REPORT ON THE PHASE 3 OF THE WORK OF THE FUTURE AVIATION SAFETY TEAM
INCREASED RELIANCE ON FLIGHT DECK AUTOMATION
DRAFT ISSUE 10
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2 Background:

2.1. JAA Safety Strategy Initiative:

In early 1998 the JAA agreed to launch the JAA Safety Strategy Initiative (JSSI). The purpose of the JSSI is to develop a focused safety agenda to achieve the JAA aim for safety which reads:

The JAA aims at continuous improvement of its effective safety system leading to further reductions of the annual number of accidents and the annual number of fatalities irrespective of the growth of air traffic.

JSSI involves Authorities and interested parties and other bodies such as ICAO, EUROCONTROL, US Commercial Aviation Safety Team (CAST). This co-operation is fundamental to achieve a worldwide safety agenda and to avoid duplication of efforts. For instance, up to now CAST has taken the lead for the “historical approach” and JSSI has taken the lead for the “Future Aviation Safety Team (FAST).

Two complementary approaches are being used to develop the focused agenda:

- One approach based on past accident analysis (“historic approach”) which has led to the identification of an initial list of 7 focus areas: Controlled Flight Into Terrain; Approach and Landing; Loss of Control; Design Related; Weather; Occupant Safety and Survivability and Runways Incursions.
- The Future Aviation Safety Team approach (“predictive approach”) based on an analysis of ongoing and future changes affecting the aviation system is aimed at revealing unidentified hazards.

3 FAST methodology issues

3.1 Main steps of the methodology as originally defined in Phase I

The main steps of the FAST methodology were defined during the first phase of the work and may be summed-up as follows:

Step 1 Identify areas of change
Step 2 Prioritize and select of areas of change
Step 3 Define methodologies, determine future hazards and prioritize future hazards for each selected area of change
Step 4 Global review and synthesis of future hazards from each area
Step 5 Validate, prioritize and select synthesized future hazards
Step 6 Develop, validate, prioritize and select interventions
Step 7 Propose actions to JSSI Steering Group
Step 8 Monitor the effect of intervention and iterate the process from the beginning

3.2 Guidelines for mining hazards defined in Phase II to complement the above:

Further guidelines for step three were developed during Phase II of the work during a prototyping exercise. These guidelines addressed the following points:

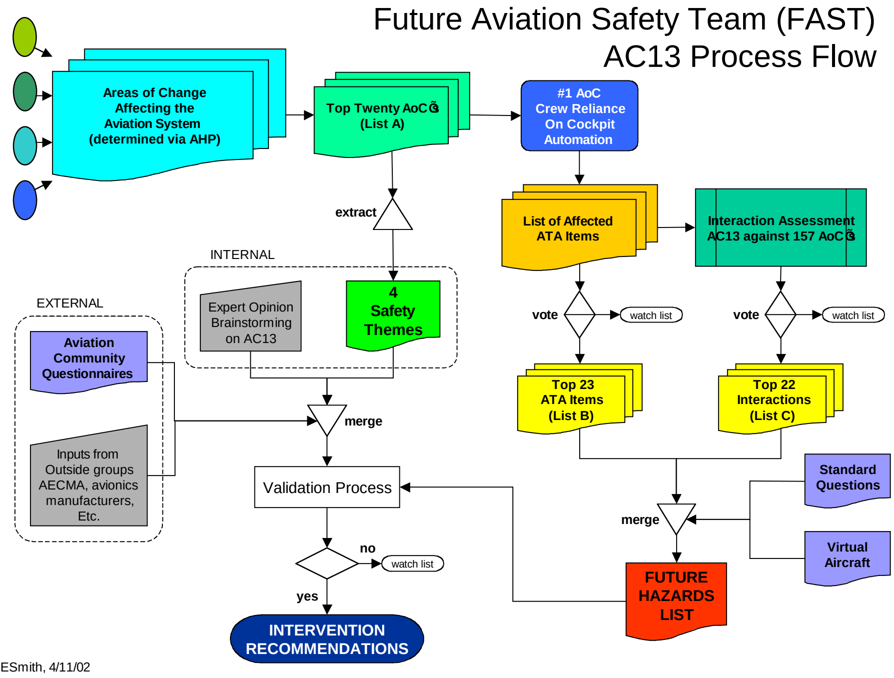
1. Convene an ad-hoc team to identify hazards
2. Review and validate the AOC characteristics
3. Investigate if any lessons learned exist
4. Focus on essential elements of AOC and on its main interactions
5. Develop the sub-methodology to identify hazards
6. Perform the sub-methodology to identify hazards

The rationale for developing such guidelines can be explained as follows: the human mind can quite easily think in terms of the risks and hazards for particular activities. However the abstract bridge between the process of change and generation of future hazards or risks is not obvious. An iterative process linking AoC’s to future hazards and risks necessarily involves expert opinion and extrapolation of trends rather than use of hard data. It is a relatively straightforward process to identify hazards and risks based on what has been encountered in the past. It’s more difficult to extrapolate to the hazards and risks of future events and circumstances that haven’t been encountered yet. It’s currently difficult to convince manufacturers to make changes to avoid undesirable events that have already happened. It will certainly be much more difficult to ask the stakeholders in the aviation system to respond to hypothetical events that are a product of expert opinion. Components and systems currently in use will stay in service for at least 20 years, with limited opportunities for retrofit or significant penetration of new technologies.

A concept of a FAST Core Team was also developed. The purpose of the Core Team was to guide the work and ensure the synthesis between more specialized ad-hoc teams that would have analyzed a specific Area of Change. The Core Team would have been made of generalist with a broad experience in the Aviation System. The sketch included in Appendix 1 paragraph 1.2.5 explain the planned interactions between the Core Team and the ad-hoc Teams

3.3 Methodology used for AC-13:

As explained the Appendix 1, it has not been possible to precisely follow the intended process plan. The diagram below illustrates the methodology that was followed for AC13 to arrive at the proposals for future work that are described in this report:



BESmith, 4/11/02

It should be noted that the methodology used for AC-13 Reliance on Flight Deck Automation focused considerable effort on confirming the validity of the exercise: the rationale for it was two fold:

1. It was the first time that the FAST methodology was used
2. A lot of work has already been performed on automation that should not be ignored.

3.4 Lessons learned using the methodology on AC-13:

Several points should be emphasized at this stage:

1. The importance of clearly defining the scope; trends; scenarios and technology road maps for the Area of Change that is being studied.

2. The importance to build a Team where the main disciplines in relation with the area of Change under review are represented.

3. For Areas of Change that have a broad scope, the need to focus on selected aspects and mine the corresponding hazards that they would create.

4. The need comprehensively identify the interactions arising from the target AoC with other areas of change and the need to focus on the most important ones.

5. When analysing hazards resulting from interactions, the importance of addressing only those truly generated by the interactions and not those that would result from the other area of change

6. When it has been necessary to focus on selected facets of an area of change, the synthesis of hazards at the level of the whole area of change is a critical exercise.

7. The importance of formulating concise and correct hazards statements

8. Necessary time should be devoted to the development of proposals for future work (perspective; discussion; amplified hazard statement; Future technology watch items)

9. Other tools than the Analytical Hierarchy Process were used to do prioritisation. For example, an ordinal ranking scheme was used whereby members were given a fixed amount of votes to distribute among possible selections (usually between one third and one half of the possible options to be voted upon) that they were entitled to use as they wish (e.g. put all votes on only one option; spread their amount of votes on several options)

10. The step 5 of the methodology was not performed because we worked only on one area of change.

3.5 FAST methodology as resulting from Phase III (See appendix 4 for definitions and brief description of tools mentioned below)

Step 1: Identification of Areas of Change (AoC) affecting the aviation system either from within or from external sources

Members of FAST, in concert with regulation authorities, expert advice and input from interested parties, first developed a list of “Areas of Change.” Areas of Change can also be identified through engineering analysis. This list would include a description of the change area, how one change area related to others, and a validation process. The horizon for such changes should be between 5 to 20 years from the date the list is established. In this context, changes must be understood as broadly as possible. To bring consistency and coherence to the process, “Areas of Change” are grouped by categories.

The listing is not meant to be all-inclusive; but a thorough, representative listing within each category is the initial goal. The categorical listing led to the creation of a matrix. The matrix (Annex 3) listed area of changes grouped by categories, onset timeframes and validation tools. It also includes a comment column that provides more details for each change.

It is important to realize that this stage is an identification of the change, not an identification of the hazards that result from the change.

Identification of the changes should be as factual and complete as possible.

Each area of change within the matrix should be examined to determine its effect on the other categories of change. This exercise assists in the identification of crosscutting issues. Subjective judgments by FAST members on the cause for the change and effect relationships would act as supplemental input when attempting to prioritize the categories and their respective areas of change.

Such list should be re-audited on a regular basis (2 to 3 Years). The exercise should be done in one session by a group of experts having a broad knowledge of the Aviation System.

Step 2: Prioritization and selection of highest priority AoC's for subsequent analysis

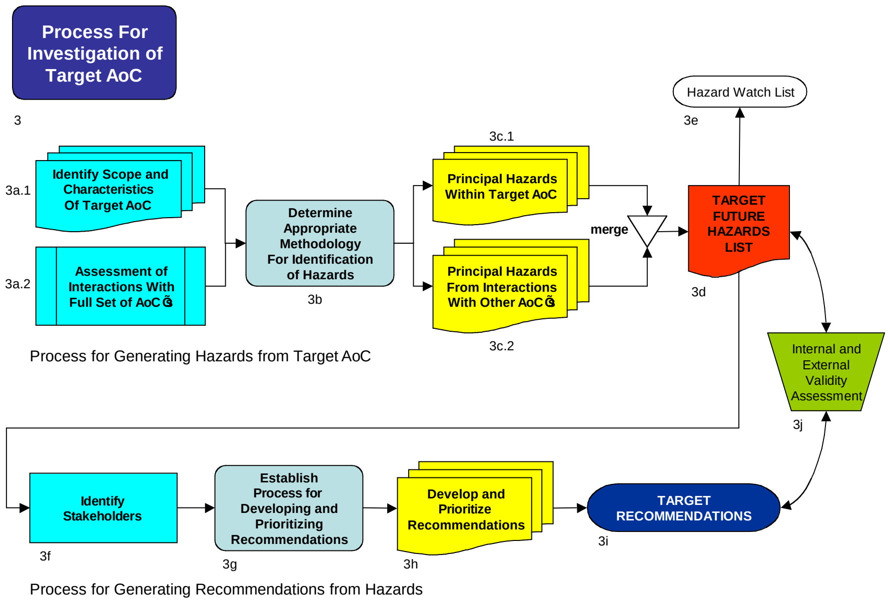
The objective of this step is to reduce the scope of the task and to determine which areas of change would be the subjects of further analysis. The prioritisation of the areas of change depend on numerous criteria, i.e., nature and scope of the change, any trends or profiles present or anticipated timing of the considered change, interactions with other areas, and sensitivity. *The criteria need to be refined (sub-criteria) and be weighted. As a consequence of this prioritisation and selection step, those areas not being actively worked are placed on an "Areas of Change Watch List" and are actively monitored.*
It was decided that an expert panel using the analytic hierarchy process (AHP) could accomplish this step. The rationale for this decision was based upon the following inputs:

- The expert panel would use both individual judgments (Delphi) and open panel discussions.
- It allowed dynamic discussion providing judgments by mutual agreement and revision of views.
- The panel would decide the variables, and
- Qualitative judgments could be scaled from 1 to 9 allowing varying degrees of choice on an issue.

This prioritization would be performed during the same session and the same expert team as in step 1

Step 3: Investigation of Target AoC's

The output of step 2 is a prioritisation and selection of the areas of change for further study. The following flowchart illustrates the sub-methodology of Step 3:



Sub-step 3a.1: Identify Scope and Characteristics of Target AoC

❶ Convene an ad-hoc Team (expert panel) to identify Hazards.

a) Chairman coming from FAST and trained Facilitator
b) Team composition: calling notice sent to “JAA List” and to CAST. Ensure that all necessary expertise is present. Having the right team is fundamental to the success of the work. Do not start without having the right team committed for the whole duration of the work.
c) Training: initiate all experts to concept and terms necessary for the work. Training should address purpose of FAST, methodology and should present examples. This includes clear objectives and methodology of the group
Note: Consideration should be given to provide FAST training to facilitators. Chairmen should also receive an introduction to facilitating techniques.
d) Agenda and schedule:
e) Identify outside bodies to be consulted in view to conduct a validation exercise.

Review and validate the AOC characteristics

a) Draft Scope/Timeframe
FAST will provide a straw man for scope. The scope is the statement of work that defines the territory to be mined for Hazards. The Straw man will be presented to the Team giving each member the possibility to react.
Time frame should be understood as a broad picture consisting of starting point, duration, trends, where do we stand today, event horizon. To help defining the draft scope/ timeframe the following questions could be asked:

- Why?

The “Why” section aims at identifying the main objectives of the Area of Change in the context of a global Air, Ground & Space system.

- How?
  While the “Who” question aims at identifying the main objectives of each of the area of Change, the “How” question aims at identifying the means by which these objectives are expected to be achieved. In addition, the “How” question raised a list of conceptual or paradigmatic prerequisites, and of functional, technical and operational aspects required for implementation.

- What?
  The “What” question aims at grasping the variety of aspects concerned, directly or indirectly, by the area of Change

- Who?
  The “Who” section therefore looks into the various actors or agents of that global system impacted by the area of Change.

- When?
  The “When” question invites to consider the various phases of the global Air, Ground & Space system live cycle impacted, at various degrees, by the area of Change. Practically all design, certification, operations and post-operations phases may need to be considered. In addition to nominal operations, special concerns were raised in case of abnormal, failure, emergency, crisis management and evacuation situations.

- Where?
  The “Where” question aims at listing the main physical locations, organisational functions or activities within the global Air, Ground and Space system directly or indirectly concerned by the area of Change

b) Current situation. Who are the stakeholders of AOC (Manufacturers, Regulators, Operators, Aviation personnel, Airports, etc.). Stakeholders should prepare presentations providing their views in their field of responsibility. This should include former and present / future assumptions (design and others), regulatory framework.
c). Emerging trends: Details of area of change, change scenario, technology road maps, what other changes will change with it?
d) Identification of related AOC’s using a simple yes/no question: the concerned AOC is “compared” to all other to evaluate possible interactions.
e) Define detailed scope and timeframe based on b), c) and d).

❷ Investigate if any "lessons learned" exist

The objective of this step is to identify broad aviation safety themes, not specific examples.

a) Lessons learned from aviation (This may go beyond lessons directly linked to the AOC under study).
b) Lessons learned outside aviation
c) Assemble a list of 4 major safety themes from the Top Twenty, highest-priority AoC’s

Sub-step 3a.2: Assessment of Interactions with full Set of AoC’s

❸ Focus on essential elements of the target AOC and on its main interactions.

Based on (2) and (3) depending on the complexity of the AOC and of its interactions a focusing exercise should be conducted using an appropriate criteria. A suggested criterion for essential elements of AOC could be as follows: participants vote keeping in mind timescales (current; future) consequence for safety (crude evaluation of consequences), existing work. A precise

identification of these essential elements should be helped by using the standard questions described in paragraph 2.
In a similar fashion it may be necessary to focus on the main interactions. A suggested method to identify main interactions is to ask each participant to review the whole list of AOC and identify the interactions. The interactions that have been identified by say two thirds of the participants are then retained.

Sub-step 3b: Determine Appropriate Methodology for Identification of Hazards

❹ Develop the sub-methodology to identify hazards

a) Brainstorming session to develop two elements of the sub-methodology (inherent hazards and hazards resulting from interactions). To assist in this brainstorming , Teams will be provided with a catalogue of questions such as:
What could go wrong (condition, event or circumstance leading to the undesired effect)?
What are the hazards and issues generated by interactions?
Are there agents who are not involved and who should be?

Sub-step 3c.1: Identify Principal Hazards within Target AoC

❺ Identify hazards inherent to the target AoC:

- Domain experts and generalists suggest possible hazards (to crew, to passengers, to third parties, etc.) and present them to the ad hoc team.
- Structured brainstorming will use the sub-methodology resulting from step 3b. Whatever the methodology chosen, all inputs should be accepted and logged without prejudice; the inputs should be definable, clear and distinct.
- Evaluation of presented hazards: the SHEL or other appropriate models can be used to classify the hazards.

Inherent: hazards that are directly related to the change being analyzed, hazards that will occur irrespective of the context outside the change.

Sub-step 3c.2: Identify Principal Hazards Arising from Interactions with Other AoC's

❻ Identify hazards resulting from intersection/interplay of target AoC with other AoC's:

- The target AoC is compared and contrasted with identified interactions (see steps 3a.1 and 3a.2). Accumulation of independent interactions should be envisaged. Only hazards resulting from interactions should be mined: the issue is not to identify all the hazards generated by the other AOC.
- Experts "think" of hazards (to crew, to passengers, to third parties) and present them to the group.
- Structured brainstorming will use the sub-methodology resulting from step 3b. Whatever the methodology chosen, all inputs should be accepted and logged without prejudice; the inputs should be definable, clear and distinct.
- Evaluation of presented hazards: the SHEL or other appropriate models can be used to classify the hazards.

Dependencies: e.g. while working through this methodology, common roots may be discovered for different AoCs, interactions among AoCs may generate other AoCs in a so-called Cascade effect.
Accumulation of independent AoCs: This may create accumulation of non-correlated hazards that together may create new kinds of accident scenarios.

Sub-step 3d: Synthesis of Hazards identified in 3c.1 & 3c.2

This is a critical issue for wide scope areas of change. It deserves a significant effort. By focusing on essential elements there is a risk the hazards found are very specific to a given issue (e.g. Fully Automated Flight in the case of Reliance to Flight Deck Automation). There is a need to find hazards that are related to the area of Change and not only to specific elements of it. All hazards (inherent or generated by interactions) could be presented using the SHEL model. Other models may be used when they are better suited for specific cases. For AC13, a list of standard questions and virtual aircraft model were also used to guide the group synthesis process.

Sub-step 3e: Compile Target Future Hazards List

❼ Prioritize future hazards in each Area of Change.

The following criteria may be used.

- Number of potential fatalities and/or accidents
  - Trend, future existence of the identified hazard
  - Geographical area & type of the operation
  - Size of A/C
- Public perception and understanding
- Any effective intervention?
- Stake holders of the area of change

Using the above criteria, establish a risk assessment matrix identifying the consequences of the hazards (e.g. impact on people, environment assets, reputation) and the probability of occurrence.

AHP is the most logical method to employ at this sub step.

It should be noted that for AC-13 a simpler criteria and a simpler prioritization methods were used. This led to a less resource intensive exercise.

Select the Future Hazards to be worked. All other hazards would be placed on a “watch list” to be monitored and examined at some period in the future. Initial selection may be based upon resources; however, additional selection considerations may be developed and employed.

Sub-step 3f: Compile Hazard Watch List

Those identified hazards that are either of low priority or only peripherally related to the target AoC are recorded in a Hazard Watch List that is periodically reviewed by the ad hoc team investigating the target AoC as well as the FAST Core Group.

Sub-step 3g: Identify Stakeholders

A critical stage in this process involves identification of those parties for whom action recommendations may have importance. The fullest possible range of stakeholders should be identified to ensure that when final recommendations are issued, the appropriate individuals, groups, and organizations are informed.

Sub-step 3h: Establish Process for Developing and Prioritizing Recommendations

This phase consist of a Brainstorming session to develop the process. . The “Perspective; Discussion; Technology Watch Items” template used for analysis of Flight Deck Automation has proven very useful. Other processes are used by CAST and may be also considered.

Sub-step 3i: Develop and Prioritize Recommendations

The CAST ratings for effectiveness and feasibility can be used as a priority filter once the recommendations are developed
Select proposed interventions that may require action by the Authorities, Industry or other Interested Parties.

Sub-step 3j: Internal and External Validity Assessment

The FAST Core Group and ad hoc teams investigating target AoC's will perform periodic assessments of the validity of their results. These assessments will be conducted using resources from within the teams as well as external sources in order to establish confidence in the identified hazards and formal recommendations. The internal validation process will consist of expert opinion assessments and comparison of the target hazards and recommendations with the full list of AoC's and with the hazard watch list. The validity of the results will also be assessed by comparison of the results with targeted surveys of the affected aviation-community constituencies (like line pilots, for instance) and by comparison of the FAST results with the outputs of other industry/government hazard lists (like the CAST Problem Statements, for instance).

