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CAN PILOTS STILL FLY?

ROLE DISTRIBUTION AND HYBRID INTERACTION IN ADVANCED AUTOMATED AIRCRAFT

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Abstract

Recent accidents of commercial airplanes have raised the question once more whether pilots can rely on automation in order to fly advanced aircraft safely. Although the issue of human-machine interaction in aviation has been investigated frequently, profound knowledge about pilots' perceptions and attitudes is fragmentary and partly out-dated. The paper at hand presents the results of a pilot survey, which has been guided by a collaborative perspective of human-automation decision-making. It puts emphasis on the hybrid interaction of human actors and non-human technical agents and the role distribution in the digital cockpit. The key question is whether pilots have confidence in human-automation collaboration, even in the case of automated systems, which act more and more autonomously.

The results are partly surprising: confidence in hybrid collaboration is rather high, depending mostly on perceived symmetry of humans and automation as well as on perceived change of competencies and role distribution. The perception of complexity is only average, and – most unexpected – this factor does not negatively affect pilots' confidence in hybrid collaboration. The differences between Airbus and Boeing pilots are much lower than assumed, but pilots of regional jets, mostly flying short- or medium-range aircraft, differ from both groups remarkably, presumably due to their specific task profile, including a high number of opportunities to collaborate with automation.

Keywords

aviation automation, human-machine interaction, confidence, complexity, survey

Zusammenfassung

Können Piloten noch fliegen?
Rollenverteilung und hybride Interaktion in hochautomatisierten Flugzeugen

Eine Reihe von Flugzeugunfällen in der Zivilluftfahrt der letzten Jahre hat die Debatte wiederbelebt, ob Piloten, die computergestützte Flugzeuge fliegen, sich auf die automatischen Systeme verlassen können. Trotz einer Vielzahl von Studien zur Mensch-Maschine-Interaktion der Luftfahrt ist unser Wissen über die Wahrnehmungen und Einstellungen von Piloten fragmentarisch und teilweise veraltet. Der vorliegende Beitrag stellt die Ergebnisse einer Pilotenbefragung vor, die das Zusammenspiel von Mensch und Technik im Prozess der Entscheidungsfindung in den Mittelpunkt rückt. Es geht also um die Kollaboration von menschlichen Akteuren und nicht-menschlichen Agenten in hybriden sozio-technischen Systemen sowie um die Rollenverteilung im digitalen Cockpit. Die zentrale Fragestellung lautet: Wie stark ist das Vertrauen von Piloten in diese neuartige Form der Mensch-Maschine-Kollaboration ausgeprägt, insbesondere im Fall hochautomatisierter Systeme, die zunehmend autonom agieren?

Die Ergebnisse der Studie sind teilweise überraschend: Das Vertrauen in die hybride Kollaboration ist sehr hoch und hängt stark mit der wahrgenommenen Symmetrie von Mensch und Technik sowie mit dem wahrgenommenen Wandel der Kompetenzen und der Rollenverteilung zusammen. Im Gegensatz dazu ergab die Frage nach der wahrgenommenen Komplexität nur mittlere Werte; die größte Überraschung war jedoch, dass sich dies nicht auf das Vertrauen in die hybride Kollaboration auswirkt. Die Unterschiede zwischen Airbus- und Boeing-Piloten sind viel geringer als erwartet. Piloten von Regionaljets, die zumeist Kurz- oder Mittelstrecke fliegen, heben sich jedoch von den beiden anderen Gruppen deutlich ab, vermutlich aufgrund des spezifischen Aufgabenprofils mit häufigen Starts und Landungen, das viele Gelegenheiten zur Kollaboration mit den automatischen Systemen mit sich bringt.

Schlagworte

Mensch-Maschine-Interaktion, hochautomatisierte Systeme, Luftfahrt, Vertrauen, Komplexität, Befragung

1. Introduction

Since advanced automated systems entered the stage of civil aviation in the 1980s, there has been a long-lasting debate among scientists as well as among practitioners, whether operators can rely on automation (Wiener/Curry 1980, Gras et al. 1994). Additionally, several factors that affect trust in automation in a positive or negative way have been identified, such as the design of displays and human-machine interface, or the training of crew communication (Sarter/Woods 1992, Parasuraman et al. 2008).

Some debates, like the one on the cockpit with only two crewmembers, have been settled. Almost all manufacturers have now adopted the cockpit design of the Airbus A320, introduced in the late 1980s (Ibsen 2009). It has proofed its performance and – above all – has got a high record among pilots (Sarter/Woods 2000, Weyer 2008).

Nevertheless, recent accidents of commercial airplanes have raised the question once again, if pilots can rely on automation in order to fly a modern aircraft safely. Issues like mode confusion, automation surprises, or loss-of-control, which have been discussed and investigated since the 1980s (Wiener/Curry 1980, Billings 1997, Sarter/Woods 1997), suddenly "pop-up" again, as if nothing had happened in between. As the recent issue of the "Statistical Summary of Commercial Jet Airplane Accidents" (Boeing Commercial Airplanes 2013) points out, loss-of-control has even been the major cause of accidents of commercial airplanes with 1648 on-board fatalities in the period of 2003 to 2012, compared to controlled-flight-into-terrain (CFIT), the second major cause with 971 on-board fatalities (p. 22).

One example is the accident of Air France flight AF-447, where an Airbus A330 crashed over the Atlantic on June 1, 2009. Press reports initially had identified a mixture of bad weather conditions, technical failures of the pitot tubes, and a malfunctioning of the airborne computer systems as causes of this accident (e.g. FAZ 09.06.2009: 9). However, the accident investigation report clearly states that the plane has never been in a critical state, but basic skills have been missing in a stressful situation of only a few minutes length, which-could have been managed by a well-trained crew (BEA 2012).[1]

In contrast, the case of the Airbus A320, which survived a severe incident by watering on the Hudson River on January 15, 2009, points to the importance of basic skills, which Charles Sullenberger, however, had acquired in other contexts such as teaching, accident analysis, or flying sailplanes etc. (FAZ 17.01.2009: 7).

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[1] This has been confirmed by Peter Dehning (interview Dec. 10, 2012), a retired Lufthansa pilot who has been captain at the A330 for several years and experienced similar situations frequently. He stated that crews needed (i) a common mental picture of the situation, (ii) basic skills of flying stolidly straight on for a while without steering inputs, and (iii) a clear division of labour between the pilot flying and the pilot non-flying, the latter of whom should concentrate on the diagnosis and troubleshooting.

The near-accident of the Qantas A380 on November 4, 2010 also underlines the significance of well-trained humans as crisis managers on board of a highly automated plane. In this case, the pilots have been able to manage an extremely dangerous situation after the explosion of an engine that could have ended in a total loss of this brand new plane (FAZ 03.12.2010).[2]

On the contrary, an Airbus A320 only survived a critical condition while landing in Hamburg (Germany) during a thunderstorm on March 1, 2008 by a fortunate coincidence. This incident again revealed the weakness of the Airbus design, which inhibits pilots to take appropriate action in an emergency situation (BFU 2010). This also raises the question, whether a Boeing plane would have performed better (Dorschner 2012, Ibsen 2009, Braunberger 2006).[3]

Hence, 25 years after the introduction of the glass cockpit and fly-by-wire technology into civil aviation, it seems to be reasonable to evaluate again if the socio-technical system "aircraft" is designed in a way that provides the human part with necessary means to cope with critical situations. Although accident rates have gone down during the last decades (Boeing Commercial Airplanes 2013), the risk of a system failure is still present and may even rise in the future due to growing air traffic, increasing performance expectations, and a growing number of autonomously operating, unmanned aerial vehicles.

These incidents and accidents point at the issue of human-machine interaction (HMI) in controlling complex socio-technical systems, which has been subject of human-factors research for decades (cf. among others Sheridan 2006, Grote 2009). However, as automation increases more and more, a deeper understanding of these topics is required, based also on novel sociological concepts, dealing with the hybrid interaction of human actors and non-human technical agents (Rammert 2011). This change in perspective also demands for new strategies to investigate HMI issues empirically.

We will argue in the following that automation research can gain by shifting from "either-or"-questions (either humans or machines) to the perspective of distributed action (Hutchins 1995), human-automation collaboration (Cummings/Bruni 2009), or coagency, respectively (Inagaki 2012), and, finally, hybrid socio-technical systems (Weyer 2006, Fink/Weyer 2014). The latter research strategy may better help to understand the role distribution in the digital cockpit and to figure out obstacles on a way to an efficient interaction between human and non-human parts of the hybrid socio-technical system aircraft.

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[2] http://www.faz.net/-gqi-6lldp.

[3] Heinz Jürgen Lachmann, former president of the German pilot association VC, has argued that a Boeing plane would never have reached this critical stage because it allows pilots to countersteer sudden wind shears even near ground level, which is impossible at Airbus (personal communication Sept. 17, 2012).

As a first step towards an investigation of human-automation collaboration in advanced automated aircraft, we are searching for empirically informed answers regarding the following questions:

1. Do pilots have confidence in human-automation collaboration, even in the case of automated systems, which act more and more autonomously?
2. Which factors, like e.g. the perception of changing competencies at the flight deck or complexity of automated systems, influence pilots' confidence?

Starting with a theoretical overview of the academic debate on aviation automation, we will frame our five hypotheses in Section 2. Section 3 will present the study's design, our methodology, and the constructs. In Section 4 we will outline and discuss our results in detail, after which Section 5 will summarize the results.

2. Theoretical background

The issue of human-machine interaction has been subject of a variety of studies in automation research as well as within the theory of distributed action in hybrid systems. With regard to trustful and reliable collaboration, the following strands of research are relevant: the empirical, partly experimental analysis on trust in automation (Section 2.1) and the conceptual models of human-automation collaboration (2.2). In the following, we will discuss these two issues as well as the research on those factors, which may affect a reliable collaboration positively or negatively (2.3).

2.1. Research on trust in automation

Many investigations have been conducted on trust in automation in the field of ergonomics and human-factors research (Moray et al. 2000, Lee/See 2004, Dzindolet et al. 2003). Many of these studies have been guided by the concept of function allocation, asking why operators sometimes disuse or even misuse automation.[4]

Overtrust – similar to complacency – can be regarded as a typical irony of automation, since systems that have proofed to be reliable for a long time may lead operators to misuse the automation in a sense that they become heedless and fail to check the system vigilantly (Inagaki/Itoh 2013). On the other hand, malfunctions and disappointed expectations have been identified as major sources of distrust in – and finally disuse of – automation. Referring to Manzey (2008, Onnasch et al. 2014), three main factors, which affect trust in automation can be identified: reliability, confirmability, and usefulness (cf. Figure 1).

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[4] Parts of our arguments in this section are based on Robin Fink's recent dissertation „Vertrauen in autonome Technik" (Fink 2014), especially on Chapter 4.

