Development of a Child Restraint System for Aircraft .......................................................... 2
Reporting Human Factors Accidents .................................................................................... 16
Australia’s Bureau of Air Safety Investigation Preliminary Report: 9501246 .................. 34
Background

Although the need for an improved level of infant restraint in aircraft is not well supported by statistical data, especially in the case of commercial aircraft, and although few adults are killed in commercial accidents yearly, adults are required to be provided with a considerably higher level of turbulence and crash protection than that provided to infants. (1)

Some progress has been made in the area of child restraints since the year the issue became personal for the author. In 1979, child restraints were forbidden on board aircraft. Infants, that is children who had not yet reached their second birthday, were required to be held in the arms of an adult. (2)

By 1984, progress had been made. At that time, Transport Canada allowed the use of specific child restraint devices on Canadian aircraft, originally by means of an exemption to Air Navigation Order (ANO) Series II No. 2, the Aircraft Seats, Safety Belts, and Safety Harnesses Order, and more recently through an amendment to the ANO. The ANO outlines the conditions under which they can be used, and specifies the standard that the child restraint must meet. (3)

However, this did not solve the problems associated with the use of child restraints. Child restraints were sometimes brought on board by parents who found that their use was subject to seat availability, dimensions of the device, and the individual policies of the airline. Some airlines still refused to allow the use of the automotive child restraints.

In 1991, following a joint 1989 Transport Canada Aviation (TCA) and Federal Aviation Administration (FAA) study of approved motor vehicle child restraint systems and the sometimes named “belly belts,” TCA published a “Summary of Policy and Procedures for the Restraint of Infant in Aircraft.” This publication contained the following recommendation:

Research and development dedicated to the design of a restraint system for infants and small children traveling in aircraft be conducted without delay. (4)

That recommendation was implemented as this joint Transport Canada Aviation/Transportation Development Centre (TDC) project.

FAA conducted a further series of dynamic tests on existing motor vehicle child restraint systems in 1993. Its report was published in 1994. (4) The tests involved the evaluation of new child restraint designs, booster seats, and forward facing child restraints, and investigation of the effects of loads imposed by adult occupants of the seat behind that in which a system was installed. A number of the seats tested were incompatible with airline seats. A number of child safety seats and restraints that are approved for use on aircraft are ineffective; however, small rear facing seats for infants weighing less than 20 lb. (9 kg) performed as advertised. The research indicates that child restraints for aircraft may require different standards than those for child restraints for automobiles.

The devices were ineffective for the following reasons:

- Lack of available space between armrests (width of base),
- Lack of space between two rows of seats (seat pitch),
- Inability to be effectively restrained with existing belt,
- Inability to remove the slack; the unit cannot be fastened tightly enough,
- Tracks or channels designed for the belts do not fit the aviation belt or the buckle.

These tests have shown that, although the problems with child restraints are well known, they have not yet been resolved.

The Regulatory Environment

Canadian Air Navigation Order (ANO) Series II, No. 2, requires an infant (defined as one who has not yet reached its second birthday) to be held in the arms of an adult or in an approved infant/child restraint system during takeoff, landing, and when seat belts are required to be worn.

The lack of effective purpose-designed child safety systems for use on aircraft has resulted in the acceptance
of usage in Canada of Canadian Motor Vehicle Safety Standards (CMVSS) approved automotive safety seats. (5) (6)

The ANO is permissive in nature. At this time, there is no mandatory requirement for the use of child restraint devices, nor is there a mandatory requirement to permit their use on board. The current regulatory structure is such that the use of a child restraint system on board aircraft is optional, and subject to availability of an adjacent passenger seat, dimensions of the device, and individual airline policies.

Child restraints are not mandatory for many reasons, primarily the operational problems associated with currently available devices.

The Aviation Environment

Currently approved infant/child restraint systems are designed primarily for use in an automobile. They may or may not be compatible in fit and function with aircraft seats; therefore, in some cases, the child restraint device cannot be installed properly and may not perform as intended.

The major differences between the aviation and the automotive environments include:

- Width between armrests,
- Location and style of armrests,
- Dimensions of the available base to rest the device on,
- Location of anchor points,
- Seat pitch,
- Installation methods (available manoeuvring space when installing the device),
- Installation frequency (In automobiles, the device is usually installed and left in the same position for several months).

Not all car safety seats fit in all aircraft passenger seats. Therefore, parents have no assurance that their automobile child restraint can be used on board a particular flight. Car safety seats are not configured to be fully compatible with an aircraft seat (e.g., break-forward seat backs; no attachment point for a tether strap), nor are car seats fully tested with the aircraft seats in mind.

The automotive industry is now considering the adoption of a universal child restraint attachment system. This would involve installing dedicated attachment points in the automobile, and mating devices on the child restraint. The options currently under consideration include both rigid and flexible brackets/mating devices, as well as combinations of both rigid and flexible attachments. This will eliminate the need to use seat belts to secure the child restraint device. Eventually, there will be no provision on a child restraint device for a seat belt attachment. With the pending adoption of such universal attachments, the compatibility problems in aircraft will likely increase.

Since child restraint devices designed specifically for use in aircraft are unavailable, it would be premature at this time to require their use. Only after the identified deficiencies associated with aircraft use of the present devices have been resolved will it be possible to consider regulations to require their use for the restraint of infants and small children traveling in aircraft.

The Project

The objective of this project was to determine the feasibility of developing a child safety system that meets the needs of the users, the airline industry, and the regulators.

The first phase of this project was the development of a specification for the device. The specification outlines in detail the specific conditions that must be met to fulfill the contract. This was preceded by a statement of task. The original statement of task included the following mandatory requirements for the prototype device:

- Affordable/lightweight/comfortable/easy to clean.
- Meets all criteria for use on board aircraft, i.e., dynamically tested for crashworthiness as required for conventional aircraft seats’ construction materials; seat cushions and fabrics meet the flammability requirements for aircraft furnishings.
- The standard aircraft seat belt hardware will be the only equipment required for securing the device.
- The device will have occupant securing straps that are simple to operate, the same as or similar to aircraft seat belt installations. Removal of the occupant from the device, and removal of the device from the aircraft with the occupant in it, must be easily accomplished.
- Fits all aircraft seats that are used in commercial aircraft.
- The unit can be easily stowed on board an aircraft.
- The device floats and is self-righting in water.
- It should accommodate an occupant up to the age of three years, but the capability of the device should be weight/height oriented as opposed to age specific.
- Focus on international acceptance of the seat.

The following desirable requirements were also included:

- Development of a device that can be mounted in either aft-facing or forward-facing position.
- A life jacket stowage provision as part of the design if the flotation requirement is not met. The life jacket must be readily accessible to the parent/guardian who is accompanying the child.
The specification phase was completed in August 1992, (7) and a Request For Proposals (RFP) was offered through the normal tender process. Three tenders were submitted. Following a review process whereby each tender was rated on factors such as scientific and technical strategy, company qualifications, and contractor team qualifications, the project contract was awarded to Aastra Aerospace in January 1993.

Project Evolution

This project has now gone through four separate design phases. The first conceptual drawings incorporated a flotation element. This concept was abandoned after the requirements for infant flotation were changed with amendment f of TSO-C13, which introduced a new category titled “Infant-Child Life Preserver” that requires persons under 35 lbs to have a means to prevent contact of the wearer’s upper torso with the water. (8) As a result, it was no longer viable to develop a safety system that could perform both roles of safety restraint and flotation. While the initial design was innovative and intriguing, it was essential that any device produced have international acceptance. The original concept would not have been able to obtain certification as a flotation device. TCA therefore eliminated the requirement for flotation, and placed greater emphasis on minimizing the folded size of the system.

The second concept was a non-floating, folding system dubbed the MARK I prototype. This prototype underwent automotive dynamic and aviation fitment testing in February 1994. While it successfully passed the automotive dynamic tests, the results indicated a need to further optimize the design for the airline environment. (9) The device was quite robust, utilizing a metal structure with some padding and vinyl covering. While it was strong, it needed to be more compact, lighter, simpler to operate,
and more aesthetically pleasing. This led to the development of the third design, an optimized folding system, also known as the Mark II prototype, or the Aastra Child Safety System (ACSS).

Both the Mark I and the Mark II prototypes have undergone fitment trials. The purpose of the trials was to:
- Test compatibility of ACSS with aircraft seats,
- Determine whether ACSS fits in various overhead bins,
- Identify any ergonomic problems

The fitment trials took place on several different aircraft types, operating scheduled and charter routes:
- Air Ontario - Dash 8 (100 & 300 Series),
- Canada 3000 - Boeing 757,
- Royal Airlines - Boeing 727, and
- Air Canada’s Multi-Aircraft Cabin Trainer, which incorporates several different types of overhead bins and seats.

