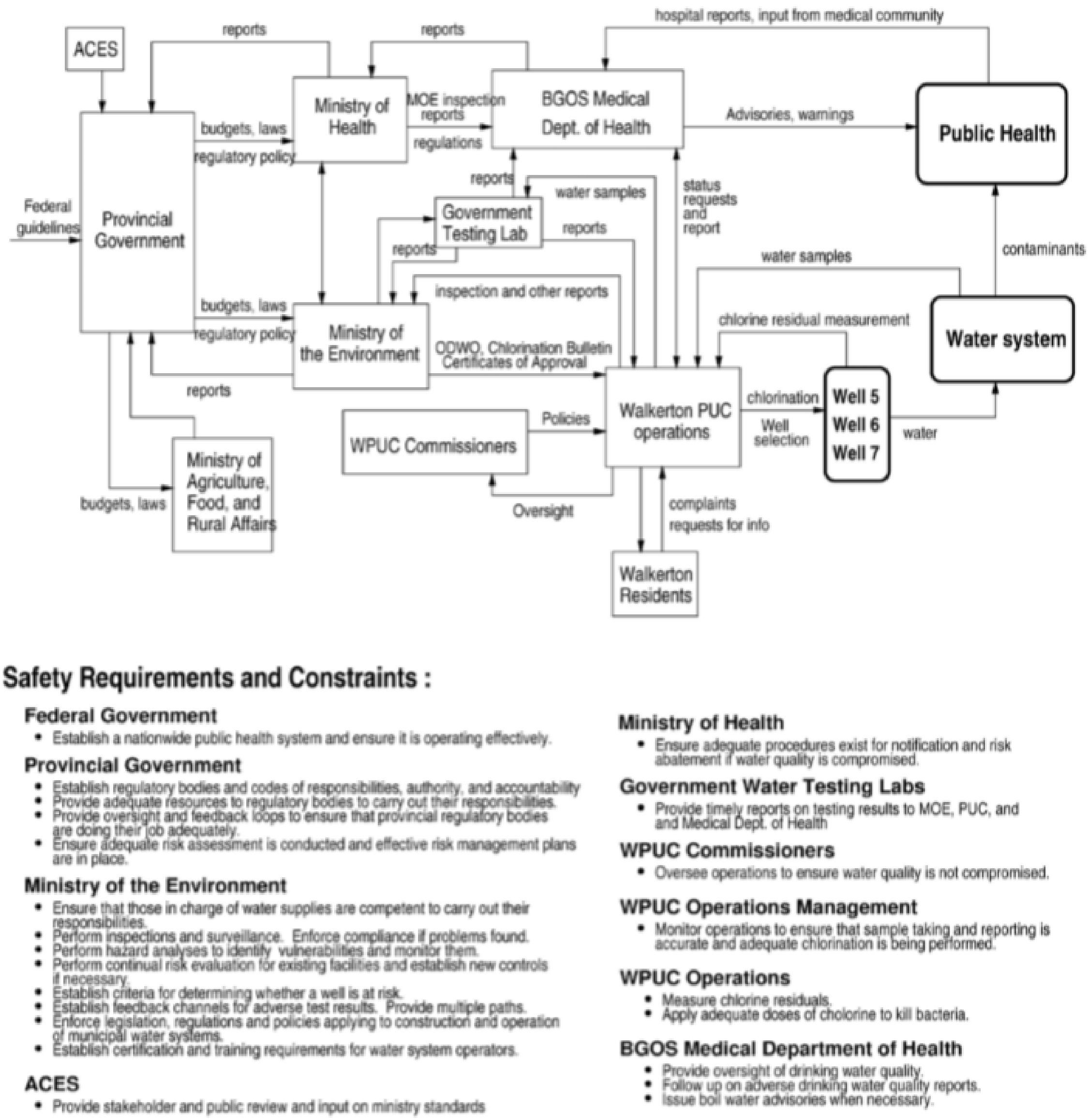

Figure B-2: Safety control structure how it should be

The second model shows (figure B-3) the system at the time of the accident. With these snapshots and its text, the changes in safety of the hierarchical structure can be found. In figure B-3 the lines have the same meaning as in figure B-2, although the dotted lines are new. They represent feedback, communication or control lines which have become inoperative or ineffective.

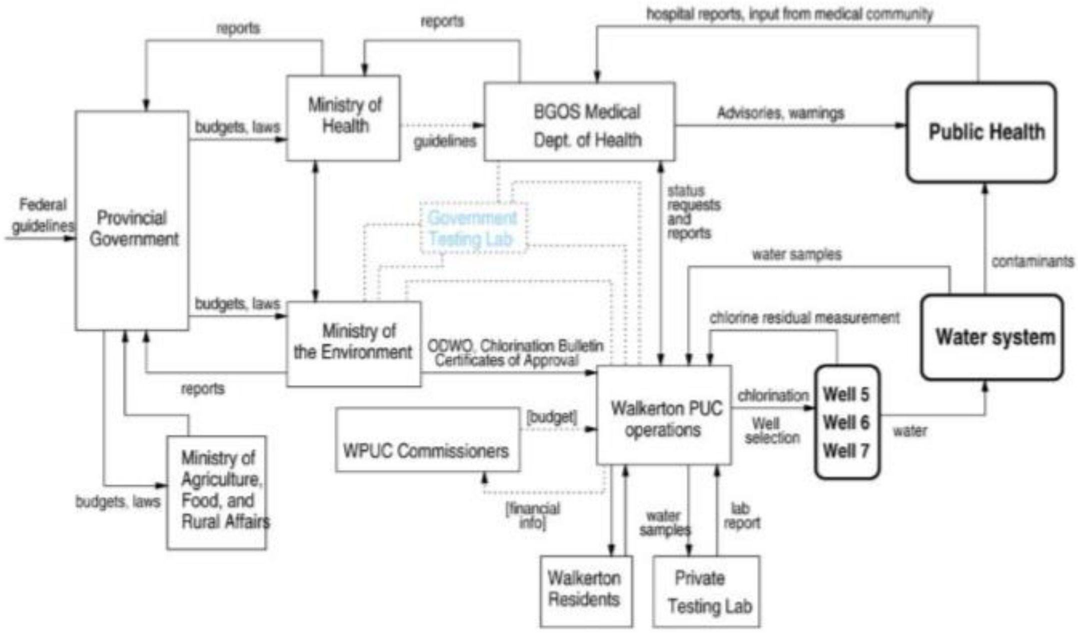

Figure B-3: Safety control structure at the time of the accident

In the second view the dynamic processes that lead to these changes are checked. To check this a model (see figure B-4) is created an described. With this model the causes for the changes become very clear. In this model the direct causes of the accident can be found in the rectangles, which are connected to the risks through double lines. Next to that are the process variables in this model, they can be seen as written text floating in the model. The lines between the different parts of the model show the causality links. With a causality link there can be a + (meaning that changing the original variable causes a change in the same direction of the target variable), a – (meaning that changing the original variable causes a change in the opposite direction of the target variable) and finally there can be a // (this shows a delay which can cause an instable system) through the link.

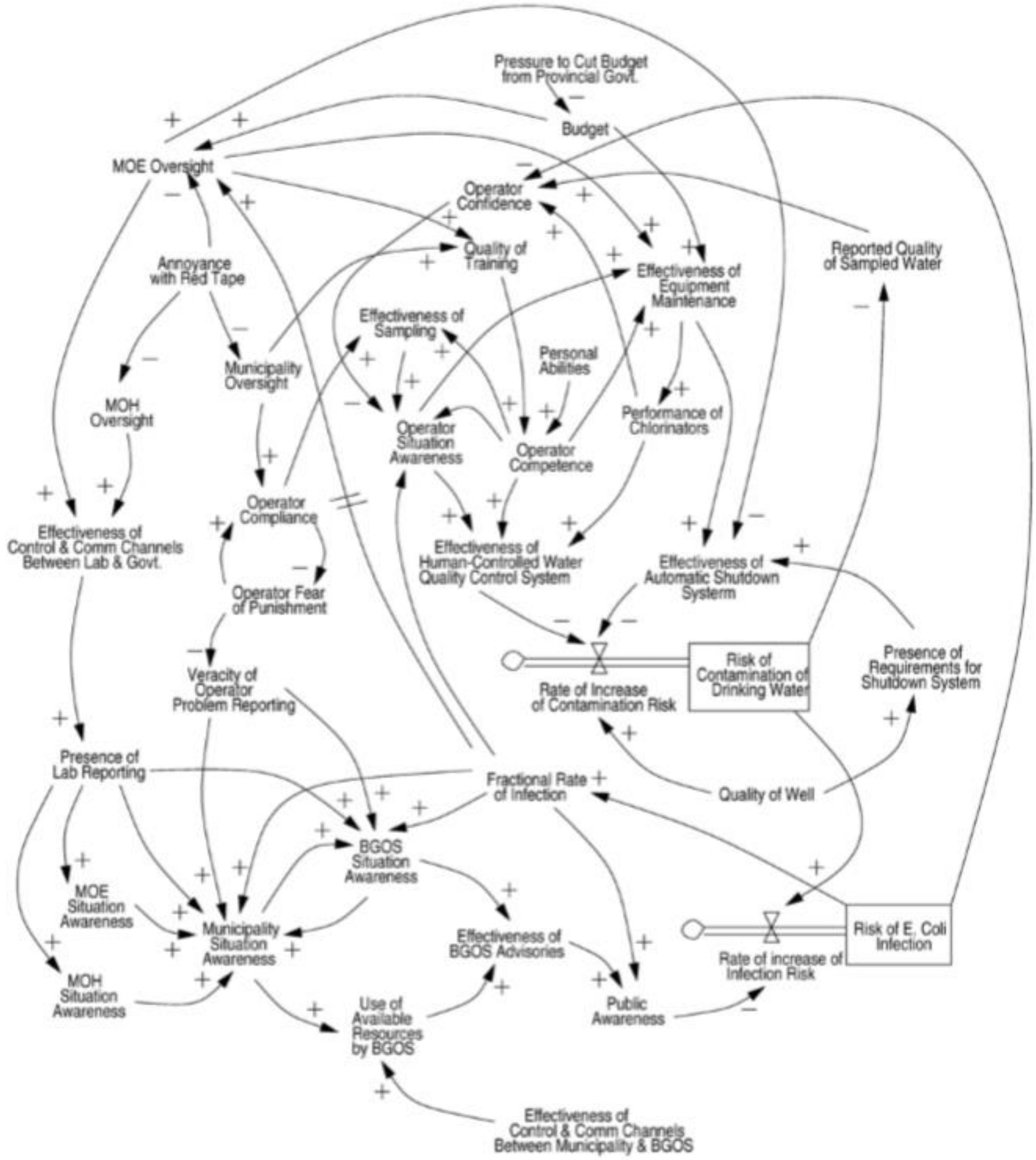

Figure B-4: Dynamic process model

In the third view an explanation of the whole accident is made. A summary of the two previous views and models is created. This is described in a written conclusion and model (see figure B-5, B-6, B-7). Every control part of the process is described/shown together with their inadequate control actions and the reason for these actions. To describe this the STAMP classification of figure B-1 is used.

Provincial Government

Safety Requirements and Constraints:

- Establish regulatory bodies and codes of responsibilities, authority, and accountability for the province.
- Provide adequate resources to regulatory bodies to carry out their responsibilities.
- Provide oversight and feedback loops to ensure that provincial regulatory bodies are doing their job adequately.
- Ensure adequate risk assessment is conducted and effective risk management plan is in place.
- Enact legislation to protect water quality.

Context in Which Decisions Made:

- Anti-regulatory culture.
- Efforts to reduce red tape.

Inadequate Control Actions:

- No risk assessment or risk management plan created to determine extent of known risks, whether risks should be assumed, and if assumed, whether they could be managed.
- Privatized laboratory testing of drinking water without requiring labs to notify MOE and health authorities of adverse test results. (Privatizing without establishing adequate governmental oversight)
- Relied on guidelines rather than legally enforceable regulations.
- No regulatory requirements for agricultural activities that create impacts on drinking water sources.
- Spreading of manure exempted from EPA requirements for Certificates of Approval
- Water Sewage Services Improvement Act ended provincial Drinking Water Surveillance program
- No accreditation of water testing labs (no criteria established to govern quality of testing personnel, no provisions for licensing, inspection, or auditing by government).
- Disbanded ACES.
- Ignored warnings about deteriorating water quality.
- No law to legislate requirements for drinking water standards, reporting requirements, and infrastructure funding.
- Environmental controls systematically removed or negated.

Feedback:

- No monitoring or feedback channels established to evaluate impact of changes

Ministry of the Environment

Safety Requirements and Constraints:

- Ensure those in charge of water supplies are competent to carry out their responsibilities.
- Perform inspections and enforce compliance if problems found.
- Perform hazard analyses to provide information about where vulnerabilities are and monitor them.
- Perform continual risk evaluation of existing facilities and establish new controls if necessary.
- Establish criteria for determining whether a well is at risk.
- Establish feedback channels for adverse test results. Provide multiple paths so that dysfunctional paths cannot prevent reporting.
- Enforce legislation, regulations, and policies applying to construction and operation of municipal water systems.
- Establish certification and training requirements for water system operators.

Context in Which Decisions Made:

- Critical information about history of known vulnerable water sources not easily accessible.
- Budget cuts and staff reductions

Inadequate Control Actions:

- No legally enforceable measures taken to ensure that concerns identified in inspections are addressed. Weak response to repeated violations uncovered in periodic inspections.
- Relied on voluntary compliance with regulations and guidelines.
- No systematic review of existing certificates of approval to determine if conditions should be added for continuous monitoring.
- Did not retroactively apply new approvals program to older facilities when procedures changed in 1992.
- Did not require continuous monitoring of existing facilities when ODWO amended in 1994.
- MOE inspectors not directed to assess existing wells during inspections.
- MOE inspectors not provided with criteria for determining whether a given well was at risk. Not directed to examine daily operating sheets.
- Inadequate inspections and improperly structured and administered inspection program..
- Approval of Well 5 without attaching operating conditions or special monitoring or inspection requirements.
- No followup on inspection reports noting serious deficiencies.
- Did not inform Walkerton Medical Officer of Health about adverse test results in January to April 2000 as required to do.
- Private labs not informed about reporting guidelines.
- No certification or training requirements for grandfathered operators.
- No enforcement of continuing training requirements.
- Inadequate training of MOE personnel.

Mental Model Flaws:

- Incorrect model of state of compliance with water quality regulations and guidelines.
- Several local MOE personnel did not know E. coli could be fatal.

Feedback:

- Did not monitor effects of privatization on reporting of adverse test results.

Coordination:

- Neither MOE nor MOH took responsibility for enacting notification legislation.

Figure B-5: Summary

Ministry of Health

Safety Requirements and Constraints:
- Ensure adequate procedures exist for notificatoin and risk abatement if water quality is compromised.

Inadequate Control Actions:
- No written protocol provided to local public health inspector on how to respond to adverse water quality or inspection reports.

Local (BGOS) Medical Dept. of Health

Safety Requirements and Constraints:
- Provide oversight of drinking water quality.
- Follow up on adverse drinking water quality reports.
- Issue boil water and other advisories if public health at risk.

Context in Which Decisions Made:
- Most recent water quality reports over 2 years old.
- Illness surfacing in communities outside Walkerton
- E. coli most commonly spread through meat.

Inadequate Control Actions:
- Advisory delayed.
- Advisory should have been more widely disseminated.
- Public health inspector did not follow up on 1998 Walkerton inspection report.

Mental Model Flaws:
- Thought were receiving adverse water quality reports after privatization.
- Unaware of reports of E. coli linked to treated water source.
- Thought Stan Koebel was relaying the truth.

Coordination:
- Assumed MOE was ensuring inspection report problems were resolved.

A&L Canada Laboratories

Safety Requirements and Constraints:
- Provide timely and accurate reports on testing results to MOE, WPUC, and Medical Dept. of Health (MOH)

Inadequate Control Actions:
- Did not follow provincial guidelines and inform MOE and MOH of adverse test results.

Mental Model Flaws:
- Did not know about reporting guidelines;
- Considered results to be proprietary.

WPUC Commissioners

Safety Requirements and Constraints:
- Oversee operations to ensure water quality is not compromised.

Context in Which Decisions Made:
- Elected officials
- No training or educational requirements.

Inadequate Control Actions:
- Relied on Stan Koebel to identify and resolve any concerns related to operation of the water supply. Did not monitor to ensure problems fixed.
- Did not establish, oversee, nor enforce policies and practices for operating the Walkerton public water system.
- Concentrated only on financial matters.

Mental Model Flaws:
- Little knowledge of water safety and operation of system.;
- Unaware of improper treatment and monitoring practices of WPUC operators.

Figure B-6: Summary part 2

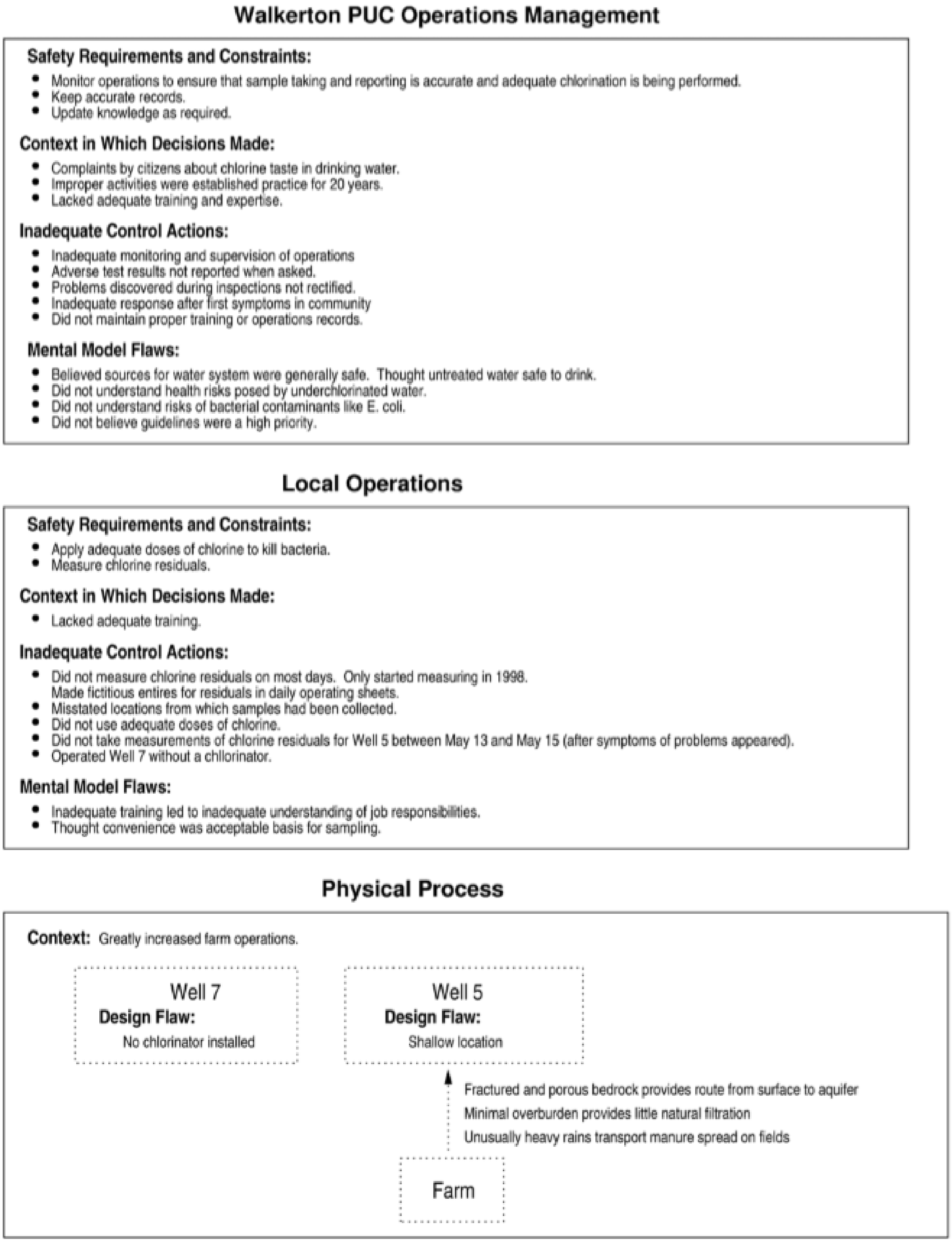

Figure B-7: Summary part 3

With all this information conclusions and recommendations can be issued. Using the STAMP model it is easier than with chain models to determine what to do differently in the future to prevent an accident from happening again.

Appendix C

FRAM[8][9][10]

i. Description of the method

FRAM (Functional Resonance Analysis Method) was designed by Erik Hollnagel of the university of Southern Denmark. It can be used for both accident investigation as for safety assessment. It is designed for usage in several domains.