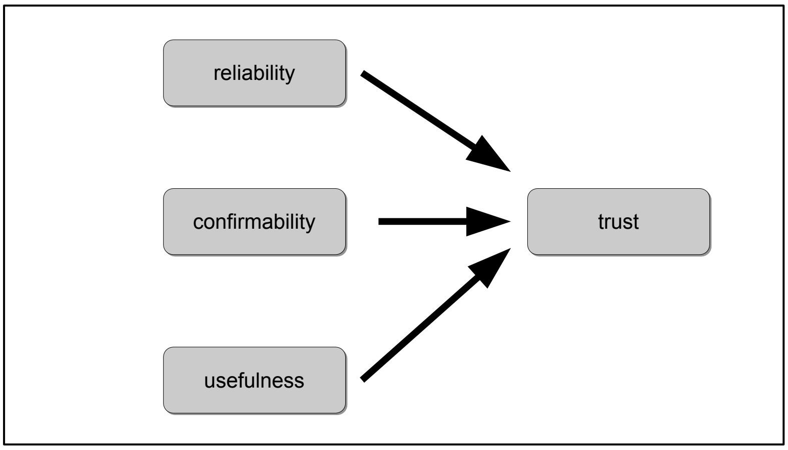

Figure 1: Factors affecting trust in automation (Manzey 2008)

Trust in automation can be defined as an attitude in an interactive constellation in which one agent attributes expectations toward the other to perform parts of a common task in a predictable and cooperative way (Lee/See 2004). The behaviour of the automation, the transparency of the system and the usefulness of its operations (always: as perceived by the human) influence the level of trust on part of humans.

Although referring to human-automation interaction, the cited concept of trust does not adopt a collaborative perspective, since trust in automation is mostly defined as a *human* activity attributing trust to technology, resulting in allocating the operation either to the automation or to the human (cf. Fink 2014: 83). Hence, we need a concept of confidence in human-machine collaboration that goes beyond the unilateral concept of trust in automation. In order to distinguish our approach from former ones, we use the term “confidence” in the following.

The next section will briefly check concepts of human-automation interaction by including other perspectives, e.g. from sociology, which go beyond the scope of engineering and ergonomics research.

2.2. Human-automation collaboration in hybrid socio-technical systems

The traditional concept of function allocation (MABA-MABA)[5], which served as a kind of starting point of human-factors research, puts forward the question of who is better: the (hu)man or the machine (Fitts 1951). The human-centred approach has gone beyond this perspective by accepting a large share of automated operations, but insisted on the ultimate decision authority on part of humans (cf. Sheridan/Parasuraman 2006: 94f.), the function of which has been described as “supervisory control” (Sheridan 1999).

In contrast to these two varieties of “either-or” thinking, recent theorizing on this issue emphasizes an even more *collaborative* perspective of human-

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[5] “Men are better at – machines are better at”.

automation decision making, which requires a "mutually supportive environment in which the human and computer collaborate to arrive at a solution superior to that which either would have come to independently" (Cummings/Bruni 2009: 437).

Distributed agency and coagency

Many researchers in the field agree with Sarter's statement that humans and automated systems should act as "team players", who communicate and coordinate their actions (2000). These collaborative settings can be regarded as socio-technical systems, the reliable functioning of which depends on "the quality of interaction of humans and automation" (Manzey 2008: 309, translated by the authors).

Hutchins (1996, 2006) describes the cockpit as a distributed socio-technical system, where "memory tasks … may be accomplished by functional systems which transcend the boundaries of the individual actor" (1995: 284). His concept of "distributed cognition" (1996) also transcends the borders of human agency, since "memory processes may be distributed among human agents, or between human agents and external representational devices" (1995: 284).

Going beyond this cognitive concept, the CASA-model ("computers are social actors", (cf. Reeves/Nass 1996)) analyses the modes of interaction in different settings (human/human, human/computers). By means of laboratory experiments, Takayama and Nass discovered that people interacting with computers "actually engage in the same kinds of social responses that they use with humans" (2008: 174) – thus confirming a new kind of role perception on part of a human interacting with a machine.

Moving one step further, Inagaki developed the concept of "human-technology coagency" (2010), which assumes an equal status of both agents acting within the socio-technical system. Stepping beyond the model of human-centred automation, he argues that "situation-adaptive autonomy, in which the human and the machine trade authority dynamically depending on the situation gives better results than the case in which the human is always in command" (2010: 154).

Hybrid interaction in socio-technical systems

This idea of collaboration exceeds the traditional frame of ontological schemes in philosophy, which attribute agency only to humans (Sturma 2001). The actor-network theory (ANT) has – in a very provocative manner – pushed forward the idea of symmetry of humans and nonhumans (Latour 1988, 1996), which needs a nonbiased analysis of mixed settings.

Rammert and Schulz-Schaeffer refined this concept of distributed agency (Rammert 2011, Rammert/Schulz-Schaeffer 2002). From their point of view, agency is not an ontological quality of an entity but results from attribution processes that may assign agency as well to humans as to machines. Due to this attribution, humans assume rational reasons for actions – an attitude they apply both in interactions with humans as with computers, as the CASA concept has already proofed.

As Fink/Weyer (Fink/Weyer 2014) have shown, these hybrid constellations of human actors and autonomous technical agents can be investigated by means of simulation experiments.

The conceptual approaches presented in this section transcend the traditional "either-or" perspective and depict a new picture of human-automation collaboration. Since the concept "trust in automation" only covers one side of the coin, we use the concept "confidence in hybrid collaboration" in the following, indicating a shift from a unilaterally directed relation between two entities to a multilateral concept of two or several agents, where confidence is not attributed from one part to another but towards the collaborative multi-agent arrangement as a whole (cf. Figure 2).

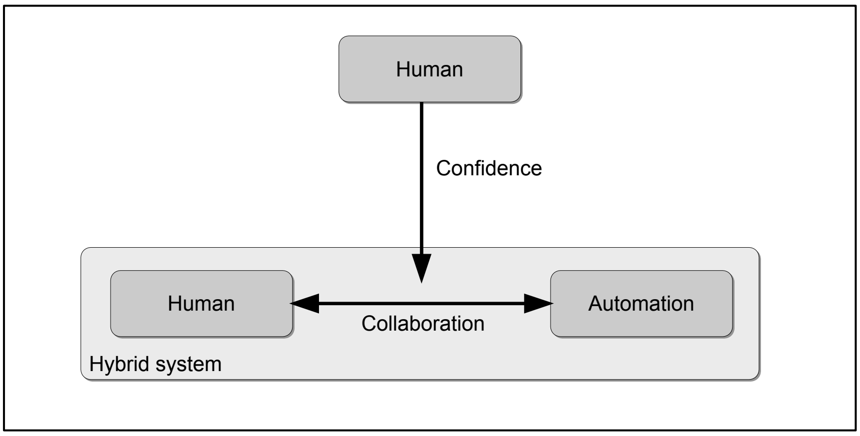

Figure 2: Confidence in hybrid collaboration

If this holds true, one source of confidence might be the symmetry of the collaborating partners. MABA-MABA and the concept of supervisory control both relate trust to the ability of the operator to override automation – and thus to an asymmetrical relation. In contrast, we assume that human-machine interaction in advanced automated systems can be regarded as a symmetrical constellation and that this symmetry serves as a source of confidence. In order to investigate this new constellation, we phrased our first hypothesis as follows:

> (H1) A high degree of perceived symmetry implies a high degree of perceived confidence in hybrid collaboration.

To countercheck the opposite paradigm of "supervisory control" (Sheridan 1999), arguing that pilots should always have the ultimate decision authority in the automated cockpit, we state as our second hypothesis:

> (H2) The more pilots want to have the ultimate authority, the lower is their confidence in hybrid collaboration.

The next three hypotheses are more closely linked to automation-related problems in aviation, which we will discuss in the following section.

2.3. Automation-related problems in aviation

At first glance, the aviation sector seems to be over-researched, especially regarding automation issues. There is a large number of academic (and non-academic) publications on topics such as automation surprises, mode errors, complacency, and other issues of human-automation interaction in advanced automated aircraft. Different methods have been applied (partly combined), ranging from case studies, inflight observations (Hutchins 1995), workplace studies, analysis of pilots' self-reports (Sarter/Woods 1997), secondary analysis of investigation reports or safety reporting systems, simulator experiments (Sarter/Woods 2000: 390) and, finally, surveys (BASI 1998, for an overview cf. Funk et al. 1999).

However, since Wiener's famous survey of pilots' attitudes towards automation published in 1989, only four comparable surveys have been conducted, partly replicating his study (see Table 1). Furthermore, only one of these four surveys (Naidoo 2008) has been conducted since the year 2000, which points at the need of replicating this kind of inquiry and to collect up-to-date evidence on aviation automation. Surprisingly, research on trust in *aviation* automation is rather scarce, compared to the large number of studies in this field in general.[6] There is only one study (Naidoo 2008) that takes this issue into account – with inconclusive results though (see below).

Comparison of pilot surveys

Furthermore, the four studies apply different methodologies, partly descriptive statistics with single items (uni-/bivariate), partly factor analysis (multivariate).

But even descriptive statistics differ insofar as some studies refer to mean values, others to percentages. For example, concerning the issue of mode understanding, McClumpha et al. calculated a mean value of 3.57 on a five-point scale, saying that most pilots understand "all the modes and features of the FMS" (1991: 110).[7]

On the other hand, the Australian Bureau of Air Safety Investigation found out that 10.9 % of the pilots disagree when being asked about mode understanding (BASI 1998: 42). However, if one recalculates this numbers using the original data, the mean value amounts to 3.8 – even slightly better than 3.57.

So the question arises, which numbers are meaningful to what extent? If a relevant share of pilots gives negative answers (or fails to perform in simulator experiments), this can be regarded as an indicator of risk. According to Sarter

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[6] We define automation as „the transfer of singular functions or even complete tasks from humans to machines" (Manzey 2008: 309f.), which may include manual operations, manual control or cognitive tasks. Aviation automation thus may refer to automated operations (e.g. maintaining speed), automated control (e.g. setting parameters) or automated decision-making (e.g. switching flight modes).

