WHAT MAKES AN AIRCREW RESILIENT IN WAKE OF PROCEDURAL UNDER-SPECIFICATION?

Thesis/Project work submitted in partial fulfillment of the requirements for the MSc in Human Factors and System Safety

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Date of submission: 2009-06-30

WHAT MAKES AN AIRCREW RESILIENT IN WAKE OF PROCEDURAL UNDER-SPECIFICATION?

AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN THE UNDERSPECIFICATION OF STANDARD OPERATING PROCEDURES AND AIRCREW RESILIENCE

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Under supervision of Professor S.W.A Dekker

ACKNOWLEDGEMENTS

Completing this Master's course at the Lund University School of Aviation has been a fantastic journey, which I will carry with me for the rest of my life. The completion of the course was not achieved easily, as already promised to me by my colleague Jephte Lafour. I would like to thank him for showing me the way to Lund and for being a very critical supporter of this adventure. Further, I would like to show my appreciation to Professor Sidney Dekker, who has always been a positive mentor during this Master's course and thesis work. Even when I appeared to be falling back to the old hindsight labelling, he managed to squeeze the most critical and analytical thinking out of me by relentlessly asking for data and arguments. Last, but certainly not least I would like to show my gratitude to my wife Renée and my daughters Guusje and Pien. They have been part of this adventure from the beginning and without their help and support this journey would not have been as enjoyable as it has been.

ABSTRACT

Between operating reliable (i.e. according the specified procedures) and ensuring system safety there is a discretionary space to fill. In this discretionary space it is the individual who brings resilience to the system, when he or she recognizes, adapts to and absorbs variations, changes, disturbances and surprises, especially disruptions that fall outside the set of disturbance the system is designed to handle (Hollnagel and Woods, page 3, 2006). With this thesis the author attempts to capture, describe and analyze the properties of aircrews, which deal with situations in this discretionary space. In order to achieve this, the author interviewed 15 (management) pilots, discussing scenarios involving resilience properties described by Dekker and Lundström (2007). The study incorporated two types of questions: one which involves a scenario in which the procedures can not close all the uncertainties and the second question involved a question where the procedures were able to close the uncertainties but at the cost of something else. The conclusion can be reached that aircrews do possess resilient properties described by Dekker and Lundström but that these properties are under threat since the current climate in the aviation industry, does not allow the aircrews to actively enhance and train those capabilities.

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INTRODUCTION

Commercial air transport is frequently heralded as the safest of all public transport modes. This safety level, despite commercial aviation being a tightly coupled and complex activity (Perrow, 1984), was not achieved easily. Especially after the introduction of the jet engine, safety levels increased significantly. However, it was not only technical advances that led to this improvement. It was also the hard way of trial and error, training, regulation and standardization.

To cope with the increasing number of flights and simultaneously increase the aviations safety level, we have to abandon some of the common assumptions about aviation safety. An example of one of these assumptions is e.g. "following the procedure guarantees safety".

This phenomenon can often be seen in the response of an organization experiencing a serious incident or accident. For example Snook (page 201, 2000) described in his book how the U.S. military send around another pile of instructions and procedures in wake of the shoot down of two U.S. Army Blackhawk helicopters over northern Iraq. These kind of responses assume that if the human operates reliable (in other words, follows the procedures), there will be no accident. But according Leveson (2008) this assumption is not true in a sociotechnical system such as commercial aviation. According Leveson (2008) safety is an emergent property, resulting from the interactions between the system components (reliability being a system component property).

It regularly happens that aircrew find themselves in a kind of a double bind. They are trained to follow the procedures, but sometimes the conditions they encounter in their operational life, actually requires aircrew to abandon those procedures. Woods and Shattuck described this double bind in 2000. There are situations that people are blamed for not being adaptable enough; sticking to the procedures despite the circumstances (with the help of hindsight vision) actually being extraordinary requiring creative crew-actions. On the other hand, people are also sometimes blamed for not adhering to the procedures, when the people are trying to adapt to the circumstances but after the act it appeared that this non-adherence was not required and that the actual context was different than the people sensed.

Consequently, we have to realize that between operating reliable (i.e. according the specified procedures) and ensuring system safety there is quite a distance to cover, a discretionary space to fill. People regularly have to take creative decisions, when they are confronted with surprising, unknown emergent results of imperfect systems at work. Rules, regulations, manuals and textbooks cannot always cover these surprising, unknown, emergent results of systems at work. There will always be a gap between the real, dynamic, ambiguous (normal) world and what the procedures describe. It is in this discretionary space in which the individual decides to continue the approach or not, accept a short cut by air traffic control or not. It is within this space that the individual can prevent the shortcomings of the system (Pellegrino, page 88, 2004). In this discretionary space it is the individual who brings resilience to the system, when he or she recognizes, adapts to and absorbs variations, changes, disturbances, disruptions and surprises especially disruptions that fall outside the set of disturbance the system is designed to handle (Hollnagel and Woods, page 3, 2006).

Resilience engineering in that sense is different from other accident models. Resilience engineering sees failure as a (temporary) failure to cope effectively with the system complexity. In that sense failure is the flip side of success. With this, resilience engineering abandons the linear cause and effect models, which themselves are based on the Newtonian belief of action and the consequential opposite reaction. Safety is created by people doing normal work in normal organizations; normal work does not mean adhering strictly to the rules and manuals, but rather work that takes place as a result of the adjustments required by a partly unpredictable environment (Hollnagel, page 13, 2006). With this normal work the individual creates efficiency for the system by its flexibility and adaptability. However these reasons for success are also the reasons for the failures that unfortunately sometimes occur, but they are rarely the cause of the failure (Hollnagel, page 13, 2006).

In order to help aircrews with their normal work, when they are trying to adapt to the variations of their dynamic environment, indicators have been set up by Dekker and Lundström (2007) to evaluate whether an aircrew possesses resilient properties:

- How does the crew handle sacrificing decisions? Sacrificing decisions are decision where the crew has to consider and negotiate how much they are willing to borrow from safety in order to achieve production (efficiency) goals.

- Does the crew take past success as a guarantee of future safety? In many cases experience with certain events will help the crew assessing a similar event. However, in a dynamic, ambiguous environment like commercial aviation these previous experiences may also mislead the aircrew because the situation may be totally different than previously experienced.

- Does the crew keep the discussion about risk alive, even when everything appears to be safe? Operational success (a good outcome) is not necessarily evidence that the process has been accomplished with safety margins. Continuous risk assessments may make the aircrews better aware of the proximity of the safety boundaries.

