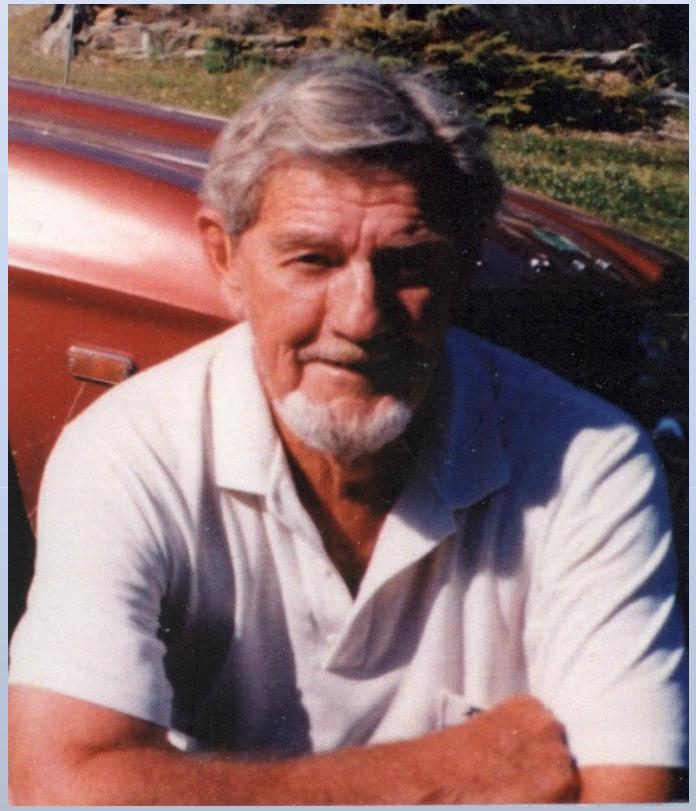
Human Factors and Systems Safety:

Past, Present, and Future

Rob Lee, PhD

PACDEFF

Dedicated to the memory of



Paul Edmond Choquenot

5 August 1928 to 2 July 2012

First Director of the Bureau of Air Safety Investigation, 1982 -1988

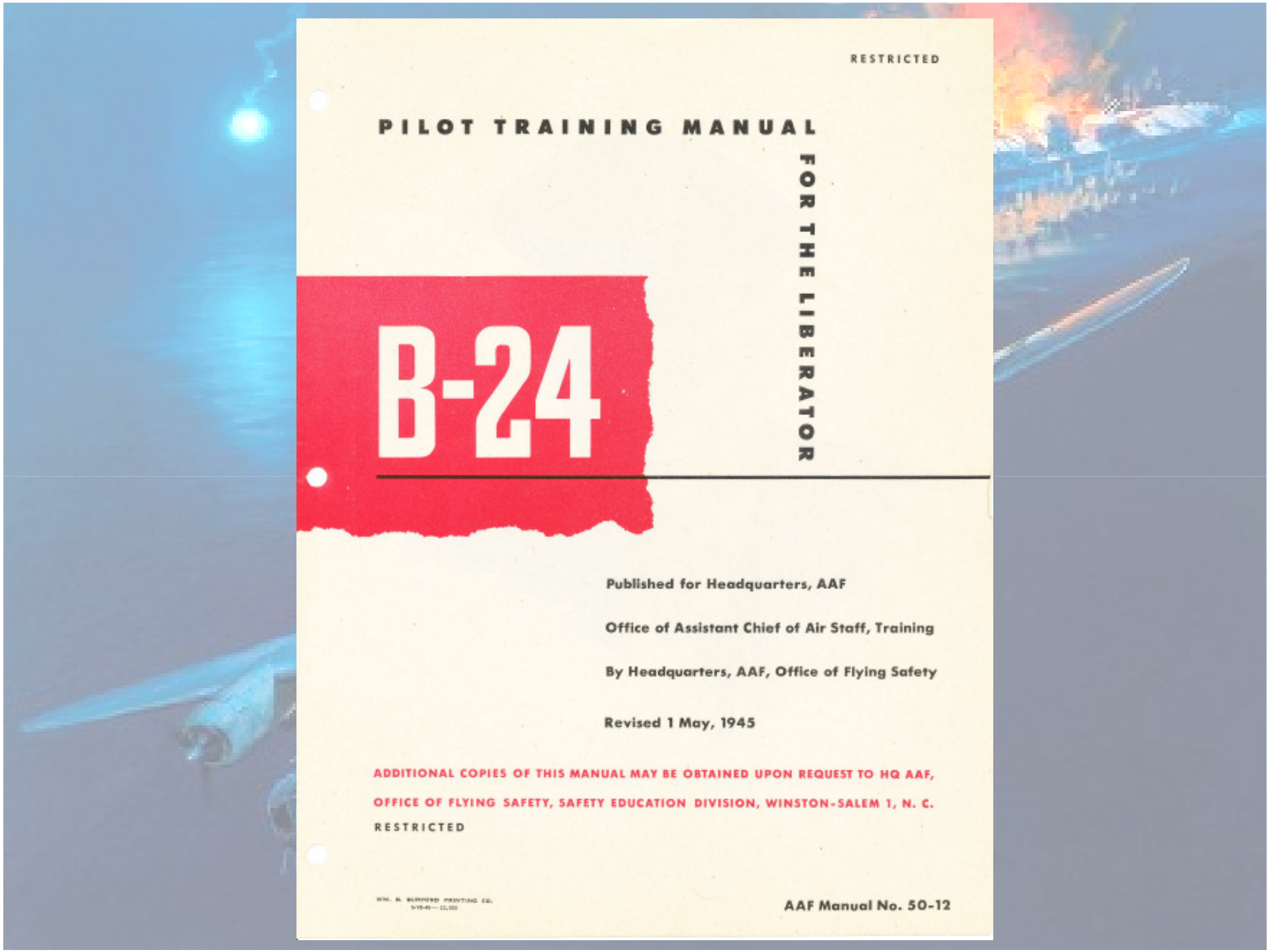
- A characteristic of many specialist fields, both inside and outside academia, but particularly in Psychology, and Human Factors, is that, over time, many ideas and concepts are re-packaged, reworded with new jargon, and presented as something genuinely new, which they demonstrably are not.
- USAAF Aviation Psychology Program; Applied Psychology Unit, Cambridge University
- Is CRM an example of this phenomenon?
- Can we learn from what has gone before, to improve what we do now?

A perspective: CRM in World War Two

B-24 Liberator, USAAF

A typical example of successful wartime crew teamwork

"The housing around the propeller and 3 cylinders of our No. 4 engine were shot out. Two feet of prop on No. 1 engine was smashed, tearing a foot-and-a-half hole in the left aileron. The engine was vibrating like a bucking bronco. And we had a wing cell leak in No. 3. We were both flying that airplane with every ounce of skill we possessed. We put on 10° of flaps to get the best lift without too much drag, and kept our wings straight by using rudder. We muddled through the fighter attack and staggered away from the target on 2½ engines. To gain altitude to cross a mountain range, we threw out everything that was movable, including oxygen bottles, gas masks, ammunition, radio equipment, and everything a screwdriver could get loose. Somehow she brought us back. We had to crash-land the plane but nobody was hurt. The first thing I did after we got away from the plane was to kiss the navigator."



RESTRICTED

PILOT TRAINING MANUAL

FOR THE LIBERATOR

B-24

Published for Headquarters, AAF

Office of Assistant Chief of Air Staff, Training

By Headquarters, AAF, Office of Flying Safety

Revised 1 May, 1945

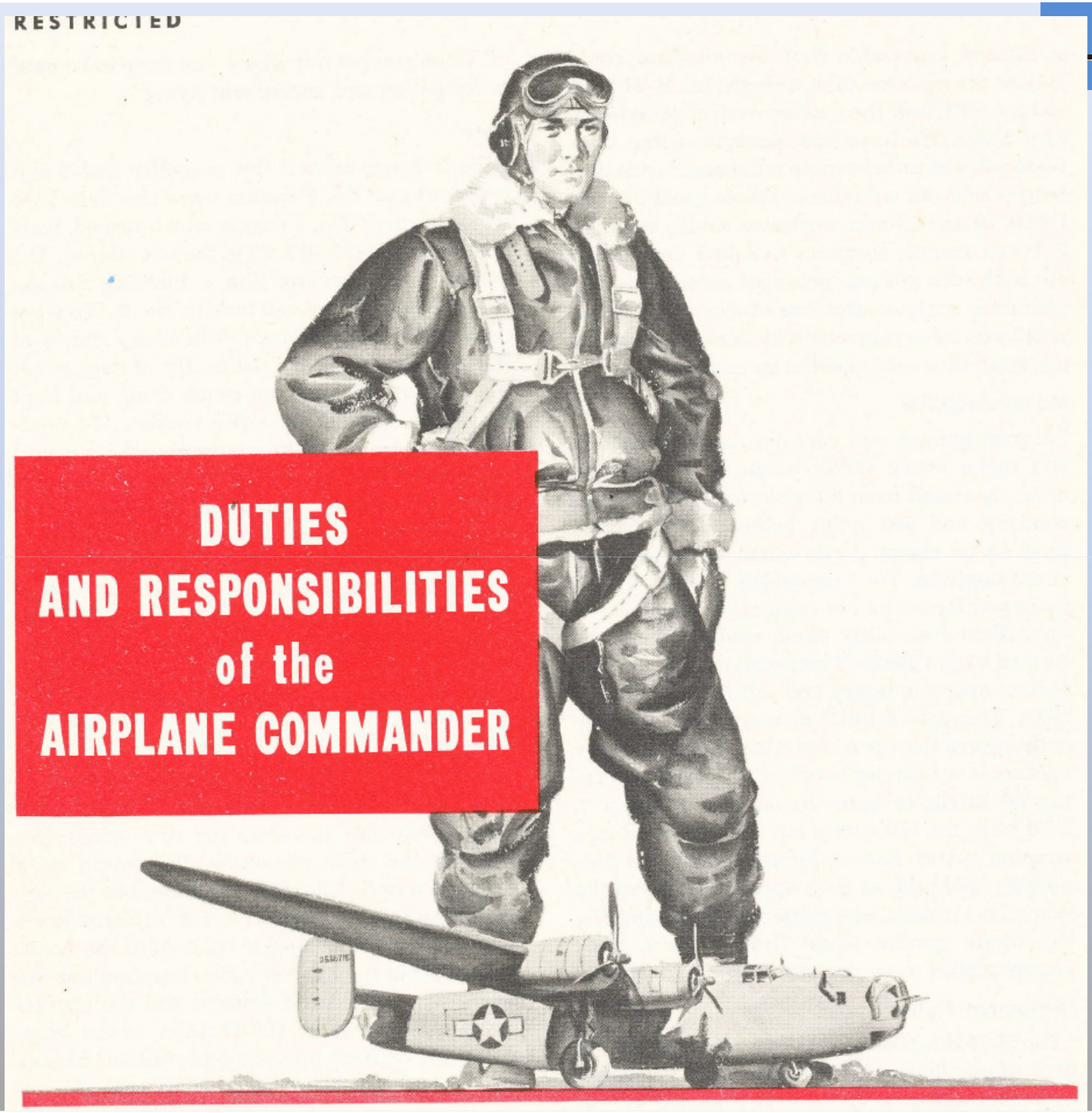
ADDITIONAL COPIES OF THIS MANUAL MAY BE OBTAINED UPON REQUEST TO HQ AAF, OFFICE OF FLYING SAFETY, SAFETY EDUCATION DIVISION, WINSTON-SALEM 1, N. C.

RESTRICTED

WM. B. BURFORD PRINTING CO.

AAF Manual No. 50-12

RESTRICTED



DUTIES AND RESPONSIBILITIES of the AIRPLANE COMMANDER

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Duties and Responsibilities of the B-24 Airplane Commander

- **Your assignment to the B-24 airplane means that you are no longer just a pilot. You are now an airplane commander, charged with all the duties and responsibilities of a command post.**
- **You are now flying a 10-man weapon. It is your airplane, and your crew. You are responsible for the safety and efficiency of the crew at all times--not just when you are flying and fighting, but for the full 24 hours of every day while you are in command.**
- **Your crew is made up of specialists. Each man -- whether he is the navigator, bombardier, engineer, radio operator, or one of the gunners -- is an expert in his line. But how well he does his job, and how efficiently he plays his part as a member of your combat team, will depend to a great extent on how well you play your own part as the airplane commander.**
- **Get to know each member of your crew as an individual. Know his personal idiosyncrasies, his capabilities, his shortcomings. Take a personal interest in his problems, his ambitions, his need for specific training.**

Crew Discipline

- **Your success as the airplane commander will depend in a large measure on the respect, confidence, and trust which the crew feels for you. It will depend also on how well you maintain crew discipline.**

- **Your position commands obedience and respect. This does not mean that you have to be stiff-necked, overbearing, or aloof. Such characteristics most certainly will defeat your purpose. Be friendly, understanding, but firm. Know your job; and, by the way you perform your duties daily, impress upon the crew that you do know your job. Keep close to your men, and let them realize that their interests are uppermost in your mind.**

- Make fair decisions, after due consideration of all the facts involved; but make them in such a way as to impress upon your crew that your decisions are to stick. Crew discipline is vitally important, but it need not be as difficult a problem as it sounds. Good discipline in an air crew breeds comradeship and high morale, and the combination is unbeatable.

- You can be a good CO, and still be a regular guy. You can command respect from your men, and still be one of them.

- "To associate discipline with informality, comradeship, a leveling of rank, and at times a shift in actual command away from the leader, may seem paradoxical," says a brigadier general, formerly a Group commander in the VIII Bomber Command.

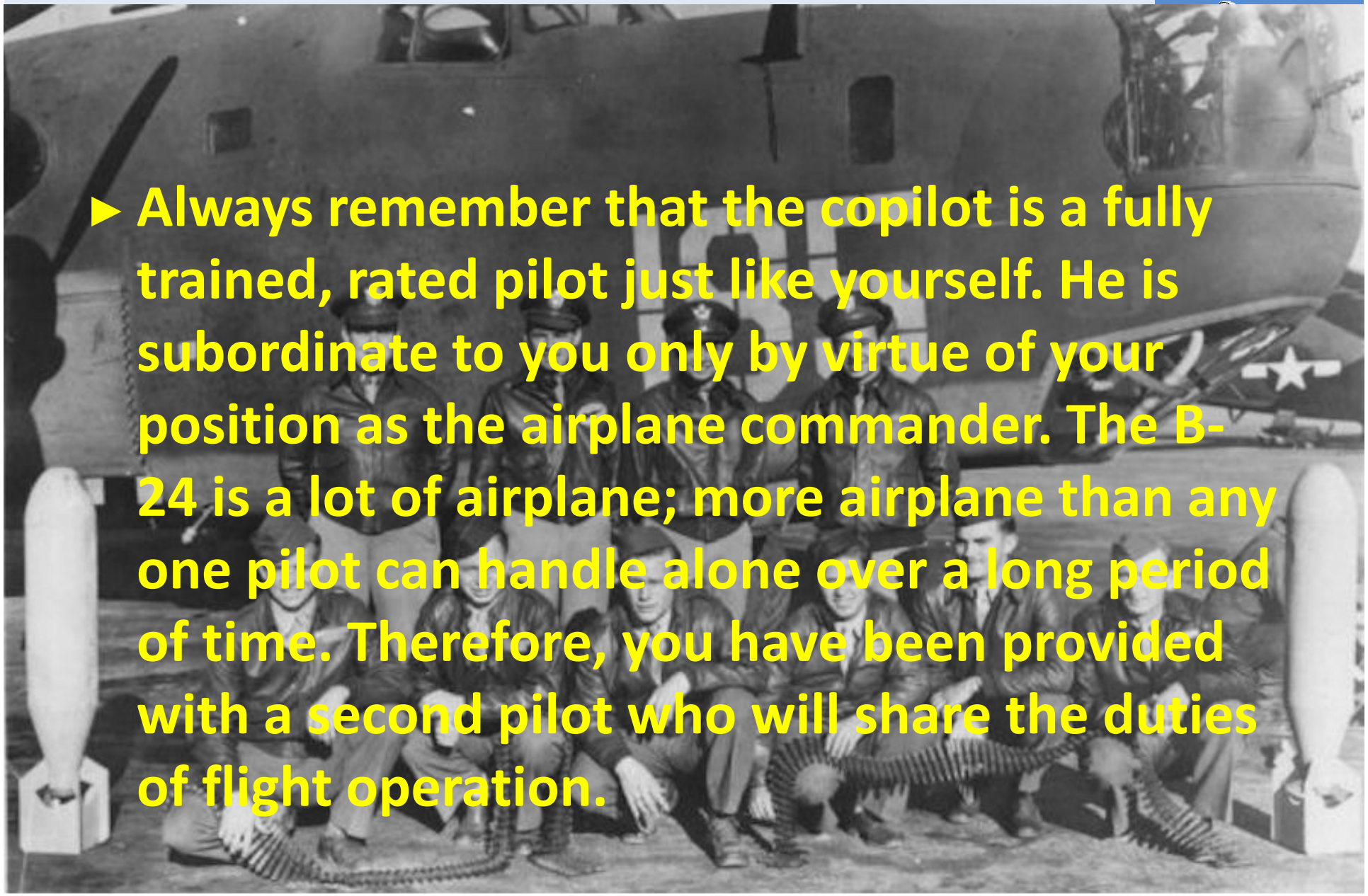
- "Certainly, it isn't down the military groove. But it is discipline just the same -- and the kind of discipline that brings success in the air."

