Evolution of Safety Critical Technologies in Air Traffic Management

The 8th International Conference on Integrated Operations in the Petroleum Industry
Prof. Dr.-Ing. Peter Hecker
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- Air Transport: The European Policy
- Aviation Safety: Status Quo
- Objectives in Aviation Safety
- Aging Systems: Instrument Landing Systems
- New Perspective: GNSS Based Landing Systems
- Challenges in
  - Standardisation
  - Certification
  - Compatibility with European ATM Masterplan
- Conclusion

Disclaimer:
All functional principles explained in this presentation are simplified. Numbers given are to be considered as being rather indicative than absolute.
Air Transport: The European Policy

• Today’s Air Transport System is one of the safest, most efficient and environmentally friendly ways of moving people and high value cargo over large distances with high speeds.

• The European Commission states that

“Aeronautics and air transport is
– a vital sector of our society and economy
– of sovereign importance for the European Union and its Member States.
– a sector in which European public and private stakeholders provide world leadership and helps to meet society’s needs.”

Source: Flightpath 2050, EC, see http://ec.europa.eu/research/transport/publications
Air Transport: The European Policy

This is achieved through

– ensuring suitable and sustainable mobility of passengers and freight,
– generating wealth and economic growth,
– significantly contributing to the balance of trade and European competitiveness,
– providing highly skilled jobs and innovation
– fostering Europe’s knowledge economy through substantial R&D investment, and
– contributing in many ways to global safety, security and self-reliance.

Source: Flightpath 2050, EC, see http://ec.europa.eu/research/transport/publications
Air Transport: The European Policy

Facing Challenges:

• **Industrial competition** from established, traditional rivals such as the US and even more so from new and strong challengers, notably Brazil, Canada, China, India and Russia.

• **Technological leadership**, the root of Europe’s current success, will continue to be the major competitive differentiator.

• **Break-through technology** will be required to secure future competitive advantage, most notably in terms of **energy**, **management of complexity** and **environmental performance**.

Source: Flightpath 2050, EC, see http://ec.europa.eu/research/transport/publications
Air Transport: The European Policy

The way forward: Flightpath 2050

Europe’s Vision for Aviation developed by
The High Level Group on Aviation Research

Goals:
• Meeting Societal and Market Needs
• Maintaining and Extending Industrial Leadership
• Protecting the Environment and the Energy Supply
• Ensuring Safety and Security
• Prioritising Research, Testing Capabilities and Education

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Flightpath 2050: Ensuring Safety

- The European air transport system has less than one accident per ten million commercial aircraft flights.
- Occurrence and impact of human error is significantly reduced through new designs, training processes, technologies that support decisionmaking.
- *Just culture*) adopted uniformly across Europe as an essential element of the safety process.
- Weather and other hazards are precisely evaluated and mitigated
- Seamless operations through fully interoperable and networked systems (incl. manned and unmanned vehicles)

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*) Just Culture means a culture in which front line operators or others are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training, but where gross negligence, wilful violations and destructive acts are not tolerated.
Air Transport: Accident Rates and Onboard Fatalities

Air Transport: Stable, Long Term Growth

Source: Challenges of Growth 2008, Summary Report, Eurocontrol
Air Transport: Fatalities by Occurrence Categories


- Loss of Control – In flight
- Controlled Flight Into or Toward Terrain
- Runway Excursion, Abnormal Runway Contact, Undershoot / Overshoot

Today’s Air Transport System is one of the safest, most efficient and environmentally friendly ways of moving people and valuable cargo over large distances with high speeds.
Air Transport: Fatal Accidents per Flight Phase

**Focus: Approach and Landing**

**Challenging Phase: Approach and Landing**

**Task:** Guide the aircraft with a certain configuration along a predefined trajectory down to the runway while maintaining a stable state vector.

**Configuration:**
Aerodynamical, mechanical and engine settings allowing lower airspeed and adequate maneuverability.

**Predefined trajectory:**
up to now typically a straight line with a glide slope of 3 degrees, aligned to the centerline of the airport.