[7] FMS – Flight Management System

Table 1: Outlook of pilots' surveys		**Wiener 1989**	**McClumpha 1991**	**BASI 1998**	**Hutchins 1999**	**Naidoo 2008**
	method	survey	survey	survey	survey	survey
	number of items	36	78	42	16	85
	N	299	572	1268	562	262
	type of analysis	descriptive	component analysis and descriptive	descriptive	descriptive, correlations, cluster and factor analysis	descriptive and factor analysis
	Uni/bivariate analysis					
1	positive attitudes towards aviation automation	**yes**	**yes**		**yes**	**yes**
2	pilot out-of-loop		**no**	**yes**		
3	pilot as manager	**yes**			**yes**	
4	boring monitoring tasks			**yes** (Airb:no)		
5	“button pusher”	**no**			**no**	
6	automation leads to head down		**no**			**undeterm.**
7	mode confusion	**no** (but 25%)	**no**	**no** (but 10,9%) **yes** (Airb:yes) **undeterm.** (but 31%) **no** (but 15%)	**no**	
8	automation surprises	**yes**	**no**	**yes** (Airb: yes)		
9	switch to manual mode		**yes**			
10	coping with problems	**no** (but 25%)	**yes**		**undeterm.**	
11	automation hinders crew communication	**no**	**no**			
12	Airbus vs. Boeing			**Airb:** **yes** (see above)		**Airb:** **yes** (design)
13	short-range vs. long-range					**yes** (training: co-pilots on long-range)
	Multivariate analysis	*descriptive*	**correlations**	*descriptive*	*descriptive*	**correlations**
14	Factor “(system) understanding”		**neg.** (age/recoded) **pos.** (experience)	*yes (but 21%, Airb:no)*	*neg. (experience)*	**neg.** (age) **neg.** (experience)
15	Factor “(good) training”	*yes*			*yes*	**neg.** (age) **neg.** (experience)
16	Factor “trust (in automation)”					**pos.** (experience, effects too small)
17	Factor “(lower) workload”		**pos.** (CPT)	*yes*	*yes*	**no signif. corr.**
18	Factor “(good) design”		**neg.** (experience)	*yes (Airb:no)*	*yes (experience)*	**pos.** (experience, effects too small) Airb:pos.
19	Factor “skills (loss)”	*yes*	**neg.** (age)	*undeterm.*	*yes*	
	Legend: pos – positive correlation (items in brackets) neg – negative correlation (items in brackets) yes – most pilots agree (mean value > 3, partly recoded) no – most pilots disagree (mean value < 3, partly recoded) but – a relevant share is mentioned by authors to vote for the opposite direction Airb – Airbus pilots differ from Boeing pilots					

et al. (2000: 399), this should be taken seriously. By means of simulator experiments on mode errors (with 18 probands) they discovered that automation surprises still exist and only 22 to 67 percent of the pilots did take appropriate action, while the others failed.[8]

Mean values tend to mask these risks, at least when percentages of negative answers or negative performance are lower than 25%. Hence, assessment of data may be very divers depending on the look at mean values or percentages.

For an overview, we therefore tried to harmonize results of five surveys in a way that makes them comparable. Percentages have been converted into mean values, but relevant shares of answers that may point to risks have been noted as well (cf. Table 1). Additionally, since questions sometimes headed into opposite directions, answers have been carefully adapted and partly recoded.[9]

Results of pilot surveys

The state of the art in research on automation in aviation, as represented by five pilot surveys (cf. Table 1), can be summarized as follows:[10]

- Pilots' attitudes towards automation are generally positive (line 1).*
- Pilots regard themselves as managers of a complex system (line 3) but not as "button pushers" who passively react to the system (line 5).*
- Most pilots understand the modes of the automated systems, but mode confusion is still an issue for 10 to 25 percent of the interviewed persons (line 7).*
- Automation surprises still occur (line 8).*
- In some cases, Airbus pilots give very different answers than Boeing pilots (lines 4, 7, 8, 12, cf. also lines 14, 18).*
- A similar difference can be observed in case of pilots on short-range flights (line 13).*

Moreover, two reports have conducted a component analysis leading to four (McClumpha et al. 1991)[11] or six factors (Naidoo 2008) partly overlapping.[12] Their findings (complemented by some of the arguments of other surveys) can be summarized as follows:

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[8] We excluded one „nasty" exercise, where only one out of 14 pilots managed to perform the task.

[9] We take line 14 ("system understanding") to explain the coding of Table 1: By means of multivariate analysis, McClumpha et al. (1991) found a negative correlation („neg") of age and system understanding but a positive correlation ("pos") between experience and system understanding. Descriptive analyses that confirm these findings are added in italics. According to BASI (1998), most pilots report a good system understanding ("yes"), except from 21% who disagree ("but:21%"). Additionally, a higher share of Airbus pilots disagree compared to Boeing pilots ("Airb:no").

[10] The asterisks indicate which items we will consider later in our study.

[11] This study is methodologically sound but based on bi-polar statements on a five-point scale, which may make some results invalid and complicate comparison with other studies.

[12] Hutchins et al. (1999) also conducted different factor and cluster analysis but mixed them up in a confusing way. It is only partly possible to compare their findings with the other two studies.

- System understanding is negatively correlated with age, which means: younger pilots report a better understanding than older ones (line 14 – strong agreement among reports).*
- System understanding is negatively correlated with experience: The more time pilots have spent with advanced flight decks automation, the less is their understanding (line 14 – partly contradictory findings).
- Trust in automation has been investigated by only one study, leading to inconclusive results (line 16).*
- Workload has been reduced by automation (line 17 – weak evidence).
- There is no clear evidence if the automated flight deck is well designed and if correlations of design and experience or design and type rating (Airbus vs. Boeing) exist (line 18).*
- The degradation of flight skills is negatively correlated with age, meaning that older pilots are less concerned (line 19 – inconsistent evidence).*

To sum it up: There is only limited consensus among experts in the field of aviation automation. Furthermore, except from a few items (namely: general attitudes, system understanding, and mode confusion) there is no clear evidence concerning the effects automation has on the ability of human pilots to successfully manage the complex socio-technical system aircraft. Empirical evidence is inconclusive concerning the questions whether pilots' skills and competencies have improved or degraded since the introduction of the advanced automated aircraft and whether pilots regard these developments as positive.

Since our study focuses on confidence in hybrid collaboration (lines 1, 14, 16), we decided to primarily include issues of role distribution (lines 3, 5, 19), type rating (lines 12, 14, 18), and complexity (lines 7, 8), and neglect other topics such as training (line 15) or workload (line 17).

To cover the changes in role distribution between pilot and automation, we phrased our third hypothesis as follows, assuming a positive impact on confidence:

> (H3) A high degree of (perceived) changing competencies implies a (perceived) high level of confidence in hybrid collaboration.

A confident collaboration between humans and automation may suffer from lacking system transparency caused by its complexity and increasing autonomy. Therefore, our fourth hypothesis reads as follows:

> (H4) The more complexity is perceived, the lower is the level of confidence in hybrid collaboration.

Differences between the product philosophies of the two big aircraft manufacturers, that show up in the surveys, are also mentioned frequently in literature, with a high level of automation control at Airbus, where the automation can even override the operator, while Boeing pilots always have more scope to take decisions (Ibsen 2009, Dorschner 2012, Naidoo 2008: 10-41). We assume that this leeway has a positive effect on confidence. Hence, our fifth hypothesis is:

> (H5) Boeing pilots perceive a higher level of confidence in hybrid collaboration.

Moreover, the results of former research reveal differences between pilots of long-range and short-range aircraft, probably caused by different task profiles with a higher frequency of landings at short-range flights and more opportunities to interact with automation. According to the state of research on aviation, we will also have to control for age and service type (short-haul vs. long-haul) which may affect the dependent variable "confidence in hybrid collaboration".[13]

2.4. Excursus on methods of automation research

Usefulness of surveys

Admittedly, doubts may arise whether a survey of pilots' attitudes is a suitable way to study these issues. Surveys and retrospective recordings provide valuable data on individual experiences and perceptions; however, they face the problem of different biases, like the one of social desirability (Sarter/Woods 2000: 391). This applies all the more in case of well-trained professionals who have studied complacency and other automated-related issues intensively – at aviation school, in further training, or maybe also because they work as instructors or supervisors.

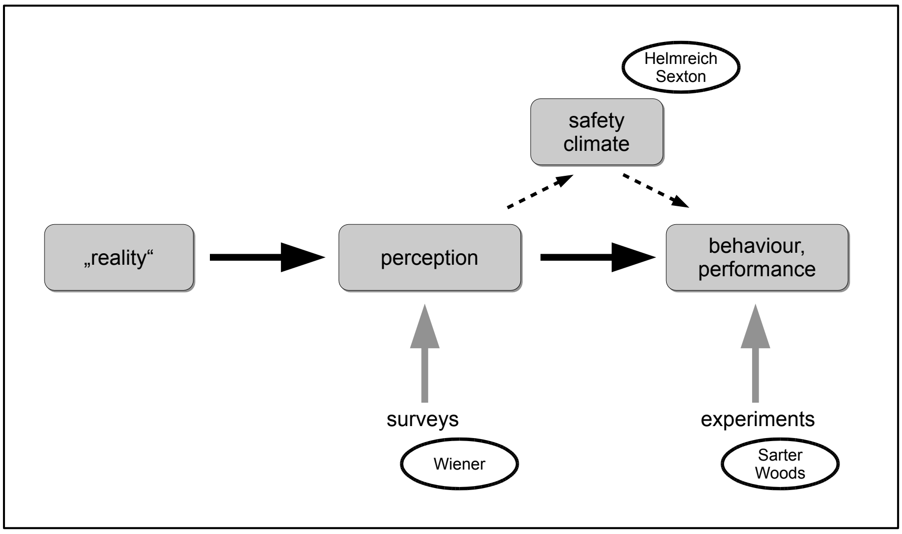

Figure 3: Outlook of research in aviation automation

Most of the questionnaires used in the past contained several plump and suggestive statements, which directly referred to theoretical discourses and forced probands to give answers in a reflective manner, such as "The overall work-

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[13] Since age is highly correlated with experience, we disregard experience as separate variable.

load on this flight deck is much lower than on a non-automated one" (McClumpha et al. 1991: 110). This kind of probes runs the risk of receiving predominantly textbook answers – instead of individual perceptions.

Of course, perceptions do neither reflect reality "correctly", nor do they offer a direct link to factual behaviour, but they provide a cue to the individual construction of reality (Berger/Luckmann 1980). These constructs are important components of decision-making, as psychological theory of behaviour (Naidoo 2008: 37ff.) or sociological theory of action (Esser 1993) tell us (cf. Figure 3).

Except from surveys, various other methods have been applied investigating automation issues in aviation.

Helmreich/Sexton: Analysis of safety climate

Helmreich, Sexton and others also conducted a large number of surveys (in health and in aviation sector)[14], but they took individual perceptions only as a means to deduce the organisational safety climate.[15] The latter (independent variable) was examined as a factor that positively or negatively affects team performance (dependent variable) (Helmreich/Sexton 2004). The scientists figured out that "highly effective cockpit crews use one third of their communications to discuss threads and errors in their environment, regardless of their workload, whereas poor performing teams spend about 5% of their time doing the same" (Sexton et al. 2000: 748).

Without a doubt, this research strategy is an important step (i) to overcome the individualistic perspective of most studies, (ii) to bridge the "gap" between perceptions and behaviour, and (iii) to move towards an analysis of organisational culture(s) similar to the studies Hofstede et al. (2010) conducted. However, although very valuable, these studies do not (or only marginally) deal with automation issues but mainly attitudes towards teamwork and hierarchy and thus do not contribute much to the debate on aviation automation.

