Rethinking the Global Air Transport System

Walter S. Baer

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PREFACE

A recent study by the European-American Center for Policy Analysis for the Netherlands Ministry of Transport, Public Works and Water Management\(^1\) has assessed safety and related issues resulting from increased air traffic at Amsterdam Schiphol Airport. This paper takes a broader view of the problems and issues surrounding the rapid growth of commercial air transport worldwide. It seeks to provide a basis for further discussion and examination of these issues and future options for the global aviation system.

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SUMMARY

After a half century of remarkable growth, the global “system” of commercial air transport is showing clear signs of stress. This paper describes the current system and the changes that are occurring which pose increasing challenges to the aviation industry, regulators and governments. It argues that improvements in individual parts of the system will not be sufficient to deal with public concerns about safety and other issues resulting from anticipated future growth and change. Rather, it is time to take a fundamental look at the total system and how it could evolve to function more effectively in the new aviation environment of the 21st Century.
I A CHANGING GLOBAL SYSTEM OF COMMERCIAL AVIATION

The modern era of commercial air transportation began in 1944, when 52 nations met in Chicago to sign the Convention on International Civil Aviation and establish the International Civil Aviation Organization (ICAO). Commercial aviation then began to develop rapidly in North America after World War II, spurred by a vigorous aircraft manufacturing industry, the availability of trained pilots and air crews, and burgeoning passenger demand in an expanding civilian economy. Aviation growth spread as economic recovery proceeded in Europe, Japan and other industrialized countries in the 1950s, and accelerated with the introduction of jet aircraft into commercial service at the end of that decade. Commercial jets also brought affordable international air travel to millions of business and leisure passengers.

Air travel is inherently a system of tightly interconnected private and public sector components: airframe and subsystem manufacturers, air carriers, training and maintenance organizations, airports, ground transportation, navigation, and air traffic control (ATC) and management (ATM) systems. The overall “system” established in the post-World War II era was characterized by strong national entities closely allied with governmental authorities. Together, they shared responsibilities for planning, implementing and regulating aviation operations and growth. These entities include:

- large airframe manufacturers, especially Boeing (and now including Airbus), who set de facto equipment standards and took on responsibility for overall system safety, both in their own interest and as a general public good.
- dominant national carriers, often state owned and subsidized.
- publicly owned airports in major cities, tightly linked to national “flag” carriers.
- strong national civil aviation authorities such as the Federal Aviation Authority (FAA) in the United States.
- national, state-owned air traffic control systems.
The balance among aviation objectives -- safety, economic growth, innovation, efficiency, environmental protection, and security -- was basically determined by national civil aviation authorities. International cooperation among national authorities was managed largely through bilateral agreements, but with some coordination of standards, operating procedures and data collection by ICAO. In Europe, regional coordination began in the 1970s with the formation of the European Civil Aviation Conference (ECAC) and was strengthened with the creation of the Joint Aviation Authorities (JAA) in 1989. Although the former Soviet Union and other socialist states were never really part of the commercial aviation system developed by the West, there was enough formal and informal coordination to allow limited flight traffic between East and West. And commercial aviation in many developing countries was established and maintained largely through relationships with carriers and manufacturers in the industrialized countries.

This “system” remained relatively stable through five decades of technological advance, economic development and passenger growth. But it now finds itself under stress from changes in nearly every important dimension:

- increasing demand for international air travel to more destinations.
- breakup of the Soviet Union and fragmentation of its aviation resources.
- growth of new players such as China and India which have relatively weak national systems for commercial aviation.
- pressures for deregulation and privatization of carriers and ATM systems.
- less stability for national “flag” carriers that face increased competition.
- capacity constraints at many airports and in national ATM systems.
- inconsistent standards and operating procedures among nations.

In sum, the fifty-year-old international system created by the Chicago Convention is showing increasing signs of strain. Existing international aviation organizations do not have the power to reform the system or effectively manage the changes that are occurring. Nowhere is this more evident than in the efforts to reduce risks and manage aviation safety.
II CHALLENGES TO AVIATION SAFETY

Maintaining public confidence in the safety of air travel poses continuing challenges to governments and the commercial aviation industry. Although commercial air travel remains among the safest modes of transportation, rapid expansion of worldwide air traffic and moves toward airline deregulation, along with several well-publicized airplane crashes in 1994, have prompted growing public concerns about air safety.