**State vector:**
attitude, airspeed, especially vertical speed.
Focus: Approach and Landing

Source: youtube.com, ILS Cat III A 18R AMS vers 4.wmv
Flight Guidance for Approach and Landing: The Instrument Landing System (ILS)

**ILS: The Functional Principle**

- Electromagnetic guidance for approach and landing
- Two transmitter stations at the airport generate beams for vertical and horizontal guidance
Flight Guidance for Approach and Landing: The Instrument Landing System (ILS)

ILS: The Functional Principle

- Electromagnetic guidance for approach and landing
- Two transmitter stations at the airport generate beams for vertical and horizontal guidance
- An on-board system receives those signals and computes angular deviations from the radial
- Commands are generated and displayed to the pilot guiding him onto the desired approach path.
- Supports landings with zero visibility under all weather conditions
Flight Guidance for Approach and Landing: The Instrument Landing System (ILS)

ILS: History and Status

• Developed late 1920s in US
• First successful operational landing 1938 (Boeing 247 landing in Pittsburgh, US in snow storm)
• Worldwide all major airports are equipped with ILS
• Example Germany: 40 airports with 80 installations
• Up to now no single accident due to malfunction of the technology
• May be considered as one of the safest flight guidance systems in aviation

Source: Popular Mechanics, June 1933
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Advantages:
- High Operational benefit (all weather operation)
- High level of safety
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Source: DFS
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- Frequent flight calibration

Source: Flight Calibration Services, FCS
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Continuous research for replacement of aging landing systems
GNSS based landing systems

Can GNSS be a solution?

- Today's global navigation satellite systems (GNSS, like GPS, GLONASS, GALILEO etc) offer worldwide positioning services.

Advantages:

- High precision (stat. ~1mm, dyn. ~10cm)
- No user ground installation required
- Cheap technology
- Enables area navigation
- Independent from weather conditions
- (almost) Worldwide coverage
GNSS based landing systems

Disadvantages:

• Dependencies from the owner and operator of the GNSS system
• Reliable*) positioning service can not be guaranteed
• Influences through e.g.
  – Obstruction
  – Multi-path effects
  – Atmospheric effects (ionospheric & tropospheric signal delays)
  – Jamming
  – Spoofing

*) See Performance Characteristics

Source: Tim Edmunds, Airliners.net
GNSS Performance Characteristics

Accuracy:
- GNSS position accuracy is the difference between the estimated and actual aircraft position.

Integrity:
- Integrity is a measure of the trust which can be placed in the correctness of the information supplied by the total system.

Continuity:
- Continuity is the capability of the system to perform its function without unscheduled interruptions during the intended operation.

Availability
- The availability of a service is the portion of time during which the system is simultaneously delivering the required accuracy, integrity and continuity.

Ground Based Augmentation Systems (GBAS)

Technical solution to overcome deficiencies:

Ground Based Augmentation Systems (GBAS)

• A geo-referenced GNSS receiver with multiple antennae is installed in the vicinity of the airport.
• By analysing the received GNSS signals and considering the precisely known position of the ground station error correction terms and status information can be generated.
• This information is sent to the aircraft via a VHF data link allowing a validation and improvement of the on board positioning.
• Additional information on the approach trajectory (with any flyable geometry) is generated and linked to the aircraft.
Ground Based Augmentation Systems (GBAS)

Source: A. Lipp, Eurocontrol
Ground Based Augmentation Systems (GBAS)

Significant Advantages:

- Flexible approach geometry (noise abatement, increase in airport capacity),
- Less expensive infrastructure,
- Several runways in a given perimeter (some 10-20 nm) can share the infrastructure,
- No flight calibration when in service.

Source: A. Lipp, Eurocontrol
GBAS: Challenges in Implementation

In technical terms GBAS is a highly promising and advantageous candidate for replacing aging ILS installations.

What are the non technical challenges of introducing new technologies in the air transport system?

- Need for standardisation allowing worldwide interoperability
  - In technical terms
  - In operational terms
- Need for certification ensuring the accepted level of safety
- Compatibility with European policy (competitiveness, growth, environmental compatibility etc.)
- Compatibility with complex “system of systems” architecture of the air transport system – and its evolution
GBAS: Standardisation

Why Standardisation?

- Landing Systems consist of airborne equipment and infrastructure which need to be fully compatible
- Aircraft operate worldwide, therefore worldwide interoperability must be ensured
- Standards in Aviation are set by a specialized agency of the United Nations, the International Civil Aviation Organization (ICAO)
- Created in 1944 to promote the safe and orderly development of international civil aviation throughout the world.
- Sets standards and regulations necessary for aviation safety, security, efficiency and regularity, as well as for aviation environmental protection.

Source: ICAO
GBAS: Standardisation

ICAO’s Constitution
- Convention on International Civil Aviation,
- drawn up by a conference in Chicago in Nov. & Dec. 1944,
- Each ICAO Contracting State is party.

Making Standards: 18 Annexes to the Convention
- **Annex 1** Personnel Licensing
- **Annex 2** Rules of the Air
- **Annex 3** Meteorological Service for International Air Navigation
- ...
- **Annex 10** Aeronautical Telecommunications
- ...
- **Annex 18** The Safe Transport of Dangerous Goods by Air
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GBAS: Certification and Safety

- Certification requires a certificate of airworthiness from a national aviation authority.
- Airworthiness is the measure of an aircraft's suitability for safe flight.
- JSP553 Military Airworthiness Regulations (2006) Edition 1 Change 5 as:

  The ability of an aircraft or other airborne equipment or system to operate without significant hazard to aircrew, ground crew, passengers (where relevant) or to the general public over which such airborne systems are flown.