Sarter et al.: Simulator experiments

As mentioned above, Sarter, Woods, and others have applied different methods, among others simulator experiments, which mostly tested pilots' ability to cope with mode errors. Sarter and Woods argue that many incidents and accidents are rooted in "breakdowns in coordination between crew and automation" (2000: 5), which, amongst others, come from a violation of "pilots' expectations about automation behaviour" (Sarter/Woods 1997: 562). They point at the mismatch between pilots' mental models and the system's state, which is less observable to the operators, when the system has a higher degree of autonomy and authority (Sarter 2008).

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[14] A variety of questionnaires, which have mostly been used in the health sector can be downloaded at https://med.uth.edu/chqs/surveys/safety-attitudes-and-safety-climate-questionnaire.

[15] It is rather difficult to figure out how the authors developed their results. Only superficial summaries have been published, but not the original research.

Complemented by Manzey (2008: 317) the following crucial factors can be identified as causes for pilot's errors (cf. Figure 4):

1. Poor monitoring of the system caused by overreliance and low vigilance;
2. poor feedback on part of the automated systems, caused by poorly designed interfaces and displays;
3. lacking transparency of the system's state, mostly caused by the system's complexity and increasing autonomy;
4. gaps in pilots' mental models (e.g. in case of lacking situation awareness).[16]

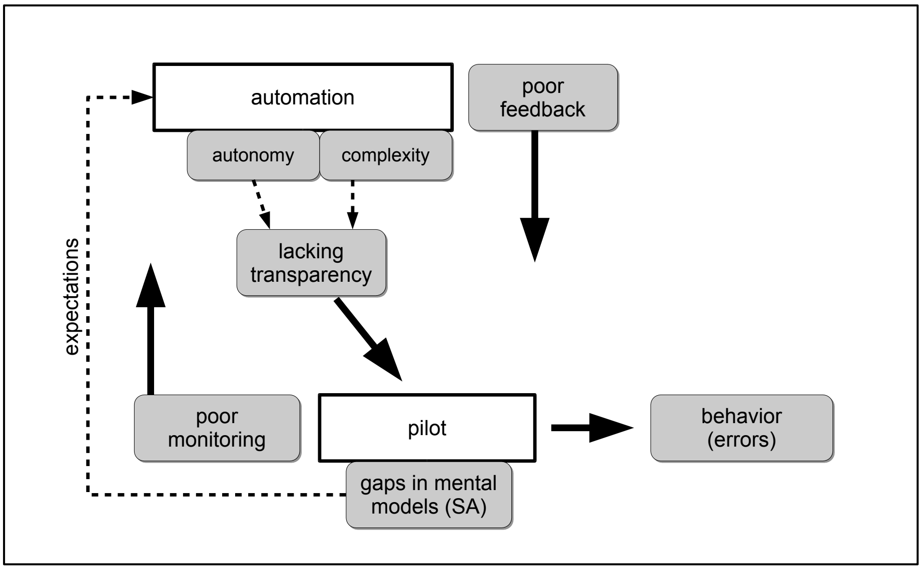

Figure 4: Causes of pilots' errors (Manzey 2008: 317, Sarter 2008: 507)

Compared to surveys, methods such as inflight observations or simulator experiments come closer to real behaviour but face other methodological limitations such as small numbers of probands or the artificial character of crisis scenarios. Additionally, they run the risk to deduce attitudes (independent variables) that cannot be measured directly from observed behaviour (dependent variable). For example, Sarter et al. assert: "As there is no direct measure of mode awareness, pilot's level of awareness of the automation configuration was inferred from their responses to scenario events" (2000: 395) – a problematic mixing of dependent and independent variables. A combination of different methods, e.g. simulator experiments andquestionnaires, might help to overcome those deficits (cf. Fink/Weyer 2014).

Are surveys still a useful method?

In spite of the limitations and alternatives discussed above, a well-designed survey seems to be an indispensable component of a comprehensive analysis

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[16] It is difficult to figure out, if Sarter et al. really have investigated all these aspects and if the design of their studies is sufficient to make far-reaching statement of this kind.

of human-machine interaction in automated systems like the digital cockpit, best combined with other methods. A survey may help to figure out pilots' perceptions and attitudes towards advanced automated aircraft, but above all they may help to find out whether (perceptions of) automation-related problems have changed in the last decades.

However, an up-to-date questionnaire ought to avoid suggestive questions and abstract statements directly derived from automation theory. It should furthermore reflect the shift from the MABA-MABA-concept[17] of the past, which forced to think "either-or", to more recent concepts of human-automation collaboration (HAC), which put emphasis on the team play and cooperation of humans and autonomous technology.

2.5. Interim conclusion and research model

Our outlook of research on aviation automation presents a surprisingly ambiguous picture. Despite decades of investigation there is only limited empirical evidence on major issues like trust in (aviation) automation as well as a lacking consensus among researchers on many other topics (cf. Section 2.3).

Moreover, recent theorizing on human-automation collaboration (Section 2.1) points at the need to reframe the theoretical model and to create a suitable research strategy to empirically investigate new types of hybrid constellations. Departing from previous research on aviation automation we want to find out if pilots have confidence in collaboration within a hybrid socio-technical system consisting of human and non-human players, and if so, which factors affect their confidence positively or negatively.

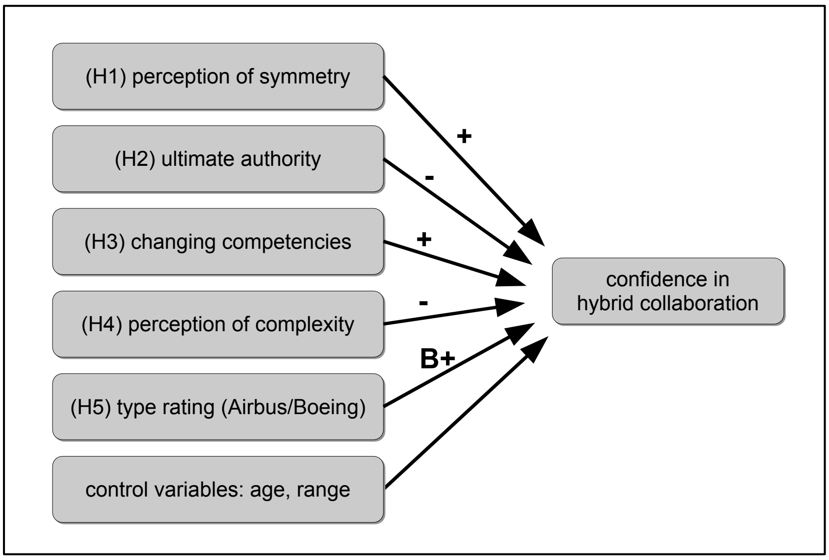

Figure 5: Research model "confidence in hybrid collaboration"

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[17] "Men are better at – machines are better at" (Fitts 1951).

Our research model (cf. Figure 5) puts *confidence in hybrid collaboration* as dependent variable and tests the five derived hypotheses by means of five independent variables, namely *perception of symmetry*, *ultimate authority*, *changing competencies*, *perception of complexity, and type rating*. Additionally, *pilots' age* and *range* (short-/long-range) are used as control variables.

3. Methodology

3.1. Design of the study, sample

Mixed methods approach

For our study, we decided to approach the issue of confidence in hybrid collaboration by means of a mixed method design in alignment with Creswell et al. (2003: 212). Our approach can be explained as a synthesis of sequential exploratory and sequential explanatory research designs by combining a qualitative interview study with a quantitative online survey in order to figure out pilots' confidence in human-machine collaboration in the advanced automated aircraft. A final step was the validation of results through aviation experts.

Questionnaire

Although there already exist several surveys in the field of aviation (cf. Section 2.3), we decided to develop a partly new questionnaire, which helps to answer our research questions and to take a conceptually new perspective.

Interviews with pilots

Therefore we conducted interviews with experts in this field, i.e. the pilots themselves. The issue of confidence has been explored by nine semi-structured interviews, which have taken place in January 2007, with pilots of an international airline at a regional German airport (cf. Weyer 2008). Given the pilots' permission, the interviews were recorded, transcribed, and anonymised. The main finding of this investigation has been the existence of different role perceptions on part of the pilots, concerning their interaction with the autopilot. Although the romantic picture of the "pilot flying the machine" is still present, most pilots regarded themselves as "system managers" of a complex system, whose primary task is not to fly the aircraft manually but to make good decisions.

Types of system managers

However, we could identify two types of system managers: (i) the system observer, who draws her/himself back to a purely monitoring position absolutely relying on technology, (ii) and the collaborator. The latter perceives her/himself as a partner in a symmetrical constellation of human and technology, which mutually control each other (P5: 121-140). The main task thus is to vigilantly monitor the system and to anticipate its actions:

> "… but you feel like you stay ahead of the game and you stay on track of what is going on." (P5: 124)
>
> "You let the automatics, too, but you keep a distance …" (P4: 396)

With the help of a content analysis we identified some further relevant and field-adjusted issues that we included in our questionnaire. The latter avoids suggestive questions and abstract statements directly derived from automation theory.

Survey and sample

The online-questionnaire has been submitted electronically in summer 2008 to a large number of pilots, using the distribution lists of the German pilots association "Vereinigung Cockpit" (VC), of the pilots' educational network "Forschungszentrum für die Hochschulausbildung von Piloten" (FHP), and of two German airlines. We received 278 completed questionnaires, out of which – after data cleansing – 199 could be used for detailed statistical analysis via SPSS. The results of our analysis have been presented to aviation experts who gave valuable feedback and hints for validation and further interpretation.

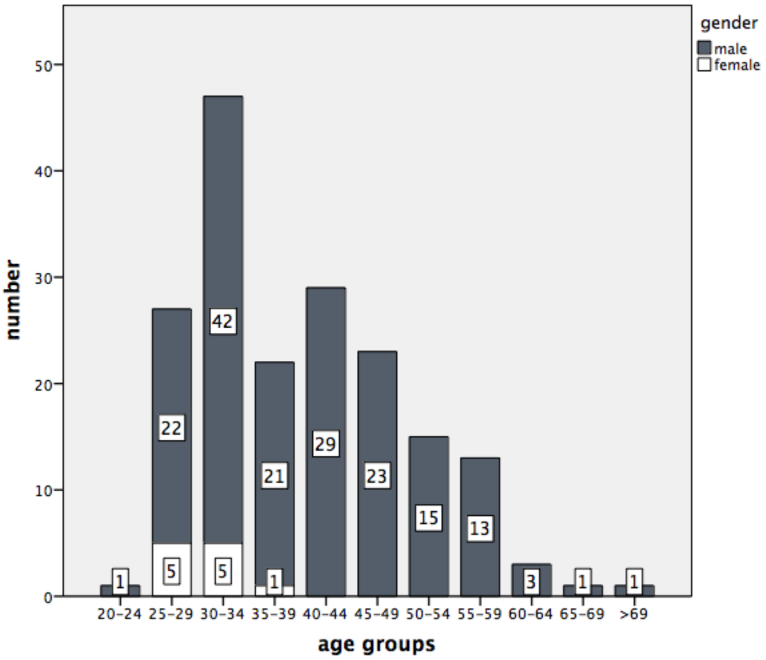

Figure 6: Age groups of pilots

Age and gender

The mean age of respondents was 39.9 years, ranging from 22 to 73. Five pilots older than 60 years participated in the survey. The distribution of gender was unequal: only 11 of 184 respondents (6.0 percent) were female. Pilots of female gender were much younger (29.7 years, ranging from 25 to 36), compared to their male colleagues (40.1 years). However, this distribution fits to the general share of female pilots in German airlines of about 6 percent.

