As a mark of his respect and high appreciation, the author dedicates this contribution to the meritorious university professor Dr.-Ing. Holger Luczak on the occasion of his 65th birthday.

Work Science and Aviation Safety

Heinz Bartsch / Rostock

1. Introduction

It has become increasingly clear in practice – the requirements placed on pilots and their crews are becoming increasingly complex and difficult. Not least of all, questions of aviation safety[1] also have to be addressed in this respect.
The problem of „aviation safety" is characterised by an extraordinarily high level of complexity.
An important causality thereby arises from the effects of the Man – Technology – Organisation interaction at many levels.
International comparable investigations of aviation accidents make it clear that the relationship has shifted strongly from the technically-related complex causes that were originally considered to human-related causes. Nowadays, it must be assumed that almost 75 % of all aircraft accidents are caused by „human error". It is therefore clear that, in the sense of their "reliability", it is above all human beings who must be regarded as the weakest link in the above-mentioned chain of interactions.
Work Science / Ergonomics deals with the conformity of human work with natural laws and the conditions for its effectiveness in a very interdisciplinary way.
On the basis of the knowledge gained from this, it is above all working systems– thereby also including „flight working systems" – that should be optimised from the viewpoint of the central importance of human beings.
A central category here will thereby be „Human Reliability".
In doing this, ergonomics attempts to achieve two major objectives by employing a systematic approach:

- Increasing the performance of the system,
- Increasing the reliability of the system.

„System reliability" thereby includes the partial reliabilities of the technology, the organisation and, above all, people as an interconnection with an integral effect.
In the following contribution, the author thereby proceeds from the hypothesis that a considerable improvement in aviation safety can be expected from a targeted optimisation of the „human reliability" and its corresponding integration into the overall reliability of the system.
Work Science / Ergonomics can thereby make a significant contribution here.

2. Accidents in air travel

Without making any claim to completeness, a summary of statistical surveys of accidents occurring in air travel (Hanke 2003) indicates the following events:

- 630 passenger aircraft were destroyed worldwide in operational use between 1958 and 2001,
- The sudden and serious increases in the „Total Losses" curve are striking (total losses of scheduled aircraft),
- The increases in accident figures are always registered after the introduction of a new aircraft generation, or in other words, after significant technical changes to the aircraft (incl. the cockpit),
- The 1st cockpit layout generation was introduced in 1960 (e.g. B707, DC8, Caravelle),
- The 2nd cockpit layout generation followed in 1965 (e.g. B727, DC9, F28),

[1] - Safety - „The state of not being threatened, which is objectively presented by the presence of protection or the absence of sources of danger, and that is perceived as the certainty of individual and social structures regarding the reliability of protective devices." / Meyers Lexikon 1980 /. Despite DIN 31619-2 and DIN 32541, however, it must be assumed that there is no generally valid definition of the expression "Safety" at the present time. The formulation „State of being protected" (Neues Deutsches Wörterbuch) or the relation to the expression „Risk" also fail to improve this situation. One can, however, assume that there is no „absolute safety". On the basis of DIN 31000, one could support the position that „Safety" could be understood as the „situation in which the expectation of damage in the socio-technical system is acceptable according to any reasonable standard of measurement".

- The introduction of the "early wide-bodies" took place in 1971 (e.g. B747-200, DC10, A300),
- Airbus placed the A310 into regular service in 1983. The era of the „glass cockpits" began with this aircraft, i.e. a modified manner of processing the information from the cockpit instruments – mainly electronically using computers / display in modified instruments of the older generation or simple small display screens,
- The 3rd cockpit layout generation, with screen technology for almost all systems, was introduced in 1986 (e.g. B747-400, MD11, A310),
- In 1988, Airbus revolutionised the market with the A320.
  On a large scale, scheduled aircraft are equipped with „Sidesticks", i.e., with a modified type of aircraft control / vector control,
- Airbus forecast the development that the number of accidents would increase strongly up to the year 2017, particularly for the 3rd generation,
- A number of A380s have been delivered to various international airlines in the meantime,
- The most extensive on-board control systems for scheduled aircraft in civil air traffic are also being increasingly discussed and investigated. Solutions of this kind have already existed for some years in military air traffic (drone systems) and in the deployment of helicopters.