FRAM is part of the wider approach of Hollnagel, called Resilience Engineering. Resilience Engineering is an approach for risk assessment which tries to find out how the organization is able to create more flexible, but still robust, processes. An accident or failure in Resilience Engineering does not show some malfunction of a system. It shows a conversion, with the necessary adjustments, of the processes to the current conditions. A system is variable due do two big reasons. First of all a process is always dynamically changing. Secondly, a process can never be prescribed in extreme detail so always unexpected things can happen.
The dynamic changing or variability of human and organizational performance is caused by six main reasons:

- Human's physiological and psychological character (lack of attention, fatigue, …)
- The higher pervasive human psychology (creativity, adaptability,…)
- Organizational requirements and conditions to succeed with any external demand or changing goal
- Team or any social psychological factor
- Context factors (too loud workspace, too cold)
- Work environment context, by factors which cannot be predicted (weather conditions, technical problems)

The FRAM method is based on four principles.
The first principle is the one of equivalence of successes and failures. As already mentioned according to Resilience Engineering, processes have to adjust all the time to the current conditions. If these adjustment cause an acceptable outcome or success, they are effective. If these adjustments cause an unacceptable outcome or accident/failure, they are ineffective. Failures and successes are inherent to every process so they should be equalized.
The second principle is the one of the inevitability of approximate adjustments. Adjustments are approximate since the process cannot be prescribed extremely detailed due to a lack of time and resources. The fact that adjustments are approximate is also one of the reasons why the process continues to be variable.
The third principle says that consequences are emergent. If the normal everyday performance varies, this is almost never enough to cause a big accident. If several functions vary together in an unexpected way, this may cause a large effect. In this way it is said that both normal performance as failures are emergent, rather than their resultant. This is since a resultant assumes a traceable system, meaning that the system can be described in detail. According to FRAM a process cannot be described in detail, which makes a system untraceable, leading to emergent outcomes.
The fourth principle is the one of functional resonance. In the FRAM method the cause-effect relation is replaced by the principle of resonance. According to the principle of resonance the variation of functions may now and then resonate. Sometimes this will happen so badly that functions will enforce each other with possible catastrophic or positive outcome.
With FRAM an organization will be described as functions which are designed to achieve certain goals. Each function description is divided in several parts. In this way it shows how every function is organized within

the total organization and if a function can be done in a safe manner or not. A model of the whole event is created. A function is always dependent on its input, which shows that variability has to be taken into account. In this method the focus lays on management, more than on technique.

ii. How to use the method

Using the FRAM method is done in five steps.
In the first step the purpose of the analysis is defined. As already mentioned the FRAM method can both be used for accident investigation as for safety assessment. In this step the situation and the purpose of the analysis will be described.

In the second step the functions in the process are described according to six parameters. These six parameters are time, control, output, resources, precondition, input (see table C-1).

Time	Time aspect which affect the function
Control	Who/what controls the function
Output	The result of the function
Resources	What is necessary for the function
Precondition	Conditions of the system which must be fulfilled before the function can be carried out
Input	What activates the function or what is transformed to get the output

Table C-1: Input parameters

Every function can be represented graphically by a hexagon (see figure C-1) and is also represented in a table form. The table form function description will add however the most to the FRAM method.

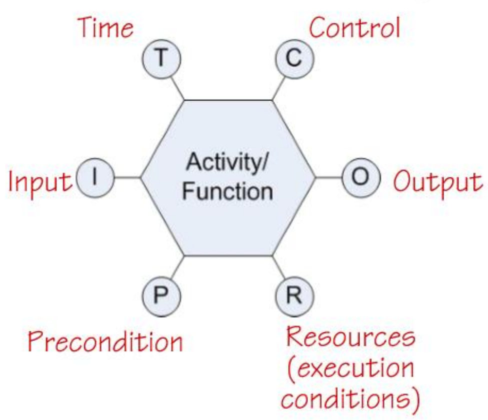

Figure C-1: Graphical representation of a function with a hexagon

Next, the couplings between the several functions are checked. These couplings are shown graphically and are based on the description of the functions in the tables. In this representation only the couplings between the functions are shown. The position of the hexagons is unimportant, no cause-effect relation or any causal flow is shown by this. In figure C-2 a small example is presented, the two functions are training and planning.

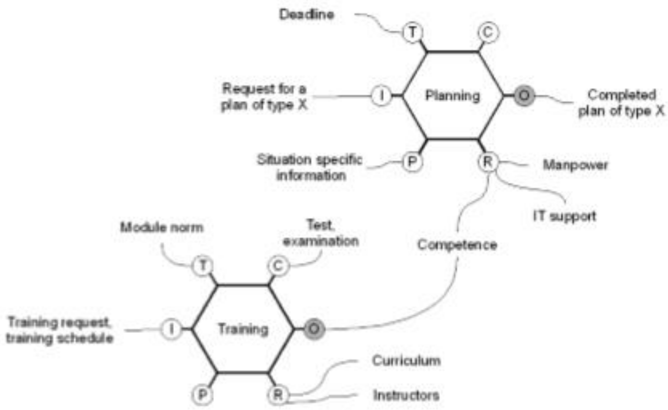

Figure C-2: Example of small system

The third step is to look for possible performance variability. As already mentioned, variability depends on the context. The effect of the context on performance is represented using the Common Conditions, as is seen in table C-2. In this table the Common Conditions can be found in the first column. These Common Conditions can be rated as adequate, inadequate or unpredictable which causes the performance variability to be small, noticeable, high or very high.

	Adequate	Inadequate	Unpredictable
Availability of resources (personnel, materials, equipment)	Small	Noticeable	High
Training and experience (competence)	Small	High	High
Quality of communication (team, organisation)	Small	Noticeable	High
Adequacy of HMI and operational support	Small	Noticeable	High
Availability of procedures and methods	Small	Noticeable	High
Conditions of work	Small	Noticeable	High
Number of goals and conflict resolution	Small	High	High
Available time, time pressure	Small	High	Very high
Circadian rhythm, stress	Small	Noticeable	High
Team collaboration quality	Small	Noticeable	High
Quality and support of the organisation	Small	Noticeable	High

Table C-2: Performance variability due to Common Conditions

The influence of the Common Conditions depends on the function. For this reason the functions are divided into three categories. The human category (M) (functions which depend mostly on humans), the technology category (T) (functions which depend mostly on technology) and the organization category (O) (functions which depend mostly on the organization). The important Common Conditions for every category can be found in table C-3.

	Functions affected		
	M	T	O
Availability of resources	X	X	
Training and experience (competence)	X		
Quality of communication	X		X
HMI and operational support	X		
Access to procedures and plans	X		
Conditions of work	X	X	
Number of goals and conflict resolution	X		X
Available time and time pressure	X		X
Circadian rhythm and stress	X		
Team collaboration quality	X		
Quality and support of the organisation			X

Table C-3: Importance of Common Conditions on every function category

Next, when all functions are categorized, the relevant Common Conditions are rated for every function. The purpose is to find the variability of every single function:

- If any of the Common Conditions are rated as inadequate, then the function's variability is assumed to be noticeable or high (depending on what is in table C-2).
- If any of the Common Conditions are rated as unpredictable, then the function's variability is assumed to be high or very high (depending on what is in table C-2).
- If for a function all Common Conditions are rated as adequate, then the variability of the function is of course small.

The fourth step is to identify the functional resonance. There are two ways how variability of a function has consequences. First the output can be a failure or not what was intended in the design of the function. The other way is that the variation can cause a change in one or more of the Common Conditions. This can influence the variability of the functions which are directly coupled to the first function, which can lead in the end to a resonance effect.
Manually looking for this resonance effect is too difficult. It should be done with a software tool.

The fifth and last step in the FRAM method is to identify effective countermeasures. Until now the performance variability (and the potential risk which comes with) have been identified for every function. With this information the known risks should be eliminated. If it is not possible to eliminate a risk, other countermeasures should be sought. A very effective one is to implement an extra barrier. Another countermeasure, if there is a lot of performance variation, is to reduce this variation. If any countermeasure is taken, it should be designed to work in the current situation.
FRAM is a method which is still under construction so not all possibilities are found yet. A user of FRAM has to know the method and can then apply it.

Appendix D

Tripod Beta[98][100][101][102]

i. Description of the method

Tripod Beta is an incident analysis tool. It can however also be used to analyse accidents. It is based on the Tripod Theory. The method is developed by a cooperation between Shell, the university of Leiden and the university of Manchester. The method was first focused on the petrochemical industry, later it was also applied in other fields. One of the users is the Dutch Safety Board[99].

It was developed to have more insight in the contribution of human behavioral factors to accidents. According to the method incidents happen when barriers are absent or inadequate to prevent things which can escalate to unwanted consequences. If an incident happens it means people made and error and failed to keep functional barriers. As it can be seen in figure, the Tripod method chain consists of three elements: underlying cause, precondition, immediate cause and barrier.
This aim of the method is to find three things:

- What was the sequence of the events?
- How did it happen, what barriers failed?
- Why did the barrier fail?

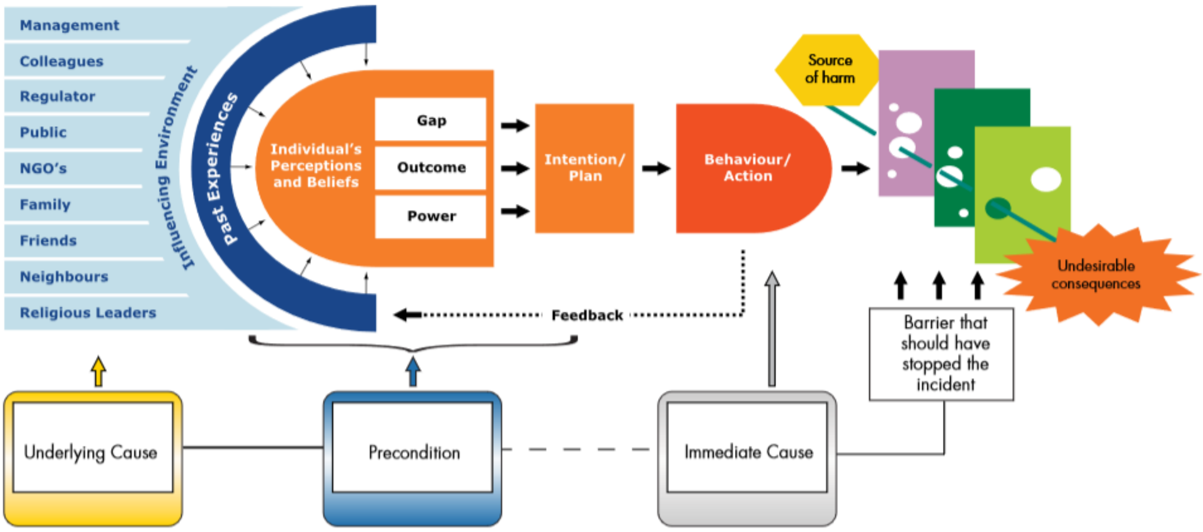

Figure D-1: Tripod approach

The first question gives a description of what happened. To answer the second question, how it happened, the immediate cause of the accident should be investigated. To see why it happened it is necessary to analyse the preconditions and underlying causes. This means understanding the human intention or plan causing the incident. Before people do something the brain asks three questions:

- Gap question: is there a gap between how it its now and how I want it?
- Outcome question: is there a reason I should do it?

- Power question: do I have the ability to do it?

The answers on the these questions are based on the actor's perception. These perceptions are influenced by past experiences and by the actions/decisions of the influencing environment (underlying causes). In this way the underlying causes of the preconditions, and so of the event, are found.
The underlying causes are categorized into Basic Risk Factors (BRF). The categories are:

- Hardware
- Housekeeping
- Design
- Incompatible goals
- Maintenance Management
- Communication
- Procedures
- Organization
- Error-enforcing conditions
- Training
- Defences

ii. How to use the method

With a Tripod analysis it is tried to identify and correct the underlying causes to prevent the incident from happening again. The way the method works is as follows (see figure D-2).
First the findings are analysed. Next an initial Tripod Tree is made. A Tripod Tree is a schematic overview of the accident where it can exactly be seen what barrier failed, how it happened and why(see figure D-3). After that more evidence is collected to complete the Tripod Tree. Then it is checked if the analysis is adequate. If not more research is necessary. If the analysis is adequate, a report can be issued containing recommendations to prevent the accident.

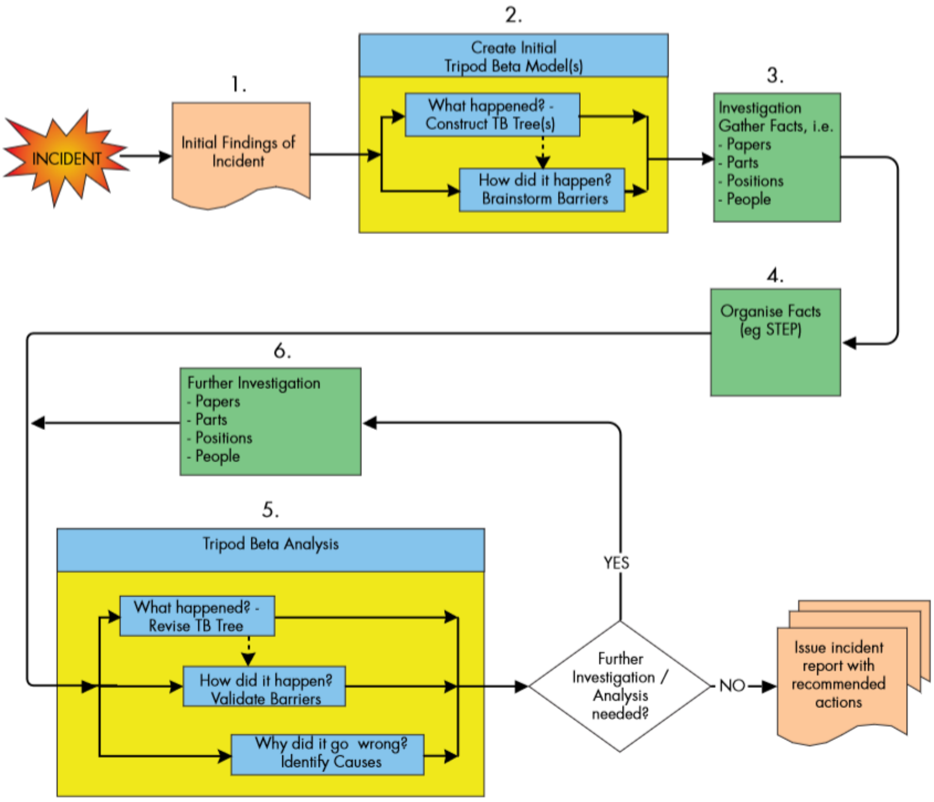

Figure D-2: Steps of the Tripod analysis

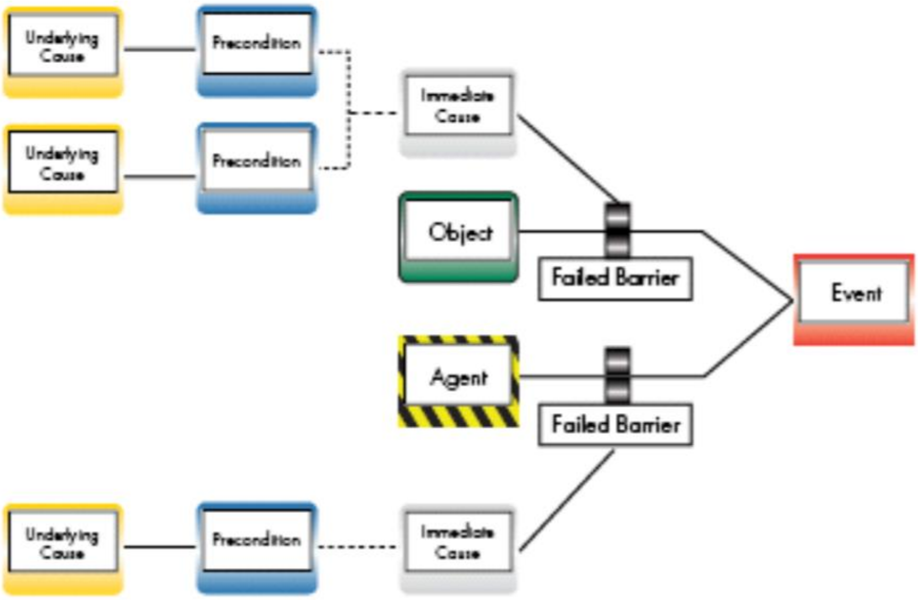

Figure D-3: Tripod tree

Appendix E

Air France flight 447

All the times in this analysis are provided in UTC.

Item	Explanation	
Description (system involved)		
Description accident	Short description	On June 1st 2009, the Air France Airbus A330-200 crashed into the Atlantic ocean. The aircraft took off as Air France flight 447 at Antônio Carlos Jobim airport, Rio De Janeiro and was heading for Charles De Gaulle International Airport, Paris. All passengers (216) and crew (12) were killed in the accident.
	What has happened (description, pictures etc.) What agents (the damaging energy source e.g. nuclear hazard)	During cruise suddenly the automatic systems disconnected (information from ACARS messages) and the pilot flying took over control. A nose-up input was given while the speed was decreasing. The aircraft reached an altitude of 38,000 ft. with an angle of attack of 40 degrees and entered a stall with a vertical speed of -10,000 ft/min. (information from the black boxes) The aircraft did not recover from this stall, hit the ocean and crashed.
	How has it happened, what were the circumstances?	At the time the automatic systems disconnected the captain was not in the cockpit and the aircraft was being flown by one of the co-pilots. Before he left, the captain did not specify with both the other pilots present who was the relief captain.

		When the automatic systems disconnected the aircraft was reconfigured to alternate control law flying. This means the high angle of attack protection is lost but the stall warning still works. During the last minutes of the flight the stall warning was triggered several times (information from the black box). The aircraft also buffeted.
	Why did it happen? Direct causes	The automatic systems were disconnected, probably due to the blocking of the pitot tubes by ice crystals. Due to that, the pilots had to take over manual control of the aircraft. The pilot flying reacted wrongly on the situation and gave a nose-up input. He probably thought the aircraft was in an overspeed situation and also the flight director gave instruction for nose-up input. He brought the aircraft into a stall situation. This stall was not recognized and so no recovery was made from this situation which caused the aircraft to crash into the ocean.
	Why did it happen? Root causes	Due to the fact that there had been problems with the speed indication in the past, the French DGAC published an airworthiness directive. This airworthiness directive required to replace all Goodrich 0851 GR probes by Goodrich type 0851HL probes or by Thales type C16195AA probes (August 2001). The problems with the speed indications were probably caused by the presence of ice crystals and/or water in the pitot probes within the upper limits of the original specifications (these specifications did not include the additional specifications defined in 1995 by Airbus). After again having inconsistencies in the speed measuring, now with the new pitot tubes, Airbus advised with a service bulletin the replacement of the C16195AA by the C16195BA (September 2007). The C16195BA performs better in case of water ingestion or icing in severe conditions. It has to be noted that the C16195BA tubes were designed to give a solution for the water ingestion problem. The ice crystal problem was not considered in the design. Although in a comparison test the C16195BA performed better in icing conditions than the C16195AA. It was also mentioned for the probes testing that it is impossible, due to technical reasons, to create all conditions that may be encountered in reality in a wind tunnel. Air France had discussed these speed indicating problems several times with Airbus, after which Air France decided to replace all the original C16195AA probes with C16195BA. The first set of new probes arrived at Air France, on 26 May 2009 (6 days before the crash). The aircraft which crashed was still equipped with the C16195AA probes.
	Other root causes	The problem of lost speed indication was underestimated by the aviation community at the time of the accident. This sort of failure in airspeed indication was classified in the safety model. It was assumed that such failure would be quickly recognized by the pilots and that appropriate measures would be taken as described in the associated procedure. With Air France 447 the pilots did not know how to react because they could not find out what the problem and reason was why the automatic systems disconnected. Since this error was unknown, the procedures were not followed and the stall protection was assumed to be still active, causing the stall warning to be invalid. It is possible that the nose-up input was given due to the instructions of the cross bars on the flight director (which were based on false information). These cross bars instruct the pilots what actions they have to take to follow the flight path. Due to the disconnection of the automatic systems the crossbars disappeared (at least temporarily). Later they reappeared. This may have caused the pilot to give a nose-up input, following the instructions of the flight director, and to ignore the stall warning.