As Figure 6 shows, the largest group are pilots in the age of 30 to 34 years.

Airlines, experience and position

The largest groups are pilots from Lufthansa (45.1%) and Eurowings (31.7%), which later became part of the Lufthansa group, while only few pilots from low-cost airlines and other competitors of Lufthansa participated in the survey (10.3%).

Most pilots were experienced (perfectly related to their age) and had a mean of 7.254 flight hours on planes with more than 20 tons maximum take-off weight (MTOW), thereof 3.490 hours on the type currently flown. 94 of them (48.7%) were first officers (FO) or senior first officers (SFO), while the other 99 pilots were higher ranked captains (CPT), none of them female.

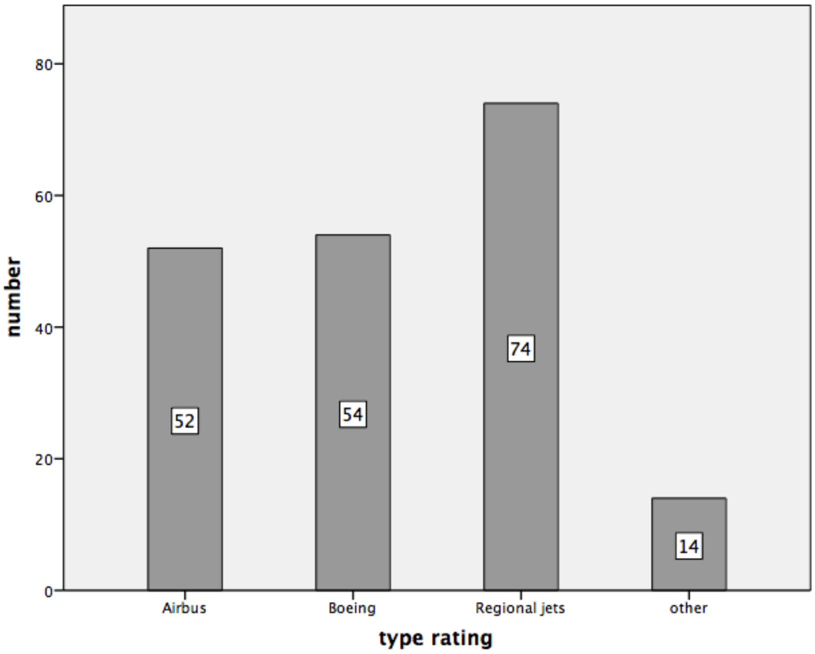

Figure 7: Type rating (grouped)

Type rating

Concerning current type rating, the largest group of pilots (21.1%) flew Canadair Regional Jets (CRJ), followed by Boeing 737 (15.5%), AVRO/BAE 146 (14.9%) and Airbus A320 (13.4%).

Grouped by manufacturers, the smaller regional jets were the largest group (38.1%), followed by Boeing (27.8%) and Airbus (26.8%, cf. Figure 7).[18]

43 pilots (22.2%) flew long-range aircraft such as Airbus A330/340 or Boeing 747, while all others flew short or medium-range planes such as Airbus A320, Canadair Regional Jet or Boeing 737.[19]

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[18] The category “regional jets” comprises aircraft of different manufacturers and ages with various levels of automation, such as CRJ, Avro/BAE 146 and others.

[19] Unfortunately our data set does not allow differentiating between the 3rd generation [beginning automation] and the 4th generation [high level of automation] of jet airliners; (cf. Scheiderer/Ebermann 2010: 3). For reasons of data protection, the questionnaire had to be cleaned of questions that might be used to identify singular individuals.

3.2. Constructs: dependent and independent variables

All constructs were developed against the background of the conceptional shift from the traditional unilateral concept of "trust in automation" towards the more recent multilateral concept "human-automation collaboration" within the hybrid socio-technical system aircraft (cf. Section 2.2).

The dependent variable "confidence in hybrid collaboration"

For the measurement of the dependent variable, we developed several items based on relevant and field-adjusted issues, which were mentioned during the interviews. Six items were measured on a six-point Likert scale (1 = totally disagree, 6 = totally agree). The scale of the dependent variable includes the following items (cf. Table 2).

Today, flying an aircraft is mainly based on routines.
Without technical assistance systems pilots feel unprotected nowadays.
Pilots monitor the system and only take control in terms of adverse events.
Pilots are developing more and more in the direction of systems administrators.
The main task of pilots is rather to navigate the aircraft, i.e. programming the flight management system, than to directly manually control it.
Pilots are increasingly becoming machine operators.

Table 2: Items referring to confidence

A principal component analysis shows that all items load on one factor (KMO-value = .765, explained variance 39.71%). The scale *"confidence in hybrid collaboration"* is acceptably reliable with Cronbach's Alpha of .685.[20]

All respondents were ranked into four percentile groups according to their factor value, indicating different levels of confidence (cf. Table 3).

Factor value	Percentile	Percentile group
2.09188 (maximum)	100	4 – very high confidence
0.7999907	75	3 – high confidence
0.0450369	50	2 – low confidence
-0.6462699	25	1 – very low confidence
-3.02093 (minimum)		

Table 3: Percentile groups (confidence)

This construct measures pilots' confidence in collaboration with automation on board of the hybrid socio-technical system aircraft.

The independent variable "perception of symmetry"

Referring to Latour (1996) and others we assume a symmetry of humans and non-humans. Translated into practical terms, this concept encompassed a mutual perception of humans and non-humans as equally ranked partners, who both can take decisions and coordinate their actions (Fink/Weyer 2014). In order to operationalise the first hypothesis that *a high degree of perceived symmetry implies a high degree of perceived confidence in hybrid collaboration*, we used three items

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[20] This scale was also used as an additive index for descriptive analysis in Section 4.2.

measured on a six-point Likert scale (1 = totally disagree, 6 = totally agree, cf. Table 4).

When entering flight commands, the computer functions as a kind of consultant who points out conflicts to the pilot.
Pilot and automated system mutually control each other.
Technical support systems in modern aircraft are designed to give action recommendations to pilots.

Table 4: Items referring to symmetry

The items load on one factor (KMO-value = .639, explained variance of 60.69%), and the scale "perception of symmetry" is also acceptably reliable with a Cronbach's alpha value of .674.

Table 5 lists the four percentile groups indicating levels of perceived symmetry between human and automation.

Factor value	Percentile	Percentile group
2,3562 (maximum)	100	4 – complete symmetry
0,7311777	75	3 – much symmetry
0,1018817	50	2 – little (??) symmetry
-0,8017398	25	1 – no symmetry
-2,56514 (minimum)		

Table 5: Percentile groups (symmetry)

The construct measures whether pilots perceive the technical systems on board of the aircraft as an equally ranked partner.

Independent variable "ultimate authority"

To test our second hypothesis, that *the more pilots want to have the ultimate authority, the lower is their confidence in hybrid collaboration*, we developed several items by using quotes from the qualitative study (cf. Table 6).

Even if it is technically possible to fly aircraft remotely controlled, pilots, who are responsible for the flight, are still required on board.
Ultimately, it always has to be a human being who is taking responsibility on board.
Even in the future, the pilot has to be superior to technology and must not be dominated by it.
Even if completely automated air traffic would be possible in the future, pilots are still needed to intervene in case of technical failure.

Table 6: Items of ultimate authority

These items load on one factor with an acceptable KMO-value of .694, an explained variance of 51.65%, and a Cronbach's alpha of .682.

In contrast to the variable "perception of symmetry", this construct measures to which extent pilots wish to have a traditional role distribution between the human operator and the non-human parts of the socio-technical system aircraft.

Independent variable "changing competencies"

The third hypothesis, that *a high degree of (perceived) changing competencies implies a (perceived) high level of confidence in hybrid collaboration*, is measured with the help of four items (cf. Table 7).

These items load on one factor (KMO-value = .753, explained variance of 54.82%). The scale is reliable with a Cronbach's alpha value of .726.

The pilot does no longer have the same decision-making power as in the past.
In former times, pilots' decisions were much more based on personal experience and assessment.
The actual flying is taking less and less room in pilots' actions.
Good flying skills are becoming less important nowadays.

Table 7: Items of changing competencies

Again, all respondents were ranked according to their factor value into four percentile groups, indicating the different levels of (perceived) change (cf. Table 8).

Factor value	Percentile	Percentile group
2,24017 (maximum)	100	4 – very much change
0.7108077	75	3 – much change
0.020132	50	2 – few change
-0.6211536	25	1 – very few change
- 2,82461 (minimum)		

Table 8: Percentile groups (competencies)

The construct measures if pilots confirm a shift in the role distribution between humans and automation compared to former times.

Independent variable "perception of complexity"

For the fourth hypothesis – *the more complexity is perceived, the lower is the level of confidence in hybrid collaboration* – we refer to Charles Perrow (1984) and others who stress that a complex system entails non-linear interactions which lead to emergent system states that are at least partly incomprehensible to its operators. Insofar the definition of complexity is always bound to the perception of intransparency and lacking understanding of the system's behaviour (Weyer 2009). Therefore, we captured pilots' perception by using a construct with two items measured on a 6-point scale (1 = totally agree, 6 = totally disagree – cf. Table 9).

Table 10 lists the four percentile groups indicating different levels of perceived complexity of highly automated systems.

Pilots do not receive sufficient background information (system knowledge) to really understand the technical systems.
Today's aircraft is a black box for the pilot. One knows how to operate it but not how it actually functions.

Table 9: Items of perceived complexity

Factor value	Percentile	Percentile group
2,16935 (maximum)	100	4 – very high complexity
0,8975639	75	3 – high complexity
0,0943712	50	2 – low complexity
-1,043244	25	1 – very low complexity
-1,84644 (minimum)		

Table 10: Percentile groups (complexity)

Type rating, range and age[21]

Additionally, we have controlled the type rating (1 = Boeing, 0 = all others) in order to test the fifth hypothesis, in which we assume that *Boeing pilots perceive a higher level of confidence in hybrid collaboration* than Airbus pilots. Finally we controlled for range (1 = long range, 0 = short range) and age by using a metric scale of age at the time of interrogation. We assume that older pilots may have had considerable experience with 3rd generation aircraft, too, while younger pilots have started their career on 4th generation advanced automated aircraft, which had been introduced in the late 1980s.[22]

4. Empirical results

The next chapter will present the main empirical results, starting with a regression analysis that later will be complemented by a more detailed breakdown of numbers.