If the flight accidents are registered in a differentiated manner, the following overview results:

Table 1: Differentiated accident incidents in civil air traffic (based on Faber-1994)

Distribution by cause			**Risk by flight phase**		
1.	**Crew:**	**75 %**	**1.**	**Landing approach:**	**25 %**
2.	**Aircraft / Technology:**	**9 %**	**2.**	**Landing:**	**24 %**
3.	**Weather:**	**7 %**	**3.**	**Take off:**	**24 %**
4.	**Flight control:**	**5 %**	**4.**	**Cruise level approach:**	**12 %**
5.	**Maintenance:**	**2 %**	**5.**	**Climbing:**	**6 %**
6.	**Miscellaneous:**	**2 %**	**6.**	**Rolling:**	**5 %**

Distribution by H - accidents (from 1963 – 1992)

Development:

H 1 = 40 %	**H 1 = 52 %**	**H 1 = 27 %**	**H 1 = conscious, deliberate work error,**
H 2 = 49 %	**H 2 = 34 %**	**H 2 = 19 %**	**H 2 = unconsious, unintentional error,**
H 3 = 11 %	**H 3 = 13 %**	**H 3 = 54 %**	**H 3 = training (qualification deficits),**
H 4 = 0 %	**H 4 = 1 %**	**H 4 = 0 %**	**H 4 = error due to nausea/ sickness.**

In this connection, the FHP e.V. (Forschungs- und Arbeitszentrum Hochschulausbildung von Piloten e. V. – Research and Higher Education Working Centre for Pilots) determined that H 3 accidents have more than *quadrupled* in the time period from 1963 – 1992.

It goes without saying that these analyses could also continued with an international differentiation. This is not the main objective of this contribution, however. Statistically secured comparisons to other modes of transport clearly indicate *that the aircraft can still be regarded as the safest means of transport*.
Every aircraft accident is one too many, however.

If you only consider the increase in the density of air traffic that is expected for the future (for European air space, it is assumed that the density of air traffic will triple by the year 2020), the increasingly cut-throat competition between the many airlines, the "masses" of people and goods to be transported (e.g. A-380) and the need for mobility due to economic development, above all in Asia (China, India, Vietnam), the extent of the damage that could arise for people and goods will become clear.
It is therefore all the more important to investigate the causes that mainly appear to be responsible for this kind of development. In the following contribution, within the sense of the Man – Technology – Organisation interaction chain, the author has thereby concentrated on the „Human reliability" factor in flight work systems, their possible determination and specific ways of influencing them.
In recent times, and in particular in Germany, Switzerland and Austria, there have been "movements" in regard to these questions, which encourage hope for fundamental solutions.
In doing this, it is clear that we must not forget Work Science / Ergonomics.

3. Findings regarding the training of transport pilots

In recent years, the work of the transport pilots in civil air traffic has experienced serious changes, for example, as a result of new technologies and increased automation, above all in the cockpit.
The increasing complexity of the overall air traffic system, the extended and qualitatively changed range of tasks in the cockpit, the growing density of air traffic, the enormous increase in competition for all airlines and an exponential increase of H 3 accidents (see Table 1) call for a critical examination of the ATPL[2] training of all pilots that has been carried out up to now.
The increasing problems that arise from the considerable increase in the demands on pilots in the increasingly complex Man – Machine – System must be solved, above all, by a high level of training.
According to earlier analyses, there are neither scientifically-based works analyses and qualification profiles for transport pilots, nor a state-recognised professional qualification (Faber-1994). If a pilot loses his flight authorisation, for example for health reasons, he can certainly fall into a deep „social abyss".
For this reason also, a university education for transport pilots should be required, which should be completed with a double qualification (graduation or Master's degree + ATPL). Against the background of the implementation of the JAR-FCL[3] (new European regulations), no further time delays should be permitted here.
If it has to be determined that aircraft technology has developed significantly faster than the training of pilots, there are indeed clear signals of this.
A new and comprehensive curriculum and its implementation must therefore be promoted here, and not another one-sided orientation on (multi-choice) examination questions.
It is generally accepted that, with higher levels of automation and thereby the higher complexity of the transport aircraft of the 3rd jet generation, pilots with higher qualifications will also be required.
As a result of the changes in air traffic described above and through the concrete development of new commercial aircraft, the working conditions for the pilots and their crews have changed radically with respect to quality. The key features are listed below:

- The „cockpit" workplace has changed considerably through automation,
- The cockpit team has shrunk from the former 5 to only 2 members,
- Motorised standard activities of the pilots are on the decrease,
- Monitoring work and system management dominate in normal operation (high cognitive requirements and influencing of the vigilance status),
- Highly automated digital fly–by– wire glass cockpits are very convenient in normal operation,
- In the case of a fault, the high level of complexity leads to a greater density of information, which can endanger the control of the system by the pilots,
- Human factor accidents of category H 3, which arise from training and qualification deficits, have increased exponentially since the 3rd jet generation.

According to Faber, the following "Qualification shifts" for the pilots will be noted above all for the 3rd jet generation of commercial aircraft: Pure operational activities – and manual flying in particular (important for certain fault situations) – will be increasingly carried out in the background.

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2 ATPL = Airline Transport Pilot Licence
3 JAR-FCL = European Directive for Crew Licensing (replaces LuftPersV).

After an extensive flight preparation in the ground, „monitoring“ will be the main task of the pilots in normal operation. Apart from the stricter vigilance problems, the new systems of the 3rd jet generation of commercial aircraft are mostly very convenient to operate.
High information densities, strong cognitive demands and thereby a heavy loading of the pilots only clearly arise in fault situations. Above all, this thereby results in a situation that is very different from the 1st generation. Previous basic skills that are no longer related to the procedure lose their significance in normal operation, while extra-functional, longer lasting and comprehensive, so-called „key qualifications“ are increasingly necessary and will have to be correspondingly defined.
These increasingly convenient, user-friendly systems with a high level of automation can certainly also be flown by pilots with lower qualifications in the normal case. So-called „Push-button operators“ can thereby certainly be successful in normal operation when working on very complex hybrid systems.
Things are, however, completely different in the case of possible fault or accident situations.
A higher level of qualification will always be required here for a successful and safe manual takeover, so that the possible defective system can still be controlled.
Aircraft manufacturers and even airline operators have ocassionally claimed that aircraft of this type can also be safely flown by less qualified pilots. If this claim seems a little dubious for the normal operation at least, it is definitively always wrong for fault situations. Under this aspect, one should also take into account the satisfaction of the large demand for pilots arising from airlines in the Asian area, and thereby on the possible endangerment of international aviation safety.
In particular, accidents in recent years have shown that the insight of the pilot into the higher system levels alone is not sufficient, and that, above all, information and/or know-how regarding the system relationships must also be guaranteed. If the pilots have deficits in this area – and this can generally be assumed – this could lead to fatal consequences in cases of faults.
At the same time, however, a warning must also be given here regarding systems that have a complexity that is sometimes unnecessary, and thereby too high. Systems of this kind can thereby often no longer be controlled, despite a comprehensive and high quality pilot training. A core question regarding the principle of the functional division between Man and Technology is thereby raised.
The difference between a trained operator and a qualified pilot with the corresponding capabilities become particularly clear in the case of faults in the system.
The qualified operator (pilot) who is just sufficient for the normal operation fails in the case of a fault, in which manual takeover, fault analysis and thereby a decision and measures to avert danger are necessary – frequently under extreme time pressure.
In contrast to the 1st generation, the following have above all become necessary for the control and operation of the 3rd generation:

- Programming,
- Monitoring,
- Fault prevention,
- Fault analyses,
- Any trouble shooting,
- And finally manual takeover (getting into the loop).