Crew Training

- **Train your crew as a team. Keep abreast of their training. It won't be possible for you to follow each man's courses of instruction, but you can keep a close check on his record and progress.**

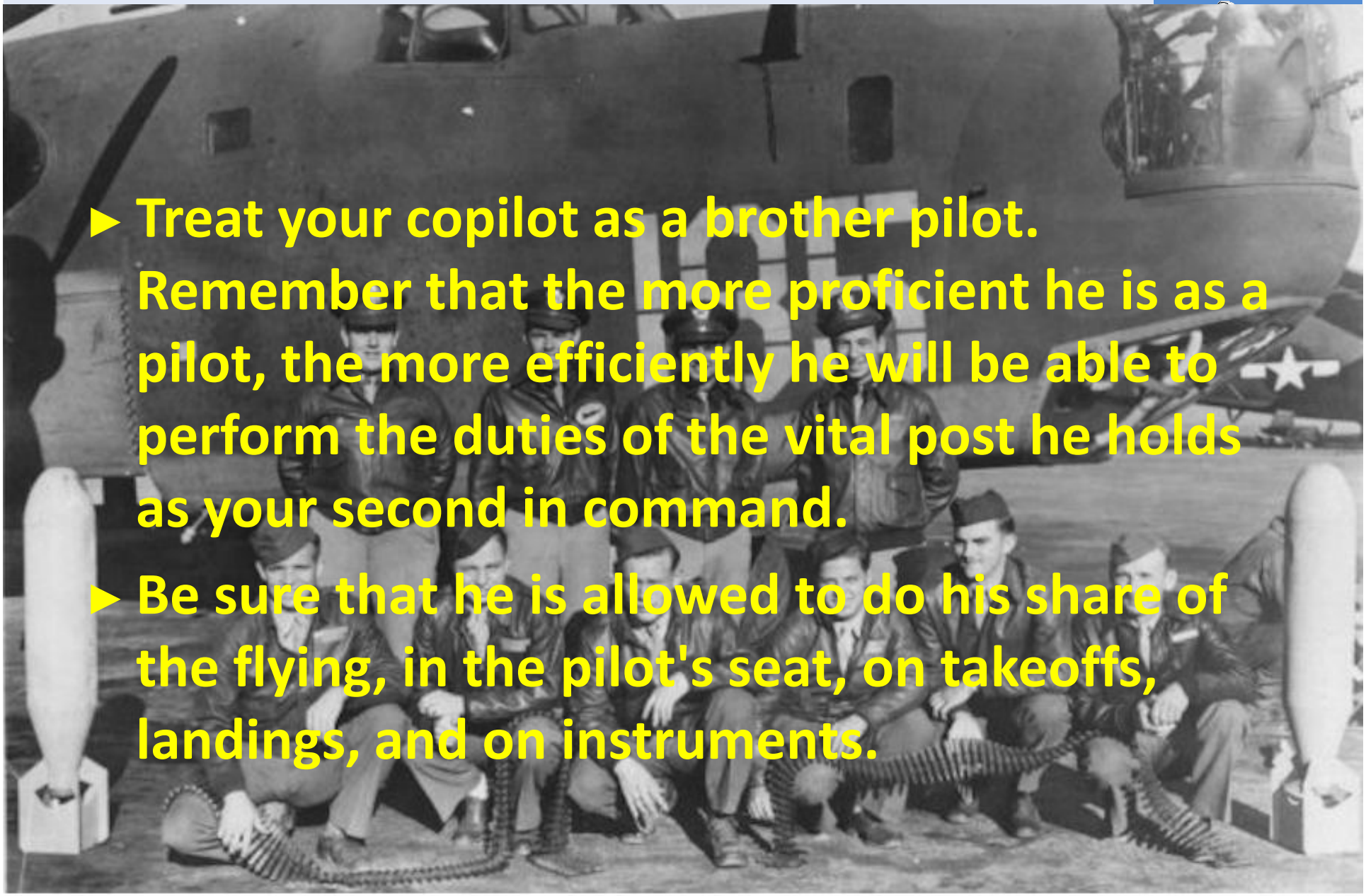
- **Get to know each man's duties and problems. Know his job, and try to devise ways and means of helping him to perform it more efficiently.**

- **Each crew member naturally feels great pride in the importance of his particular specialty. You can help him to develop his pride to include the manner in which he performs that duty. To do that you must possess and maintain a thorough knowledge of each man's job and the problems he has to deal with in the performance of his duties.**



- Always remember that the copilot is a fully trained, rated pilot just like yourself. He is subordinate to you only by virtue of your position as the airplane commander. The B-24 is a lot of airplane; more airplane than any one pilot can handle alone over a long period of time. Therefore, you have been provided with a second pilot who will share the duties of flight operation.

Standing L-R: 1/Lt Russell E. Paules, pilot; 1/Lt Richard R. Sandoz, copilot; 1/Lt Ben Ortenberg, navigator; Capt Ernest R. Morton, bombardier.
Kneeling (exact identities unknown): S/Sgt Ervan J. Cook, engineer; T/Sgt Tommie Whittington, radio operator;
gunners S/Sgt Arthur E. MacDonald, S/Sgt John A. Morris, and S/Sgt Elmer C. Hardy. The identity of the 6th man in the front row is not known.



- Treat your copilot as a brother pilot. Remember that the more proficient he is as a pilot, the more efficiently he will be able to perform the duties of the vital post he holds as your second in command.
- Be sure that he is allowed to do his share of the flying, in the pilot's seat, on takeoffs, landings, and on instruments.

Standing L-R: 1/Lt Russell E. Paules, pilot; 1/Lt Richard R. Sandoz, copilot; 1/Lt Ben Ortenberg, navigator; Capt Ernest R. Morton, bombardier.
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- **The importance of the copilot is eloquently testified to by airplane commanders overseas. There have been many cases in which the pilot has been disabled or killed in flight and the copilot has taken full command of both airplane and crew, completed the mission, and returned safely to the home base. Usually, the copilots who have distinguished themselves under such conditions have been copilots who have been respected and trained by the airplane commander as pilots.**

- **Bear in mind that the pilot in the right-hand seat of your airplane is preparing himself for an airplane commander's post too. Allow him every chance to develop his ability and to profit by your experience.**

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- **Sounds a lot like "optimising the trans cockpit authority gradient"**

Standing (l. to r.): 1/Lt Russell E. Paules, pilot; 1/Lt Richard R. Sandoz, copilot; 1/Lt Ben Ortenberg, navigator; Capt Ernest R. Morton, bombardier.
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RAAF multicrew training

RAAF Bristol Beaufort

Beaufort Aircrew Operational Training

- Frequently the crew all held the same rank but irrespective of rank the pilot was always captain of the aircraft and responsible for its safety.
- Training included many practical exercises by day and by night, often in very hazardous conditions.
- It was very thorough and covered most situations likely to be encountered in operational squadrons.
- **At the conclusion of the course, the crew had bonded, with a strong sense of confidence and trust in each other's ability.**

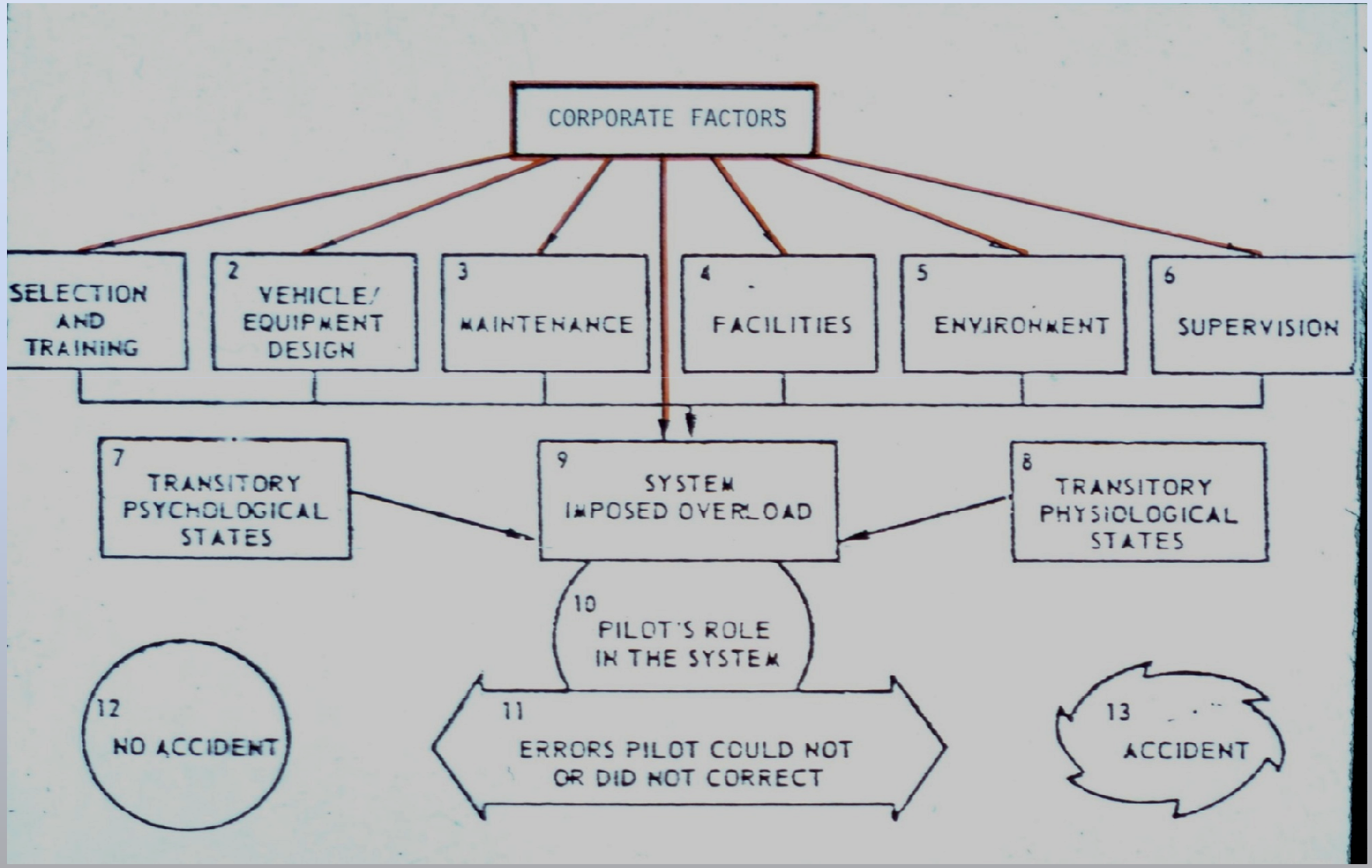
Current ADF CRM Modules

1. Introduction
2. Human Behaviour
3. Human Performance Limitations
4. Error Management and Adaptability
5. Communication and Assertiveness
6. Teamwork/Leadership/Followership
7. Situational Awareness
8. Decision Making
9. Workload Management and Automation
10. Task/Mission Planning
11. Briefing/Debriefing
12. Summary.

- The core elements of what we now call CRM were being trained and practiced in World War Two
- This training is well worth revisiting, to see if there are insights and ways in which we could enhance or improve today's CRM training.

The systemic approach to safety management: lessons learnt

BASI human factors systemic approach before James Reason (mid 1980s)



Sources: Alan Burrows, Douglas Aircraft; Rob Lee, BASI

The Reason Model of Systems Safety

- Developed in the 1980s by

  Professor James Reason,

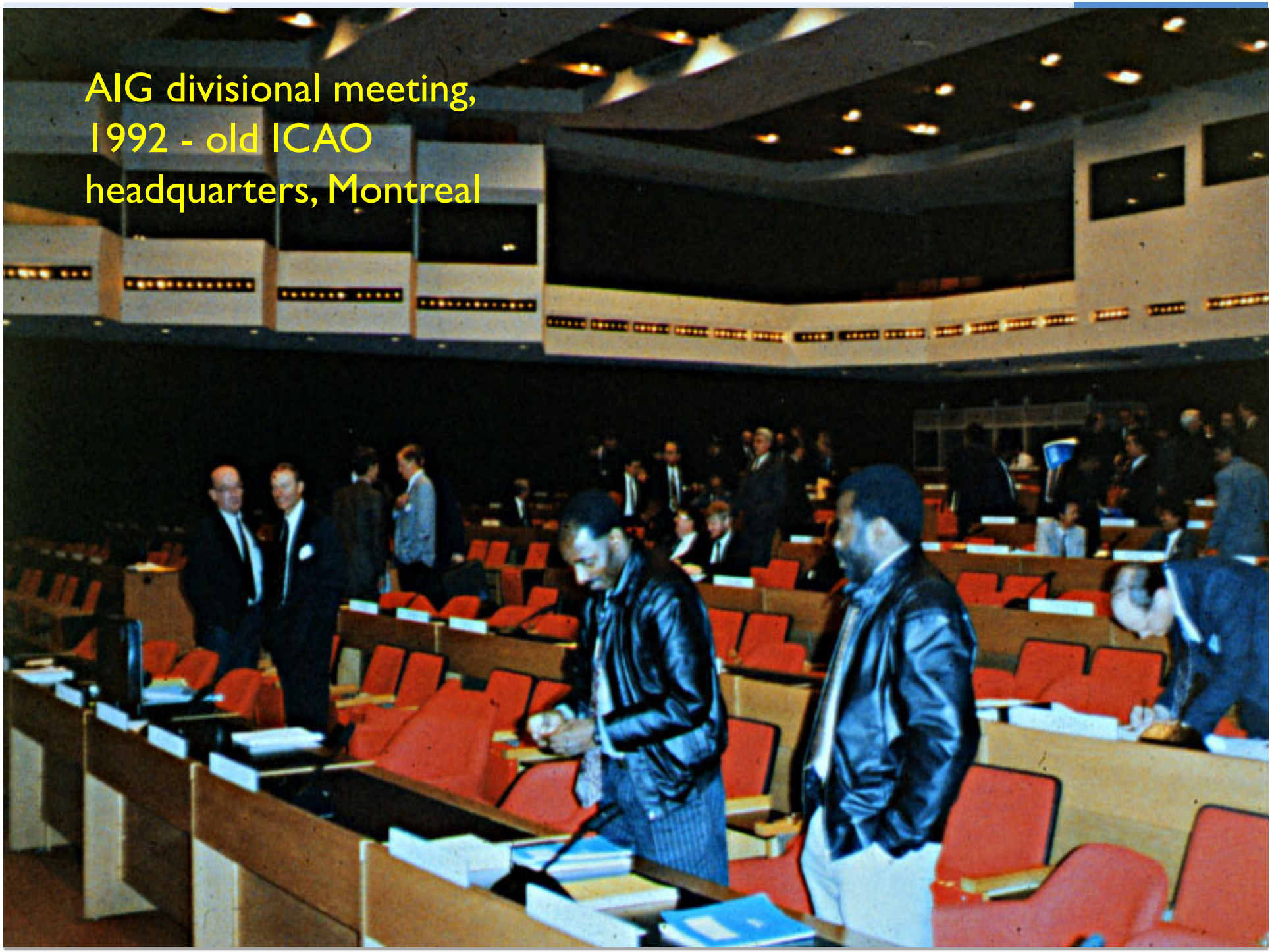
  Department of Psychology,

  University of Manchester

- Research funded by Shell

The systemic approach to air safety investigation became an ICAO Standard in Annex 13 in1994