The findings from those trials were as follows:
- ACSS was fully compatible with all aircraft types and all seats in forward facing position,
- ACSS fit in virtually all overhead bins when folded,
- ACSS seat back angle was too reclined in the rearward facing position, thus causing some difficulty on aircraft with small seat pitch,
- In operation, the following problems were noted:
  - Improper placement of wedge by trial users,
  - Too much strap friction when adjusting the harness,
  - Limited access to harness adjuster, especially for the rearward installation.

The findings from the fitment trials were incorporated into the Mark II prototype. It must be emphasized that, to date, ACSS is a design prototype. Production prototypes of this design were not developed.

ACSS

ACSS was constructed with three major components:

1. SEAT BACK FEATURES:
   - Graphite/epoxy sandwich panel construction,
   - Reinforced side panels,
   - Reinforced pivot/pin holes,
   - Integrated harness adjusters.

2. WEDGE FEATURES:
   - Non structural - graphite/epoxy sandwich panel construction

3. BASE FEATURES:
   - Incorporated seat belt channels for installation

It had the following features:
- Accommodates children up to 2 years or 22 kg
- Secured to aircraft seat with lap belt
- Lightweight - 14 lb
ACSS

- Foldable for stowage in overhead bin (ACSS: Figure 1)
  - Folded dimensions: 4.75” x 14” x 23”
- Fully compatible with aircraft seat in the forward and rearward facing positions
- Meets dynamic test requirements
- Satisfies flammability requirements
- Easy to use and maintain
- Equipped with a five point harness with single point release
- Seat back locking mechanism inaccessible to occupant

The device opens by removing a Velcro closure strap between the wedge and the top of the seat back. (ACSS: Figure 2) With the Velcro strap removed, an elasticised strap assists in folding the wedge toward the base and into its proper position. (ACSS: Figure 3) The seat back is attached to the base with bolts and is free to pivot around the rear end of the base. The ACSS continues to open until the locking pins of the seat back automatically click into holes in the side panels of the base. (ACSS: Figure 4) There are two locking positions for the seat back. The first position is used for children weighing between 9 and 22 kg (20 - 48 lb). In this position the ACSS is installed on the aircraft seat in a forward facing position. (ACSS: Figure 5)

The second position allows the user to recline the seat back to provide a more comfortable sitting angle for children weighing less than 9 kg (less than 20 lb). The angle can be adjusted by pulling a lever near the top of the seat back. (ACSS: Figure 6) With the seat back in the more reclined position, ACSS is installed on the aircraft seat in a rearward facing position. (ACSS: Figure 7)

With the upholstered seat pan raised, the aircraft lap belt is routed through a recessed channel on the base of the child seat. (ACSS: Figure 8) There are two of these channels. One is used when ACSS is forward facing and the other is used for the rearward facing installation. Once the lap belt has been secured, the seat pan is lowered and the child or infant may be secured with a five point safety harness. (ACSS: Figure 9)

The shoulder straps are easily tensioned by pulling up on the loose end of the shoulder strap webbing at the top of the device. (ACSS: Figure 10) They may be loosened by pulling up on adjuster tabs while introducing slack into the harness. (ACSS: Figure 11) Two shoulder strap heights are available. The upper position is used for children in the forward facing position, and the lower position is used for infants in the rearward facing position. The shoulder straps may be lowered by inserting the webbing behind a recessed support part. (ACSS: Figure 12)
ACSS Figure 2. Opening

ACSS Figure 3. Wedge positioning
ACSS Figure 4. Wedge positioning

ACSS Figure 5. Forward facing
ACSS Figure 6. Recline lever

ACSS Figure 7. Aft facing
ACSS is currently upholstered with a wool/nylon fabric commonly used for seats on commercial aircraft. The upholstery is attached to ACSS with Velcro and is easy to remove for cleaning, replacement, or repair. In operation, to maintain cleanliness and reduce maintenance, the upholstery could be covered with a disposable dress cover.

Testing

ACSS prototype has completed dynamic testing; this established compliance with the dynamic requirements of Canadian Motor Vehicle Safety Standard (CMVSS) 213 and 213.1. To be certified for use in automobiles in Canada, a forward facing child restraint device must pass CMVSS 213, and a rearward facing infant restraint device must pass 213.1. These standards also specify the current requirements for the use of automotive child seats on transport category aircraft.
Aastra conducted further dynamic testing to demonstrate that ACSS safely restrains infants and children in an aircraft seat environment. These tests were conducted in accordance with the current methodology of FAA and in co-operation with Transport Canada.

CMVSS Compliance

The dynamic tests to establish compliance with CMVSS 213 and 213.1 were performed at the Defence and Civil Institute of Environmental Medicine (DCIEM) in North York, Ontario. Aastra conducted a test using an infant anthropomorphic test dummy (ATD) and a test with a Child ATD. Both ATDs were subject to 20 g loading with a velocity change of 48 km/hr (30 mph). The ACSS prototype was installed on a NHTSA bench seat which was mounted on a test sled.

Infant Test - Compliance with CMVSS 213.1

For this test, a six month old ATD was used, and the ACSS was installed in a rearward facing position. Video
documentation and a post test inspection confirmed that ACSS satisfied the following critical requirements: (See Table 1)

- The angle between the seat back of the infant restraint and the vertical shall not be greater than 70 degrees. (See Figure 2)
- The movement of the ATD is restricted so that the target point on the head does not pass through the transverse vertical plane passing through a) the forwardmost point on the top of the infant restraint system and b) Point X on the standard seat. (See Figure 3)
- The infant restraint device shall not exhibit structural damage that could result in the exposure or protrusion of injurious surfaces.

Child Test - Compliance with CMVSS 213

The three year old ATD used for this test was instrumented with tri-axial accelerometers in the head and chest in order to calculate the peak chest acceleration and the Head Injury Criterion (HIC). While HIC is not part of CMVSS 213, it is used in the United States to provide an indication of the head acceleration experienced by the ATD. In general, the maximum acceptable HIC is 1000. Consistent with CMVSS 213, a tether strap is attached to the top of the carrier.
The critical dynamic requirements of CMVSS 213 are summarized as follows:

- The forward facing child seat must limit the resultant acceleration of the ATD’s chest to not more than 60 g’s, except for intervals, the cumulative duration of which does not exceed 3 milliseconds.
- The child seat must not allow any portion of the ATD head to pass through the vertical transverse plane that is 71 cm (28.4”) forward of point Z on the standard seat assembly measured along the centre Seat Orientation Reference Line. (See Figure 1)
- The child seat shall not exhibit structural damage that could result in the exposure of injurious surfaces.

The test results are summarized in Table 2. A post test inspection confirmed that there were no injurious surfaces exposed after the impact and the device met all the criteria.

Two further tests were performed outside the scope of the tests for CMVSS 213 and 213.1. The purpose of these tests was to provide some insight into the behaviour of ACSS without a tether strap, in order to simulate the aircraft seat environment. These preliminary tests indicated that ACSS required structural optimization in specific areas. After a design modification that involved reinforcement of the seat back and the base, two ACSS prototypes were ready for testing in a simulated aircraft seat environment.

**FAA-CAMI Compliance**

Currently, no aircraft-specific regulation or standard governs the use of child restraint devices in North America. However, FAA’s Civil Aeromedical Institute (CAMI) in Oklahoma City, Oklahoma, has developed a dynamic impact test program to evaluate the performance of child restraint devices in commercial transport aircraft passenger seats.

Aastra brought two prototypes to CAMI for testing in June 1995. Five separate runs were completed. Those runs are outlined in Table 3. In all tests they were subject to 16 g loading with a velocity change of 48 km/hr (30 mph).