The above remarks certainly make it clear *that the training of the pilots must be carried out according to the basic principle of having the best-possible qualification of pilots and crews available for the worst possible situation (fault)*.
In this prospective sense, it can be justifiably assumed – as is also possible in other areas of working life –that the sources of danger will be identified and eliminated, so that damage cannot arise at all. Although the fixed costs in the sense of a prospective work planning (e.g. a university education) may be somewhat higher, the variable costs can, however, be reduced enormously in the medium to long term through the minimisation of risks and damage.

4. Human reliability in work systems

As a synonym for the expressions „Man - Machine – System“ or „Socio – technical system“, the expression “Work system” can also be used, which has generally become increasingly established in the Work Science literature.
The advantage of the system approach is that it permits a generally valid method of presentation for the structure of very different phenomena.
The performance and reliability of a work system from the viewpoint of Work Science / Ergonomic objectives can be established above all through the use of findings from the *Stress – Demands concept* (deployment of the person) and from the viewpoint of the transformation of information with the help of ergonomic system considerations.
The following illustration shows this connection:

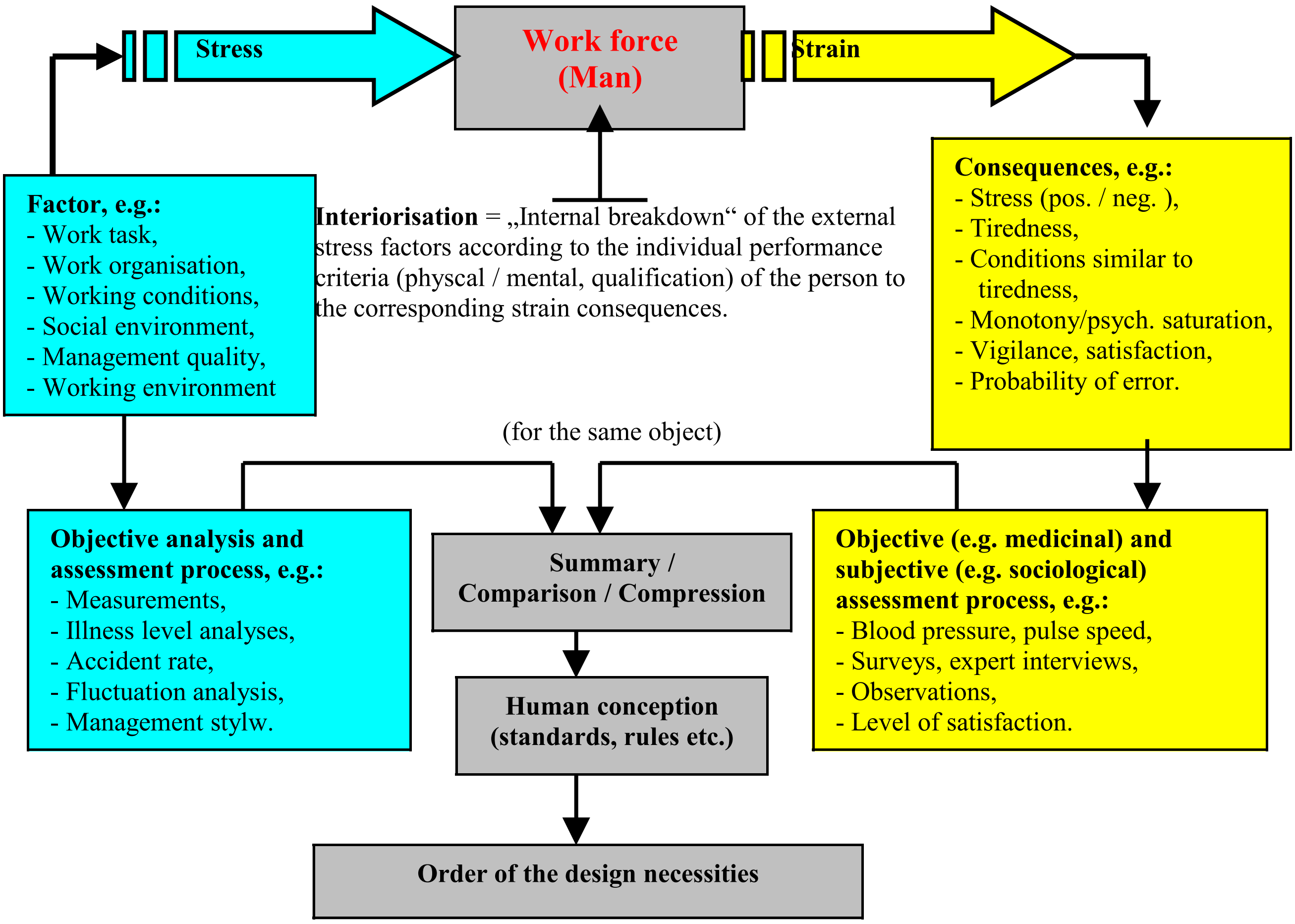


Fig. 1: Stress – Strain concept (Bartsch-2004)

