Multi Linear Events Sequencing

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A Case Study

When we investigate an accident, we need to establish *what* has happened, before we try to diagnose *how* or *why* a mishap occurred. Multilinear Events Sequencing, hereafter and for ever more to be known as MES, will help us to do this. It focuses on the actions that took place during an accident sequence, without attempting to go back to deeper causation. The basic concept is that “Everybody and everything has to be somewhere, and doing something, during an accident”. Our job, in the early stages of an investigation, is to find out *where*, and doing *what.*

MES is a form of time-line, but unlike a simple time-line, it takes account of the way things usually happen in parallel. If you’ve ever found yourself wanting to write ‘Meanwhile, back at the ranch…’ you need MES to display what you’ve found. But additionally, MES sets out to establish physical causation. The wing didn’t just fall off; something made it – *what?* It does this by linking the various actions we’ve discovered; any blank connections mean we don’t yet know what happened, and indicate to us where we need to look for evidence, while it is still available. Again, a simple time-line won’t do this.

MES moves from one event to another during the accident sequence. There is learned dispute about what we really mean by an ‘event’[1], which we will set aside by defining the basic element of MES as an ‘Event Building Block’ (EBB), which is a single actor, performing a single action.

The form of an MES is deceptively simple. We can start by writing down all the actors we can think of, animate or inanimate, and by convention they are listed vertically on the left of the page. Then, as we establish what went on, we show the linkages as one acted on another, across the page. If we have exact time, well and good, but what really matters is whether one action occurred before another. These linkages must show that the previous EBBs are necessary and sufficient to account for those that follow.

Here’s a simple case, where we have a pilot and an aircraft (Figure 1).

First EBB: pilot acts on aircraft – ‘Pilot pulls on stick’

Second EBB: aircraft responds – ‘Aircraft pitches nose-up’

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[1] See e.g. Bennett, J. (1988). Events and their names. Oxford, Oxford University Press.

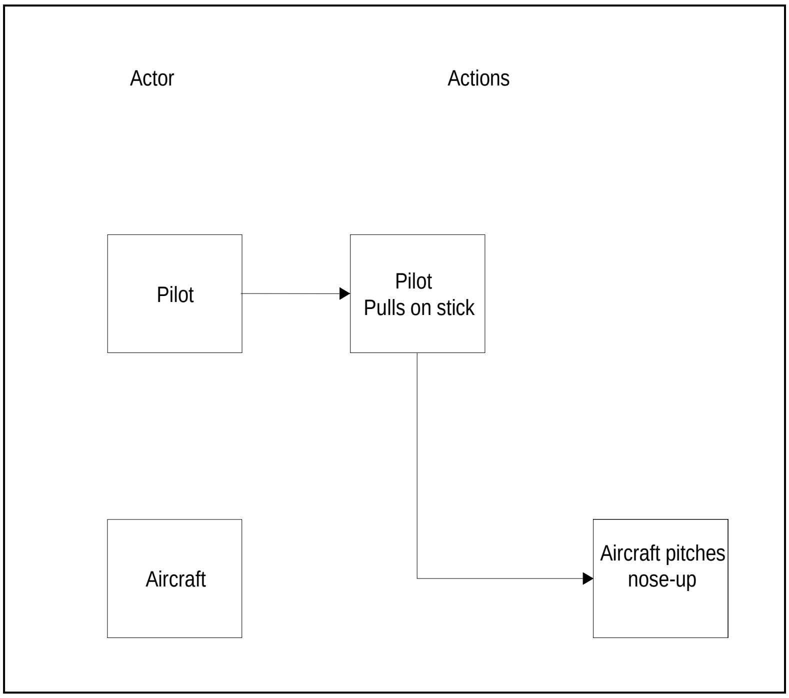


Figure 1: Event Building Blocks

A single actor (the pilot, or the aircraft) performing a single action. Notice the use of active voice: we should say ‘aircraft struck tree’, not ‘tree was struck by aircraft’. The reason for this is that passive voice can hide lack of understanding of what really happened. The use of active voice enables us to construct a ‘mental movie’: we can visualise what happened, and gaps in our understanding become obvious.