		The procedure for stall recovery and for the reconfiguration of flight law were not reviewed during the ECPs (recurrent training on flight simulators). So when the aircraft was brought into this stall situation, although all the warnings in the cockpit, the pilots did not diagnose it. No stall recovery maneuver was performed. The pilots did not communicate well. The pilot flying kept giving nose up inputs without informing the pilot not flying. Later the pilot not flying took over control without clear communication.
	When did it happen? Timeline of main events	The aircraft took off at 22h 29 min (May 31st 2009). At around 2h 00min (June 1st 2009) the captain left the cockpit. About 10 minutes later at 2h 10min 05 the automatic systems were disconnected and the pilots took over manual control. At 2h 11min 42 the captain re-entered the cockpit. The black box last record was taken at 2h 14min 28, the last known position was given at 2h 10min 00 and the last radio contact was at 1h 35min 43. It took the investigators about 23 months to find the black boxes of this aircraft. The final report was published in July 2012 [11].
	Historical events	As already mentioned before, there had already been problems in the past with inconsistent speed measuring. Due to that Air France was about to replace the pitot tubes on the entire A330/A340 long-haul fleet. Air France started replacing these tubes on the 30th of May 2009. The A330 flight 447 was still equipped with the old pitot tubes at the time of the crash. On December 1st 1974 a Boeing 727 of Northwest Airlines, flight 231, stalled and crashed. The stall was caused due to inappropriate reaction of the crew on erroneous speed indication. This erroneous speed indication happened because the pitot tubes were blocked (the probe heating was not on). It was recommended by the NTSB to the FAA to emphasize to pilots to use pitch attitude information when displays connected to speed are unreliable. This recommendation had to be spread among all operators. Two other accidents concerning the loss in speed measuring are known: flight 603 of Aeroperu and flight 30 of Birgenair. For both accidents recommendations were issued to improve the pilot training.
	Place Context of event and system (general environment, topography, weather)	Atlantic Ocean, the last known position was 2° 58.800’N 30° 35.400’W. The weather conditions were normal for the time of the year and there was some turbulence.
	Sector involved	Aviation industry, SAR services and the international rules and regulations organizations ICAO and EASA.
Type of event	Content aspects: primary activity, operational aspect involved	The crash happened during the scheduled passenger flight of Air France from Rio de Janeiro to Paris.

	General or macro description of plant or system involved	Air France is the French national Airline Company. Air France has a fleet of 246 aircraft, from which 15 are A330-200s. It performs 1500 flights a day[12].
	Local or micro description of process/system involved in accident	This Airbus A330 was delivered to Air France in April 2005. In January 2014, 1055 Airbus A330s were built and delivered. The pitot tubes which were used on this A330 were unreliable under certain circumstances.
	Structural aspects: e.g. relevant organizational structures, infrastructure, buildings etc.	The pitot tube was certified by the authorities although the speed issue problems. Air France wanted to have this problem solved and decided to replace all the pitot tubes. The procedure for reacting at a stall recovery was not considered worthy to review during the ECPs (recurrent training on flight simulators).
	Cultural aspect: personal safety culture company safety culture	Clear communication between the pilots was not part of their personal or company culture.
	Contextual aspects e.g. industrial safety culture	It was thought by the aviation industry that the problem was classified in the safety model and that this kind of problem would be recognized by the pilots., Like this appropriate measures could be taken as described in the procedures.
	Area and stakes vulnerability to the system	The safety model did not work since it was assumed to cover these type of failures, but it did not. The pilot training has been proven to be insufficient to deal with a failure in airspeed measuring and to deal with a stall situation. The authorities failed since they certified this pitot tube, which could give problems and they did not do anything about it. Airbus failed in its design of the speed measuring system.
Magnitude of damage to system involved	Scale and kind of property damage	The A330-200 was completely destroyed.
	Victims	All 12 crew members and 216 passengers were killed.
	Magnitude of damage financial environmental	The salvage operation cost 32 million euros[13]. With only public information it was not found who will pay this salvage operation. There was no serious damage to the environment.

	Down time	Air France and the A330-200 kept on flying, so no down time.
	After the event, aftermath actions to restore, repair, de-pollution, compensate	Immediately after the crash Air France paid 100,000€ in total to the families of the victims[14]. Later Air France was ordered to pay 126,000€ per passenger to the relatives. Airbus did not pay anything yet, they will only pay if they are found liable in a trial[15].
	Speed/pace of recovery completely back into business	Since there was no down time, business continued as usual. Air France still flies to Rio De Janeiro.
Investigations known	By safety board/special commission involved	As according to Annex 13, an investigation was performed by the country of registration of the aircraft, in this case France (BEA). Representatives from Brazil, USA, UK, German and Senegal were associated with the investigation. Some countries also sent observers since one or more of their citizens were among the victims.
	Public authorities	/
	By companies involved	An internal investigation at Air France was done by international experts to check for its safety organization and culture. The investigators found that the governance structure of Air France is “overly complex, leading to an overlap and blurring of the lines of responsibility”. A report was made, stating that the airline needs to change “the governance arrangements starting at the top”. Some conclusions of the report, were: • Absence of strong safety leadership at all levels of the management. • The flight data monitoring analysis was by the pilots more seen as a policeman to check them than as a proactive tool which could help them and prevent accidents. • It is allowed by pilots to deviate from procedures when necessary but some captains abuse this. Some conclusions are recommendations. In total 35 recommendations have been made. These are categorized later in the cube (not all 35 are made public so only the ones known are taken into this report). It was also stated that Air France will rapidly implement most recommendations. Afterwards the CEO of Air Franc announced a “reformed and heightened safety-culture”. Unfortunately this report was not made public.[16][17][18]
Dimensions of lessons learned: operations		
Content	Elements of the primary process to be improved	• Replacement of the pitot tubes by models which have higher reliability. • Crew’s mutual communication should be more clear in the future. The captain needs to clearly say to the pilots whose the relief captain in his absence. Among the pilots, actions taken should be communicated to each other. • Flight simulator sessions need to contain unreliable airspeed situations, which includes the change of normal to alternate law. Stall recovery and approach to stall situation should be implemented in the pilot’s training. • Improvement of the flight director after disconnection of automatic systems.

		• Improve certification of pitot static tubes.
Structure	Organizational structure	• The role of the co-pilot was reinforced and modified so that the cockpit communications will be better and more clear in the future at Air France. • Air France created a flight safety committee within the board of directors since this was recommended in the internal report. • A responsible person is appointed which is in charge of safety for the Air France Group. This was recommended in the internal report. • New flight handling chain is set up by Air France. The role of dispatcher will be extended so that operational support is given to the crew during all stages of the flight. This was recommended in the internal report. • A joint proposal committee is set up at Air France to have meetings between the pilot unions and the management. This was recommended in the internal report. • The FAA issued an advisory circular AC120-STALL which contains major information of interest (about preventing, recognizing and recovering from stall) for the operators. • The DGAC is recommended to review the organization of its oversight to improve its cohesion and effectiveness. • Air France implemented a LOSA program because this was recommended in the internal report. • An airworthiness directive was issued by EASA. The directive states not to reconnect the autopilot (when it was disconnected) until speed data is shown consistent with flight for 30 seconds. • Flight simulator training to practice unreliable airspeed situations was added to the pilot's training at Air France. • The training and way of working of augmented crews and relief captains were improved at Air France. • Airbus reviewed its "unreliable speed indication" procedure. • At Air France all the manufacturer's documentation was changed to English. • Air France created the "Innovation and Transformation management". • EASA should review the content of the check and training programs. Manual aircraft handling on stall approach and stall recovery exercises should be made mandatory. • To ensure better task-sharing extra criteria to access the role of relief captain have to be defined by EASA. • To ensure better task-sharing extra criteria to access the role of relief captain have to be defined by DGAC. • EASA has to make sure that exercises concerning all law reconfigurations are integrated into all type rating and recurrent training programs. • EASA has to make sure that the design specifications of the aircraft will be taken into the type rating and recurrent training programs. • Recurrent training programs have to be defined by EASA to make sure that, via practical exercises, the theoretical knowledge of the flight dynamics is well understood. • The requirements for pilot's initial, recurrent and type rating training should be reviewed by EASA to make sure crews can handle unexpected situations.

		• It should be ensured by EASA that operators reinforce their CRM (Crew Resource Management) training to ensure crews maintain their adequate automatic responses in case of unexpected situations. • Criteria have to defined by EASA for selection and recurrent training of instructors so that a high level of standardized instruction can be reached. • EASA should make sure that the effects of surprise are part of the training scenarios. • The DGAC should improve the relevance and quality of incident reports written by pilots and their distribution, specifically to the manufacturers. • The conditions of recruitment and training have to be ensured by the DGAC. In this way all inspectors possess the required skills to perform their functions. • Air France introduced the Pilot Flying/Pilot Monitoring program.
	Technological structure	• First Air France sped up the planned replacements of the original pitot probes C16195AA by the C16195BA. • After that and following an airworthiness directive Air France replaced all the Thales C16195BA probes by the Goodrich Probes, which are more reliable. • Maintenance intervals on the pitot tube were reduced. • It was also recommended by the investigation report that EASA should review the re-display and reconnection of the flight directors after their disappearance. Specifically a review of the conditions in which action of the crew to re-engage them is necessary. • EASA should do a review of the flight director display to check if it disappears or if the orders generated, certainly in case of a stall situation, are appropriate. • The European technical specification for the pitot and pitot-static tubes was updated. • New certification rules were proposed under the rulemaking task 25.058 "Large Aeroplane Certification Specifications in Supercooled Large Drop, Mixed phase, and Ice crystal Icing Conditions". This has to assure that flight instrument external probes are designed and installed in such way that they can operate normally in the new icing environment. • The airworthiness directive AD 2009-0195 was issued which prohibits the installation of the Thales C16195AA probes on the A330/A340 aircraft. • Using the knowledge about the composition of cloud-masses, certification criteria need to be improved by EASA. • The Brazilian and Senegalese authorities have to make ADS-C (Automatic Dependent Surveillance–Contract) and CPLDC (Controller- Pilot Data Link Communications) functions mandatory in the zones in question. • ICAO should request the involved states to speed up the operational implementation of air traffic control and communication systems. These provide a reliable and permanent link between the ground and the aircraft in areas were HF (High Frequency) is the only way of communication. • The conditions at which the stall warning activates when the speed is really low should be reviewed by EASA.

		• The conditions when a dedicated visual indication combined with an aural warning on the approach of stall should be mandatory, have to be determined by EASA. • EASA should, by modifying the regulations, ensure better fidelity of the simulators to reproduce realistic scenarios of abnormal situations.
Culture	Change of culture Change of behavior	• It was found that in many departments the safety culture was more event based than proactive. Every event should be analysed so that lessons could be learned on a more broad level. This was recommended in the internal report. • Team building exercises are advised to reflect the trust and cooperation to every individual employee. This was recommended in the internal report. • Redefine the relationship between the management and the pilot unions. This was recommended in the internal report. • Operational and human factors analysis of in-service events has to become mandatory so that measures can be taken. Like this EASA should improve the feedback from the operators. • Some pilots treat the maintenance and cabin crew in a very arrogant and autocratic manner. This is very bad for the morale, discipline and the crew resource management. Air France should, because of that, review its selection and training program for pilots to get a more team-oriented pilot workforce. This was recommended in the internal report.
Context	Supporting conditions Development of knowledge: managerial, scientific and technological research and innovative practice aimed at finding solutions or allow solution for safer system	/ • The relevance of a dedicated warning to the crew to make sure they understand the situation should be studied by EASA. • EASA monitored the Airbus test activity in the icing facilities and flight tests. In this way data was retrieved concerning the behavior of pitot probes in ice crystal environments. • A group was formed containing manufacturers, operators, pilot associations and authorities to make the “Aeroplane upset recovery training aid” guide. This guide’s purpose is to optimize both the academic and practical training on upset recovery issues. The guide gets regularly reviewed. • To further improve the knowledge of high altitude icing conditions, EASA contributes to international research projects to optimize certification in the future. • EASA needs to determine very accurate the composition of cloud-masses at high altitude. • Test pilots of EASA re-evaluated multiple pitot probe blockages in an Airbus simulator. With the data obtained from this test the certification concerning the severity of the condition can be improved. • It was recommended by the report that the FAA and EASA should evaluate the relevance of an angle of attack indicator which is directly accessible to the pilots.

Dimensions of lessons learned: system levels involved		
Micro	Solutions at the company level, subcontractors at company level	• First Air France sped up the planned replacements of the original pitot probes C16195AA by the C16195BA. • After that and following an airworthiness directive Air France replaced all the Thales C16195BA probes by the Goodrich Probes, which are more reliable. • Flight simulator training to practice unreliable airspeed situations was added to the pilot's training at Air France. • The training and way of working of augmented crews and relief captains were improved at Air France. • At Air France all the manufacturer's documentation was changed to English. • Air France created the "Innovation and Transformation management". • The role of the co-pilot was reinforced and modified so that the cockpit communications will be better and more clear in the future at Air France. • Airbus reviewed its "unreliable speed indication" procedure. • Air France created a flight safety committee within the board of directors after this was recommended in the internal report. • A responsible person is appointed which is in charge of safety for the Air France Group. This was recommended in the internal report. • New flight handling chain is set up by Air France. The role of dispatcher will be extended so that operational support is given to the crew during all stages of the flight. This was recommended in the internal report. • A joint proposal committee is set up at Air France to have meetings between the pilot unions and the management. This was recommended in the internal report. • Some pilots treat the maintenance and cabin crew in a very arrogant and autocratic manner. This is very bad for the morale, discipline and the crew resource management. Air France should, because of that, review its selection and training program for pilots to get a more team-oriented pilot workforce. This was recommended in the internal report. • Team building exercises are advised to reflect the trust and cooperation to every individual employee. This was recommended in the internal report. • Redefine the relationship between the management and the pilot unions. This was recommended in the internal report. • Air France implemented a LOSA program. This was recommended in the internal report. • It was found that in many departments the safety culture was more event based than proactive. Every event should be analysed so that lessons could be learned on a more broad level. This was recommended in the internal report. • An airworthiness directive was issued by EASA. The directive states not to reconnect the autopilot (when it was disconnected) until speed data is shown consistent with flight for 30 seconds. This to avoid any unsafe condition. • Air France introduced the Pilot Flying/Pilot Monitoring program.

	Timeline of implementation of solution months/years	Air France: • The replacement of the original C16195AA pitot tube by the C16195BA started on 27 April 2009. Due to the accident the replacement of all these tubes on the A330/A340 was accelerated and it was finished by June 11th 2009. • Finally all the C16195BA probes were replaced by the Goodrich probes. For position one and three this happened from 4 to 7 august 2009. For probe 2 this happened from 18 January until 8 February 2010. • Regulations for relieving the captain were modified in March 2010. • The extra flight simulator training was added to the training program in the summer of 2009. • The new flight handling chain and new role for the dispatcher was implemented in the summer of 2011. It would take two-three years to implement it in all Air France flights. • The joint proposal committee was implemented soon after the accident • Until March 2011 LOSA observations were done. • The flight safety committee within the board of directors was implemented soon after the publication of the internal report (somewhere during the end of 2010/begin of 2011). Together with this, a person was appointed in charge of safety for the Air France Group. • The B777 division was the first to change its documentation into English at Air France in October 2012. • The Pilot Flying/Pilot Monitoring program first became active on the A380 at Air France in 2012. Airbus: a Flight Operations Telex was issued on the 9th of September 2009. This telex recommended that the next recurrent training course should include a session in the simulator at high altitude in normal and alternate law. In this session manual aeroplane handling and carrying out the unreliable speed indication speed procedure should be checked. The autopilot reconnection airworthiness directive was issued in December 2010.
Meso	Actions of safety authorities, what actions? Branch involvement?	• The DGAC is recommended to review the organization of its oversight to improve its cohesion and effectiveness. • To ensure better task-sharing extra criteria to access the role of relief captain have to be defined by DGAC. • The DGAC should improve the relevance and quality of incident reports written by pilots and their distribution, specifically to the manufacturers. • The conditions of recruitment and training have to be ensured by the DGAC. In this way all inspectors possess the required skills to perform their functions. • A group was formed containing manufacturers, operators, pilot associations and authorities to make the “Aeroplane upset recovery training aid” guide. This guide’s purpose is to optimize both the academic and practical training on upset recovery issues. The guide gets regularly reviewed. • The airworthiness directive AD 2009-0195 was issued which prohibits the installation of the Thales C16195AA probes on the A330/A340 aircraft.

	Timeline of implementation of solution months/years	• The Brazilian and Senegalese authorities have to make ADS-C (Automatic Dependent Surveillance–Contract) and CPLDC (Controller- Pilot Data Link Communications) functions mandatory in the zones in question. • ICAO should request the involved states to speed up the operational implementation of air traffic control and communication systems. These provide a reliable and permanent link between the ground and the aircraft in areas were HF (High Frequency) is the only way of communication. • An advisory circular AC120-STALL was issued by the FAA which contains major information of interest (about preventing, recognizing and recovering from stall) for the operators. • The European technical specification for the pitot and pitot-static tubes was updated. • The update describing the advancement of the recommendations by the DGAC covered October 2012 until August 2013[19]. • The prohibition of the pitot tubes was issued immediately after the crash. • The update for the European technical specification for the pitot and pitot-static tubes was launched on October 14th 2009.
Macro	EU-level development, directive or standard being changed or research program being started or …	EASA: • Operational and human factors analysis of in-service events has to become mandatory so that measures can be taken. Like this EASA should improve the feedback from the operators. • EASA has to make sure that exercises concerning all law reconfigurations are integrated into all type rating and recurrent training programs. • EASA has to make sure that the design specifications of the aircraft will be taken into the type rating and recurrent training programs. • EASA should review the content of the check and training programs. Manual aircraft handling on stall approach and stall recovery exercises should be made mandatory. • To ensure better task-sharing extra criteria to access the role of relief captain have to be defined by EASA. • Recurrent training programs have to be defined by EASA to make sure that, via practical exercises, the theoretical knowledge of the flight dynamics is well understood. • The requirements for pilot’s initial, recurrent and type rating training should be reviewed by EASA to make sure crews can handle unexpected situations. • It should be ensured by EASA that operators reinforce their CRM (Crew Resource Management) training to make sure crews maintain their adequate automatic responses in case of unexpected situations. • Criteria have to defined by EASA for selection and recurrent training of instructors so that a high level of standardized instruction can be reached. • EASA should make sure that the effects of surprise are part of the training scenarios. • EASA should, by modifying the regulations, ensure better fidelity of the simulators to reproduce realistic scenarios of abnormal situations.

		• Using the knowledge about the composition of cloud-masses, certification criteria need to be improved by EASA. • EASA monitored the Airbus test activity in the icing facilities and flight tests. In this way data was retrieved concerning the behavior of pitot probes in ice crystal environments. • New certification rules were proposed under the rulemaking task 25.058 “Large Aeroplane Certification Specifications in Supercooled Large Drop, Mixed phase, and Ice crystal Icing Conditions”. This has to assure that flight instrument external probes are designed and installed in such way that they can operate normally in the new icing environment. • To further improve the knowledge of high altitude icing conditions, EASA contributes to international research projects to optimize certification in the future. • The conditions at which the stall warning activates when the speed is really low should be reviewed by EASA. • The relevance of a dedicated warning to the crew to make sure they understand the situation, should be studied by EASA. • The conditions when a dedicated visual indication combined with an aural warning on the approach of stall should be mandatory, have to be determined by EASA. • It was also recommended by the investigation report that EASA should review the re-display and reconnection of the flight directors after their disappearance. Specifically a review of the conditions in which action of the crew to re-engage them is necessary. • EASA should do a review of the flight director display to check if it disappears or if the orders generated, certainly in case of a stall situation, are appropriate. • EASA needs to determine very accurate the composition of cloud-masses at high altitude. • Test pilots of EASA re-evaluated multiple pitot probe blockages in an Airbus simulator. With the data obtained from this test the certification concerning the severity of the condition can be improved. It was recommended by the investigation report that the FAA and EASA should evaluate the use of a directly accessible angle of attack indicator. Using this indicator a stall situation could be quickly recognized.
	Timeline of implementation of solution months/years	The new certification rules were proposed in 2010 and published on 21 March 2011.
Dimensions lessons learned: depth of learning		
Optimize		• The DGAC is recommended to review the organization of its oversight to improve its cohesion and effectiveness. • The role of the co-pilot was reinforced and modified so that the cockpit communications will be better and more clear in the future at Air France.

		• An airworthiness directive was issued by EASA. The directive states not to reconnect the autopilot (when it was disconnected) until speed data is shown consistent with flight for 30 seconds. • Airbus reviewed its “unreliable speed indication” procedure. • It was found that in many departments of Air France the safety culture was more event based than proactive. Every event should be analysed so that lessons could be learned on a more broad level. This was recommended in the internal report. • Some pilots treat the maintenance and cabin crew in a very arrogant and autocratic manner. This is very bad for the morale, discipline and the crew resource management. Air France should, because of that, review its selection and training program for pilots to get a more team-oriented pilot workforce. This was recommended in the internal report. • Maintenance intervals on the pitot tubes were reduced. • Redefine the relationship between the management and the pilot unions. This was recommended in the internal report. • The European technical specification for the pitot and pitot-static tubes was updated. • New certification rules were proposed under the rulemaking task 25.058 “Large Aeroplane Certification Specifications in Supercooled Large Drop, Mixed phase, and Ice crystal Icing Conditions”. This has to assure that flight instrument external probes are designed and installed in such way that they can operate normally in the new icing environment. • The airworthiness directive AD 2009-0195 was issued which prohibits the installation of the Thales C16195AA probes on the A330/A340 aircraft. • First Air France sped up the planned replacements of the original pitot probes C16195AA by the C16195BA. • After that and following an airworthiness directive Air France replaced all the Thales C16195BA probes by the Goodrich Probes, which are more reliable. • The FAA issued an advisory circular AC120-STALL which contained major information of interest (about preventing, recognizing and recovering from stall) for the operators. • New flight handling chain is set up by Air France. The role of dispatcher will be extended so that operational support is given to the crew during all stages of the flight. This was recommended in the internal report. • The training and way of working of augmented crews and relief captains were improved at Air France. • At Air France all the manufacturer’s documentation was changed to English. • To further improve the knowledge of high altitude icing conditions, EASA contributes to international research projects to optimize certification in the future. • EASA monitored the Airbus test activity in the icing facilities and flight tests. In this way data was retrieved concerning the behavior of pitot probes in ice crystal environments. • The requirements for pilot’s initial, recurrent and type rating training should be reviewed by EASA to make sure crews can handle unexpected situations.