BCA in the foregoing key refers to the aft-most anchor location for the lap belt attachment to the aircraft seat. WCA is the forward most anchor location for the lap belt attachment to the aircraft seat. The distinction between

### Table 1.

<table>
<thead>
<tr>
<th>CRITERION</th>
<th>REQUIREMENT</th>
<th>ACSS TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEAD EXCURSION LIMITS</td>
<td>Forwardmost Point</td>
<td>passed</td>
</tr>
<tr>
<td></td>
<td>Readwardmost Point</td>
<td>passed</td>
</tr>
<tr>
<td>ROTATION LIMIT</td>
<td>Carrier Seating angle: &lt; 70 degrees</td>
<td>passed (43 degrees)</td>
</tr>
<tr>
<td>STRUCTURAL INTEGRITY AND SAFETY</td>
<td>No injurious surfaces</td>
<td>passed</td>
</tr>
</tbody>
</table>

### Table 2.

<table>
<thead>
<tr>
<th>CRITERION</th>
<th>MAXIMUM PERMISSIBLE VALUE</th>
<th>ACSS TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX. CHEST ACCELERATION</td>
<td>60 g’s over 3 msec</td>
<td>45 g’s : passed</td>
</tr>
<tr>
<td>HEAD EXCURSION LIMIT</td>
<td>28.4”</td>
<td>22.1” : passed</td>
</tr>
<tr>
<td>HEAD INJURY CRITERION (HIC)</td>
<td>1000</td>
<td>374 : passed</td>
</tr>
</tbody>
</table>

### Table 3.

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAMI Run No.</td>
<td>A96059</td>
<td>A96060</td>
<td>A96061</td>
<td>A96062</td>
<td>A96063</td>
</tr>
<tr>
<td>Single Row</td>
<td>Child, BCA</td>
<td>Child, WCA</td>
<td>n/a</td>
<td>Child, WCA</td>
<td>n/a</td>
</tr>
<tr>
<td>Double Row</td>
<td>Infant, BCA</td>
<td>n/a</td>
<td>Infant, BCA, WCA</td>
<td>n/a</td>
<td>empty, BCA</td>
</tr>
<tr>
<td>Row 1</td>
<td>n/a</td>
<td>n/a</td>
<td>Infant, BCA, WCA</td>
<td>n/a</td>
<td>Infant, BCA</td>
</tr>
<tr>
<td>Row 2</td>
<td>n/a</td>
<td>n/a</td>
<td>Infant, BCA, WCA</td>
<td>n/a</td>
<td>empty, BCA</td>
</tr>
</tbody>
</table>

**Table 3.**

**FAA TEST CASES**

- Single Row - Test sled set-up where only one row of aircraft seats is installed
- Double Row - Test sled set-up where two rows of aircraft seats are installed
- Child - A three-year-old ATD similar to the one used at DCIEM
- Infant - A six-month-old Child Restraint Airbag Interaction (CRABI) ATD which has provisions for head and chest instrumentation
- BCA - Best Case Anchor Position
- WCA - Worst Case Anchor Position
- HIC - Head Injury Criterion
anchor locations is important, because, during horizontal impact, a child restraint device must translate forward until the belt path angle is sufficiently close to horizontal for belt tension forces to restrain the device. The two locations tested represent the "best" and "worst" anchor locations seen from a sampling of aircraft passenger seats at that time. FAA has since determined that there are some anchor locations that are worse (or further forward) than those that were tested. (FAA Test Figure 1)

Test A95062 was performed with the aircraft seat cushion removed. For this test, ACSS was installed directly on the aircraft seat frame. Some of the data is not available for this run due to difficulties with the instrumentation during this run.

Infant Tests—CAMI

CAMI’s criteria for evaluating child restraint devices with infant ATDs are as follows:

- Prevent excessive forward translation and rotation of child restraint device during impact sequence,
- Maintain proper restraint of infant ATD,
- Protect infant ATD’s head during impact, and
- Preserve structural integrity of child restraint device.

Tests A95061 and A95063 were performed with an infant ATD.

The video footage revealed that ACSS, when installed in the rearward facing direction, performed very well. The forward motion of the child seat was minimal, and the ATD was securely supported during the impact sequence. A HIC of 226.5 was calculated for Test A95063. This value is very low compared to the allowable value (used for a three-year-old ATD) of 1000. No HIC calculation was made for test A95061. Test A95063 was conducted with ACSS in the second row. The video footage showed very little interference between ACSS and the aircraft seat in the first row. Post-test inspections showed no structural damage to ACSS. The results are summarized in Table 4.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>A95061</th>
<th>A95063</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRITERION:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No excessive forward translation or rotation</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>Secure restraint of ATD</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>Protection of ATD’s head</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>Maintain structural integrity</td>
<td>pass</td>
<td>pass</td>
</tr>
</tbody>
</table>

Table 4.

Child Tests—CAMI

CAMI’s criteria for evaluating child restraint devices with child ATDs are as follows:

- Prevent excessive head excursion;
- Prevent resultant chest accelerations from exceeding 60 g’s for more than 3 msec;
- Prevent HIC from exceeding 1000;
- Ensure proper restraint of ATD; and
- Maintain structural integrity of child restraint device.

Tests A95059 through A95062 were conducted with a child ATD.

The video footage revealed that the forward facing ACSS performed exceptionally well. In test A95061, where ACSS was installed in the second row using the worst case anchor location, the head of the child ATD did not strike the aircraft seat in the first row. Analysis of the other three tests, which were performed on a single row test sled, also indicated that the head excursions were all limited to the same extent.

The chest accelerations for tests A95059 - A95061 were all within acceptable limits. In addition, there were no excessive HIC values computed for tests A95059 - A95061. Results for test A95062 are not available because there were difficulties with the instrumentation during this run.

The video footage showed that the child ATD was securely restrained in all four tests. Post test inspections for the tests showed that there was no significant structural damage to the ACSS. The results are summarized in Table 5.

Current Status

Transport Canada embarked on this project to determine the feasibility of developing a child restraint system.
specifically for use on aircraft. This project is still underway.

This device has not yet been developed for practical application. Test results so far indicate that satisfactory performance is achievable with a device such as this. However, incorporating a design concept into an operational application has just begun, and the economic and operational factors have not yet been fully evaluated. In-flight operational trials have been recommended in order to provide further information for design optimization and logistical considerations.

The Civil Aviation Directorate (formerly known as Aviation Regulation Directorate) of Transport Canada has agreed in principle to the next phase, and has provided additional funding. Several airlines have volunteered to participate in the trials.

In order to produce the required number of devices suitable for full operational testing, it is necessary to develop a production model. The design prototypes were constructed utilizing composite structure technology, which is extremely labour intensive and time critical, and therefore expensive. Following a design reassessment process in which three different construction materials were evaluated against three risk factors (time, financial, and technical), a fourth design emerged. The new design will incorporate the basic geometry and design features of the ACSS Mark II into an aluminium structure.

Aluminium has the advantages of being light, relatively inexpensive, load bearing, predictable, and stable. Additionally, it incurs moderate tooling costs and low revision costs, does not require specially skilled labour, and is capable of assuring quality. While reinforced thermoplastic has a very low production cost, it has very high costs in the event of revision to the design. Thermoplastic also requires reinforcement to the extent that the design would not maintain its current size.

The ACSS Mark IIA is in the process of being constructed and tested at this time.

Although the data is preliminary, it appears that the operational deficiencies associated with aircraft use can eventually be resolved with the manufacture of a device specifically designed for use in aircraft.

As the results of this research project appear to be positive, the Canadian Aviation Regulatory Advisory Council Technical Committee VII has been tasked to consider regulatory options that address the safety of infants and children on board Canadian aircraft.

### References


Frances Wokes is the Manager, Cabin Safety Projects, in the Commercial & Business Aviation Branch of Civil Aviation with Transport Canada. As such, she is responsible for the development of the new Canadian Aviation Regulations respecting Cabin Safety issues, associated Standards, and guidance material and has also been responsible for the Child Restraint Development Project.
Introduction

There is general agreement that about three-quarters of all accidents are due to human factors. In recent years, the work of Reason (1)(2) and Helmreich (3) has been valuable in helping us to unravel these human factors, and so understand how these accidents occur. We then have a fair chance of making recommendations that really will minimise the chances of such accidents recurring in the future — which is, after all, the whole purpose of the exercise.

It is not the slightest use understanding exactly what happened, and making brilliant recommendations, if all that happens is blind rejection of the report. At the 1991 ISASI Conference in Canberra, Mick Charles (4) described the problems that many of us have encountered in trying to investigate human factors — personal attacks, legal obstruction, and corporate pressure on the investigating authority. Dave King (5) expressed the hope that, by discussing human factors outside the superheated atmosphere of a major investigation, they might gain general acceptance and so not arouse knee-jerk reactions when investigated in the context of accidents. This approach has not been overly successful in New Zealand, and I suspect that your experience has been similar. Corporations profess that safety is their first objective, that blame is not their intention, and that systems must be made error-tolerant — until they are called to account.