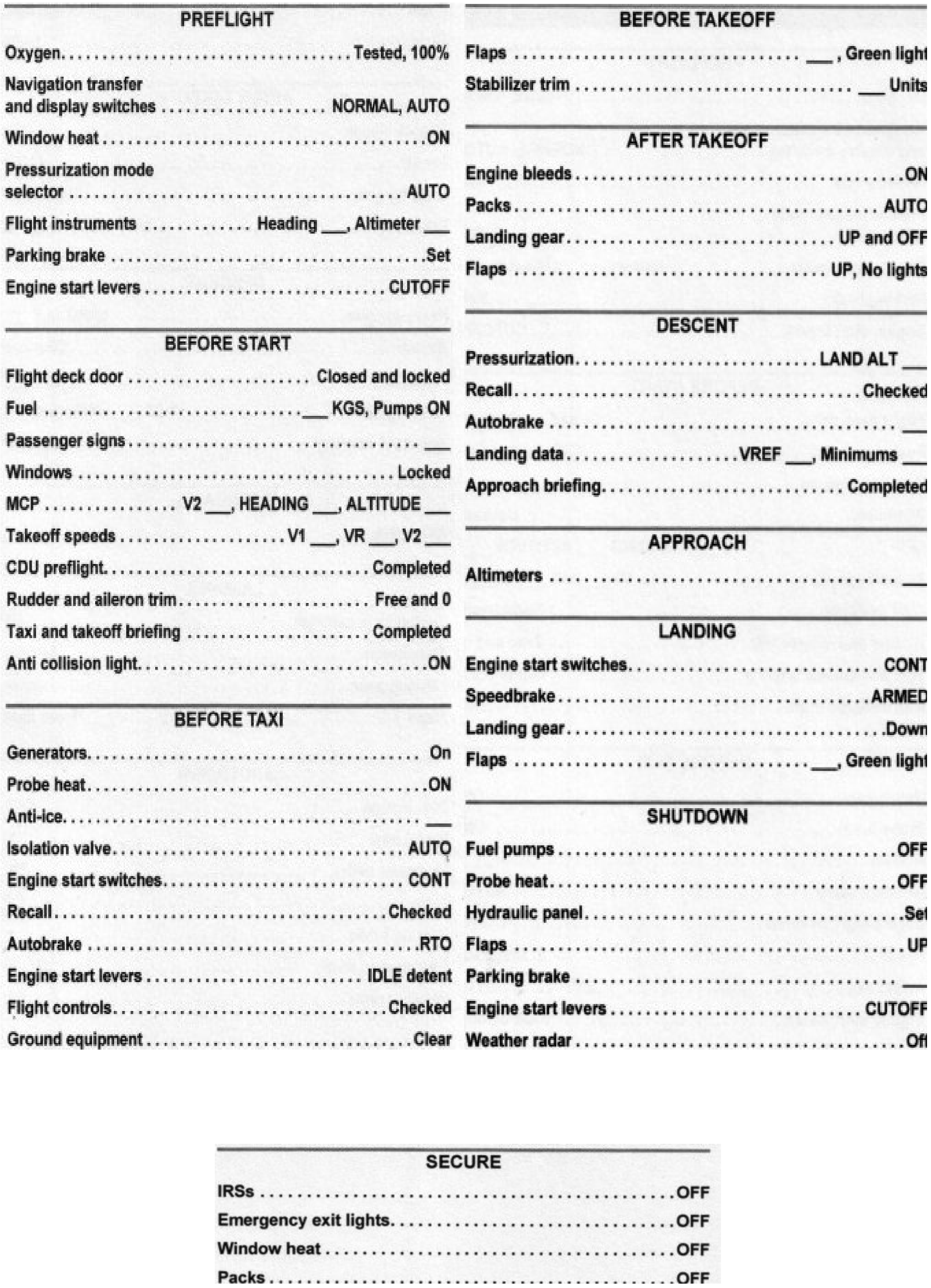
- Does the aircrew leave themselves an out in dynamic, ambiguous situations in order to have an escape possibility when the situation does not develop as anticipated? In other words, does the aircrew have the capability to avoid fixation problems (see De Keyser and Woods, page 232, 1990).

- Does the crew actively look for similarities with other incidents or accidents for their own operation? Is the crew willing to look further than the differences with those incidents and accidents? If they do that, the aircrew can apply those lessons for their own operation or situation.

Transition of specified checklists to less specified checklists.

Keeping the discussion about resilience in mind, several airlines in the Netherlands have decided to adapt the less specified Boeing Standard Operating Procedures instead of their own more specified Standard Operating Procedures. At one of the airlines e.g. the slogan used during the conversion was “less rules, more airmanship”. Consequently, there is less guidance in the Standard Operating Procedures to operate reliable as an aircrew. This reduced guidance stretches the discretionary space, where safety is relied upon the human factor. The contradiction arises when we realize that the current training programs, stated in the JARFCL, are mainly focused on textbook situations within a limited framework. This creates a conflict: on one hand aircrew are mainly trained and checked on textbook situations, which they can deal with their over trained reliable behaviour (e.g. Standard Operating Procedures and QRH handling), but as we have seen, on the other hand the real world does not only consists of textbook situations where the reliable behaviour will suffice. This creates a dilemma because the current training requirements do not cover this discretionary space, while at the same time we heavily rely on the human factor to create safety in this discretionary space. In other words, because of the stretching of the discretionary space, system safety has become more dependent on the resilient capabilities of the aircrew, while at the same time the regulator does not recognize this.

Let’s demonstrate this principle by some examples. On the next two pages you will see an example of a normal checklist of a Boeing 737 operator in Western Europe. The checklist on page 9 is the standard checklist designed by Boeing. This checklist comes with all the manuals when an airline starts operating a Boeing 737. The checklist on page 10 is a checklist that was used by an organization when it had its own Standard Operating Procedures.



PREFLIGHT

Oxygen .... Tested, 100%
Navigation transfer and display switches .... NORMAL, AUTO
Window heat .... ON
Pressurization mode selector .... AUTO
Flight instruments .... Heading ___, Altimeter ___
Parking brake .... Set
Engine start levers .... CUTOFF

BEFORE START

Flight deck door .... Closed and locked
Fuel .... ___ KGS, Pumps ON
Passenger signs .... ___
Windows .... Locked
MCP .... V2 ___, HEADING ___, ALTITUDE ___
Takeoff speeds .... V1 ___, VR ___, V2 ___
CDU preflight .... Completed
Rudder and aileron trim .... Free and 0
Taxi and takeoff briefing .... Completed
Anti collision light .... ON

BEFORE TAXI

Generators .... On
Probe heat .... ON
Anti-ice .... ___
Isolation valve .... AUTO
Engine start switches .... CONT
Recall .... Checked
Autobrake .... RTO
Engine start levers .... IDLE detent
Flight controls .... Checked
Ground equipment .... Clear

BEFORE TAKEOFF

Flaps .... ___, Green ligh
Stabilizer trim .... ___ Units

AFTER TAKEOFF

Engine bleeds .... ON
Packs .... AUTO
Landing gear .... UP and OFF
Flaps .... UP, No lights

DESCENT

Pressurization .... LAND ALT ___
Recall .... Checked
Autobrake .... ___
Landing data .... VREF ___, Minimums ___
Approach briefing .... Completed

APPROACH

Altimeters .... ___

LANDING

Engine start switches .... CONT
Speedbrake .... ARMED
Landing gear .... Down
Flaps .... ___, Green ligh