❽ AC13 Validation Exercise

The AC13 ad hoc team used both an internal and external assessment process to validate the reasonableness of the resulting hazard identification process. The internal exercise consisted of comparing and contrasting the hazard results with formal, structured brainstorming sessions in the group with the conclusions derived from the previously identified 4 Safety Themes. The external validations process consisted of comparison of the ad hoc team findings with results from a survey of automation usage by line pilots conducted by FAST. FAST members also reviewed relevant research work and available. In addition the identified hazards were compared with the current set of CAST problem statements as a sanity check.

Step 4: Compile Master Future Hazards List

The FAST Core Group will compile and maintain a master list of future hazards. This list should be presented in an organized manner (To be determined: present list is the list of Hazards of AC-13 and it uses the SHEL model). The compilation should also avoid duplications and use a concept comparable to the CAST concept of standard problem statements.

Step 5: Compile Master FAST Recommendations

The FAST Core Group will compile and maintain a master list of recommended actions and/or interventions. The JSSI Steering Group (and the Commercial Aviation safety Team – CAST) will need to integrate intervention recommendations coming from the Future Hazards and Historic approaches**.** The concept of an Action Plan Team could be used, as it is generic enough to be applied to various kinds of interventions.

Step 6: Ongoing Monitoring of Aviation Safety Trends

Each member state or party could develop their own methodology to monitor selected interventions and their effect on the identified hazards.
It is proposed that for all identified hazards there is a continuous analysis of occurrences and trends against developed hazards scenarios. The goal is to provide early emphasis on Hazards to validate and update the on-going actions. Further development of this monitoring will be performed by the JSSI-ODAS Working Group (Occurrence Data Analysis Specifications).

➓ Periodic reviews of the AC13 hazards and recommendations Watch Lists

3.6 Policy relative to the use of FAST in the future:

At the end of this phase, FAST developed a policy relative to how to best employ the FAST approach in the future:

Based on lessons learned on AC-13 and on a review of possible options, FAST “systemic” methodology should be used to:

- List and prioritise (1 session) changes affecting the Aviation System (Horizon: 5 to 20 years) by one team; list to be re-audited on a regular basis. (2 to 3 years)
- Develop scenarios and technology road maps; identify, prioritise hazards and develop prioritised interventions on selected changes by dedicated sub-teams normally in three 5 days meetings of organised brainstorming.
- a general monitoring process must be run:
- For all identified hazards, continuous analysis of occurrences against developed hazard scenarios, Goal: provide early emphasis on hazards to validate and update the ongoing actions. Review and update of the future work proposals initially made.

4. Areas of Change Affecting the Aviation System

4.1 History of Areas of Change (AOC) List

As the Future Aviation Safety Team (FAST) began its work, the team arrived at an early consensus position that to predict future hazards possibly affecting the aviation system, one must first understand the context in which aviation operations occur. These contextual factors consist of both changes within the aviation system and changes external to the industry. To this end, the FAST embarked on an effort to identify all potential factors and categories of dynamic phenomena that could conceivably affect the safety of aviation operations. This was accomplished using the expert opinion of the wide variety of participants during the initial set of FAST meetings. Representatives were drawn from major air carriers, pilot communities, regulation and certification authorities, airframe and avionics manufacturers, research laboratories. The FAST included membership from both Europe and the United States

4.2 Categories of AOC's

The FAST identified eleven broad areas of change affecting the aviation system ranging from aircraft design to larger issues such as organizational structure and environmental considerations. A key output of the FAST is the matrix containing a comprehensive list of ongoing and future changes that may affect the international aviation system. The matrix attempts to capture and consolidate the significant categories of change that policy makers will need to consider as the international aviation system evolves to meet future commercial demand and safety requirements. 157 individual areas of change were identified by the FAST. The change areas have been assigned to the following major categories:

- Aircraft (AC)
- Maintenance, Repair & Overhaul (MRO)
- Operations (OP)
- Crew (C)
- Passenger (P)
- Organization (OR)
- Authority (AU)
- Air Navigation System (ANS)
- Airport (AP)
- Environment (E)
- Space (S)

Definitions of each of these change categories are described in appendix 2.

4.3 Description of the Areas of Change Matrix

The Areas of Change matrix is found in Appendix 3. The first column of the matrix contains a code for each item in the list. An example entry is as follows. "AC1" stands for item 1 in the Aircraft (AC) category. The code is simply a convenient means for identifying the individual items in the matrix.

In the second column is the list of the areas of change. Ongoing and future changes that may affect the aviation system are described in short phrases. For certain categories, such as Crew and Air Navigation System, human factors considerations are quite similar, and for this reason analogous areas of change related to human/machine interaction phenomena appear in both categories. To avoid possible omission of different but related perspectives on a similar issue, the FAST opted to err on the side of including apparently duplicative entries in one or more categories.

The FAST felt it was important to estimate the onset time frame for each of the areas of change. The projected year or estimated time span for the various areas of change is listed in next column. In some cases, the change is already in progress and will continue for the foreseeable future. This characteristic is identified as "ongoing."

In order to determine whether a postulated change is in fact occurring, concrete indicator(s) should be used by safety analysts and policy makers. Potential indicators are listed in the column entitled "Validation Tool." The various indicators must permit experts to determine the nature and extent of the change if it is actually taking place.

The last column contains comments that serve to clarify and expand upon the description of the change area. Some comments also contain illustrative examples of the significance of a particular area of change. References are listed as appropriate. The FAST felt that is was important to indicate where possible that the identified area of change is significant and worthy of active monitoring by appropriate government and industry leaders.

4.4 Prioritisation of AOC's:

In February, 2001, (during the second phase of FAST), a team of experts met in Brussels, Belgium at EUROCONTROL to consider and prioritize the 157 AOC's using the Analytic Hierarchy Process (AHP). The experts examined (using a technique called pair-wise comparison, i.e., one item compared to another) the objectives and sub-objectives for their importance. AHP had a unique method of using pair-wise comparisons to derive priorities that accurately reflected each expert's perceptions and values. AHP synthesized or combined the priorities derived for each facet of the problem to obtain the overall priorities of alternatives as agreed to by the experts.

This examination ultimately resulted in the list of 157 AoC's by AHP output calculation. When the AoC's calculations were placed in chart form from highest output calculation to lowest, natural breaks occurred in the output. It was decided by the FAST team to select the top twenty AoC's (A natural breaking point):

1. Increasing reliance on flight deck automation (AC-13)
2. Emergence of new concepts for airspace management (ANS-1)
3. Introduction of new technologies with unforeseen human factors aspects (C-1)
4. Proliferation of heterogeneous aircraft with widely-varying equipment and capabilities (AC-11)
5. Discrepancies in pace and approach in development and implementation of airborne vs. ground-based technology systems (OP-5)
6. Increasing number of aviation operations (ANS-2)
7. Introduction of new technologies with unforeseen human factors aspects (ANS-7)
8. Variation of sophistication of hardware and software within an individual aircraft type (AC-10)
9. Ageing avionics, powerplants, electrical and mechanical systems, and structures. (AC-26)
10. Decreasing numbers of qualified maintenance personnel (MRO-1)
11. Decreased separation standards (ANS-5)
12. Increasing pressure for outsourcing of maintenance/modifications of aircraft (AC-23)
13. Increasing lack of standardization in cockpit controls, displays, and automated systems interfaces among aircraft (AC-12)
14. Shift in responsibilities for collision avoidance from ATC to crew (C-6)
15. Increasing level of information inequality in shared decision-making contexts (C-2)
16. Increasing Reliance on active flight controls (AC-17)
17. Increasing numbers of aircraft operations at lower altitude and/or in adverse weather conditions (OP-4)
18. Increasing need for maintenance of complex integrated aircraft (AC-24)
19. Discrepancies in the pace and direction of development of ground vs. in-flight CNS systems (ANS-21)
20. Decreasing maintenance expertise (MRO-2)

4.5 Four Major Safety Themes

Following the process of prioritisation of the full set of Areas of Change using the AHP process, twenty of the highest priority items were identified. FAST produced a synthesis of major ongoing and future aviation safety issues extracted from the above twenty highest priority Areas of Change. This synthesis represents a summary of key future safety concerns.

The four major safety themes are described hereafter:

1) Introduction of new air, ground, and satellite-based automated systems.
2) Increased heterogeneity of: aircraft types & flight capabilities, equipage & software, airspace utilization approaches, and development directions & timelines for airborne, ground, and space-based aviation support systems.
3) Increase in absolute numbers of aviation operations and corresponding reduction in safety margins as a result of: increased demand, decreased separation and more frequent operation in or near adverse weather conditions.
4) Ensuring adequate maintenance of air- and ground-based systems in an environment of increased outsourcing of work, increased complexity of hardware, firmware & software, and a shortage of qualified maintenance personnel.

The FAST envisions two potential uses for this summary:

- To illustrate the FAST work to outside groups and within the FAST methodology as a way to summarise the work to date
- To be used as a part of a Regulatory Impact Assessment of a rulemaking project to evaluate how the risk addressed by the project involve in time.

5 Synthesis and analysis of Flight Deck Automation issues

5.1 List of Principal Automation Hazards:

Using the analysis process described in 5.3 FAST came with the list of principal automation hazards shown hereunder.
This list is organized using 4 time frames: 6 principal hazards are considered current (Up to 1 year); 7 are considered future-near (1-5 years); 6 are considered future-medium (5 to 10 years); 2 are considered future-long (more than 10 years).

This list represents the Top-21 out of a total of 286.

One important observation should be made here as one may be surprised to find hazards in relation to fully automated Flight in the time-frame future-medium:
Fully Automated Flight (FAF) has been used as automation extreme with the objective to avoid overlooking essential details
FAST does not foresee FAF for Commercial Air Transport before 20 years from now.
However, in FAST opinion, the operation of UAVs (Uninhabited aerial vehicles) mixed with normal traffic in civil airspace will be the first step towards FAF and this poses already major safety issues.

Hazards List			
	Current (Up to 1 year)		Related Hazards
1	LIVE 4.1	**Flight crews - Conflict between air / ground information sources**:	

		Poor escape manoeuvre decision due to conflict between different information sources (e.g. TCAS, ATC verbal messages, data link) and lack of explicit prioritisation	
2	LIVE 6.11	**Flight crews - Crew-automation interactions issues**: Abnormal/emergency situations combined with automation breakdown or failure (subtle or sudden) may create situations exceeding crew experience or training level	Live 6.1.1 Soft 4.26 Soft 6.4
3	LIVE 6.2	**Flight crews - Crew-automation interactions issues**: Predominant use of automation may cause aircrew to have trouble performing traditionally simple operations such as manually switching to other runways, or overriding the autopilot in tight situations. Lack of aircrew training and/or experience coupled with manual flight in highly automated airplanes may lead to loss of aircraft control in unusual situations such as upsets, traffic avoidance or manoeuvring. Loss of basic piloting skills through further automation may increase this problem further	
4	Soft 6.3	**Operations - Flight operations / interactions with automation**: Loss of automation behaviour awareness due to complexity of automation modes. Pilot needs to know what the airplane "thinks" is going on (matching expectations) (C3)	Live 6.9b Soft 4.25 Soft 6.1
5	Hard 7.4.1	**Databases, software products & applications**: Failures in databases caused by wrong data or errors in updating the databases can affect the integrity and result in inaccurate, misleading (content errors), obsolete or inadequate information. (AC10) (C7) (AC20)	
6	LIVE 15.5	**CNS/ATM/ATC and SCC – Adverse conditions / failure / emergency / crisis mgt issues**: Sabotage; Intentional damage or degradation of systems, either through physical means or through cyber attacks is a possibility	
	Future – near (1 – 5 years)		
7	LIVE 6.1.4	**Flight crews - Crew-automation interactions issues**: A poor automation logic/interface may lead to decision-making based on false or misleading assumptions	
8	Soft 2.8	**Operating Procedures**: Inadequate processes for certification of computer software (including interactions with other software systems and artificial intelligence) onboard the aircraft and in the larger airspace system (C1, ANS20)	
9	LIVE 15.4	**CNS/ATM/ATC and SCC – Adverse conditions / failure / emergency / crisis mgt issues**: Sole reliance on an off board navigational	

		information source such as GPS, combined with the unavailability of that system, causes CNS-ATM system failure and severe accident hazards simultaneously throughout the ATM System	
10	Env 2.3	**Hazards inherent to new airspace paradigm and from a large, distributed and inter-related Air / Ground / Space (AGS) system**: Loss of situation awareness (global, local)	
11	Hard 4.4b	**Compatibility, integration, configuration management issues** *(Including for HM Interfaces and Software applications):* Failure or malfunction caused by incorrect functional interfaces	
12	Hard 7.1b	**Databases, software products & applications**: Widespread power failures and software failure / error propagation increases the potential for unknown failure conditions	
13	LIVE14.1	**CNS/ATM/ATC and SCC – Operational issues**: Use of automation or of automated systems outside of intended function cause safety problems. Example: “climb in trail” with TCAS/ACAS	
	Future-Medium (5 to 10 years)		
14	Env 2.1	**Hazards inherent to new airspace paradigm and from a large, distributed and inter-related Air / Ground / Space (AGS) system**: Failure to integrate onboard and ground systems, e.g. control functions, data link, personnel, responsibilities - ATM/ATC and aircraft control functions (distributed multi-agent control system) - Data link with many outside partners: ATM / ATC and SCC (under the Fully Automated Flight hypothesis) - ATM / ATC / OPS / SCC (under the FAF hypothesis) / Flight Crew / Cabin Crew, including security and medical personnel (in particular for FAF) / Maintenance (in particular for FAF)	
15	Env 2.5	**Hazards inherent to new airspace paradigm and from a large, distributed and inter-related Air / Ground / Space (AGS) system**: Inability of individual & total system to deal with aircraft not behaving as expected, with sudden weather problem, airport closure, air or ground accident, etc. (more serious hazard regarding Fully Automated Flight)	
16	LIVE5.3	**Flight crews - Absence of human agent (onboard):** When functioning, onboard sensors may not give ground crew sufficient information to correctly analyse and resolve situations	
17	LIVE6.1.2	**Flight crews - Crew-automation interactions issues**: Loss of strategic and tactical situation awareness, including automation & mode awareness and airspace system functions may occur if flight	

		management, system management and control of flight is transferred completely or partly from on-board crew to ground based crew.	
18	LIVE15.2	**CNS/ATM/ATC and SCC – Adverse conditions / failure / emergency / crisis mgt issues**: Use of automation could allow controller/manager to exceed human recovery capabilities in the event of failure or automation breakdown. For example, CNS/ATM system failures could have more severe consequences when airplanes are more closely spaced, increasing the likelihood of collision when compared to current system+C54	
19	LIVE13.2	**CNS/ATM/ATC and SCC – Crew / automation interactions issues**: Local or wide-area loss of control may result due to data-link failures, unintentional or intended interference or other factors	
	Future-Long (more than 10 years)		
20	Hard 2.2	**Absence of human agent (onboard):** Lack of mechanisms to replace human cross-check of misleading or inaccurate data transmitted to & from the aircraft (in particular for Fully Automated Flight) may result in inappropriate actions being taken to ensure safety of flight. Lack of human redundancy (in particular for Fully Automated Flight) (MRO5)(AC1)(AC19)	
21	Hard 2.1a	**Absence of human agent (onboard):** Mechanisms to replace human sensing and processing of abnormal conditions: smoke, odours, vibration, noise, etc. (in particular for Fully Automated Flight) may be insufficient to cope with critical situations.	

5.2 Vision of future of automation:

FAST developed the following vision of automation:
Cockpit automation will be continuously developed as one of the major contributing factors to increase safety through aircrew situational awareness.
It is expected to increase aircraft efficiency and airspace capacity as part of a large integrated system.
Appendix 15 further develops this vision.

5.3 The AC-13 Analysis Process

This paragraph describes how FAST did analyse AC-13.
It starts by outlining the list of future automation items and how FAST selected the 6 topics. (5.3.1)
It then gives an explanation relative to the theory of the SHEL model. (5.4)
The process to identify and select Interactions with other Areas of Change is also described. (5.5.)
The method used to analyse the 6 topics is described together with an outline of the results. (5.5.1)
The paragraph continues by describing the synthesis process from the 6 topics back to AC-13 in details. (5.6)
The paragraph provides a summary of the Hazards that were found. (5.7)

The paragraph concludes by outlining the hazards prioritisation process. (5.8)

5.3.1 The list of future automation items and its prioritisation as a way to provide focus:

FAST decided to use the ATA classification as a way to organise its list of future automation items. This list of around 100 items was developed using brainstorming. The ATA classification also provided a means to be systematic.

A first prioritisation exercise led to a list of 23 items that were further prioritized by a voting technique. (See appendix 4, List of 23 Automation Items)

The technique of voting can reduce a list containing a large number of items to a manageable few. At the beginning of the process, each FAST member received a number of votes (10). FAST members cast their votes for the items they perceived as most important on the list, they were allowed to distribute their votes in the manner they saw fit up to a total of ten votes, i.e., from 0 to ten votes on one item but only to a total of 10 votes overall.

This voting technique reduced the list to six items that stood out from the others. The selected items were:

[31] CRM issues arising from "Automation"
[34] Flight management systems
[34] Situational awareness display
[34] CNS-ATM (Free Flight)
[22] Fully automated flight
[34] Terrain recognition and navigation system

These six items were selected for further analysis and the remaining items were placed on a watch list for later study.

The “ten-vote” technique was very successful and it was decided that this technique may be used in the future.

5.4. The SHEL Analysis: its conceptual framework

5.4.1. Definition and concepts of the SHEL model

Edwards (1972) originally developed the SHEL (Software, Hardware, Environment, and Liveware) concept. In 1987, Hawkins proposed a modified version of the model in order to explicitly represents the man-man interaction, and make the Liveware element central in the model. This resulted in the introduction of another Liveware block, to symbolically represent the fact that the human beings (Liveware) not only interact with H-S-E, but also with the other human beings, i.e. the second L of SHELL. This also allowed the correct spelling of the English word ‘shell’, which made this acronym easier to remember.

The following definitions are proposed (ICAO 1989):

- Liveware = "*Human*"
- Hardware = "Machine"
- Software = "Procedure*, symbology, etc.*"

- Environment = the socio-technical and physical "*situation in which in which the L-H-S systems* must *function*".

In addition, the modified model proposed by Hawkins is much more concrete, as it also considers the *interfaces* between the various components (Figure 1).

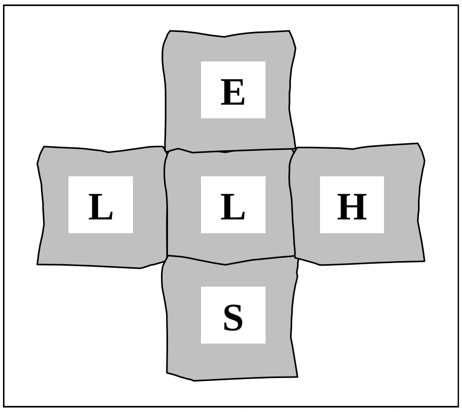


Figure 1. The SHELL model (after Hawkins, 1987)

Therefore, it is worth making reference to this modified model (SHELL) in the definitions that follow (ICAO 1989). These concepts are retained also in the ADREP-2000 (Accident Date Reporting Manual) of ICAO (1997):

- **Liveware**
  The human beings, persons or operators that are object of the analysis.
- **Liveware-Hardware**
  The L-H interface considers the relations between the human operators and all machine components designed to *"match the sensory and information processing characteristics of the use*r", such as "seats, controls, coding and location".
- **Liveware-Software**
  The L-S interaction (or S-L as the order doesn’t matter) *"encompasses humans and the non physical* aspects *of the system, such as procedures, manuals and checklists, etc.”*.
- **Liveware-Environment**
  The L-E interaction encompasses all aspects of the physical working context as well the *"broad political and economical constraints"* related to the organisations and corporate/national cultures that affect human behaviour.
- **Liveware-Liveware**
  "This is the interface between people". The L-L interface concerns all persons directly involved in the management and performance of a task that either collaborate directly in contact with each other, or co-operate and communicate at a distance[1]. An example if the flight crews - air traffic controllers interaction.

One originality and interest of the SHELL model is thus that it features interfaces. For example, a condition for system performance is that the Hardware be adapted to the Environment. And as far as safety is concerned, the SHELL model also suggests that risks will concentrate at these interfaces. Problems can indeed arise if a piece of Software (e.g. an emergency procedure) is not well adapted to the corresponding

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[1] This definition solves the slight confusion and overlapping between the L-E and L-L regarding staff/management relationship originally contained in the ICAO circular of 1989.

Hardware component (e.g. the cockpit), Lifeware component (e.g. the cockpit crew) or Environment (e.g. fume in the cockpit after failure).

In addition, in the perspective of the SHELL model, the issue of human factors in system safety basically refers to the quality of the coupling between humans and machines, humans and information, humans and environment, and last but not least, humans and humans. Regarding these four couplings, improvements might therefore come either from a better adaptation of the human component to the rest of the system (mainly a selection and training issue) or from a better adaptation of the rest of the system to humans (mainly a design issue).