		• It should be ensured by EASA that operators reinforce their CRM (Crew Resource Management) training to make sure crews maintain their adequate automatic responses in case of unexpected situations. • EASA should, by modifying the regulations, ensure better fidelity of the simulators to reproduce realistic scenarios of abnormal situations. • The DGAC should improve the relevance and quality of incident reports written by pilots and their distribution, specifically to the manufacturers. • It was also recommended by the investigation report that EASA should review the re-display and reconnection of the flight directors after their disappearance. Specifically a review of the conditions in which action of the crew to re-engage them is necessary. • EASA should do a review of the flight director display to check if it disappears or if the orders generated, certainly in case of a stall situation, are appropriate. • Using the knowledge about the composition of cloud-masses, certification criteria need to be improved by EASA. • ICAO should request the involved states to speed up the operational implementation of air traffic control and communication systems. These provide a reliable and permanent link between the ground and the aircraft in areas were HF (High Frequency) is the only way of communication. • The conditions at which the stall warning activates when the speed is really low should be reviewed by EASA. • Test pilots of EASA re-evaluated multiple pitot probe blockages in an Airbus simulator. With the data obtained from this test the certification concerning the severity of the condition can be improved. • EASA needs to determine very accurate the composition of cloud-masses at high altitude. • A group was formed containing manufacturers, operators, pilot associations and authorities to make the "Aeroplane upset recovery training aid" guide. This guide's purpose is to optimize both the academic and practical training on upset recovery issues. The guide gets regularly reviewed. • Criteria have to defined by EASA for selection and recurrent training of instructors so that a high level of standardized instruction can be reached. • The conditions of recruitment and training have to be ensured by the DGAC. In this way all inspectors possess the required skills to perform their functions.
Adapt		• Air France created a flight safety committee within the board of directors after this was recommended in the internal report. • A responsible person is appointed which is in charge of safety for the Air France Group. This was recommended in the internal report. • Team building exercises are advised to reflect the trust and cooperation to every individual employee. This was recommended in the internal report. • Flight simulator training to practice unreliable airspeed situations was added to the pilot's training at Air France. • Air France implemented a LOSA program after this was recommended in the internal report.

		• EASA has to make sure that exercises concerning all law reconfigurations are integrated into all type rating and recurrent training programs. • EASA has to make sure that the design specifications of the aircraft will be taken into the type rating and recurrent training programs. • Recurrent training programs have to be defined by EASA to make sure that, via practical exercises, the theoretical knowledge of the flight dynamics is well understood. • EASA should make sure that the effects of surprise are part of the training scenarios. • Air France introduced the Pilot Flying/Pilot Monitoring program. • The Brazilian and Senegalese authorities have to make ADS-C (Automatic Dependent Surveillance–Contract) and CPLDC (Controller- Pilot Data Link Communications) functions mandatory in the zones in question. • Air France created the "Innovation and Transformation management". • A joint proposal committee is set up at Air France to have meetings between the pilot unions and the management. This was recommended in the internal report. • The conditions when a dedicated visual indication combined with an aural warning on the approach of stall should be mandatory, have to be determined by EASA. • The relevance of a dedicated warning to the crew to make sure they understand the situation, should be studied by EASA. • To ensure better task-sharing extra criteria to access the role of relief captain have to be defined by EASA. • To ensure better task-sharing extra criteria to access the role of relief captain have to be defined by DGAC. • Operational and human factors analysis of in-service events has to become mandatory so that measures can be taken. Like this EASA should improve the feedback from the operators. • EASA should review the content of the check and training programs. Manual aircraft handling on stall approach and stall recovery exercises should be made mandatory.
Innovate		• Until now the angle of attack was not directly accessible for pilots. Therefore the investigation report recommends the FAA and EASA to evaluate the relevance of a direct accessible angle of attack indicator.
Impact		
Changes identified	What really changed	• First Air France sped up the planned replacements of the original pitot probes C16195AA by the C16195BA. • After that and following an airworthiness directive Air France replaced all the Thales C16195BA probes by the Goodrich Probes, which are more reliable. • Flight simulator training to practice unreliable airspeed situations was added to the pilot's training at Air France. • The training and way of working of augmented crews and relief captains were improved at Air France. • At Air France all the manufacturer's documentation was changed to English. • Air France created the "Innovation and Transformation management". • The role of the co-pilot was reinforced and modified so that the communications in the cockpit in the future will be better and more clear at Air France.

		• Airbus reviewed its “unreliable speed indication” procedure. • Air France created a flight safety committee within the board of directors, after this was recommended in the internal report. • A responsible person is appointed which is in charge of safety for the Air France Group. This was recommended in the internal report. • New flight handling chain is set up by Air France. The role of dispatcher will be extended so that operational support is given to the crew during all stages of the flight. This was recommended in the internal report. • A joint proposal committee is set up at Air France to have meetings between the pilot unions and the management. This was recommended in the internal report. • Air France implemented a LOSA program after this was recommended in the internal report. • For the autopilot reconnection, airworthiness directive 2010-0271 was issued by EASA. The directive states not to reconnect the autopilot (when it was disconnected) until speed data is shown consistent with flight for 30 seconds. This to avoid any unsafe condition. • Air France introduced the Pilot Flying/Pilot Monitoring program. • The maintenance intervals for the pitot tube were reduced. • The airworthiness directive AD 2009-0195 was issued, which prohibits the installation of the Thales C16195AA probes on the A330/A340 aircraft. • A group was formed containing manufacturers, operators, pilot associations and authorities to make the “Aeroplane upset recovery training aid” guide. This guide’s purpose is to optimize both the academic and practical training on upset recovery issues. The guide gets regularly reviewed. • An advisory circular AC120-STALL was issued by the FAA which contains major information of interest (about preventing, recognizing and recovering from stall) for the operators. • The European technical specification for the pitot and pitot-static tubes was updated. A whole list of recommendations was issued in the investigation report. Several reports were published about their follow-up. One of them was published, in French, by the DGAC[19][20] and concerned the follow-up of DGAC: • DGAC defined extra criteria to access the role of relief captain. • DGAC reviewed its own organization. • DGAC improved the relevance, quality and distribution of incidents reports. • EASA and ICAO are still working on the possibility to make it mandatory to activate the emergency locator transmitter (ELT) when an emergency situation occurs. They are also still working on the possibility to transmit data when emergency situation happens. With the crash of Malaysian Airlines flight 370, these processes are sped up. This recommendation is closed for the DGAC.

		Other reports were the ones of the annual safety recommendations review of 2011[60], 2012[61] and 2013[62] by EASA. If a recommendation is closed it can have three statuses, namely “agreement”, “partial agreement” or “disagreement”. The first two mean a concluding action is decided. Disagreement means no concluding action will be run. These reports state: • The BEA recommends that EASA and ICAO extend as rapidly as possible to 90 days the regulatory transmission time for ULB’s installed on flight recorders on airplanes performing public transport flights over maritime areas: closed agreement; will be done by January 1st 2018[62]. • The BEA recommends that EASA in coordination with the other regulatory authorities, based on the results obtained, modify the certification criteria: closed-agreement[62]. • The BEA recommends that EASA and ICAO make it mandatory, as rapidly as possible, for airplanes performing public transport flights over maritime areas to be equipped with an additional ULB capable of transmitting on a frequency (for example between 8.5 kHz and 9.5 kHz) and for a duration adapted to the pre-localisation of wreckage (2018): closed-agreement. will be done by January 1st 2018[62]. • The BEA recommends that EASA undertake studies to determine with appropriate precision the composition of cloud masses at high altitude: closed-agreement[61]. • The BEA recommends that EASA review the requirements for initial, recurrent and type rating training for pilots in order to develop and maintain a capacity to manage crew resources when faced with the surprise generated by unexpected situations: closed-agreement, it is taken under consideration[61]. • The BEA recommends that EASA define criteria for selection and recurrent training among instructors that would allow a high and standardized level of instruction to be reached: closed-agreement, it is taken under consideration[61]. • The BEA recommends that EASA review the content of check and training programmes and make mandatory, in particular, the setting up of specific and regular exercises dedicated to manual aircraft handling of approach to stall and stall recovery, including at high altitude: closed-partial agreement, under review without mentioning high altitude[62]. • The BEA recommends that EASA define additional criteria for access to the role of relief Captain so as to ensure better task-sharing in case of relief crews: closed-partial agreement[62]. • The BEA recommends that EASA evaluate the relevance of requiring the presence of an angle of attack indicator directly accessible to pilots on board airplanes: closed-partial agreement, direct angle of attack indicator will not be implemented[62]. • The BEA recommends that EASA ensure the integration, in type rating and recurrent training programmes, of exercises that take into account all of the reconfiguration laws. The objective sought is to make its recognition and understanding easier for crews especially when dealing with the level of protection available and the possible differences in handling characteristics, including at the limits of the flight envelope: closed-partial agreement, under consideration[62].

		• The BEA recommends that EASA ensure that type rating and recurrent training programmes take into account the specificities of the aircraft for which they are designed: closed-partial agreement[62]. • The BEA recommends that EASA define recurrent training programme requirements to make sure, through practical exercises, that the theoretical knowledge, particularly on flight mechanics, is well understood: closed-partial agreement[62]. • The BEA recommends that EASA ensure the introduction into the training scenarios of the effects of surprise in order to train pilots to face these phenomena and to work in situations with a highly charged emotional factor: closed-partial agreement[62]. • The BEA recommends that EASA ensure that operators reinforce CRM training to enable acquisition and maintenance of adequate behavioural automatic responses in unexpected and unusual situations with a highly charged emotional factor: closed-partial agreement[61]. • The BEA recommends that EASA and ICAO study the possibility of making it mandatory for airplanes performing public transport flights to regularly transmit basic flight parameters (for example position, altitude, speed, heading): open[61]. • The BEA recommends that EASA and ICAO make mandatory as quickly as possible, for airplanes making public transport flights with passengers over maritime or remote areas, triggering of data transmission to facilitate localisation as soon as an emergency situation is detected on board: open[61]. • The BEA recommends that EASA and ICAO study the possibility of making mandatory, for airplanes making public transport flights with passengers over maritime or remote areas, the activation of the emergency locator transmitter (ELT), as soon as an emergency situation is detected on board: open[61]. • The BEA recommends that EASA modify the basis of the regulations in order to ensure better fidelity for simulators in reproducing realistic scenarios of abnormal situation: open[61]. • The BEA recommends that EASA require a review of the re-display and reconnection logic of the flight directors after their disappearance, in particular to review the conditions in which an action by the crew would be necessary to re-engage them: open[61]. • The BEA recommends that EASA require a review of the functional or display logic of the flight director so that it disappears or presents appropriate orders when the stall warning is triggered: open[61]. • The BEA recommends that EASA determine the conditions in which, on approach to stall, the presence of a dedicated visual indications, combined with an aural warning should be made mandatory: open[61]. • The BEA recommends that EASA require a review of the conditions for the functioning of the stall warning in flight when speed measurements are very low: open[61]. • The BEA recommends that EASA improve the feedback process by making mandatory the operational and human factors analysis of in-service events in order to improve procedures and the content of training programmes: open[61].

		• The BEA recommends that EASA and the FAA make mandatory the recording: of the position of the flight director crossbars and of the parameters relating to the conduct of the flight displayed on the right side, in addition to those displayed on the left side: open[60]. • The BEA recommends that EASA and the FAA evaluate the relevance of making mandatory the recording of the air data and inertial parameters of all of the sources used by the systems: open[60].
Change/learning agent	Who/what takes care for follow-up	All companies using the A330. French ministry of civil aviation DGAC. It keeps track of the advancement of all the recommendations given in the investigation report [19][20]. Airbus. EASA FAA
	Who/what keeps memory/knowledge alive	All companies using the A330. DGAC Airbus. EASA FAA
	Who/what keeps monitors effectiveness	No information was found on that.
Change timeline	Can phases be identified in their implementation process are implemented measures lost in time	Some actions (like the changes of pitot tubes on the A330 and A340 aircrafts of Air France) were taken immediately after the crash. After the official accident report came out recommendations were analysed, to decide if they are implemented or not. How long it takes to take a decision depends from the recommendation. It is also possible that it takes some time to implement it. No information is found about implemented measures lost in time.
Change of investigation process		This was a very difficult investigation since it took a lot effort to locate pieces of the wreckage. It also took a very long time before the black boxes were found. Due to that some recommendations were issued to make future investigations more easy: • EASA and ICAO should investigate the possibility to make the activation of an emergency locator transmitter (ELT), when an emergency situation occurs, mandatory. Data transmission should also be made mandatory when an emergency situation happens. • It was suggested that the first airplanes to arrive on a crash site would drop drift measuring buoys. In this way it would be more easy to locate the crash site. • EASA and ICAO should extend the transmission time of the underwater locator beacon (ULB) to 90 days. They should also equip aircrafts with an extra ULB capable of transmitting on a frequency and for a duration adapted to the pre-localization of the wreckage.

		• EASA and ICAO should investigate the option to transmit regularly basic flight parameters • Equip aircraft with deployable recorders of the Eurocae ED-112 type. It was also recommended by the investigation report to make the use of an image recorder mandatory. In this way it is possible for the investigators to check the whole instrument panel at the time of the crash. Recording air data and inertial parameters of all of the sources used by the systems should be also be investigated. This includes the position of the flight director's crossbars and the flight parameters on the right side in addition to those shown on the left side. These recommendations were not taken into the cube since it are not recommendations to prevent the accident. It are recommendations to improve SAR and the investigation process. If they would be taken into the cube a wrong image could be created.
Evaluation of accident and follow-up		
	Conclusions and comment with respect to/ specific experiences/ observations/ discussion by ESReDA group Are changes sustained	See paragraph 4.1.3 and chapter 5. No information is found on that. It is assumed that until now all the actions taken are still in use.
References		
Communication of findings, recommendations	Reports government, safety board, investigation commission Report inspectorate/third party Company reports	Official investigation report[21] Interim report 1[22], 2 [23]and 3[24] Recommendation follow-up DGAC[19] Recommendation follow-up DSAC [20] Annual Safety Recommendations Review 2011 EASA[60] Annual Safety Recommendations Review 2012 EASA[61] Annual Safety Recommendations Review 2013 EASA[62] / /
Other transfer of knowledge by parties involved,	Articles in journals, magazines, internet Courses, training	See section References: [11][12][13][14][15][16][17][18]

professional organizations, scientists etc.	Relevant links	

Comments about the ESReDA Cube method

In this official report, recommendations were also made concerning the SAR. They are not taken into the analysis since they are of no influence on the accident itself. Some difficulties were encountered when applying the method:

- The questions about solutions, actions taken or lessons learned are not clear. It is not mentioned if it is meant to summarize everything (also the recommendations that are not in use yet) or only the changes implemented until now. In this thesis everything is put in the cube.
- The difference between adapt and optimize is in some cases very small, which makes it really difficult to categorize lessons precisely. The rules which are used here are as follows. If the concept already exists and it is changed so that its work is improved it is put under the category optimize. If something new, extra is added to the concept which changes the content but the basic working method is still the same, it is put under adapt. If the concept's basic principle is changed to something which was never used before, then it is put under innovate. These rules are unfortunately not water tight, discussion is possible.
- The theory in the ESReDA Cube method's paper states that the meso level includes the holding branch of the industry and the macro level includes the government agencies. In the template on the other hand, it is asked at the meso level what actions the safety authorities take. According to the theory of the paper this should be put at the macro level. Not, like in the template, at the meso level since a safety authority is a government agency. In this thesis it is solved by putting everything of the local safety authorities under meso and everything from the European/American safety authority under macro.
- For the aviation sector it is seen that the meso level is hollowed out by the macro level concerning regulations and actions of safety authorities (except for a few items). In aviation the ability to take actions is moved from the local safety authorities at the meso level to the EASA/FAA at the macro level. Sometimes a recommendation is set specific for the safety authority of the country. However, most actions and recommendations on the meso level are issued for/taken by the aviation industry.
- At the meso level actions of safety authorities have to be categorized. At the macro level actions by the EU have to be categorized. For Europe this is easy to divide. If an action is taken by EASA it is put under the macro level. If it taken by a safety authority of a country of the EU it is put under meso. In the United States this more difficult, since it is one country. However, the FAA can regulate every aspect of the American civil aviation which gives it an equal status as EASA. Conclusion: FAA can be put both under meso and macro. In this thesis it is chosen to categorize it under macro because of the equal status.
- At the operation level, specifically in the aspect of content, the measures, which could prevent the accident or delete the system's weak parts, are suggested. These can later also be found back in the aspects of structure, culture or context as a recommendation or action. Because of this some items are counted double when putting everything in a cube. Ones as a recommendation or action and ones as a possible measure to prevent the accident. It is better to leave the aspect of content open when items are plotted in the cube. Otherwise it can give a non-correct image of the number of recommendations/actions taken, which is what this cube focuses on. In this thesis the aspect of content will be left open when plotting everything in a cube form.
- When categorizing the items at the culture part of the operation level also some rules have to be set. Items which under change in behaviour are specifically about personal, individual behaviour, including the behaviour of an individual towards another individual. Behaviour of one group towards another group is part of change of culture.

Some questions from the template are also difficult to answer with only public information:

- It is not made public when some decisions taken (which makes it difficult to answer the timeline part).

- Some aspects are just not made available for the public, like in this case the internal investigation report of Air France.

Appendix F

Colgan Air, Continental Connection flight 3407

Item	Explanation	
Description (system involved)		
Description accident	Short description	On February 12th 2009 a Bombardier DHC-8-400 from Colgan Air, operating as Continental Connection flight 3407, crashed in New York, five nautical miles northeast of the arrival airport. The aircraft took off at Newark Liberty International Airport and was on route to Buffalo Niagara International Airport. All 49 people onboard were killed as well as one person on the ground.
	What has happened (description, pictures etc.) What agents (the damaging energy source e.g. nuclear hazard)	During the approach the stick shaker was activated. The captain responded inappropriate to this, causing an aerodynamic stall. The aircraft never recovered from this stall and crashed.
	How has it happened, what were the circumstances	During approach, to reach the correct speed for landing, the captain reduced speed. The gear was lowered and the flaps were extended. Suddenly the stick shaker was activated and the autopilot was disengaged. The steer column was moved aft by the captain, he overpowered the stick pusher. Next the aircraft stalled and crashed.
	Why did it happen? Direct causes	The stick shaker was activated on which the captain reacted by pulling the steer column. By doing this he overpowered the stick pusher which was activated. In this way the aircraft entered an aerodynamic stall from which it did not recover

		and the aircraft crashed. If the captain just let the stick pusher work, the aircraft might have gone back to normal stable flight, avoiding the crash.
	Why did it happen? Root causes	The aircraft was not flying at stall speed yet on the moment the stick shaker was activated. The reason that it activated was because the ref speeds switch was in the INCR (increase) position. The ref speeds switch has two positions INCR or OFF. This switch is put on INCR when the aircraft is going through icing conditions. In icing conditions it is possible that the aircraft stalls at a lower AOA and that the stall speed of the aircraft increases. Due to this switch the stick shaker is activated earlier than normal, at a lower AOA and above normal stall speed to anticipate with the icing conditions. The fact that the stick shaker would be activated earlier was not described in the procedures of Colgan Air. The use of the ref speeds switch was not taken into the pilot training at Colgan Air. The stick pusher, which has to prevent stall, only activates at the prescribed angle of attack. This angle is not changed when the ref speeds switch is on INCR. Before the stick shaker was activated a visual warning, namely a low speed cue (red and black vertical bars on the speed indicator) appeared for the pilots which they did not see.
	Other root causes	Both of the pilots did not have a lot of sleep before the flight. The first officer came from her home in Seattle. The captain just completed a two day trip sequence. During the entire flight the pilots were often talking about non-flight related flight subjects, so they did not keep to the sterile cockpit procedures.
	When did it happen? Timeline of main events	The flight was scheduled to leave Newark at 19:10 on the 12th of February. Due to delay the aircraft finally took off at 21:18. At 22:16:21 a sound similar to the stick shaker was recorded by the CVR. At 22:16:27, the control column was moved aft. Next at 22:16:52 the captain said “we’re down” and at 22:16:54 the CVR stopped recording. The captain flew to Newark on the 9th of February, coming from his home in Florida. The day before the accident at 15:44, he completed a 2-day trip sequence. He spend the night in the crew room at Newark. The first officer left her home town near Seattle on the 11th of February at 19:51 and arrived at Newark on the 12th of February at 06:23 in the morning. The first two flights which were scheduled for this crew on that day were cancelled.
	Historical events	In 1994 the United Express flight 6291 British Aerospace Jetstream 41 crashed due to an inappropriate reaction of the pilot to the stall warning. The aircraft stalled and crashed[25]. In 1995 a Boeing 757 of American Airlines, flight 956, crashed into a mountain after bad situational awareness of the pilots[26]. In 2004 a Bombardier CRJ-200 of Pinnacle Airlines crashed after irresponsible pilot behavior during a ferry flight (flight 3701) to reach flight level 410[27]. In 2004 a British Aerospace Jetstream 32 of Corporate Airlines, flight 5966, crashed due to a pilot error. One of the contributing factors to the accident was the lack of professional attitude in the cockpit by the pilots. Fatigue would also have contributed to their degraded performance[28].