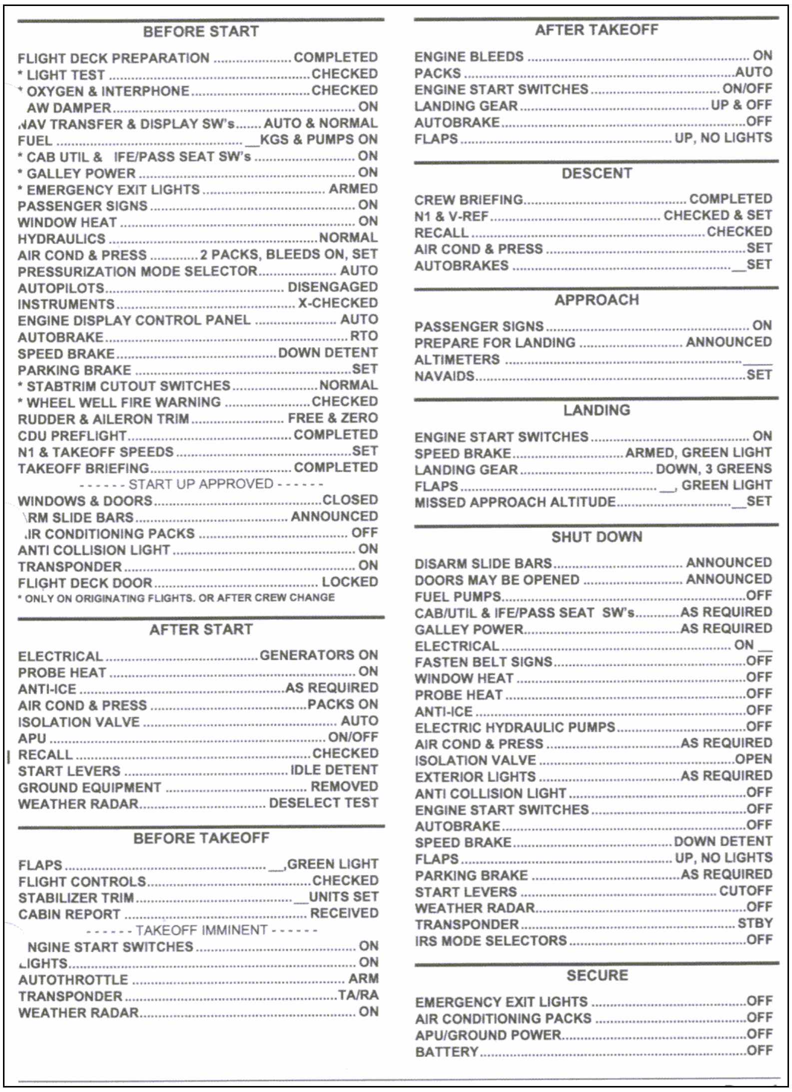
SHUTDOWN

Fuel pumps .... OFF
Probe heat .... OFF
Hydraulic panel .... Set
Flaps .... UP
Parking brake .... ___
Engine start levers .... CUTOFF
Weather radar .... Off

SECURE

IRSs .... OFF
Emergency exit lights .... OFF
Window heat .... OFF
Packs .... OFF

Figure 1: standard checklist designed by Boeing



BEFORE START

FLIGHT DECK PREPARATION	COMPLETED
* LIGHT TEST	CHECKED
* OXYGEN & INTERPHONE	CHECKED
AW DAMPER	ON
NAV TRANSFER & DISPLAY SW's	AUTO & NORMAL
FUEL	__KGS & PUMPS ON
* CAB UTIL & IFE/PASS SEAT SW's	ON
* GALLEY POWER	ON
* EMERGENCY EXIT LIGHTS	ARMED
PASSENGER SIGNS	ON
WINDOW HEAT	ON
HYDRAULICS	NORMAL
AIR COND & PRESS	2 PACKS, BLEEDS ON, SET
PRESSURIZATION MODE SELECTOR	AUTO
AUTOPILOTS	DISENGAGED
INSTRUMENTS	X-CHECKED
ENGINE DISPLAY CONTROL PANEL	AUTO
AUTOBRAKE	RTO
SPEED BRAKE	DOWN DETENT
PARKING BRAKE	SET
* STABTRIM CUTOUT SWITCHES	NORMAL
* WHEEL WELL FIRE WARNING	CHECKED
RUDDER & AILERON TRIM	FREE & ZERO
CDU PREFLIGHT	COMPLETED
N1 & TAKEOFF SPEEDS	SET
TAKEOFF BRIEFING	COMPLETED
- - - - - - START UP APPROVED - - - - - -	
WINDOWS & DOORS	CLOSED
RM SLIDE BARS	ANNOUNCED
IR CONDITIONING PACKS	OFF
ANTI COLLISION LIGHT	ON
TRANSPONDER	ON
FLIGHT DECK DOOR	LOCKED

* ONLY ON ORIGINATING FLIGHTS. OR AFTER CREW CHANGE

AFTER START

ELECTRICAL	GENERATORS ON
PROBE HEAT	ON
ANTI-ICE	AS REQUIRED
AIR COND & PRESS	PACKS ON
ISOLATION VALVE	AUTO
APU	ON/OFF
RECALL	CHECKED
START LEVERS	IDLE DETENT
GROUND EQUIPMENT	REMOVED
WEATHER RADAR	DESELECT TEST

BEFORE TAKEOFF

FLAPS	__,GREEN LIGHT
FLIGHT CONTROLS	CHECKED
STABILIZER TRIM	__UNITS SET
CABIN REPORT	RECEIVED
- - - - - - TAKEOFF IMMINENT - - - - - -	
NGINE START SWITCHES	ON
LIGHTS	ON
AUTOTHROTTLE	ARM
TRANSPONDER	TA/RA
WEATHER RADAR	ON

AFTER TAKEOFF

ENGINE BLEEDS	ON
PACKS	AUTO
ENGINE START SWITCHES	ON/OFF
LANDING GEAR	UP & OFF
AUTOBRAKE	OFF
FLAPS	UP, NO LIGHTS

DESCENT

CREW BRIEFING	COMPLETED
N1 & V-REF	CHECKED & SET
RECALL	CHECKED
AIR COND & PRESS	SET
AUTOBRAKES	__SET

APPROACH

PASSENGER SIGNS	ON
PREPARE FOR LANDING	ANNOUNCED
ALTIMETERS	____
NAVAIDS	SET

LANDING

ENGINE START SWITCHES	ON
SPEED BRAKE	ARMED, GREEN LIGHT
LANDING GEAR	DOWN, 3 GREENS
FLAPS	__, GREEN LIGHT
MISSED APPROACH ALTITUDE	__SET

SHUT DOWN

DISARM SLIDE BARS	ANNOUNCED
DOORS MAY BE OPENED	ANNOUNCED
FUEL PUMPS	OFF
CAB/UTIL & IFE/PASS SEAT SW's	AS REQUIRED
GALLEY POWER	AS REQUIRED
ELECTRICAL	ON __
FASTEN BELT SIGNS	OFF
WINDOW HEAT	OFF
PROBE HEAT	OFF
ANTI-ICE	OFF
ELECTRIC HYDRAULIC PUMPS	OFF
AIR COND & PRESS	AS REQUIRED
ISOLATION VALVE	OPEN
EXTERIOR LIGHTS	AS REQUIRED
ANTI COLLISION LIGHT	OFF
ENGINE START SWITCHES	OFF
AUTOBRAKE	OFF
SPEED BRAKE	DOWN DETENT
FLAPS	UP, NO LIGHTS
PARKING BRAKE	AS REQUIRED
START LEVERS	CUTOFF
WEATHER RADAR	OFF
TRANSPONDER	STBY
IRS MODE SELECTORS	OFF