Per flight, the risk of a fatal aviation accident has fallen nearly 50 percent during the past thirty years.\(^1\) Yet while statisticians and other experts focus on the accident rate per million departures or per million passenger-miles, public perceptions of air travel risks appear based more on the number of fatal accidents in a given time period, or the total number of lives lost. By these measures the future looks less sanguine. Fatal accident rates have not declined appreciably in the past decade, and the number of flights and passengers continues to grow. A simple extrapolation of current data and trends would inexorably forecast continuing increases in the number of people who will die in future airplane crashes.

As a consequence, many in the aviation field believe it urgent to focus more effort on lowering accident rates significantly, with a goal of reducing risk by factors of two or three over the next twenty years. But is this a realistic goal? How can it be accomplished? What are the priorities and next steps?
III INTERRELATED SAFETY FACTORS

Concerns about aviation safety involve at least six important risk factors: air traffic growth; deregulation and increased competition among air carriers; changes in the aircraft fleet mix; constraints on airport construction, expansion, and operations; inadequate or incompatible national systems and standards; and terrorism and other threats to security. We first outline these factors in turn, and then consider the interactions among them.

Air Traffic Growth.

Spurred by improving national economies and burgeoning international trade, commercial air traffic continues to expand throughout the world. Since every flight involves some risk, more flights imply the likelihood of more accidents (assuming other factors remain the same). And more flights at peak hours when passengers want to travel bring added congestion that itself increases risk.

Passenger enplanements in Europe have been growing at a 5-6 percent annual rate for the past five years, and are forecasted to grow only slightly more slowly through the first decade of the 21st Century. This implies that passenger enplanements within the European Union (EU) will double from slightly over 500 million in 1994 to more than 1 billion annually by 2010. In the United States, the Federal Aviation Administration (FAA) forecasts average annual passenger growth of 3.5 percent for domestic traffic and 6.6 percent for international air travel. Air travel outside of Europe and North America is growing even more rapidly, although accurate and timely data are often lacking. We do know that expanding international trade generates more air traffic, both for passengers and cargo. ICAO estimates that every one percent increase in exports generates a 1 1/2 percent increase in air cargo shipments.

Deregulation and Increased Competition Among Air Carriers.

The United States deregulated air carrier entry, routes and prices in 1978. The European Union is committed to liberalizing its regulations and to open the European market to all EU carriers in 1997. Other countries are implementing or seriously considering deregulation of commercial carriers.
Beyond simply spurring competition, liberalization has a number of significant effects, many of which can be estimated from the experience of commercial air carriers in the U.S. since deregulation. Likely changes include:

- entry of many new carriers, followed by a period of consolidation.
- more mergers, acquisitions and strategic alliances among carriers.
- lower ticket prices resulting in higher traffic volumes on many routes.
- more volatility in airline profits and financial stability.
- elimination or reduction of subsidies to national airlines.
- weakened ties between national airlines and airports.
- pressures to privatize airports and air traffic control systems.
- changes in airline fleets and flight schedules; e.g., to concentrate flights around central "hub" airports.

Will greater liberalization and increased competition affect air safety? Many people in the United States voiced concerns, both before and after the Airline Deregulation Act of 1978, about possible adverse consequences of deregulation on safety. They argued that carriers would feel increased pressures to control costs and would reduce safety-related expenditures such as crew training and aircraft maintenance. However, these trends have been followed closely in the U.S., and no overall erosion of safety has been observed since deregulation.4 In particular, there is little support for the assertion that lower airline profits translate into higher risks or poorer safety performance.5 Nonetheless, critics question airline commitments to safety whenever crashes occur.