- **The safety outcomes of the international adoption of a systemic approach to air safety investigation since 1994 have been the key drivers for the adoption of safety management systems in civil aviation.**
- ***The ADF adopted the systemic approach to safety investigation at around the same time***


AIG divisional meeting,
1992 - old ICAO
headquarters, Montreal

A World War Two precedent

Brigadier General William H. Tunner

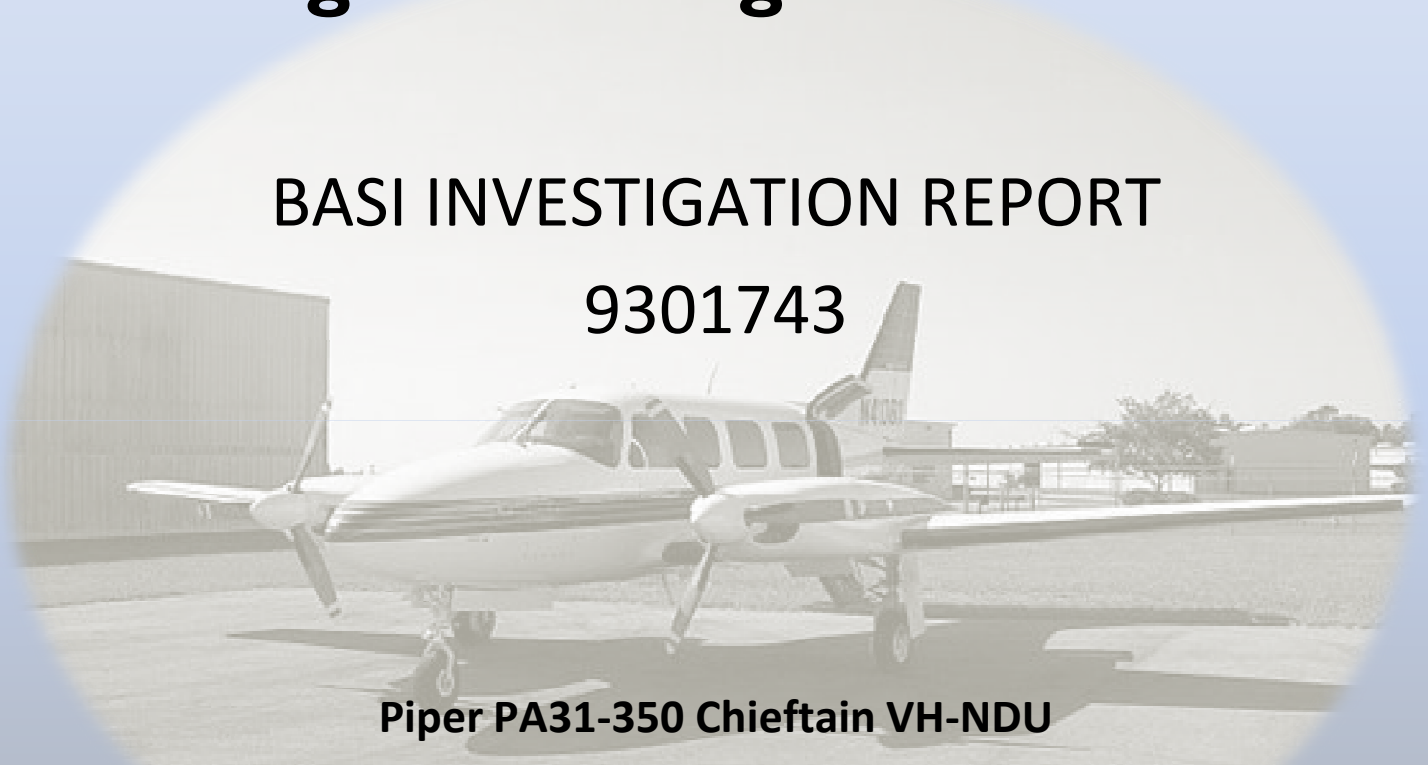
Flying the Hump

The first aviation safety management system

First investigation using the Reason Model:

BASI INVESTIGATION REPORT

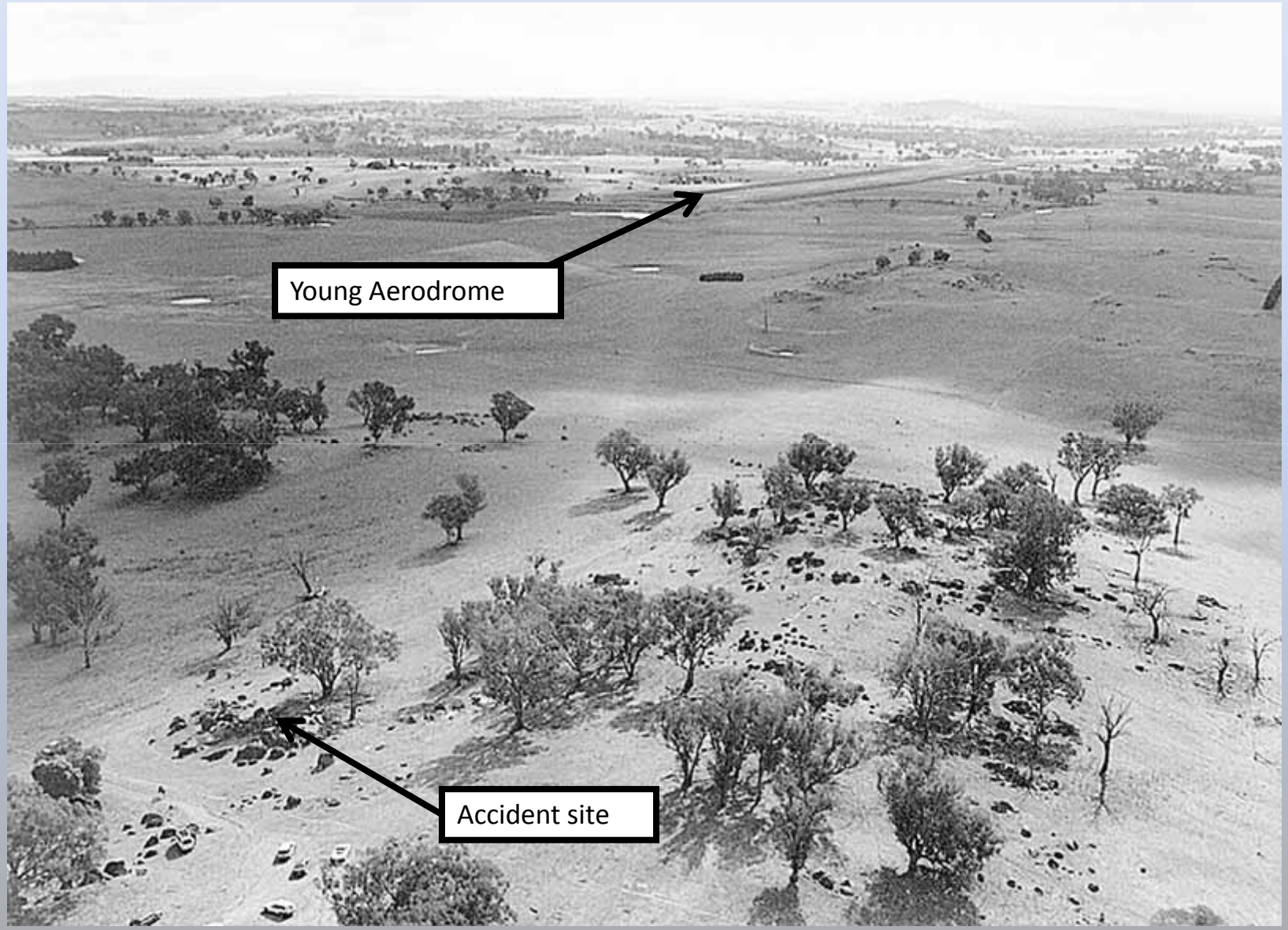
9301743



Piper PA31-350 Chieftain VH-NDU

Young, NSW

11 June 1993


Young Aerodrome
Accident site

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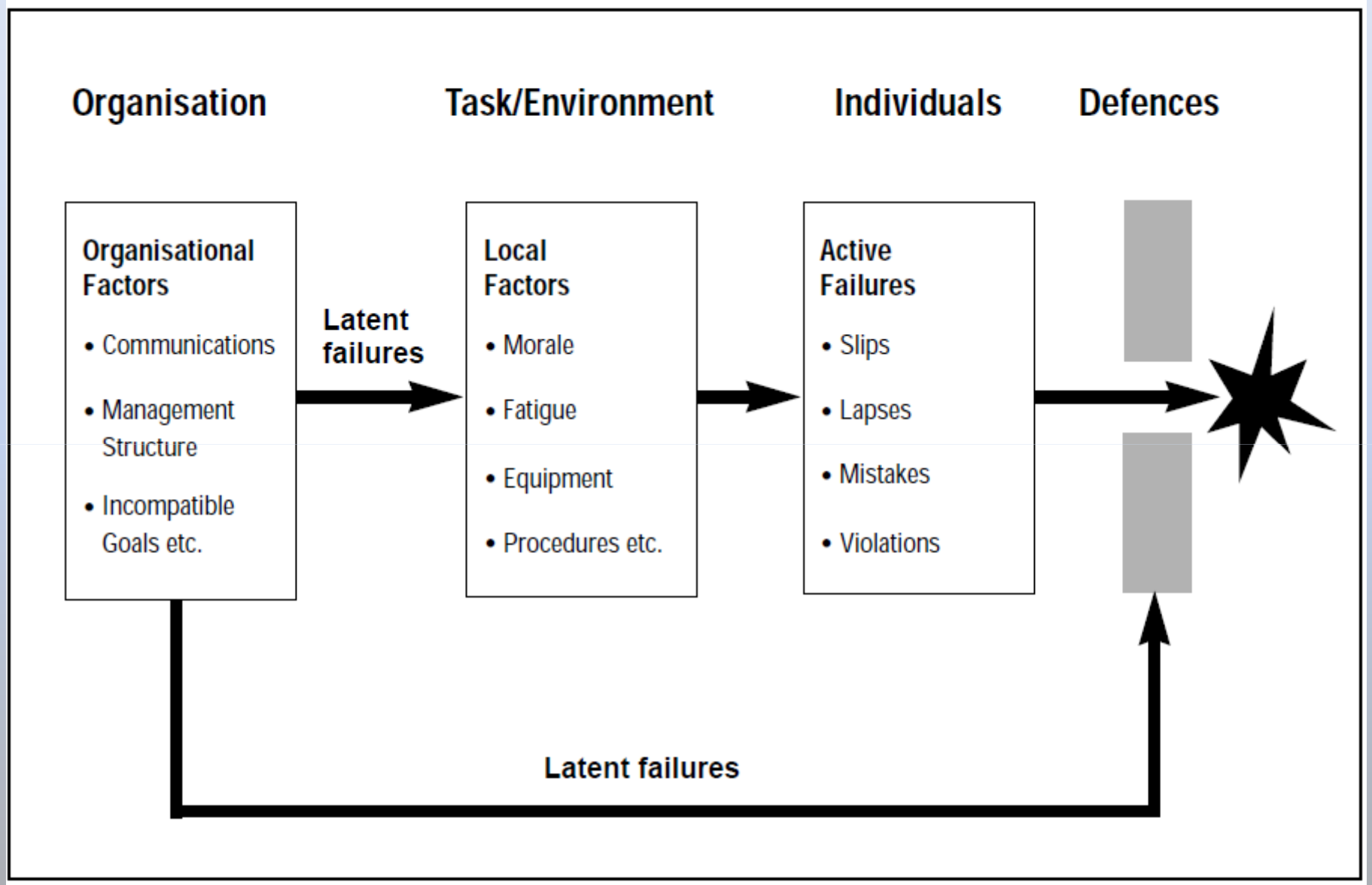
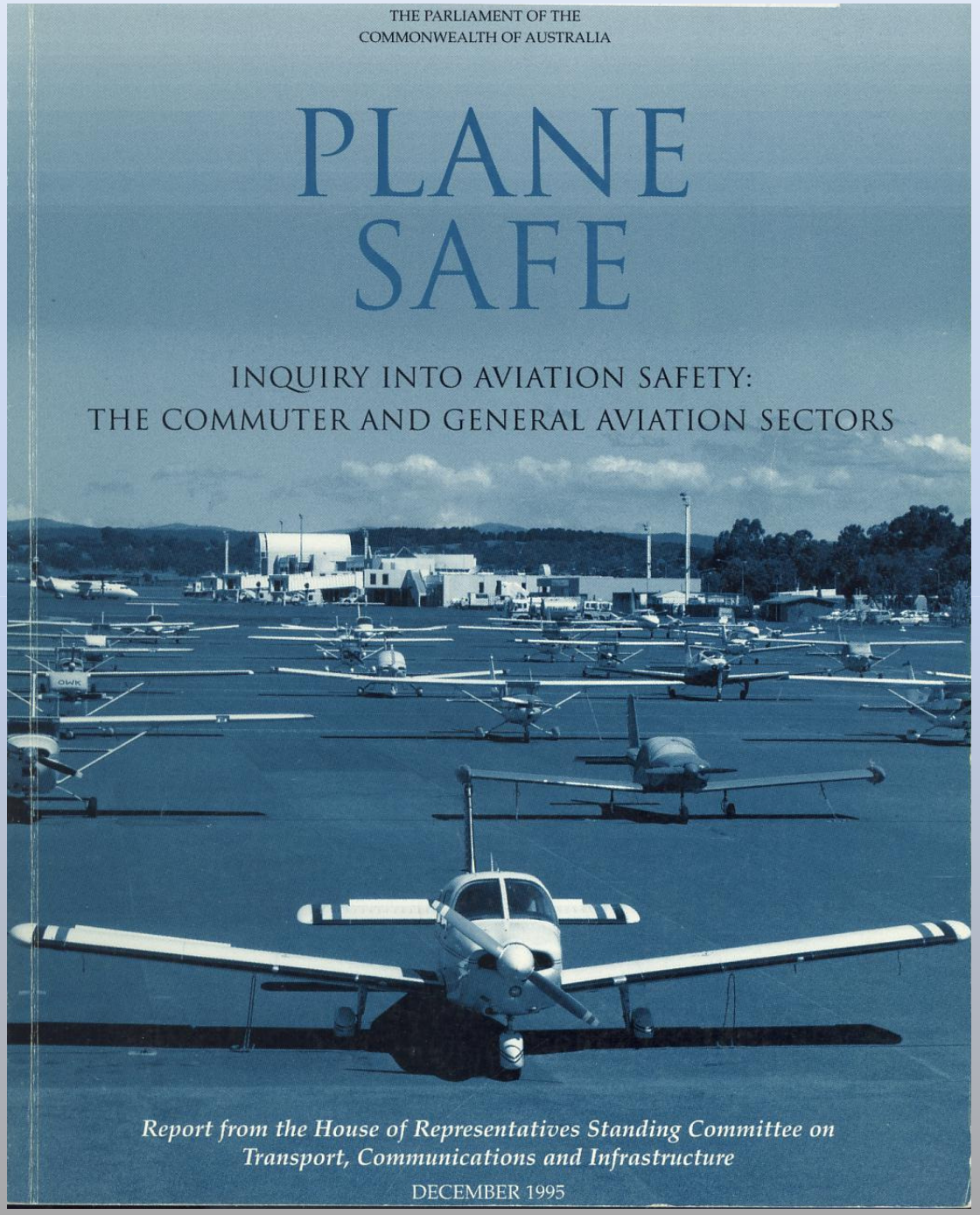


Figure 14 Diagram of the basic Reason model showing the elements of an 'organisational accident'.