Reason drew our attention to Westrum’s analysis of corporate reactions (6). A ‘Denial Response’ is, regrettably, to be expected even where there is no financial or other liability: “Shoot the messenger!” If that doesn’t work, find a scapegoat, or suggest that it was a local problem which has now been fixed — the ‘Repair Response.’ Only if we can get past these reactions to engender a ‘Reform Response’ — acceptance that there is a general problem, requiring global action to put it right — are we going to achieve our aim of averting future accidents.

I submit that our time-honoured ICAO Report format is a part of the problem. It has undoubted merits. It is a useful tool for investigators: if we have gathered all the information needed by the various sections in Part 1, then we are unlikely to have overlooked anything important when we come to write the analysis. It is a useful format for researchers, who know where to look for particular items over a number of Reports. It was developed in the first place for dealing with accidents that have a physical explanation, and for these it has served well.

However, human factors information may be tucked away in the various sections of Part 1, while organizational matters are relegated to the new Section 17. There is no particular format for Part 2, the only guidance on analysing human factors being to take each line of inquiry in turn and follow it back to its origin (7). While we may investigate an accident in this fashion, to report it thus is likely to be misleading. It suggests that the various factors act in isolation, whereas in reality it is the interaction of factors that results in the accident.

Imagine that you are an executive in an organization whose actions may be called into question after an accident, reading the draft report. The first indication you find that your organization may be “blamed” (as the Press insists on putting it) is a bald series of facts, perhaps derogatory to the organization, somewhere in Part 1. On the face of it, they appear only remotely connected to the accident. Hackles rise.

Then, in the Analysis, among other strings of information, you find a catalogue of errors, perhaps going back for years, made by various levels of your organization — maybe going as high as the Board.

In the Findings there will then be a series of apparently unsupported assertions, in all likelihood accusatory.

Perhaps it is not surprising that irrational corporate wrath descends on the investigating organization.

The Corporation will have an apparently valid point if (as is usually the case) it can argue that the accident might still have occurred, absent the organization’s contributions. The legal mind (and Corporations have lots of lawyers) has been brought up on ‘chains of causation’: ‘A caused B, which caused C which caused D…’ If the accident could still have occurred without C, then C could not have been a causal factor. Add into this
the legal concept of ‘Remoteness of Damage’ — other intervening events make A too remote to have been a material factor — and we are going to have difficulty presenting the concept of a complex network of interacting events having caused the accident.

Reports ought to be readily understandable by non-aviation people. Aside from the general right of the public to be informed (and the Press might do a better job if some of our reports were less obscure), we should bear in mind that the aviation industry has not been immune from the general fashion for amateur management. In all probability the senior executives will not have any aviation background — accountants and lawyers, more likely. Here in New Zealand we have had a Real Estate salesman at the head of the ATC organization, a Geography teacher at the head of the CAA, and a Conveyancing Solicitor running the accident investigation authority. Such people have no intuitive understanding of the structure of accidents; a structured systems approach is more likely to be comprehensible to them.

Another reason that reports ought to be readable by laymen is that, in the event of point-blank refusal to take corrective action, we are dependent on public pressure to force the organizations involved to act. For this to happen, the public has to be informed, and before journalists can inform it they must understand what you are saying.

There have been a number of attempts to make human factors investigations comprehensible. At one end of the scale we have the Commission of Inquiry into the Dryden accident. Justice Moshansky dealt with a very complex investigation by presenting all the evidence as he received it, with a commentary, and expanded on theories of causation (8). He undoubtedly succeeded, but this could not be a workable report format. The report occupied four volumes, each of about 800 pages: no one would have the time to read even the 20 or so reports on jet hull-loss accidents each year.

An alternative approach was tried by BASI, which used the Reason concept of systems accident structure to write a report on a commuter accident (the Monarch Airlines report) (9), more or less in the ICAO format. This was a relatively simple accident, but reporting it in this fashion had its difficulties, as we shall see below.

Of course, a report does not, intrinsically, have to be in writing. Diagrammatic presentation has been advocated, and where the accident structure is complex it undoubtedly has a place.

Before looking at possible report formats in detail, we ought to have a brief review of the Helmreich and Reason models of accident causation. The Helmreich model may not be as widely known as it deserves: it first appeared in an annex to the Dryden report. The Reason model, by contrast, is widely known, but evidently not all of those quoting Reason have actually read his book.

Models of Accident Causation

The Helmreich Model

A Fokker F28 operated by Air Ontario (a subsidiary of Air Canada) attempted to take off from Dryden, Ontario, with thick snow on the wings. The aircraft got airborne, but failed to climb out of ground effect, struck trees and caught fire. The crew were aware that it had been snowing during their stopover in Dryden, and the real question for the investigators was, how could a very experienced pilot (24 000 hours) make such a faulty decision to attempt the take-off?

Dr. Helmreich, who advised the Commission on human factors aspects, envisaged the crew working within a series of environments, each of which might put pressure on the crew, and degrade their performance. (3).

This series of environments was visualised as concentric spheres of influence, each affecting those inside. (See Diagram 1).

In this diagram, the innermost environment concerns matters among the crew such as communication, personality, and Crew Resource Management.

The crew is affected by the physical environment: the aircraft, with its idiosyncrasies, defects, and performance characteristics; the weather, both local and general; and the aerodrome environment.

Outside these is the organization of the airline, which purchased and maintained the aircraft, trained the crews, and should support their actions.
Surrounding all of these is the regulatory environment, in which regulatory action by Transport Canada should ensure safe standards of operation.

Helmreich considered each environment in turn, to discover deficiencies and how they affected the other environments within. He described deficiencies in all.

1. The Regulatory environment.

“Several aspects of the [current] Regulations provided an indirect, deleterious influence on the crew’s operational environment” (p. 6). These included Failure to provide clear guidance for organizations and crews regarding the need for de-icing, “There are no...approved guidelines which dispatchers or flight and ground crews may use to assist them in making a reasoned judgement...”

The various interactions at this level are represented in Diagram 2.

2. The Organizational Environment.

A number of factors surrounding the nature and performance of Air Ontario created an environment conducive to operational error (p. 8).

An example was Lack of operational support from Air Canada for financial reasons. Disruptive impact of mergers and strikes - “not conducive to effective team performance” (p. 9). High turnover of management personnel following the merger. Lack of organizational experience in jet operations. Deficiencies in the dispatching system - untrained dispatchers and pilot self-dispatch. Inconsistencies in training F28 crew members - various contractors, and internal training by newly-qualified pilots. Deficient leadership for the F28 programme - chief pilot also responsible for (turboprop) Convair 580 fleet, with little experience on either type. Informal culture at Air Ontario - indulging in practices “in violation of Transport Canada regulations” (p.13). Maintenance problems with the F28 exacerbated by the groundcrew’s unfamiliarity with the aircraft, and shortage of spare parts. Flight Attendant training permitted no questioning of the pilots.
The interactions may now be shown as in diagram 3.

3. The Physical Environment.

The physical environment contained a number of negative features. For example, there were mechanical problems, especially an inoperative Auxiliary Power Unit. Dryden had no external power source to restart the engines; if both engines were stopped, there would be a long delay while a Ground Power Unit was brought in. The aircraft had to be refuelled with one engine running, because of this; it was not permissible to de-ice the wings of the aircraft with engines running.

The interactions at this level are shown at Diagram 4.


The crew environment comprises interpersonal coordination and communications, both within the aircraft (cockpit and passenger cabin) and with the ground (company). [Helmreich included air traffic control (ATC) within this environment]. A number of factors were identified as significant stressors that can reduce crew effectiveness, including situational factors and characteristics of individual crew members. An example was Difficulties in working together:

a. The two pilots came from two different airlines that had merged.
b. Both pilots were accustomed to flying as Pilot in Command.
c. There were no standard operating procedures, and, in particular, no specified division of duties between pilot flying and pilot not flying.
d. This was the first trip the two pilots had made together (a factor known to militate against crew effectiveness). (10)

Helmreich considered that these factors would tend to reduce the effectiveness of the crew as a team.

The interactions at this level are shown at Diagram 5.
An overall picture can be obtained by combining these levels, as seen in diagram 6.

We can well understand that the crew might have begun to feel like a pin-cushion!

Overall, Helmreich commented:

The results of this analysis suggest that the concatenation of multiple factors from each category allowed the crew to decide to take off with contaminated wings. According to this view, no single factor taken in isolation would have triggered the crew’s behaviour prior to and during the takeoff, but in combination they provided an environment in which a serious procedural error could occur. This array of contributory influences without a single, proximal cause warrants classification of the accident as a system failure (p. 2).