In the author’s opinion, there are a number of direct connections between these considerations of the Stress – Strain concept and human reliability.

Bubb (1992) defined human reliability as follows:

„Human reliability is the capability of the person to carry out a task under predefined conditions for a given time period within the range of acceptance.“ / 3 /

Using the same basic approach, Bartsch (2004) extended this definition by naming the important boundary conditions, and formulated it as follows:

„The ability of the person in the work system to bring a suitable qualification and the corresponding physical and mental performance preconditions into a specific work process, and to become effective. This should contribute towards a predefined task being carried out under specific conditions and in a predefined time period, whereby technical, economic, humanitarian and ecological criteria and a failure acceptance range are respected.“ (Bartsch 2004).

Figure 2 shows the major factors that influence human reliability:

Fig. 2: Factors influencing human reliability (Bartsch 2004)

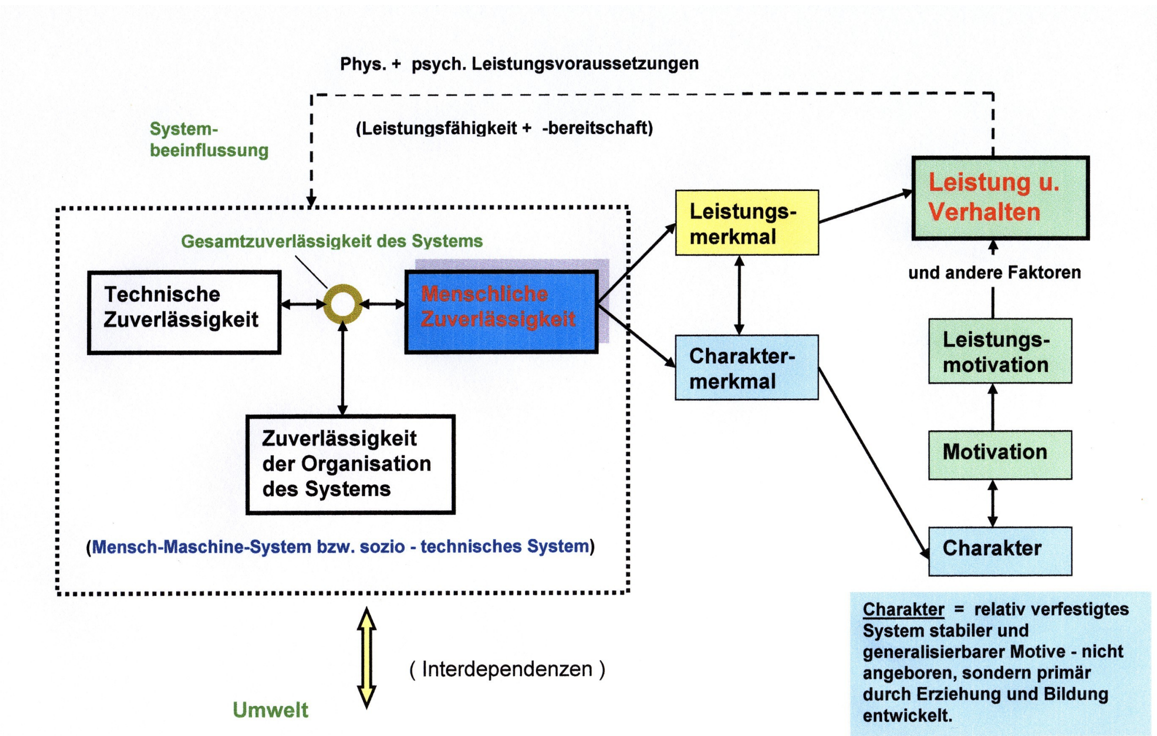
In contrast to Bubb, who saw a linear dependence between human probability for error and human reliability, the author regards human reliability as a structure that is far too complicated to allow itself to be adequately determined simply by a mathematical relationship of this kind.
The value of a statement assigned in this way is, in the opinion of the author, also controversial from the viewpoint of the other levels:

1. In this case, it is quite clear that „Error” has been equated and/or confused with the actual „Cause“. Between the actual „causes“ of a possibly different human reliability (assignment, execution or working conditions, human disposition factors, etc.) and the „errors“ or the „error probability“, however, there are the „Interiorisation process“ that are so important for the respective individual human reliability (see also Fig. 1).
Through this interiorisation process, the author see a greater „proximity“ to human reliability than to the probability of human error . Human error or the probability of human error are to be understood in the scientific sense (e.g. Black–Box method) as a „Result“ or „Output“ of the upstream processes.
You therefore come closer to human reliability if you consider the dominant characteristics of this interiorisation process. There are, however, no linear, mathematical relationships to be expected here.

2. Up to today, one cannot assume that there is a uniform and convincing opinion in the specialist literature regarding the possibilities of the classification of human error (see Rigby -1970, Meister-1977, Rasmussen-1981, Hacker-1984, Rouse & Rouse-1988, Zimolong-1990).

There could be occurrence- and achievement-orientated, cause-orientated, or combined methods. Human error can have a stochastic or deterministic character. Furthermore, a classification can only be carried out if human error occurs randomly, sporadically or systematically. What will then be the relation to the above-mentioned „aAcceptance range“ if we assume that there is a “human right to make errors”?

That human reliability can be understood in this context as a characteristic/feature, as well as a performance characteristic/feature at the same time, is shown in a simplified manner in Figure 3:



The author assumes that at least the correlations shown in Fig. 2 must be verified by systematic investigations. Extensive results are already available in some areas in the form of dissertations, habilitation dissertations and other scientific works using the example of different target groups (e.g. pilots, surgeons, managers). This work should be continued, and could be used to obtain a corresponding overall picture of the determination of human reliability in the work process.

5. Behaviour in the flight work system

The preceding items and explanations will be used in the following as an example relating to the problem of aviation safety.
In doing this, it is assumed that the fulfilment of tasks in flight work systems depends in particular on the manner in which the tasks are handled. The question of *the behaviour of the work system that can be expected* arises in this context, among other things.
Characteristic system features for this are (Dorn / Bartsch - 2004):

- The work system exists in reality and is relatively open to its environment. It presents itself as a natural entity, and follows the scientifically known natural descriptions within its areas of validity,
- The work system forms a network of interactions with and within its elements and its environment,
- A main element of the work system is the operating material: it is a technical product that is largely characterised by linearity (Eilenberger-1990). It works in a functional manner, and the behaviour can be generally described and predicted through causal chains,
- A further main element of the work system is the human being: A natural object that is characterised by non-linearity. Although the human being works in a „goal-oriented“ manner (Bullinger 1997), his behaviour can, however, only be partly described by means of through high-dimensional, complex causal fabric (Eilenberger 1990, P. 80). An essential orientation aid for the description of the behaviour of the human being is, among others, also the „conception of man“.