Critics of deregulation also cite other structural changes that could have negative effects on safety:

- greater use of turboprop aircraft by air commuter and air taxi firms, which have generally had poorer safety records than all-jet carriers.
- extended use of older aircraft by cash-strapped carriers or new entrants.
- "hub-and-spoke" scheduling, which concentrates flights to and from the hub airport in brief time windows and thus may increase airport congestion.
m. mergers among airlines which may have different aircraft configurations and operating procedures. Thus, pilots and crew may find themselves flying aircraft with which they are less familiar.

Changes in Aircraft Fleet Mix.

Growth in air traffic and the likely entry of new carriers implies that in addition to new purchases, many airplanes will be kept in service longer. Whether aging aircraft present higher safety risks has been the subject of much recent study and debate. What is clear, however, is that older aircraft require more intensive programs of inspection, maintenance and repair. Maintaining and enforcing such standards in an era of regulatory liberalization poses challenges to aircraft manufacturers, carriers and governmental authorities worldwide. These issues are of particular concern among charter operators and carriers in developing countries, who often purchase or lease older aircraft when they are taken out of service by carriers in developed countries.

Each new series of aircraft has proved safer and more reliable than the last. Yet the changing mix of aircraft in the commercial fleet brings other safety concerns. For example, aircraft manufacturers are developing new planes that can hold more than 500 passengers for service on high traffic routes. Larger planes imply fewer flights on these routes and probably less risk per passenger mile traveled, but more serious consequences should an accident occur. The public reaction to a single accident with large loss of life may be much more negative than it would be to several smaller accidents resulting in the same number of fatalities. Moreover, the financial consequences of aviation accidents have increased dramatically in recent years. A large aircraft disaster could bankrupt small airlines and financially cripple even the largest carriers.

Constraints on Airport Construction, Expansion, and Operations

Air traffic growth requires more airport capacity, which implies building new airports and/or enlarging and improving existing ones. But airport construction or expansion has become increasingly difficult in the face of citizen concerns about noise and other environmental degradation, new construction, auto and rail congestion, and safety risks. Such concerns have greatly lengthened the time required for new airport construction projects or, in some cases, have forced their cancellation. Yet without
additional airport capacity, traffic growth brings more congestion and higher accident risks.

Addressing noise and other environmental concerns may also introduce tensions with safety. Today, flight routing near airports may be constrained to reduce noise, leading to more complex and perhaps more hazardous maneuvers. Flights are also often prohibited during certain hours, thus increasing congestion at times when operations are permitted.

**Inadequate or Incompatible National Systems and Standards.**

Air traffic control and related air traffic management systems have reached capacity ceilings in many countries. This is due both to inherent capacity limits of installed systems, and to the need to coordinate national systems, often manually, for cross-border flights. Problems may also arise when an international flight crew is not fluent in the language used by air traffic controllers.

The need for system upgrading and harmonization is well recognized in Europe. Large programs are under way to harmonize existing ATC and ATM systems, as well as to design and build advanced systems with far greater regional capacity. Although these programs are largely funded by the European Union, their reach must extend beyond EU members to provide comprehensive coverage throughout Western and Eastern Europe. The 32-nation European Civil Aviation Conference, which includes both EU and non-EU countries, plays a key role in implementing these regional systems. Similarly, the EU-based Joint Aviation Authorities certifies aircraft airworthiness for its 23 member countries and 9 more conditional members in Western and Eastern Europe. The European Commission is also committed to developing a common EU system for accident and incident reporting. However, there are as yet no European-wide standards for airport operations and safety procedures.

Economic development and increased trade drive double-digit growth in air traffic among developing countries in Asia, Africa, and Latin America, as well as in Eastern Europe and the former Soviet Union. Although carriers in developing countries that fly internationally must comply with ICAO minimum safety standards, and some maintain higher levels; the record is spotty, and fatal accident rates have been far worse outside Europe, North America and Australia/New Zealand (Table 1.). As more accidents
have occurred, safety problems among air carriers in China, India, Russia and other parts of the former Soviet Union have come under particular scrutiny.\textsuperscript{8}