- Significant Hazard / Safe flight:
  to not exceed a generally accepted level of risk expressed as probability of failure for one hour of operation.
GBAS: Certification and Safety

- Generally accepted level of risk:
  - Derived from the minimum mortality rate of healthy human beings
  - Defined as 10 E-7 per hour of operation.
- As historically an aircraft was estimated to consist of approx. 100 systems the probability of failure per system and hour of operation was defined to be less than 10 E-9.
- Conventional methods used for safety assessment are
  - Failure Mode and Effects Analysis (FMEA) and
  - Fault tree analysis (FTA).
GBAS: Certification and Safety

Safety Assessment of “conventional” Landing Systems

• Ground-based systems such as VHF omni-directional radio range (VOR) and instrument landing system (ILS) have relatively repeatable error characteristics.
• Performance can be measured for a short period of time (e.g. during flight inspection).
• Assumption: The system accuracy does not change after the measurement.

Challenge for GNSS based landing systems:

• GNSS errors can change over a period of hours due to satellite geometry changes, the effects of the ionosphere and augmentation system design.
GBAS: Certification and Safety

Solution (simplified):

- Introducing Monitoring Functions
- Computing “Protection Levels”
- Defining Alert Limits and Time to Alert according to the phase of flight
GBAS: Certification and Safety

Solution (simplified):
- Performance requirements then can be defined as

<table>
<thead>
<tr>
<th>Performance Requirements</th>
<th>GBAS Service Level</th>
<th>Accuracy</th>
<th>Integrity</th>
<th>Continuity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lateral NSE 95%</td>
<td>Vertical NSE 95%</td>
<td></td>
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<tr>
<td>CAT I</td>
<td>C</td>
<td>16.0 m (52 ft)</td>
<td>4.0 m (13 ft)</td>
<td>1-2 x 10^-7</td>
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<td>Time to Alert</td>
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<td>Lateral Alert Limit</td>
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<td>40 m (130 ft)</td>
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<td>Vertical Alert Limit</td>
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<td>10 m (33 ft)</td>
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<td></td>
<td>Continuity Probability</td>
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<td></td>
<td></td>
<td>1-8 x 10^-6</td>
</tr>
<tr>
<td>CAT II/III</td>
<td>F</td>
<td>5.0 m (16 ft)</td>
<td>2.9 m (10 ft)</td>
<td>1-1 x 10^-9</td>
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<tr>
<td>TBD — requirements not finalised yet</td>
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<td>Time to Alert</td>
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<td>Lateral Alert Limit</td>
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<td>17 m (56 ft)</td>
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</tbody>
</table>

Source: Aircraft Precision Approach, ENC, By Eduarda Blomenhofer, Dr. Xiaogang Gu, NavPos Systems GmbH and Dr. Winfried Dunkel, DFS Deutsche Flugsicherung GmbH, Germany
GBAS: Compatibility with European ATM Masterplan

- The Air Transport System is a highly complex system involving numbers of different stakeholders, complex infrastructures and critical interfaces to other modes of transportation.
- How to ensure the technical and operational compatibility of GBAS with European strategies of evolving Air Traffic?
- How to avoid an isolated development purely driven by technology?
The Solution =

2.1 bio€
15 members
13 associate partners = 110 companies in total *)
Present in 27 countries *)
2,000 people working on SESAR *)
300 projects

*): status as in 2011

Source: SESAR Joint Undertaking
## SESAR IS ORGANISED IN THREE PHASES

<table>
<thead>
<tr>
<th>Definition phase</th>
<th>Development phase</th>
<th>Deployment phase</th>
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</table>

**Managed by the SESAR Joint Undertaking**

- **EUROPEAN COMMISSION**
- **EUROCONTROL**
- **THE INDUSTRY**
  - public-private partnership

### Budget: € 2.1 billion

**Public-Private Partnership: a première**
- Innovation from private sector
- Public financial stability & enforcement power

*Source: SESAR Joint Undertaking*
SJU INVOLVES ALL ACTORS

A Multi-Stakeholders approach at the heart of our way of working
Conclusion

• Aviation is a major contributor to the growth and development of societies
• Socio-economic challenges require the continuous evolution of architectures, technologies, and operations
• Consequently, infrastructure needs to be replaced continuously
• Challenges
  – Highest Standards in aviation Safety must be maintained.
  – Worldwide interoperability requires substantial efforts in deploying new systems
  – Compatibility with European and Worldwide policies in developing the air transport system has to be ensured