Significant factors

1. The cloudbase in the Young circling area was below the minimum circling altitude, associated with dark night conditions and limited ground lighting.
2. The workload of the pilot-in-command was substantially increased by the effects of aircraft equipment deficiencies, with a possible consequent degrading of his performance as a result of skill fatigue.
3. The instrument approach and landing charts did not provide the flight crew with terrain information adequate for the assessment of obstacle clearance during a circling approach.
4. The Monarch operations manual did not provide the flight crew with guidance or procedures for the safe avoidance of terrain at Young during a night-circling approach.
5. The aircraft descended below the minimum circling altitude without adequate monitoring of obstacle clearance by the crew.
6. The visual cues available to the flight crew were insufficient as a sole source of height judgement.
7. **There were organisational deficiencies in the management and operation of RPT services by Monarch.**
8. **There were organisational deficiencies in the safety regulation of Monarch RPT operations by the CAA.**



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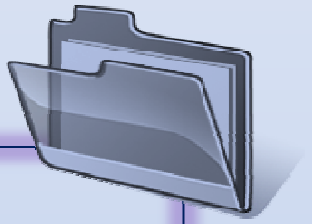
Outcome:

CAA split into

Air Services Australia

and CASA

Annex 13 Paragraph 1.17 - Organisational and Management Information



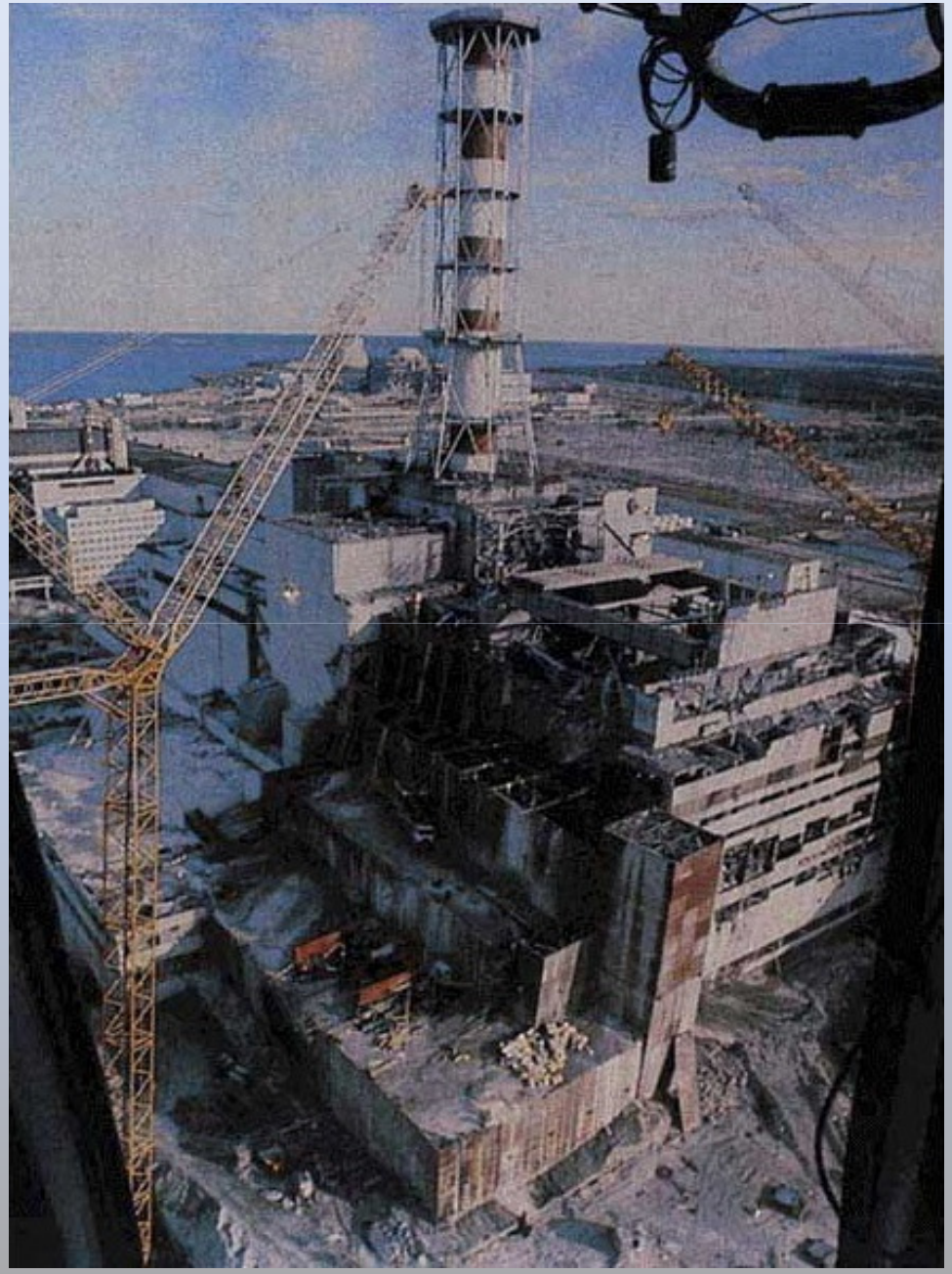
"Pertinent information concerning the organizations and their management involved in influencing the operation of the aircraft.

The organizations include, for example, the operator; the air traffic services, airway, aerodrome and weather service agencies; and the regulatory authority.

The information could include, but not be limited to, organizational structure and functions, resources, economic status, management policies and practices, and regulatory framework."

The Reason Model of Systems Safety

- The Reason Model was endorsed by ICAO as a guide to the investigation of organisational and management factors.



Chernobyl, April 25-26, 1986

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Herald of Free Enterprise, capsized off Zeebrugge, Belgium, 6 March 1987

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Space shuttle Challenger, 28 Jan,1986

Kings Cross Underground Fire, 18 November, 1987

Tenerife, 27 March, 1977, two B747s collide on the runway

A320, Bahrain, 23 August 2000, 143 fatalities

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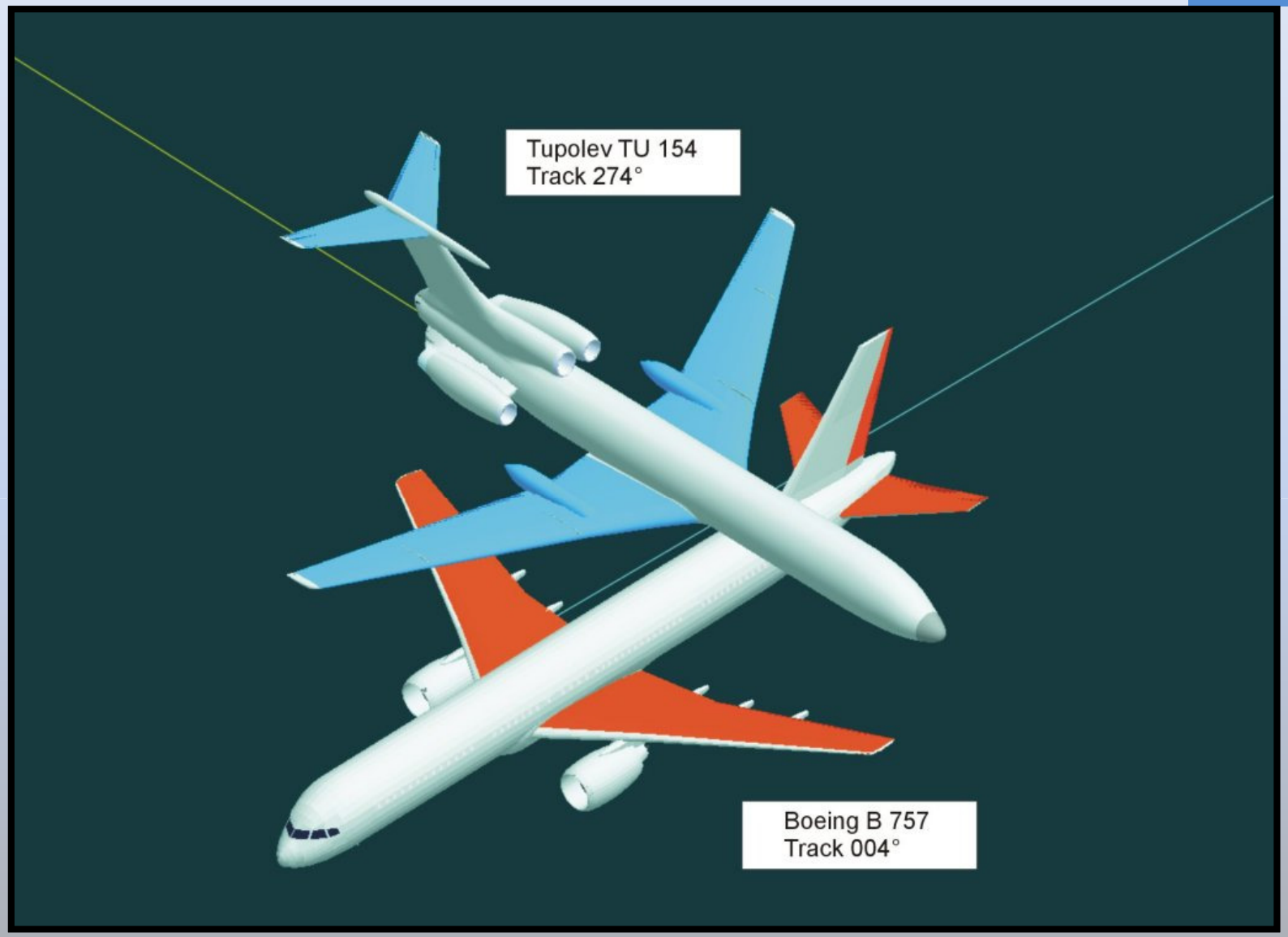
Ueberlingen, Germany, 2 July 2001



Collision between B757-200 and TU154M showing the relative positions of the aircraft at impact

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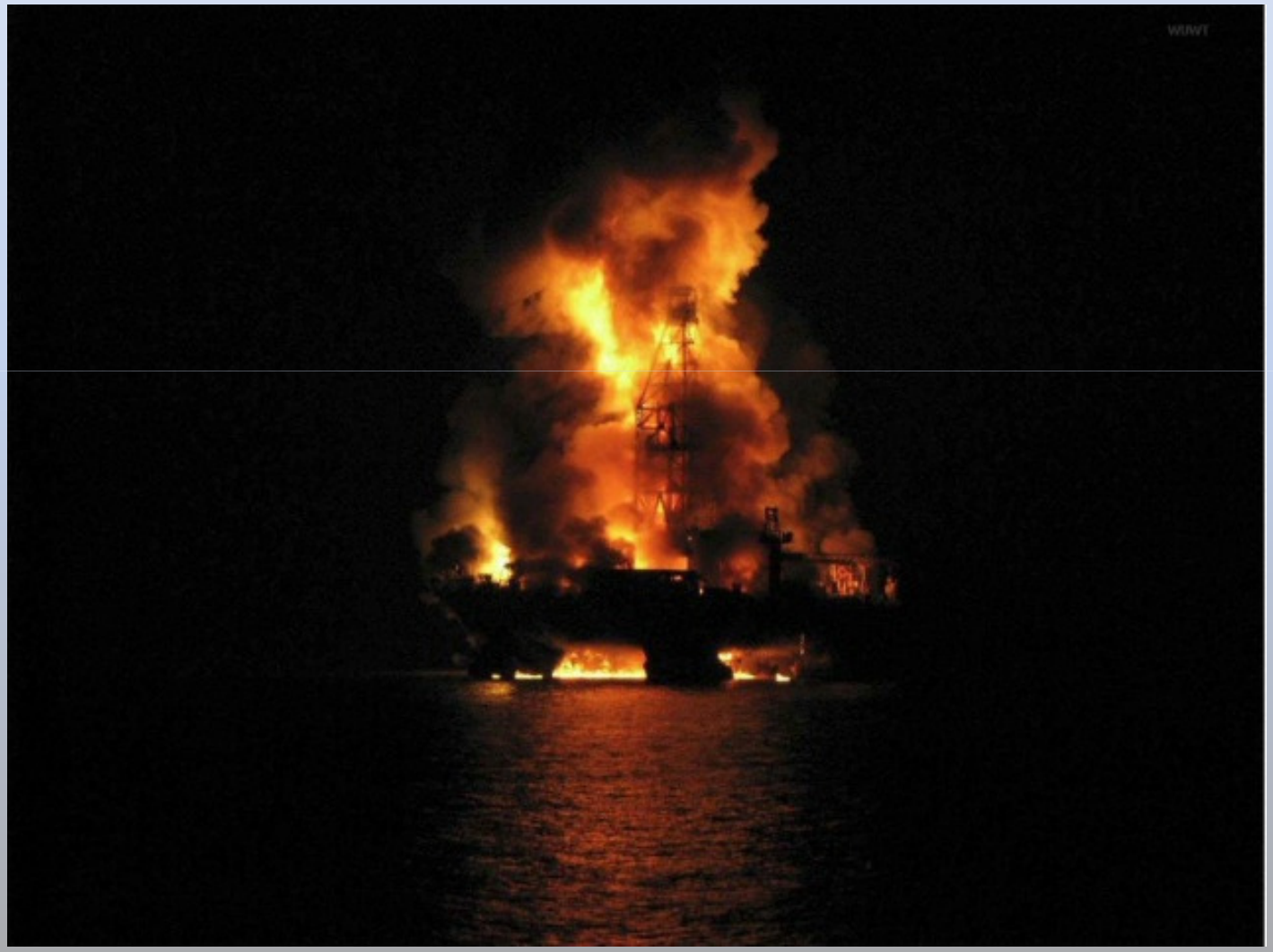
BP Texas City, March, 2005

BP Gulf of Mexico, April, 2010



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No.107

Accident Review

BOEING 707 ACCIDENT

Loss of RAAF
B707, East Sale

29 October, 1991

RAN Sea King, Nias, Indonesia, 2 April, 2005, 9 fatalities

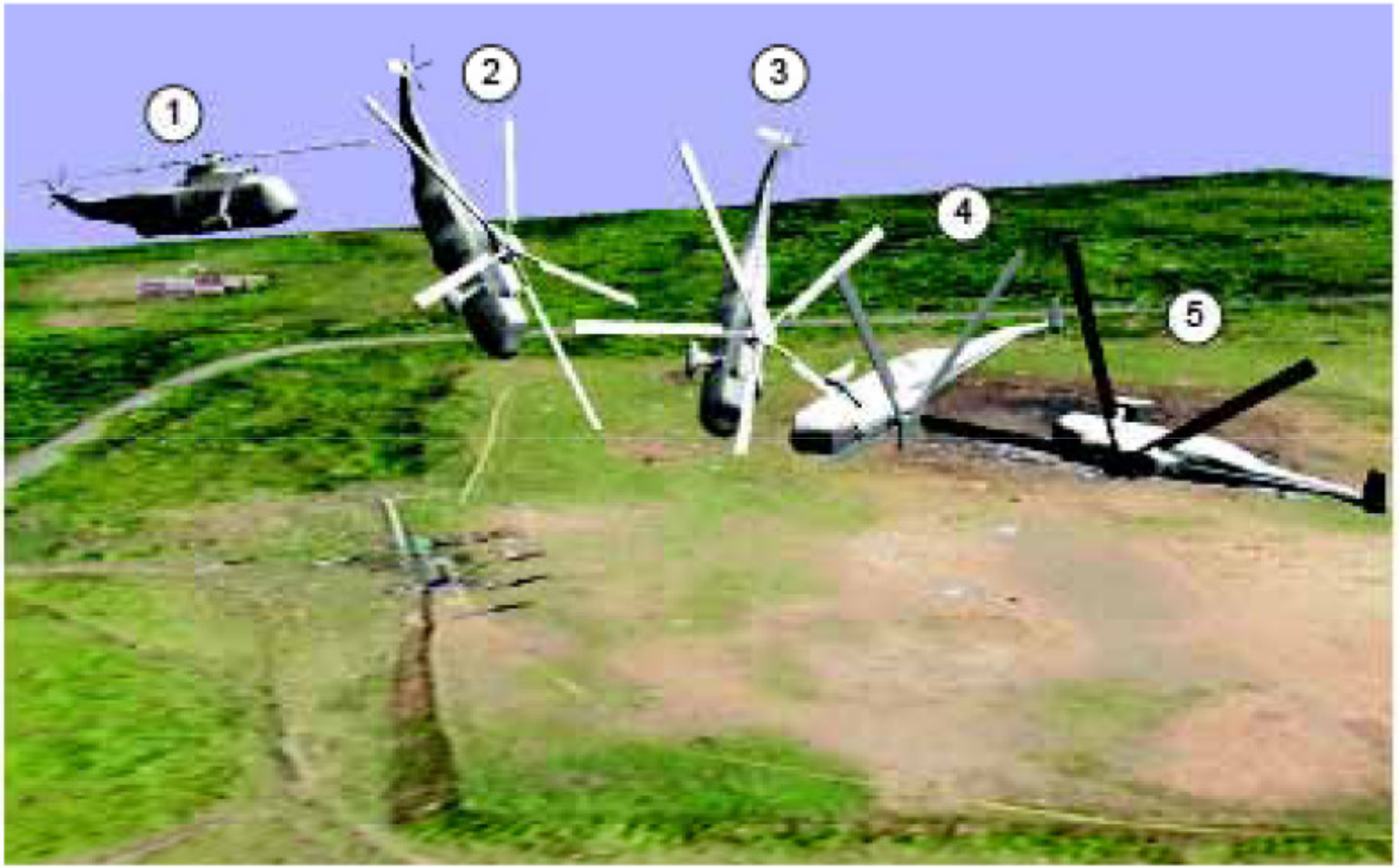

Figure 5.6: Five-Stage Accident Sequence Model

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Army Black Hawk, HMAS Kanimbla off Fiji, 29 November, 2006.