		In 2003 a DC-10 of FedEx Express, flight 647, crashed during the landing. One of the contributing factors was the absence of overview of the first officer by the captain[29]. In 1994 a Jetstream 32 of Flagship Airlines, flight 3379, crashed while it was executing a missed approach due to a pilot error. One of the crash's causes was the airline company's failure to document, identify, remedy and monitor all deficiencies in the performance and training of the pilot[30]. In 1995 Tower Air flight 41 veered of the runway after the captain failed to reject takeoff. One of the contributing factors for this accident was the lack of overview by the air carrier[31]. In 1997, an Embraer 12 RT Brasilia of Comair, flight 3272, crashed upon approach. A contributing factor for the crash was the decision of the pilots to work in icing conditions near the end of the flight envelop with retracted flaps. Comair itself did not set any minimum airspeed values to its pilots for icing conditions and for flap configurations[32]. In 1994 an ATR-72 of American Eagle, flight 4184 crashed after flying in icing conditions[33]. The contributing factor of these crashes also contributed to the crash of Colgan Air flight 3407. Because of these crashes several recommendations were done by the NTSB to the FAA(see further "contextual aspects e.g. industrial safety culture").
	Place Context of event and system (general environment, topography, weather)	The aircraft crashed on a single family house in Clarence center some five nautical miles east-northeast of Buffalo airport. The weather at that moment indicated a wind at 240° of 15 knots with gusts reaching 22 knots. The visibility was about three miles with light snow and mist. The temperature reached 1°C and the dew point was -1°C. At the day of the accident many pilots reported icing conditions.
	Sector involved	Aviation industry and regulation organizations.
Type of event	Content aspects: primary activity, operational aspect involved	The flight was operated as flight 3407 of Continental Connection. The flight was one of the seven flights to Buffalo that day of Continental.
	General or macro description of plant or system involved	The flight was operated by Colgan Air, an American certified regional airlines and part of the Pinnacle Airlines Corp. This flight was performed for Continental Connection. This was the name of the brand several regional airlines used to perform flights for Continental Airlines. Colgan performed about 350 flights a day. In April 2012 the mother company of Colgan Air, Pinnacle Airlines Corporation, filed for bankruptcy protection under chapter 11. In September 2012 Colgan Air ceased to exist and its activities were taken over by other subsidiaries of the mother company. Colgan Air had 49 Aircraft of which 15 were Bombardiers Dash 8[34] [35].
	Local or micro description of	The Bombardier Dash 8 is a medium-range, T-tail, high wing, twin turboprop engine aircraft. It is certified for flying in icing conditions. It can carry 74 passengers and 4 crewmembers. This Bombardier Dash 8 was manufactured in April

	process/system involved in accident	2008. At the time of the accident this aircraft had flown 1,819 hours and done 1,809 flight cycles. Colgan began to use Dash 8 aircrafts in February 2008 and since July 2008 they provided training for this aircraft themself.
	Structural aspects: e.g. relevant organizational structures, infrastructure, buildings etc.	As mentioned earlier, several recommendations concerning contributing factors of this accident were already issued in the past by the NTSB to the FAA. These recommendations were put into flight standards information bulletins, were still being developed or were impossible to do according to the FAA. The recommendations included better stall warning recognition and recovering techniques (put into a bulletin), improve the fidelity of the simulators (FAA stated it was not possible) and develop a document which improves training concerning familiarity with the stick pusher system (was developed by the FAA). Also several recommendations were already made concerning remedial pilot training and additional oversight. Programs which allow extra voluntary oversight were recommended by the FAA to the operators. Other recommendations which have already been issued concern the check of pilot records (open), air carrier oversight (closed), air carrier safety (closed), airplane icing (closed), weather information (closed) and low airspeed alerting system (open). Some recommendations were already closed by the NTSB, but some were still open at the time of the accident.
	Cultural aspect: personal safety culture company safety culture	• The pilots did not hold to the sterile cockpit procedure. • The captain spend the night at the crew room, which is not allowed according to company policy. Both the pilots were also not well rested before the flight. • The company allowed to call in if the pilot could not do a flight due to fatigue. Between May 2008 and February 2009 about a dozen pilot called in. There is a witness pilot which states that he called in twice and that there were no repercussions about it. • At the time of the accident there was no information provided to the pilots about fatigue prevention. • The company had several safety programs at the time of the crash. These were the aviation safety action program (ASAP), the line operations safety audit (LOSA) program and the flight operational quality assurance (FOQA) program which was under development. • Every quarter a safety council meeting was held at the company's headquarter with the purpose to increase safety awareness, facilitate group discussions, develop positive outcomes and discuss unresolved issues. Next to this, safety personnel attended the company's daily operations meetings. • Two safety manuals were in use at Colgan at the time of the crash. One was the Employee Manual, which stated "Safety-Our primary goal is to provide 100% safe transportation for our customers. Safety is the first priority of Colgan. No other value or goal has priority over safety". The other manual is the Flight Operations Policies and Procedures Manual, which stated "In all aspects of Colgan's operation safety shall be given primary consideration. Each and every employee is responsible for ensuring safety in his own daily operations and shall promote safety among his fellow employees". In 2008 the company president travelled around the company to present the "safety road show" to the personnel. In this show ASAP and LOSA were talked about. For the rest safety and safety culture in general were presented. Although all these efforts, Colgan's principle

		operations inspector stated that the safety culture at the airline company was more of a reactive than of a proactive kind. • The employees could give feedback, on which the company would take corrective actions. At the company there was also a safety hotline, where employees could 24 hours long report safety related concerns in an anonymous way. According to the director no calls had been received. Another way to give feedback was by filling a form to report safety concerns. Although all these possibilities, there was not a lot of feedback to the company from the pilots. The pilots were not enough informed about the procedures to give feedback. During the 12 months before the accident no feedback reports were received concerning the sterile cockpit procedure, the stall warning activations, severe icing or temporary loss of control of the aircraft.
	Contextual aspects e.g. industrial safety culture	As mentioned earlier, several recommendations were made by the NTSB to the FAA over the last years concerning important factors which have contributed to this crash like sterile cockpit adherence, situational awareness, pilot professionalism, monitoring pilot responsibilities, flight crew fatigue, stall training, remedial training and additional oversight, pilot records, air carrier safety programs, air carrier oversight, low-airspeed alerting system, airplane icing and weather information for pilots. These recommendations were issued by the NTSB as a result of crash reports they had published. These recommendations were not always followed up.
	Area and stakes vulnerability to the system	Pilot training, FAA regulations, company procedures.
Magnitude of damage to system involved	Scale and kind of property damage	The complete aircraft was destroyed together with a house and two cars which were standing on the driveway. The separate garage remained intact but a garage of the neighbors was damaged.
	Victims	All 45 passengers, 4 crew members and one person on the ground died.
	Magnitude of damage financial environmental	No information was found on how much the damage cost.
	Down time	Colgan Air just kept flying after the accident, as did the Bombardier Dash 8, so no down time.
	After the event, aftermath actions to restore, repair, de-pollution, compensate	After the crash more than 40 lawsuits were filed against the FAA, Colgan Air, Pinnacle Airlines, Continental Airlines and Bombardier. These lawsuits were settled and the terms are confidential so the financial compensation is not known[36] [37] [38] [39].

	Speed/pace of recovery completely back into business	Since there was no down time, business just continued as normal.
Investigations known	By safety board/special commission involved Public authorities By companies involved	The accident investigation report by the United States National Transportation Safety Board (NTSB)[45]. / An internal safety audit was performed at Colgan on request of Colgan. In this audit safety culture and operations were investigated. The safety audit report is not made public, except for the lawyers representing the families of the victims[40] [41].
Dimensions of lessons learned: operations		
Content	Elements of the primary process to be improved	• The pilot training concerning stall and concerning the use of the ref speeds switch should be improved. • Regulations regarding pilot’s fatigue, commuting and scheduling should be reviewed. • Better warnings when stall speed is approached should be implemented. • Company policy regarding the sterile cockpit should be reviewed. • The activation of the stick pusher should be linked to the ref speeds switch position.
Structure	Organizational structure	• New hired pilots and pilots who want to become captain at Colgan have to do more hours before getting the job now. • Colgan decided the icing box should be checked by dispatchers on the aircraft’s release if ice conditions are present in the departure/arrival city. • If a pilot changes company its airline company must provide the pilot records to the new hiring company. • Operators need to review their standard operating procedures to check if they are consistent with the flight crew monitoring techniques. These are stated in the advisory circular 120-71A “Standard Operating procedures for Flight Deck Crewmembers”. If inconsistencies are found, the procedures should be corrected according to this advisory circular. • Airline operators should document and retain pilot records. In these records the pilot’s training and checking events should be described. This makes it possible for the airline to check easily the complete training performance of a specific pilot. • The training records should also include the CV of the pilot concerning any leadership training in the past. • Procedures should be developed for operators using aircrafts equipped with a ref speeds switch or any similar device. In this way reference bugs, during approach and landing, are matched to the position of the switch. Together with this, specific training for the pilots should be provided so that they achieve the right skills. • Additional flight maneuvers were added to Colgan’s pilot training. One of these extra maneuvers is a new stall recovery training. • The sterile cockpit procedure was more clearly defined to the pilots of Colgan.

		• Operators should review the programming of adverse weather phenome reporting and the forecast subsystems are programmed. This to make sure that weather documents for each flight, generated by these subsystems, contain all the important weather information. Weather information which is not valid anymore should be deleted. • Airliners' operations inspectors should periodically review the weather documents provided by the company. They should check if the documents are consistent with the content of weather reports asked in the previous recommendation. • Extra simulator training should be provided by the operators to the pilots regarding stick pushers. • The top-of-descent to touchdown phase during flight for both the Saab 340 and the Bombardier Dash 8 aircraft were reviewed at Colgan. • After the accident several operation bulletins were issued by Colgan regarding the ref speeds switch. These bulletins contained new rules when to use it and more clarification on how it works. • A process should be developed to verify, audit, validate and amend pilot training records so that it is guaranteed for operators that their records are complete. • The operators and training centers should develop and conduct fully developed stall training. This training should include everything: unexpected stall, autopilot disengagement and aircraft specific features (in this case the ref speeds switch). • Presence of flight operations management was increased at the crew bases of Colgan. • The surveillance on Colgan's Dash 8 aircraft was increased by making use of check airmen. • Pilots have to fly with a check airman after an incident at Colgan. • After the crash Colgan plans to implement the FAA's air transportation oversight system (ATOS) and a company safety management system. This should increase the company's safety. • The FOQA program at Colgan, which was under construction before the crash, was established after the crash. For this the Dash 8 Bombardiers fleet was equipped with a QAR. • The operators should develop and implement flight operational quality assurance programs. These programs should collect objective flight data and analyse it. If necessary corrective actions have to be taken if there is any safety issue in the system. These data should also be shared with other interested parties in the aviation industry. • After the accident Colgan implemented a formal monitoring program to recheck pilots who were considered weak. • FAA should provide more stringent standards for surveillance of operators which are growing very fast, have increasing complex operations, accidents, incidents or other changes which need more oversight. The FAA should make sure there are enough qualified inspectors to check the operators' new standards. Also enough training centers should be available to be able to guarantee the quality of the operators' aircrew program designee workforce.

		• Colgan announced it would increase the visibility of the company's safety department after the accident. This would be done by personnel of the safety department conducting monthly observations of crew bases and observing flight crews during line operations. • The VVM (verbalize, verify, and monitor) program is introduced at Colgan. It helps pilots with difficulties they may encounter. • Colgan announced to train LOSA observers. • Airplanes which are vulnerable to tailplane stall should be identified. With this information the FAA should require specific tailplane stall recovery procedures in the training and company manuals of operators who use such aircrafts. Operators not using these aircrafts should ensure their company and training manuals state that their aircrafts are not vulnerable to tailplane stall. In such case also no reference at all of tailplane stall recovery procedures should be made. • Operators should download and analyse all sources of safety information which are available as part of their flight operational quality assurance program. With this data any deviation from established norms and procedures should be identified. This data should later be well protected so that it stays confidential and that it is only used for safety related purposes, not for punitive ones. • The definition of reportable icing intensities should be updated in the Aeronautical Information Manual. In this way the definitions are consistent with what was written in the "Pilot Guide: Flight in Icing Conditions". • Airline companies should collect and evaluate all information concerning disapproval for flight checks, for certificates and ratings for all pilots who are applying. This has to be done before they are hired. • A process should be used to document actions are taken by the operators to respond to safety critical information. This information is transmitted via the safety alert for operators process or other methods. In this way it is sure that operators have not missed information. • Operators should implement training programs for pilots who have shown deficiencies or failures during training which need a review of the total performance history at the airline. Extra training and oversight should also be provided to make sure performance deficiencies are taken care of. • The communication flow to the crews of Colgan is increased, including CrewTrac messages and read-and-sign memos for every challenge or event which may be encountered by the crew. • After the accident reemphasizing of the ASAP was announced by Colgan. ASAP was also discussed in the new company's crew resource management and in the threat and error management training. • Pilot training programs should be changed so that they include teach, monitoring and workload management skills. The program should also contain practice possibilities to test the pilot's proficiency. • The FAA should issue an advisory circular with advice about leadership training for the upgrade to captain. In this advisory circular methods and techniques for effective leadership, professional standards of conduct, strategies for briefing and debriefing, reinforcement and correction skills and other abilities and skills which are important for airline operations should be described.

	Technological structure	• The airline companies should provide a course in leadership training for pilots who are upgraded to captain. The content of this course should be consistent with the advisory circular which the FAA should issue. • The airspeed indicators display systems which are equipped with an electronic flight instruments system should show a yellow/amber cautionary band on top of the low speed cue when the airspeed is near the low-speed cue. Another possibility is that the airspeed digits change color form white to yellow/amber. • It is recommended that airplanes which fly under 14 Code of Federal Regulations Parts 121, 135 and 91 K, will be installed with a low-airspeed alert system. This system provides the pilots redundant visual and aural warnings if there is an impending low-speed hazard situation. • The FAA should codify and define the minimum fidelity requirements for the simulator model so that it is able to perform a set of expanded stall recovery trainings. These requirements concern the required angle of attack, the motion cueing, the side slip angle ranges, the warnings when the simulator flight envelope has been crossed and the proof-of-match with post-stall flight test data.
Culture	Change of culture Change of behavior	• At Colgan a zero tolerance policy will be used for pilots who make egregious mistakes. • It was suggested to leave some light on in Colgan's crew room during the night to prevent people from sleeping there. • Fatigue policy at Colgan was changed to prevent abuse (which happened a lot after the accident). A comprehensive fatigue program is also going to be implemented in the future. • Airline operators should address the topic of fatigue and its risks associated with commuting. The pilots who commute should be identified. Also specific guidance and policy concerning fatigue should be established so that fatigue risks are minimized. This can be done by identifying or developing rest places and with scheduling practices for commuting pilots. • An operational bulletin was issued by Colgan with more information for the crew about fatigue. • Explicit guidance to pilots should be provided by the operators to remind them of their checklists and the fact that personal electronic devices are forbidden on the flight deck.
Context	Supporting conditions Development of knowledge: managerial, scientific and technological research and innovative practice aimed at finding solutions or allow	• Statutory and/or regulatory authority should be sought so that operators' data shared with the FAA is protected. This data concerns flight operational quality assurance programs. • Multimedia guidance material on professionalism during aircraft operations should be developed and distributed among pilots. In this material several topics need to be addressed, like the standards of performance for professionalism, for sterile cockpit adherence, examples and scenarios, techniques for assessing and correcting pilot deviations and reviews of accidents where the failure in the sterile cockpit and other procedures is contributing to the accident (including this accident). To develop this material airline operators and pilot groups have to provide input and later they have to distribute it.

	solution for safer system	
Dimensions of lessons learned: system levels involved		
Micro	Solutions at the company level, subcontractors at company level	• Colgan announced to train LOSA observers. • The surveillance on Colgan's Dash 8 aircraft was increased by making use of check airmen. • Presence of flight operations management was increased at the crew bases of Colgan. • Pilots have to fly with a check airman after an incident at Colgan. • Colgan announced it would increase the visibility of the company's safety department after the accident. This would be done by personnel of the safety department conducting monthly observations of crew bases and observing flight crews during line operations. • At Colgan a zero tolerance policy will be used for pilots who make egregious mistakes. • It was suggested to leave some light on in Colgan's crew room during the night to prevent people from sleeping there. • Fatigue policy at Colgan was changed to prevent abuse (which happened a lot after the accident). A comprehensive fatigue program is also going to be implemented in the future. • Colgan decided the icing box should be checked by dispatchers on the aircraft's release if ice conditions are present in the departure/arrival city. • New hired pilots and pilots who want to become captain at Colgan have to do more hours before getting the job now. • Additional flight maneuvers were added to Colgan's pilot training. One of these extra maneuvers was a new stall recovery training. • After the accident Colgan implemented a formal monitoring program to recheck pilots who were considered weak. • After the accident several operation bulletins were issued by Colgan regarding the ref speeds switch. These bulletins contained new rules when to use it and more clarification on how it works. • The sterile cockpit procedure was more clearly defined to the pilots of Colgan. • An operational bulletin was issued by Colgan with more information for the crew about fatigue. • The FOQA program at Colgan, which was under construction before the crash, was established after the crash. For this the Dash 8 Bombardiers fleet was equipped with a QAR. • After the crash Colgan plans to implement the FAA's air transportation oversight system (ATOS) and a company safety management system. This should increase the company's safety. • After the accident reemphasizing of the ASAP was announced by Colgan. ASAP was also discussed in the new company's crew resource management and in the threat and error management training. • The communication flow to the crews of Colgan is increased, including CrewTrac messages and read-and-sign memos for every challenge or event which may be encountered by the crew.

	Timeline of implementation of solution months/years	• The top-of-descent to touchdown phase during flight for both the Saab 340 and the Bombardier Dash 8 aircraft were reviewed at Colgan. • The VVM (verbalize, verify, and monitor) program is introduced at Colgan. It helps pilots with difficulties they may encounter. For items which are already in use, it is not always described when they got in use. Items of which the timeline is known will be stated next. The LOSA observers from Colgan should be able to conduct 50 observations by September 2009. This failed and the new deadline was the end of the first quarter of 2010, with a minimum of 100 LOSA observations. All QARs were to be implemented by July 1st 2009. The analysis of FOQA data can help in the future for accident prevention. By October 2009 already 14 aircraft were equipped with a QAR.
Meso	Actions of safety authorities, what actions? Branch involvement? Timeline of implementation of solution months/years	/ /
Macro	EU-level development, directive or standard being changed or research program being started or …	• Airline operators should address the topic of fatigue and its risks associated with commuting. The pilots who commute should be identified. Also specific guidance and policy concerning fatigue should be established so that fatigue risks are minimized. This can be done by identifying or developing rest places and with scheduling practices for commuting pilots. • If a pilot changes company, its airline company must provide the pilot records to the new hiring company. • Operators need to review their standard operating procedures to check if they are consistent with the flight crew monitoring techniques. These are stated in the advisory circular 120-71A "Standard Operating procedures for Flight Deck Crewmembers". If inconsistencies are found, the procedures should be corrected according to this advisory circular. • The FAA should issue an advisory circular with advice about leadership training for the upgrade to captain. In this advisory circular methods and techniques for effective leadership, professional standards of conduct, strategies for briefing and debriefing, reinforcement and correction skills and other abilities and skills which are important for airline operations should be described. • The airline companies should provide a course in leadership training for pilots who are upgraded to captain. The content of this course should be consistent with the advisory circular which the FAA should issue.

