Flying is the safest way to travel: How aviation was a pioneer in independent accident investigation

John A. Stoop* and James P. Kahan**
* Delft University of Technology
Delft
The Netherlands
e-mail: johns@tbm.tudelft.nl

** The RAND Corporation

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Independent investigations of aviation accidents and incidents have been broadly accepted within the aviation sector throughout its history as a valuable tool to enhance safety. Such investigations enable the sector to learn by establishing the sequence of events that provides a satisfactory explanation of the accident leads to the drafting of recommendations to prevent reoccurrences. In addition, these investigations, which are publicly disseminated, encourage public confidence in the sector. Other transport sectors, including road, rail and water, have been slower in coming to enjoy the same acceptance of independent investigations; here, there is considerable variation amongst nations, and—with the exception of the International Civil Aviation Organization agreement—almost no international consistency. This article examines why aviation has had a different tradition in this regard. Reasons are found in parallel growth of aviation technology and the philosophy of investigative bodies, the inherently international aspect of commercial aviation, and the role of public and political pressure following major accidents. The safety investigative orientation of the aviation sector is gradually expanding to other transport sections and beyond that to other sectors such as fixed site production plants, health care, and management of natural disasters. With the newly installed Safety Investigation Board, the Netherlands has arguably placed itself at the head of this league table.

Keywords: aviation, accident investigation, safety

1. Taking off on the right foot

Aviation accident investigation is as old as aviation itself. Even before the Wright brothers, accident investigation at the international level has been an integral part of aviation policy making. Starting with 'lighter than air' craft, there was a need for supra-national agreements because hot air balloons could drift across national state borders and the vulnerability and limited manoeuvrability of zeppelins made them unsafe. The first international aviation conference in 1889 raised four fundamental juridical questions with regard to national sovereignty of the airspace and safety of aviation (Freer, 1986a):

- Should governments license civil aviation?
- Should there be special legislation to regulate responsibility of aviators towards their passengers, public and owners of the land where descent is made?
- Should the salvage of aerial wrecks be governed by maritime law?
- Should there be new rules for establishing the absence or death of lost aviators?

Establishing rules for uncontrolled flights in airspace or above territorial waters led to the first international aerial congress amongst 21 states in 1910 in Paris. The First World War spurred aviation technology, leading in 1919 to the International Air Convention on technical, judicial, and military aspects of aviation and the establishment of the International Commission for Air navigation (ICAN) (Freer, 1986b). The answers to these questions firmly establish safety and the investigation of accidents as a distinguishing feature of the aviation sector.

Compared to the other transport modalities, aviation may be seen as the safest way to travel. In aviation, the absolute number of fatalities in 2004 has regained the level of 1945 with about 430 fatalities worldwide, while production increased from 9 million to 1.8 billion passenger kms. Consequently, aviation has improved its safety performance since 1945 by a factor of 200. Simultaneously, road traffic production has tremendously increased on a global scale, but counts for about 1.2 million fatalities and 50 million injuries per year worldwide. The WHO identifies road safety as a global public health issue because road accidents are expected to become the third cause of death in 2020 (WHO, 2004). Maritime shipping and railways take an intermediate position in the safety comparison, because they contain specific safety critical issues such as ro-ro vessels and ferry disasters and track worker and level road crossing accidents respectively. It is an open debate whether accident investigations have been a main contributor to the increase in safety performance in aviation. In this article, the role of accident investigation as a systemic tool for safety improvement is explored across the modes of transportation.

The aviation sector was not the only sector to institutionalize its focus on accident investigation. Aviation and railways have a common background in recognizing the importance of understanding failure of complex systems, in particular where public confidence in their operational performance is at stake. Both modalities have a safety performance that far exceeds the performance of other modalities (Litman, 2005). Both aviation and railways do not only have a function as public transport modality, but also are subjected to a high public profile in case of a major event due to the numbers of casualties and material damage inflicted during the accident. During the early development of both these public transport systems, the precaution principle has been applied as the most sophisticated engineering design approach of the 19th century. This precaution principle combines a timely response to failure with an in-depth analysis in order to

understand the failure mechanisms. It was only during the Second World War that a probabilistic component in safety thinking was added as a second school of thinking to this approach to facilitate prioritization and cost-effectiveness estimates of safety enhancement measures. After the Second World War, risk management on a company level was introduced as a third school in thinking, evolving into a public safety and governance between all actors involved in safety in the transportation area (McIntyre, 2000).