5.4.2 *How was the SHEL model used in the FAST project?*

The objective was to use the SHEL model to identify the main potential hazards and safety concerns regarding the six, highest-priority ATA items related to the Area of Change (AoC) AC13, “Increasing Reliance on Flight Deck Automation”, including of their interactions with other high-priority AoCs.

5.4.3 *Special meaning of the Software and Hardware terms*

The difference between the classical meanings of the terms “Hardware” and “Software” and the ones these terms have in the SHEL model has been emphasized. As mentioned above, “Software” is defined as “the non-physical aspects of the aviation system, such as information, procedures, manuals, checklists, etc.”

In other words, the physical aspects of what is classically called “software”, such as computer codes, software products and applications, are considered in the “Hardware” section in the SHEL model. In this particular context, the term “Software” is therefore used with the meaning of information only.

5.4.4 *The four S, H, E, L components and their interfaces*

In practice, an intermediary approach between the original SHEL model and its SHELL revision was used.

Indeed, only the four components of the SHEL model, i.e. S, H, E and L, were explicitly considered, in order to keep the analysis as simple as possible. In other words, the four L-S, L-H, L-E and L-L interfaces were not used as categories of analysis, but were implicitly accounted within each S, H, E and L category. More precisely, in absence of specific instructions, each component was considered as tacitly encompassing all of its interfaces with the rest of the model, i.e.:

- The S component also encompasses the S-H, S-E and S-L interfaces,
- The H component also encompasses H-E, H-L and H-S,
- The E component also encompasses E-L, E-S and E-H,
- And the L component the L-S, L-H, L-E and L-L interfaces.

Higher-level interactions, like S-H-E (e.g. procedures-cockpit-environment), S-H-E-L (e.g. procedures-cockpit-flying environment-flight crew) and S-H-E-L-L (e.g. procedures-cockpit-flying environment-flight crew-ATC personnel) may also have been implicitly accounted in *S*, H, E or L basic category. For instance, the same S-H-E interface may thus appear in all three S, H and E components or in only some of these. This somehow explains the certain degree of *repetition* or duplication that may be found across the various S, H, E and L categories.

This bias is however acceptable, as the SHEL model was essentially used as an *organizer*, in order to guide and structure the identification of hazards. The degree of repetition that is sometimes found between the hazards listed under the four S, H, E and L categories affect very little the interest of the findings.

5.4.5 Introduction of further levels of classification

The original organization provided by the SHEL model was furthermore completed by additional groupings related to the nature of the hazards:

- In the S category, groupings were performed on the basis of the same type of information, procedural component or activity domain, e.g. “Operating procedures”, “Certification”, “Design”, “Training”, “Licensing”;
- In the H category, groupings were performed on the basis of common domain or activity issues, such as “Absence of human agent onboard”, “Communication issues”, “Compatibility, integration and configuration management issues including human-machine interface and software applications”;
- Similarly, in the E category, chunking was performed on the basis of the common domain or environment type, e.g. “Change of airspace paradigm”, “Public opinion and political issues”, and “Education and training issues”;
- And in the L category, further groupings were established between items concerning the same type of personnel or actors in the system, e.g. “Organizational agents, “Designers”, “Flight crew”, “CNS/ATM/ATC and SCC personnel (under the FAF hypothesis)”.

Those additional categories were created during the process of hazards synthesis; in order to further structure the lists of hazards obtained so far (See Section 2).

References

Edwards, E. (1972). Man and machine: Systems for safety. In Proceedings of British Airline Pilots Association Technical Symposium. British Airline Pilots Association, London. pp. 21-36.

Hawkins, F. H., (1987) *Human Factors in Flight,* Gower Technical Press, 1987.

ICAO (1989). Circular 216-AN/131. Human Factor Digest No. 1: Fundamental in Human Factors Concept, ICAO, Montreal, Canada.

ICAO (1997). Accident/Incident Reporting Manual-ADREP 2000 draft (1997), ICAO.

5.5. Interaction assessment between AC13 and all other AoCs:

In parallel, the interactions between AC 13 and all other AoCs were assessed.

This is specific to the FAST process, which, for each AoC, considers all interactions between this AoC and all other AoCs. This methodological originality confers to the FAST process a “systemic dimension” as all elements of the analysis (here AoCs) are considered in relation to the rest of the system. FAST members were asked to identify by a Yes or a No if they believed that there was an interaction with AC-13 for the 157 interactions. 15 members replied.

Again a prioritisation system featuring a voting system was used in order select the most important AoCs interacting with AC13: the basic idea was to retain the Areas of Changes that have been identify as interacting with AC-13 by two-thirds of the replies.

34 AoCs were selected, while the other ones were put in a watch list.

Those top AoCs are:

1. C1 - Introduction of new technologies with unforeseen human factors aspects
2. C4 - Introduction of artificial intelligence
3. ANS1 - Emergence of new concepts for airspace management
4. ANS7 - Introduction of new technologies with unforeseen human factors aspects

5. AC10 - Variation of sophistication of hardware and software within an individual aircraft type
6. C6 – Shift in responsibility for collision avoidance from ATC to crew
7. ANS19 - Complex interactions among highly-automated ground-based and flight-deck systems
8. C5 - Widening gap between skills, abilities, and attitude toward technology and automation among future crew members and design philosophies used in the past for development of current aircraft
9. AC22 – Increasing use of cockpit warning and alert systems
10. C3 - Increasing amount of information available to flight crew
11. AC12 - Pressure for standardization in cockpit controls, displays, and automated systems interfaces among aircraft
12. AC17 - Reliance on active flight controls
13. C7 - Obsolescence of current training methodologies for operation of advanced aircraft
14. ANS22 - Evolution of Flight Management System databases
15. AC11 - Proliferation of heterogeneous aircraft with widely-varying equipment and capabilities
16. ANS21 - Discrepancies in the pace and direction of development of ground vs. in-flight CNS systems
17. AC20 - Implementation of advanced synthetic-vision technologies
18. C8 - Loss of average pilot airmanship
19. ANS20 - Introduction of artificial intelligence
20. ANS5 - Decreased separation standards
21. MRO5 - Reliance on automation for fault detection, diagnosis, resolution, and tracking
22. OP2- Requirement for performance validation and self-checks of complex systems
23. AC14 - Reliance on automated vehicle health management systems
24. AC4 - Introduction of new design concepts for general aviation aircraft
25. AC21- Implementation of advanced supplementary cockpit weather
26. E6 - Obsolescence of hardware and software systems in use both on the ground and in the air as well as space-based systems
27. E8 - Use of Commercial Off-The-Shelf (COTS) products in aviation
28. MRO9 -Aging avionics, power plants, electrical and mechanical systems, and structures
29. AC1 - Introduction of new aircraft types
30. OP3 – Integration of Regional Jets, with possibly more advanced avionics, in today’s operational environment
31. AC8 - Introduction of fly-by-light, power-by-wire aircraft control systems
32. C11 - Unresolved cultural aspects of Crew Resource Management (CRM)
33. E9 - Rapid pace of software and technology development
34. E20 - Vulnerability of data links to security breaches and/or transmission failures

Occasionally, the next two AoCs in terms of priority were also considered:

35. AC19 - New higher energy propulsion and control systems
36. C2 – Increasing level of information inequality in shared decision making contexts

5.5.1 Analysis of each of the 6 highest priority topics within AC13

These highest priority topics were investigated by sub-groups of FAST members during the meetings held in Amsterdam (April 2002), Paris (June 2002) and Ispra on (August 2002).
Each group had to go through a list of questions designed to guide and facilitate the identification of hazards related to each topic, including those arising from interactions.

5.5.2 *Topic identification*

Six basic questions [2] were asked in order to better identify each topic and put it in context. Those questions are:

- Why?
The "Why" section aims at identifying the main objectives of cockpit automation, or more specifically, of each of the 6 topics selected in AC13, in the context of a global Air, Ground & Space system.

- How?
While the "Who" question aims at identifying the main objectives of each of these 6 topics, the "How" question aims at identifying the means by which these objectives are expected to be achieved. In addition, the "How" question raised a list of conceptual or paradigmatic prerequisites, and of functional, technical and operational aspects required for implementation.

- What?
Reliance on cockpit automation will not only affect the aircraft but also the whole Air, Ground and Space system. The "What" question aims at identifying the items concerned by each of these six topics. The interest is to grasp the variety of aspects concerned, directly or indirectly, by the six AC13 topics selected.

- Who?
Automation affects a larger number of actors than just the flight crews, and not only does it affect individual agents but also a global Air, Ground and Space system. The "Who" section therefore looks into the various actors or agents of that global system impacted by each of the six AC13 topics selected.

- When?
The "When" question invites to consider the various phases of the global Air, Ground & Space system live cycle impacted, at various degrees, by each of the selected AC13 topics. Practically all design, certification, operations and post-operations phases were considered. In addition to nominal operations, special concerns were raised in case of abnormal, failure, emergency, and relative to crisis management and evacuation situations.

- Where?
The "Where" question aims at listing the main physical locations, organisational functions or activities within the global Air, Ground and Space system directly or indirectly concerned by cockpit automation, or, more specifically, by each of the sic AC13 topics selected.

5.5.3 *Hazard identification*

This is the questionnaire section in which reference is made to the SHEL model.

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[2] Those questions are commonly used, for instance in the Quality domain, to start investigating a problem or initiate an analysis.

5.5.4 *Inherent hazards*

The question was:
What could go wrong (condition, event or circumstance leading to undesired event)?

5.5.5 *Potential hazards*

Potential hazards had to be assessed considering each component of the SHEL model, namely Software, Hardware, Environment and Liveware (See section 1).
The question was:
What could go wrong in each of the S, H, E and L categories of the SHEL model?
As explained in Section 1, in absence of specific instruction, all interactions between the S, H, E and L element of the model (level 2, e.g. L-S, level 3, e.g. L-S-E, and level 4, S-H-E-L) may have been implicitly considered in whatever S, H, E, or L component, which explains a certain degree of repetition in the hazards identified in each category.

5.5.6 *Hazards and issues generated by interactions*

Further hazards and concerns can arise from the interactions between each of the top-six automation topics and the 34 AoCs selected after prioritisation (see Step 3.2).
The question was:
What are the impacts of flight deck automation interactions with other high-priority AoCs?

5.5.7 *Identification of agents who should be involved*

In order to complement the “Who?” question presented above, another question was posed:

5.5.8 *Are there agents who are not involved today who should be*?

This question aimed at identifying agents, personnel, actors or organisations that are not involved today in the six AC13 topics selected, but who should become involved, given the evolution expected.

5.5.9 *Results of the analysis of the 6 topics:*

The analysis of these top-six AC13 topics can be found in the following six documents:

1. Document 1 in appendix 5, for topic 1 Situation Awareness (SA) displays;
2. Document 2 in appendix 5, for topic 2 Flight Management Systems (FMS);
3. Document 3 in appendix 5, for topic 3 Crew Resource Management (CRM);
4. Document 4 in appendix 5, for topic 4 Terrain recognition and navigation systems (TRNS);
5. Document 5 in appendix 5, for topic 5 Fully Automated Flight (FAF)
6. Document 6 in appendix 5, for topic 6 CNS/ATM free flight (CNS/ATM).

5.6 Synthesis of the hazards under the four S, H, E and L categories

All hazards were eventually synthesized under the four S, H, E and L categories.
After having analysed each of the top-six topics separately, the objective of this phase was to combine the analyses for synthesizing the results and get a more “global picture” of the hazards identified so far.
Several intermediary steps were involved.

5.6.1 *Processing of the Why, How, Who, What, Where and When questions*

After having tried to merge the answers given to the Why, How, Who, What, Where and When questions across the six AC13 topics, it was quickly realised that such merging didn't always produce meaningful results.

In other words, it revealed difficult to derive the answers regarding the whole AC13 "Reliance on flight deck of automation" by combining the answers provided in the context of the analysis of the six AC13 topics selected, which represent only part of the AC13 domain.

The answers to those questions remain however valid in the context of each topic.

5.6.2 Processing of the "Agents who should be involved" section

The answers to the question "Are there agents who are not involved today who should be?" were not analysed, as almost all agents of the global Air, Ground and Space system were already listed as answers to the "Who" question.

In other words, it was clear that reliance on cockpit automation will affect a larger number of actors than just the flight crews, and that almost all actors in the global system are directly or indirectly concerned.

5.6.3 Merging of all other hazards into the S, H, E and L categories

The three "Inherent hazards", "Potential hazards" and "Hazards related to interactions" sections were merged, and all hazards identified in the six topics were grouped into the four S, H, E and L categories of the SHEL model.

This implied in particular the subsequent codification of the "Inherent hazards" and the "Hazards related to interactions" in S, H, E and L categories. The 6 original lists of hazards regarding the top-six AC13 (Figure 2) were thus synthesized into four lists of hazards using the four categories of the SHEL model (Figure 3).

AC13		Topic 1	Topic 2	Topic 3	Topic 4	Topic 5	Topic 6
W, H,W,W,W,W? Questions							
Inherent Hazards							
Potential Hazards	S						
	H						
	E						
	L						
Agents who should be involved							
Hazards related to Interactions							

Figure 2 – Analysis of the top-six topics of AC13 (matrix presentation)

AC13 top-6 topics	S	H	E	L
Hazards aggregated across the 6 topics	S-related Hazards	H-related Hazards	E-related Hazards	L-related Hazards

Figure 3 – Hazards grouped into the four categories of the SHEL model

5.6.4 Further grouping and classification of hazards within each SHEL category

In addition, further classification was introduced in each S, H, E and L categories on the basis of content similarities (e.g. Cockpit crew, ATC/ATM and SCC personnel under the FAF hypothesis, Design, Certification, Operations, Licensing, Education and Training issues, etc.). Those categories were used to group the hazards with comparable object. Further comments on this classification process can be found in 5.4.5 and the full list of groupings can be found in 5.7.

5.6.5 Validation and consolidation of the hazards classified according to SHEL

Steps from 3.4.1 to 3.4.4 were prepared as homework by some of the FAST members, who produced draft documents.

The process and results were then presented to the FAST Sub-Group during the September 26th-27th meeting, and consolidated in plenary session during the October 15th-16th meeting, both held at the JAA Headquarters in Hoofddorp.

In this second meeting, four sub-groups were constituted, each one having to work out one of the four S, H, E and L hazards synthesis (draft version).

Those instructions were:

- To check that every statement was written in terms of hazards or safety concern, and to rewrite them if need be;
- To check, validate or re-write all additional categories created (e.g. Cockpit crew, ATC/ATM and SCC personnel under the FAF hypothesis, Design, Certification, Operations, Licensing, Education and Training issues, etc.), to check the location of all the hazards, and to re-locate them under another category if need be;
- To check that no information contained in the original six documents regarding the six AC13 selected topics was left out, and to reintroduce such missed information in need be;
- And to consider only valid or meaningful interactions.

This process produced four consolidated lists of hazards, which were then used as the basis for the next two steps in the FAST process, namely Hazards prioritisation and validation, and Production of recommendations.

While those next two steps will be presented and described next in the report, we conclude this section dedicated to the SHEL analysis by a brief presentation of those four consolidated lists of hazards produced in the FAST project.

5.7 Summary of the SHEL classification

5.7.1 Software-related Hazards

See document 1 in appendix 7

85 hazards or problem statements were organised into 6 categories:

1. Operating procedures (SOFT1)
2. Certification (SOFT2)
3. Design (SOFT3)
4. Training (SOFT4)
5. Licensing (SOFT5)
6. Operations (SOFT6)

5.7.2 Hardware-related Hazards

See document 2 in appendix 7

52 hazards or problem statements were organised into 7 groups:

1. General issues (HARD1)
2. Absence oh human agent (onboard) (HARD2)
3. Communication issues (HARD3)
4. Compatibility, integration, configuration, management issues (HARD4)
5. Upgrades, updates and retrofit issues (HARD5)
6. Human-Machine interfaces (HARD6)
7. Databases, software products and applications (HARD7)

5.7.3 Environment-related Hazards

See document 3 in appendix 7

47 hazards or problem statements were organised in 13 categories:

1. Change to airspace paradigm (ENV1)
2. New airspace paradigm and large distributed and inter-related Air, Ground and Space system (ENV2)
3. Certification and regulation issues (ENV3)
4. Legal issues (accident-related) (ENV4)
5. Public opinion and political issues (ENV5)
6. Work Market issues (ENV6)
7. Education and Training (ENV7)
8. Cultural and social aspects (ENV8)
9. Company, alliance management, market issues (ENV9)
10. Operational environment aspects (ENV10)
11. Design issues (ENV11)
12. Security issues (ENV12)
13. Physical environment aspects (ENV13)

5.7.4 Liveware-related Hazards

See document 4 in appendix 7.

102 hazards or problem statements were organised in 21 categories, from which 8 concerns the flight crews and 8 the CNS/ATM/ATC and SCC personnel (under the FAF hypothesis):

1. Organisational agents
2. Designers
3. Flight crews - New airspace management / Multi-agent issues
4. Flight crews - Conflict between air / ground information sources
5. Flight crews - Absence of human agent onboard
6. Flight crews - Crew - automation interactions issues

7. Flight crews – Physical and physiological problems
8. Flight crews – Operational issues
9. Flight crews – Training issues
10. Flight crews – Qualification and cultural issues
11. CNS/ATM/ATC and SCC - New air space paradigm / Multi-agent issues
12. CNS/ATM/ATC and SCC - Operations with mixed aircraft performance capabilities
13. CNS/ATM/ATC and SCC - Crew - automation interaction issues
14. CNS/ATM/ATC and SCC - Operational issues
15. CNS/ATM/ATC and SCC - Adverse conditions/failure/emergency/crisis mgt issues
16. CNS/ATM/ATC and SCC - Training issues
17. CNS/ATM/ATC and SCC – Qualification and cultural issues
18. Maintenance
19. Cabin Crew
20. Passengers
21. General

5.8 Prioritization:

The SHEL statements were prioritized using a technique called the data grid method. Each of the SHEL statements was assessed by severity (if it occurs, how bad will it be) and temporal horizon (when will it occur). The categories of severity were modeled after JAR/AC 25.1309, i.e., no effect to Catastrophic. The temporal horizon ranged from current to future-long (>20 years). This process resulted in a listing that could be grouped by SHEL Category and severity within a pre-determined temporal horizon. Unfortunately, the resultant listings within each temporal horizon were grouped quite closely, so the “ten-vote” method (first used in the prioritization of the ATA listings) was used to identify the top candidates in each temporal zone across SHEL categories. The results were used to create consolidated lists of hazards for future use by the FAST team. The list of principal hazards is included in paragraph 5.1.

6 Validity of FAST Process:

A significant validity exercise was undertaken for several reasons:

- This was the first time that the FAST methodology was actually used. It was also refined in parallel with the actual analysis of Flight Deck Automation.
- Automation is not a new issue. Therefore there was a need to review research work (EU, EUROCONTROL, etc.) and well known reports.
- FAST is presented as necessary complement to CAST. Therefore there was a need to compare the list of FAST Top-21 hazards to the CAST problem statements.

In addition, it was agreed to send a questionnaire to people in the field to have their perspective on automation and associated issues.

6.1 Review of existing work: (see appendix 8)

A set of relevant reports (43 in all) was built coming from various sources and was put on a CD-Rom that was distributed to all FAST members. The task of reviewing the reports was shared between FAST members. The result of the review is described in detail in appendix 8.

The review was organized in four levels as follows:

- Validity of the FAST concept (from changes to hazards, the importance of interactions).
- Validity of the FAST top 20 and of the 4 main safety items.
- Validity of the top 6 topics of Automation.
- Validity of the "findings" resulting from our analysis of the top 6 items.

The review for the topic CNS/ATM was not completed but to a certain extent has been covered by the validity of the FAST Top-20 and of the 6 topics.
The results can be summed-up as follows:
-The FAST methodology seems quite unique in particular by addressing interactions.
- It has a good potential to improve safety.
- No obvious omissions or weaknesses were identified.

6.2 Relevance of Professional Pilots Survey: (see appendix 9)

The objective of this survey was to determine the opinion of senior members of the airline sector on the JAA industry based research project “Future Hazards Associated with Flight Deck Automation”. This survey was an integral part of the validation process of the work performed by the ad-hoc expert panel convened for this area of research. The target response group for this survey was experienced and senior members of airline operations departments and regulatory authorities. More specifically this survey was aimed at those involved in pilot training and testing.

This study contained three areas of examination with respect to reliance on flight deck automation.