		• Airline operators should document and retain pilot records. In these records the pilot's training and checking events should be described. This makes it possible for the airline to check easily the complete training performance of a specific pilot. • The training records should also include the CV of the pilot concerning any leadership training in the past. • The operators and training centers should develop and conduct fully developed stall training. This training should include everything: unexpected stall, autopilot disengagement and aircraft specific features (in this case the ref speeds switch). • Extra simulator training should be provided by the operators to the pilots regarding stick pushers. • Operators should download and analyse all sources of safety information which are available as part of their flight operational quality assurance program. With this data any deviation from established norms and procedures should be identified. This data should later be well protected so that it stays confidential and that it is only used for safety related purposes, not for punitive ones. • Explicit guidance to pilots should be provided by the operators to remind them of their checklists and the fact that personal electronic devices are forbidden on the flight deck. • Operators should review the programming of adverse weather phenome reporting and the forecast subsystems are programmed. This to make sure that weather documents for each flight, generated by these subsystems, contain all the important weather information. Weather information which is not valid anymore should be deleted. • Airliners' operations inspectors should periodically review the weather documents provided by the company. They should check if the documents are consistent with the content of weather reports asked in the previous recommendation. • Airline companies should collect and evaluate all information concerning disapproval for flight checks, for certificates and ratings for all pilots who are applying. This has to be done before they are hired. • The operators should develop and implement flight operational quality assurance programs. These programs should collect objective flight data and analyse it. If necessary corrective actions have to be taken if there is any safety issue in the system. These data should also be shared with other interested parties in the aviation industry. • Operators should implement training programs for pilots who have shown deficiencies or failures during training which need a review of the total performance history at the airline. Extra training and oversight should also be provided to make sure performance deficiencies are taken care of. • Multimedia guidance material on professionalism during aircraft operations should be developed and distributed among pilots. In this material several topics need to be addressed, like the standards of performance for professionalism, for sterile cockpit adherence, examples and scenarios, techniques for assessing and correcting pilot deviations and reviews of accidents where the failure in the sterile cockpit and other procedures is contributing to the accident (including this accident). To develop this material airline operators and pilot groups have to provide input and later they have to distribute it.

		• The airspeed indicators display systems which are equipped with an electronic flight instruments system should show a yellow/amber cautionary band on top of the low speed cue when the airspeed is near the low-speed cue. Another possibility is that the airspeed digits change color form white to yellow/amber. • It is recommended that airplanes which fly under 14 Code of Federal Regulations Parts 121, 135 and 91 K, will be installed with a low-airspeed alert system. This system provides the pilots redundant visual and aural warnings if there is an impending low-speed hazard situation. • Pilot training programs should be changed so that they include teach, monitoring and workload management skills. The program should also contain practice possibilities to test the pilot's proficiency. Because of this recommendation, regulations were changed by the FAA. In July 2013 qualification requirements were increased for pilots to become a first officer[42] and in November 2013 rules about commercial pilot training were changed [43]. • FAA should provide more stringent standards for surveillance of operators which are growing very fast, have increasing complex operations, accidents, incidents or other changes which need more oversight. The FAA should make sure there are enough qualified inspectors to check the operators' new standards. Also enough training centers should be available to be able to guarantee the quality of the operators' aircrew program designee workforce. • The FAA should codify and define the minimum fidelity requirements for the simulator model so that it is able to perform a set of expanded stall recovery trainings. These requirements concern the required angle of attack, the motion cueing, the side slip angle ranges, the warnings when the simulator flight envelope has been crossed and the proof-of-match with post-stall flight test data. • Procedures should be developed for operators using aircrafts equipped with a ref speeds switch or any similar device. In this way reference bugs, during approach and landing, are matched to the position of the switch. Together with this, specific training for the pilots should be provided so that they achieve the right skills. • A process should be developed to verify, audit, validate and amend pilot training records so that it is guaranteed for operators that their records are complete. • Airplanes which are vulnerable to tailplane stall should be identified. With this information the FAA should require specific tailplane stall recovery procedures in the training and company manuals of operators who use such aircrafts. Operators not using these aircrafts should ensure their company and training manuals state that their aircrafts are not vulnerable to tailplane stall. In such case also no reference at all of tailplane stall recovery procedures should be made. In June 2014 a notice was made by the FAA to check the training of the crews flying with aircraft which are vulnerable to tailplane stall. The FAA had categorized all aircraft into three categories regarding their tailplane stall vulnerability[44]. • The definition of reportable icing intensities should be updated in the Aeronautical Information Manual. In this way the definitions are consistent with what was written in the "Pilot Guide: Flight in Icing Conditions".

		• A process should be used to document actions are taken by the operators to respond to safety critical information. This information is transmitted via the safety alert for operators process or other methods. In this way it is sure that operators have not missed information. • Statutory and/or regulatory authority should be sought so that operators' data shared with the FAA is protected. This data concerns flight operational quality assurance programs.
	Timeline of implementation of solution months/years	Most of these items are recommendations made to be implemented in the future. For items which are already in use, it is not always described when they got in use. If the timeline is known for the items on the macro level it is included in the description of the item.
Dimensions lessons learned: depth of learning		
Optimize		• At Colgan a zero tolerance policy will be used for pilots who make egregious mistakes. • The FOQA program at Colgan, which was under construction before the crash, was established after the crash. For this the Dash 8 Bombardiers fleet was equipped with a QAR. • FAA should provide more stringent standards for surveillance of operators which are growing very fast, have increasing complex operations, accidents, incidents or other changes which need more oversight. The FAA should make sure there are enough qualified inspectors to check the operators' new standards. Also enough training centers should be available to be able to guarantee the quality of the operators' aircrew program designee workforce. • Presence of flight operations management was increased at the crew bases of Colgan. • Operators should review the programming of adverse weather phenome reporting and the forecast subsystems are programmed. This to make sure that weather documents for each flight, generated by these subsystems, contain all the important weather information. Weather information which is not valid anymore should be deleted. • The definition of reportable icing intensities should be updated in the Aeronautical Information Manual. In this way the definitions are consistent with what was written in the "Pilot Guide: Flight in Icing Conditions". • The top-of-descent to touchdown phase during flight for both the Saab 340 and the Bombardier Dash 8 aircraft were reviewed at Colgan. • The communication flow to the crews of Colgan is increased, including CrewTrac messages and read-and-sign memos for every challenge or event which may be encountered by the crew. • After the accident reemphasizing of the ASAP was announced by Colgan. ASAP was also discussed in the new company's crew resource management and in the threat and error management training. • Operators need to review their standard operating procedures to check if they are consistent with the flight crew monitoring techniques. These are stated in the advisory circular 120-71A "Standard Operating procedures for Flight Deck Crewmembers". If inconsistencies are found, the procedures should be corrected according to this advisory circular. • Extra simulator training should be provided by the operators to the pilots regarding stick pushers.

		• Fatigue policy at Colgan was changed to prevent abuse (which happened a lot after the accident). A comprehensive fatigue program is also going to be implemented in the future. • New hired pilots and pilots who want to become captain at Colgan have to do more hours before getting the job now. • The sterile cockpit procedure was more clearly defined to the pilots of Colgan. • An operational bulletin was issued by Colgan with more information for the crew about fatigue. • After the accident several operation bulletins were issued by Colgan regarding the ref speeds switch. These bulletins contained new rules when to use it and more clarification on how it works. • The FAA should codify and define the minimum fidelity requirements for the simulator model so that it is able to perform a set of expanded stall recovery trainings. These requirements concern the required angle of attack, the motion cueing, the side slip angle ranges, the warnings when the simulator flight envelope has been crossed and the proof-of-match with post-stall flight test data.
Adapt		• The VVM (verbalize, verify, and monitor) program is introduced at Colgan. It helps pilots with difficulties they may encounter. • The operators should develop and implement flight operational quality assurance programs. These programs should collect objective flight data and analyse it. If necessary corrective actions have to be taken if there is any safety issue in the system. These data should also be shared with other interested parties in the aviation industry. • After the crash Colgan plans to implement the FAA’s air transportation oversight system (ATOS) and a company safety management system. This should increase the company’s safety. • Statutory and/or regulatory authority should be sought so that operators’ data shared with the FAA is protected. This data concerns flight operational quality assurance programs. • Colgan announced to train LOSA observers. • A process should be used to document actions are taken by the operators to respond to safety critical information. This information is transmitted via the safety alert for operators process or other methods. In this way it is sure that operators have not missed information. • A process should be developed to verify, audit, validate and amend pilot training records so that it is guaranteed for operators that their records are complete. • Airline operators should document and retain pilot records. In these records the pilot’s training and checking events should be described. This makes it possible for the airline to check easily the complete training performance of a specific pilot. • The training records should also include the CV of the pilot concerning any leadership training in the past. • Airline operators should address the topic of fatigue and its risks associated with commuting. The pilots who commute should be identified. Also specific guidance and policy concerning fatigue should be established so that fatigue risks are minimized. This can be done by identifying or developing rest places and with scheduling practices for commuting pilots.

		• Airline companies should collect and evaluate all information concerning disapproval for flight checks, for certificates and ratings for all pilots who are applying. This has to be done before they are hired. • If a pilot changes company, its airline company must provide the pilot records to the new hiring company. • Pilot training programs should be changed so that they include teach, monitoring and workload management skills. The program should also contain practice possibilities to test the pilot's proficiency. • Additional flight maneuvers were added to Colgan's pilot training. One of these extra maneuvers was a new stall recovery training. • Airliners' operations inspectors should periodically review the weather documents provided by the company. They should check if the documents are consistent with the content of weather reports asked. • The operators and training centers should develop and conduct fully developed stall training. This training should include everything: unexpected stall, autopilot disengagement and aircraft specific features (in this case the ref speeds switch). • Explicit guidance to pilots should be provided by the operators to remind them of their checklists and the fact that personal electronic devices are forbidden on the flight deck. • Operators should implement training programs for pilots who have shown deficiencies or failures during training which need a review of the total performance history at the airline. Extra training and oversight should also be provided to make sure performance deficiencies are taken care of. • Procedures should be developed for operators using aircrafts equipped with a ref speeds switch or any similar device. In this way reference bugs, during approach and landing, are matched to the position of the switch. Together with this, specific training for the pilots should be provided so that they achieve the right skills. • Colgan decided the icing box should be checked by dispatchers on the aircraft's release if ice conditions are present in the departure/arrival city. • The airline companies should provide a course in leadership training for pilots who are upgraded to captain. The content of this course should be consistent with the advisory circular which the FAA should issue. • It was suggested to leave some light on in Colgan's crew room during the night to prevent people from sleeping there. • Pilots have to fly with a check airman after an incident at Colgan. • The FAA should issue an advisory circular with advice about leadership training for the upgrade to captain. In this advisory circular methods and techniques for effective leadership, professional standards of conduct, strategies for briefing and debriefing, reinforcement and correction skills and other abilities and skills which are important for airline operations should be described. • Operators should download and analyse all sources of safety information which are available as part of their flight operational quality assurance program. With this data any deviation from established norms and procedures should be identified. This data should later be well protected so that it stays confidential and that it is only used for safety related purposes, not for punitive ones.

		• Airplanes which are vulnerable to tailplane stall should be identified. With this information the FAA should require specific tailplane stall recovery procedures in the training and company manuals of operators who use such aircrafts. Operators not using these aircrafts should ensure their company and training manuals state that their aircrafts are not vulnerable to tailplane stall. In such case also no reference at all of tailplane stall recovery procedures should be made. • The airspeed indicators display systems which are equipped with an electronic flight instruments system should show a yellow/amber cautionary band on top of the low speed cue when the airspeed is near the low-speed cue. Another possibility is that the airspeed digits change color form white to yellow/amber. • It is recommended that airplanes which fly under 14 Code of Federal Regulations Parts 121, 135 and 91 K, will be installed with a low-airspeed alert system. This system provides the pilots redundant visual and aural warnings if there is an impending low-speed hazard situation. • After the accident Colgan implemented a formal monitoring program to recheck pilots who were considered weak. • Colgan announced it would increase the visibility of the company's safety department after the accident. This would be done by personnel of the safety department conducting monthly observations of crew bases and observing flight crews during line operations. • The surveillance on Colgan's Dash 8 aircraft was increased by making use of check airmen.
Innovate		• Multimedia guidance material on professionalism during aircraft operations should be developed and distributed among pilots. In this material several topics need to be addressed, like the standards of performance for professionalism, for sterile cockpit adherence, examples and scenarios, techniques for assessing and correcting pilot deviations and reviews of accidents where the failure in the sterile cockpit and other procedures is contributing to the accident (including this accident). To develop this material airline operators and pilot groups have to provide input and later they have to distribute it.
Impact		
Changes identified	What really changed	• One of the contributing factors is fatigue. To prevent this from happening again Colgan has already taken measures. • Colgan announced to train LOSA observers. • The surveillance on Colgan's Dash 8 aircraft was increased by making use of check airmen. • Presence of flight operations management was increased at the crew bases of Colgan. • At Colgan a zero tolerance policy is used for pilots who make egregious mistakes. • Colgan decided the icing box should be checked by dispatchers on the aircraft's release if ice conditions are present in the departure/arrival city. • New hired pilots and pilots who want to become captain at Colgan have to do more hours before getting the job now. • Additional flight maneuvers were added to Colgan's pilot training. One of these extra maneuvers was a new stall recovery training.

		• The communication flow to the crews of Colgan is increased, including CrewTrac messages and read-and-sign memos for every challenge or event which may be encountered by the crew. • After the accident Colgan implemented a formal monitoring program to recheck pilots who were considered weak. • After the accident several operation bulletins were issued by Colgan regarding the ref speeds switch. These bulletins contained new rules when to use it and more clarification on how it works. • The sterile cockpit procedure was more clearly defined to the pilots of Colgan. • An operational bulletin was issued by Colgan with more information for the crew about fatigue. • The FOQA program at Colgan, which was under construction before the crash, was established after the crash. For this the Dash 8 Bombardiers fleet was equipped with a QAR. • After the crash Colgan plans to implement the FAA's air transportation oversight system (ATOS) and a company safety management system. This should increase the company's safety. • The VVM (verbalize, verify, and monitor) program is introduced at Colgan. It helps pilots with difficulties they may encounter. On the website of the NTSB the status of the recommendations can be found back. An overview[91]: **Closed-acceptable action** • Require that airspeed indicator display systems on all aircraft certified and equipped with electronic flight instrument systems depict a yellow/amber cautionary band above the low-speed cue or airspeed indicator digits that change from white to yellow/amber as the airspeed approaches the low-speed cue[63]. • Require operators to revise the methodology for programming their adverse weather phenomena reporting and forecasting subsystems so that the subsystem-generated weather document for each flight contains all pertinent weather information, including Airmen's Meteorological Information, Significant Meteorological Information, and other National Weather Service in-flight weather advisories, and omits weather information that is no longer valid (Safety Recommendation A-10-32)[64]. • Require principal operations inspectors of operators to periodically review the weather documents generated for their carriers to verify that those documents are consistent with the information requested in Safety Recommendation A-10-32[65]. • Require all air carrier operators to establish programs for flight crewmembers who have demonstrated performance deficiencies or experienced failures in the training environment that would require a review of their whole performance history at the company and administer additional oversight and training to ensure that performance deficiencies are addressed and corrected (Safety Recommendation A-05-014)[66]. **Closed-acceptable alternate action** • Direct operators of airplanes equipped with a reference speeds switch or similar device to (1) develop procedures to establish that, during approach and landing, airspeed reference bugs are always matched to the

		position of the switch and (2) implement specific training to ensure that pilots demonstrate proficiency in this area[67]. **Closed-no longer applicable.** • Requite operators to (1) develop and implement flight operational quality assurance programs that collect objective flight data, (2) analyse these data and implement corrective actions to identified systems safety issues, and (3) share the deidentified aggregate data generated through these analyses with other interested parties in the aviation industry through appropriate means[68]. • Seek specific statutory and/or regulatory authority to protect data that operators share with the Federal Aviation Administration as part of any flight operational quality assurance program[69]. **Closed-unacceptable action** • Require operators to incorporate explicit guidance to pilots, including checklist reminders as appropriate, prohibiting the use of personal portable electronic devices on the flight deck[70]. • Require all operators to address fatigue risks associated with commuting, including identifying pilots who commute, establishing policy and guidance to mitigate fatigue risks for commuting pilots, using scheduling practices to minimize opportunities for fatigue in commuting pilots, and developing or identifying rest facilities for commuting pilots[71]. • Require operators to review their standard operating procedures to verify that they are consistent with the flight crew monitoring techniques described in Advisory Circular 120-71A, Standard Operating Procedures for Flight Deck Crewmembers; if the procedures are found not to be consistent, revise the procedures according to the AC guidance to promote effective monitoring[72]. **Open-acceptable response** • For all airplanes engaged in commercial operations require the installation of low-airspeed alert systems that provide pilots with redundant aural and visual warnings of an impending hazardous low-speed condition (Safety Recommendation A-10-012)[73]. • Require operators to document and retain electronic and/or paper records of pilot training and checking events in sufficient detail so that the carrier and its principal operations inspector can fully assess a pilot‘s entire training performance (Safety Recommendation A-10-017)[74]. • Require operators to include the training records requested in Safety Recommendation A-10-17 as part of the remedial training program requested in Safety Recommendation A-05-014[75]. • Require operators to provide the training records requested in Safety Recommendation A-10-17 to hiring employers to fulfil their requirement under the Pilot Records Improvement Act[76]. • Develop a process for verifying, validating, auditing, and amending pilot training records at operators to guarantee the accuracy and completeness of the records[77].

		• Define and codify minimum simulator model fidelity requirements to support an expanded set of stall recovery training requirements, including recovery from stalls that are fully developed. These simulator fidelity requirements should address areas such as required angle-of-attack and sideslip angle ranges, motion cueing, proof-of-match with post-stall flight test data, and warnings to indicate when the simulator flight envelope has been exceeded[78]. • Identify which airplanes operated under are susceptible to tail plane stalls and then (1) require operators of those airplanes to provide an appropriate airplane-specific tailplane stall recovery procedure in their training manuals and company procedures and (2) direct operators of those airplanes that are not susceptible to tailplane stalls to ensure that training and company guidance for the airplanes explicitly states this lack of susceptibility and contains no references to tailplane stall recovery procedures[79]. • Develop more stringent standards for surveillance of operators that are experiencing rapid growth, increased complexity of operations, accidents and/or incidents, or other changes that warrant increased oversight, including the following: (1) verify that inspector staffing is adequate to accomplish the enhanced surveillance that is promulgated by the new standards, (2) increase staffing for those certificates with insufficient staffing levels, and (3) augment the inspector staff with available and airplane-type-qualified inspectors from all Federal Aviation Administration regions and training centres to provide quality assurance over the operators' aircrew program designee workforce[80]. • Update the definitions for reportable icing intensities in the Aeronautical Information Manual so that the definitions are consistent with the more detailed intensities defined in Advisory Circular 91-74A, Pilot Guide: Flight in Icing Conditions[81]. • Require all air carriers to obtain any notices of disapproval for flight checks for certificates and ratings for all pilot applicants and evaluate this information before making a hiring decision (Safety Recommendation A-05-001)[82]. • Require that all pilot training programs be modified to contain modules that teach and emphasize monitoring skills and workload management and include opportunities to practice and demonstrate proficiency in these areas (Safety Recommendation A-07-013)[83]. **Open-acceptable alternate answer** • Require operators to (1) routinely download and analyse all available sources of safety information, as part of their flight operational quality assurance program, to identify deviations from established norms and procedures; (2) provide appropriate protections to ensure the confidentiality of the deidentified aggregate data; and (3) ensure that this information is used for safety-related and not punitive purposes[84]. **Open-unacceptable response** • Issue an advisory circular with guidance on leadership training for upgrading captains, including methods and techniques for effective leadership; professional standards of conduct; strategies for briefing and debriefing;

		reinforcement and correction skills; and other knowledge, skills, and abilities that are critical for air carrier operations (Safety Recommendation A-10-013)[85]. • Require operators to provide a specific course on leadership training to their upgrading captains that is consistent with the advisory circular requested in Safety Recommendation A-10-013[86]. • Develop, and distribute to all pilots, multimedia guidance materials on professionalism in aircraft operations that contain standards of performance for professionalism; best practices for sterile cockpit adherence; techniques for assessing and correcting pilot deviations; examples and scenarios; and a detailed review of accidents involving breakdowns in sterile cockpit and other procedures, including this accident. Obtain the input of operators and air carrier and general aviation pilot groups in the development and distribution of these guidance materials (Safety Recommendation A-10-015)[87]. • Require operators and training centres to develop and conduct training that incorporates stalls that are fully developed; are unexpected; involve autopilot disengagement; and include airplane-specific features, such as a reference speeds switch[88]. • Require all operators of stick pusher-equipped aircraft to provide their pilots with pusher familiarization simulator training (Safety Recommendation A-10-023)[89]. • Implement a process to document that all operators have taken appropriate action in response to safety-critical information transmitted through the safety alert for operators process or another method[90].
Change/learning agent	Who/what takes care for follow-up Who/what keeps memory/knowledge alive Who/what keeps monitors effectiveness	The Federal Aviation Administration (FAA) and NTSB. FAA and NTSB. No information was found on this.
Change timeline	Can phases be identified in their implementation process are implemented measures lost in time	Some actions were taken immediately after the crash. After the official accident report came out recommendations were analysed, to decide if they are implemented or not. How long it takes to take a decision depends from the recommendation. It is also possible that it takes some time to implement it. No information is found about implemented measures lost in time.
Change of investigation process		/
Evaluation of accident and follow-up		

	Conclusions and comment with respect Specific experiences/ observations/ discussion by ESReDA group	Some recommendations were already issued in the past and are now repeated in this report because they were not implemented yet. These are: • Require all air carriers to obtain any notices of disapproval for flight checks, for certificates and ratings for all pilot applicants and evaluate this information before making a hiring decision (Safety Recommendation A-05-001). • Require all air carrier operators to establish training programs for flight crewmembers who have demonstrated performance deficiencies or experienced failures in the training environment that would require a review of their whole performance history at the company and administer additional oversight and training to ensure that performance deficiencies are addressed and corrected (Safety Recommendation A-05-014). • Require that all pilot training programs be modified to contain modules that teach and emphasize monitoring skills and workload management and include opportunities to practice and demonstrate proficiency in these areas (Safety Recommendation A-07-013). Four other recommendations from the past are superseded by recommendations made in this report. Because of that the old recommendations are closed. These four old recommendations are: • Convene a multidisciplinary panel of operational, training, and human factors specialists to study and submit a report on methods to improve flight crew familiarity with and response to stick pusher systems and, if warranted, establish training requirements for stick pusher-equipped airplanes based on the findings of this panel (superseded by Safety Recommendation A-10-023). • Work with pilot associations to develop a specific program of education for air carrier pilots that addresses professional standards and their role in ensuring safety of flight. The program should include associated guidance information and references to recent accidents involving pilots acting unprofessionally or not following standard operating procedures (superseded by Safety Recommendation A-10-015). • Convene a panel of aircraft design, aviation operations, and aviation human factors specialists, including representatives from the National Aeronautics and Space Administration, to determine whether a requirement for the installation of low-airspeed alert systems in airplanes engaged in commercial operations would be feasible, and submit a report of the panel's findings (superseded by Safety Recommendation A-10-012). • If the panel requested in the previous recommendations determines that a requirement for the installation of low-airspeed alert systems in airplanes engaged in commercial operations is feasible, establish requirements for low-airspeed alert systems, based on the findings of this panel (superseded by Safety Recommendation A-10-012). Rest of conclusions see section 4.2.3 and chapter 5.
	Are changes sustained	No information is found on that. It is assumed that until now all the actions taken are still in use.