SECURE

EMERGENCY EXIT LIGHTS	OFF
AIR CONDITIONING PACKS	OFF
APU/GROUND POWER	OFF
BATTERY	OFF

Figure 2: checklist of an airline

One can immediately see the differences between the two checklists. The checklist by Boeing is much shorter than the one designed by the organization. Some items don't show in the checklist anymore, other items are done at a different time. E.g. the "BEFORE TAKEOFF" checklist not only contained more items, the checklist was also split into two parts; the second part being read as soon as the aircraft was given permission by air traffic control to enter the runway with the intention to take-off. As one can see, in the second part items like transponder and weather radar are shown. These items do not show anywhere in the current Boeing checklist. This policy by Boeing is explained in the Normal Checklist Introduction in the Quick Reference Handbook which is part of the Flight Crew Operating Manual. The manual says (page CI.1.2, March 28, 2005):

"The checklist has the minimum items needed to operate the airplane safely. Normal checklists have items that meet any of the following criteria:

1) items essential to safety of flight that are not monitored by an alerting system, or
2) items essential to safety of flight that are monitored by an alerting system but if not done, would likely result in a catastrophic event if the alerting system fails, or
3) needed to meet regulatory requirements, or
4) items needed to maintain fleet commonality between the 737, 747-400, 757, 767, and 777, or

5) items that enhance safety of flight and are not monitored by an alerting system (e.g. auto brakes), or
6) during shutdown and secure, items that could result in injury to personnel or damage to equipment if not done".

The crucial sentence is the first one where it states that the checklist is designed to cover minimum items needed to operate the airplane safely. With this it means items like flaps and stabilizer trim because if these items are not set properly for take-off, the airplane will most likely fail to get airborne. But with this philosophy it is also shown that the manufacturer does not look to the safety of the airplane with a systems view. Flaps and stabilizer trim are crucial to ensure the reliability of the operation of the airplane once it is taking off. However if we would take a systems view (Leveson, 2008), trying to anticipate the possible interactions with the airplane's environment, we would definitely like to have the weather radar and transponder switched on (with the weather radar the pilot can detect adverse weather and when the transponder is switched to TA/RA, the traffic collision avoidance system is enabled). So, in order to ensure the safety of the system the airplane operates in, the resilient capabilities of the aircrew comes to play in order to switch the weather radar and transponder on. Without these capabilities the safety of the aviation system would be seriously degraded. One can imagine that in this manner the discretionary space Pellegrino wrote about is increased.

Another example of required aircrew resilience is in the "AFTER TAKE OFF" checklist. Both checklists contain the items ENGINE BLEEDS…..ON and PACKS…..AUTO. Both items are in the checklist to ensure that the bleed air system is switched on (the bleed system draws air from the engines) by which the packs can assure that the pressurization and air conditioning of the airplane functions properly. But with these actions (whether the switches are in the correct position) the crew is not required to check whether these correct switch positions have the desired result, which is whether the airplane is being pressurized while climbing (e.g. a seal leak near a cabin door might cause the pressurization to fail because the air which is pumped into the cabin by the bleed air system is directly leaving the airplane cabin through that seal). Whether the airplane is pressurizing properly can be checked on a different indicator, the cabin altitude panel. On this indicator the aircrew can see the results of the bleed switches in the on position and the pack switches in the auto position: in other words what is the amount of depth of checking the aircrew applies (De Keyser and Woods, page 235, 1990).
However this cabin altitude panel is not mentioned in the "AFTER TAKE OFF" checklist and consequently aircrews have to ensure the proper functioning of the pressurization and air conditioning system by not relying on past success as a guarantee for future safety but actively seeking for information. In this manner the aircrew can show resilient behavior to ensure system safety (note that reliable behavior in this example would mean that the aircrew only looks at the correct position of the bleed and pack switches, as prescribed by the Standard Operating Procedures).

METHOD OF INVESTIGATION

In order to investigate the research question "What makes an aircrew resilient in wake of procedural underspecification", the author conducted a field study among numerous aircrews and management pilots. The aircrews were mostly interviewed by telephone using a questionnaire the author developed prior to the interview; with others a personal interview was held. As the interview went along, most of the times sub-questions emerged as the pilots answered the questionnaire. Therefore often the interview became more of a kind of a discussion, where the crews philosophized about the questions and their dilemmas. Each interview averaged 90 to 120 minutes and the responses from the aircrews indicated that they acknowledged the existence of the discretionary space. The aircrews varied both in aviation experience and age. The oldest pilot to be interviewed was a Captain, 46 years of age, with 20 years of service with an international airline. He also had been a type rating instructor and examiner for over 10 years. The youngest pilot to be interviewed was a First Officer, aged 28. He had joined the airline he worked for two years ago, previously flying for a commuter airline in the UK.
The other pilots which were interviewed had less experience than the most experienced pilot described above, but more than the most junior pilot described above. By selecting a group of pilots with a wide range of experience, the author attempted to describe an as close as possible average pilot in the study.
Further, management pilots of a West-European airline were also interviewed in order to evaluate the change over from specific airline procedures to more generic manufacturer procedures and to assess whether the model that an airline management has is similar to the current dynamic reality.

The method chosen for the study was the qualitive method. This method was chosen because it is not possible to quantify someone's resilience and therefore the study was not aimed at generating definite of comparative findings (see Hollnagel and Woods, page 347, 2006). It is very hard, if not impossible to define a perfect definition of how resilient aircrew act in case of non-textbook situations. With the data generated through the interviews, the author aims to capture, describe and analyze how aircrews deal with events in the discretionary space described earlier in the introduction of this thesis. The conclusion then can be drawn that resilience is something an individual/team/organization *does* and not what an individual/team/organization *has*.

In order to be able to capture as accurate as possible the resilience properties of the different aircrews, the questions most of the times described a certain scenario in which the crew had to indicate which options came to mind in their decision making process. Further, there were two type of questions developed here. These two different types of questions may lead to insights about different cognitive activities that may be associated with the creation of resilience in situations for which the guidance from procedures is different. The first type of question addresses a situation in which procedural guidance is available to address certain aspects of the issue at hand (e.g. how much crosswind to accept, how to do the AFTER TAKEOFF checklist) but where such guidance is insufficient to close all the uncertainty associated with the decision. In other words, crew discretion is necessary to help close that uncertainty. The various options will involve various kinds of costs in operational terms, which will doubtlessly enter a crew's decision making process, but the procedural guidance available does not specify which option to take.

The second type of question involves a situation in which procedural guidance is capable of closing the uncertainty of the decision entirely. In other words, procedural guidance will specify precisely what to do in that type of situation, but there are significant operational costs associated with taking that specified option. Discretion on part of the aircrew is necessary to weigh whether the option specified is worth taking relative to the sacrifice that is expected to exist from other important goals of the operation. This could ask crews more directly to make a sacrificing decision against the background of clear procedural guidance that suggests only one acceptable alternative (which might indicate a situation where the idea of how work is done, is different than how work is really done in real life, see e.g. Dekker, page 89, 2006).