4.1. Regression analysis

For further multivariate analysis, we used OLS-regression analysis to test our hypotheses. Table 11 shows the result of the regression model where we present the effects by standardized beta-coefficients, so that they are comparable in their relative strength.

Confidence in hybrid collaboration	Beta
(H1) Perception of symmetry	**.258****
(H2) Ultimate authority	-.066
(H3) Changing competencies	**.360****
(H4) Perception of complexity	-.001
(H5) Type rating (1=Boeing)	-.101^{+}
Range (1=long)	-.160*
Age (metric scale)	.096
N	*199*
Adjusted r^2	*.330*

**p<0,01 *p<0,05 $^{+}$p<0,1

Table 11: OLS-Regression "confidence in trustful collaboration"

For the whole sample, the factors contribute well to one third of the variance as the adjusted r^2-value of .330 shows.

As this brief overview demonstrates, hypotheses H1 and H3 can strongly be confirmed, while H2 and H4 have to be rejected. The following section will refer to these findings and complement them with a more detailed analysis of our variables and their relations among each other.

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[21] The descriptive analysis of the sample related to these variables is to be found in Section 3.1.

[22] We didn't include gender as additional variable because numbers are too small.

4.2. Descriptive analysis

Confidence in hybrid collaboration

First, we want to point to the fact that pilots in general have confidence in hybrid collaboration with a mean value of 4.37 (median 4.50), which is remarkably above the average of 3.5. A large share has got high (56.0%) or very high confidence (32.1%), while low confidence is small (11.5%) and very low confidence non-existent.[23] There is no correlation with age or experience.

Perception of symmetry (H1)

The level of perceived symmetry is almost normally distributed among pilots (mean 3.54; median 3.67), indicating that various groups of pilots have different opinions. The two extremes – complete symmetry (9.5%) and no symmetry at all (10.0%) – comprise only small groups, while the majority opted for the positions in between, divided into two parts: much (44.8%) and little symmetry (35.6%). Again, there is no correlation with age or experience.

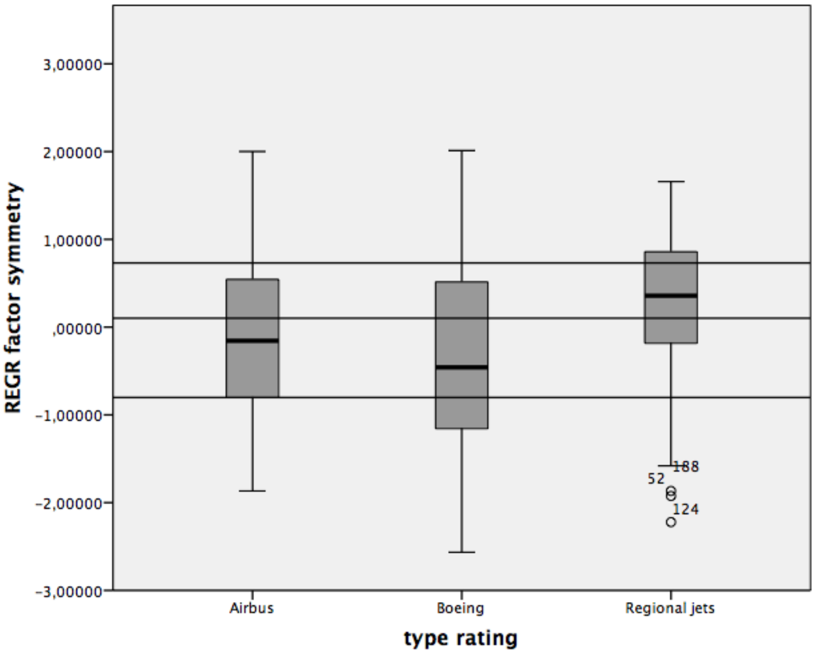

Figure 8: Symmetry by type rating

However, Figure 8 demonstrates differences regarding type rating: pilots of regional jets belong to percentile group 3 (much symmetry - median ,3580744), which ranks them higher than Airbus (-,1557835) and Boeing (-,4587311) pilots, both belonging to group 2 (little symmetry), but with remarkable differences concerning factor values. This distinction can also be found between short-range (,1364762) and long-range aircraft (-,1839000 – no figure).[24]

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[23] These numbers refer to the six-point Likert scale aggregating six expressions into four groups similar to the four percentile groups.

[24] Only the difference between Boeing and regional jets has been confirmed by t-tests, the other tests have failed.

Pilots flying short or medium distances with a high number of take-offs and landings perceive automation to a higher extent than others as equally ranked partner, maybe because of a higher number of experiences, where pilots and automation act as team players.

Referring to our main issue of confidence, regression analysis has shown a positive and significant effect for the first indicator (.258**): A high degree of perceived symmetry between (human) pilots and (non-human) technical components of the socio-technical system aircraft implies a high degree of confidence in hybrid collaboration (this is also supported by Figure 9, which presents the level of confidence on part of the four percentile groups of "symmetry"). Reliable collaboration – as in the case of two humans – seems to depend on the idea of an equal status of two partners, be it humans or non-human devices, that collaborate while operating and controlling the aircraft.

(H1) Therefore, our first hypothesis is supported.

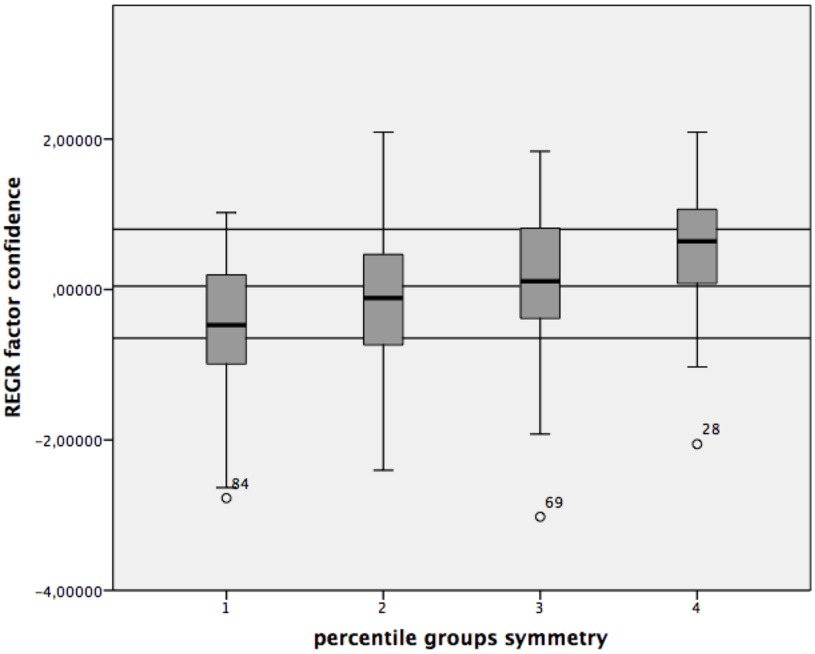

Figure 9: Distribution of confidence by four factor groups of perceived symmetry

Ultimate authority (H2)

Our data show an almost unanimous voting for ultimate decision authority on part of human pilots (mean 5.75, median 6.00), indicating that almost all pilots totally agree with this argument. Hence, further descriptive analysis of this variable makes little sense.

Regression analysis has already shown a (weak) negative impact (-,066) of the independent variable "ultimate authority" on confidence in hybrid collaboration. Apparently, the more pilots adhere to the traditional role definition of the human as ultimate decider and the more they claim to have the ultimate authority (in any case), the less they confide in hybrid collaboration. They ascribe a superior position to humans, which can in no case be substituted or complemented by autonomous technical systems. However, this negative effect is not significant.

(H2) Hence, we have to reject our second hypothesis.

At first sight, this adherence to a traditional role distribution seems to contradict our findings concerning the high level of confidence pilots have in hybrid collaboration (see above). However, this effect is only weak and not significant, which allows reconciling these two findings. Besides, debating these results with aviation experts, most pilots could not see a conflict. They claimed an ultimate authority on part of the pilot, including the option to forgo this right and to collaborate with automation on an equal footing, but also to withdraw to a superior position if necessary.

Changing competencies (H3)

The descriptive analysis of pilots' responses again demonstrates a divided population with a mean of 3.86 and a median of 4.00. The majority opted for very much (18.6%) or much change (42.6%), while little (30.5%) and very little change (7.5%) is represented far less. There is no single correlation – neither with age nor with other variables.

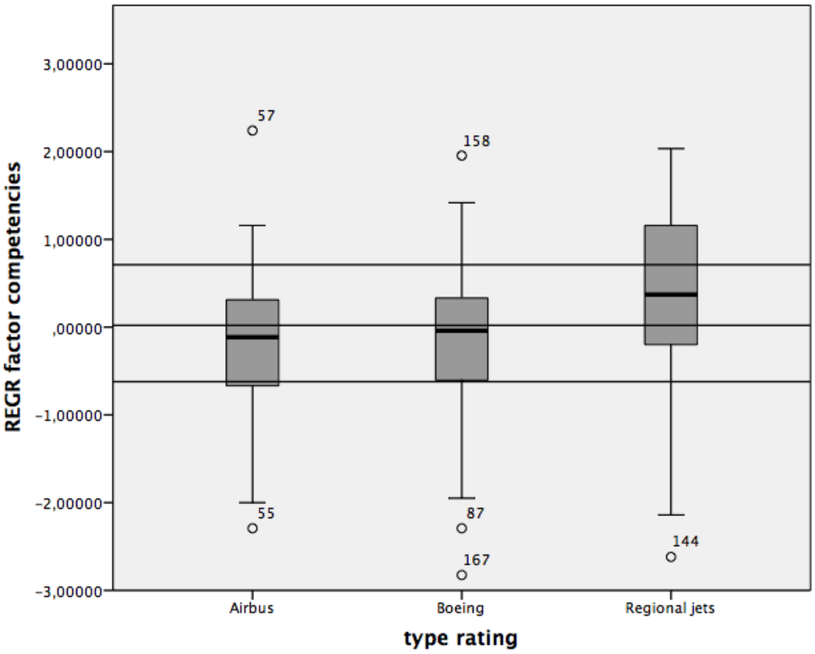

Figure 10: Competencies by type rating

Nevertheless, as Figure 10 shows, type rating seems to matter again, since pilots of regional jets belong to percentile group 3 (much change – median ,371118), while Airbus (-,1146763) and Boeing pilots (-,0408733) belong to group 2 (few change) – with rather similar values. Additional t-tests confirm the significance of this difference.