1. Relevance and Establishment of Level of Manual Flying Skills Associated with Current Levels of Flight Deck Automation.
2. Training Requirements as a Result of Advances Made in Flight Deck Automation.
3. Safety, Human Factors & Operational Procedures.

The survey addressed potential hazards associated with advances made in flight deck automation with respect to manual flying skills. It also attempted to identify the industry opinion on the acceptance of flying airplanes with a high level of automation. The survey attempted to gauge the opinion of the industry respondents on the level and effectiveness of training for procedures on highly automated aircraft as opposed to previous methods used in older generation non-automated aircraft.

The survey sought the opinion from the industry on the importance of the level of education and flying experience for new entrants in the industry as a consequence of the anticipated high levels of flight deck automation.

An additional aim of the survey was to determine if pilots experienced difficulty formatting information and monitoring or verifying the actions of the flight deck automation during initial training on a new aircraft type. The question of change in pilot workload due to a high level of flight deck automation and the corresponding change in training requirements was also addressed.

The relationship between potential hazards associated with advances in flight deck automation and levels of operational safety was addressed. Issues such as ‘hands on’ currency, the amount of useful information available to pilots and enhancement of situational awareness were covered.

Misunderstanding or hesitation by pilots due to the level of flight deck automation as well as the level of stress after a day’s work in a highly automated cockpit compared to previous generation aircraft was addressed. The potential hazards associated with advances made in flight deck automation leading to change in stress and fatigue levels when the flight crew does not fully understand what the flight deck automation is programming the aircraft to do, was also explored. Usability and pilot understanding or cognition as a key feature of any future design of the elements of flight deck automation was questioned.

Finally, the candidates were asked, as a result of advances made in flight deck automation, what was the minimum number of technical crew (pilots) necessary to operate a large passenger aircraft on long distance flights in the future.

6.3 Comparison with CAST problem statements:

A one-to-one comparison was performed between the 21 top-priority potential hazards produced by FAST and the 335 problem statements identified by CAST. This comparison was made during the FAST meeting hosted by Airbus in Toulouse on 18-20 February 03 (see appendix 10).

- The FAST hazards are in general more generic than the CAST problem statements.
- The FAST hazards are also wider in scope and more systemic, or less mono-domain (e.g. ATC, flight crew, manufacturers), especially when they are derived from interactions.
- Apart from these differences in nature and scope, there are a number of similarities, or of relations, between the CAST problem statements and the FAST hazards, even if there are no perfect matches between the items of the two lists.
- Such relations have been identified mainly in the current (up to 1 year) and future near (up to 5 years) time frames of FAST. This suggests that there is no discontinuity between the historical or retrospective approach followed by CAST and the prospective one adopted by FAST when limited to a 5-year horizon, in other words, before main changes will be introduced to the current airspace paradigm.
- Regarding longer-term horizons, it is not surprising to see similarity decreasing between the two lists of results. This demonstrates the difference of nature between a retrospective and a prospective approach, the originality and interest of FAST and its complementary to CAST. Would the results of these two approaches have been identical or very similar, the added value of FAST could indeed have been questioned.

7 **Summary & proposals Recommendations for future work to AC-13:**

7.1 How were the proposals for future work developed?

7.1.1 Phase 1 – Preparation

The 9-12 Dec. 03 meeting at Boeing Research and Technology Centre in Madrid was mainly devoted to finalizing the hazard prioritization process and to applying this process in order to identify the highest priority hazards for each time frame. See paragraph 5.8 of this report.

At the end of this meeting, it was decided that FAST members would try, on an individual basis, to produce recommendations for each of the 21 top priority hazards identified using an agreed template. (See appendix 11).
Some FAST members made that exercise as homework and all available recommendations were collected before the 19-20 Feb. 03 meeting held at Airbus in Toulouse. It was planned that this meeting would allow to validate the recommendations available so far and/or to produce new ones as a group.
However, the team encountered problems to produce recommendations in session. This might be due to a certain unbalance in the overall FAST process, where roughly

70% of the resources were spent on defining the methodology, 20% on defining and ranking the hazards and only 10% on formulating recommendations. The group realized that the production of recommendation was not straightforward. In addition, the lack of an appropriate method at that time also partially explains this difficulty.

Subsequent to this, and after approval by the JSSI steering group FAST staged one other 3 day meeting [14 – 16 October, 2003] and 3 teleconferences with the following goals:

- Refine the recommendations with respect to quality and language.
- Prioritize the recommendations

In the end agreement was reached on 27 prioritized recommendations in three time domains, for details see chapter 7.

7.1.2 Drafting of a method

The fact that recommendations or "proposals for future work" need to be produced and agreed by the whole FAST group, and not by some individuals, indeed requires a dedicated method. Such a method was drafted during the 10 March 03 sub-group meeting at JAA in Hoofddorp.

At the Toulouse meeting indeed, the co-chairs took, after a rather protracted discussion, an action item to define a "text template" for proposals for future work. The first version of this text template mainly consisted of examples. However, it clearly appeared that such an open format wouldn't be sufficient to facilitate and structure the works in plenary session.

A more methodical approach was thus drafted:

1. For each hazard, merge all recommendations from individuals available so far.
2. For each hazard, produce relevant background information (e.g. the co-chairs' examples plus available CAST Problem Statements, Interventions and Safety Enhancements).
3. Divide the FAST group into sub-groups and ask them to produce a common list of proposals for changes for each hazard on the basis of the merged list, of the background information, and of in-house expertise and creativity.
4. Then harmonize and validate the findings of the different sub-groups in plenary session, complemented if need be by homework.
   This approach presents three advantages: it is very simple, it structures the work of the FAST experts in an efficient manner and it supports appropriation by the FAST members.

In addition, the template was enriched by introducing a list of agents to which proposals for future work can be assigned: Authorities, Manufacturers including equipment providers, ATM / ATC / CNS, Flight crew, Cabin Crew, Passengers, Operators, Maintenance, Airports, etc.

7.1.3 Refinement of the method

This methodology was successfully used on 2 hazards and the proposals for future work produced then served as examples during the following plenary meeting held on the 8-10 April 03 again at the JAA in Hoofddorp.

In accordance with the decision made before, the participants were divided in six sub-groups, each one having to produce proposals for future work for 3 hazards. Furthermore, all the participants to the 10 March sub-group meeting served as "facilitators" in one of these sub-groups.

The method was presented in session, adopted by the whole FAST group, and enriched following a proposal made by Tim Porter. Viewing this output as the key value that FAST brings to the aviation community, Tim proposed that the template should feature the following sections:

7.1.4 *Statement of Hazard*

Statement of Hazard is a short description of the hazard, as produced by the FAST hazard identification and ranking process. See paragraph 5.1

7.1.5 *Perspective*

This is the section in which the team records its views regarding the hazard and a simple verbal explanation of the technology roadmap associated with that hazard. Essentially, this section is intended to “set the stage” to allow any reader that has basic understanding of the commercial aviation world to understand the context in which the FAST group is making its observations and recommendations.

Most probably, each focus area of each AOC will have only one perspective statement. In other words, all hazards sharing the same background are also likely to share the same Perspective statement.

7.1.6 *Discussion*

This is where the team reports the results of the discussions it had in addressing the hazard and focus area. It must support the Perspective statement and must provide the context in which the team extended its findings. It is intended to inform regarding the details of the perspectives of the team. The team’s collective experience, thoughts, anecdotes, wisdom, and basis for forwarding recommendations should be noted here. It should lead the reader to a deep understanding of the team’s discussion so that the Amplified Problem Statement, Technology Watch Items and Recommendations for Future Works (see below) are natural extensions of the conclusions the reader is forming.

Again, each focus area of each AOC will most probably have only one Perspective statement. In other words, all hazards sharing the same background area will also probably have the same Discussion section.

7.1.7 *Amplified Hazard Statement*

This is an optional section, which can also come just after section 1 in order to amplify the definition of the hazard. This Amplified Hazard Statement may be required because a more specific or modified problem statement may be useful, based on the reader’s improved knowledge resulting from the Perspective and Discussion sections.

Each hazard statement will have its own Amplified Hazard Statement as required.

7.1.8 *Future Technology Watch Items*

This section is a key section, because it describes the technology drivers that enable the turns, curves and intersections of the technology roadmap. It provides the reader with a set of items to watch. It should include not just technical items, but “social science” items and business/affordability perspectives.

Each Hazard Statement may have its own Future Technology Watch Items statement. Alternatively, the Future Technology Watch Items statement may apply to a focus area or an AOC.

7.1.9 *Proposals for Future Work*

This section contains the recommendations from the team to the aviation community regarding who should do what to address hazards. If the hazard is really a far future hazard, the recommendation may be to simply watch the Future Technology Watch Items; in this case, “if” statements should be used, tied to the appropriate Technology Watch Items. Recommendations should be specific; stating things like “fly safer” are not acceptable. Recommendations should be optional; if no recommendations are needed, none should be written.

Each Hazard Statement may call for its own Proposals for future work. Alternatively, the Future Technology Watch Items statement may apply to a focus area or an AOC.

If the Future Technology Watch Items above indicate that the un-crewed passenger airplane could become a reality, then there are several things that aviation R&D

managers should do. The main task will be to ensure that the other technology areas mentioned in the Future Technology Watch Items section are addressed, and that designers begin to conceive of their designs with current technology. Regulators must also immediately begin work to accommodate such a design. Part 25 and also the operational requirements assume a pilot; the regulations will have to be overhauled to accommodate autonomous operations.

7.1.10 Application of the method

The version of the template presented above was applied during the 8-10 April meeting in order to produce recommendations.

Grouping of hazards was then proposed on the basis of similarities regarding their background and/or proposals for future work.

The final groupings and list of recommendations regarding the 21 top-priority hazards produced by FAST are presented in appendix 11

7.2 Theme I: GLOBAL AIR–GROUND–SPACE SYSTEM ISSUES

7.2.1 Introduction:

By the year 2020, we expect aircraft, Air Traffic Control Centres, Airline Operation Centres, and satellites to be the nodes of an integrated Air Ground Space System (AGS) that will operate during the all phases of flight (gate-to-gate) and communicate through data-link.

The airspace system will undergo significant changes (e.g. free routing/free flight; new airspace classification; development of 4 Dimensions trajectories) that will change the way the different actors or “stakeholders” will operate, individually and globally, co-ordinate their activities, and co-operate.

The progressive development of such a “distributed multi-agent system” in which artificial agents, automation, computers, data-bases and even Artificial Intelligence will play an important role is a response to the challenges posed to the future civil aviation. That is: increased airspace capacity, better respect to the environment (in a “sustainable growth” approach), and improved safety.

The various changes that will affect the aviation system are therefore oriented towards improved performance and safety. But this future global Air-Ground-Space system will also give rise to a series of Hazards, which require attention today. FAST has tried to identify those hazards and to formulate recommendations, or proposals for future work, in order to prevent, control, or manage them in a proactive way.

7.2.2 Seven hazards grouped in one theme:

With the above perspective in mind, seven Hazards out of the 21 prioritised ones form the “Global Air-Ground-Space System Issues” theme. These seven Hazards are:

1) Hazards inherent to new airspace paradigm and from a large, distributed and inter-related Air / Ground / Space (AGS) system: Failure to integrate onboard and ground systems, e.g. control functions, data link, personnel, responsibilities
   - ATM/ATC and aircraft control functions (distributed multi-agent control system)
   - Data link with many outside partners: ATM / ATC and SCC (under the Fully Automated Flight hypothesis)

   ATM / ATC / OPS / SCC (under the FAF hypothesis) / Flight Crew / Cabin Crew, including security and medical personnel (in particular for FAF) / Maintenance (in particular for FAF): **Env 2.1** (future-medium)
2) Flight Crews - Conflict between air/ground information sources: Inadequate escape manoeuvre decision due to conflict between different information sources (e.g. TCAS, ATC verbal messages, data link) and lack of explicit prioritisation: **Live 4.1** (current)

3) CNS/ATM/ATC and SCC – Adverse conditions / failure / emergency / crisis mgt issues**: Live 15.4** (future-near)
4) CNS/ATM/ATC and SCC – Crew / automation interactions issues ---Local or wide-area loss of control may result due to data link failures, unintentional or intended interference or other factors: **Live 13.2** (future-medium)
5) Hazards inherent to new airspace paradigm and from a large, distributed and inter-related Air / Ground / Space (AGS) system -- Loss of situation awareness (global, local): **Env 2.3** (future-near)
6) Hazards inherent to new airspace paradigm and from a large, distributed and inter-related Air / Ground / Space (AGS) system -- Inability of individual & total system to deal with aircraft not behaving as expected, with sudden weather problem, airport closure, air or ground accident, etc. (more serious hazard regarding Fully Automated Flight): **Env 2.5** (future-medium)
7) Inadequate processes for certification of computer software (including interactions with other software systems and artificial intelligence) onboard the aircraft and in the larger airspace system (C1, ANS20): **Soft 2.8** (future-near)

One of these hazards, **Live 4.1** is already present today, while the others should start to appear from future-near (1 to 5 years) to future-medium (5 to 10 years). In addition, all of them of them are expected to *evolve* as time is passing by and changes are introduced in the global AGS system.

7.2.3 Perspective:

7.2.3.1 A new AGS system

In the next twenty years, we expect aircraft, Air Traffic Control Centres, Airline Operation Centres, and satellites are the nodes of an integrated Air Ground Space System (AGS) that will operate during the all phases of flight (gate-to-gate) and communicate through data-link. This AGS system recognizes the interdependence of stakeholder operational decisions, e.g., Collaborative Decision Making, Flexible Use of Airspace.

The airspace system will undergo significant changes (e.g. free routing/free flight; new airspace classification; development of 4 Dimensions trajectories).

This is likely to occur step by step, such system will be performance oriented, but *compatibility and safety* will come first.

7.2.3.2 Technological moves

Older technologies and modern technologies will co-exist both for aircraft and ground systems, at least in a transitory period.

Human operators remain in the loop but are assisted by automation tools and use elaborate displays. Automation tools will be supported by sophisticated databases. Data and warning/alert information will be generated at an ever-increasing pace within the aviation system and these data will play an increasingly important role in flight critical situations. These data are stored in air and ground repositories and the information generated from the data will be presented to both airborne and ground-based operators.

More generally, there will be an increasing use of computer software, including complex software systems and artificial intelligence. Specialised techniques and tools may in particular be used to support co-operation and Collaborative Decision Making, such as Groupware, Computer Support to Cooperative Work (CSCW) and Computer-based Operating Aids and Management Systems.

7.2.3.3 on the way to Fully Automated Flight

New vehicles such as Vertical Take-Off and Landing aircraft (VTOL) (Other than helicopters) and Un-inhabited Aerial Vehicle (UAV) may use the airspace. Furthermore, single pilot or supervisory pilot freighter operations might appear in the decade 2010-2020 and might pave the way in the longer term for Commercial Fully Automated Flight.

7.2.4 Discussion:

7.2.4.1 Globalization, failure propagation and required system responses

In the future airspace paradigm and AGS system, failures, unintended or intended interferences (including security infringements), human errors and other adverse conditions (i.e., weather) may have global effects such as loss of situation awareness or loss of control. Such failures could be local or global, e.g., GPS failures.

Interactions, interferences and failure propagation should be assessed from the design stage and assumptions and requirements made at the design stage should be monitored all through the life cycle.

The system should ideally be designed, operated and maintained to ensure that failures (intended and unintended) will be prevented or won't propagate through the system (containment). Because this might not be always possible, global multi-actors responses e.g., crisis management, need to be provided to global, or "globalized" failures. All interested actors should be adequately trained to prevent and/or manage such failures and manage crises, individually and jointly.

7.2.4.2 Computer, software, and Artificial Intelligence issues

All six automation topics identify computer software safety and security issues, either as inherent hazards or as hazards generated by interactions. Artificial Intelligence and rapid pace of software and technology development were identified as two of these interactions.

In particular the following issues were raised:

1) What the system learns is not predictable and may not be shared with subsequent operators;
2) Certification issues with Artificial Intelligence (e.g. neural nets, fuzzy logic), etc.; 3) Formal V&V techniques lacking, increasing demand for complex V&V; 4) Inconsistent versions of software within the same fleet; 5) CRM adaptation to artificial intelligence automation; 6) Malicious code and/or data (e.g. virus, Trojan horse, intentional uplink corruption).

In addition current issues were also identified, such as configuration management, programming errors, data corruption, incorrect or partial requirements definition, update and upgrade issues. As such issues are dealt with by current certification standards, no proposals have been made hereunder to address them.

7.2.4.3 Air-ground inconsistencies: the need for conflict resolution

Unsafe situations may also develop when there are inconsistencies between air/ground databases as well as conflicts between alerts and warnings generated from separate systems. In absence of clear prioritization or conflict resolution rule, the way in which flight crew and ground controllers prioritize and respond to these inconsistencies and conflicts are subject to their own interpretation, in particular of the related information from automated systems as TCAS, EGPWS and systems to prevent runway incursion.

The inadequate escape manoeuvre decisions due to conflict between different information sources (e.g. TCAS, ATC verbal messages, data link) and lack of explicit prioritisation that were already experienced nowadays prefigure what the situation could look like in the future multi-agent system. In the future, the wide variety of information sources available to the flight crew will therefore require strict prioritization of cockpit warnings and alerts.

7.2.4.4 *Related Human Factor issues*

There are significant Human Factors issues in how to integrate and differentiate presentation of these alerts. Issues such as sensory modality to use for warning/alert presentation (visual, auditory, etc.), colour, clutter, etc. must be addressed.

Furthermore, in accordance with HF principles, systems should also be designed so that human errors (or, in the SHEL model terms, "Human-Software-Hardware-Environment interaction breakdowns") which may reasonably be expected to occur in service:

a) Are not contributed to by design characteristics.
b) Can be detected by the operators (directly or indirectly), or if not readily detectable, the system must be tolerant of such error
c) Have means to be reversed or recovered from, or in not possible, the effect on the system must be evident or not result in catastrophic outcome.

7.2.5 **Future Technology Watch Items**:

Monitoring the following advances in technology should help determining the possible realization and evolution of these Global Air-Ground-Space System related Hazards. 12 topics of concern have been identified. They are presented below without prioritisation:

1) It is advisable to maintain a close monitoring of the strategies developed by bodies responsible for Air Navigation Services such as the EUROCONTROL ATM 2000+ strategy. In a similar fashion it is advisable to also monitor the development of Strategic Research Agenda such as ACARE in Europe that give good indications of the technologies being developed.
2) Emergence of FMS Systems designed and certified for sole means of navigation.
3) Decommission plans of ground navigation aids.
4) Systemic use of satellite for communication, navigation and surveillance and development of associated technologies and services (e.g. Ground or Space Based Augmentation Systems (GBAS, SBAS); Automatic Dependant Surveillance- Broadcast (ADS-B); Data-link Technologies (ACARS; VDL 4; High Band-with))
5) Free-flight / free-routing plans such as Free Routing Airspace Plans (FRAP) or Mediterranean Free Flight (MFF).
6) Introduction of new warning systems and alerting techniques, and consolidation/integration of warnings and alerts involving problems with internal vehicle systems (such as HUMS) with those from external traffic, terrain, and weather avoidance/alerting systems.
7) Emergence of 4D trajectories.
8) Development of system using Artificial Intelligence (e.g. neural nets, fuzzy logic). Monitoring of general and applied research in these areas should be made to identify scientific breakthroughs.
9) Development of "intelligent" aircraft (e.g. active flow control using a combination of propulsive forces; micro surface actuators and fluidic device operated by an intelligent flight control system; Intelligent system of smart sensors, microprocessors and adaptive control will monitor performance and environment and help operators to avoid danger).
10) Development of "intelligent" vehicles (e.g. smart cars) as cross fertilisation can be very beneficial.
11) Nanotechnologies, new computing techniques such as molecular computing and intelligent materials. Monitoring of general and applied research should be made in these areas to identify scientific breakthroughs.

12) In addition, significant developments should be tracked in the following technological domains: Collaborative decision making (CDM); Computer Support to Cooperative Work (CSCW), Computer-based operating aids and management systems, Groupware, Monitoring and Supervisory Control, Industrial, Human, and Cognitive Engineering (Main application: ATM-ATC and SCC control rooms and operations; crisis management).
13) In addition, significant developments should be tracked in the following technological domains (supported in particular by the EC in the 6th FWP): eSafety of road and air transport and eHealth, Information and Communications Networks based upon all-optical technologies and new Internet protocols, advanced Middleware, global networking and distributed architectures, Multimodal Interfaces, Semantic-based knowledge systems, Networked audio-visual systems, technology-enhanced learning, advanced displays, optical, opto-electronic, photonic functional components, open development platforms for software and services, cognitive systems, GRID-based Systems for solving complex problems, risk management.