Safety problems among air carriers in developing countries come as no surprise. These carriers operate older aircraft, many obtained in trickle-down fashion from Western carriers after completing their normal economic lives. Their flight crews generally have less training and experience. They often lack the funds and internal capabilities for high quality maintenance programs. Airport operations and air traffic management systems are generally not up to developed-country standards. The carriers and aviation authorities in developing countries may have only rudimentary systems for reporting and investigating accidents and safety incidents. And flights in developing countries are more subject to, and vulnerable to terrorist attacks.

\begin{table}
\centering
\begin{tabular}{lcc}
\hline
Region & Fatal Accidents per 1 Million Departures & Death Risk per 1 Million Departures \\
\hline
North America & 0.88 & 0.53 \\
Western Europe & 1.15 & 0.80 \\
Australia/N.Z. & 1.34 & 1.09 \\
Eastern Europe & 4.11 & 2.53 \\
Asia & 4.66 & 2.97 \\
Middle East & 5.47 & 3.78 \\
Latin America & 6.04 & 4.87 \\
Africa & 13.25 & 10.52 \\
\hline
\end{tabular}
\caption{Accidents and Fatality Risk by Geographic Region, Scheduled Passenger Flights, 1977-1989}
\end{table}

Source: Oster et al, 1992
These safety issues among air carriers in developing countries affect not only flights within their territories, but also their increasing number of flights to and from other countries. Today, aircraft and air crews on international flights need meet only ICAO minimum standards for airworthiness, navigation and training, which are generally below the level of standards in North America, Europe, Japan and other developed countries. Moreover, recent FAA inspections of safety standards in 31 countries that fly to and from the United States found that nine did not meet even the ICAO minimum standards, and four others were marginal.\(^9\)

**Terrorism and Other Threats to Aviation Security.**

The recent hijacking of an Air France flight in Algeria, with a reported plan to destroy the plane in midair over Paris, points out once again the vulnerability of commercial aviation to terrorist bombings and other acts of sabotage. The U.S. Office of Technology Assessment reports that between 1985 and 1992, breaches of security were a causal factor in 11 percent of fatal aviation accidents and 28 percent of total fatalities.\(^10\)

Aviation authorities, airports and air carriers devote substantial resources to combating terrorism, with notable success. Internationally, the ICAO is responsible for developing and promulgating aviation security policies, but its standards again fall below those already implemented in Western Europe, North America and Japan. The technical means to identify bombs and weapons are improving, but the new technology is often too expensive to install at every airport, particularly those in developing countries.
IV A SYSTEMS APPROACH TO AVIATION SAFETY

Historically, both government and industry have looked to technology to improve aviation safety performance. Advances in aircraft and aviation system technology have in fact led to large reductions in risk over the past thirty years, and one can confidently predict continuing safety improvements in the new generations of airframes, engines, avionics and air traffic management systems. Yet new technological systems interact strongly with human factors and organizational behavior; and they generally require changes in training, maintenance, and operating procedures. As illustrations:

- The reliability of aircraft components and subsystems continues to increase remarkably as a result of improvements in design, manufacturing and quality control. In the past, aircraft manufacturers have looked to redundancy to provide backup systems in case of component or subsystem failure. Today’s technology, however, increasingly emphasizes component reliability rather than redundancy,\(^\text{11}\) which makes aircraft inspection and maintenance even more critical than before.

- Ground proximity warning systems (GPWS) warn pilots when their aircraft is near or heading toward the ground. Installation of GWPS devices can thus help avoid “controlled flight into terrain” accidents which have accounted for 13 percent of aviation fatalities since 1985.\(^\text{12}\) Since GWPS systems are expensive, questions remain about how quickly carriers will install them, and when (or whether) regulatory authorities should mandate them. Moreover, some early GWPS systems gave so many warnings that flight crews soon learned to ignore them or simply turned the systems off. Human factors design and crew training are obviously critical elements to realizing actual risk reduction from GWPS and other technical systems. Designers must also pay attention to the implications of new technical systems for crew workload and attentiveness.\(^\text{13}\)

- Use of the global positioning satellite (GPS) system, originally developed by the U.S. Department of Defense for military purposes, permits accurate worldwide aircraft location for flexible en-route navigation and non-precision airport
approaches. The FAA is incorporating augmented GPS service into its planning for precision approach navigation at U.S. airports later in this decade.\textsuperscript{14} However, European authorities appear leaning toward adoption of the already-developed Microwave Landing System (MLS).\textsuperscript{15} Adopting different approach systems in the U.S. and Europe would require carriers to install two sets of navigation equipment in their trans-Atlantic aircraft and complicate crew training and operating procedures.