In contrast to railways, which developed as a national transport system rather than on an international basis, aviation has maintained its international orientation throughout its development. Consequently, accident investigation has been based on an international consensus across stakeholders and nations through the implementation of Annex 13 of the ICAO agreement.

1.1 ICAO Annex 13

The landmark Annex 13 on accident investigation of the treaty establishing the International Civil Aviation Organization (ICAO) in 1944 was itself part of an evolutionary process aimed at assuring a safe, international aviation industry. As early as in the Interbellum, accident investigation in aviation was a crucial tool in safety enhancement. This type of dealing with failure emerged from the military aviation and rapidly spread to the civil sector. The British Air Accidents Investigation Branch had its origin in the Royal Flying Corps in 1915. The Air Navigation Act 1920 gave the Secretary of State for Air power to make regulations for investigating air accidents. By that time, air crashes were investigated in almost every country in Europe as a prerequisite for developing an international civil aviation network.

Towards the close of the Second World War, the USA, Canada and the UK took the initiative to establish ICAO to harmonize international civil aviation and set standards and procedures for developing the sector on a global scale. The Chicago conference dealt with routes, rates, fares and frequencies, elaborating on the commission that gathered in Paris in 1910 on the technical aspects of air navigation. The conference was not a total success; many issues were settled along lines of bilateral agreements rather than global treaties.

But accident investigation was successfully negotiated. As part of the treaty, a series of Annexes was drafted, including Annex 13, setting rules and standards for accident and incident investigation. To avoid a conflict between States, this Annex set forth conditions facilitating participation of stakeholder States -such as nations of manufacture, operation or registration- in an accident investigation conducted by the State of occurrence. (Freer, 1994). Key to the agreement was a strict separation is maintained between technical investigations and judicial inquiries, as a result of a clear distinction between blame and causation for the benefit of taking rapid and necessary measures.

As the flywheel for progress the level of technical harmonization is selected focusing on navigation, communication and reliability. The precaution principle and a timely feedback of findings are pivotal. Annex 13 set the terms for cooperation between states which are involved in an aviation accident, namely the States of occurrence, operations, registry and manufacturing. (ICAO, 2001).

This agreement, which now appears to be simple common sense, needs to be understood in the context of its era. In 1944, the US and UK national administrations fulfilled the role of problem

owner. Operators were still in their infancy and focused on their own world region. A fierce, wartime related competition was going on between the many American and British aircraft designers and manufacturers. Due to the war, many former European competitors had not even started with their revival, if allowed at all by the allies in contrast with the UK and US aviation industries, which were on their peak production due to the war. The UK and US took their natural role as the advocates for internationalization of civil aviation. However, they had to cope with a careful coordination and cooperation with other sovereign national state interests.

After the war, the implementation of accident investigation primarily focused on technological development of the aircraft. Many resources had to be invested in improving the technical reliability of the aircraft, because new technologies were in their infancy, causing teething troubles in various areas. New technologies involved the introduction of pressurized cabins, jet engine technology, radar and all-metal airframes.

The large-scale introduction of civil aviation required a change in aircraft design. Before the war, civil aircraft were derivatives of military aircraft with respect to their design concepts as well to their construction and materials. After the war, large civil aircraft had to transport great numbers of passengers over long distances, based on regular timetables, putting high demands on endurance, range and comfort. In contrast to these requirements, military aircraft were designed for relatively short-range combat performance, serving as airborne battle stations. National administrations were tasked with certification of these civil aircraft, in contrast with military aircraft, which remained submitted to a manufacturer based certification process.