Furthermore, pilots of long range aircraft (median -,0501337) perceive less change than others (,0816573).[25] Taken together, these data point to the fact that the biggest change – as perceived by pilots – towards automated flying has taken place in the field of short- and medium-range regional jets, where older and less automated types of aircraft have been replaced by more modern ones but are still partly operated. Nevertheless, even on board of up-to-date regional jets, the automation has less depth of intervention than in other aircraft, as aviation experts confirm. In contrast, pilots of Airbus and Boeing typically have operated 4th generation aircraft with a high level of automation for a longer period. Regression analysis has already shown a positive and significant influence from perceived changing competencies on confidence in hybrid collaboration (.359**).

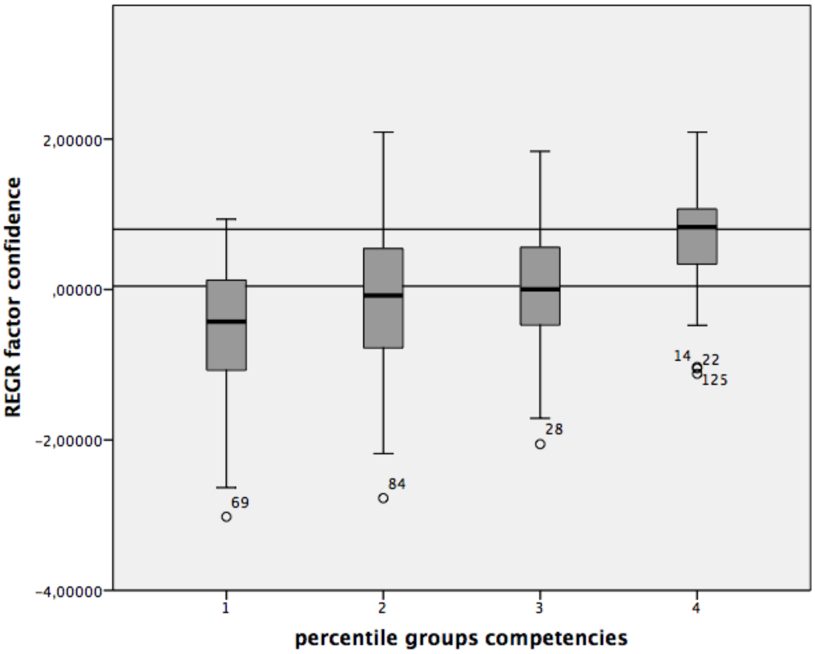

Figure 11: Distribution of confidence by four factor groups of competencies

As also shown in Figure 11, pilots who experience much change in role distribution and competencies between human operators and (partly) autonomous technical agents mostly belong to percentile groups 3 or 4 (high or very high level of confidence), while all others belong to percentile group 2 (low level). Evidently, members of the former group can arrange themselves with the new mode of hybrid collaboration in the socio-technical system aircraft better than others.

(H3) Thus, our third hypothesis is supported.

Perceived complexity (H4)

Pilots' answers are slightly below average with a mean of 3.31 (median 3.50). The share of pilots that perceived high (24.7%) or very high complexity (14.5%) is smaller than the one of those with low (33.7%) or very low com-

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[25] As confirmed by t-tests, the difference between regional jets and both Airbus and Boeing is significant, while all other tests fail.

plexity (26.1%), indicating a broad distribution of opinions as well as a lacking consensus on this issue.

There is a strong positive correlation with experience (,228**) and age (,192**), indicating that older, skilled pilots do perceive more complexity than younger, less experienced ones.

The following factors may help to explain these differences:

- Older pilots may have had more opportunities to experience automation failures during their career.
- They may have developed a more reflexive attitude towards automation-related issues, partly because they work as instructors, too.
- Since they have experienced the change form 3rd to 4th generation jet airliners, their attitude towards automation may be more reserved compared to younger pilots who grew up in a world full of computers and who are used to steer advanced automated "Atari planes" without any prior experience with conventional aircraft. In contrast, older pilots may still remember the "good old times" of less automated flying and cockpits with a large number of analogue displays.

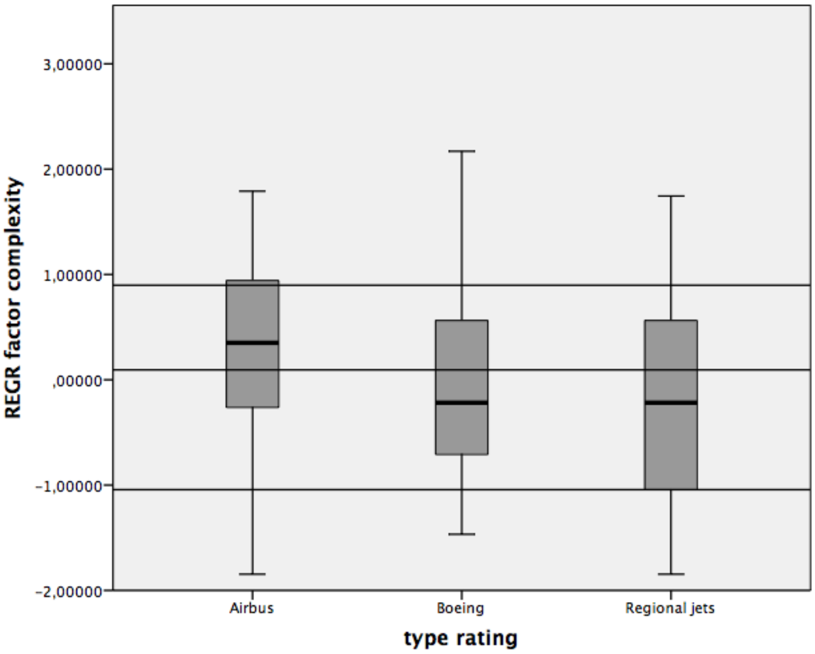

Figure 12: Complexity and type rating

Concerning the issue of type rating, Figure 12 demonstrates remarkable differences between Airbus pilots, belonging to percentile group 3 (high level of perceived complexity – median ,3511475), compared to Boeing (-,2176602) and regional jet pilots (-,2176602), both belonging to group 2 (low complexity), with surprisingly similar values. Additionally, pilots of long-range aircraft perceive more complexity (,5631412) than others (-,1952689 – no figure). As confirmed by t-tests, the difference between Airbus and regional jets as well as between long- and short-range airplanes is significant while the other tests fail.

By combining the two dimensions "age" and "type rating", we can gain additional insights into the issue of complexity. As Figure 13 demonstrates once more, younger pilots perceive less complexity than older ones, but within the group of younger pilots (21 to 35 years old), Airbus pilots stand out with a much more negative opinion compared to the other two groups (Boeing and regional jets), pointing to more trouble in getting accustomed to this specific type of aircraft during one's first career years.

Within the group of medium-aged pilots (36 to 50 years old), Boeing pilots differ from their peer group with a more positive opinion, indicating the opposite, namely less concern in terms of complexity issues related to this type of aircraft. Although concerns are slightly higher compared to younger professionals, this may be counted as an indicator for less automation surprises and a well-functioning collaboration between humans and automation on board of Boeing aircraft compared to other types.

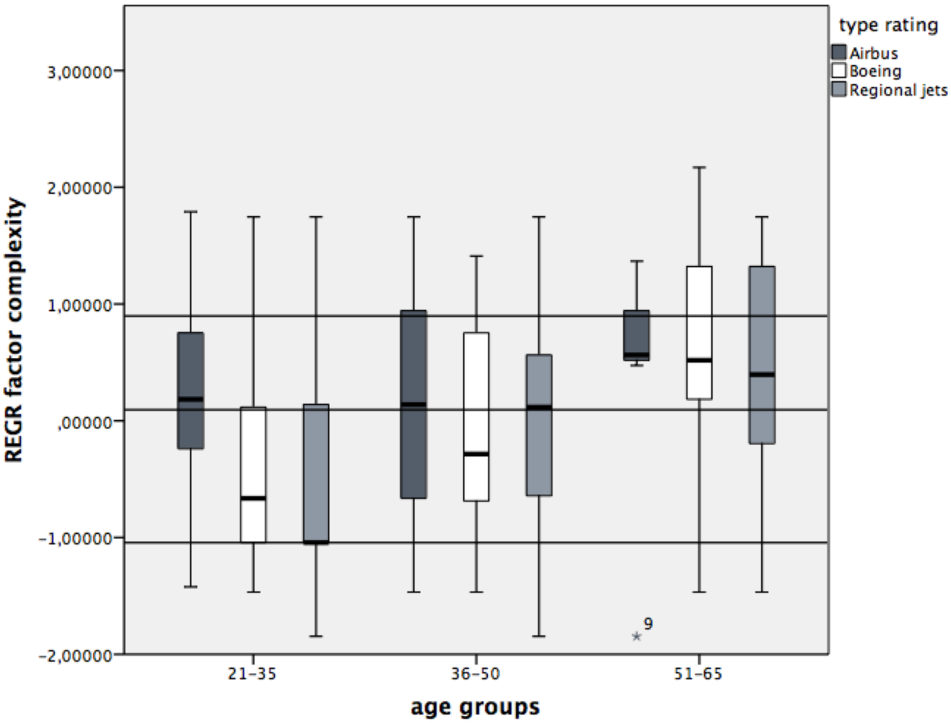

Figure 13: Complexity, related to age (N= 80, 76, 32) and type rating

In sum, we can clearly identify different opinions between Airbus and Boeing pilots concerning the issue of complexity, confirming differences between the automation philosophies of those two aircraft manufacturers.

Finally, our main concern is the relation between perceived complexity and confidence in collaborative human-machine interaction at the flight deck. As shown above, the regression analysis could not reveal a relation (-.001) between those two variables.

(H4) Hence, we have to reject our fourth hypothesis.

Type rating (H5)

Previous analysis has already shown that type rating matters in almost any regard. Pilots of regional jets perceive more symmetry and more change of competencies than their colleagues on board of Airbus and Boeing aircraft. With regard to the issue of complexity, Airbus pilots stand out with much more concern in general – with remarkable differences in various groups of age.

Regarding the central issue of confidence in hybrid collaboration, Figure 14 presents distinct differences between pilots of regional jets belonging to percentile group 3 (high confidence – median ,5593656), compared to Airbus (-,0892897) and Boeing pilots (-,2748664), mostly belonging to group 2 (low confidence – confirmed by t-tests). At this point, distinctions between the design philosophies of Airbus and Boeing apparently do not show up.