With the results of these two types of questions, the author is curious whether there are different kinds of cognitive processes and resources necessary to be brought to bear to deal with the two different types of questions. Are the aircrews using different kind of cognitive processes in the creation of resilience to deal with these two types of questions described above?

RESULTS OF SITUATIONS WHERE THE PROCEDURES DO NOT CLOSE ALL THE UNCERTAINTIES.

In this section we will discuss some questions which were discussed with the aircrew. As stated earlier the questions in the interview were based on the resilience properties described by Dekker and Lundström in their 2007 article. Besides the properties described in this article the following discussion involves situations where the procedural guidance is not sufficient to close all the uncertainties. In other words creative decisions are required to solve the situation. Let us start with a scenario described to the aircrew:

> "When entering the airspace of your destination airport you are told that due to strong westerly winds (28 knots), you are required to hold over the initial approach fix for 30 minutes. Because of this strong westerly wind, the destination airport is only able to accept landing traffic on the runway which allows a landing in to the wind, and therefore a sequence of arriving aircraft develops. This delay in the landing time is not really a big problem since you have anticipated this already, and therefore you took some extra fuel with you which will enable you to hold for 30 minutes. While approaching the initial approach fix, you are offered a landing on the southerly runway, which will expedite your arrival. What are your intentions? Are you are going to hold overhead the initial approach fix for 30 minutes and land into the wind or do you accept a landing in a southerly direction with 28 knots of crosswind (crosswind limit for the particular aircraft was 33 knots)? And above all, why do you do that?"

This decision can be considered creative because the manual will specify the maximum crosswind limit, but the manual will not specify which decision to take in this instance which includes multiple options. Aircrews will have to take into account the sacrifices it will take (in this case more risk during the landing since the aircraft is operating at or near it's certified crosswind limits and most likely near or at the limits of the capabilities of the aircrew) versus the operational gain following such a decision. Manuals can not close these uncertainties entirely, so aircrew discretion is required.

80% of the pilots indicated that they would accept a landing on the southerly runway and consequently the 28 knots of crosswind. They indicated that they did not feel this as commercial pressure or other kinds of pressure. They rather indicated they found it a waste of time and fuel (and by that a financial waste) to hold for 30 minutes, while having the option to land without having to hold.

A pilot with 8 years of experience as a Captain:

> "I would choose runway 18C (the runway in southerly direction), purely because of commercial reasons. It is true that you take more risk but the wind velocity is within the margins of the airplane and my capabilities. However, the First Officer has to agree on the course of action and with gusting wind conditions I pose additional requirements such as sufficient visibility and the clouds not being too low".

A First Officer with almost 4 years of experience flying a Boeing 737:

> "Given the situation described, I would take runway 18C. The requirement is that it should not be a gusting wind; it should be a steady wind. Am I taking more risk? Yes, definitely but sometimes you get a certain runway assigned by ATC and then you don't have a choice at all. Also there are lots of airports with no runways available for a landing into the wind. Further if

> I was the Captain, I would decide that the Captain should be the one who is flying the approach and landing and both crewmembers should be comfortable with the decision; in other words it should not become a single pilot approach".

Similar to the two statements above, other aircrews also indicated that additional requirements had to be met. These requirements consisted e.g. of the necessity of both pilots agreeing on the decision. They would not allow a situation to develop where an approach was started with one of the pilots actually not wanting to start the approach at all. Other requirements included: no gusting component in the crosswind (this would make the landing even more difficult since then it is hard to anticipate whether the wind strength will increase or decrease in that split-second), good visibility and no presence of low clouds (this would complicate the landing further since the runway than only can be seen in a later stage of the approach and thereby increasing the difficulty of the landing), aircrew was not allowed to be fatigued and lastly the pilots indicated the preference for having the Captain acting as pilot flying and with that the person with the most experience at the controls.

Another scenario where procedures were not able to close all the uncertainties was presented to the pilots. This time it involved an approach into an airport which was dealing with showers of rain and thunderstorms. In such a scenario it is hardly possible to close all the uncertainties, since this scenario will involve a dynamic, rapidly changing context which is often presented to the aircrews in the form of ambiguous (weather) information.
The scenario presented to the aircrews consisted of the following: the ceiling of the clouds during the approach would be 800 ft, being comfortably above the 200 ft. minimum altitude during the approach. During the turn towards the final approach the pilots are informed of a pilot report of the preceding airplane. The aircrew of this airplane reported a smooth approach, indicating no problems with the current weather conditions. The question then arose whether the aircrew would accept commencement of the approach while their weather radar showed presence of showers on the final approach.

A 38 year old First Officer flying with an intercontinental freight airline:

> "Depending on the situation shown by the weather radar (where are the echo's?), wind direction and the many changes possibly combined with wind shear alerts, I would decide whether to start the approach or not. The report of the previous airplane that all was ok does not mean a lot to me. It can be totally different when I am on final approach for landing. What determines whether I will start with the approach or not, is the picture painted by the weather radar combined with other information such as wind direction and velocity".

A 46 year old type rating examiner of a Boeing 737:

> "What is the total picture regarding the weather? Are the (rain) showers moving away quickly, or are they the more stationary type of showers? Is it a squall-line or are the (rain) showers and thunderstorms more scattered so that I can navigate around them? These are some thoughts whether or not to start with an approach. Also I would like to know what type of aircraft the pilot was flying when he or she made the rapport. On top of that I want to discuss the possibility of a missed approach with my First Officer. If necessary I would ask Air Traffic Control for a revised missed approach procedure when that would be necessary in order to stay clear of the showers."

Similarly to the statements above, other pilots also indicated that the pilot report of the preceding aircrew absolutely did not indicate that everything would be fine during the approach. Actually there was one remark of a pilot who declared to be even more suspicious when he would hear that kind of report. On the other side, the pilot report also did not indicate that it would be unsafe to start the approach. Rather the aircrew made their decision whether to start the approach or not based on information seen on the weather radar (is it a local rain/thunder shower or is more like a squall line?), the wind direction reported at the airport and the wind direction at the current flight altitude (in other words, where are the showers moving to?) and the possibility of a break-out; would the approach allow the airplane perform a go-around in the direction of an area without significant weather.

Lastly the aircrews were presented the following scenario which included performance issues during the take-off:

> "During your final preparations for a flight commencing from an airport with a relatively short runway, you have the option to take off with the standard flap setting (flaps 5) with full thrust on both engines or to take off with a non standard flap setting (flaps 15, which will allow the airplane to leave the ground earlier, which is quite handy on a short runway) and reduced thrust on both engines (note: reduced thrust is a world wide accepted method to take off with less than full thrust in order to save the wear and tear on the engines, thereby accomplishing a financial gain for the organization. These performance calculations are based on approved performance manuals and aircrews have to make these calculations every time they take-off). Which option would you choose?"