1.2 Separation from blame

Even before the Second World War, the concept of learning from deficiencies was promulgated in aviation. Safety was viewed as an industry-wide problem, rather than one for any single operator, manufacturer or State. The concept was further developed in wartime aviation. Flanagan et al. (1948) conducted possibly the first study of incidents and "near misses" in aviation when he surveyed U.S. Army Air Corps crews to determine what factors influenced mission success and failure. Anticipating modern results, he found that the critical factors were to be found more in human performance than aircraft technology. In order to keep public faith in the aviation industry, a common process of learning without allocating blame was deemed necessary. In order to provide a timely feedback to all stakeholders in the sector, accident investigations had to be separated from judicial procedures, which focus on individual responsibilities and liability.

This attitude of the aviation sector in this regard may be viewed as a precursor to the precautionary principle, which finds its current expression with regard to aviation in RIVM (2003):

In order to protect the aviators from threats of serious or irreversible damage, a timely response is required, while a lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent further degradation.

Consequently, two types of investigations emerged, which could be conducted parallel to each other: an independent technical investigation into the causes of an accident and a judicial inquiry into responsibilities and liability.

The blame-free approach has clearly borne fruit. Technical investigations into the failure of designing and operating aircraft have seen an impressive development. Based on a limited number of 'showcases' design principles were developed, such as fail-safe, safe life, damage tolerance, crash worthiness, situation awareness or graceful degradation. Several famous cases such as the De Havilland Comet, Tenerife, UA-232 Mount Erebus, TWA-800, Valuejet and Swissair have identified deficiencies in the aviation system, sometimes at some remove from the proximal cause of the triggering event. They have led to many practical changes as well as new expertise on specific academic areas varying from as metal fatigue to human failure, crew resource management or life-cycle maintenance.

1.3 Independence from state interference

During the 1960s, the issue of independence was raised in order to relieve investigations from a dominant influence of the State. During investigations, the influence of State interests, secondary causal factors and circumstantial influences should also be addressed. The debate on this matter can be traced to around 1937, after a series of major air crashes. Arriving at such independence, however, proved to be a long process, and still is not completed. The current situation ranges from full independence—largely to be found in North America, Australia and New Zealand, Scandinavia and the Netherlands, nominal dependence but factual independence—such as in Germany and the United Kingdom, and dependence. Progress has been slow as nations own national airlines and therefore are both stakeholders and expertise providers in accident investigation (see Cairns, 1961). Smart (2004), reviewing the history of accident investigation, also views the fundamental differences between inquisitory and accusatory legal systems in the various European countries as having a role in the different paces of development, as well as the slowness in implementing the recommendations of the 1988 Wilkinson and Rapp reports calling for harmonization of European aviation investigation.

Today, the European Union seems to be heading for a single-mode, international accident investigation board, exclusively focusing on aviation. Major players are the UK, France and Federal Republic of Germany, counterbalancing the influence of a strong US/Canadian industrial position.

The introduction of the EU Directives on mandatory, independent maritime and railway investigation agencies strengthens a wider application of accident investigation along lines of modality specific developments (ETSC, 2001).

In responding to specific European needs in harmonizing practices current in the States of the Community, an additional procedural arrangement on ICAO Annex 13 has been developed. This development led to the EU Directive 94/56/EC on Accident Investigation, despite fundamental differences between legal systems in the various countries of the Community. Conflicts of interest linked to the issue of double inquiries by technical permanent bodies and by judicial authorities were recognized, but nevertheless lead to a Community strategy to adaptation of the existing legal and institutional framework, harmonizing national legislation and strengthening cooperation between Member States.

As a consequence of the notion that incident investigation and analysis could be a source for safety recommendations, the EU has issued a Directive 2003/42/EC on mandatory incident registration in aviation. Sofar, the aviation sector has been unique in issuing mandatory investigation of incidents in addition to accident investigations.
Although strong relations have remained between military and civil accident investigations, military accident investigations have had its counterpart of ICAO Annex 13 in the NATO Standardization Agreement (Stanag) on the Investigation of Aircraft/Missile Accidents/Incidents.

2. Other transport modalities have had more difficulty getting off the ground

Other transport modalities - rail, sea, road - have not enjoyed the success of aviation in establishing independent, blame free investigation. Here, we briefly summarize the evolution of these other modalities, using the Netherlands as a not atypical case in point.
For further reading on this topic a reference is made to Roed-Larssen, Stoop and Funnemark (2005).