Development of the Helmreich Model

This model was originally devised to examine a specific accident, one in which ATC played little part. Helmreich considered the local controller to be part of the crew: interaction was via aircraft communications, as are other crew interactions. However, to make the model more general, we need to make specific provision for ATC. Controllers, whether by mistake or by overloading the pilot, can generate an environment every bit as hostile as the physical environment may be. (Consider, for example, the Avianca disaster, in which a Boeing 707 ran out of fuel over New York as a result of ATC delays) (11).

Since the ATC input will generally come after the organizational input, the ATC environment may conveniently be placed inside the organizational environment.

A major advantage of the Helmreich model is that it eliminates an opportunity for regulators and organizations (or their legal advisers) to argue that their actions should not be discussed in the report. It is frequently argued that an accident is the end-result of a chain of events: if a supposedly causal factor can be removed and the accident could still have occurred, then ipso facto that factor cannot be causal. The Helmreich model demonstrates clearly that it is the accumulation of factors, rather than their chaining together, that can affect the crew.

The Helmreich model of accident causation is crew-centred. It looks at the way pressures build up from faulty actions or decisions by external agencies. However, it does not seek to address the question of how the mistakes by those agencies arose. This aspect was investigated by Professor Reason of Manchester University.

The Reason Model

The Reason model (1)(2) is based on the underlying systems structure, and is intended to discover the deficiencies that led to the crew being put in the sort of situation that Helmreich examined. It takes the view that correcting individual failings is unlikely to prevent future accidents: we must seek out and remedy the underlying causes, which Reason terms General Failure Types.
He developed the model after studying reports of a number of major disasters, including the Kings Cross Underground fire in London, the Clapham Junction rail collision, the Piper Alpha oil rig disaster, the sinking of the Herald of Free Enterprise off the Belgian coast, and accidents at nuclear power plants.

Reason’s model of an organizational accident postulates three basic elements:

1. Organizational processes
2. Task and environmental conditions
3. Individuals performing a variety of unsafe acts

Causality commences with organizational processes, through the task and environmental conditions that promote unsafe acts, to the errors and violations of individuals at the “sharp end,” whether on the flight deck or on the hangar floor. Finally, the defences built into the aircraft, such as stall warning and recovery, fail or are disabled, and the accident occurs.

While unsafe acts are performed by individuals, the conditions that encourage or provoke those acts (e.g. shortage of time allotted to a task) are the province of management.

Reason considered that any technical organization was continuously involved in four related processes: designing, building, operating, and maintaining.

Ideally, these four processes should be connected by feed-forward and feed-back communication pathways, but they very seldom are. (3, p. 42).

Surrounding these processes are two contextual frames, the Goal Statement, and an Organizational framework in which a company is organized to achieve its goals.

Note that Reason treats “organization” as being monolithic, and this may very well be true of railways, and nearly true of ferry companies. However, it is certainly not true of airlines. Not
only are airlines ("operate" and "maintain") entirely separate from manufacturers ("design" and "build"), with virtually no opportunity for airlines to affect the design and construction of their aircraft, but also, as we have already seen in the Helmreich model, they operate within the influence of other organizations — the regulatory authority, and air traffic service providers. This difference gives rise to some difficulties that will be considered later.

Having identified these elements, Reason then identified General Failure Types associated with each.

<table>
<thead>
<tr>
<th>Process</th>
<th>General Failure Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td>Incompatible Goals</td>
</tr>
<tr>
<td>Organize</td>
<td>Inappropriate Structure</td>
</tr>
<tr>
<td>Manage</td>
<td>Communications Poor Planning Inadequate Control and Monitoring</td>
</tr>
<tr>
<td>Design</td>
<td>Design Failures</td>
</tr>
<tr>
<td>Build</td>
<td>Unsuitable Materials</td>
</tr>
<tr>
<td>Operate</td>
<td>Poor Operating Procedures Poor Training</td>
</tr>
<tr>
<td>Maintain</td>
<td>Poor Maintenance Scheduling Poor Maintenance Procedures</td>
</tr>
<tr>
<td>and</td>
<td>Inadequate Regulation</td>
</tr>
</tbody>
</table>

Table 1. General Failure Types

While these are not the only possible General Failure Types, they are ones that feature in many aircraft accidents.

These principles of accident causation allow the underlying latent failures to be identified step by step, by backtracking from the accident via the failed defences to the unsafe acts, the conditions that gave rise to those acts, and ending with the fallible top-level decisions that set the accident sequence in motion.

The main steps in this analysis would then be:

**Defences**

- What aspects of the aircraft’s defensive system were absent, failed, or circumvented?

**Unsafe Acts**

- What types of actions were involved in breaching or bypassing the defences?
- Were these individual or group failures?

**Preconditions**

- What task, situational or environmental factors promoted these unsafe acts?

**General Failure Types**

- Which of the General Failure Types were implicated in creating these preconditions?
- What factors shaped the underlying conditions?
- What shortcomings are revealed in the organization’s safety culture?

At each level it may be possible to make detailed connections between the identified accident facts, and their precursors at the preceding level. However, this process will become more difficult at the higher levels, where many-to-many mapping may be needed between top-level decisions and General Failure Types.

**Difficulties with the Reason Model**

The Reason model poses some difficulties for investigators who seek to use it as the basis for analysis, or to structure the analytical section of a Report. An illustration of this is the Report on the Monarch Airlines accident produced by the Australian Bureau of Air Safety Investigation, which was widely distributed for comment (9).

The Report was, to the author’s knowledge, the first attempt to analyze an accident using the protocols suggested by Reason. The following comments may appear critical, but should not be taken to decry BASI’s effort. Like all pioneering efforts, it may contain defects, but provides a basis for subsequent development.

**The Monarch Airlines Accident Report**

In June 1993 a Piper PA31-350 Chieftain twin-engine commuter aircraft was making a scheduled airline flight from Sydney to Young, NSW. At Young the weather was marginal for landing. It was night, and the cloudbase was 750 feet above aerodrome level (aal).

The instrument approach procedure at Young is a circling approach; ie the procedure does not align the aircraft with the runway, but leaves the aircraft in the proximity of the aerodrome. Thereafter the pilot has to position the aircraft for the final approach to land by visual reference.

The crew reported commencing an instrument approach at 1842. Witnesses at Young saw the aircraft overfly the runway from the east; minutes later it overflew from the west and climbed away. The aerodrome lighting, which had to be switched on by a radio signal from the aircraft, was not illuminated. At 1903 the aircraft reported on another instrument approach; another aircraft was holding in the vicinity.
Some time afterwards the runway lights were switched on and the second aircraft landed at 1912. At 1916 the first aircraft reported in the circuit area.

The aircraft passed over the northern end of the aerodrome from the west, then turned right as though on a right-hand downwind leg for runway 01. It turned right again, and passed south of the aerodrome to enter a right-hand downwind leg for runway 19. Abeam the aerodrome it again turned right and crossed the runway to enter a second right-hand downwind leg for runway 01, then right again onto base leg. The navigation lights disappeared from sight and almost immediately a fireball was observed. The time was about 1918.

The aircraft wreckage was found on a hill 275 feet aal, about 1 nautical mile SSE of the aerodrome. The aircraft had been in generally level flight at impact. The two pilots and five passengers were killed.

No technical defect which would have disabled the aircraft was found.

The Factual Information section of the Report followed normal lines, except that some discussion would ordinarily be regarded as belonging in the Analysis (for example the misleading visual reference that the cockpit coaming might provide, relative to ground features).

The Analysis section used a format based on the Reason model. Having dismissed mechanical failures and pilot incapacitation, the Report proceeds to list:

- Active Failures
- Local Factors
- Organizational Factors and Latent Failures
- Failed or absent defences

(These are not in the sequence of the model).

The Report does not make it clear exactly what the investigators believe happened. It is axiomatic that you cannot find the underlying causes without first “solving” the accident — that is, determining exactly what happened, and in what order. While the investigators no doubt solved the accident to their own satisfaction, the reader seems to be left with bald conclusions. This is analogous to the famous line: “Trust me, I know what I’m doing!”

While General Failure Types are identified, it is by no means clear how the investigators believe that these contributed to the accident. The backtracking advocated by Reason is not described, perhaps because it would have been difficult to do so. The linkages have not been made. The result is that not only is the Report not coherent, but it may not persuade those who are in a position to take action of the need to do so.

Some of the difficulties that BASI experienced appear to stem from treating “the aviation organization” as the monolithic unit envisaged by Reason. It may have been this concept that led them to treat training as a “defence” — a considerable extension beyond the ultimate defences such as stall warning and GPWS envisaged by Reason.

It would be fair to say that BASI has not found it easy to apply the Reason model to what was, by comparison with others, an uncomplicated investigation.