References		
Communication of findings, recommendations	Reports government, safety board, investigation commission Report inspectorate/third party Company reports	Official accident investigation report by the NTSB of the Colgan Air Crash: [45] Accident reports related to the Colgan Air crash: [25][26][27][28][29][30][31][32][33] FAA regulation change: [42][43] FAA notice: [44] NTSB follow-up recommendation: [63][64][65][66][67][68][69][70][71][72][73][74][75][76][77][78][79][80][81][82][83][84][85][86][87][88][89][90][91] / /
Other transfer of knowledge by parties involved, professional organizations, scientists etc.	Articles in journals, magazines, internet Courses, training Relevant links	See section References: [34][35][36][37][38][39][40][41]

Comments about the ESReDA Cube method

- At the operation level it is difficult without clear rules to categorize items between organizational-structure or context-supporting conditions. Also in the ESReDA Cube method's paper this is not clear. In some examples of the paper change in regulations is categorized under organizational structure (Aasta train collision) and in another example it is put under supporting conditions (Toulouse Disaster). In this thesis everything which changes, renews an organization or process is put under organization (including implementing a new process). Only when a recommendation/action implies that still a solution has to be found for a specific problem regarding an organization or process, it is put under supporting conditions. If no clear rules are set for that every user of the ESReDA Cube method can have a different outcome (which already happened with the regulations example in the ESReDA Cube method's paper).
- The line between organizational-structure and culture (at the operation level) should also be well defined. Hiring more people for the safety department can prove the change of culture, that safety is taken more seriously. On the other hand it can also be seen as organizational change. In this thesis human factors and organization safety policy changes are categorized under safety culture, because these will cause change in behavior and in culture. An exception are the changes concerning the pilot technical flying training. These are also dealing with human factors but they are put under organizational change. The rest of the process and organizational change or renewal is categorized under organizational structure.
- At the system level it is also not clear which recommendation/action has to be categorized where. Therefore some rules are used in this thesis. A recommendation has to be categorized on the level where it will first have effect on. If a recommendation concerns implementing/developing a regulation,

advisory circular or procedure it first has an effect on the safety authority which needs to implement it. Only after that it affects the operators, manufacturers or the industry. This means such recommendation should be categorized on the macro level (for FAA and EASA) or on the meso level (if its needs to be implemented by a local safety authority). If the recommendation implies something should be done in the industry or by one specific company directly (without mentioning the implementation of regulations, advisory circulars or procedures), it should be categorized on the micro (if it is for one company) or on the meso (if it is for the whole industry) level. If an already implemented regulation, procedure or advisory circular has to be categorized, this has to be put on the level for whom the regulation, procedure or advisory circular is meant.

- Again as with the previous case, the line between adapt and optimize at the depth of learning level is very unclear. The same rules as they were suggested in the previous case are used.
- At the depth of learning level, sometimes a recommendation/action with the same subject can change between optimize/adapt/innovate. In this case it happened with the recommendations concerning FOQA. For Colgan the action they took to speed up the implementation of FOQA is categorized under optimize, since it was already planned. The FOQA implementation was just optimized due to the crash. The general recommendation, to have a FOQA program for all operators, is categorized under adapt since it is something new which is added to the safety programs (for Colgan it was not new, it was already planned). The general recommendation adapts the safety programs by implementing a new program. If there would be no safety programs yet and if this would be the first one, this recommendation would be categorized under innovate.
- Sometimes actions and recommendations overlap each other. Using the example of FOQA again, two items are put in the cube concerning that. The first one is the action of Colgan to implement it more quickly. The second one is the recommendation to implement it at all operators. The action of Colgan can in fact be deleted in the cube by the second recommendation since they overlap (Colgan is an operator). On the other hand it also shows that (at the micro level) immediate action is taken by Colgan. The other item is a recommendation which still has to happen in the future (meso level).

Appendix G

Turkish Airlines flight 1951

Item	Explanation	
Description (system involved)		
Description accident	Short description	On February 25th 2009 a Boeing 737-800 crashed upon approach near Schiphol Airport. The aircraft took off at the airport of Istanbul Atatürk. Aboard the aircraft were 135 people (128 passengers, 4 cabin crew members and 3 pilots). During the crash 9 people died, 120 got injured and the rest got out without harm.
	What has happened (description, pictures etc.) What agents (the damaging energy source e.g. nuclear hazard)	On approach the autothrottle set the thrust into approach idle. At the same time the autopilot put the nose higher to follow the glide path since speed was decreasing. Suddenly the stick shaker was activated and the aircraft lost speed and altitude. The first officer, who was on a training flight, immediately reacted by pushing the steer column forward and by increasing throttle. Later the captain also reacted on the stick shaker. It is assumed that the captain overruled the first officer and that that’s why the increasing of the throttle did not happen completely. The autothrottle kept being active and pulled the thrust, which was increased by the first officer, immediately back. In the end the autothrottle was finally switched off and the thrust was increased but it was too late. The aircraft continued its stall and crashed.
	How has it happened, what were the circumstances?	During this flight there were three pilots in the cockpit. The captain who was providing training and instructions for the first officer. The first officer who was on a trainings flight to get experience. The third one was an observer pilot to check if the other two pilots did not make any mistakes during the flight. The aircraft had to intercept the glide path from above (see figure F-1) during the approach, unlike during normal approaches when the glide path is intercepted from below (see figure F-2).

		 **Figure G-1: Normal approach procedure, intercepting glide path from below[46].**  **Figure G-2: Intercepting glide path from above[46].**
	Why did it happen? Direct causes	The left radio altimeter, which provides information for the autothrottle, was broken. No procedure was available to respond on a broken radio altimeter. During approach the autothrottle went from vertical speed modus into retard flare modus. This is normally only used right before touch down but all conditions were fulfilled. These conditions are: being below 27 feet (the radio altimeter showed -8 feet), flaps minimally at 12.5°, an autothrottle mode active and not climbing or descending to a set altitude. Because of this the autothrottle was pushed backwards to idle approach, so the speed was decreased. Together with that the nose moved up because the autopilot (which's information was based on the right altimeter, which was correct) wanted to follow the glide path as long as possible. When the aircraft goes into retard flare mode, this is shown on the primary display. When the speed decreased this was also shown by visual warnings on the primary display, together with a nose-up on the artificial horizon which was much

		too high. The pilots did not notice anything, probably because in the beginning the actions of the aircraft corresponded to the crew's inputs of descending and decreasing speed. The stick shaker was activated. The first officer, who was the pilot in command, immediately pushed the throttle and steer column forward. He stopped doing this after a second since the captain called out "I have". Due to this action and the fact that the autothrottle was still on, the thrust decreased back to idle. Next the autothrottle was switched off. It still took seven seconds before full thrust was selected but it was too late and the aircraft crashed.
	Why did it happen? Root causes	Although the pilots knew that the radio altimeter on his side was broken (the captain already switched off earlier aural warnings concerning lowering landing gear and he said "radio altimeter", also later during flight the captain confirmed this problem to the observer pilot) they did not know that this information was given to the autothrottle. This information was not mentioned in procedure books or during pilot training. Few years Turkish and other airline companies had problems with broken radio altimeters and also Boeing was informed of the problem. It was seen as a technical problem and not as one which could endanger the flight. That's why pilots were not warned about it. Normally an aircraft has to fly horizontally during the final approach track before intercepting the glide path and it has to intercept the glide path from below. In this case the line-up of the aircraft happened in a distance of 5-8 NM from the runway threshold without the command to descend. This resulted in a glide path interception from above. Because of that the aircraft had to descend and decrease speed to intercept the glide path (this masked the autothrottle change into retard flare modus). This kept the crew of finishing their landing checklist before they reached 1000 feet. If it is not finished by 1000 feet, pilots should abort the landing according to Turkish Airlines procedures (with bad visibility all actions should be finished before passing 1000 feet, with good visibility this changes to 500 feet). The workload was enormous for a flight phase where the crew should normally only monitor. Approaching the runway between 5 and 8 NM of the threshold is allowed if two conditions are fulfilled. It has to be offered to the pilots and pilots need to get instructions to descend below 2000 feet so that the glide path is intercepted from below. These two conditions were not fulfilled.
	Other root causes	The crew was not sufficiently trained for stall recovery actions. Information in the Quick Reference Handbook about autopilot, autothrottle and the necessity to trim the horizontal stabilizer during stall recovery is not clear and sufficient.
	When did it happen? Timeline of main events	The aircraft took off from Istanbul Atatürk at 8.23 local time on the 25th of February 2009. At 10.15:02, during contact with Schiphol approach, the aural warning of the landing gear went off for a minute and a half. After this the captain said "radio altimeter". At 10.17:11 the warning went off again for 2 seconds and little time later the captain made the remark "landing gear". Minute and half later the warning sounded again for two seconds. On the flight data recorder it was seen that during this period that the warning went off the radio altimeter showed an altitude of -8 feet on the primary display. During line up, the warning went off again at 10.23:43. Again the primary display showed minus 8 feet. After this the landing gear was put down and the flaps were set at 15. Around 10.24:20 the pilots selected the

		vertical speed mode. Immediately after this selection the flight mode annunciation on both the primary flight displays changed to “retard”. Because of this the throttles moved back to idle. At 10.24:36 the observer pilot noticed the error of the radio altimeter and said it to the captain who confirmed it. The landing checklist was completed around 10.25:46, at an altitude of 500 feet. At 10.25:47, at an altitude of 460 feet, the stick shaker was activated. The throttle was pushed forward halfway, but immediately went back to idle because of the autothrottle. At 10.25:50 the autothrottle was switched off and a second later the autopilot was switched of and the steer column was pushed forward. Four seconds later the stick shaker switched off and activated again two seconds later. At 10.25:56 the throttles were pushed forward to their maximum, what caused full power of the engines four seconds later. The aircraft crashed and recording of the flight data recorder stopped at 10.26:02.
	Historical events	This aircraft had, in the 48 hours before the crash, already two similar problems with the radio altimeter. During both flights the retard flare mode was activated on approach. Both flights ended well because the pilots switched off the autothrottle and autopilot. The pilots of these flights did not report these incidents. Next to these ones, several other similar incidents with other Boeing 737s are known. On this specific aircraft maintenance was already performed to fix this broken radio altimeter problem.
	Place Context of event and system (general environment, topography, weather)	The aircraft crashed in a field at a distance of 1.5 kilometers of the threshold of the runway. That day some clouds were present at 700 feet. It was heavily clouded at 800 feet and between 1000 and 2500 feet it was completely clouded. Visibility was 4500 meter.
	Sector involved	Aviation industry, SAR services, the international rules and regulations organization ICAO, FAA, EASA and the Turkish Directorate General of Civil Aviation (DGCA).
Type of event	Content aspects: primary activity, operational aspect involved	The crash happened during the scheduled passenger flight of Turkish Airlines from Istanbul to Amsterdam.
	General or macro description of plant or system involved	Turkish Airlines is the national flag carrier of Turkey. At the time of the accident the company had 134 Boeing and Airbus aircraft, including 52 Boeing 737-800. Turkish Airlines is self-responsible for the maintenance of the fleet.
	Local or micro description of process/system involved in accident	The Boeing 737-800 is a twin engine aircraft which was put on the market in 1998. It is the next generation model of the 737 class. This Boeing 737-800 was delivered to Turkish Airlines on March 27th 2002.

	Structural aspects: e.g. relevant organizational structures, infrastructure, buildings etc.	The crew was not sufficiently trained for stall recovery actions. Information about autopilot, autothrottle and the necessity to trim horizontal stabilizer during stall recovery in the Quick Reference Handbook is not clear and sufficient. No procedure to react on a broken radio altimeter during flight. Pilots did not know the consequences of a broken radio altimeter.
	Cultural aspect: personal safety culture company safety culture	The company procedures to have every landing check finished before 1000 feet was not respected. The landing was not aborted as was stated in Turkish Airlines procedures. The air traffic controller did not offer the suggested route to the pilot, which is mandatory.
	Contextual aspects e.g. industrial safety culture	Boeing, the FAA and the operators knew about the broken radio altimeter problem and no appropriate action was taken so that this accident could have been prevented.
	Area and stakes vulnerability to the system	Pilot training, aircraft design, authority certification and air traffic control.
Magnitude of damage to system involved	Scale and kind of property damage	The Boeing 737-800 was completely destroyed.
	Victims	Of the seven crew members four died, including the three pilots. The other three crew members were wounded. Of the 128 passengers five died and 117 were wounded. The rest got out safely.
	Magnitude of damage financial environmental	No information about the financial or environmental damage was found.
	Down time	The aircraft crashed in front of the Polderbaan at Schiphol. Because of that the Polderbaan was out of use for five days. For the rest there was no down time.
	After the event, aftermath actions to restore, repair, de-pollution, compensate	Turkish Airlines paid every passenger at least 5000€ and if the passenger was wounded and had to go to the hospital it was at least 10,000€. Families of the deceased passengers received 50,000€[47]. Boeing also gave a compensation to the victims, but what amount is not made public[48].

	Speed/pace of recovery completely back into business	After five days, on March 1st the Polderbaan was in use again.
Investigations known	By safety board/special commission involved Public authorities By companies involved	The official accident investigation report by the Dutch Onderzoeksraad Voor Veiligheid[49][107]. / There was an audit performed at Turkish Airlines[95]. The report could however not be found and is probably not publicly available.
Dimensions of lessons learned: operations		
Content	Elements of the primary process to be improved	• Improve pilot training so that stall recovery is better practiced. • Improve pilot training/knowledge about broken radio altimeters. • Fix or replace the radio altimeter on the Boeing 737 so that it works and that these accidents can be avoided. • Reporting of incidents to the airline company, the manufacturer and the safety authority should be improved. • Change/review the Dutch air traffic control procedures concerning aircraft line up. • Provide several speed sources to the autothrottle so that invalid information will not be used.
Structure	Organizational structure	• The FAA published the Aircraft Evaluation Group (AEG) appendix 7 ‘flight crew monitoring during automatic flight’ of the 737NG Flight Standards Board Report. In this document extra training scenarios are described together with the effects of incorrect radio altimeter values. • The “fasten seatbelt sign” procedure was revised at Turkish Airlines to increase safety. • To effectively monitor non-stable approaches via “flight data monitoring” at Turkish Airlines, a bulletin was issued where the 500 feet criteria was increased to 1000 feet. • Turkish Airlines implemented an online reporting system to increase the spread and accessibility of information. • Next to a three-monthly safety meeting with the higher management, a monthly operational safety meeting is implemented at Turkish Airlines. • The investigation of the Flight Safety Division of Turkish airlines to coherent risks is sped up and a system is implemented to inform pilots about such risks. • At Turkish Airlines an extra two day simulator session is added to the syllabus of the second half year repetition training to improve flying safety. The most important subject added is the extra stall recovery procedure. • Independent of the periodic simulator sessions, an extra stall recovery simulator session is implemented for all pilots of Turkish Airlines. • An aircraft reliability report is prepared at Turkish Airlines. With this report it should be possible to calculate the reliability of every aircraft in the fleet.

		• All swap requests at Turkish Airlines should now be approved by the Maintenance Control Center. • At Turkish Airlines, the changed swapping procedures will be added to the periodic training of the technical personnel. • A flight operations technical bulletin was issued by Boeing. This bulletin recommended the pilots to carefully monitor the primary flight instruments for the aircraft's performance and the flight mode annunciation for the autoflight modes. • A bulletin was issued by Turkish Airlines for all its Boeing pilots after receiving an engineering bulletin of Boeing. • A warning bulletin was issued by Turkish Airlines for the Boeing fleet after technical information was received by Boeing. • The procedure of the Dispatch Deviation Guide, stating to not use the autothrottle during landing and approach if the radio altimeter showed malfunctions before, was added by Boeing to the MMEL. • Turkish Airlines engineering department will issue a technical information bulletin to inform the personnel about the maintenance tips from Boeing. Also extra training will be provided. All this will be done when all maintenance tips by Boeing are issued. • EASA published the safety information bulletin "Erroneous low range radio altimeter (LRRA) operations". This publication was a repetition of Boeing's flight operations technical bulletin which recommended the pilots to carefully monitor the primary flight instruments and the flight mode annunciations. • Boeing needs to review the stall recovery procedure concerning the use of the autopilot and autothrottle and the necessity to trim. • ICAO, FAA and EASA should include in their regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs. • The Turkish Directorate General of Civil Aviation (DGCA) should include in its regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs. • FAA and EASA should make (renewed) efforts to ensure airline companies are aware of the importance of reporting and make sure reporting procedures are respected. • DGCA should make (renewed) efforts to ensure airline companies are aware of the importance of reporting and make sure reporting procedures are respected. • Boeing should make (renewed) efforts to make sure airline companies flying Boeing aircraft are aware of the importance of reporting. • Turkish Airlines should make efforts to make sure their pilots and technicians are aware of the importance of reporting. • Turkish Airline should change its safety program to improve the deficiencies which were found in the report.

	Technological structure	• The procedures of the Dutch air traffic control (LVNL) for lining up aircrafts, described in the rules and instructions air traffic control (VDV), should be harmonized with the ICAO procedures. The LVNL should also ensure that the air traffic controllers work in compliance with these rules of the VDV. • The Inspectie Verkeer en Waterstaat (IVW) (now Inspectie Leefomgeving en Transport (ILT)) need to check if the LVNL is working according to the national and international air traffic control procedures. • Turkish Airlines issued a bulletin on stabilized approaches[95]. • Turkish Airlines issued an advisory circular to help reduce and eliminate the rate of unstabilized approaches[95]. • Turkish Airlines established criteria for unstabilized approaches into specific airports[95]. • Boeing issued a maintenance tip which states that the antennas of the radio altimeter system cannot be tightened too much to the coax connections. Boeing issued later that it will revise this tip. They want to add a control procedure for the connector component to the antenna on the aircraft side. • Boeing issued a second maintenance tip which states "discrepant low range radio altimeter (LRRA) operation while the airplane is airborne". • Boeing updated its Fault Isolation Manual (FIM). In the FIM reference is made now to a maintenance tip which gives extra advice about radio altimeter failures. • A new job card has been issued by Turkish Airlines in correspondence with Boeing's publication "Boeing 737NG-FTD-34-09001, LRRA flags and warnings". The job card states "corrosion coax cable cont. of connector wrap on RA". • A second new job card has been issued by Turkish Airlines in correspondence with Boeing's publication "Boeing 737NG-FTD-34-09001, LRRA flags and warnings". The second job card states "fuselage drain valves func. ins. around RA antennas". • Boeing needs to improve the reliability of the radio altimeter system. • The FAA and EASA should make sure that the undesired response of the autothrottle and flight management computer to the broken radio altimeter is evaluated. They should also ensure the autothrottle and the flight management system is improved so that it is in accordance with the design specifications. • Turkish Airlines prohibited to swap flight data recorders between aircrafts. • Turkish Airlines prohibited to swap ETOPS related components on the same aircraft.
Culture	Change of culture Change of behavior	No information was found on this. No information was found on this.
Context	Supporting conditions Development of knowledge: managerial, scientific	/ • Information was given by Boeing to its operators about a future service bulletin. This service bulletin contains information about the software versions P4.0 and P5.0 of the Rockwell Collins Enhanced Digital Flight Control System (EDFCS). In this new software version a comparison function will be used which compares the

	and technological research and innovative practice aimed at finding solutions or allow solution for safer system	measured speed of the left and right radio altimeter. It is also investigated by Boeing if the GE Aviation autothrottle software can be improved so that it can compare left and right radio altimeter values in the future. • Boeing, the FAA and EASA should investigate the use of an aural low speed warning. If it is effective, it should be made mandatory. • A new study is performed at Turkish Airlines concerning the quality of aircraft maintenance (MOQA). Using the Flight Data Monitoring data the analysis of predetermined fault conditions is monitored. In this way it will be possible to discover predetermined detected faults which occur in components or systems. With this process corrective actions can be taken in time.
Dimensions of lessons learned: system levels involved		
Micro	Solutions at the company level, subcontractors at company level	• A flight operations technical bulletin was issued by Boeing. This bulletin recommended the pilots to carefully monitor the primary flight instruments for the aircraft's performance and the flight mode annunciation for the autoflight modes. • Information was given by Boeing to its operators about a future service bulletin. This service bulletin contains information about the software versions P4.0 and P5.0 of the EDFCS. In this new software version a comparison function will be used which compares the measured speed of the left and right radio altimeter. It is also investigated by Boeing if the GE Aviation autothrottle software can be improved so that it can compare left and right radio altimeter values in the future. • Boeing issued a maintenance tip which states that the antennas of the radio altimeter system cannot be tightened too much to the coax connections. Boeing issued later that it will revise this tip. They want to add a control procedure for the connector component to the antenna on the aircraft side. • Boeing issued a second maintenance tip which states "discrepant LRRA operation while the airplane is airborne". • The procedure of the Dispatch Deviation Guide, stating to not use the autothrottle during landing and approach if the radio altimeter showed malfunctions before, was added by Boeing to the MMEL. • Boeing updated its FIM. In the FIM reference is made now to a maintenance tip which gives extra advice about radio altimeter failures. • A warning bulletin was issued by Turkish Airlines for the Boeing fleet after technical information was received by Boeing. • A bulletin was issued by Turkish Airlines for all its Boeing pilots after receiving an engineering bulletin of Boeing. • The "fasten seatbelt sign" procedure was revised at Turkish Airlines to increase safety. • To effectively monitor non-stable approaches via "flight data monitoring" at Turkish Airlines, a bulletin was issued where the 500 feet criteria was increased to 1000 feet. • Turkish Airlines implemented an online reporting system to increase the spread and accessibility of information.