2.1 The railway sector

In the railway sector, accident investigation into the technical causes of railway disaster was established in the middle of the 19th century. Although the role of the state was initially asserted in order to control private railway companies, the nationalization of railways in many countries eliminated hampered any international harmonization. Unlike aviation, rail infrastructure was on the ground and strictly within national boundaries. Even the gauge of track width was not immediately standardized, and international rail traffic was not as rapid to develop as international aviation. Thus, the issue of railway safety was on a national level, and because railways were by and large nationalized, the responsibility of the owning national government. Only recently have trends such as privatization of the rail system, high-speed trains that increase the international component of rail traffic, and the European Commission-sponsored encouragement of Trans European Networks taken some of the notion of national ownership of rail safety away; this remains work in progress. This, in conjunction with rapid technological developments in high-speed trains, light-rail developments and the establishment of dedicated cargo or passenger railway corridors, has led to a call for common safety standards throughout Europe. At the same time, several major railway accidents have occurred in the UK, Germany and Norway, triggering public interest in safety of the railways.
The Dutch have been leaders in the separation between blame and causation in rail (SOR, 1997). The groundwork for this was laid in the middle of the 19th century, when the Dutch government took a role in technical investigations into railway accidents. In 1860, a Supervisory Council was established, based on the need to monitor technical failure during implementation of improvements on the railways such as exploding steam boilers, derailment of trains, deficient pneumatic braking systems, signalling failures and railway crossings with bridges and roads. From 1925, on an investigative State Committee with permanent members existed, which were ad-hoc available in case of railway accidents. This State Committee however never assembled.

Full maturity of rail accident investigation in the Netherlands only occurred after a series of major accidents in the early fifties. The Dutch Parliament established a permanent and independent Railway Accident Investigation Board (SOR for its Dutch name) in 1956 (Jongerius, 1993). The SOR was merged with the other transport modes in 1999 into the Dutch Transport Safety Board and in February 2005, this board was itself merged into a general Safety Investigation Board.

From its inception, the Dutch SOR has been a pioneer in accident investigations with respect to combining its systems approach with independence. This example has been followed by other countries from the 1990's on, being the USA, Canada, Sweden, Finland, Australia, New Zealand and India. Other countries more and more accept the concept of a systems approach, but only the above mentioned have chosen the combined concept.

This SOR developed a vision which copied the orientation of aviation. In this vision, it was assumed that duplicate investigations of the same accident—by the railway company, by the government railway inspectorate, and by the SOR itself—was inefficient. For blame, the first two investigations were sufficient, and the SOR could only add value in adopting a different approach. Consequently, the SOR did not focus on disciplinary actions against a train driver, but focused on identifying accident causation factors on higher systems levels. Organization, management responsibilities for training, equipment, rolling stock, signalling and infrastructure came under scrutiny as well. The SOR was probably able to develop this vision because its membership came from a combination of technological experts from the Delft University of Technology, judicial magistrates and experienced operators. This composition enabled the SOR to identify systemic deficiencies in the railway system based on a combined expertise in technological analysis, ability in causal thinking and operational practice.

2.2 The maritime sector

In shipping, the international component has always been present, but technology was not so fast to develop. Although similarities exist between ICAO Annexes and International Maritime Organization (IMO) resolutions, the shipping sector has seen a different development with respect to accident investigation. Technological innovations such as navigation and communication electronics did not occur at the same time as other developments such as double hull development, nuclear power propulsion, or other safety-related advances in merchant shipping. A territorial state interest was not pervasive because most maritime accidents take place in international waters, often far from the country of registry. Because voyage and data recorders are recent additions to maritime shipping, accident investigation tended to focus on the human factor. This in turn led to an historical focus on blame, with the countervailing force of maritime guild organizations taking control of investigations to protect their membership from "inexpert" blame. The Dutch Maritime Board, founded in 1909, is a classical example of this, with a membership selected from amongst sector veterans, and a concentrated focus on policing its own membership instead of letting civil courts adjudicate human errors.

Maritime safety has entered public awareness largely through human disasters (the Herald of Free Enterprise ferry and others) and environmental damage (the Exxon Valdez and others). Here, compensation for victims largely dominated accident prevention, and the focus was clearly

upon blame. National interests were also so dominant that a fully independent investigation was hindered.