Some of the matters discussed appear to be easier to handle using the Helmreich model:

- Adverse weather (but not particularly bad)
- Lack of terrain guidance lighting (which is not unusual)
- Equipment deficiencies
- Lack of training in this particular aerodrome
- High cockpit workload

These are all items which individually should not have caused an accident but, cumulatively, applied pressure to the crew with sufficient potential to lead to deficient performance.

**Elaborations of the Reason Model**

One critically important area of corporate activity to which the Reason model does not refer is Personnel. Weaknesses in recruitment and training procedures have
Diagram 12. Combined Organizational Error Map
featured prominently in a number of recent investigations, notably the Skyferry Public Inquiry into the loss of a Cessna Caravan off the east coast of the South Island of New Zealand (12), which will be discussed in more detail later. This area could be addressed by incorporating in the Organization Processes box ‘Staff,’ and under the ‘Design-Build-Operate-Maintain’ box a second box: ‘Recruit-Train-Promote’; See Diagram 11.

At the individual level, Reason makes no provision for illusions. The accidents he reviewed did not involve them; they are unlikely to occur in nuclear power plants, for example. However, they are not-infrequently contributory to aircraft accidents.

The category of ‘active failures’ includes logical errors that give operators an incorrect appreciation of the real situation. This is exactly what an illusion does. An illusion involves a perceptual error, so it seems appropriate to add to ‘errors and violations’ a third category of ‘misperceptions.’

An environmental situation may give rise to an illusion, for example misperception of approach angle when the runway is apparently shortened by poor visibility. However, the misperception is done by the pilot. This demonstrates the linkage Reason postulated between the environmental condition (poor visibility) and the resulting unsafe act (misperception). (See Diagram 11)

A greater difficulty, however, lies in assuming that the industry has a monolithic structure. In airlines we have:

- Separation between manufacturer and airline;
- Not infrequently, separation between airline and maintenance organization;
- Various external inputs from the regulatory authority and from Air Traffic Control;
- Inputs from international sources, in particular from the International Civil Aviation Organization.

For example, the feedback and feedforward of information between manufacturer and airlines is normally accomplished through the airworthiness branches of national civil aviation authorities.

It will not do to treat “the industry” as the operator:

- We cannot assume a common safety culture between, for example, CAA and Michael Rodent Airlines;
- We could not track the feedforward and feedback of information through the separate entities;

There would be a great loss of information — within each entity systems failures can occur, and we need to locate these to remove accident causes.

If we are to use the backtracking proposed by Reason, we would have to represent each entity separately, which would be rather unwieldy.

Rather than try to resolve the difficulties in applying the Reason model to the airline industry by making it general, a much simpler approach can be achieved by using the Helmreich model to show which areas are of interest. The Helmreich model shows interactions that affect the crew and they are, after all, the penultimate bastion. If something does not affect them, directly or indirectly, it is probably not a factor in the accident. (This is not to say that such non-factors should be ignored: if we find something unsafe we have the opportunity to put it right without the expense and trauma of an accident.) Having identified the particular areas of interest, we can then apply the Reason model to each of those areas to locate the General Failure Types in them.

**Diagrammatic Presentation**

Alternatively, diagrammatic representation may provide a way of grasping the complexities of inter-organizational mapping.

An accident seldom happens in isolation: usually it is a concatenation of events. This idea gave rise to the concept of a ‘causal chain.’ However, this concept is usually unhelpful, because it is an oversimplification. The reality is likely to be a complex web of interacting events, culminating in the accident. To grasp such a web of events while investigating the accident can be difficult. To present it in purely verbal form, in such a way as to be comprehensible to even a well-informed reader, may be well-nigh impossible.

The flow chart showing the causative events in the Skyferry accident (12), is derived from a presentation made to the Court of Inquiry, with this difficulty in mind.

Skyferry, a company whose primary operation had been flying passengers across Cook Strait (between the North and South Islands of New Zealand), decided to branch out into night freight operations between Wellington and Christchurch, using two Cessna 208 ‘Caravans.’

A month after the service started, one of the aircraft was lost at sea off the Kaikoura coast. The subsequent investigation showed that at about midnight the aircraft had encountered severe icing while flying at 11 000 feet, stalled, and spun into the sea killing the pilot and a passenger. The aircraft had no airframe de-icing equipment, and there were various deficiencies in maintenance. But why had the pilot continued to fly in severe icing, when he could have escaped by descending to a
Months Before

Appointment Referred to CAD

Appointment as Chief Pilot/Ops Manager/Line Pilot

Unsuitability For Position

Excessive Workload

Regularly Excessive Crew and Duty Times

Inadequate Base Inspections

CASO 3 Breaches

Faulty Instructions Actions in Event of Icing

No Assessment of Training

Chronic Fatigue

Difficulty with Instrument Rating Renewal

Inadequate Reg 77 Check

Supervisory Function Impaired

Ops Manual Approved Without Guidance on Height Route Icing

Failure to Notify ASLA of New Service

New Service WH - CH

Direct Route High MSA - Known Heavy Icing Above Freezing Level

Training for Night Freight Role: No Overall Responsibility

Appointment of new Chief Pilot (Limited NZ IFR Experience)

Burning the Candle at Both Ends

Ordered Without Deicing Equipment

Inadequate Base Inspections

Aircraft flown with Defects

Aircraft not Airworthy

HeadOffice Audits

Pilots Unaware of Some Defects

No Feedback to Regional Office

Jobs accepted by General Manager

Use of Pilots as Loaders

Regularly Excessive Crew and Duty Times

Inadequate Base Inspections

Aircraft flown with Defects

Aircraft not Airworthy

HeadOffice Audits

Pilots Unaware of Some Defects

No Feedback to Regional Office

Direct Route High MSA - Known Heavy Icing Above Freezing Level
Days Before

No Proving Flight

No Route Inspection

Pilot Ignorance
- Height/Route Choice
- Effects of Icing

Inspection

- Hypoxia

Pilot Ignorance

Selection of Direct Route - 11000 feet

Mild Hypoxia

Hours Before

Scheduled Night Flight

Unscheduled Afternoon Flight

Early Call

Pilot Loaded 10 Tons of Freight

Pilot Soaked by Rain While Loading

Aircraft Heater U/S?

Rostered Pilot Not Instrument Rated

BAD WEATHER

Physical Workload

Pilot Cold

Unscheduled Afternoon Flight

CASO 3 Breaches
- Duty Hours
- Meal Breaks

Physical Workload

No Ice Detection Lights

Pilot Heat Intermittent

Pilot Frozen?
Pilot Unaware of Extent of Icing

Acute Fatigue

Low Arousal Circadian Dysrhythmia

Tiredness

Inattention/Inability to Function

Failure to act

SEVERE ICING

Knowledge of correct action?
lower level? In the words of one member of the Court of Inquiry, “What was he using for a brain?”

Perhaps not much. It transpired that the pilot had worked for 18 hours before the accident, had loaded and unloaded by hand some ten tons of freight, was soaked by rain while doing so (no foul weather gear was provided), had had no proper meal break before the flight and was eating sweets to sustain himself. He had had no oxygen indoctrination course, and would have been mildly hypoxic. Around midnight, his body would have been reaching a low point in its circadian rhythm. The cabin heater may not have been working.

Further investigation showed that the pilot, who was the Operations Manager, and had until recently also been the Chief Pilot, had been having difficulty passing his instrument rating renewal. Previous tests of his general flying had been unsatisfactory. He had a record of previous accidents and incidents which reflected adversely on his judgement.

Surveillance by the Civil Aviation Division (CAD) of the Ministry of Transport ought to have alerted them to these shortcomings, to the excessive hours being worked, and to deficiencies in maintenance. So severe were the deficiencies in surveillance that the Chief Inspector of Air Accidents considered that he was required to bring the matter to the attention of the Attorney General, who ordered a Court of Inquiry under Mr Justice Carruthers.

An algorithmic format for the presentation seemed appropriate, the causative factors being seen to modify inputs after the fashion of transfer functions, with descriptive comments to indicate the ensuing effects. Time is difficult to represent. Some of the events took place years before the accident (for example, the events that led to the Civil Aviation Division having no Inspectors in the Wellington Region with any Air Transport experience). Others happened in the hours before the accident. Naturally, when the accident was being investigated, events were put in their proper time-frame. However, to be able to contain the events of a number of years on a uniform timebase, and portray them in sufficient detail, required rather a large chart (some three metres by one metre). This might not be a practical proposition for a Report.