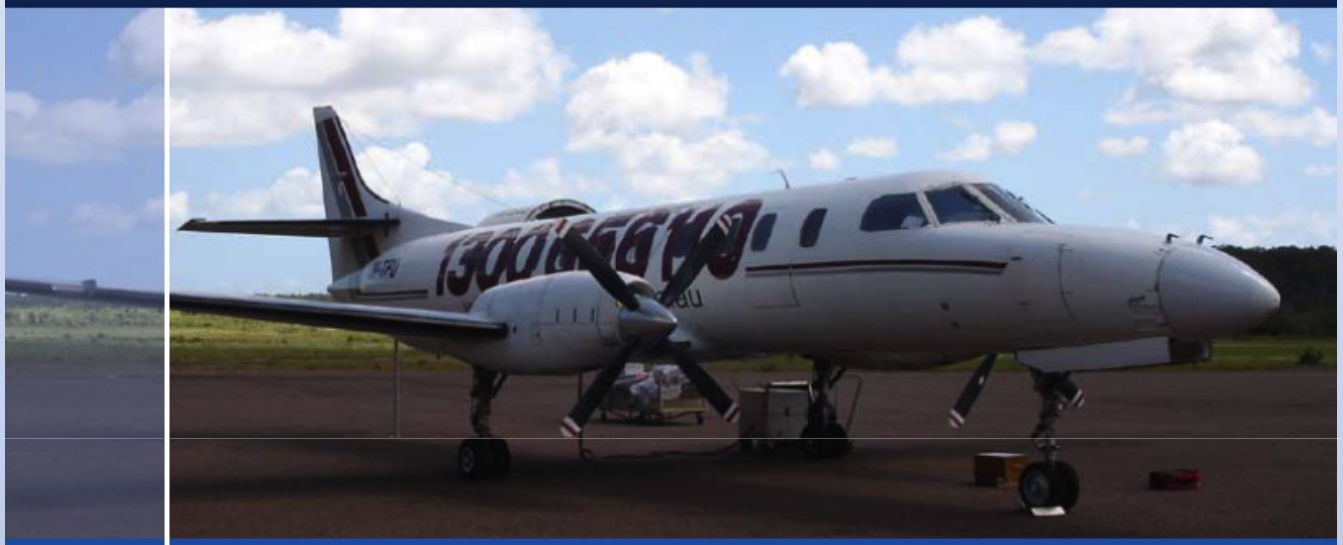
RAF Nimrod XV230

RNZAF Iroquois, Anzac Day, 2010

Australian Government

Australian Transport Safety Bureau

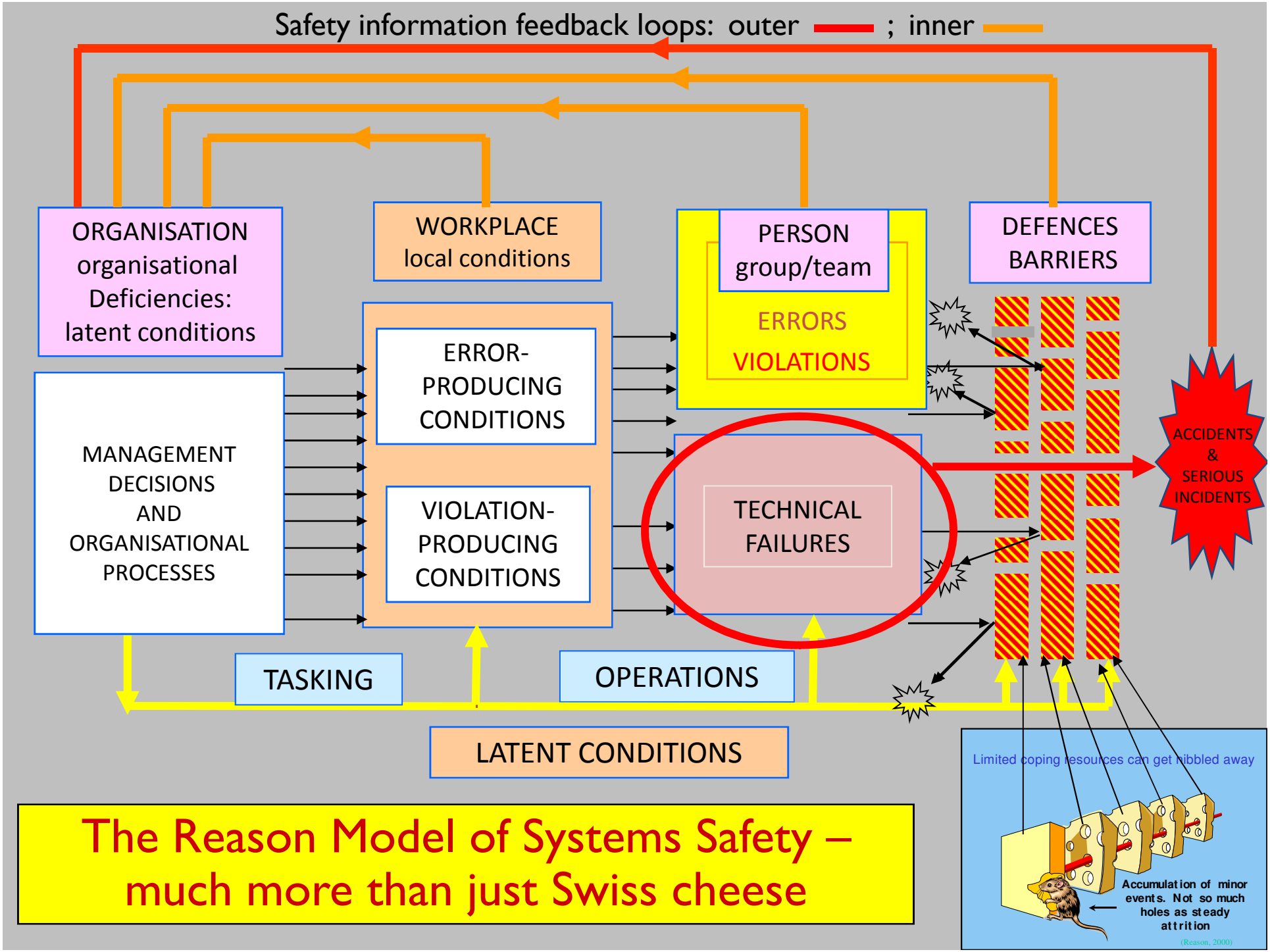
PACDEFF



ATSB TRANSPORT SAFETY INVESTIGATION REPORT
Aviation Occurrence Report 200501977
Final

Collision with Terrain
11 km NW Lockhart River Aerodrome
7 May 2005
VH-TFU
SA227-DC (Metro 23)

The "awful sameness" of major accidents

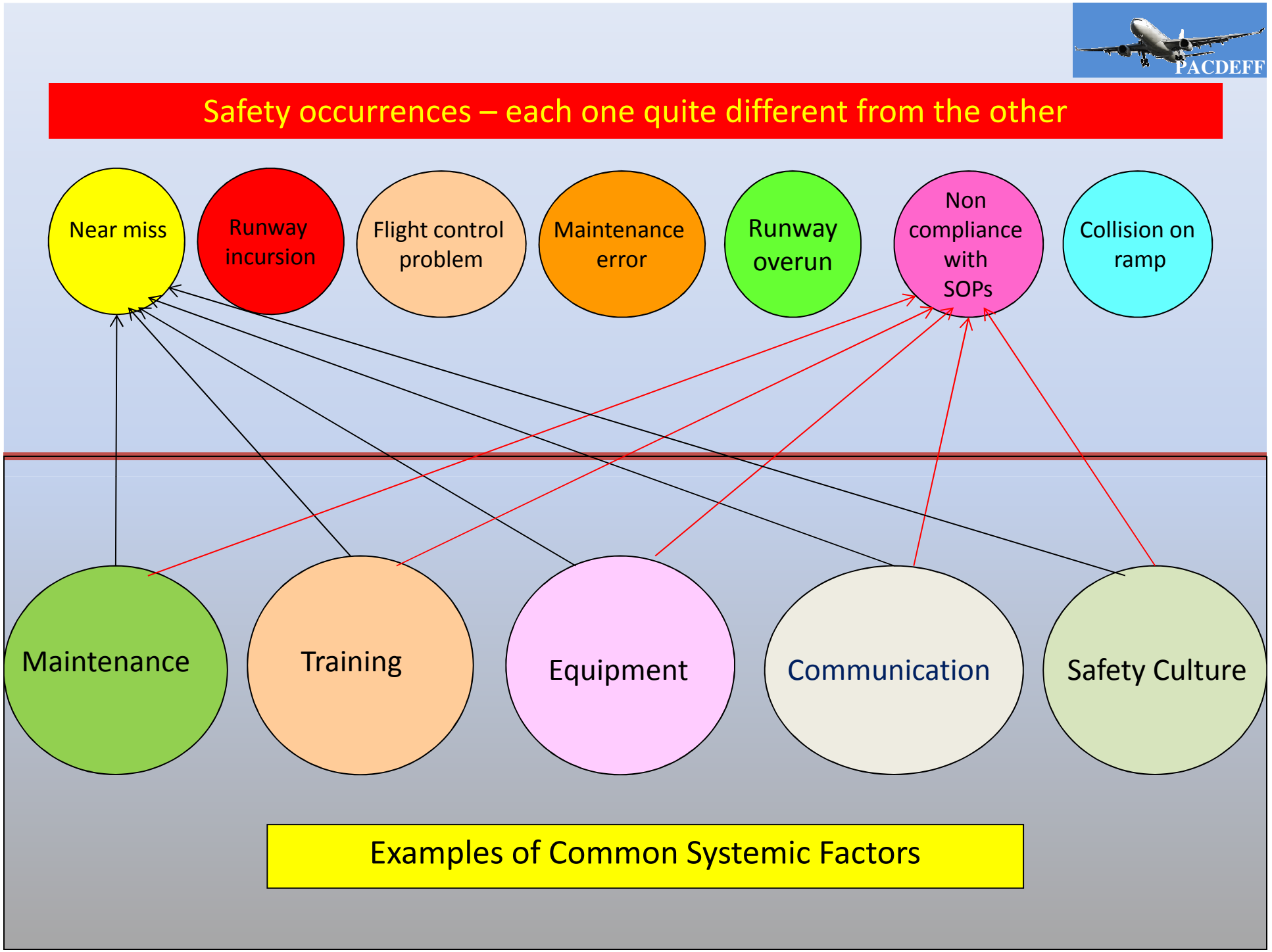

Safety information feedback loops: outer ; inner
ORGANISATION organisational Deficiencies: latent conditions
WORKPLACE local conditions
PERSON group/team
ERRORS
VIOLATIONS
DEFENCES BARRIERS
MANAGEMENT DECISIONS AND ORGANISATIONAL PROCESSES
ERROR-PRODUCING CONDITIONS
VIOLATION-PRODUCING CONDITIONS
TECHNICAL FAILURES
ACCIDENTS & SERIOUS INCIDENTS
TASKING
OPERATIONS
LATENT CONDITIONS
Limited coping resources can get nibbled away
Accumulation of minor events. Not so much holes as steady attrition
(Reason, 2000)
The Reason Model of Systems Safety – much more than just Swiss cheese

Why the 'traditional' approach to safety management ultimately does not enhance safety

- Concentration on the 'surface' issues of safety incidents or accidents, such as maintenance error, or pilot error, means that underlying systemic factors may be missed
- Operational experience, accident investigation, and research has shown that if the underlying systemic factors which contribute to an occurrence are not rectified, other occurrences will occur due to the same contributing factors

- All too often, intensive, protracted, and very expensive accident investigations ultimately simply identify the presence of underlying systemic safety deficiencies that were present long before the accident, were well known to sections of the industry, and had been formally documented.
- Nothing to do with hindsight – just facts