7.2.6 Risk Monitoring

Risk monitoring should be performed at the AGS system level by developing integrated operational feed-back and feed-forward from / to the manufacturers, regulators, education and training organizations, and other relevant actors.

All actors of the AGS system should work with the rest of the aviation community to develop processes that will establish and maintain historical documentation containing the requirements, design details and assumptions that were made during initial design and any subsequent changes to the system. This process should include the establishment of reporting requirements and preservation of in-service feedback.

Because the future AGS is bound to evolve, new Hazards can emerge over time. All actors should therefore monitor the frequency and trends of events (e.g. system/ component failures) arising from unknown or unexpected reasons.

In addition, it is recommended to monitor the realization of the AGS related Hazards over time in order to continually and timely update the list of hazards identified by FAST and the corresponding recommendations or proposals for future work.

7.3 Theme II: FLIGHT CREW-AUTOMATION INTERACTIONS ISSUES

7.3.1 Introduction:

The developments of cockpit automation serve the main objective of increasing airspace capacity by increasing navigation accuracy and by supporting the transfer of some of the control functions currently performed by the ATM/ATC to the flight crews.

Cockpit automation also improves flight performance and increases economy by decreasing operation and maintenance costs. Automation is also a means of improving safety, in particular by enhancing the crew awareness of the external environment, e.g. taxiway (ground), terrain (low altitude), traffic (air and ground), airways, weather, navigation path, threats and communication through improved situation awareness (SA) means (displays, visual, auditory and tactile signals and alerts).

At the larger level of the Total AGS System, automation should also contribute to enhancing the awareness of the global AGS distributed multi-agents control, command and management system to all personnel concerned: flight crew, cabin crew, ATM/ATC staff and maintenance personnel, and Strategic Command and Control (SCC) personnel under the Fully Automated Flight (FAF) hypothesis.

Automation of course doesn’t presents only advantages. Different studies, especially in the Human Factors domain, have indeed indicated that automation modifies the ways the pilots interact with the aircraft and between themselves. The literature widely covers the problems flight crew are facing when interacting with automated systems.

In addition, new automated control, command and assistance systems will surely modify the ways the different personnel will interact with the technology and between themselves, not only in the cockpit but also in the other nodes of the global AGS system. Some problems are likely to be resolved and other to be reinforced, while new problems due to the unique characteristics of the future global AGS system will probably arise. Among them are for instance the difficulty for each agent to be and remain aware of the state and dynamic behavior of the other agents, human and artificial, within the global system, and the difficulty to operate in case of failure, breakdown or inoperability of the automated systems.

In order to get the best possible results in terms of efficiency and safety from the future automation, "accompanying measures" such as adapted regulations, procedures, education and training, in particular Crew Resource Management (CRM) are therefore recommended.

7.3.2 Four hazards grouped in one theme:

Four Hazards out of the 21 prioritised ones form the "Flight Crew-Automation Interactions Issues" theme. These four Hazards are:

1. Flight Crews - Crew Automation Interactions Issues: Abnormal/emergency situations combined with automation breakdown or failure (subtle or sudden) may create situations exceeding crew experience or training level: **Live 6.11** (current)
2. Flight Crews - Crew Automation Interactions Issues: A poor automation logic/interface may lead to decision-making based on false or misleading assumptions: **Live 6.1.4** (future-near)
3. Operations - Flight operations / interactions with automation: Loss of automation behavior awareness due to complexity of automation modes. Pilot needs to know what the airplane "thinks" is going on (matching expectations) (C3): **Soft 6.3** (current)
4. Flight crews - Crew-automation interactions issues: Predominant use of automation may cause aircrew to have trouble performing traditionally simple operations such as manually switching to other runways, or overriding the autopilot in tight situations. Lack of aircrew training and/or experience coupled with manual flight in highly automated airplanes may lead to loss of aircraft control in unusual situations such as upsets, traffic avoidance or maneuvering. Loss of basic piloting skills through further automation may increase this problem further: **Live 6.2** (current)

Three of these Hazards are already present today and one is foreseen in the near future. But all of them are expected to *evolve* in the future AGS system.

7.3.3 Perspective:

The introduction of Glass Cockpit technology into modern airline aircraft has shown that there are a lot of issues associated with flight mode confusion as well as the complexity or perceived complexity of straightforward tasks by flight crew.

Fatal accidents and significant incidents and "near misses" have occurred due to mode confusion leading to loss of situation awareness and loss of control. Information regarding observed instances of flight crew mode confusion is well documented (e.g. CAST Safety Enhancement-36).

Many loss of control accidents/incidents involved cockpit displays of engine parameters, flight information and auto flight system mode status as contributory factors. The problems centred on not having sufficient, obvious and unambiguous information to the pilot to adequately assess the aircraft status and then to accomplish the appropriate action to resolve problems (CAST SE-34).

Changed training and operational requirements have also become important issues as well as the development and maintenance of manual flying skills. During times of high demand and low supply of experienced pilots (which is today the case for instance in South-East Asia), basic training of manual flight may be minimal and as low as a few hundred flight hours on light aircraft before beginning training on highly automated aircraft in a very different weight class than the aircraft and simulators used during the training towards the license.

Predominant use of automation may cause aircrew to have trouble performing traditionally simple operations such as manually switching to other runways, or overriding the autopilot in tight situations. Lack of aircrew training and/or experience coupled with manual flight in highly automated airplanes may more easily lead to loss of aircraft control in unusual situations such as upsets, traffic avoidance or maneuvering. Loss of basic piloting skills through further dependency on automation may increase this problem further.

Finally, design changes, by nature, take a long time and cost a lot of money. Incorporating new safety features into new aircraft designs is technically feasible and desirable. However, it may take many years for these changes to have a significant impact on overall fleet safety, given the time it takes to develop a new aircraft and for these aircraft to become a significant part of the fleet (CAST SE-36).

7.3.4 Discussion:

7.3.4.1 Various sorts of changes

The hazards associated with advances in cockpit technology have to be explored in order to make appropriate recommendations. These hazards are possibly related to both physical and psychological changes that flight crew have been, and will be, subjected to.

These changes have in some cases had the effect of inducing a misunderstanding by the flight crew of the automation behaviour and consequently have led to incorrect decision making in both critical and non-critical situations.

Changes to certification rules normally only affect new aircraft designs; therefore any near-term benefits to be realized through retrofit of the existing fleet require voluntary implementation by manufacturers and operators (CAST SE-36).

The trend is for pilots to have fewer flight hours in armed forces or lighter commercial aviation than before when upgrading /downgrading to medium/large commercial transports with highly automated cockpits, as well as less actual prior stick time. Better automation and flight planning may have decreased previous exposure to conditions such as adverse weather, saturated airspace, etc.

7.3.4.2 Difficulties in interacting with automation

Problems have arisen with the development and implementation of logical and user-friendly man-machine interfaces such as systems used in previous versions of same type certificated aircraft when they are updated and automation developed in newer generation of same aircraft. In the past this issue has not been completely addressed by the manufacturers and the regulators.

There is plenty of evidence (coming for instance from LOSA, flight checks, simulator training, accident and incident analysis and surveys) that flight crews (particularly those new on type) do not always fully understand what the automation is doing and want to override it even if functioning properly.
It has also been shown that flight crews do not always understand the information being presented to them in highly automated cockpits and make errors in diagnostic analysis and decision-making. The reason for this may be inadequate training, flight department operational policies or poorly designed man-machine interfaces.

In addition, actual range of pilot behaviour (cultural/CRM/responses to automation failures) and skill levels have not always been understood by designers.
Poor understanding of what operation the flight deck automation is commanding the aircraft to perform has the potential to increase the stress and fatigue levels of the flight crew. This can have an adverse effect on the decision making process.

On the other hand, pilots fully familiar with flight deck automation have brought themselves and the aircraft in extremely dangerous situations, not being able to program themselves out of it, nor disconnecting the automation to hand fly themselves to safety. Reasons for this may include pilot fatigue, sudden or subtle developments of automation failures resulting on “automation surprises” and the like.

7.3.5 Future Technology Watch Items:

Monitoring the following signs and advances in technology should help determining if these Flight Crew – Automation Interactions associated hazards are coming about:

1. Implementation of new technology in future cockpits modifying crew interface (e.g. Emergence of 4D trajectories) and modifying crew-automation interaction (e.g. systems using Artificial Intelligence).
2. Introduction of “Free flight” concept introducing new automation modes (e.g. Free-flight / free-routing plans such as Free Routing Airspace Plans (FRAP) or Mediterranean Free Flight (MFF)).
3. Emergence of FMS Systems designed and certified for sole means of navigation.
4. Decommission plans of ground navigation aids.
5. Systemic use of satellite for communication, navigation and surveillance and development of associated technologies and services (e.g. Ground or Space Based Augmentation Systems (GBAS, SBAS); Automatic Dependant Surveillance- Broadcast (ADS-B); Data-link Technologies (ACARS; VDL 4; High Band-with)).
6. Introduction of new warning systems and alerting techniques, and consolidation/integration of warnings and alerts involving problems with internal vehicle systems (such as HUMS) with those from external traffic, terrain, and weather.
7. In addition, this list should be revisited on a regular basis or after significant events (e.g. accidents, critical incidents, near-misses). The use of technology watch items is therefore linked to Risk Management.

7.3.6 Risk Monitoring

The level of operational risk should be assessed with respect to the crew behaviour whist operating with a highly automated cockpit.

It should be determined whether risk of accident / incident is increased or decreased through greater reliance on technology.

Information reporting and sharing, in particular between operators and manufacturers, should be used as a tool in order to identify problems.

7.4 THEME 3: GENERAL THREATS

7.4.1 Introduction:

Five Hazards, considered as affecting several area's, in particular “Crew Automation issues”, “Air to Ground Systems Interactions”, and “Fully Automated Flights” have been classified as General Threats.

Three of the threats are in Hardware - one already present today and two in the future-near category, the two others are in Liveware - one present today, one in the future-near category. This highlights the fact that hardware including its software and Liveware also present interacting new hazards especially on the interfaces.

7.4.2 Five hazards grouped in one theme

Five main hazards are listed in this theme General Threats, two of which were already grouped for producing recommendations.

- **LIVE14.1** addresses the use of automation or of automated systems outside of intended function that may cause safety problems.
- **Hard 4.4b** addresses compatibility, integration, configuration management issues (including for Human-Machine Interfaces and Software applications): Failure or malfunction caused by incorrect functional interfaces.
- **LIVE 15.5** addresses sabotage or intentional damage or degradation of systems, either through physical means or through cyber or electronic interference attacks.
- **Hard 7.4.1 and Hard 7.1b** address database integrity failure and software issues such as lack of software capability to recover from some hardware failures. Both may concur to aggravate a situation.

7.4.3 Perspective

The aviation system is faced with increasing technical and business complexity. Systems now cost more than in the past, and this investment is causing extreme longevity of use of systems. The experience base for system design is eroding, with system longevity far outliving the careers of the designers, builders and the regulators that developed it. All these factors contribute to increased likelihood of unforeseen or forgotten system failures and system interface failures having major safety impact. In the far future these issues may cause increasing hazards unless systematic structures are put in place to avoid those hazards**.**

7.4.3.1 Use of systems outside intended use

Operators today sometimes use systems for tasks for which they were not intended. Four examples:

- Use of FMS as sole means to determine V speeds.
- Use of FMS as sole means of navigation.
- Use of TCAS to maintain separation.
- Use of TAWS as primary means of navigation.

There are many reasons why that occur. Some of the main reasons why systems are improperly used are as follows:

- The designers of the system make it possible to do so.
- Operators are under pressure to meet efficiency requirements and so are tempted to misuse systems.
- *Pilots percieve the technology as so compelling that they may use ad-hoc procedures.*
- *In some cases regulators allow its use under temporary conditions, e.g. FMS for PRNAV in the TMA under TGL 10.*

The human tendency is to minimise complexity and workload.

7.4.3.2 *Databases*

Use of databases has evolved into many aerospace applications, both on board as well as on the ground. Typical examples are databases in FMS, but also in EGPWS, TCAS, AFCAS, EICAS/ECAM/MFDS, ATC systems, etc. Use of databases is currently only in its infancy, with an exponential increase just around the corner, if only for CNS/ATM use. The same is even true for interactions where the integrated AGS will also call for an exponential increase.

7.4.3.3 *Sabotage and cyber attack*

Use of computer software has evolved into many aerospace applications, both on board as well as on the ground. The connections of S/W with the "outside world" are through a) Loading in the shop: Initial Program Load on the chip/EPROM, b) physical on board S/W loading by means of floppy or cable and c) logical, through a data link or wireless network. Today, the threat of cyber terrorism against aircraft is minimal. But when looking into the future airspace paradigm, with many aircraft and ground systems in a multi-agent distributed air ground [AGS] system, *ever more critical information* will be transmitted via data link, this is considered a serious threat.

7.4.4 Discussion

Items for consideration:

- Increasing complexity
- Attrition of experience
- Increasing business pressure for diverse organisations building components
- Making design of very complex systems safe – recommendation for R&D
- Concise, simple, not dependant on legacy relationships
- Isolation of simple safety practices in system design

7.4.4.1 *Database errors/malfunctions*

Data base errors/malfunctions may lead in part to loss of situational awareness, or misleading and/or incorrect information or just a plain overload of the human being. This being the case where the right information is given at the right time, but is simply either not processed or incorrectly processed due to this situation.

Items for consideration:

- Increasing complexity that gives room for failure propagation with increased difficulty to predict.
- Interaction between component failures and S/W design

- Use of processors with ever increasing complexity. The concern is transfer of risk from current technology to future technology. All processors have the potential for errors, while RISC [Reduced Instruction Set Computer] chips minimise the chance for unknown failure modes like the Pentium 4 floating point calculation, and other, not tested processor specific risks.
- Inadequate data link protocols.
- What if a node in the system, in flight or on the ground, does not respond at all, are “light flares” (as used for sea rescue) to be used to get the non-responder to wake up?
- Use of flight critical Software to be promoted.
- Increasing number of components
- Increasing probability of multiple IEEE parts failure.
- Obsolescence of IEEE parts creates maintenance and/or configuration management issues
- Design specifications to be made compatible with very ambitious Safety requirements and systems complexity.
- Design trace ability and resources to take care of systems aging
- More involvement of automated systems in flight safety.
- Discussion placed in the frame of 1.10-7 TLS.
- Increasing importance of precursors to detect incidents that in worst cases may propagate throughout the system and end up in serious situations.

7.4.4.2 *Sabotage/cyber attack*

Sabotage/Cyber attack maybe the presence of unwanted and/or malicious code fed into the box, the absence of a code or the removal of a code, either directly or attached to a timing device that would allow the removal and/or destruction of a code during flight.

7.4.4.3 *Hazard amplification for Data bases:*

Since the use of databases will increase exponentially, ever more information will be uploaded and downloaded increasing the risk for errors. Database integrity, i.e. *"end-to-end aeronautical data integrity"* starts at the beginning, e.g., two DME's (4 nm apart) were given the same identifier and then processed through the system into the FMS. Other issues: how is certification maintained after incremental uploads?
Examples: 1. Where an Authority upon checking an EGPWS in a simulator could not find the highest obstacle (>100M) next to the airfield because it was not in the database. 2. Lookup table upon A/C go-around looks at wrong engine thrust table 3. One operator regularly comparing a 28-day FMS revision cycles with the previous edition using software tools finding numerous errors.

IEEE parts and S/W failures and propagation of these errors throughout the system.
This statement considers that:

- SW never fails, has only design and coding errors, and may be inadequately designed to face all envisaged power and electronic hardware failures. SW design / functional breakdown errors can be understood as procedural errors satisfying SHEL definition.
- Increasing technical complexity goes with an increased number of components making hardware more sensitive to accumulation of component failures, and especially the [unknown] failure modes of ever more complex processors are a source of concern.
- When the same type or IEEE parts exist in a given system, a common failure mode affecting a batch becomes more likely.
- Long life of electronic systems will (while facing components obsolescence) create maintenance burdens and possible configuration management errors.

- Configuration management issues / changes due to maintenance during systems life can create new types of failures.
- Since an increasing number of systems will communicate via data links, the protocol that will be used between (layers of) systems, needs to be sufficiently protected [ref today's discussion for implementation of new IP address protocol for the internet and static or dynamic addressing]
- If the industry is to succeed in preventing these errors, true modularity of all component building blocks need to be assured.

All these factors contribute to increased likelihood of unforeseen or forgotten system failures and system interface failures having possible safety impact. In the far future, these issues may cause increasing hazards *unless systematic structures, and a building block approach*, are put in place to avoid those hazards.

7.4.4.4 Sabotage/cyber attack

Sabotage in the military world used to be cutting wires, i.e. cutting physical connections. In a highly automated aircraft, breaking the logical connection between stick and controls maybe the next option for sabotage and/or terrorism. This could take the form of a high power RF source in the wing close to the aileron controls, with the intent to break or interrupt the roll control logic. Another option could be to change the code logic via a cyber attack.

Sabotage used to be predominantly done and found by maintenance. Future sabotage/cyber attack may be more difficult to find and may be accomplished by individuals without physical access to the aircraft.

7.4.5 Technology watch items

Monitoring the following signs and advances in technology should help determining if these security hazards are coming about:

R&D and Industry work to ensure that the lessons learned from specific experience is permanently captured and made readily available to the aviation industry.*

Appearance, development & implementation of more robust approach to design and a process that challenges the assumptions made in the safety analysis of flight critical functions.*

Manufacturers, trainers and regulators increasingly sharing applicable experience and lessons learned.*
Note: all of these *) watch items are related to Certification Process Study (CPS) conducted in the USA.

7.4.5.1 Use of systems outside intended use - watch items

- Airlines & training institutions insisting that crews are made aware of manufacturers' design assumptions and regulators' requirements in execution of company operating procedures.
- Active awareness programs.

7.4.5.2 Database Technology watch items

- Tools to speed uploads including proper certification,
- Changes to Software Certification rules that would speed up the process.
- Regulators allowing red label S/W use during revenue flights.
- Pressure from manufacturers to self certify or reduce certification time /effort, in order to reduce cost and or reduce time to market of upgrades!
- Appearance of more RISC processors in system applications.

- Increased use of flight critical S/W (especially for FMS) and increased use of ARINC specs for data link applications.

7.4.5.3 Security Technology watch items

- Increases in jamming technology capability.
- Identification of change/modify/delete existing code attack plans on the internet.
- Increase in cyber threat level directed at aviation.
- Availability of devices on the internet, pre-built or as a kit to accomplish them.
- Appearance of movies and or books on the subject that would give people ideas [we are not talking about the average person, state sponsored vs. the individual attack].
- Social- [organized crime] and Political issues [tension between states].

7.4.6 Risk monitoring

- Set up of a data base incident tracking system including error resolution.
- Pursue accident pre cursors
- Track S/W revisions by number and complexity
- Reporting and tracking of cyber attack/sabotage anomalies

7.5 Theme IV: ABSENCE OF HUMAN AGENT (On Board)

7.5.1 Introduction:

Detection technologies for unexpected problems will be developed if un-crewed passenger carrying airplanes are to be built. If these technologies are not developed, then those airplanes will not be built. Therefore, the hazards associated with future detection systems for unexpected problems lie in failure to accurately detect, or solve, an unexpected safety-related hazard on a so-equipped airplane.

Despite the low probability of operational fully automatic flights within the next 20 years, FAST decided to investigate this possibility as an extreme case of automation permitting:

- to highlight tendencies valid for automated manned flights (e.g. situation awareness)
- To highlight that in a silent cockpit of a plane, crew awareness of phenomena maybe poor and new detection technologies may be necessary in the near future.

There are several required technologies that could contribute to the technical solutions of these detectors. Improved aural (hearing), olfactory (smell), tactile (feel), and visual sensors could be part of the technology. Nano-sensors and “smart” sensors that do not broadcast information unless the information is deemed significant could provide a network of basic sensors, which if properly interpreted, could sense a problem. Networking technologies will also play a part; wireless detection and transmission to the decision-making computer will be a key for manufacturing purposes. The “decision-making computer” must also “ping” remote sensors if problems are expected and no information is flowing to it from the sensors.