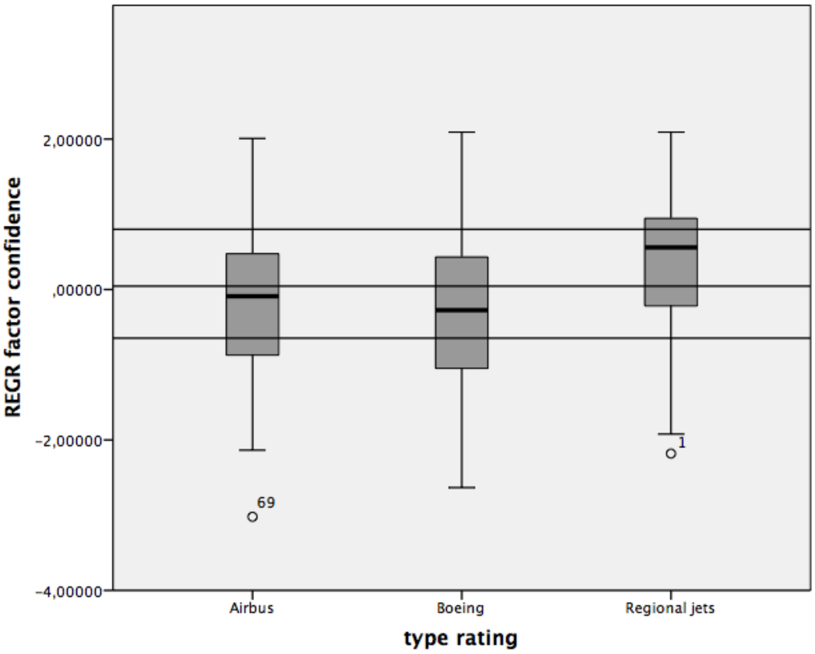

Figure 14: Confidence by type rating

Regression analysis has also figured out a (weak) negative relation (-,101$^+$), refuting the assertion that flying Boeing aircraft has a positive effect on pilots' perceived confidence in hybrid collaboration.

(H5) Hence, our fifth hypothesis cannot be confirmed.

Instead of revealing differences between Airbus and Boeing aircraft, which we assumed referring to public and academic discourses, the analysis detected the relevance of range, especially in case of regional jets, which remarkably affects pilots' perceptions regarding automation. This effect is much stronger than presumed discrepancies between Airbus and Boeing aircraft.

Control variable range

The second control variable points to the fact (frequently) mentioned above that it is not only the aircraft manufacturer but also the task profile and the type of mission (short, medium or long range) that shape the experiences and thus the perceptions concerning human-machine interaction at the flight deck of advanced automated aircraft. As depicted in Figure 15, pilots of short-range aircraft are more confident (,1416048) compared to others (median -,4756400 – confirmed by t-tests), which fits well with previous results regarding their positive attitudes towards symmetry and changes of competencies.

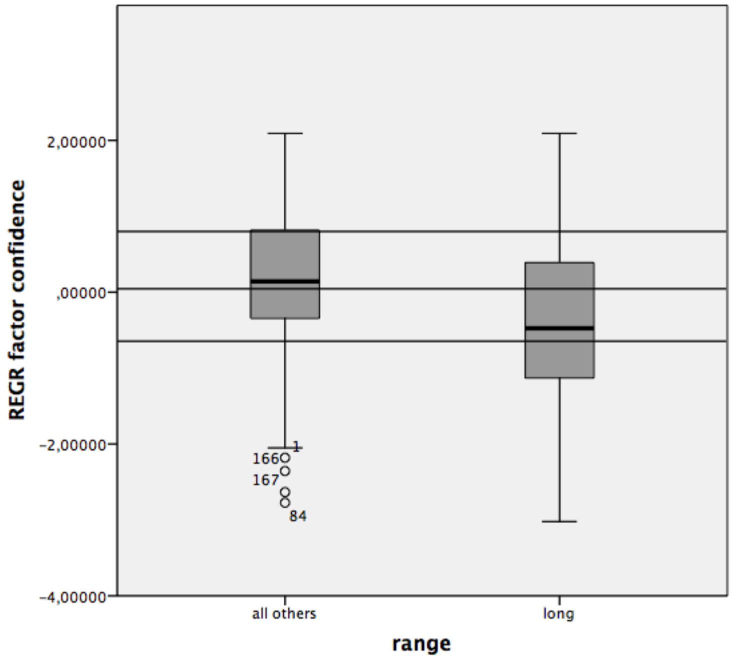

Figure 15: Confidence by range

Pilots flying short or medium distances with a high number of take-offs and landings and thus more opportunities to collaborate with automation obviously have developed a higher level of confidence compared to their colleagues on long distance flights.

Control variable age

As mentioned above, age matters solely in the case of perceived complexity: Younger pilots reported a lower level of perceived complexity than older, more experienced pilots.

However, referring to confidence in hybrid collaboration, neither correlation nor regression analysis (.096) could reveal any relevance of age. This is surprising given the suspicion that a higher level of perceived complexity on part of older pilots might also affect their confidence in hybrid collaboration negatively.

However, since the variables "complexity" and "confidence" do not correlate, we cannot transfer findings related to perception of complexity to the issue of confidence.

Figure 16 clearly demonstrates the missing relevance of age in terms of confidence in human-automation collaboration at the flight deck.

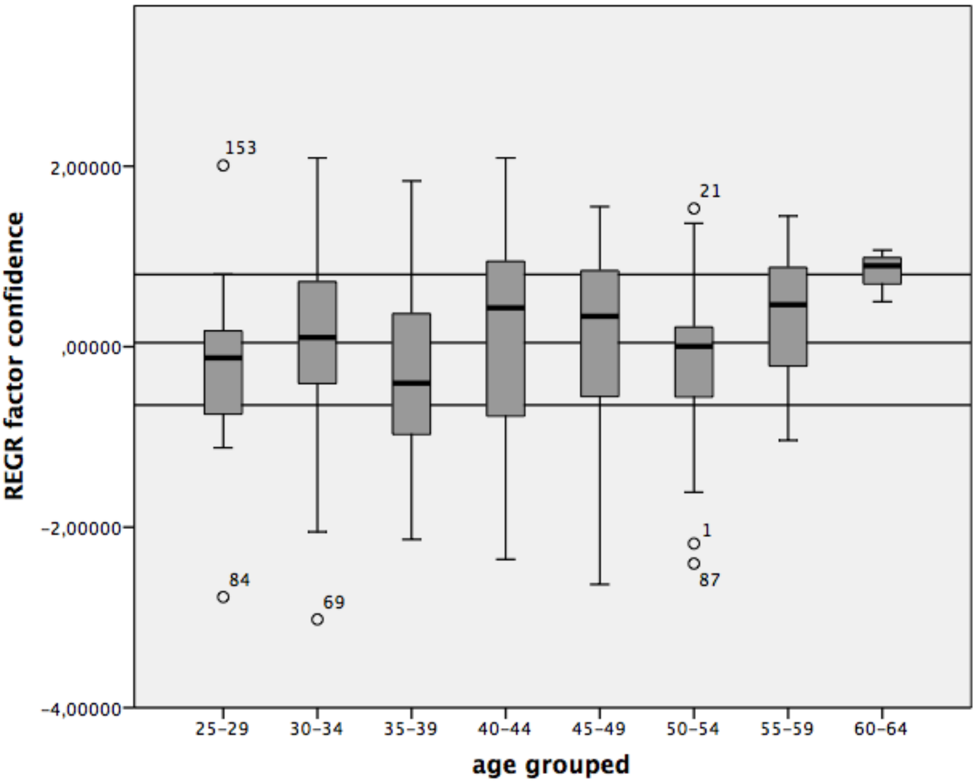

Figure 16: Confidence by age

5. Conclusions, limitations and implications

This paper has tried to investigate a well-known issue from a new perspective. Pilot surveys have been conducted frequently in the past, but they mostly have been guided by a traditional "either-or" perspective assuming that humans cannot (and should not) be replaced by automation.

We have studied the issue of human-machine cooperation in the cockpit from a new viewpoint of human-machine *collaboration*, which has evolved during the last decade. Our questionnaire has been designed to find out whether collaboration at the flight desk works and which are the most influential factors that may explain this.

5.1. Summary of results

Table 12 presents a short summary of our results.

Univariate analysis

The descriptive analysis of our five constructs has revealed that most pilots have established a confiding relation to automation, regarding this part of the hybrid human-machine system as a collaborating team player (dependent variable). Perceptions of symmetry, changing competencies and complexity are rather equally distributed among pilots, while agreement on the ultimate authority is nearly unanimous.

	uni-variate	multivariate		bivariate			
		assumed effect on confidence	confidence	symmetry	authority	competencies	complexity
confidence	high						
symmetry (H1)	medium	positive	conf.				
authority (H2)	very high	negative	not conf.				
competencies (H3)	medium	positive	conf.				
complexity (H4)	medium	negative	not conf.				
type rating (H5)		Boeing positive	not conf. *(RJets conf.)*	RJets pos	.	RJets pos	Airbus pos Boeing neg
range			neg	short pos	.	short pos	long pos
age			.	.	.	.	old pos

Table 12: Summary of results

Multivariate analysis

As confirmed by the regression analysis (cf. Section 4.1), hypotheses H1 and H3 hold true: a high level of confidence in hybrid collaboration can be related both to a high level of perceived symmetry (H1) and to a high level of perceived change of competencies (H3). In other words: confidence is positively affected by an attitude that accepts a symmetrical relation of humans and automation at the flight deck (H1) as well as the changes in role distribution, which have taken place during the last decades (H3) and shifted the pilots' tasks from manually flying to being a manager of a complex hybrid system.

On the contrary, hypotheses H2 and H4 have to be rejected. Neither the adherence to a traditional role distribution with an ultimate authority on part of the human pilot (H2) nor the perception of complexity of highly automated aircraft (H4) has a significant negative effect on pilots' confidence, as supposed by our hypotheses. Especially in case of complexity this result is rather surprising, considering the broad academic discourse on automation related problems in aviation (cf. Section 2.3).

Bivariate analysis

Type rating, range, and – partly – age do matter, helping to better understand the descriptive results concerning the independent variables. Differences between Airbus and Boeing only show up in terms of complexity, not in terms of confidence, as supposed by our fifth hypothesis (H5), which therefore has to be rejected.

However, the most surprising result is the higher confidence among pilots of regional jets and short-range flights. Because of their specific task profile, they have got more opportunities to collaborate with automation – obviously in a way that shapes their attitudes positively. This positive effect can also be detected to work on other variables such as "symmetry" or "competencies".

In contrast, age evidently is of no importance explaining attitudes towards automation.

5.2. Limitations

The most obvious limitation of this paper is the missing distinction between 3rd and 4th generation aircraft, as mentioned, due to restrictions in our questionnaire. Aircraft type, such as Boeing 737, does not allow differentiating these generations, e.g. 737-200 and 737-900. Further research should test other strategies to investigate this generational change and its impact on pilots' perceptions. Similarly, the category of regional jets should be inspected more closely.

Finally, our analysis unfortunately has to abstain from statements concerning mode confusion because data do not allow deducing them.

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