According to Gerok 1990, the preconditions thereby exist for the situation in which a system can no longer be fully predicted, despite knowledge of the initial conditions. *Processes that run in accordance with the conditions described above can thereby no longer be mathematically described with the help of a linear differential equation*.
For the problem that we are considering, it can thereby be assumed that „Order“ and „Chaos“ represent the corresponding behavioural elements of this work system.
The practical results of investigations from air travel partly confirm this conclusion.
For further processing of the problem, it can therefore be assumed that the flight crew can be considered to be a „collective construction“ of the corresponding employees of the commercial aircraft under consideration.
It can thereby also be assumed that, among other things, the complex, natural behaviour of the flight crew will pursue the goal of ensuring the corresponding protection [4] of the work system.
No protection of the work system against threats can take place, however, if the aircraft crew finds itself in a state in which it is no longer capable of regulating its own relationship with the environment or of self-regulation.
According to this principle, a theoretical-hypothetical approach can be developed that takes the following positions into account:

- A certain level of internal self-organisation and/or the regulatory behaviour feedback of the flight crew on the basis of limited resources,
- The flow („Interiorisation flow“ / see Fig. 1) of collective interiorisation parameters as a measure of the common Stress-Strain level of the crew in this case. It forms the „cause“ of the regulatory activity of the flight crew,
- The level of apportioned *agility*, i.e., the „flexibility“ of the flight crew in bringing a different level of regulatory activity into the system and allowing it to take effect (see: Definition of the expression „Human reliability“ by Bartsch).

A „flight crew subsystem“ feedback of this kind is shown in a very simplified way in Figure 4.

Initially, only those elements have been picked out from Fig. 4 that could be particularly relevant for the determination of a possible mathematical model.
The job holders receive the corresponding information from the respective *air operation status* (*Flugbetriebszustand)*.
The resulting perceptions are then processed in a cognitive process through the safety-orientated comparison of the objective operational risk with a corresponding subjective operational imaging system (OAS). Possible perceptual distortions remain initially unconsidered.
The result of this leads to a subjective assessment of the effective objective risk potential (Hacker 1998). The subjective attitude of the human being to the risk (in relation to the characteristics of his awareness of danger and safety) is an important *activation parameter* for protective measures, in which the findings from the risk compensation theory must be taken into account (Bubb 1992).

Decisions, selections and activation of actions that become genuinely effective for the protection from dangers are understood as „protective measures“. The corresponding protective measures will be agreed with the crew. The agreement on action on this (Multi Crew Coordination und Crew Resource Management) thereby represents an essential element of the internal self-organisation of the work system.
The time that is necessary for this is integrated into the system behaviour as the corresponding reaction time of the flight crew.
The work requirements that arise from the operational phases of the work system (Phases of Flight – POF, see ATA iSpec 2200), the respective work content and the associated miscellaneous working conditions lead to the corresponding *work stresses.*

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[4] According to DIN 31004, Part 1, „Protection“ is understood to be the reduction of the risk through suitable precautions, that reduce either the frequency of occurrence or the extent of the damage, or both. Risk is described through the frequency (probability of occurrence) and through the extent of the damage to be expected (significance).