The criteria used to devise the diagrammatic format presented here were:

- a. Having as a starting point the various organizations involved
- b. Minimising the number of different symbols
- c. Showing the flow in a single direction, to the greatest extent practicable
- d. Having a time domain, on a quasi-logarithmic base. In general, the exact sequence of events some time before the accident is unlikely to have been critical: for example, the precise date that a deficient Base Inspection was performed is probably immaterial. On the other hand, it may well be important to know whether something happened a few days before rather than a few months, and in the hours leading up to the accident the exact sequence of events could be critical. Hence, the events depicted have been grouped by
  - ‘Years before’
  - ‘Months before’
  - ‘Days before’
  - and ‘Hours before’ the accident.

Commencing the action with the organizations involved has led to some crossing of flow lines, but this is an accurate portrayal of reality, the ‘complex web of interacting events’ already mentioned.

An unexpected bonus from this representation is the very clear indication of the major sources of problems—the difficulties which the Civil Aviation Division (CAD) had in performing surveillance of air transport operations, and the undercapitalisation of the company. These are highlighted by the large number of ‘effect lines’ radiating from each of the appropriate boxes. Both of these sources of problems, in turn, stemmed from Government policy: attempts to minimise the cost of CAD, and deregulation of air transport operations. It might be difficult to bring out this point so clearly in any other way.

To facilitate the process of leading the reader through the diagram, it would be better to have the diagram as a centrefold at a suitable point in the analysis, rather than having it tucked away as an annex to which the reader must constantly refer.

We now have the tools to describe a human factors accident accurately to the reader:

- The Helmreich model, showing how the pressures on the crew built up until the active failure occurred that led to the accident;
- The Reason model, to trace back from the active failure to the latent failures in one or more organizations;
- Diagrammatic representation which may help the reader to grasp the interactions in a complex accident.

Let us now examine the way in which these elements could be combined into a new standard format.
Format of the Report

Section 1 - Factual Information

There is little reason to remove the distinction between Factual Information and Analysis. However, organizations involved are likely to find the Report more acceptable if the order of presentation of material in Factual Information (Section 1) is rearranged. At present, the information relating to an organization is presented in 1.17, Organizational and Management Information. It is thus likely to be perceived by organizations as a chapter of misdeeds, unrelated to the remaining information. If the information in Section 1 is presented in the order of the Helmreich model, with which we propose to start the human factors investigation, the reader will start to build up a picture of how the various items are inter-related. For the general reader, the Report should read more coherently.

The Helmreich model can be described in the following sequence:

| Crew Environment       | Experience                  |
|                        | Training                    |
|                        | Health and Medical          |
| Physical Environment   | Aircraft                    |
|                        | Airport                     |
|                        | Weather                     |
| ATC Environment        | Controllers                 |
|                        | Communications              |
|                        | Navigation and Radar        |
|                        | Organization and Management |
|                        | ATC Regulations             |
| Organizational         | Company History             |
| Environment            | Organization and Management|
|                        | Maintenance Organization    |
| Regulatory Environment | Regulatory Authority Structure|
|                        | Regulations                 |
|                        | Surveillance and Monitoring |

Table 2   Helmreich Model

Evidently, we will need to start this section with the History of the Flight, as at present, in order to set the scene. It would be appropriate to conclude the history with a discussion of fire and survivability, since these are the conclusion of the action sequence, and move on to discuss the physical evidence at the impact site. The narrative then moves logically to the crew, who were first to arrive at the scene of the accident, and out through the progressive layers of environments that affected them.

The overall format for Section 1 will then be as shown in Table 3.

<table>
<thead>
<tr>
<th>Table 3. Section 1 - Factual Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 History of the Flight</td>
</tr>
<tr>
<td>1.2 Fire and Survival Information</td>
</tr>
<tr>
<td>1.3 Wreckage and Impact Information</td>
</tr>
<tr>
<td>1.4 Crew Environment</td>
</tr>
<tr>
<td>1.4.1 Personal Information</td>
</tr>
<tr>
<td>1.4.2 Experience and Training</td>
</tr>
<tr>
<td>1.4.3 Health and Medical</td>
</tr>
<tr>
<td>1.5 Physical Environment</td>
</tr>
<tr>
<td>1.5.1 Aircraft</td>
</tr>
<tr>
<td>1.5.2 Airport and Terrain</td>
</tr>
<tr>
<td>1.5.3 Weather</td>
</tr>
<tr>
<td>1.6 ATC Environment</td>
</tr>
<tr>
<td>1.6.1 ATC Situation</td>
</tr>
<tr>
<td>1.6.2 Controllers</td>
</tr>
<tr>
<td>1.6.3 Communications</td>
</tr>
<tr>
<td>1.6.4 Navigation and Radar</td>
</tr>
<tr>
<td>1.6.5 Organization and Management</td>
</tr>
<tr>
<td>1.6.6 ATC Regulations</td>
</tr>
<tr>
<td>1.7 Organizational Environment</td>
</tr>
<tr>
<td>1.7.1 Company History</td>
</tr>
<tr>
<td>1.7.2 Organization and Management</td>
</tr>
<tr>
<td>1.7.3 Maintenance Organization</td>
</tr>
<tr>
<td>1.8 Regulatory Environment</td>
</tr>
<tr>
<td>1.8.1 Regulatory Authority Structure</td>
</tr>
<tr>
<td>1.8.2 Applicable Regulations</td>
</tr>
<tr>
<td>1.8.3 Surveillance and Monitoring</td>
</tr>
<tr>
<td>1.9 Tests and Research</td>
</tr>
<tr>
<td>1.10 Additional Information</td>
</tr>
</tbody>
</table>

While this order of presentation is designed to suit a human factors investigation, there is nothing about it that would be detrimental to an investigation that hinged on technical defects. This format would thus be of general application.

Section 2 - Analysis

As already discussed, any analysis should begin with ‘solving’ the accident; and, where the accident sequence is complex, a flow diagram will be a considerable aid to understanding.

Then follows the ‘why’ of the accident. In a technical accident this may be relatively straightforward, though it is not necessarily so. In a human factors investigation, as exemplified by the Skyferry accident, experience has shown that complexity is the norm. A human factors analysis could conveniently have a series of standard sections. Starting with the Helmreich model (we could entitle this section ‘Factors Affecting Crew Performance’), we will isolate for further study those organizational areas where difficulties arose. We can then examine these difficulties in turn, using the method advocated by Reason, to work back from the token failures to seek out the Latent Failures in each case.
In doing this, we are likely to find, in the author’s experience, that the sequence adopted by Helmreich in the Dryden Report is the most logical. Helmreich reversed the order in which the factual information was presented, and began the analysis with the outermost environment, the Regulatory field. This sequence enables the reader to see how each of the environments affects those inside it, and how the overall effect builds up pressure on the crew.

The following format meets these requirements:

---

**Section 2 - Analysis**

2.1 The Accident Sequence (the ‘solution’ of the accident)
   (This will include such items as determining the flightpath, and physical causes, eg icing)

2.2 Factors Affecting Crew Performance (the Helmreich model, starting from the outside)
   2.2.1 The Regulatory Environment
   2.2.2 The Operating Environment
   2.2.3 The ATC Environment
   2.2.4 The Physical Environment
   2.2.5 The Crew Environment

2.3 Organizational Factors (Latent Failures)

---

Table 4.

One virtue of having a set format for the Analysis is that organizations will no longer be able to apply pressure to avoid having their shortcomings discussed in the Report. Even were they to succeed, the omission of a standard section would, of itself, draw attention to their actions.

The aim of the Crew Performance and Organizational Factors sections of the presentation is to show how various organizational deficiencies contributed towards the accident. By avoiding the appearance that any one organization is being ‘blamed’ for the accident, we should be able to promote an atmosphere where lessons learnt can be applied for the prevention of future accidents, rather than the present situation where organizations refuse to accept that anything is amiss.

The proposed format would discard the present subheadings of ‘Findings’ and ‘Probable Cause.’ In the author’s opinion, these are entirely counterproductive. ‘Findings,’ stripped of their qualifying circumstances, invariably strike an accusatory note. The various causal factors have been canvassed at length in the ‘Analysis’; to single out one (or even a few) runs counter to our knowledge of the way in which accidents happen.

Consider the Erebus Report by Mr Justice Mahon (13). After a masterly overview of all the things that came together to cause the disaster, Mahon felt impelled for (as he said) purely legal reasons, to ascribe it all to the

“single dominant and effective cause...” (the airline’s failure to notify the flight crew that the route had been changed) (p. 159). Had he not done this, the Report would probably have been seen for what it was — the first study of the systemic causes of accidents, ten years before Reason. And future disasters, not only in aviation, might have been averted by applying the lessons to be learnt, in advance.