- The same underlying systemic factors may be common to many different accident and incident scenarios, each with different combinations of triggering events and circumstances.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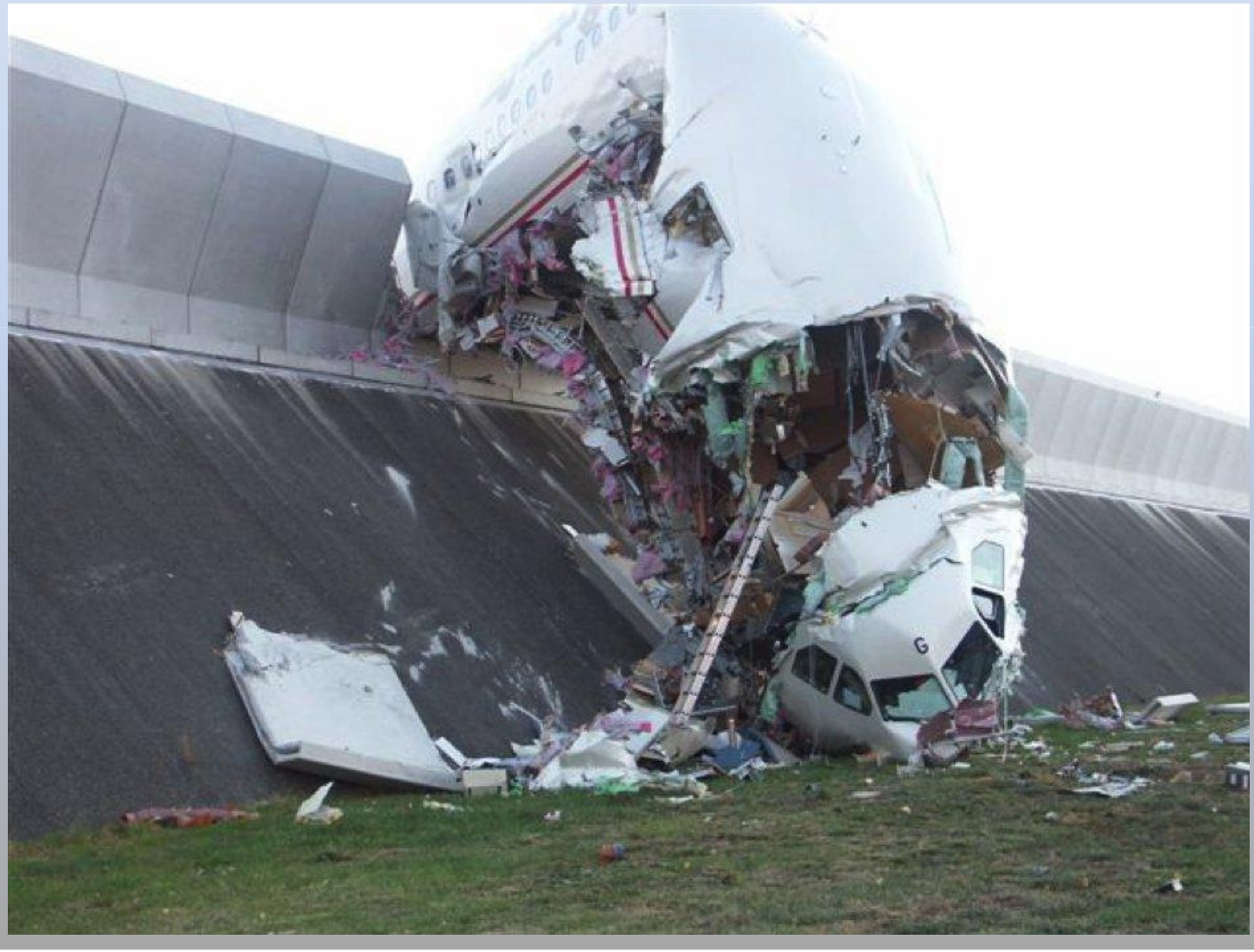
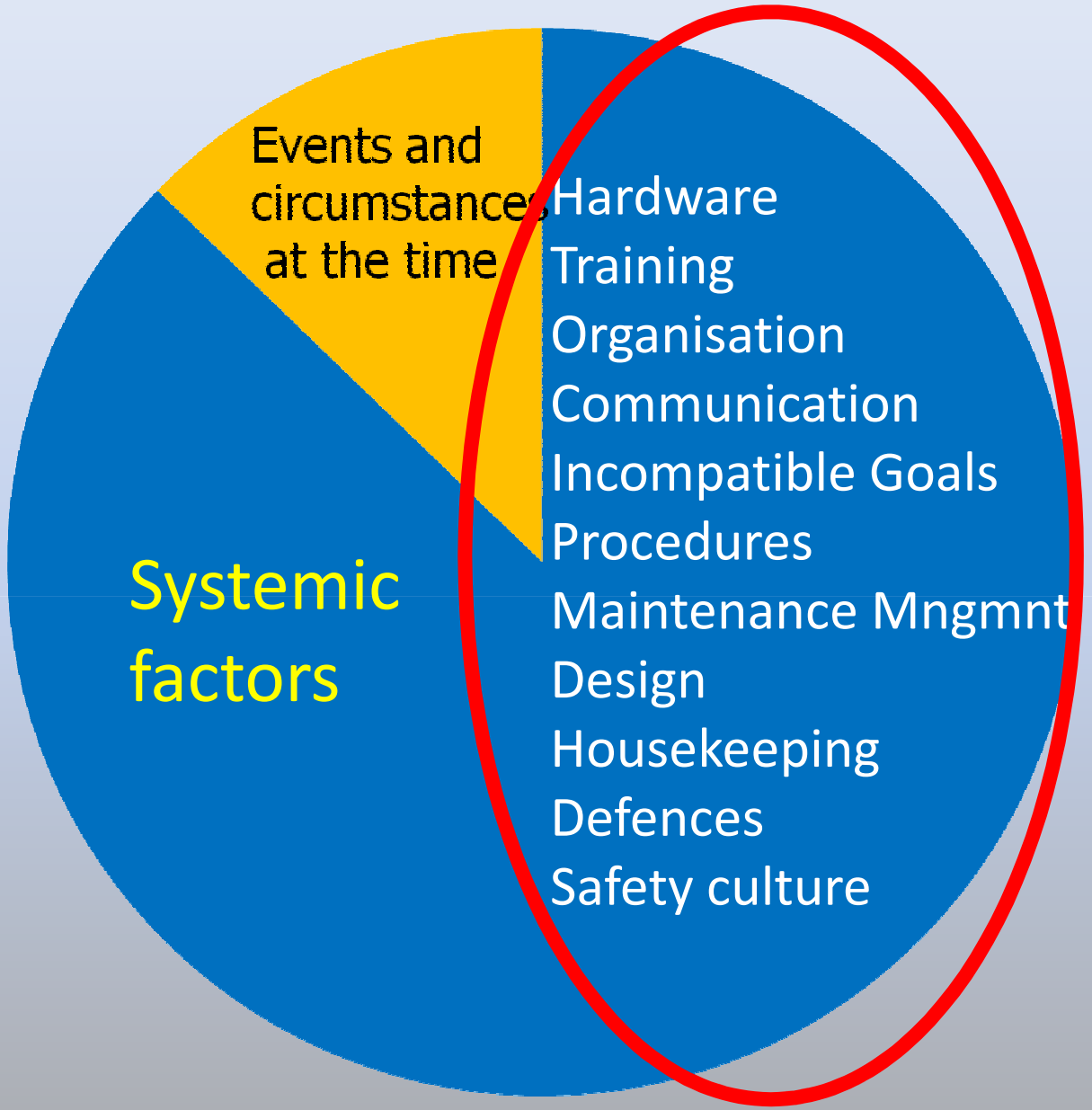
Safety occurrences – each one quite different from the other
Near miss
Runway incursion
Flight control problem
Maintenance error
Runway overun
Non compliance with SOPs
Collision on ramp
Maintenance
Training
Equipment
Communication
Safety Culture
Examples of Common Systemic Factors

Considered systemically, most major accidents are variations on the same theme – the “awful sameness”.





Total factors contributing to accidents

What are the key lessons for safety management from these insights?

- If we make the underlying systemic factors as good as they can be, the system will be far more capable of dealing with adverse events and circumstances that may arise
- In other words, it will be more **resilient**

Consider a military force

If the military force has excellent...

- **Leadership at all levels**
- **Communication**
- **Just and fair culture**
- **Risk management**
- **Procedures**
- **Equipment**
- **Training**
- **Maintenance management**
- **Design**
- **Financial management**

It will be better able to meet and defeat any unexpected, or unforeseen, threats

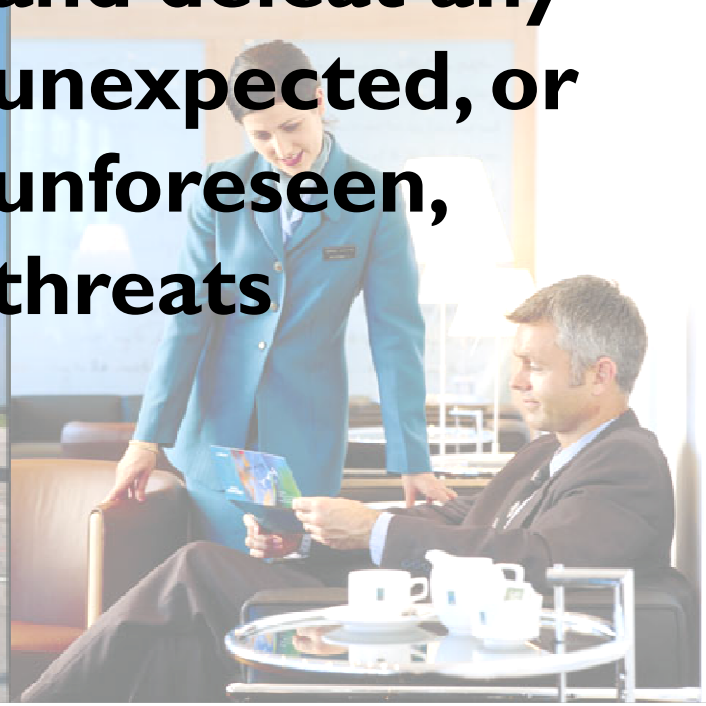
Now, consider an airline...

PACDEFF

If the airline has excellent...

- Leadership at all levels
- Communication
- Just and fair culture
- Risk management
- Procedures
- Equipment
- Training
- Maintenance Management
- Design
- Financial support

It will be better able to meet and defeat any unexpected, or unforeseen, threats



Qantas, A380 VH-OQA, No. 2 Engine

...a catastrophic, unforeseen, uncontained, engine failure

The crew of QF32 saved the aircraft and its passengers

- They had excellent leadership, training, equipment, communication, culture, maintenance support, organisation
- They were well prepared to handle the unforeseen events and circumstances of the emergency on the day
- The basic systemic factors were in place beforehand

A major challenge for safety management

- It is far easier for governments and organisations to address events themselves – such as an accident or serious incident
- **It is extremely difficult to obtain the organisational and political leverage necessary to change the basic underlying systemic factors**
- However, without these fundamental changes in such systemic factors, everything else is just tinkering at the edges.
- And we will continue to have accidents which are variations on the same theme

Most accidents are triggered by known but ignored compromises that became critical due to their cumulative effect in a foreseeable set of circumstances.

As a result, the traditional accident investigation seldom produces new insights in accident causation and avoidance, while an honest accident report can do little more than reiterate how the familiar handwriting on the wall failed to draw a timely response from those concerned.

Gerry Bruggink, 1917-2005, ex NTSB

"Systems for managing safety" versus "Safety management systems"

For many years aviation has had in place systems for managing safety, and these have served us well

However, with few exceptions, we have not had in place fully integrated safety management systems

- Often, people from aviation organizations, civil and military, will tell you that they have a safety management system, and they may genuinely believe that they do.
- What they actually have in place is a range of different systems for managing safety, in areas such as maintenance, flight operations, and so on, which function independently of each other, with little or no cross communication between them.
- ***It is still rare to find in aviation a fully integrated safety management system***


Integrating the SMS:
the greatest challenge
Australian Government
Department of Defence

PACDEFF

WWAT.010.002.0006

*If the SMS is not **integrated**, but standalone and fragmented, it will function independently of other management systems. This usually results in hazards, errors, violations, and safety deficiencies being overlooked, or not communicated throughout the organisation. The result is [an organisation] does not learn or improve its ability to manage the safety of its operations.*

The Honourable Peter Aloysius McInerney QC,
Special Commission of Inquiry into the Waterfall Rail Accident, 2005

Consider an engine. All the necessary components may be present...

Chevrolet Corvette Z06

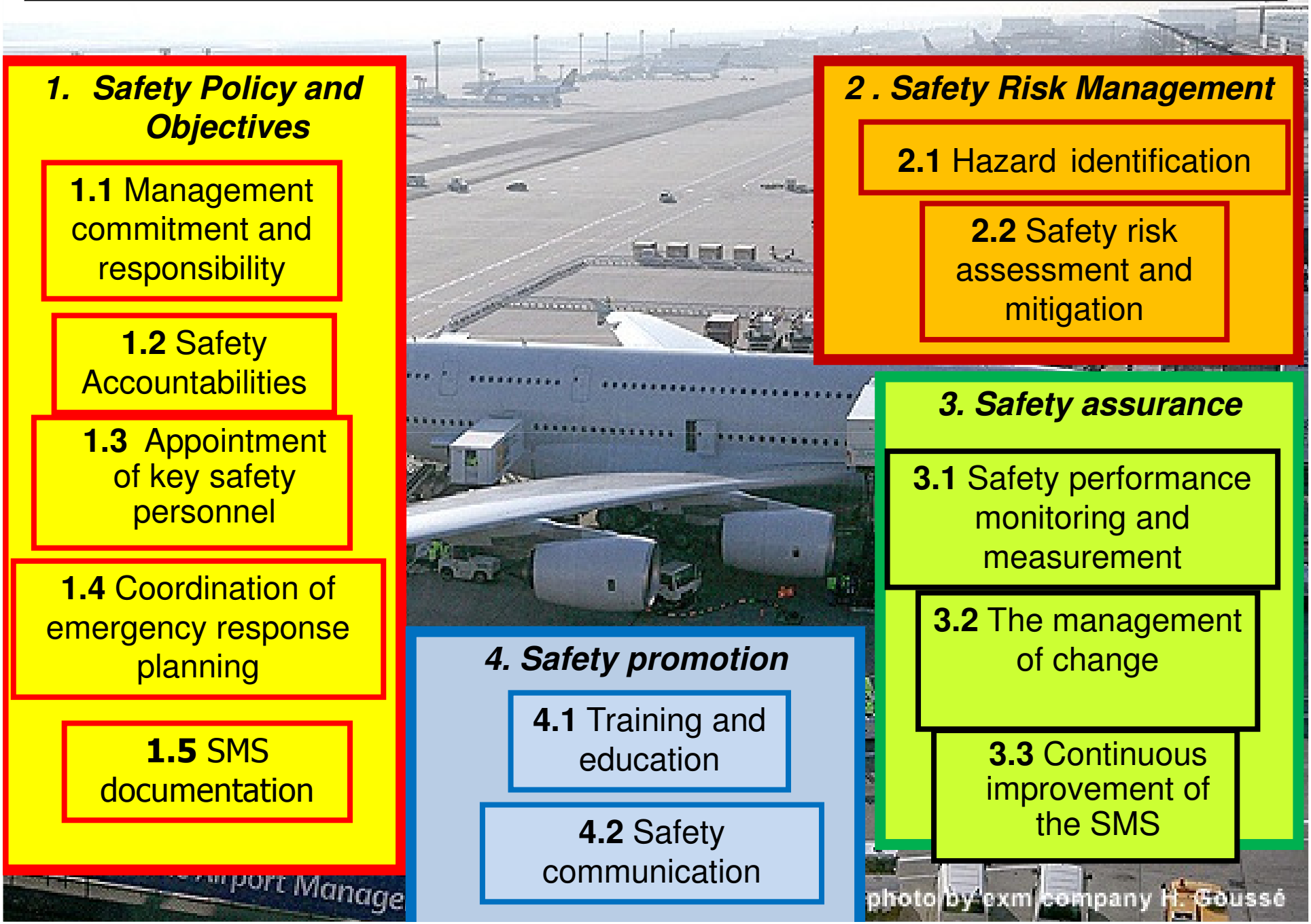
LS7
2006 7.0L V-8 (LS7)

But, until the separate parts are properly assembled, fuelled and lubricated, you do not have a functioning engine, but you could pass an audit.

The assembled engine then needs to be installed in a vehicle, to have a functioning, integrated system at the "organisational" level

However, even a fully integrated system will fail if the design of the system itself, the "engine", is fundamentally flawed.