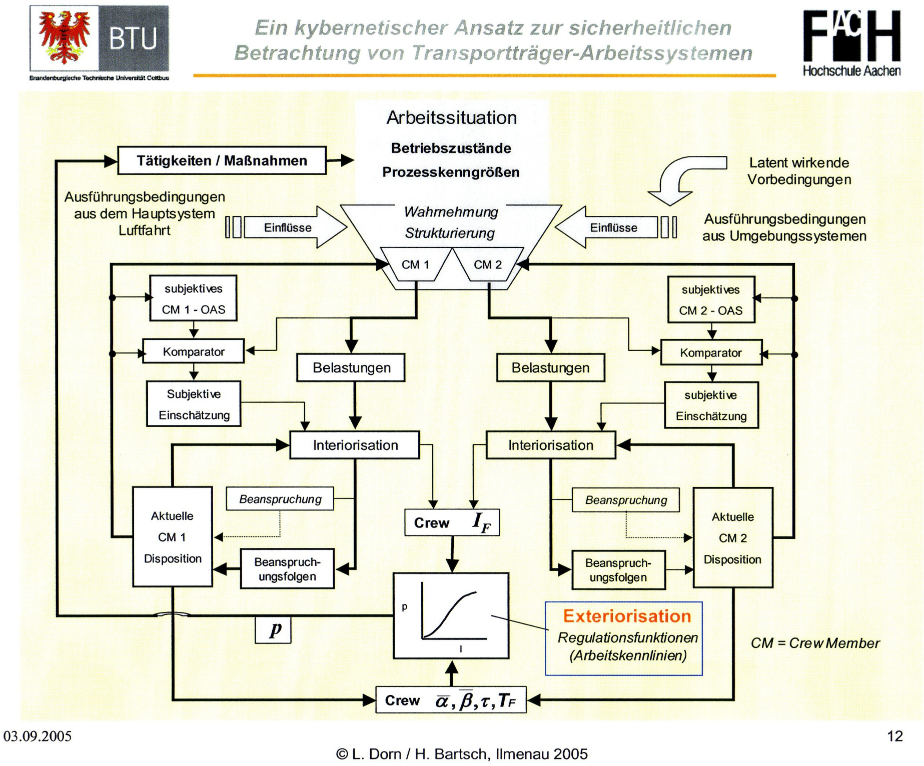

Fig. 4: Hypothetic „flight crew subsystem“ with feedback (Dorn / Bartsch-2004)

These work stresses – together with the subjective assessment of the objective risk as a possible special mental stress component – then lead through the *individual interiorisation process* to a corresponding *stress level* with given *consequences*.
The author hereby assumes that the change in the „interiorisation flow“ represents the root cause of the „regulatory activity“ of the flight crew (for example, to ward off threats). Many and very complex correlations thereby exist between the characteristics of the human reliability (see Fig. 2) and the inner performance disposition of the person/persons.

On the general basis of the above description, there is now the possibility, in line with Blome, Mertens, Dorn-2004, of describing the behaviour that was described above and the stability of flight work systems in the form of a mathematical model using non-linear differential equations.
The treatment of this mathematical model step-by-step is not completely possible here for reasons of space. The factors of tiredness (vigilance) and regeneration are not initially taken in to account in this model, however.
The main expressions are „set“ with:

- Regulation activity P_F
- Carrier capacity T_F
- Relative regulation activity p
- Interiorisation flow I_F
- Agility of the aircraft crew A_F
- Level of the relative regulation activity at Work Point P_0
- Marking the output position of the system status consideration Index 0
- Control parameter α

The behaviour of the sub-system, starting from the initial status p_0 (work point), can thereby be considered through the increase or decrease of the interiorisation flow.

For the determination of statements regarding the *stability behaviour* of systems with feedback, the reaction times of the crews (which arise through the intake and processing of information and the cognitive processes and internal agreements on action that arise from these) must also be taken into account.

6. Summary

With this contribution, the author wishes to draw attention to the fact that there is clearly a close relationship between human reliability und effective, safe and humane flight work systems, above all from the viewpoint of aviation safety.
Despite, or perhaps because of the increasing cockpit automation, the rapid increase in air traffic density, the increased competition between the airlines and other safety-relevant factors in aviation traffic, it is above all the human being, with his capabilities, but also with his weaknesses and performance limitations, that is subject to a particularly critical consideration in this contribution.
The increasing number of aircraft accidents that are caused by human factors give alarming signals in this respect.
It is therefore necessary to rigorously face up to this problem, both scientifically and in practice, and to relatively quickly find solutions here that will completely and comprehensively identify this continually increasing risk factor and that can react to it with suitable measures.
An initial possibility for this is outlined in this contribution, which requires further intensive research work, however.
The part that could be played here by Work Science / Ergonomics, among others, has also been indicated in this contribution.
If our purpose here is above all to improve the air traffic management, and thereby also aviation safety, through a prospective work design so that users and customers will achieve a higher level of satisfaction, we should also consider this complexity in the context of scientific research in the future, and learn to think and work in a genuinely interdisciplinary manner, and thereby make a valuable contribution to the better qualification of the personnel who determine and accompany flights.
This contribution will have served its purpose if it has been able to stimulate further reflection on the subject.

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