By all means bring the Report to a tidy conclusion, perhaps by summarising the Latent Failures or General Failure Types discovered, but ‘Probable Cause’ should have no place in modern accident investigation.

**Summary**

In the past, Reports on accidents that have involved human factors have frequently generated more heat than light. In the author’s opinion, a great deal of the difficulty has been caused by the present standard ICAO format for accident reports. This format was evolved to deal with accidents having technical causes, for which purpose it has served well.

However, when used for a human factors investigation, the way in which information suggesting organizational deficiencies is tagged onto the end of the Factual Information section, without (at that stage) apparent justification, is likely to arouse corporate opposition.

The lack of format for the Analysis section has tended to result in each of the branches of the causation tree being presented in turn. Where several organizations are involved, each is apparently ‘blamed’ in isolation; each could reasonably claim that without their alleged deficiencies the accident might still have occurred.

The proposed format should overcome these difficulties, and also be readily comprehensible to readers without specialised knowledge. At the same time, it would not adversely affect the presentation of investigations into technical factors.

We know that the format discussed in this paper will work well when applied to the Dryden and Skyferry investigations, because they were used in developing it. However, this does not establish its generality. An existing report has also been reshaped in this fashion, taking us a step further towards generality, and is available on request (through Massey University) (14). In recasting that report, the proposed format was revised in a number of respects. It will very likely be found, when other accident reports are recast in similar fashion, that further fine-tuning is required; the proposed format is strictly a working draft, and the author would welcome feedback from other investigators.
References


Dmitri Zotov served in the Royal Air Force for 18 years, for much of the time being involved in aircraft trials and operational research. After a period of instructional and commuter flying in New Zealand, he spent seven years as an Inspector of Air Accidents. He is now Associate Lecturer in Air Safety Investigation at Massey University.
Category 1

These are the most serious occurrences which are perceived to present a threat to public safety or are the subject of widespread public interest. In general, accidents involving international, interstate, and regional air carriers will fall into this category. The investigation normally will involve a full on-site investigation directed at the collection and analysis of all relevant facts, the issue of recommendations and the production of a final report in the ICAO-style within about 12 months. All accidents to RPT aircraft over 5,700 kg which involve a fatality, in-flight collision, on-board fire or explosion or an engine or propeller tear-away will be investigated as a category-1 occurrence.

Category 2

This category is assigned to those occurrences where the facts, as revealed by reported circumstances or from a preliminary investigation, indicate a reasonable concern for public safety or the potential for formal recommendation action. In general, most serious accidents which may have widespread implications for safety and incidents with significant accident potential, particularly those occurrences involving commercial passenger carrying operations, will fall into this category.

The scope and detail of a category-2 investigation are similar to those for a category-1 investigation differing only in the size, structure and organisation of the investigation team. The final ICAO-style report, including recommendations, should be completed in less than 12 months.

Category 2 encompasses charter and RPT operations and may include serious incidents such as critical or potential airmisses, explosive decompression as well as many other occurrences.

Category 3

This category is the minimum to be allocated to fatal accidents (except in the case of sport aviation where category 4 may be allocated). The depth of investigation will be determined with respect to the information received. For example, if examination of the site and the aircraft, and interviews with those involved, allow the investigator to establish a sequence of events which does not identify deficiencies with a potential for safety action, then the investigation will be concluded at that point.

Category-3 occurrences often relate to operations other than charter or RPT. The category includes occurrences involving danger to the public, ATC or FS procedural breakdowns, and breakdowns in separation in CTA.

Category 4

This category applies to all occurrences where the facts, as revealed by the reported circumstances, suggest neither a concern for public safety nor a serious safety deficiency.

This category is used to respond to minor non-fatal accidents and to those occurrences where there is no need for formal recommendation action, but where the circumstances are sufficiently complex to require more detailed information from the pilot or operator. The investigation concentrates on capturing data for long-term trend analysis or for identifying and disseminating a worthwhile safety lesson that does not warrant formal recommendation action.

This category is limited to those occurrences where the overall circumstances are not complicated and/or the occurrence involves private recreational, business, or commercial non-passerenger carrying operations. Category 4 is the minimum level of investigation for an accident involving an Australian-registered aircraft.

Category 5

This category is reserved for occurrences where the facts, as revealed by the circumstances, clearly indicate no need for safety action by BASI. The response is directed at capturing, normally by telephone at the time of notification, sufficient data to permit long term trend analysis. A report will be prepared only in special cases. Many sport aviation occurrences are grouped in category 5.
The information contained in the preliminary report is derived from initial investigation of the occurrence. Readers are cautioned that there is the possibility that new evidence may come to light that alters the circumstances as depicted in this report.

Occurrence Number: 9501246

Location: 9km NW Alice Springs

State: NT

Date: Thursday 27 April 1995

Time: 1027 hours

Time Zone: UTC

Aircraft Manufacturer: Israel Aircraft Industries Ltd

Aircraft Model: 1124

Aircraft Registration: VH-AJS

Damage to Aircraft: Destroyed

Departure Point: Tindal NT

Departure Time: 0904 UTC

Destination: Alice Springs NT

Type of Operation: Charter

Highest Injury Level: Fatal

Injuries:

<table>
<thead>
<tr>
<th>Group</th>
<th>Fatal</th>
<th>Serious</th>
<th>Minor</th>
<th>None</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Passenger</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Ground</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Crew Details

<table>
<thead>
<tr>
<th>Role</th>
<th>Class of Licence</th>
<th>Hours on type</th>
<th>Hours Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot-In-Command</td>
<td>ATPL</td>
<td>2530</td>
<td>10109</td>
</tr>
<tr>
<td>Co-Pilot/1st Officer</td>
<td>ATPL</td>
<td>85</td>
<td>3747</td>
</tr>
</tbody>
</table>

Factual Information:

The aircraft was on a scheduled freight service from Darwin via Tindal, Alice Springs, and Adelaide to Sydney. The flight from Darwin to Tindal was apparently normal, and the aircraft departed Tindal slightly ahead of schedule at 1834 CST. On descent into Alice Springs, the crew advised on the MTAF frequency its intention to conduct a twin locator (Locator/NDB) approach to runway 12.
At approximately 1950 EST, witnesses in a housing estate on the eastern side of the Ilparpa Range, approximately 5 km NW Alice Springs Airport, observed aircraft lights approaching from the north-west. They described the lights as appearing significantly lower than those of other aircraft they had observed approaching Alice Springs from the same direction. The lights illuminated several buildings as the aircraft passed overhead before proceeding towards the western escarpment of the range. Witnesses then heard the sound of impact and observed flames at the top of the ridge.

Examination at the accident site revealed that impact occurred near the top of the Ilparpa Range at approximately 2,250 ft AMSL while the aircraft was in a shallow climb, in a wings-level attitude. The landing gear was down at impact and aircraft track was approximately 103 degrees M. The aircraft was destroyed by impact forces and post-impact fire.

The Locator/NDB approach at Alice Springs involves an outbound track of 292 degrees M from the Alice Springs NDB, overhead the Temple Bar Locator to the turn point at the Simpsons Gap Locator. The initial approach altitude is 5,000 ft and the intermediate altitude at Simpsons Gap is 4,300 ft. The inbound track is 112 degrees. On the inbound leg, the ‘not below’ altitude between Simpsons Gap and Temple Bar is 3,450 ft, and between Temple Bar and the Alice Springs NDB is 2,780 ft. The Minimum Descent Altitude, with actual area QNH, is 2,300 ft for aircraft in performance categories A and B, and 3,100 ft for aircraft in performance category C. VH-AJS was a performance category C aircraft.

Both the flight data recorder and the cockpit voice recorder which were fitted to the aircraft were recovered from the accident site. A preliminary examination of these recordings has revealed the following information.

The flight data recorder showed that during descent from cruise altitude, the aircraft tracked directly to the Simpsons Gap Locator, arriving there at about 4,300 ft. After passing the Simpsons Gap Locator, the aircraft continued to the Temple Bar Locator, arriving there at about 3,500 ft. Beyond this point, the aircraft continued to track approximately 112 degrees M and descended to 2,300 ft, where it leveled briefly before climbing slightly immediately before impact.

The cockpit voice recorder revealed that, in discussing the approach prior to descent, the crew intended to fly the approach to a minimum of 2,780 ft. In the event, however, after passing Temple Bar, a minimum of 2,300 ft was called and the aircraft descended to that altitude.