Structure and Elements of the ICAO Integrated Safety Management System



1. Safety Policy and Objectives

- **1.1** Management commitment and responsibility
- **1.2** Safety Accountabilities
- **1.3** Appointment of key safety personnel
- **1.4** Coordination of emergency response planning
- **1.5** SMS documentation

2 . Safety Risk Management

- **2.1** Hazard identification
- **2.2** Safety risk assessment and mitigation

3. Safety assurance

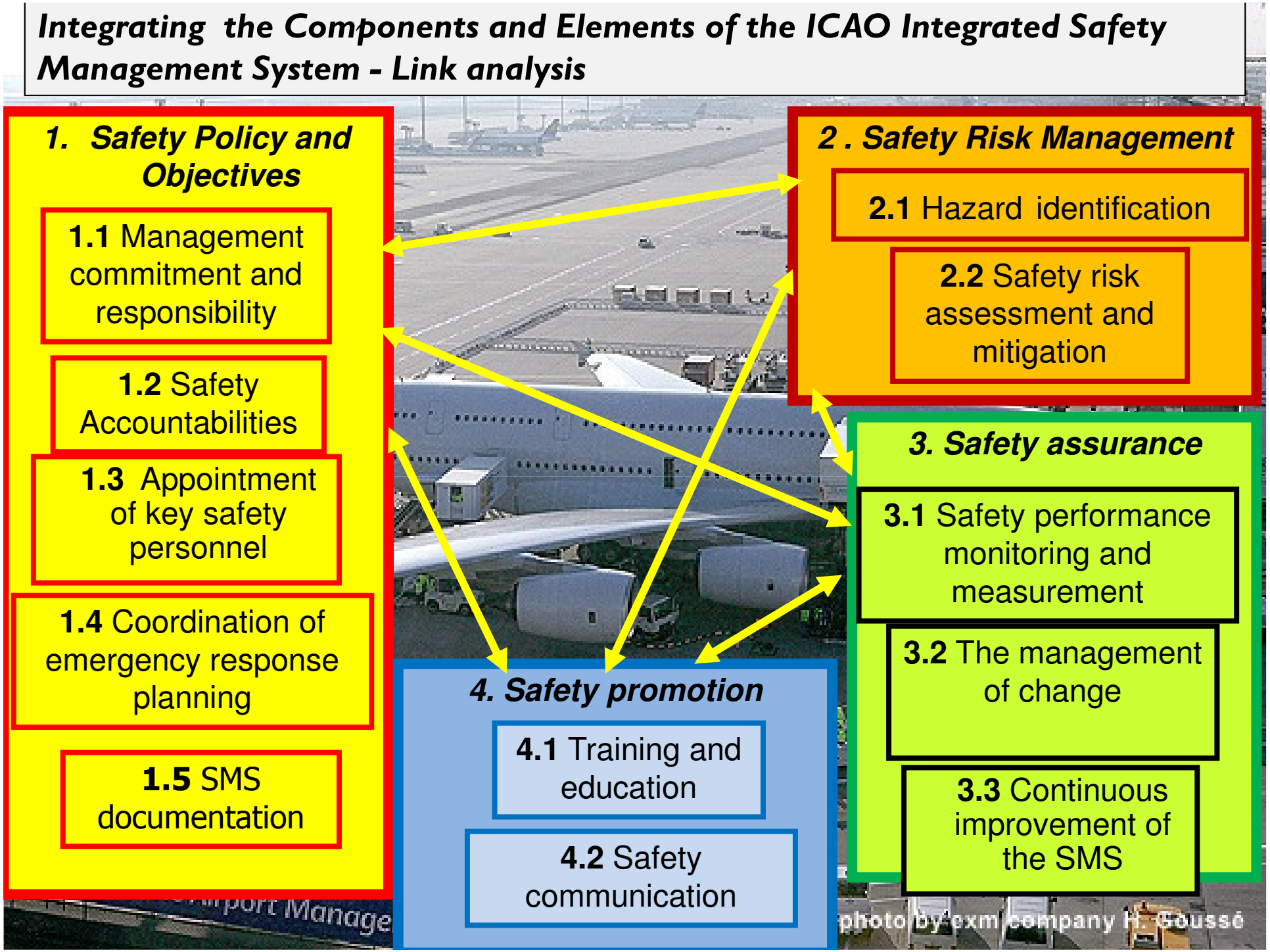
- **3.1** Safety performance monitoring and measurement
- **3.2** The management of change
- **3.3** Continuous improvement of the SMS

4. Safety promotion

- **4.1** Training and education
- **4.2** Safety communication

photo by cxm company H. Goussé

Integrating the Components and Elements of the ICAO Integrated Safety Management System - Link analysis



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Integration

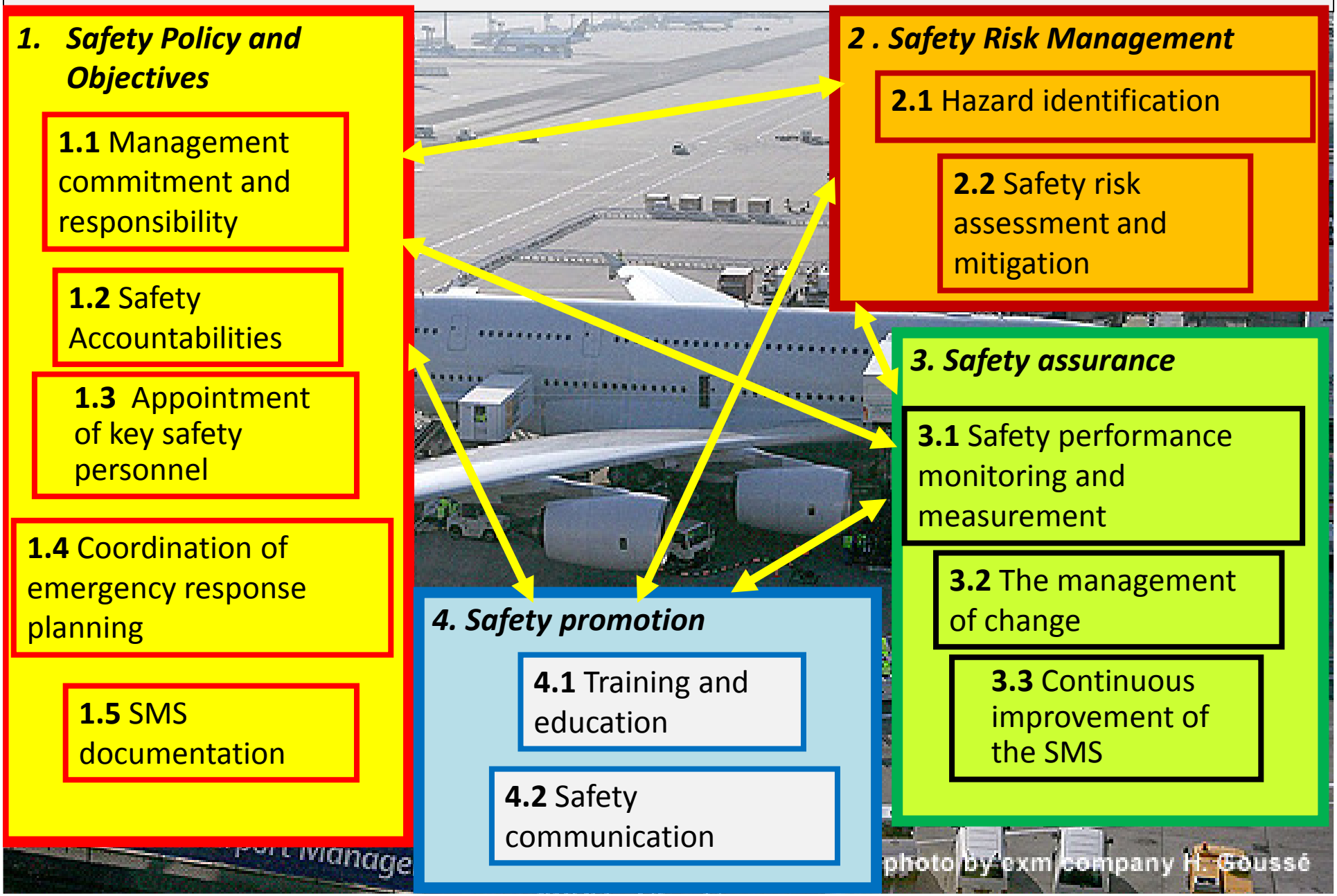
Disintegration

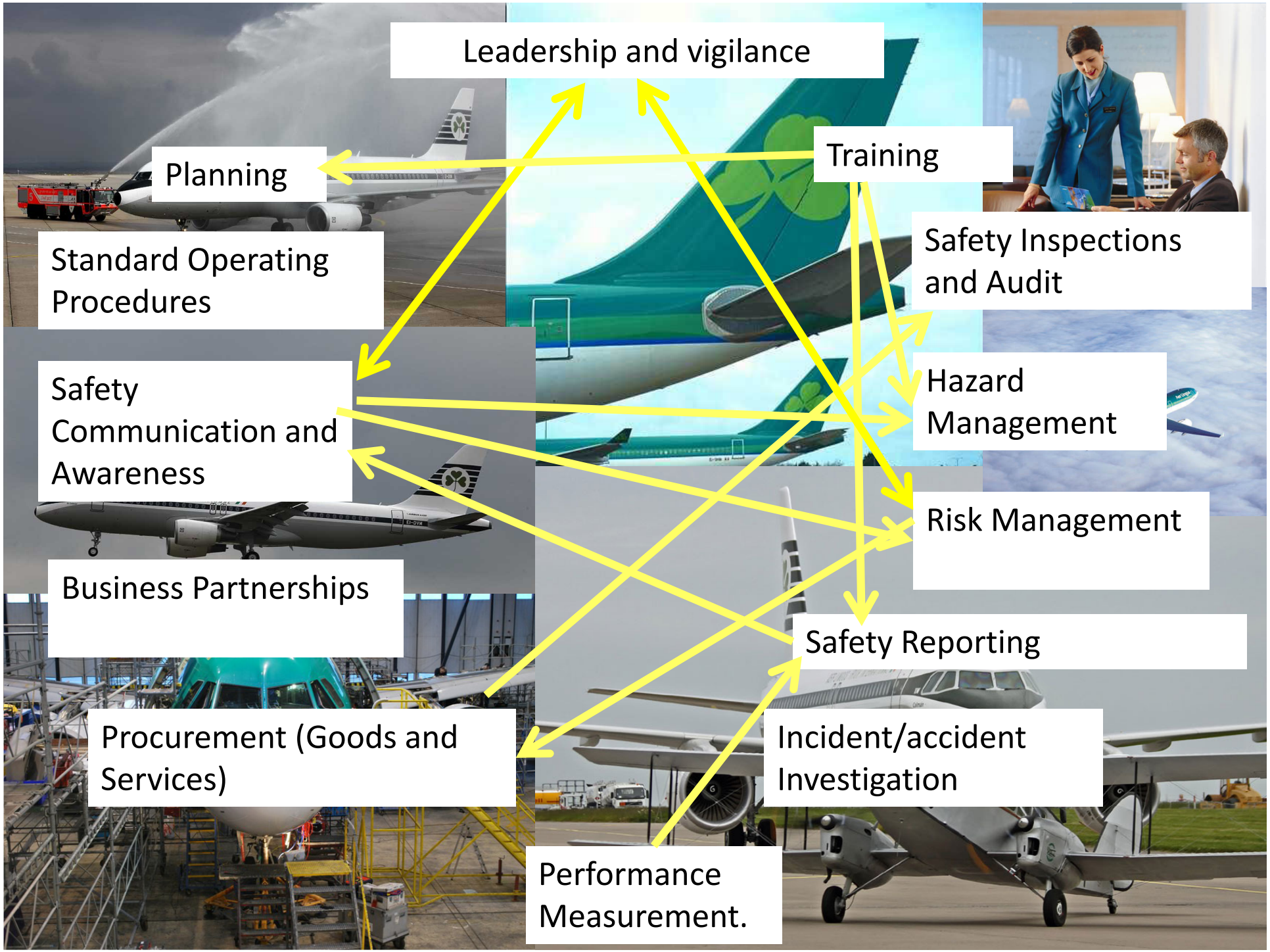
- An airline may have within it all of the elements of a safety management system
- However, if they do not function as an integrated system, the airline does **not** have an SMS

Integration 1: Integrating the components of an ISMS with each other

- To achieve integration of all the different elements of a SMS, they must communicate using a common language.
- The different SMS elements must be constructed using a common paradigm.
- This paradigm is provided by systems safety and human factors concepts, at both the individual and organisational levels.

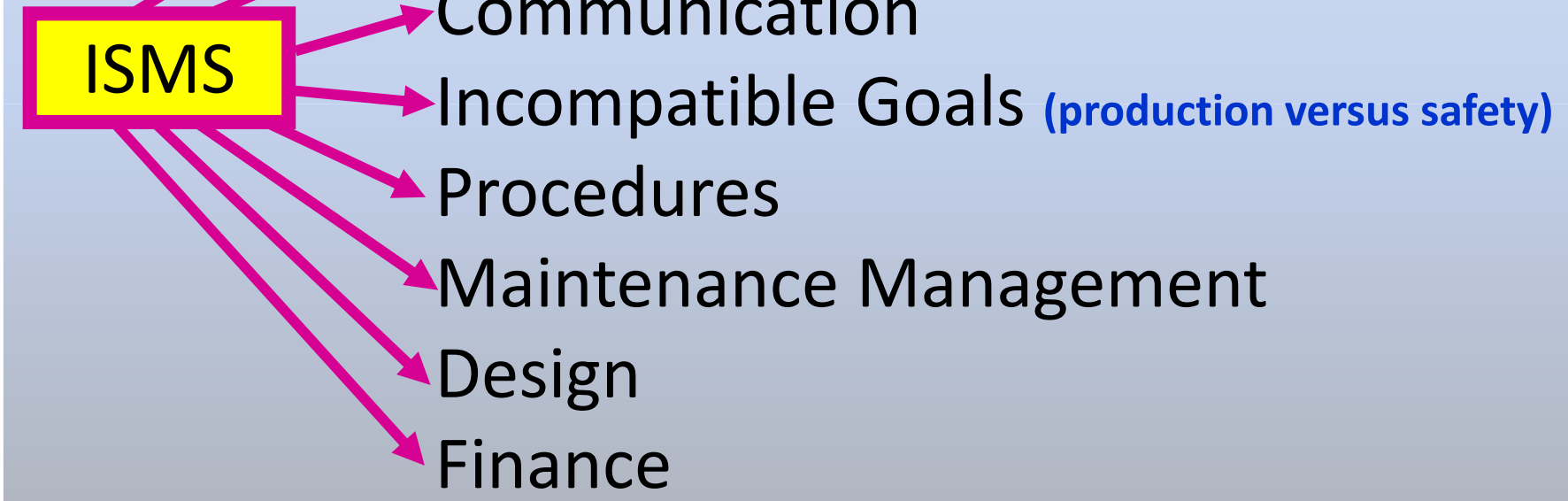
Integrating the Structure and Elements of the ICAO Integrated Safety Management System - Link analysis




Leadership and vigilance
Planning
Training
Standard Operating Procedures
Safety Inspections and Audit
Safety Communication and Awareness
Hazard Management
Risk Management
Business Partnerships
Safety Reporting
Procurement (Goods and Services)
Incident/accident Investigation
Performance Measurement.

Integration 2: Integrating the ISMS into the Business and Operational Processes of the Organisation

Consider each of these key organisational areas:



Senior Management must ensure formally that the organisation's ISMS has an input in each of these areas,

ICAO SMS Elements

Organisational Factors

1. Safety policy and objectives

1.1 Management commitment and responsibility
1.2 Safety accountabilities
1.3 Appointment of key safety personnel
1.4 Coordination of emergency response planning
1.5 SMS documentation

2. Safety risk management

2.1 Hazard identification
2.2 Safety risk assessment and mitigation

3. Safety assurance

3.1 Safety performance monitoring and measurement
3.2 The management of change
3.3 Continuous improvement of the SMS

4. Safety promotion

4.1 Training and education
4.2 Safety communication

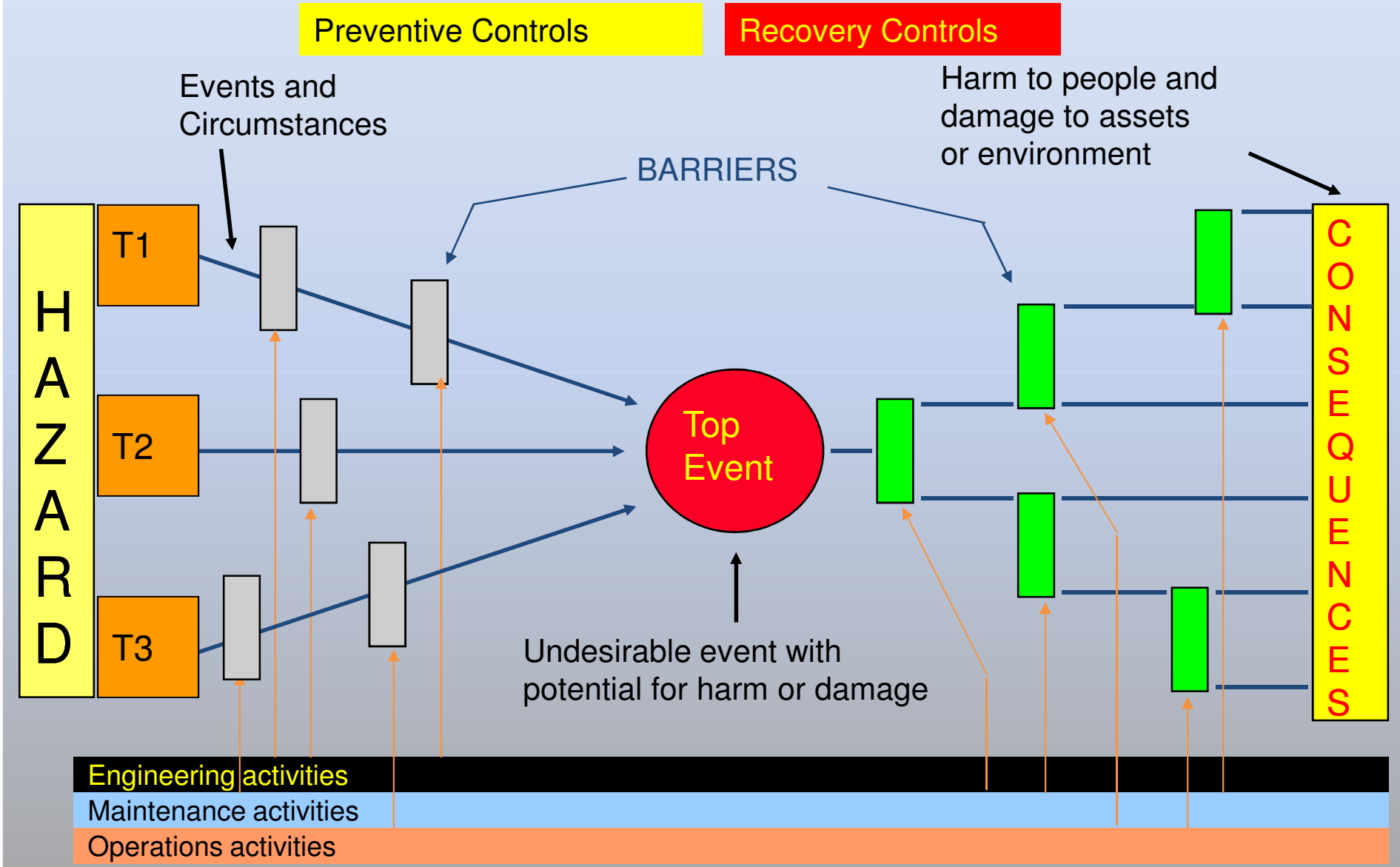
Equipment
Training
Communication
Incompatible Goals
Procedures
Maintenance Mgt
Finance