7.5.2 Main hazards in one theme

There are 4 main hazards that need to be addressed for Commercial Fully Automatic Flight, these are:

1. Mechanisms to replace human sensing and processing of abnormal conditions: smoke, odors, vibration, noise, etc. (in particular for Fully Automated Flight) may be *insufficient* to cope with critical situations, hazard: **Hard 2.1a**
2. Lack of mechanisms to replace human cross-check of *misleading* or *inaccurate* data transmitted to & from the aircraft (in particular for Fully Automated Flight) may result in inappropriate actions being taken to ensure safety of flight. Lack of human redundancy (in particular for Fully Automated Flight), hazard: **Hard 2.2,** area's of change (MRO5) (AC1)(AC19) interact with this hazard.
3. Even when functioning properly, onboard sensors may give to airline operation centers and ground controllers' *insufficient information* to correctly analyze and resolve situations. Lack of mechanisms to replace human cross-check of misleading or inaccurate data transmitted to & from the aircraft (in particular for Fully Automated Flight) may result in inappropriate actions being taken to ensure safety of flight. Lack of human redundancy (in particular for Fully Automated Flight), hazard: **Live 5.3**, area's of change (MRO5) (AC1)(AC19) interact with this hazard.
4. Crew automation interactions issues: Loss of strategic and tactical situation awareness, including automation & mode awareness and airspace system functions may occur if flight management, system management and control of flight is transferred completely or partly from on-board crew to ground based crew, hazard **Live 6.1.4.**

7.5.3 Perspective

In the next 10 years, we will see a continually increasing percentage of airplanes operating in civil airspace having a continually increasing level of "autonomy". Autonomy in this case is defined as operation without human control. This transition will not occur all at once. It will have a phased introduction. Increasingly autonomous military airplanes will be introduced along with long endurance communication and civil surveillance platforms for detecting fires, security threats and the like.

7.5.3.1 A gradual introduction of ever more "autonomous" aircraft

In the future operational scenario, it may become desirable if not outright necessary to develop autonomous aircraft that do not require the presence of a human flight crew on board. Such airplanes operating in civil airspace will have a continually increasing level of "autonomy." Autonomy in this case is defined as gate-to-gate operation without the presence of human pilots on board.

This transition will not occur all at once. It will have a phased introduction. Increasingly autonomous military airplanes will be introduced along with long endurance communication and civil surveillance platforms for detecting fires, security threats and the like. Twenty years from now, it is possible that there will be fairly autonomous cargo carrying airplanes flying, and passenger airplanes may be being designed at that time.

7.5.3.2 Processing of inconsistent or misleading information:

Today (2003), the human operator of a vehicle can often identify and process inconsistent or misleading information sooner and sometimes more accurately than onboard systems. Current flight crew operate in a data-rich environment. This enables them to respond appropriately to unforeseen circumstances and maintain safety of flight

Present-day airplane systems are able to detect and process data that are outside pre-established standard values. For instance, today's transport airplanes detect low hydraulic pressure and inform the flight crew in order to facilitate corrective action. However if the state data being provided by the onboard systems is inconsistent with other related information, misleading conclusions maybe drawn by automated systems or even human pilots. Human pilots are trained in methods for recognition, confirmation, and subsequent recovery from abnormal situations.

7.5.3.3 *Similar capabilities must be provided in any kind of future automatic flight capability.*
In the future, there will be public demand that passenger airplanes must automatically sense and identify anomalous and/or inconsistent data in order to prevent unwanted and perhaps hazardous responses to situations that are not real.

In order to replace the capability of the human to perform data/information cross check functions, some kind of automated decision-making functionality must be provided. This may take the form of artificial **"**intelligent **agent(s)"** (e.g. a computer or network of computers) that must compare sensor readings to identify unusual patterns and "outlier" information.

The development of such a robust capability is in itself a significant technology challenge. It should take care of and analyse the whole set of flight data from incident effect and criticality analysis to flight contingency management strategy (e.g. alternate fields are in FMS, but including check with ATC, airfield runway conditions, etc available).

Therefore it should trade-offs all information available with quasi human intelligence with equivalent confidence level. If artificial intelligent agents cannot at least functionally replicate human cross checks unsafe situations may be created. Automated systems can generally be programmed to detect and respond to expected system failures or to recognize expected anomalous indications.

However, in future scenarios in which no flight crew is present in the aircraft to make sense of the available information, the safety risk may increase due to the inability of automated systems to adequately sense and diagnose unexpected events and situations.

7.5.3.4 *Sensor processing, Artificial Intelligence*
Sensor information from many good sources is useless unless it can be interpreted regarding what the unexpected problem is. For instance, a flight crewmember could walk to the aft cabin while in flight, see a mist trailing the right wing, and determine that a fuel leak probably exists. Having a similar sensing and deduction capability will be necessary for decision-making and subsequent problem-solving.

This may require substantial application of diagnostic, decision-making, planning and action capabilities, most of them being currently addressed by Artificial Intelligence (AI). It must be noticed however that such capabilities of functionalities can be dispatched on both the aircraft and the ground, and can be performed by either artificial (computers) or natural agents (human crew). It is then likely that final decision, planning, and strategic and tactical choice of actions will be left to ground personnel (e.g. ATM/ATC crew, SCC crew under the FAF hypothesis).

But onboard sensors may not give airline operation centres and ground controller's *sufficient* information to correctly analyse and resolve unexpected situations. Two issues must be addressed:

- Signal quality (lost communications, communication congestion, signal interference)
- Adequacy of information during dramatic in-flight events (such as in-flight fires, required ditching, emergency diversion to alternate fields or unforeseen interactions with other traffic due to weather or airport capacity problems.)

Current data streams, integrity as well as the quantity of raw data available, are not sufficient for ground control teams to select the optimal course of action. In the future, provision must be made for "electronic mayday" calls that create high-priority communication channels. In addition, for fully automated flight, consideration must be given for increased communications bandwidth for the aircraft in distress.

Without a human operator, replication or substitution of human information processing and interpreting capability will become a technical challenge for designers. Passenger-carrying un-crewed airplanes will present an additional challenge because the public will demand a higher level of "safety" for passenger airplanes and because passengers are sensitive to additional non-safety-related irritations.

Even if these very challenging technologies are developed, the burden of proof for its acceptability will be "that a FAF airplane will need to be at least as good as a piloted aircraft".

One serious concern will be that this may lead to a regulatory overkill due to the many uncertainties around FAF, a typical example from the past being automatic landing. Under autoland conditions, unrealistically harsh conditions need to be simulated, for instance under crosswind limits, leading to manual landings when crosswind exceeds the simulated limit of e.g. 25 knots. Flight testing has shown that the automatics under these conditions would have made a perfect landing, while the manual landings in excess of 25 kts crosswind have shown in several cases to end up in significant mishaps.

The issue of transition from an intermediate level of automation (no pilots on aircraft but monitor or stand-by crew on ground) to fully automated flight (no flight crew in air or on ground) must be addressed. For instance, aircraft and support systems required for intermediate level of automation may be inadequate or require major revision if fully automated flight is to be realized.

All these questions could potentially be addressed by technology. Unless they are solved economically, the un-crewed airplanes will never be a reality, and hence, no hazards will exist. All of these issues could be avoided if there was public acceptance of an un-crewed airplane that could not deal with unexpected safety-related problems. From today's view, the main barrier to implementation of an un-crewed passenger airplane is lack of public acceptance of an airplane. If public acceptance of additional risks changes, then the un-crewed airplane could proceed with minimal technology changes.

7.5.3.5 towards fully automatic flight: mixing of piloted and non-piloted aircraft

Under the fully automated flight (FAF) hypothesis, flight management, system management and control of flight will be transferred completely or partly from on-board crew to ground-based crew.

Such transfer of functions might be done step by step, so that there might be a transition before management and control will be mainly or totally exerted by the ground.

In addition, the management and control of FAF need to be co-ordinated to classical ATM/ATC. This co-existence of various management and control functions or systems (under the hypothesis of secure control and command (SCC) facilities) further determines what the future AGS system may look like at the 20+ year horizon.

7.5.3.6 Transfer of functions to a SCC [Secure Command & Control]

The transfer of certain functions to ground-based SCC crew introduces particular safety requirements:

a) Ground-based SCC crew should receive and be capable of processing all necessary information in order to carry out his missions and maintain a proper situation awareness and control (local and global) control
b) ATM/ATC personnel should be provided with all necessary information in order to maintain a proper situational awareness (SA) (local and global) and perform his management and control missions in relation to SCC ground-personnel (under the SCC hypothesis)
c) Flight crew in piloted aircraft should receive and be capable of processing all information necessary to share the airspace with FAF vehicles
d) Co-operation and communication issues, which will become more and more crucial in this new, distributed air ground space system (AGS) system, must be supported by appropriate technologies, design, organisation, procedures and training. Co-operation and communication issues mainly concern 4 categories of personnel: 1) Ground-based SCC, 2) ATM/ATC personnel, 3) Flight crew on-board piloted aircraft and 4) Personnel (e.g. Cabin crew) on-board the un-piloted aircraft

7.5.3.7 *From ATC's to SCC's: the integrated Air Ground System*

Before 2020, we expect aircraft Air Traffic Control Centres, Airline Operation Centres, airports and satellites to be the nodes of an integrated Air Ground Space System (AGS) that will operate during the all phases of flight (gate-to-gate) and communicate through data-link. This AGS system recognises the interdependence of stakeholder operational decision, e.g., Collaborative Decision Making, Flexible Use of Airspace

Human operators remain in the loop but are assisted by automation tools and use elaborate displays. Automation tools are supported by sophisticated databases. However single pilot or supervisory pilot freighter operations might appear in the decade 2010-2020.

Under the FAF hypothesis, i.e. Commercial Fully Automated Flight, which won't be implemented before 2020+, flight management, system management and control of flight will be transferred completely or partly from on-board crew to ground-based crew. This transfer of functions might, especially in abnormal or emergency conditions, introduce a risk of loss of strategic and tactical situation awareness, including automation & mode awareness and airspace system functions.

Maintaining a proper situation awareness and situation control is made even more complex as the management and control of FAF must be performed in co-ordination with the management and control of piloted flights.

In order to prevent loss of situation awareness and loss of control, it is therefore essential to perform research of the implications of FAF in all personnel directly or indirectly concerned, to derive from research appropriate safety requirements and to satisfy these requirements through adapted technological, design, procedures, organisation and training solutions.

7.5.4 DISCUSSION

7.5.4.1 *Biggest hurdle*

The biggest technology hurdles however are data merging, diagnostic, interpretation, decision-making and problem solving. Sensor information from many good sources is useless unless it can be interpreted regarding what the unexpected problem is. For instance, a flight crewmember could walk to the aft cabin while in flight, see a mist trailing the right wing, and determine that a fuel leak probably exists. Having a similar (at least functionally) sensing and deduction capability will be necessary for decision-making and subsequent problem-solving (When a problem is rightly detected and interpreted, appropriate recovery measures still need to planned and executed). This may require substantial application of diagnostic, decision-making, planning and action and capabilities, most of them being addressed by Artificial Intelligence (AI).

Even if these very challenging technologies are developed, the burden of proof for its acceptability will be “that a FAF airplane will need to be at least as good as a piloted aircraft”.

One serious concern will be that this may lead to a regulatory overkill due to the many uncertainties around FAF, a typical example from the past being automatic landing. Under autoland conditions, unrealistically harsh conditions need to be simulated, for instance under crosswind limits, leading to manual landings when crosswind exceeds the simulated limit of e.g. 25 knots. Flight testing has shown that the automatics under these conditions would have made a perfect landing, while the manual landings in excess of 25 kts crosswind have shown in several cases to end up in significant mishaps.

7.5.4.2 *Can "cross checking" technology be as good as a pilot?*

All these questions could potentially be addressed by technology. Unless they are solved economically, the un-crewed airplanes will never be a reality, and hence, no hazards will exist.

Crew cross checks consist of mental comparisons of various sources of data to confirm whether a situation is the same or different than the current perception and mental model of the aircraft state and flight progress. Cross-checks provide a means to confirm situational diagnosis and a means to identify unusual events and or conditions within or external to the aircraft.

Normal cockpit procedures call for cross checks of flight parameters (airspeed, altitude, heading, track, vertical speed, etc.), navigation and planning displays, charts and maps (4-D position awareness and planning), traffic checks (visual, TCAS, and radio), etc.. Cross checks in abnormal situations may additionally include other cues from caution and warning panels, aural indicators, abnormal sounds and noises, and smoke, vibration, information from other humans on board, in the vicinity of the aircraft or on the ground.

7.5.4.3 *Cross checking of misleading or inaccurate data*

Human operators have the ability to quickly identify misleading or inaccurate data. Cockpit instrumentation in transport category aircraft provides such a rich suite of information that unusual indications can be quickly cross-checked against other related information by the flight crew. In many cases, the human in the cockpit is the last line of defence against failures in other domains.

Examples of these failures may include inappropriate design, weather conditions not as forecasted, traffic separation failures on the ground an in the air, procedural weaknesses, and failures in management and operational procedures. In a future scenario in which onboard pilots may be replaced by automated flight systems, such cross checks may not happen.

7.5.4.4 *Insufficient information*

Even when functioning properly, onboard sensors may give airline operation centre and ground controller’s insufficient information to correctly analyse and resolve situations. Situations to consider include lost communications, communication congestion, and signal interference.

In unexpected or unforeseen circumstances such as in-flight fires, required ditching or emergency diversion to alternate fields current data streams available are not sufficient for ground control teams to select the optimal course of action. In the future, provision must be made for “electronic mayday” calls that create high-priority communication channels. In addition, for fully automated flight, consideration must be given for increased communications bandwidth for the aircraft in distress.

7.5.5 Future Technology Watch Items:

Look for these signs to determine if this technology and associated hazards are coming about:

- Artificial Intelligence technology advancements enabling inexpensive replication or substitution of human sensing and reasoning to an extent that a machine can successfully interpret a situation that it has never encountered, diagnose the problem with at least human reliability, and instigate system changes to address the problem.
- Networking technologies that support efficient, high-bandwidth communication; wireless network, smart sensors, etc.
- Track technology progress and public acceptance of safety-sensitive domains such as other transportation modes Track advances in the medical field such as remote surgery and automated, implanted medical devices
- Systemic use of satellite for communication, navigation and surveillance and development of associated technologies and services (e.g. Ground or Space Based Augmentation Systems (GBAS, SBAS);
- Automatic Dependant Surveillance- Broadcast (ADS-B); Data-link Technologies (ACARS; VDL 4; High Band-with))
- Free-flight / free-routing plans such as Free Routing Airspace Plans (FRAP) or Mediterranean Free Flight (MFF)
- Collaborative decision making (CDM)
- Assuming that " decision making computers" will have a learning capability, track appearance of solutions to share/exchange the individual learning between decision making computers [via " learning ground nodes/hubs"?]

7.5.6 Risk monitoring

This will also be an essential ingredient for continued safe operation:

- Develop tools and methods for monitoring frequency and trends of system/component failures arising from unknown or unexpected reasons
- Identify, track, and process occurrences of incomplete, misleading, conflicting or insufficient data where flight crew performed this function

7.6 Summary: the four hazards themes and the related technology watch items:

7.6.1 The four hazards themes:

- Theme I: GLOBAL AIR–GROUND–SPACE SYSTEM ISSUES:

A new AGS system

In the next twenty years, we expect aircraft, Air Traffic Control Centres, Airline Operation Centres, and satellites are the nodes of an integrated Air Ground Space System (AGS) that will operate during the all phases of flight (gate-to-gate) and communicate through data-link. This AGS system recognizes the interdependence of stakeholder operational decisions, e.g., Collaborative Decision-Making, Flexible Use of Airspace.

The airspace system will undergo significant changes (e.g. free routing/free flight; new airspace classification; development of 4 Dimensions trajectories).

This is likely to occur step by step, such system will be performance oriented, but *compatibility and safety* will come first.

Technological moves

Older technologies and modern technologies will co-exist both for aircraft and ground systems, at least in a transitory period.

Human operators remain in the loop but are assisted by automation tools and use elaborate displays. Automation tools will be supported by sophisticated databases. Data and warning/alert information will be generated at an ever-increasing pace within the aviation system and these data will play an increasingly important role in flight critical situations. These data are stored in air and ground repositories and the information generated from the data will be presented to both airborne and ground-based operators.

On the way to Fully Automated Flight

New vehicles such as Vertical Take-Off and Landing aircraft (VTOL) (Other than helicopters) and Un-inhabited Aerial Vehicle (UAV) may use the airspace. Furthermore, single pilot or supervisory pilot freighter operations might appear in the decade 2010-2020 and might pave the way in the longer term for Commercial Fully Automated Flight.

- Theme II: FLIGHT CREW-AUTOMATION INTERACTIONS ISSUES:

The developments of cockpit automation serve the main objective of increasing airspace capacity by increasing navigation accuracy and by supporting the transfer of some of the control functions currently performed by the ATM/ATC to the flight crews.

Cockpit automation also improves flight performance and increases economy by decreasing operation and maintenance costs. Automation is also a means of improving safety, in particular by enhancing the crew awareness of the external environment, e.g. taxiway (ground), terrain (low altitude), traffic (air and ground), airways, weather, navigation path, threats and communication through improved situation awareness (SA) means (displays, visual, auditory and tactile signals and alerts).

At the larger level of the Total AGS System, automation should also contribute to enhancing the awareness of the global AGS distributed multi-agents control, command and management system to all personnel concerned: flight crew, cabin crew, ATM/ATC staff and maintenance personnel, and Strategic Command and Control (SCC) personnel under the Fully Automated Flight (FAF) hypothesis.

Automation of course doesn't presents only advantages. Different studies, especially in the Human Factors domain, have indeed indicated that automation modifies the ways the pilots interact with the aircraft and between themselves.

In addition, new automated control, command and assistance systems will surely modify the ways the different personnel will interact with the technology and between themselves, not only in the cockpit but also in the other nodes of the global AGS system. Some problems are likely to be resolved and other to be reinforced, while new problems due to the unique characteristics of the future global AGS system will probably arise. Among them are for instance the difficulties for each agent to be and remain aware of the state and dynamic behavior of the other agents, human and artificial, within the global system, and the difficulty to operate in case of failure, breakdown or inoperability of the automated systems.

- Theme III: GENERAL THREATS:

The aviation system is faced with increasing technical and business complexity. Systems now cost more than in the past, and this investment is causing extreme longevity of use of systems. The experience base for system design is eroding, with system longevity far outliving the careers of the designers, builders and the regulators that developed it. All these factors contribute to increased likelihood of unforeseen or forgotten system failures and system interface failures having major safety impact. In the far future these issues may cause increasing hazards unless systematic structures are put in place to avoid those hazards**.**

Use of systems outside intended use
Operators today sometimes use systems for tasks for which they were not intended. (E.g. Use of FMS as sole means to determine V speeds; Use of TCAS to maintain separation; Use of TAWS as primary means of navigation)

Databases
Use of databases has evolved into many aerospace applications, both on board as well as on the ground. Typical examples are databases in FMS, but also in EGPWS, TCAS, AFCAS, EICAS/ECAM/MFDS, ATC systems, etc. Use of databases is currently only in its infancy, with an exponential increase just around the corner

Sabotage and cyber attack
Use of computer software has evolved into many aerospace applications, both on board as well as on the ground. The connections of S/W with the "outside world" are through a) Loading in the shop: Initial Program Load on the chip/EPROM, b) physical on board S/W loading by means of floppy or cable and c) logical, through a data link or wireless network. Today, the threat of cyber terrorism against aircraft is minimal. But when looking into the future airspace paradigm, with many aircraft and ground systems in a multi-agent distributed air ground [AGS] system, *ever more critical information* will be transmitted via data link, this is considered a serious threat.

- Theme IV: ABSENCE OF HUMAN AGENT (On Board)

In the next 10 years, we will see a continually increasing percentage of airplanes operating in civil airspace having a continually increasing level of “autonomy”. Autonomy in this case is defined as operation without human control. This transition will not occur all at once. It will have a phased introduction. Increasingly autonomous military airplanes will be introduced along with long endurance communication and civil surveillance platforms for detecting fires, security threats and the like.

A gradual introduction of ever more "autonomous" aircraft should occur. One main issue will be processing of inconsistent or misleading information: Similar capabilities as in piloted aircraft must be provided in any kind of future automatic flight capability. This could be achieved by improving Sensor processing and introducing Artificial Intelligence. When moving towards fully automatic flight a mix of piloted and non piloted aircraft will have to be envisaged and successfully addressed. Functions will be transferred to a SCC [Secure Command & Control]. Moving from *ATC's to SCC's* will achieve the integrated Air Ground System

7.6.2 Technology watch items related to the four Hazards themes:

Monitoring the following advances in technology should help determining the possible realization and evolution of the hazards related to these 4 trends. The following Technology Watch Items have been identified and they are presented below without prioritisation. They may evolve in time and it is advisable to maintain a close monitoring of the strategies developed by bodies responsible for Air Navigation Services such as the EUROCONTROL ATM 2000+ strategy. In a similar fashion it is advisable to also monitor the development of Strategic Research Agenda such as ACARE in Europe that give good indications of the technologies being developed.