Most of the pilots (70%) opted for the possibility to take off with more flaps (flaps 15 in this case) and take off with reduced thrust. The motivation for them was pure commercially; it saved the organization money by not having the engines working to the limit. Safety, according them was not really an issue, since the margins of both take offs would fairly remain the same.

A recently promoted Captain:

> "With this scenario I would opt for the flaps 15 take-off because of several reasons. First of all you save the organization money by having the engines not working to their limits. Secondly, if an engine failure occurs, you still have the possibility to add additional thrust up to the maximum take off thrust. Besides that, I think the chance of having engine troubles with reduced thrust is less than when the engines are working at the maximum. However, to remind myself that we are about to do a non standard take off with a different flap setting, I will put a clothes peg at the flap handle during the performance calculations. This is a physical reminder that we have to select a different flap setting than usual".

The scenario described to the aircrews itself did not pose major issues. However, in their decision the aircrews had to take the consequences of the option for flaps 15 into account. The issue the pilots indicated was how to remember to take off with the non-standard flap setting of flaps 15. Since 99% of the take offs are done with flaps at 5, there is a risk that the calculations are done for flaps 15 (and with that reduced thrust on the engines and flaps 15 margins), but the actual take off is done with flaps 5 which would seriously degrade the aircrafts take off performance. Complicating this story is the fact that the particular airplane most aircrews were flying did not have a take-off configuration warning system which would compare the calculated flap setting during the performance calculations and consequently put in the Flight Management Computer with the actual flap stetting; in other words it is possible to calculate to take off with flaps 15 and put that number in the Flight Management Computer and take off with flaps 5 since the actual flap setting (flaps 5) is an approved take off flap setting and thus consequently would not trigger the configuration warning system. The aircrews involved indicated that they were fully aware of this potential danger. Creative solutions were revealed such as putting a paper through the flap-handle in the cockpit or putting a plastic cup on it. This then would trigger the aircrew upon physically selecting the required flap setting. Also the crews indicated that these kind of take offs required a more consciousness than the regular take offs where performance issues are not the case (in other words longer runways). This consciousness according the aircrews is achieved by doing the preparations at a slower pace combined with these kind of creative solutions described above.

RESULTS OF SITUATIONS WHERE THE PROCEDURES CAN CLOSE THE UNCERTAINTIES, BUT AT A CERTAIN COST.

The second type of question involved questions which described situations where the textbooks and procedures are able to close all the uncertainties, but will do so at the cost of something else. It is up to the aircrew to decide how far they will go to accept that certain procedures are not practical or even safe in a given situation. Let us start with an example of a so called category 3 approach.
These kinds of approaches occur when the airports suffer from foggy weather conditions. Typically in "normal" weather conditions, the most standard approach (the so called Instrument Landing System) allows the aircraft and their aircrews to fly the approach in instrument conditions down to an altitude of 200 ft. above the ground with a visibility of around 600 meters. After that the aircrews have to complete the landing manually by steering the airplane visually to the runway. When (heavy) fog is present at an airport these values may not be enough to allow an aircraft to land, since the visibility and cloud ceiling will be below those values and consequently force an aircraft to abandon the approach and divert to another airport.

For this reason so called low visibility approaches have been developed, where the technical equipment of the airport and airplane in combination with training for the aircrew will allow the aircraft to land in these foggy weather conditions. These approaches are called category 2 approaches (limits typically being 100 ft. ceiling and a visibility of 300 meters) or category 3 approaches (limits being typically 50 ft. ceiling and a visibility of 200 meters). Landings in these kind of conditions require the aircrew to perform an automated landing (auto lands in various airplanes require that multiple autopilots to be engaged, e.g. in the Boeing 737 it requires two autopilots and in the Boeing 777 it requires three autopilots giving the system a certain redundancy), where the airplane will land itself guided by the instruments both on the ground and in the airplane. This is considered to be safer since the human eye will have difficulties adjusting itself to the rapid changing conditions and therefore spatial disorientation would be very likely. As everybody will imagine, landing in those conditions requires a clear task description for both crewmembers in order to avoid any ambiguities. A lot of airlines therefore developed strict procedures regarding the task description of both crewmembers during the category 3 approach. Typically this will see the Captains adjusting their vision more and more to the outside world from an altitude of 500 ft. From about 150 ft. (being 100 ft. above the decision altitude) the Captain will have his vision solely outside, looking for cues of the runway environment. At an altitude of 50 ft. the Captain will decide whether to land or not.
The First Officer will typically only look inside the cockpit during the whole approach, scanning for potential failures and monitoring the progress of the approach by watching the airspeed, heading and altitude closely. If any deviation from certain prescribed parameters or any failure occurs, it is the task of the First Officer to inform the Captain instantaneously.

As described earlier, recently several airlines have decided to implement the Standard Operating Procedures of the manufacturer of the airplane they are flying. The only specifications those procedures make is that the Captain should be the one who is flying the airplane and that the pilot monitoring the approach (in this case the First Officer) should "expand the instrument scan to include outside visual cues when approaching the Decision altitude (Height)" (Boeing Flight Crew Operating Manual, Volume 1, page SOP 5.5. And 5.6., February 18, 2009).

This creates a dilemma because when the pilot monitoring (First Officer) is looking outside for visual cues, the Captain must be looking inside monitoring his approach. This means that at a very low altitude (50 ft.) both pilots have to change their field of vision: the Captain must change his field of vision from the inside instrument scan to the outside world because he has to decide whether to land or not, the First Officer consequently has to change his field of vision from the outside scan to the inside instrument scan and to monitor the flare manoeuvre by the autopilot (which is indicated on the Flight Mode Annunciator located above the artificial horizon) and the retarding of the thrust levers to enable a landing without excessive speed. One can question whether it is desirable to have both pilots change their field of vision at such a low altitude potentially leading to spatial disorientation.

When the aircrew is to perform an actual Category 3 approach they are now faced with a dilemma. The procedures do not describe specific tasks during the approach and especially not below 500 ft. A situation can arise where at low altitude either both pilots are looking outside for visual cues to complete the landing (and thus nobody is looking inside to monitor the flight instruments) or both pilots have to change their field of vision.
When this situation was presented to the pilots in the interviews virtually all of them indicated that they would do the Category 3 approach in the old fashioned way.

A First Officer with 4 years of experience and 29 years old:

> "As a Captain I would brief the following items: the standard approach briefing done with a normal ILS approach; on top of that when the engagement of the second autopilot has to take place and besides that, emphasize who will be looking inside and outside the aircraft. When there are failures, stress the obligation to mention them. The task description who does what has become very important since the introduction of the Boeing procedures. Last few months I have had experience with actual Category 3 approaches and all the Captains I have flown with suggested doing it the old fashioned way. They indicated the First Officer (the pilot not flying) was not in a position to decide whether to land or not, that had to be done by the Captain since he is the one who is flying the airplane."

Other aircrews indicated that the ambiguities created by the current manufacturer's manual are potentially decreasing the safety level of the flight during the last part of the approach. Various pilots indicated that the approach briefing had become even more crucial to discuss the tasks both pilots are required to perform. The potential safety degrading consequences of the way the current procedures are written are forcing the aircrews to create clarity themselves because the procedures are creating a discretionary space where the task description of both pilots may be unclear and ambiguous.