- Improved aircraft crashworthiness and fire resistant materials can increase the chance of survival in event of accident or other emergency. According to FAA data, fire onboard the aircraft was a significant causal factor in one-half of fatal accidents since 1985.\textsuperscript{16} Yet the relative cost-effectiveness of investments in structures and materials, versus fire detection and suppression systems, or cabin design and crew training for evacuation, is not at all clear. Estimating the tradeoffs must also take into account the changing demographics of air travel, with more children, older people and disabled passengers.

- Better prediction of windshear and severe turbulence is becoming feasible with new radar and other weather sensors. Again, real risk reduction requires integrating the technology into both aircraft and airport equipment, training flight crews and ground controllers, and adopting new approach and landing procedures.

Each of the technological approaches outlined above is important to pursue, but no single area offers prospects of a two- or three-fold reduction in accident risk. Moreover, recent reports in Europe\textsuperscript{17} and the United States\textsuperscript{18} point out that current government funding for research and development on aviation safety does not correlate well with the highest risk factors or with the interactions noted above. In the U.S., for example, equal shares of the FAA's safety-related Research, Engineering and Development budget -- 25% -- are addressed to human factors, which are principal causes of 75% of fatal accidents, and to aircraft structures, which are implicated in only 9 percent of fatal accidents.\textsuperscript{19}

Human errors persist as the principal causes of aviation accidents, despite the resources and attention that have been devoted over several decades to
reducing them. New technologies or procedures introduced to deal with human errors in one area may, by increasing workloads or changing established work patterns, inadvertently add risk in another dimension. And the growth in international air traffic brings more interactions among pilots, ground crews and controllers who have different backgrounds and different levels of training with different sets of technical equipment.

Developing and enforcing international safety standards, procedures and regulations are also important. Identifying higher risk carriers and airports, and bringing them up to contemporary standards of “good practice” could yield significant improvements in overall safety. But this may require new international agreements and new or strengthened international organizations. Moreover, regulations are essentially reactive. They follow technical and commercial developments; they do not lead them. And they typically deal with specific issues such as aircraft certification or air traffic procedures, but do not address the entire aviation system.

What seems essential is to view aviation safety as a systems problem. Each of the problem areas described above interacts with the others, and so will the accident risks derived from them. Each flight includes some risk of accident. The number of flights is determined by airport and ATM capacities, by aircraft fleet mix, and by passenger demand, which itself depends on pricing and other factors heavily influenced by regulation. The specific risk per flight depends on such factors as airport and terminal area congestion, takeoff and landing patterns, ATM capabilities, type of aircraft, safety equipment onboard the aircraft, security measures in place, crew training and experience, crew workload and related human performance issues. All these factors are becoming increasingly interdependent.

We need to better understand these interactions and their implications, both qualitatively and quantitatively. Developing common standards of accident and incident reporting, and sharing these databases among countries can help analysts identify important risk factors and trends. Understanding public perceptions of safety and risk can focus R&D and policy efforts on those aspects which contribute most importantly to public confidence.
Advanced modeling techniques -- bottom-up and top-down -- are also useful. Bottom-up approaches, including fault tree and other probabilistic risk assessment models, and detailed simulations of airport operations, can help identify particular areas of risk or vulnerability. Top-down, system-oriented models can show how changes in one area will interact with other areas, as well as affect ultimate safety goals. They can also inform public decisionmakers and other stakeholders about how different programs and policies will influence not only the area they specifically address, but other parts of the system as well.