1. **Aircraft and CNS/ATM technologies:**
    i. Systemic use of satellite for communication, navigation and surveillance and development of associated technologies and services
    ii. Introduction of Free flight / free-routing plans. These concepts will introduce new automations modes.
    iii. Emergence of 4D trajectories and their consequences of crew interface.
    iv. Decommission plans of ground navigation aids.
    v. Emergence of FMS Systems designed and certified for sole means of navigation.
    vi. Introduction of new warning systems and alerting techniques, and consolidation/integration of warnings and alerts involving problems with internal vehicle systems with those from external traffic, terrain, and weather avoidance/alerting systems.
    vii. Development of "intelligent" aircraft

2. **Aviation processes:**
    i. Aircraft design and certification and circulation of safety information:

        1. R&D and Industry work to ensure that the lessons learned from specific experience is permanently captured and made readily available to the aviation industry.
        2. Appearance, development & implementation of more robust approach to design and a process that challenges the assumptions made in the safety analysis of flight critical functions.
        3. Manufacturers, trainers and regulators increasingly sharing applicable experience and lessons learned.
        4. Airlines & training institutions insisting that crews be made aware of manufacturers' design assumptions and regulators' requirements in execution of company operating procedures.
        5. Active awareness programs.
    ii. Software and data bases certification processes
        1. Tools to speed uploads including proper certification,
        2. Changes to Software Certification rules that would speed up the process.
        3. Regulators allowing red label S/W use during revenue flights.
        4. Pressure from manufacturers to self certify or reduce certification time /effort, in order to reduce cost and or reduce time to market of upgrades!
        5. Appearance of more RISC processors in system applications.
        6. Increased use of flight critical S/W and increased use of ARINC specs for data link applications.

3. **Security technologies:**
    i. Increases in jamming technology capability.
    ii. Identification of change/modify/delete existing code attack plans on the Internet.
    iii. Increase in cyber threat level directed at aviation.
    iv. Availability of devices on the Internet.
    v. Appearance of movies and or books on the subject that would inspire terrorists.

- vi. Social- [organized crime] and political issues [tension between states].

4. **Scientific and Technological advances:**
    - i. Artificial Intelligence:
        1. Development of system using Artificial Intelligence (e.g. neural nets, fuzzy logic) and their consequences on crew automation interaction.
        2. Assuming that " decision making computers" will have a learning capability, track appearance of solutions to share/exchange the individual learning between decision making computers [via " learning ground nodes/hubs"?].
        3. Artificial Intelligence technology advancements enabling inexpensive replication or substitution of human sensing and reasoning to an extent that a machine can successfully interpret a situation that it has never encountered, diagnose the problem with at least human reliability, and instigate system changes to address the problem
        4. Monitoring of general and applied research in these areas should be made to identify scientific breakthroughs.
    - ii. Micro and Nanotechnologies
        1. Nanotechnologies, new computing techniques such as molecular computing and intelligent materials.
        2. Monitoring of general and applied research should be made in these areas to identify scientific breakthroughs
    - iii. Computer-aided decision-making and cognitive engineering:
        1. Collaborative decision-making (CDM); Computer Support to Cooperative Work (CSCW), Computer-based operating aids and management systems, Groupware, Monitoring and Supervisory Control, Industrial, Human, and Cognitive Engineering.
    - iv. Network Technologies:
        1. Information and Communications Networks based upon all-optical technologies and new Internet protocols, advanced Middleware, global networking and distributed architectures, Multimodal Interfaces, Semantic-based knowledge systems, Networked audio-visual systems, technology-enhanced learning, advanced displays, optical, opto-electronic, photonic functional components, open development platforms for software and services, cognitive systems, GRID-based Systems for solving complex problems, risk management. (Supported in particular by the EC in the 6th FWP)
    - v. Other fields technologies:
        1. Track advances in the medical field such as remote surgery and automated implanted medical devices. eHealth
        2. eSafety of road and air transport.
        3. Track technology progress and public-acceptance of other safety sensitive domains.

7.7 Recommendation refinement and prioritization [methodology and results]

Summary of the steps:

1) After the Hazards were prioritized a first attempt was made by the two co-chairs to define recommendations addressing the Hazards by asking members to produce individually recommendations. (December 2002)

2) At its meeting in February 2003, FAST discussed at length if it was appropriate to develop recommendations because FAST had not defined a thorough process to develop them. The comparison with the CAST JSIT process was frequently made as such process delivers well-established Safety Enhancements. It was nevertheless agreed that recommendations should be developed (called proposals for future work) and it was agreed that a sub-group should prepare a template.

3) The sub-group met on March 10 and realised that it should propose more than a template and a more methodical approach was thus drafted:

1. For each hazard, merge all recommendations from individuals available so far.
2. For each hazard, produce relevant background information (e.g. the co-chairs' examples plus available CAST Problem Statements, Interventions and Safety Enhancements).
3. Divide the FAST group into sub-groups and ask them to produce a common list of proposals for changes for each hazard on the basis of the merged list, of the background information, and of in-house expertise and creativity.
4. Then harmonize and validate the findings of the different sub-groups in plenary session, complemented if need be by homework.

This approach presents three advantages: it is very simple, it structures the work of the FAST experts in an efficient manner and it supports appropriation by the FAST members.

4) During the FAST April meeting, the method was further refined, the template containing now the following items:

Statement of Hazards; Perspective; Discussion; Amplified Hazards statements; Future Technology watch items and the proposals for future work. (More details can be found in the report paragraph 7.1)

FAST divided in small sub-groups that worked in parallel during the meeting with regular plenary sessions to compare results.
Grouping of hazards was then proposed on the basis of similarities regarding their background and/or proposals for future work.
The final groupings and list of recommendations regarding the 21 top-priority hazards produced by FAST are presented in appendix 12 of the report.

5) During the preparation of the report in view of the May meeting of the JSSI Steering Group the recommendations were grouped into 4 main themes:

Theme I: Global Air-Ground-Space System Issues
Theme II: Flight Crew-automation Interactions Issues
Theme III: General Threats
Theme IV: Absence of Human Agent (On Board)

6) During discussion at the JSSI Steering Group in May and July it was agreed that it was necessary to review the quality of the recommendations and to prioritize them further. This was done by a sub-group of FAST in October.
Each of the proposed recommendations was evaluated by three factors: Importance, power, and confidence.

- The "importance" value generated at the November 2002 FAST meeting in Madrid was used to maintain consistency in importance ranking.

- Power was defined as the effectiveness of a specific intervention in reducing the likelihood that a specific accident would have occurred had the intervention been in place and operating as intended (“perfect world”).

- Finally, confidence was defined as the level of confidence that you have that this specific intervention will have the desired effect if implemented properly. A fourth factor (time horizon) was used to separate the proposed recommendations into “time categories” for ease of presentation.

The total number of points received for any proposed recommendation was computed by multiplying the three factors together, i.e., importance (fractional value from 0 to 1), power (ordinal value from 0 to 6) and confidence (ordinal value from 0 to 6). The resultant number (total score) was used to rank (or prioritize) the proposals.

An initial listing (grouped by time horizon and prioritized by total score received) was produced and an arbitrary cut-off score was selected for each theme (Air/ground systems, CNS/ATM, Fully Automated flight, etc.). Cut-off values were selected in order to separate those items “standing high” from the rest of the lists. All those non-selected items also require attention, but are, in overall, of a lower priority.

This listing was further refined by grouping the results in categories specific to the parties upon whom the action was being delegated (Regulator, Manufacturer, Research community, etc.) and time horizons (current and future-near, future-medium, and future-long).

7) As a result, the following 27 recommendations were presented to the JSSI Steering Group at its November meeting:

Regulators:	7
Research Community	6
Manufacturers	5
CNS/ATM	3
Education & Training	2
Operators	2
Risk Monitoring	1
Others	1

Current and Future - Near	Total Score
1. REGULATORS: Regulatory agencies should ensure that organizations updating databases have an adequate system to validate updates and check the changes incorporated. The complete chain of the data base production and update process should be made visible, incl checking routines, not only for the FMS, but also EGPWS, that is from land measurement all the way till on aircraft data base loading. Eurocae/RTCA efforts in this respect should be verified. Database software systems including those in the total AGS system should be looked at throughout the total life cycle, i.e., initial design through production to the ultimate updating and upgrading to the next generation.	19.2

2. <u>REGULATORS:</u> Ensure functional and S/W design assurance with respect to security; therefore establish new set of requirements with respect to identified threat (combination of Integrity, availability, reliability, continuity).	9.8
3. <u>REGULATORS:</u> Require standards developed by standardization bodies (ARINC, RTCA, EUROCAE, etc) or equivalent, be used in datalink applications.	9.2

4. <u>RESEARCH COMMUNITY</u>: Conduct research to identify methods to harden [RF] aircraft systems against cyber attack, robust encryption technology) and to improve integrity through better detection of deviation from initial performances.	12.3
5. <u>RESEARCH COMMUNITY</u>: Research into secure transmission and reception capabilities. Learning from military experience.	12.3

6. <u>MANUFACTURERS:</u> Manufacturers should decrease the number of different auto flight system modes and increase the integration of systems involving autopilot functionality.	18.0
7. <u>MANUFACTURERS:</u> Manufacturers should ensure aircraft type technical ground courses and operational training provide an adequate understanding of the processes of automation.	10.8
8. <u>OPERATORS</u>: Operators should ensure that aircraft type technical ground courses and operational training adequately cover a good understanding of the processes of automation.	10.8

9. <u>RISK MONITORING</u>: Reporting, tracking, evaluating of cyber attack/sabotage anomalies and take appropriate action in a global system.	13.1

Future - Medium

10. <u>REGULATORS:</u> Based upon previous research, adopt and implement standards for certification and operation defining safety targets and safety analysis at the total system level for present and future air/ground/space (AGS) systems and enable total system safety assessment accross organisational boundaries.	19.0
11. <u>REGULATORS</u>: Combine ATM safety regulations and Aircraft safety regulations in order to achieve a total system approach.	19.0

12. REGULATORS: Review and if necessary improve as appropriate todays certification process to ensure adequate resolution of existing interface of the total system.	14.3
13. CNS/ATM: Based on previous research and rule making, use required safety targets and safety analysis to develop and design components of the air/ground/space (AGS) system and enable total system safety assessment accross organisational boundaries.	23.8
14. CNS/ATM: Develop appropriate procedures for abnormal and emergency situations, in particular failure conditions involving multiple alerts from various sources (for example, one alert from ground system and one from airborne system)	15.2
15. ALL: Work with the rest of the aviation community to develop processes that will establish and maintain historical documentation containing the requirements, design details and assumptions that were made during initial design and any subsequent changes to the system (documentation should answer Know How, Know Why, Know Where). This process should include the establishment of reporting requirements and preservation of in-service feedback.	15.2

16. RESEARCH COMMUNITY: Work with the rest of the Aviation Community (including Regulators) to establish and evaluate safety targets and safety analysis at the present and future air/ground/space (AGS) system level, e.g., interaction both normal and abnormal conditions and security infringements, etc.	15.2
17. EDUCATION AND TRAINING: Training programs should emphasize pattern recognition and skill-based procedures to cope with time critical situations, rather than relying on knowledge based analysis. (CAST Intervention 487)	8.2

18. MANUFACTURERS: Based on previous research and rule making, use required safety targets and safety analysis to develop and design components of the air/ground/space (AGS) system and enable total system safety assessment accross organisational boundaries.	23.8

19. OPERATORS: Require training/standardization programs, which teach situation awareness. (The knowledge and understanding of the relevant elements of the pilot surroundings, including aircraft systems, and the pilots intentions) (CAST Intervention 147)	8.2

Future - Long

20. RESEARCH COMMUNITY: Develop sensor and data management technology that detects unique and unplanned-for problems that replicates human sensory capability	19.2
21. RESEARCH COMMUNITY: Develop data sensing, data merging, data filtering, data analysis and diagnostic techniques (Artificial Intelligence, expert systems – in particular neural nets)	19.2
22 RESEARCH COMMUNITY: Develop compensation technology that replaces pilot and cabin crew reasoning and problem-solving abilities especially for those unique situations that require novel and immediate responses by ground or automatic systems	15.3
23. MANUFACTURERS: Develop data sensing, data merging, data filtering, data analysis and diagnostic techniques (Artificial Intelligence, expert systems – in particular neural nets) for supporting software and equipment	19.2
24. MANUFACTURERS: Work with the rest of the aviation community to develop processes that will establish and maintain historical documentation containing the requirements, design details and assumptions that were made during initial design and any subsequent changes to the system (documentation should answer Know How, Know Why, Know Where). This process should include the establishment of reporting requirements and preservation of in-service feedback	12.3
25. REGULATORS: Develop new regulatory measures dealing with issues of absence of human agents aboard aircraft (as well as absence of human agents in Supervisory Command and Control (SCC) facilities)	15.3
26. CNS/ATM/SCC: Devise methods to keep SCC advised of current aircraft performance capabilities that would normally be evaluated and communicated by flight crew and devise methods to intervene and correct anomalies.	12.3
27 EDUCATION AND TRAINING: Use education and training requirements as a cornerstone of the design process and use training as a source of feedback to the design process.	11.4

“Actor” category	Items within that category
Regulators	7

Research Community	6
Manufacturers	5
CNS/ATM	3
Education and Training	2
Operators	2
Risk Monitoring	1
All	1
Total Recommendations	27

The Steering Group requested FAST to have a final go at the value of recommendations, i.e. link with the appropriate hazard and show validity.

This has been done in the following manner, two tables were made, the first one to link the hazards to the recommendations, see below.

Hazard	Theme	Recommendation
Live 4.1	I	14, 10, 13, 16, 18, 15
Live 6.11	II	6, 7, 8, 15
Live 6.2	II	6, 7, 8, 15
Soft 6.3	II	6, 7, 8, 15
Hard 7.4.1	III	1, 10, 13, 16, 18, 15
Live 15.5	III	2, 3, 4, 5, 9, 10, 13, 16, 18, 15
Live 6.1.4	II	6, 7, 8, 15
Soft 2.8	I	12, 11, 10, 13, 16, 18, 15
Live 15.4	I	10, 13, 16, 18, 15
Env 2.3	I	14, 10, 13, 16, 18, 15
Hard 4.4b	III	12, 10, 13, 16, 18, 15
Hard 7.1b	III	1, 10, 13, 16, 18, 15
Live 14.1	III	10, 13, 16, 18, 15
Env 2.1	I	10, 13, 16, 18, 11, 12, 15
Env 2.5	I	10, 13, 16, 18, 15
Live 5.3	IV	20, 21, 22, 23, 24, 25, 26, 27, 17, 19
Live 6.1.2	IV	20, 21, 22, 23, 24, 25, 26, 27, 17, 19
Live 15.2	Not Applicable	To ANS-1
Live 13.2	I	2, 3, 10, 13, 16, 18, 11, 12, 15,
Hard 2.2	IV	20, 21, 22, 23, 24, 25, 26, 27, 17, 19
Hard 2.1a	IV	20, 21, 22, 23, 24, 25, 26, 27, 17, 19

To be able to link the recommendations to the hazards, a new Appendix 17 has been created.

Validity of the recommendations has been shown by adding a justification section after each group of recommendations in the executive summary. The text for these justifications has been taken from the main body of the report in chapters 7.2 through 7.5. This was done to avoid creating new texts which was felt to be unnecessary in view of the extensive work to fine tune these texts during the preparation of the report.

Finally, a complete listing of all of the proposed recommendations is appended as Attachment 16. These recommendations, although not selected are useful and will be put, together with all hazards identified, in a Data-base.

7.8 Lessons learned from FAST phase 3 for future work

7.8.1 Introduction

FAST explored a new way in accident prevention with the ambitious challenge to identify preventative measures for incidents or accidents that haven't yet happened, neither shown any precursor.
The aviation world is full of preventative measures, already part of standard processes, partly state of the art, giving the impression that everything is already done.
Safety level is already impressive, supported by excellent reliability numbers of all components.

But changes will happen anyway. Some are predictable (e.g. new ATM rules and repartition of tasks between pilots and controllers – free flight, data link, massive use of data bases, satellite-based navigation, separation and obstacle avoidance, etc.), some other are more insidious such as cultural changes.

However, when such **changes** that define new **paradigms** are expected, then prospective studies like FAST are needed.

Another example of such a paradigm shift is the European initiative for "eSafety" that will affect road vehicle behaviour. Two of the most important causes of accidents appear to be lane changes and voluntary lane departure. One goal is to exchange information between vehicles – communication technology for intelligent vehicles – to reduce/prevent such accidents and incidents.

The above case clearly shows that the above change is more of a **revolution** than an **evolution,** and that will so much *"change the rules of the game"* that we can talk of a change of paradigm, which justifies a truly prospective approach.

The same goes for several changes that FAST has identified, however, events we are looking for with the view to improve further Safety have low occurrence probability that makes perception and prediction very difficult.

In addition, most of the changes FAST has identified are *"piloted changes".* This means that most of these changes are wanted, and set up in order to resolve current problems an/or improve parameters such capacity, costs, delays while reducing environmental impacts, etc.
From one system generation to another, it is normally required through *safety cases* to demonstrate that every new system version is, from a safety perspective, *at least as good* as the former one. But the analyses performed in these safety cases may not be wide enough.
Because it adopts a *system of systems* approach, FAST can help reveal risks, related in particular to interactions, that local safety cases can be unable to highlight.

This note intends to draw lessons learnt from FAST phase 3 with the view to better define a sound strategic road map for future work.

7.8.2: Rating and Ranking:

Preventative Safety initiative generates a significant amount of orientations (Hazards) based on **expert judgment**. Further investigations are needed to strengthen validity and to keep only the best for further processing.
FAST phase 3 has dedicated much energy and got skills in Rating, ranking techniques and applications. Acquired know-how how is fundamental for further development of any Safety process in particular for FAST.

With respect to expert judgment FAST has found that:

- Knowledge of the domain – FAST could have benefited from the contribution of more domain specialists, or from a better attendance
- Aggregation and ranking techniques
  - State-of- the art techniques like AHP were used
  - Furthermore, techniques were adapted to the resources and time available, e.g. use of the 10 vote system instead of AHP

All of these techniques are ready for use, and are **essential** to arrive at manageable sets of hazards and recommendations.

7.8.3 Interactions: a fundamental issue

Design and certification make aircraft resistant to multiple failures.
Accidents are more and more due to accumulation of and interactions between non-correlated events.
FAST was permitting to highlight importance of interactions, their role in accidents and the necessity to predict accident scenarios for a more efficient prevention.
Therefore, more resources, development of engineering methods and associated propagation analysis techniques look necessary to address:

- Origins of hazards,
- Propagation paths, aggravating factors [e.g. Sneak Path analysis].
- Probability and severity of resulting events.

In addition to that, the recommendation exercise showed that **establishing a precise interaction scenario will allow to:**

- Tag precise facts and avoid wide scope general statements
- Measure Efficiency of recommendation. (Difficult when concerning accident that will never happen if prevention works).
- Therefore make better recommendations.

FAST Interactions need a Total System approach based on Systems Management and corresponding Systems Engineering background from experts involved. The same comment applies to Industrial Organization expertise.

Future work must address the **link between past, present and future to be mediated via the notion of** paradigm**.**

- As far as we are facing **evolutions**, we can fairly well predict the future on the basis of past and present data. Precursor analysis will find an outstanding place here.
- But when we address **revolutions**, truly prospective studies are needed.

7.8.4 Dealing with low probability events.

Achieving more ambitious Safety Levels requires to control and to reduce further low probability events.
Accumulation of non-correlated events, their propagation paths are low probability events, whose perception, criticality assessment is difficult and prediction very challenging. A magnified perception is accessible to few people in organizations who are gathering information from wide fleets. Information covering millions of flights provides examples that give visibility on low probability events and creates a specific state of mind necessary for going further in Safety prevention. FAST needs this specific experts background.

Experts from QA + Field Services and Incident Investigation will be needed to ***monitor the effects*** of revolutions (i.e. major changes in the paradigm, e.g. RVSM, free flight, one crew cargo, UAV), when and after such changes have been introduced.

7.8.5 New approach to Areas of Change:

The tendency noticed in Rating and Ranking exercise, was to eliminate a recommendation simply because some existing practices were dealing with the matter (opening an already open door). It forced us to raise the following questions:

- Are current practices systematic? (What is their confidence level)
- If done within a specific Aviation System (e.g. Aircraft), are they also applied and efficient to analysis interfaces and interactions with other systems (e.g. ATC)?
- Are current Safety practices robust to changes (AOC)?
    - Are they / will they still be efficient for new technologies?
    - Sensitivity analysis / fragility to changes of any nature including time erosion (accumulation of different factors). Should be analyzed.

A new approach to Area of Changes called Analysis of Changes and Extensiveness of existing practices is born. It reveals to be fundamental for the future because it will be permitting to detect insidious degradation modes.