		• Next to a three-monthly safety meeting with the higher management, a monthly operational safety meeting is implemented at Turkish Airlines. • The investigation of the Flight Safety Division of Turkish airlines to coherent risks is sped up and a system is implemented to inform pilots about such risks. • At Turkish Airlines an extra two day simulator session is added to the syllabus of the second half year repetition training to improve flying safety. The most important subject added is the extra stall recovery procedure. • Independent of the periodic simulator sessions, an extra stall recovery simulator session is implemented for all pilots of Turkish Airlines. • An aircraft reliability report is prepared at Turkish Airlines. With this report it should be possible to calculate the reliability of every aircraft in the fleet. • A new study is performed at Turkish Airlines concerning the quality of aircraft maintenance (MOQA). Using the Flight Data Monitoring data the analysis of predetermined fault conditions is monitored. In this way it will be possible to discover predetermined detected faults which occur in components or systems. With this process corrective actions can be taken in time. • A new job card has been issued by Turkish Airlines in correspondence with Boeing's publication "Boeing 737NG-FTD-34-09001, LRRA flags and warnings". The job card states "corrosion coax cable cont. of connector wrap on RA". • A second new job card has been issued by Turkish Airlines in correspondence with Boeing's publication "Boeing 737NG-FTD-34-09001, LRRA flags and warnings". The second job card states "fuselage drain valves func. ins. around RA antennas". • All swap requests at Turkish Airlines should now be approved by the Maintenance Control Center. • Turkish Airlines prohibited to swap flight data recorders between aircrafts. • Turkish Airlines prohibited to swap ETOPS related components on the same aircraft. • At Turkish Airlines, the changed swapping procedures will be added to the periodic training of the technical personnel. • Turkish Airlines engineering department will issue a technical information bulletin to inform the personnel about the maintenance tips from Boeing. Also extra training will be provided. All this will be done when all maintenance tips by Boeing are issued. • Boeing needs to improve the reliability of the radio altimeter system. • Boeing needs to review the stall recovery procedure concerning the use of the autopilot and autothrottle and the necessity to trim. • Boeing should make (renewed) efforts to make sure airline companies flying Boeing aircraft are aware of the importance of reporting. • Turkish Airlines should make efforts to make sure their pilots and technicians are aware of the importance of reporting.

		• Turkish Airline should change its safety program to improve the deficiencies which were found in the report. • The procedures of the Dutch air traffic control (LVNL) for lining up aircrafts, described in the rules and instructions air traffic control (VDV), should be harmonized with the ICAO procedures. The LVNL should also ensure that the air traffic controllers work in compliance with these rules of the VDV. • Turkish Airlines issued a bulletin on stabilized approaches[95]. • Turkish Airlines issued an advisory circular to help reduce and eliminate the rate of unstabilized approaches[95]. • Turkish Airlines established criteria for unstabilized approaches into specific airports[95].
	Timeline of implementation of solution months/years	• The flight operations technical bulletin was issued by Boeing on March 19th 2009. • The information about the future service bulletin was issued By Boeing on July 31st 2009. • Boeing's maintenance tip about the coax connections was issued on September 9th 2009 and the other maintenance tip on July 31st 2009. • The procedure stating to not use the autothrottle was added to the MMEL in October 2009. • The FIM was updated on October 15th 2009. • The warning bulletin for the Boeing fleet was issued by Turkish Airlines on March 12th 2009. • The bulletin for its Boeing pilots was issued by Turkish Airlines on March 20th 2009. • The "fasten seatbelt sign" procedure was revised on March 20th 2009. • The bulletin, in which the 500 feet criteria was increased to 1000 feet, was issued on May 18th 2009. • The online report system was implemented by Turkish Airlines on September 23rd 2009. • The two extra days of simulator sessions at Turkish Airlines were added on July 1st 2009. • The first job card was issued on April 20th 2009 and the second one on 8th April 2009. • The system to notify pilots of respective risks was implemented on June 1st 2009.
Meso	Actions of safety authorities, what actions? Branch involvement?	• The Inspectie Verkeer en Waterstaat (IVW) (now Inspectie Leefomgeving en Transport (ILT)) need to check if the LVNL is working according to the national and international air traffic control procedures. • The FAA published the AEG appendix 7 'flight crew monitoring during automatic flight' of the 737NG Flight Standards Board Report. In this document extra training scenarios are described together with the effects of incorrect radio altimeter values. • EASA published the safety information bulletin "Erroneous low range radio altimeter (LRRA) operations". This publication was a repetition of Boeing's flight operations technical bulletin which recommended the pilots to carefully monitor the primary flight instruments and the flight mode annunciations. • The Turkish (DGCA) should include in its regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs. • DGCA should make (renewed) efforts to ensure airline companies are aware of the importance of reporting and make sure reporting procedures are respected.

	Timeline of implementation of solution months/years	• The AEG appendix 7 'flight crew monitoring during automatic flight' of the 737NG Flight Standards Board Report was published by the FAA on December 11th 2009. • EASA published its safety information bulletin on April 30th 2009.
Macro	EU-level development, directive or standard being changed or research program being started or …	• The FAA and EASA should make sure that the undesired response of the autothrottle and flight management computer to the broken radio altimeter is evaluated. They should also ensure the autothrottle and the flight management system is improved so that it is in accordance with the design specifications. • Boeing, the FAA and EASA should investigate the use of an aural low speed warning. If it is effective, it should be made mandatory. • ICAO, FAA and EASA should include in their regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs. • FAA and EASA should make (renewed) efforts to ensure airline companies are aware of the importance of reporting and make sure reporting procedures are respected.
	Timeline of implementation of solution months/years	No information was found on this
Dimensions lessons learned: depth of learning		
Optimize		• The "fasten seatbelt sign" procedure was revised at Turkish Airlines to increase safety. • To effectively monitor non-stable approaches via "flight data monitoring" at Turkish Airlines, a bulletin was issued where the 500 feet criteria was increased to 1000 feet. • The investigation of the Flight Safety Division of Turkish airlines to coherent risks is sped up and a system is implemented to inform pilots about such risks. • At Turkish Airlines an extra two day simulator session is added to the syllabus of the second half year repetition training to improve flying safety. The most important subject added is the extra stall recovery procedure. • Independent of the periodic simulator sessions, an extra stall recovery simulator session is implemented for all pilots of Turkish Airlines. • Boeing needs to improve the reliability of the radio altimeter system. • The FAA and EASA should make sure that the undesired response of the autothrottle and flight management computer to the broken radio altimeter is evaluated. They should also ensure the autothrottle and the flight management system is improved so that it is in accordance with the design specifications. • Turkish Airline should change its safety program to improve the deficiencies which were found in the report. • FAA and EASA should make (renewed) efforts to ensure airline companies are aware of the importance of reporting and make sure reporting procedures are respected. • DGCA should make (renewed) efforts to ensure airline companies are aware of the importance of reporting and make sure reporting procedures are respected.

		• Boeing should make (renewed) efforts to make sure airline companies flying Boeing aircraft are aware of the importance of reporting. • Boeing needs to review the stall recovery procedure concerning the use of the autopilot and autothrottle and the necessity to trim. • All swap requests at Turkish Airlines should now be approved by the Maintenance Control Center. • Turkish Airlines prohibited to swap flight data recorders between aircrafts. • Turkish Airlines prohibited to swap ETOPS related components on the same aircraft. • At Turkish Airlines, the changed swapping procedures will be added to the periodic training of the technical personnel. • The procedures of the Dutch air traffic control (LVNL) for lining up aircrafts, described in the rules and instructions air traffic control (VDV), should be harmonized with the ICAO procedures. The LVNL should also ensure that the air traffic controllers work in compliance with these rules of the VDV. • Boeing updated its FIM. In the FIM reference is made now to a maintenance tip which gives extra advice about radio altimeter failures. • Turkish Airlines engineering department will issue a technical information bulletin to inform the personnel about the maintenance tips from Boeing. Also extra training will be provided. All this will be done when all maintenance tips by Boeing are issued. • Boeing issued a maintenance tip which states that the antennas of the radio altimeter system cannot be tightened too much to the coax connections. Boeing issued later that it will revise this tip. They want to add a control procedure for the connector component to the antenna on the aircraft side. • Boeing issued a second maintenance tip which states “discrepant LRRA operation while the airplane is airborne”. • The Inspectie Verkeer en Waterstaat (IVW) (now Inspectie Leefomgeving en Transport (ILT)) need to check if the LVNL is working according to the national and international air traffic control procedures. • Turkish Airlines should make efforts to make sure their pilots and technicians are aware of the importance of reporting. • A bulletin was issued by Turkish Airlines for all its Boeing pilots after receiving an engineering bulletin of Boeing. • A warning bulletin was issued by Turkish Airlines for the Boeing fleet after technical information was received by Boeing. • A flight operations technical bulletin was issued by Boeing. This bulletin recommended the pilots to carefully monitor the primary flight instruments for the aircraft’s performance and the flight mode annunciation for the autoflight modes. • EASA published the safety information bulletin “Erroneous low range radio altimeter (LRRA) operations”. This publication was a repetition of Boeing’s flight operations technical bulletin which recommended the pilots to carefully monitor the primary flight instruments and the flight mode annunciations.

		• Turkish Airlines issued a bulletin on stabilized approaches[95]. • Turkish Airlines issued an advisory circular to help reduce and eliminate the rate of unstabilized approaches[95].
Adapt		• Turkish Airlines established criteria for unstabilized approaches into specific airports[95]. • Next to a three-monthly safety meeting with the higher management, a monthly operational safety meeting is implemented at Turkish Airlines. • A new study is performed at Turkish Airlines concerning the quality of aircraft maintenance (MOQA). Using the Flight Data Monitoring data the analysis of predetermined fault conditions is monitored. In this way it will be possible to discover predetermined detected faults which occur in components or systems. With this process corrective actions can be taken in time. • An aircraft reliability report is prepared at Turkish Airlines. With this report it should be possible to calculate the reliability of every aircraft in the fleet. • Information was given by Boeing to its operators about a future service bulletin. This service bulletin contains information about the software versions P4.0 and P5.0 of the Rockwell Collins EDFCS. In this new software version a comparison function will be used which compares the measured speed of the left and right radio altimeter. It is also investigated by Boeing if the GE Aviation autothrottle software can be improved so that it can compare left and right radio altimeter values in the future. • The FAA published the AEG appendix 7 ‘flight crew monitoring during automatic flight’ of the 737NG Flight Standards Board Report. In this document extra training scenarios are described together with the effects of incorrect radio altimeter values. • Boeing, the FAA and EASA should investigate the use of an aural low speed warning. If it is effective, it should be made mandatory. • The procedure of the Dispatch Deviation Guide, stating to not use the autothrottle during landing and approach if the radio altimeter showed malfunctions before, was added by Boeing to the MMEL. • ICAO, FAA and EASA should include in their regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs. • The Turkish (DGCA) should include in its regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs. • A new job card has been issued by Turkish Airlines in correspondence with Boeing’s publication “Boeing 737NG-FTD-34-09001, LRRA flags and warnings”. The job card states “corrosion coax cable cont. of connector wrap on RA”. • A second new job card has been issued by Turkish Airlines in correspondence with Boeing’s publication “Boeing 737NG-FTD-34-09001, LRRA flags and warnings”. The second job card states “fuselage drain valves func. ins. around RA antennas”. • Turkish Airlines implemented an online reporting system to increase the spread and accessibility of information.
Innovate		/

Impact		
Changes identified	What really changed	• The problem of the broken radio altimeter is well known now in the industry. Boeing issued maintenance tips and technical operational bulletins to inform the operators, technicians and pilots. • Boeing updated its FIM, with a reference to a maintenance tip. • The procedure of the Dispatch Deviation Guide, stating to not use the autothrottle during landing and approach if the radio altimeter showed malfunctions before, was added by Boeing to the MMEL. • A warning bulletin was issued by Turkish Airlines for the Boeing fleet after technical information was received by Boeing. • A bulletin was issued by Turkish Airlines for all its Boeing pilots after receiving an engineering bulletin of Boeing. • The "fasten seatbelt sign" procedure was revised at Turkish Airlines to increase safety. • To effectively monitor non-stable approaches via "flight data monitoring" at Turkish Airlines, a bulletin was issued where the 500 feet criteria was increased to 1000 feet. • Turkish Airlines implemented an online reporting system to increase the spread and accessibility of information. • At Turkish Airlines an extra two day simulator session is added to the syllabus of the second half year repetition training to improve flying safety. The most important subject added is the extra stall recovery procedure. • Independent of the periodic simulator sessions, an extra stall recovery simulator session is implemented for all pilots of Turkish Airlines. • An aircraft reliability report is prepared at Turkish Airlines. With this report it should be possible to calculate the reliability of every aircraft in the fleet. • A new study is performed at Turkish Airlines concerning the quality of aircraft maintenance (MOQA). Using the Flight Data Monitoring data the analysis of predetermined fault conditions is monitored. In this way it will be possible to discover predetermined detected faults which occur in components or systems. With this process corrective actions can be taken in time. • A new job card has been issued by Turkish Airlines in correspondence with Boeing's publication "Boeing 737NG-FTD-34-09001, LRRA flags and warnings". The job card states "corrosion coax cable cont. of connector wrap on RA". • A second new job card has been issued by Turkish Airlines in correspondence with Boeing's publication "Boeing 737NG-FTD-34-09001, LRRA flags and warnings". The second job card states "fuselage drain valves func. ins. around RA antennas". • It was decided that the swapping process at Turkish Airlines should be improved. To do so the procedures were changed. To summarize quickly, the first change was that all swap requests should now be approved by the Maintenance Control Center. Secondly, it was prohibited to swap flight data recorders between aircrafts. Next

		it was not allowed to swap ETOPS related components on the same aircraft. If these changes influence procedures, these procedures will be added to the periodic training of the technical personnel. • A new safety meeting is implemented at Turkish Airlines. • The FAA published the AEG appendix 7 'flight crew monitoring during automatic flight' of the 737NG Flight Standards Board Report. In this document extra training scenarios are described together with the effects of incorrect radio altimeter values. • EASA published the safety information bulletin "Erroneous low range radio altimeter (LRRA) operations". This publication was a repetition of Boeing's flight operations technical bulletin which recommended the pilots to carefully monitor the primary flight instruments and the flight mode annunciations. • IVW has approved the internal quality improvement plan of the LVNL[92]. • LVNL changed its procedures so that they are harmonized with the ICAO regulations[93]. • Boeing reviewed its approach to stall procedure for all Boeing models, with regard to the use of autopilot and autothrottle, by November 2011[59]. • Boeing added an aural "airspeed low alert" which triggered when the airspeed decreases below 70% of the margin to stall speed, which is represented by an amber band. The aural alert is produced by the Enhanced Ground Proximity Warning Computer (EGPWC). It is triggered at same time as the existing flashing amber box surrounding the digital airspeed display on the primary flight display. It was introduced for production on line number 3329, which will be delivered in July 2010. It is also possible to retrofit existing aircraft. An alert service bulletin has been send to the operators for this[94]. • DGCA forced all Turkish Boeing 737 users to update their training programmes and to implement EASA SIB 2009-12. Operators also had to revise their Flight Crew Training Manual[95]. • DGCA did not change anything concerning the reporting system[95]. • Turkish Airlines organises training and motivation meetings with a special emphasis on the importance of reporting[95]. • A system to notify pilots of respective risks has been implemented[95]. • Turkish Airlines reviewed and improved its safety system[95]. • The FAA should include in their regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs: agreed and notice of proposed rulemaking change was issued[96]. • FAA should make (renewed) efforts to ensure airline companies are aware of the importance of reporting and make sure that reporting procedures are respected: open[96]. • ICAO should include in their regulations that airline companies and flying training organizations have to include stall recovery training in their recurrent training programs. According to ICAO "proper flight crew coordination and training in all type of emergency and abnormal situations or procedures caused by power plant, airframe or systems malfunctions fire or other abnormities" are already part of the regulations. In addition ICAO will develop guidance material with details concerning upset recovery training manoeuvers

		within and beyond the normal flight envelope. For this material the use of flight simulation training devices is suitable. This material will be developed by the end of 2012. ICAO will also develop, by the end of 2011, evidence-based training guidance that will describe generation-specific recurrent training for inclusion in a manual. Later generation-specific type-rating programs will be added to this manual[97]. In reports of the annual safety recommendations review of 2011[60] and 2013[62] by EASA, an overview of what is decided concerning Turkish Airlines 1951 is found. If a recommendation is closed it can have three statuses, namely “agreement”, “partial agreement” or “disagreement”. The first two mean a concluding action is decided. Disagreement means no concluding action will be run. These reports state: • EASA should make (renewed) efforts to make airlines aware of the importance of reporting and ensure that reporting procedures are adhered to: closed-agreement[60]. • EASA should change their regulations in such a way that airlines and flying training organizations see to it that their recurrent training programmes include practicing recovery from stall situations on approach: closed-partial agreement, under consideration[62]. • The FAA and EASA should ensure that the undesirable response of the autothrottle and flight management computer caused by incorrect radio altimeter values is evaluated and that the autothrottle and flight management computer is improved in accordance with the design specifications: open[60].
Change/learning agent	Who/what takes care for follow-up Who/what keeps memory/knowledge alive Who/what keeps monitors effectiveness	Dutch Safety Board, Boeing, Turkish Airlines, EASA, FAA DGCA, LVNL, IWV and all operators flying with the Boeing 737. Dutch Safety Board, Boeing, Turkish Airlines, EASA, FAA DGCA, LVNL, IWV and all operators flying with the Boeing 737. No information was found on this.
Change timeline	Can phases be identified in their implementation process are implemented measures lost in time	Some actions were taken immediately after the crash. After the official accident report came out recommendations were analysed, to decide if they are implemented or not. How long it takes to take a decision depends from the recommendation. It is also possible that it takes some time to implement it. No information is found about implemented measures lost in time.
Change of investigation process		/
Evaluation of accident and follow-up		

	Conclusions and comment with respect to/ specific experiences/ observations/ discussion by ESReDA group Are changes sustained	See paragraph 4.3.3 and chapter 5. No information is found on this. It is assumed that until now all the actions taken are still in use.
References		
Communication of findings, recommendations	Reports government, safety board, investigation commission	Official accident investigation report by the Nationale Onderzoeksraad voor Veiligheid[49][107]. Annual Safety Recommendations Review 2011 EASA[60] Annual Safety Recommendations Review 2013 EASA[62] Response Ministerie van Infrastructuur en Milieu[92] Response LVLN[93] Response DGCA[95] Response FAA[96] Response ICAO[97]
	Report inspectorate/third party	/
	Company reports	Boeing Response to Safety Recommendation 4[59] Boeing Response to Safety Recommendation 3[94]
Other transfer of knowledge by parties involved, professional organizations, scientists etc.	Articles in journals, magazines, internet Courses, training Relevant links	See section References: [46][47][48]

Comments about the ESReDA Cube method

Same remarks as described earlier returned.