Modern independent safety investigation in the maritime is generally only found where multimodal safety boards have been established (e.g., USA, Canada, Finland, Sweden, the Netherlands), and even there, success is slow in coming. The Dutch Maritime Board successfully avoided integration into the multimodal Transport Safety Board for several years. The Estonia ferry disaster, jointly investigated by Sweden and Finland, is not regarded as a highly successful investigation. An interesting exception to this pattern is the UK Maritime Accident Investigation Branch, which, although nominally not independent of government, effectively functions independently.

At a European level, mandatory maritime accident investigations are restricted to specific segments of the maritime sector such as high speed passenger crafts and ro-ro ferries. This obligation has been established in the EU 1999/35/CE Directive. Previously, the IMO (International Maritime Organisation) has set the context for investigating maritime casualties and incidents by issuing Resolution A.849(20) and A.884(21).

2.3 The road traffic sector

In the road traffic sector, the dominance of the private sector and the fact that road accidents are very frequent but not severe compared to other modal accidents, have led to a slow development of modern accident investigation. Most accident investigations are done by the police and insurance companies instead of independent boards; indeed, the boards would be overwhelmed if required to investigate all but a small minority of road accidents. Technical investigations have been restricted to the automotive industry as a responsibility of car manufacturers. A limited number of leading car manufacturers have contributed to a major extent to the improvement of the safety of road vehicles. Emphasis has been laid on the safety of the occupants. In addition to the technical reliability of the cars, a reduction of the secondary effects to occupants in reducing injuries has been focal. National states have had very limited interest in accident investigation apart from police investigation for judicial purposes. Insurance companies and the health care system cover non-judicial issues. There does not seem to be a structural need within the road traffic sector itself by the abundant presence of compensatory mechanisms at a societal level.

In addition, public pressure seems to be weak. Public perception of road accidents indicates that such accidents are classified and perceived by the public as high-probability/low-consequence events. Such small-scale events leave little public concern and are psychologically different from events with multiple casualties in the group risk segment of public risk perception. Due to the involvement of the health sector in road injury and mental trauma treatment, road traffic safety frequently is defined as a health problem rather than a transportation problem.

3. Unifying modalities to level the playing field

The head start of the aviation sector is being compensated for by the growth of multimodal investigation boards. This growth is powered by three engines of change.

3.1 Multimodality

The initiative for this development started in the USA, where in 1967 the National Transportation Safety Board becomes the first multi-modal investigation agency in the world. Multi-modal boards followed in Canada, Australia, New Zealand, Sweden, Finland and the Netherlands. In addition to a visionary approach, based on the concept of multi-modal and systemic learning, arguments of economy of scale, critical mass in investigative resources and organizational efficiency play an important role in particular in smaller countries (Kahan, 1998).
Establishing such multi-modal boards is frequently initiated by parliamentary interference after one or more major events, which disrupt a public confidence in the transport systems. A breakthrough of independent investigations in the public eye occurs after a series of major events outside the transportation sector, such as with disco fires in Sweden and the Netherlands. The European Union takes initiatives to advocate independent accident investigations as a consequence of the introduction of the Seveso Directive on major hazards.
Recently, a new development in accident investigation has emerged. Transportation Safety Boards are faced with new missions, dealing with public faith, serving as a public safety assessor, support to victims and relatives in taking care of family assistance and focusing on rescue and emergency services in their performance in dealing with the aftermath of major accidents (MPM, 2002; Stoop, 2002; Stoop, 2004).
In an even wider context, due to the occurrence of disasters in other sectors, various Transportation Safety Boards in Europe are developing into multi-sectorial agencies, covering other sectors such as health, defence, industrial sectors, natural disaster, and events such as explosions, major fires and collapse of buildings. In this respect, independent accident investigation is considered every citizens' right, society's' duty (Van Vollenhoven, 2001).
In the USA, this broadening of the concept of independent investigations has lead to the establishment of the Chemical Safety Board and National Construction Safety Team Act following the role model of the National Transportation Safety Board.