FAST has to further develop this analysis in which distinction has to be made between:

- Evolutionary changes (possibly insidious)
- Revolutionary or abrupt changes (more detectable but less predictable).

FAST should take care of both.

Sensitivity of some fundamental procedures to insidious drifts requires setting up or reinforcing specific monitoring. (Evaluation criteria, audits, alert).

7.8.6 Legal issues

Legal issues that disturb the historical process may not disappear at all for a variety of reasons. One reason being that in many cases, lawyers have for years driven engineers to write down less and less. With accidents becoming more and more due to accumulation of and interactions between non-correlated events, there is no drive for improvement. And new paradigms will make it even more complicated.

FAST would like the lawyers to build a new legal interpretation system that reflects the new paradigm. E.g. who is responsible for an accident (= system breakdown) in a global and distributed AGS system? The pilot? The controller? The data base manufacturer?

FAST believes the reference to the past will remain, but has to be *revised* according to the changes in the system, and their repercussions in the process of attributing responsibility and apportioning civil and penal sanctions.

7.8.7 Link between Safety Initiatives

Many Working Papers, during FAST phase 3, were highlighting the merits of deep treatment to identify all possible roots of Hazards, together highlighting the necessary complementarity's between the 3 categories of Safety of Initiatives: Historical, Deep treatment (also called diagnostic) and pro-active approaches.

In this way, FAST has built on system approach in recent accident investigation, which includes considering the influence of organizational, management, regulations, cultural factors, and the like. E.g. The Dryden Accident (1989) Report by the Honorable judge Virgil Moshanski and the CAST activities.

The intention is to create synergy and to avoid duplication of effort. This is particularly true for creating interventions.
Fig 5.2 in chapter 8.7 provides principles of an integrated Safety Plan.

Let's take ATC / Aircraft interfaces for example:

- FAST having identified increased importance of ATC / Aircraft interfaces deep treatment of the accident underscore the need to investigate Institutional and Organization aspects at the interface between Aircraft and ATC systems.
- Robustness to time erosion and to changes of existing practices should be part of the investigation.
- FAST recommendations should tag area that presents possible weaknesses in interactions analysis possibly permitting errors to propagate through interfaces.
- Based on deep diagnostic example, FAST can establish a scenario based propagation of events should trigger investigations that will give birth to Interventions
  - → Deep diagnostic creates new state of mind of FAST experts with organization and institutional oriented analysis.
  - → FAST recommendations are then capable to orient investigation addressing other bodies, (e.g. JSAT) permitting afterwards to issue interventions.

7.8.8 Preventative (or pro-active) measures address more management issues

As shown in the previous paragraph, preventative approach like FAST are more related to management / organization than the others that usually issue recommendations applicable at execution level. Some of the reasons could be:
Organization is due to create or adapt working practices capable to detect and control new Hazards. DOD, NASA, and ESA, whose Management standards are vital to introduce Quality and Safety in new projects, give example. Columbia Accident Investigation Board highlighted the importance and fragility of the organization matters.
Very mature and stable Aviation Organizations probably underestimated this fragility and, for various reasons do not like showing organization issues in accident analysis.

However, the Columbia accident reports shows that a management / organization approach can *also* be applied in retrospective analysis. The same applies to the Dryden accident (already mentioned) and several other ones.

> We believe that the FAST preventive approach quite naturally addresses Organizational and especially International issues first, in the belief that that is where accident prevention will work best.

In view of this, FAST should investigate Organizational differences, safety cultures of various different international organizations to see whether there are Lessons learned for Aviation.

Considerations on Recommendations

Recommendations that were produced required a lot of work, but have been refined in several steps, including the October 2003 Hoofddorp meeting and several teleconferences. Inputs from several team members have greatly helped to demonstrate feasibility of the FAST recommendations.
They came late in FAST phase 3 but are found to be fundamental. It also demonstrates FAST validity with a "Strict End to End analysis logic". Another key requirement is that FAST outputs have to be clearly understood by other panels.
Future work shall therefore explore the whole process in close look with destination bodies in order to define the nature of FAST outputs. Refer to paragraph 7: Link between Safety Initiatives and creation of a complete Safety Plan.
FAST future work should refine Hazards identification, propagation mechanism and optimize FAST to the benefit of better recommendation techniques.

Convincing decision makers

Presentation to decision makers of recommendations concerning incidents and accidents that already happened is quite difficult. Convincing them to accept preventative measures for events that never happened yet, require specific approach. FAST future has to develop convincing scenarios and acquire specific presentation convincing skills.

In this case, The JSSI steering group is invited to judge, an possibly help FAST on its recommendations.

7.8.11 FAST goals.

The prognostic part of the job FAST was tasked was a *truly* difficult part. And FAST has experienced difficulties in part because of this intrinsic difficulty, and in part because it was trying to define a methodology while at the same time testing / applying it to produce results.

The composition of the FAST group might also have been more balanced, and we sometimes suffered the absence of domain specialists.

Nevertheless, FAST has prototyped a methodology. FAST validity is linked to its capability to issue valid recommendations in a sense that it brings added value to existing processes.

Future Work has to establish the application scheme: Where, How, Who, When to apply FAST logic.

> In particular, do we start ANS-1 and pattern it much like AC-13, or do we see enough of ANS-1 in the AC-13 recommendations. If this is true, then we may have to structure ANS-1 into a scenario type exercise. The JSSI steering group is invited to provide direction.

7.8.12 Future work - summary

- **Rating & ranking –** Improve and advertise FAST ranking techniques
- **Interactions –** advertise and promote the FAST technique
- **Dealing with low probability events -** monitor the effects of revolutions (i.e. major changes in the paradigm, e.g. RVSM, free flight, one crew cargo, UAV), when and after such changes have been introduced.
- **New approach to Area of Changes** – distinguish between a] Evolutionary changes (possibly insidious) and b] Revolutionary or abrupt changes.
- **Legal issues –** revise system to take paradigm shift of responsibilities into account
- **Link between Safety Initiatives –** promote “deep treatment”
- **Preventative (or pro-active) measures address more management issues-** investigate Organizational differences, safety cultures of various different international organizations to see whether there are Lessons learned for Aviation.
- **Recommendations -** refine Hazards identification, propagation mechanism and optimize FAST to the benefit of better recommendation techniques.
- **Convincing decision makers –** JSSI steering group to help and provide direction on proposed recommendations

- **FAST goals -** do we start ANS-1 and pattern it much like AC-13, or do we see enough of ANS-1 in the AC-13 recommendations. If this is true, then we may have to structure ANS-1 into a scenario type exercise. The JSSI steering group is invited to provide direction.

7.8.13 Conclusion on lessons-learned:

Difficulties that show up within the FAST group, in particular those dealing with recommendations revealed that a Proactive Safety initiative is not a simple exercise.

Analysis of problems is permitting to better identify FAST major “Competitive Advantage” through its complementarities to and interfaces with other Safety initiatives.
Lessons learnt described above are permitting to establish a road map for future work.

Note: Lessons-learned have also been identified in paragraph 3.4.

8 Future work

8.1 FAST works!

Over the last 3 years, FAST has demonstrated that a practical generic methodology using areas of change as a start can be developed and successfully be used. The AC13 results provide the example for this.

FAST has also provided some spin-off, notably the use of AHP in the Netherlands by CAA-NL and the NLR, see chapter 2.1.3.

In addition, the FAST work has given increased emphasis to incident trend analysis, including Accident/Incident Precursors to validate the work, see paragraph 6.5.

However, FAST also feels that improvements are possible, see 6.2.

In addition, it will take at least a year of frequent communication with the aerospace community to:

- Get the FAST concept known
- Get results from follow on work, e.g. ANS-1
- Get the FAST process accepted
- Get the FAST methodology used.

8.2 Road map for future FAST AoC analysis

Based on lessons learned on AC-13 and on a review of possible options, FAST “systemic” methodology should be used to:

- List and prioritise (1 session) changes affecting the Aviation System (Horizon: 5 to 20 years) by one team; list to be re-audited on a regular basis. (2 to 3 years)
- Develop scenarios and technology road maps; identify, prioritise hazards and develop prioritised interventions on selected changes by dedicated sub-teams normally in three 5 days meetings of organised brain-storming.
- a general monitoring process must be run:
- For all identified hazards, continuous analysis of occurrences against developed hazard scenarios, Goal: provide early emphasis on hazards to validate and update the ongoing actions. Review and update of the future work proposals initially made.

8.3 Initiate Ad Hoc team on New Concepts for Airspace Management (ANS1)

Given the improvements as given under 6.2, it is recommended to initiate ANS-1. A preliminary list of team members has been established [see appendix 13], the chairman should come from EUROCONTROL.

8.4 Institutionalization of FAST leading to define Resources.

From the experience of the investigation of AC 13, it appears that the investigation of the rest of the 157 Areas of change identified by the FAST Team will need a considerable amount of work: at least three 3 day meeting for 10 people, which is about the range of 15 000 man day. Even assuming that the people and the funding were available, it has to be noted that the process would be so long that the investigation of the last areas of change would take place much after the change has occurred, which would ruin the FAST concept.

To address this problem, the following proposals can be made:

- The FAST should become a continuous process, lead by a permanent organisation.
- The FAST process should be considered as a research work, and as a consequence, the necessary budget should be a research budget.
- The continuous FAST process should be iterative: the priorities should be reconsidered regularly, in particular, the priorities of the areas of change to be investigated.
- At any time, only the top priority areas of change should be investigated (that does not mean however that a low priority area of change will never be investigated, as priorities are redefined on a continuous basis)

The FAST leading organisation could be of various kinds:

- research center,
- EASA (in particular the research department of EASA)
- A private organisation
- The leading team of a European network (eg network of excellence in the frame of the Research Framework Programme of the European Union): in that case the FAST Team members (including the experts for each area of change) would be the members of the network.

Whatever the structure of the FAST is, it will need funding: it should be taken into account that the identification and the monitoring of future hazards is listed as a necessary task by the ACARE committee: as a consequence, this task should benefit of appropriate funding, in particular in the frame of the present and future research framework programmes of the European Union.

The foreseeable budget can be established as follows:

Hypotheses:

- 4 AOC are investigated per year,
- each of them needing three 3 day meeting of 10 people
- in addition, reprioritisation of the AOC is processed on a 4 year basis (work equivalent to one AOC investigation)

Budget:

AOC investigation: 12 yearly 3 day meetings for 10 people (360 man day):
270 000 Euros
Travel cost for those meetings:
150 000 Euros
Permanent team: (2 man)
200 000 Euros
4 yearly reprioritisation (average pro year):
70 000 Euros

The annual budget could then be around 700 000 Euros per year (not including the task of future hazard monitoring)

8.5 Emphasis on incident trend analysis to validate results & identify accident precursors:

The Future Aviation Safety Team is attempting to identify what can go wrong in the aviation system and to recommend proactive measures that can be taken before accidents happen. Therefore, the importance of the precursors of incidents and accidents that can be used as early warnings of future safety is paramount within the FAST effort.

As a consequence of interactions with the JSSI Design Related Working Group, the FAST has determined that most organisations are using already processes dealing to some extent with so-called precursors. Some practices are well formalised and efficient within a limited system or domain (e.g. aircraft engines) but are not well suited for analysis of interactions between and among agents within the aviation system (e.g. ATC/aircraft interactions).

Many accidents are already due to accumulation of contributing events, often without common roots. Improved safety requires elaborating more complex accident scenario made of addition of contributing factors. FAST “Interaction” analysis intends to deal with the accumulation of non correlated events that make accident possible.

The key issue is the confidence level of these processes. Failures in triggering pro-active prevention based on precursors are mostly linked to:

- Difficulty in detecting events
- Criticality classification and corresponding allocation of priorities for investigation
- Analysis of consequences, trend analysis, interactions in particular accumulation of non-correlated but aggravating factors. Inefficient, slow or biased decision making often linked to analysis outputs and to presentation of results.
- Detection of anomalies is not the primary issue; procedural weaknesses are mostly related to communication, analysis and decision.

Therefore precursors’ detection should improve in relation with more and more ambitious Safety objectives and be capable to detect and process incidents wherever they are, that if combined with other events may end up into accidents.

This goes through an improvement in Safety Analysis that through accidents scenario are capable to predict where and when precursors could show up, in which form, who could detect. Organization, procedures and training are then necessary to make actors capable of playing their role.

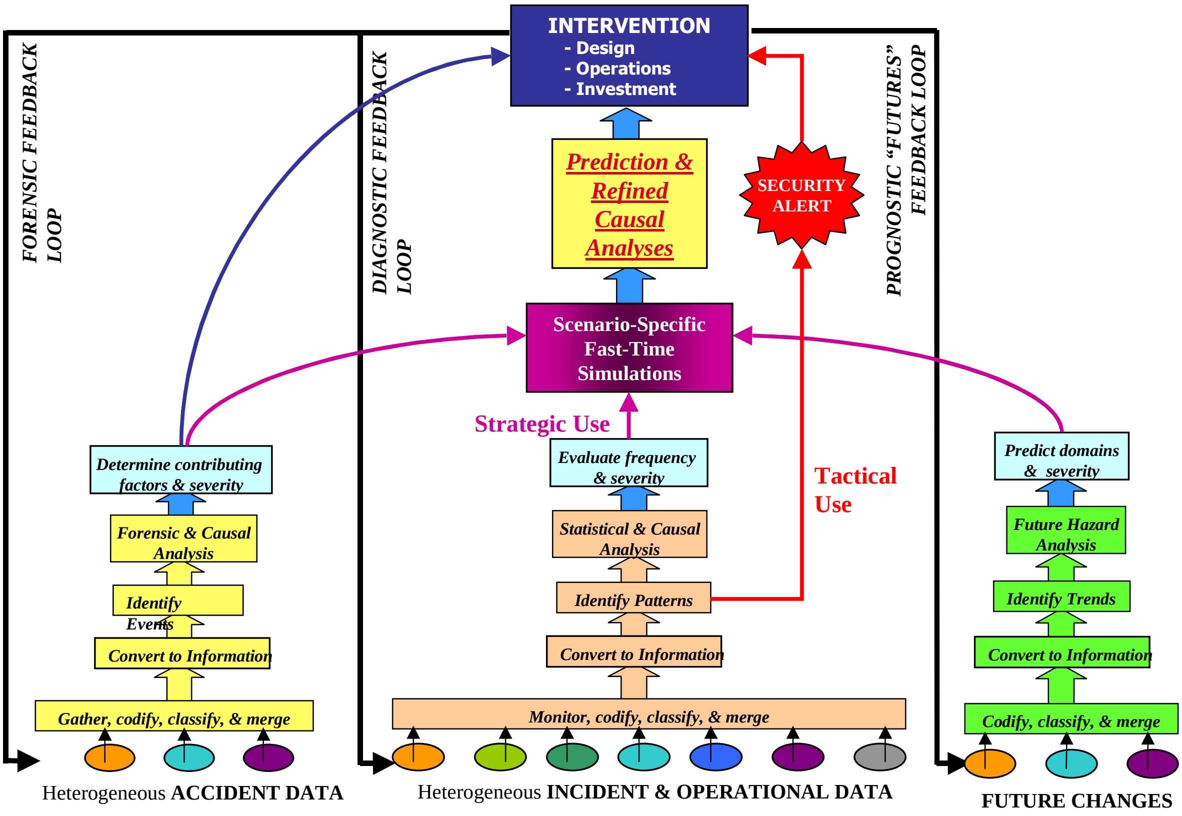
The diagram below summarizes the process. Considering FAST limited resources and potential interest of the precursors to many initiatives, it was decided to shift the leadership of this activity to another JSSI body, the ODAS group with the duty to take due consideration of FAST concerns in close relationship between both groups.

Details of the work done can be found in appendix B

8.6 Integration of FAST with other world-wide safety efforts & need for consideration of collateral effects of one domain on another

One member of FAST has presented an overall scheme of analysis, see below.

The title is: **Pro-Active Management of Aviation Risk - Past, Present, and Future**



One could argue that the left-hand side of this scheme is primarily the domain of CAST [Commercial Aviation Safety Team], whereas the right-hand side – Future changes – is that of FAST.

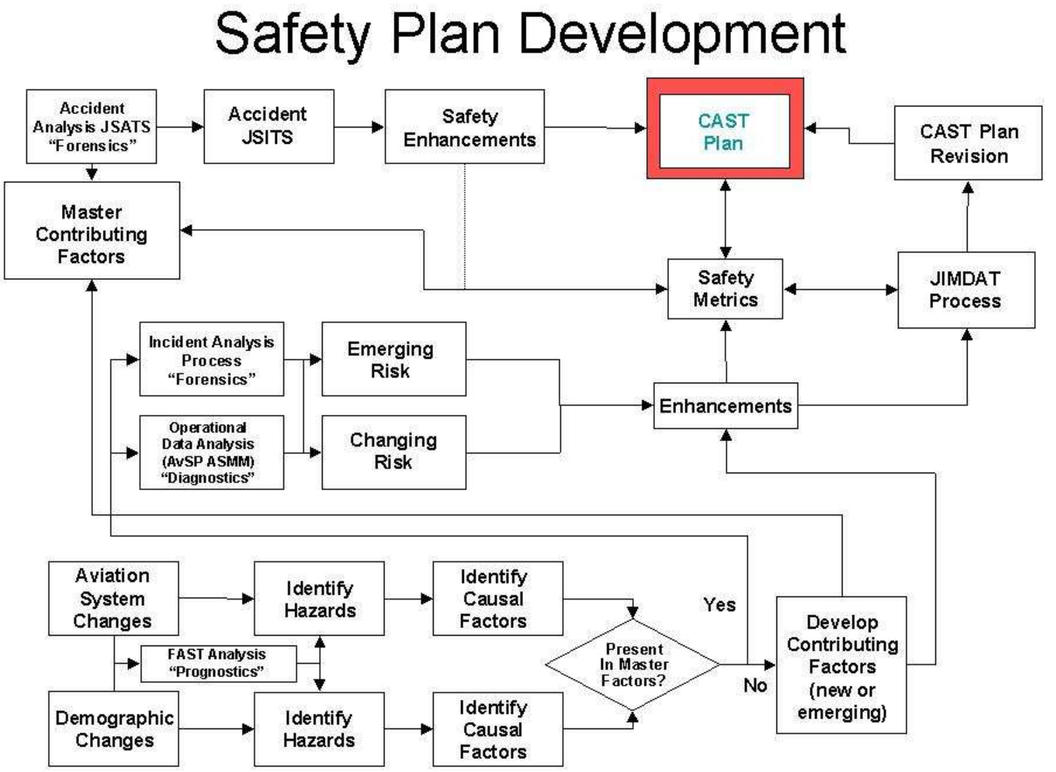
The middle route, that is Heterogeneous INCIDENT & OPERATIONAL DATA should bridge the gap between CAST & FAST. Important domain players are:

1. Airline reporting and analysis of incidents. The JSSI-ODAS team is currently looking at this, including accident pre-cursors.
2. FAA, JAA and EASA and other authorities
3. JSSI as it provides a forum for discussion to stimulate and provide focus for SECURITY (safety?) ALERTS. Recent discussions on Total loss of radio communication over Europe, Altitude Level busts, Potential Loss of control through asphalt damage on tail surfaces are good examples.
4. CAST's JIMDAT is a similar breeding place for new ideas, security alerts and is also looking to co-ordinate safety matters across the industry.
5. Regional Safety Team Leaders like in
6. ATC providers, like EUROCONTROL
7. International bodies like IATA, ICAO

FAST considers it vital that better co-ordination is provided to integrate the 3 streams and that SECURITY ALERTS, e.g. like fuel leak procedures for all aircraft are mandated earlier than the step by step introduction as happened over the last 5 years.

8.7 Integration with the Commercial Aviation Safety Team [CAST]

Earlier in the report it has been indicated that FAST & CAST are complementory, especially where the “historic- & predictive” processes meet, see chapter 2. In chapter 8.6 this can also be observed.



B. Smith; 7/15/03

As a result, CAST has looked how the two process flows can be integrated. CAST has already decided to start investigating Aviation- and Demographic changes and add to their work scope.

FAST has also looked into this and has proposed some additions. The resulting integrated process flow is given in above figure:

FAST therefore proposes the following:

- Improve the quality of the Draft [AC13] recommendations and prioritize them
- Get broader concurrence within the JAA system, incl. sectorial teams
- Put the prioritized recommendations forward to CAST
- Cooperate for joint EU & US enhancements.

The above should be considered as an excellent opportunity to arrive at single standard interventions across the Atlantic Ocean.

8.8 Improvement to FAST methodology

As`explained in paragraph 3.4 and paragraph 7.8, the paragraphs describe lessons learned from this phase 3. Paragraph 7.8 in particular contains recommendations for future work relative to methodology and it is proposed that this work be carried further.