Another example of procedures which principally close a certain situation but at a certain cost occurs during a "normal" Instrument Landing System approach. With "normal" this time I mean an approach with weather conditions sufficient for a Category 1 approach (see above). During this approach the landing must be conducted manually by visually steering the airplane to the runway. The approach itself can be done by the autopilot till reaching the minimum altitude during the approach (typically being 200 ft. above the runway).

The current procedures for the Boeing 737 prescribe this kind of approaches to be flown with two autopilots engaged, similar to the Category 3 approaches. This engagement of the two autopilots has the following two consequences: an automated go-around is possible (go-around is the manoeuvre where the airplane aborts its landing attempt and starts climbing again) and secondly at an altitude of 400 ft. the stabilizer trim starts to trim the airplane in a nose up attitude (the system is designed this way since the autopilot is thinking that it will be performing an automatic landing, the stabilizer trim up is needed in the event of a go-around and it also needed for the airplane to be able to perform the flare manoeuvre during the last phase of the landing).

If an aircrew has to perform an approach in to an airport having a Category 1 landing system, then the crew has two options: 1) Perform the approach as described by the manuals, in other words engage two autopilots, disengage both autopilots at a convenient time and land the airplane manually, or 2) engage only one autopilot during the approach, which in itself is a violation of the procedures, and disengage the autopilot at a convenient time and land the airplane manually.

The scenario presented to the pilots during the interview was the following:

> "When you perform an approach to an airport which only has a Category 1 approach, do you engage one or two autopilots? The weather during the approach is near the limits for the approach, being 200 ft. overcast and 600 meters visibility".

All the aircrews interviewed were fully aware of the advantages and disadvantages of the two options described above. They were indicating that despite the procedures prescribing the use of two autopilots during the approach and consequently having to deal with the aircraft being in a trimmed nose up attitude, they considered this highly undesirable at a low altitude with these weather conditions.

A 28 year old First Officer:

> "I am aware of the potential possibility of an automated go around and the pitfalls of having the airplane out of trim at a low altitude. I would opt for having one autopilot engaged since the advantage of the automated go around is less important than the disadvantage of having an out of trim airplane with these weather conditions. An out of trim situation can potentially change your flight path and you don't want that to happen. I will only do an approach with two engaged autopilots when we will perform an auto land."

A 43 year old Captain:

> "I will absolutely do it only with engaged autopilot; I am aware of the fact that the books say that I have to engage both autopilots, but I find it far more important to have an in trim airplane at such a low altitude with these weather conditions."

Similarly to the two above statements, other pilots indicated that they also would use one autopilot during the approach. With the prescribed weather conditions of 200 ft. overcast and 600 meters of visibility it was considered undesirable, potentially unsafe and more difficult to disengage the two autopilots at such a low altitude and consequently getting an aircraft in their hands which would be significantly out of trim complicating the landing in these conditions. Also the possibility of a tail strike was mentioned (this is a situation where the nose of the aircraft has such a high attitude that the underside of the fuselage near the tail of the aircraft touches the ground first). The advantage of having the possibility of doing an automated go-around when the two autopilots are engaged was not considered to be significantly important because the go-around manoeuvre was not considered to be a difficult task by the aircrew interviewed.

As a last example of a situation where the procedures can close the situation but with certain disadvantages, I will describe a situation regarding the loading of freight and luggage on an airplane.

Luggage and freight is loaded in the belly of the aircraft; most aircraft have two separate cargo doors; one in front of the wing and the other one behind the wing. As one can imagine this cargo and luggage loading can have a significant impact on the stability of the airplane. If al the cargo and luggage is put in the rear cargo compartment, one can imagine that the airplane becomes tail heavy and subsequently will display an unstable equilibrium. Also if all the cargo and luggage is loaded in the front compartment, one can imagine that the airplane will be nose heavy and it might have difficulties to get airborne when taking off. For this reason most organizations have set up rules how to distribute the cargo and luggage; not only in quantities but also which section to unload first or last and also which section to load first or last.

Procedures with a particular organization mandated the aircrew to load the cargo and luggage 50%/50%; in other words 50% of the total cargo weight must be loaded in the front compartment and the other 50% must be loaded in the rear compartment. The organization implemented this rule after one of its aircraft suffered a tail strike during the take-off due to an uneven distributed cargo and luggage weight.

The situation described to the pilots was the following:

> “Imagine yourself performing a flight with two destinations (a.k.a. a triangle flight); for the first destination 30 passengers are expected (and thus also roughly 30 pieces of luggage) and for the second destination 150 passengers are expected (and consequently roughly 150 pieces of luggage). Do you insist on the 50%/50% division, or will you accept a loading of the luggage which will separate the luggage for the two destinations. In other words will you allow the ground handling to put 30 pieces of luggage in one hold and the remaining 150 pieces of luggage in the other hold (most likely the rear compartment because that compartment is bigger). The weight and balance calculation indicates that the airplane is within its limits during the flight.”

The fact that the weight and balance calculations indicated that the airplane would stay within limits during the flight was the reason for many pilots during the interviews to accept this division of luggage as illustrated by the statement below:

A 35 year old First Officer:

> “I will accept this situation because the load sheet indicates that it is possible. Besides that, an aft centre of gravity reduces the fuel flow during flight and it saves time during turnarounds. I am aware that the manual indicates a 50/50 division, but at that time I have to deal with an actual situation and not a theoretical situation described in a certain manual.”

They also indicated that they really liked it to do this way since it would not cause any complications during the turnarounds of the aircraft at both destinations; if they would insist on the loading the luggage 50%/50%, then the luggage of two different destinations would get mixed and consequently it would take longer to unload and reload the luggage and there would be a great danger of forgetting a small number of luggage pieces at one destination.

The aircrews were also aware of the possibility that during the turnaround at the ground, the airplane could become out of balance when the front luggage compartment would be emptied (especially when also a considerable number of passengers is present in the back of the airplane). According the aircrews then the risk existed that the airplane would start tail tipping, in other words the nose gear of the airplane would leave the ground and the airplane would rotate around its main gear till the tail of the airplane would hit the ground).

According to the aircrews the only way to prevent this from happening was a close coordination with the cabin staff and ground handling during disembarkation, in which the cabin staff had to monitor the situation and make sure that the passengers would leave the airplane in an evenly distributed way; preferably by disembarking through both the front and rear of the airplane or otherwise make sure that the aisle of the airplane would be constantly filled and thus make sure that there would not be a risk for tail tipping.