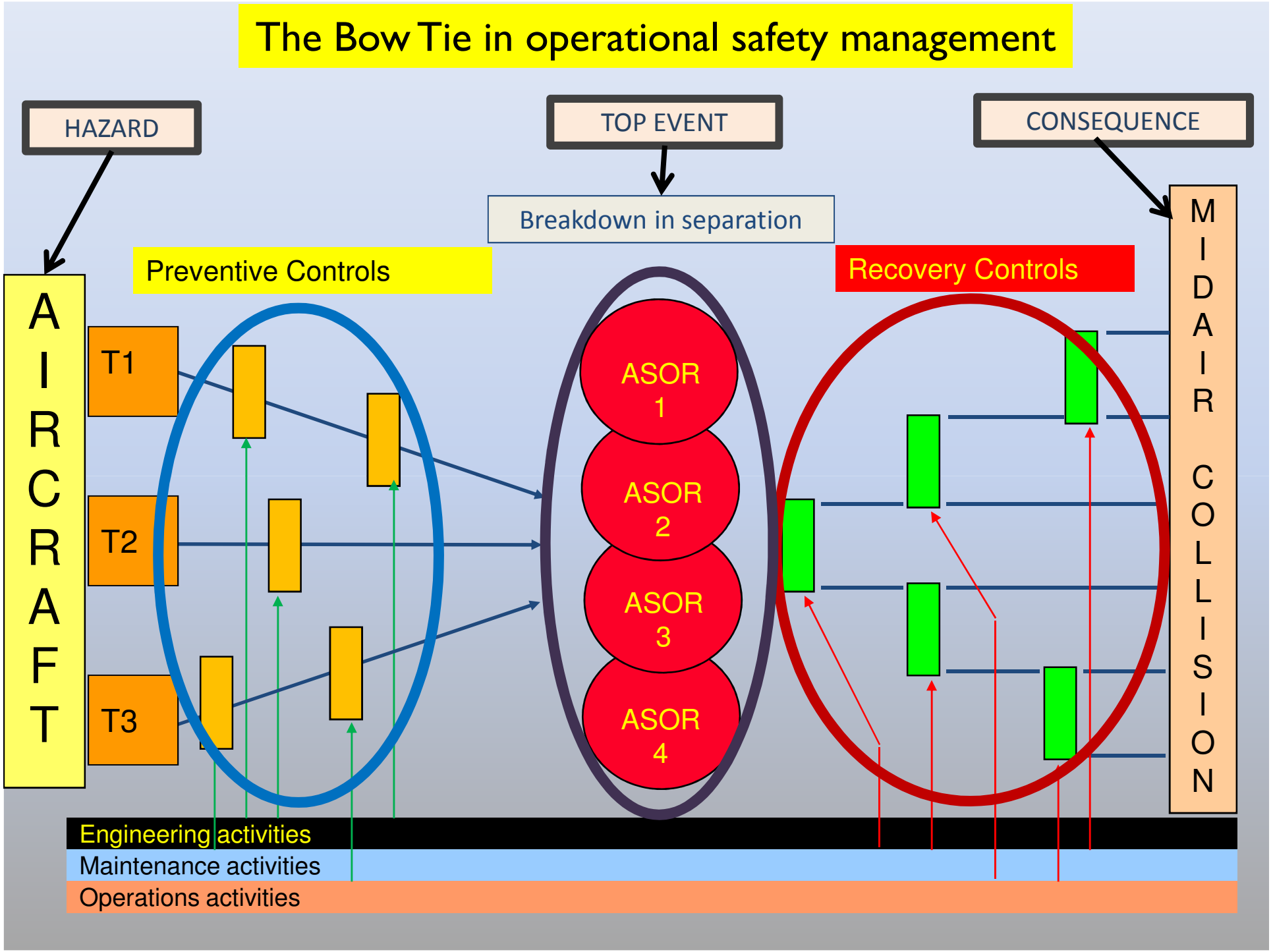

Leadership and vigilance
Planning
Training
Standard Operating Procedures
Safety Inspections and Audit
Safety Communication and Awareness
Hazard Management
A just and fair organisational culture
Risk Management
Business Partnerships
Safety Reporting
Procurement (Goods and Services)
Incident/accident Investigation
Performance Measurement.

New thinking in safety management

- Change our primary focus from the events to their **potential outcomes**, and:
  - the **preventive** controls that failed
  - the **recovery** controls that worked
- **The same sets of preventive and recovery controls are common to many generic categories of adverse operational events**

Basic Bow Tie Concept




The Bow Tie in operational safety management
HAZARD
TOP EVENT
CONSEQUENCE
Breakdown in separation
Preventive Controls
Recovery Controls
AIRCRAFT
T1
T2
T3
ASOR 1
ASOR 2
ASOR 3
ASOR 4
MIDAIR COLLISION
Engineering activities
Maintenance activities
Operations activities

The Bow Tie and operational safety management

HAZARD

TOP EVENT

Part fitted incorrectly

CONSEQUENCE

MAINTENANCE OPS

Preventive Controls

T1

T2

T3

ASOR 1

ASOR 2

ASOR 3

ASOR 4

Recovery Controls

AIRCRAFT UNARWORTHY

Engineering activities

Maintenance activities

Operations activities

Key questions for organisational safety management:

- What **controls** do we have in place now?
- Are they effective?
- What can cause them to fail?
- What are we going to do to stop that happening?

The ARMS Methodology for **Operational Risk Assessment** in Aviation Organisations

Developed by the ARMS Working Group, 2007-2010

ARMS Working Group members and contributors:

Capt. Charles Barbknecht Air Berlin
Capt. Andreas Beaujean Air Berlin
Harard Hendel Airbus
Jari Nisula Airbus
Jean-Marc Cluzeau Air France Industries
(replaced by Franck Danthez)
Tom O'Kane Aviation Safety Consultant (ex-BA)
Dr. Kwok Chan Dragonair
Gavin Staines DHL
Capt. Dave Prior easyJet
Capt. Philippe Pilloud easyJet Switzerland
Ivan Sikora Emirates
Dave Stobie Emirates
Marie Ward SR Technics
Capt. Carlos Nunes TAP
Capt. Martin Fleidl Tyrolean Airways

Harri Koskinen Finnair
Capt. Mika Pyyhtiä Finnair
Capt. Kristjof Tritschler Germanwings
Martin Nijhof KLM
Capt. Ruud Wittebol KLM
Simon Gill Mirce Akademy
Andrew Rose NATS (ex-BA)
Joao Brites Netjets
Claudia Cabaco Netjets
Gerard van Es NLR
Michel Piers NLR
Filip Denoulet Privatair
Jan Peeters Privatair
Bob Dodd Qantas Airways
Nancy Harmer Shell Aircraft International
Liam Sisk SR Technics, Dublin

Airline Risk Mgt Solutions (ARMS) Working Group

- Aim: Significantly improved methodology
- Safety practitioners from airlines and other organizations
- Over 150 man-days of work since Jun-07
- Two levels of deliverables by the end of 2008:
  - Conceptual methodology → Universal
  - Matrices etc. → Customizable at company level

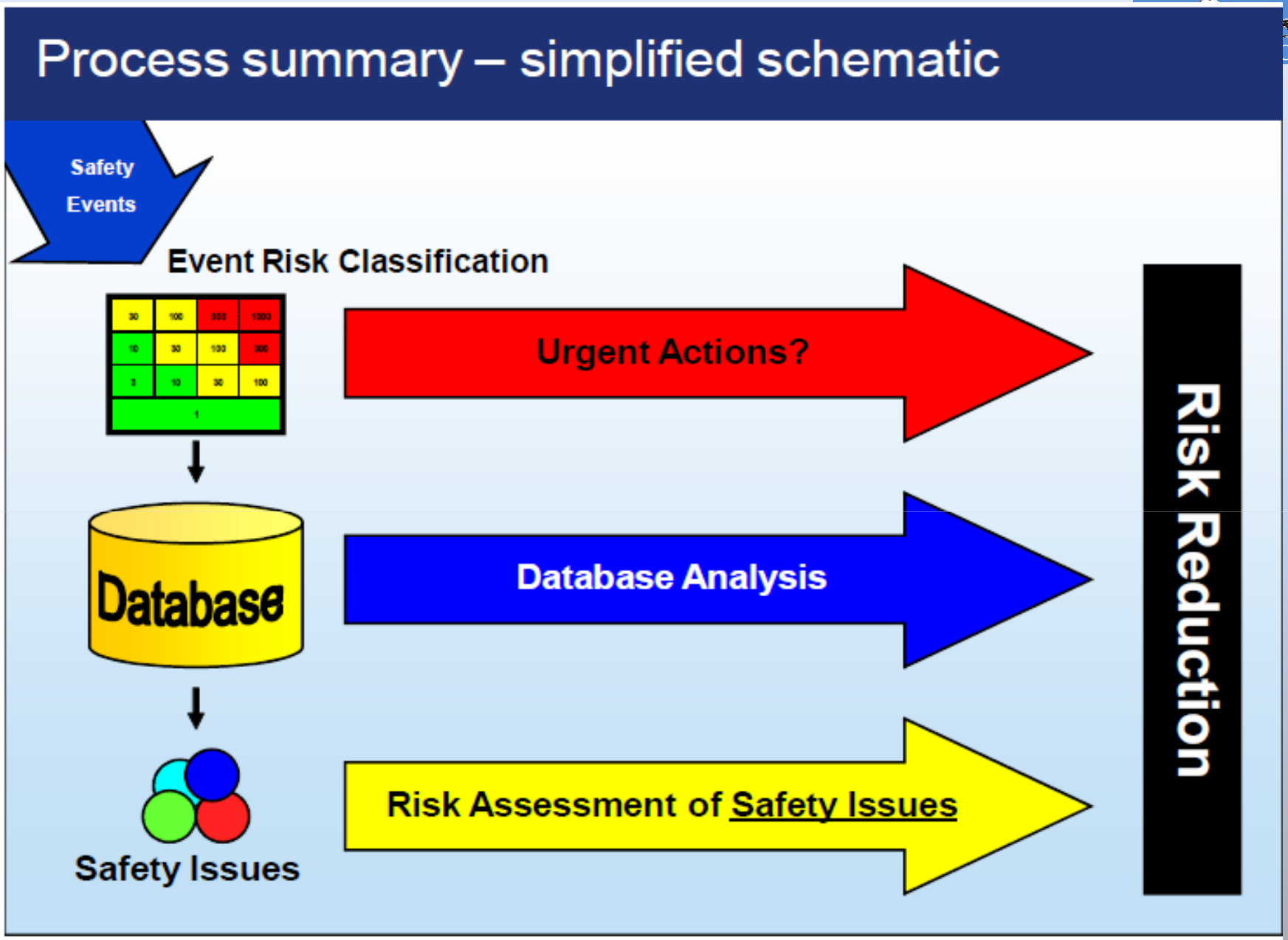


Figure 1. Simplified way to present the Risk Assessment process.

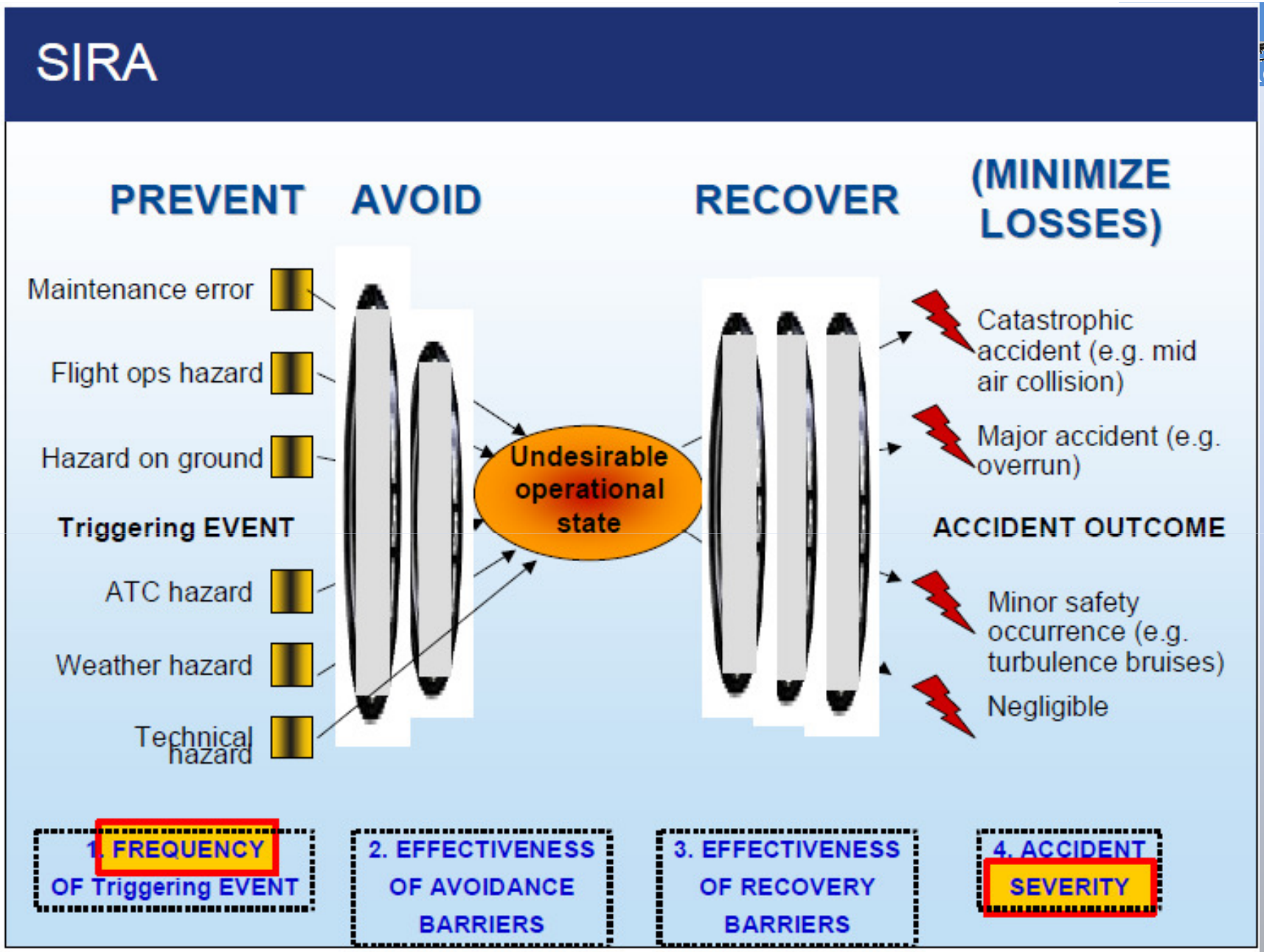


Figure 7. The model behind the Safety Issue Risk Assessment.

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Thank you