3.2 The engines of change

Three engines for change can be identified which each by themselves, are a necessary condition for accident investigation. In addition, they have to occur simultaneously in order to implement the concept in a sector on a sustainable basis.
These engines are:

- The role of the state and its sovereignty in an international context.
- Technological innovation and its reliable performance on a large scale.
- Separation of technical investigations and judicial inquiries, based on the principle of precaution.

As these engines coincide, a structural need for timely adaptations and system change occurs. Impulses for change can be explained based on the structural needs of the sector itself, not by a public concern on the credibility of a sector. In case of an outside impulse, such as with aviation disaster, sometimes several similar accidents have to occur before a sector responds.

A worldwide implementation of accident investigation in aviation may be considered a unique coincidence of three necessary conditions for a sector-internal motivation to conduct accident investigations.
This implementation has not only lead to a significant increase in safety, but also contributed to developing expertise and knowledge about the actual safety performance of the sector. A vital issue has been maintaining public confidence in the sector in order to develop a worldwide aviation industry.
On one hand, in passenger transport, the public is the customer who puts its faith in a safe, efficient and smooth performance of the services rendered. Once this faith is lost, the sector will have to face the fear of going out of business as has been recently demonstrated by the WTC attack, Gulf war and SARS.
On the other hand, the performance of the transport sector is in the public domain. Accident are visible in the public eye, being bystanders and potential risk bearers in case of a transportation disaster, such as an air crash in an apartment building, a release of hazardous materials or a tunnel fire. Rescue and emergency in incident and disaster handling are public duties in case of a transportation disaster. Public governance is a direct stakeholder in transportation accidents in contrast to site managers of fixed installations in other sectors of industry.
Due to the complexity and high-technology nature, aviation has additional specific characteristics, which necessitate a technical investigation into unexplained failure of such transportation systems, based on the precaution principle. Similar characteristics are emerging in railway systems with the development of Trans-European Networks, technological innovation and privatization of national railway companies.

3.3 Aviation and rail remain more advanced

It may not be surprising in this context that a present trend towards multi-modal national safety boards primarily covers the aviation and railway sector.
In aviation, both schools dealing with failure have been applied, providing a basis for a redundant strategy for safety performance. Combining both schools provides a synthesis between a deterministic approach, based on understanding failure and a probabilistic approach, based on predicting failure.
Historically, the railway sector has not seen such a worldwide implementation of independent accident and incident investigation as in aviation. The engines that have driven change were not so powerful due to the characteristics in national railway companies in the various countries across the world. Recent developments in railways, such as interoperable international networks, introduction of technological innovation and the changing role of the state have brought more similarities with the aviation sector.
Due to these major changes, the advocacy for independent accident investigation agencies in railways is growing. In various countries, such as in Japan, Korea, Scandinavia, the UK, the Netherlands, USA, Canada, Australia and New Zealand, combined independent safety investigation agencies include at least aviation and railways. They seem to be the pathfinders for a multi-modal safety strategy.

4. Conclusion

The driving forces for independent accident investigations come from both within a sector and without. From within, improvements in technology and a need for awareness of potential negative effects of technology drive the need to understand the causes of accidents. From without, public trust, political pressure and international coordination drive the need to prevent and mitigate accidents. For the commercial aviation sector, all of these came together at the same time, as the need for interoperability, punctuality and reliability, international determination of responsibility and responding to the inherent human fear of being in the sky with nothing between you and the ground but air converged to demand the highest standards of proactive safety. In other sectors, legacy systems such as guild protection, intra-national needs for guilt assignment and punishment, and a different rate of technological development meant that pressures for adoption of causality-oriented safety science were not as great.

Nowadays, at the European level, it is recognized that independent safety investigations represent a citizens' right and society's duty for investigating systems deficiencies in all sectors of society (Van Vollenhoven, 2001). The European Commission has installed a Group of Experts with the task to harmonize investigations by developing a common methodology and to adapt existing investigation techniques and methods to new requirements of changing technologies and institutional constraints.

In recent times, the increasing internationalization of nearly everything, the accelerated rate of technological development and increased consumer demand for safety have brought not only transport but also other sectors to adopt the accident investigation methods pioneered in aviation.

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