REFLECTIONS OF THE RESULTS ON EXISTING LITERATURE

With the first type of question, the question describing where procedures do not close all the uncertainties, it was remarkable what kind of creative inventions aircrews exercise in order to create safety. These creative inventions often include resilience enhancing properties without the aircrew being actually aware of it. E.g. the scenario describing whether or not to accept a landing with a large crosswind component, is a good example of a sacrifice judgment unconsciously created by pressures to be faster, better and cheaper at the same time (Woods, page 24-25, 2006). As indicated the aircrews did not experience these pressures to be explicit, but as the aviation industry struggles with its profitability, these (implicit) pressures may have been normalized (Vaughan, 1996) in the past decades.
A consequence might be that an organization is operating closer to the marginal boundary than it realizes (Cook and Rasmussen, 2005). In that situation the aircrew might consider it normal to accept these sacrifices in order to gain efficiency, but I found it remarkable that in those instances the aircrew would pose additional constraints such as no gusting wind component and good visibility in the crosswind example. In the other example of the taking off and having the option to choose between multiple flap positions creative constraints like putting a clothes peg on the flap handle in the cockpit emerged.
By maintaining the discussion about risk alive in these instances, the aircrews left the possibility open for e.g. a missed approach (see example about landing with rain showers and thunderstorms). In that sense they had given them selves a role break-out, enhancing resilience of the operation.

These properties make it clear that the construction of risk by the aircrews is a process which involves requisite imagination (see Adamski and Westrum, page 193-220, 2003); anticipating for key aspects of the future the aircrew is planning to pursue.
The question then arises whether this anticipation for the future is vulnerable for degrading factors. It is known e.g. that in complex situations requiring controlled cognitive processing, acute stress hampers skilled performance by narrowing attention and reducing working memory capacity (Staal, 2004 in Dismukes, Berman and Loukopoulos, page 299, 2007). Also as mentioned earlier a macro-level organizational drift might have an internalized and sub-conscious influence on micro-level decision making (Vaughan, 1996).
If we would apply the traditional way of risk assessments, then we would try to remove the stress factors and influences on decision making (e.g. by constructing barriers in the process). However, taking a resilience engineering approach to this matter, it might be better to try to enhance those anticipating capabilities. It is suggested that we not only should focus on rule and procedural following like it is done nowadays, but also ways have to be explored how to enhance the sensitivity of aircrews to variety of the dynamic, often ambiguous situations they regularly encounter. In that way aircrews will be better able to evaluate whether skill and rule based behaviour will suffice in that situation or that the situation requires a proactive approach, where the aircrew needs to apply resilience enhancing strategies in order to avoid the unconsciously crossing of safety boundaries by anticipating the consequences of the possible interactions between the diverse system components.

With the second type of question, the question describing situations where the procedures are able to close all the uncertainties but at certain cost of something else, two major items can be observed.
First of all, the phenomenon of “work as imagined versus work as actually done” appears to be present in this issue (see e.g. Dekker, page 89, 2006). In this situation the organization involved has a different view how actual work on the work floor is done. Consequence of this can be that

the applicable procedures are not matching the actual working conditions. People then have to "invent" procedures themselves which give them the opportunity to accomplish the multiple goals they pursue. This can e.g. clearly be seen in the example of the approach into an airport having a Category 1 landing system. The aircrew have to choose between two options; either follow the procedures completely and that means engage both autopilots for this approach and consequently having to deal with an airplane which is out of trim when disengaging the autopilot at a low altitude or the other option is only to engage one autopilot (contrary to the procedures) and consequently not having to deal with landing an out of trim airplane.
In the other example of the Category 3 approach the same phenomenon could be seen. The experience of the aircrews with other (non manufacturer) procedures, gave the aircrews the possibility to compare both procedures (in other words they kept the discussion about risk alive). In this comparison the aircrews weighed the pros and cons of the procedures of the manufacturer against those of the airline involved. In the opinion of the aircrews such Category 3 approaches are so critical because of the need of clarity concerning the roles to be fulfilled by both crewmembers and the critical low altitude where all this happening during such an approach.

When one of airlines was asked about this issue, they acknowledged the existence of this discrepancy. An employee of the department Safety and Quality Assurance stated that he would like to see that the actual operations would be the same as the procedures in the book. In his view that would lead to enhanced safety because there would be no vagueness how to execute a certain procedure among the aircrew (because it is in the book). Of course this is true to a certain extent but the side-effects of those procedures have to be anticipated by the aircrew and the negative side-effects of the procedures described above are very real. In this sense one can argue that the procedures developed by the aircraft manufacturers are written with a different perspective; a manufacturer has other (legal) priorities than an airline and the airlines must ask themselves whether it makes sense to have procedures which the airline already knows are not really fitted for the real operational world.

The second phenomenon that could be seen with the question where the procedures are able to close the uncertainty completely but at a certain cost was the implicit influence of macro efficiency pressures upon an organization. In the example of the loading of an airplane in case of a flight with multiple destinations the question arises whether it is reasonable to expect a loading of 50% in the front hold and 50% in the aft hold when such (large) differences in the number of passengers can exist for the two destinations. When the organization at the same time insist on 40 minute turnaround times (turnaround time is the time an aircraft spends on the ground with the intention to disembark passengers, clean the aircraft, refuel the aircraft, perform a security check in the cabin and finally embark the next load of passengers) people are forced to make tradeoffs between thoroughness and efficiency (Hollnagel, page 152-155, 2004). Again, in this instance the aircrews are subconsciously forced to apply a creative solution, because the procedures do not synchronize with the dynamic reality. By distributing the luggage in such a way that the balance issues of the aircraft are not a factor, the aircrews show resilient behaviour. The danger of this resilient behaviour is not that the airplane will be out of balance, but that an organization takes past success (a safe flight, within balance and an on-time departure) as a guarantee for future safety. An organization can be tempted to e.g. shorten the turn-around times, squeezing the time pressure even more in order to be more efficient and the result can again be that the organization is operating closer to the marginal boundaries than it realizes (Cook and Rasmussen, 2005).

CONCLUSION

An answer to the question “What makes an aircrew resilient in wake of procedural underspecification?” was not found easily. After this study I am convinced the answer to this question is a combination of requisite imagination, sensitivity to dynamic variety and having experiences with both good and bad occurrences. This combination creates a foresight, which aircrews use to make their risk assessments in order to create safety. The results suggest that the underspecification of procedural guidance implies foremost an insensitivity to contextual fluctuations and subtleties, and goal conflicts. The resilience of flight crews to deal with situations in which there is no specification, or underspecification, expresses itself through the need for them to extemporize, even invent procedures to accomplish multiple active goals simultaneously, and to manage the negative side effects of procedures. This sort of response is testimony to the embellishment or increase of requisite variety that is necessary to meet situations that fall outside existing or even possible procedural guidance.

However, the risk aircrews will have to deal with is that the context they operate in does not help to develop this foresight and requisite variety as described above. Regulations are nowadays only limited to (technical) skills and rules. Aircrews are therefore often left to their own, to develop these skills. Airlines, under the pressures of severe economic constraints, are more and more relying on the creation of safety by the people at the sharp end. This leads to a situation in which the creation of safety by people at the sharp end actually degrades the model organizations have of their current safety level. Situations then can arise where organizations have a disjointed idea how actual work takes place, potentially seducing them to rely more and more on the people at the sharp end. This process will ultimately break at a point (Woods and Wreathall, page 143-158, 2008) where the sharp end is unable to cope with the diverse constraints and pressures exercised upon them. Therefore in order to keep the sharp end (in this thesis the aircrews of airlines) resilient, organizations have to realize that this resilience starts at their own organization by continuously investing in the anticipation of failure by assuming that their model of safety is imperfect.

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