Aviation accident rates in industrialized countries are already low and have been declining for several decades. Consequently, there is no single "magic bullet" that will dramatically reduce the risk of aviation accidents. Enhanced safety depends on taking a system-wide view of the problem, recognizing the interactions among system components, and estimating both the direct and indirect effects of proposed solutions.
V TOWARD A BROADER SYSTEMS REVIEW OF GLOBAL AVIATION

These same interactions among system components affect not only safety but the multiple other objectives of commercial aviation, including:

- economic performance of carriers, airports, equipment manufacturers and other parts of the aviation industry.
- economic benefits to local regions and nations from improved air transport.
- accessible, convenient and affordable service to business, government and individuals.
- integration with other modes of transport.
- reduced noise, pollution, congestion, and other environmental impacts.
- technological innovation and related benefits.

Of course, different stakeholders within a country, and even countries themselves will value these objectives differently and assign different weights to them, which is why developing international aviation standards is so complex and difficult.

A review of how international aviation is faring according to these objectives would be likely to conclude that many individual parts of the system are doing well, and even improving; but that the patchwork quality of the overall system is beginning to fray. Additional patches or quick-fixes seem unlikely to resolve the basic issues. Accordingly, this paper argues that the time is right to examine the total system of international commercial aviation from several perspectives -- technical, commercial, administrative, political, and public perception -- and to access the options for its future evolution.

Such a review would entail a three-step process. The first step is to conduct an exploratory analysis of emerging problems in the international aviation system, focusing on the interactions among system components such as those described above. This effort would seek to identify the interactions having the greatest impact on safety and other aviation objectives; gather data to quantify
the problems and issues insofar as possible; and develop simple, transparent models and analysis to estimate how changes in one component will affect others and the system as a whole.

The results of this exploratory analysis could then form the basis for convening a series of workshops on the future of international aviation. The initial workshop would be a brainstorming session to identify and explore future options. Subsequent workshops would focus on such topics as:

- appropriate roles for regulation in a competitive aviation environment.
- prospects for regional aviation authorities outside Europe.
- future roles for ICAO; and the need, if any, for other international entities.
- strengthening, harmonizing and enforcing international standards.
- aiding developing countries in meeting world standards.
- specific aviation issues in China, Russia, India.
- planning for new technology in a global context.

Although a consensus might emerge from the workshops on a preferred evolutionary path, it seems more likely that no single option will dominate, and many issues will remain unresolved. Consequently, the third step is to structure what appear to be the most promising scenarios and assess their impacts -- under a range of technical, economic and political assumptions -- on the aviation system as a whole, as well as on individual private and public sector stakeholders. Here several tools of systems analysis can be applied that RAND has successfully used in other transportation and infrastructure studies, including modeling of ways to improve efficiency and reduce environmental costs of freight transportation, the "Assumption-Based Planning" methodology developed for highly uncertain future scenarios, and "Exploratory Modeling" techniques for situations involving multiple dimensionality as well as high uncertainty.

This kind of evaluation, we believe, can raise the level of understanding of the issues and stimulate an informed debate within the international aviation community, as well as among the general public, about evolutionary changes and new options to create a successful global aviation system for the 21st Century.
NOTES AND REFERENCES

1 Clinton V. Oster, Jr., John S. Strong and C. Kurt Zorn, *Why Airplanes Crash*, New York, Oxford University Press, 1992, p. 77. Risk is commonly defined as the product of an event's probability and its consequence. Accident rates are typically measured and compared in terms of number per 100,000 flight hours, per 100,000 aircraft departures, per million passengers enplaned, or per million passenger-miles. For a discussion of different measures of risk, see Richard Hillestad et al, *Airport Growth and Safety*, Delft and Santa Monica, EAC/RAND, MR-288-EAC/VW, 1993, pp. 6-13.


7 Hillestad et al, *op. cit.*

8 "Who Cleared These Airlines for Takeoff?" *Business Week*, June 20, 1994, p. 56.

9 Everitt, *op cit.*


15 Kieran Daly, “FAA is unable to meet GPS results deadline,” *Flight International*, 2-8 November, 1994, p. 5.


Ibid.


This is not the case in many developing countries, however, where significant reductions in accident risks appear feasible, as discussed above.