Constructing and placing the EBBs during an investigation is straightforward. While they can be displayed on a graphics program, I’ve found it easier to use Postit notes, laid out on something like a bed sheet, because this lets you see detail while being able to take in the whole display, and it is easy to move items as more evidence becomes available. An MES can become quite large.

Common questions are where should the MES start and end? Ira Rimson suggested that it should start at the first perturbation from the normal flow of events. If in doubt, start earlier than seems necessary: it can always be edited later. The end point is usually easy to see: it is when the mayhem has stopped. The aircraft has come to a halt, any post-crash fire has burned out, and survivors have been evacuated. MES is about the dynamics of an accident.

A further function of MES is review of a draft report, or indeed of a completed report during litigation. The adequacy of investigations has been challenged on many occasions, and with the trend to criminalisation of accidents, such challenges are more likely to arise in future, in the course of legal action. Methods of improving the quality of investigations are therefore desirable. An MES review is an important Quality Control check. It is this function that we’ll look at in the case study next, though as we go along, it will be clear that the investigators could have benefited greatly had they had this tool at their disposal during the investigation. The value of MES has now been recognised by ISASI, which is including it in the Training Manual.

Before we go further, I want to emphasise that this case study - the Ansett accident - is not intended as a criticism of the investigators. As we review the report and the evidence, you may find yourself asking ‘How on earth could they have missed that?’ But the investigators were not incompetent: they were highly respected Inspectors of Air Accidents. They simply lacked the tools for the job. That MES makes errors and oversights obvious, is a testimony to the power of this tool.

MES is a tool for manipulating the data gathered during an investigation, so as to be able to form a coherent picture of the occurrence. It is intended to display the logical linkages between the events in the accident sequence, and to indicate where insufficient evidence has been gathered, so that this deficiency can be rectified. It can be used either during an investigation, or as a post-investigation review. In this case study, it will be used primarily to review the official report (TAIC 1995), but where deficiencies in the report are found, reference to other evidence will be made to resolve these deficiencies. The purpose of this analysis is to demonstrate the function of MES as an investigation and quality control tool.

(Benner 1994) advises that, when constructing an MES graph from an existing report, the following procedure should be adopted:

- Underline every actor and every action
- For each actor, tag all the verbs which say or imply that someone did something, especially where someone moved, decided or concluded something
- Circle the specific actions by the person that initiated a change of state in that person or in someone or something else
- Prepare Event Building Blocks (EBBs) for each circled action, in the ‘actor-action’ format. Annotate the source on the EBB
- Check for 'poison words': plural actor names ('aircrew'), passive verbs, pronouns, opinion ('misjudged'), editorial adjectives ('incorrectly'), or statements of what did not happen ('did not descend').

In Benner's view, passive voice should be treated as an indicator that the investigator is covering up unsatisfactory investigation practices. Statements of what did not happen introduce investigator bias, unless supported by data describing the pre-existing standard on which a logical comparison of expected and actual action can be made (Benner 1994). The procedure advocated by Benner (1994) was adopted, and the MES graph was constructed in the stages described in the following section. Where paragraph numbers and pages are quoted, without further reference, they refer to the official report (TAIC 1995).

History of the Flight (1.1, pp. 7, 8)

Information from the history of the flight is shown in Fig. 2. Generally, the wording from the report is used. Where the past tense required by the ICAO recommended report format (ICAO, 1994) has been used in the report, it has been retained.

The ambiguity which can arise from compound words is evident ("the pilots briefed themselves": in reality, one briefed the other, as indicated in the CVR transcript

(TAIC, 1995, Appendix C, p. 111 et seq.)), but it could be argued that at this point, precisely what happened during the briefing sequence is immaterial. However, the ambiguity arising from the use of passive voice could potentially be relevant at other times, for example "the aircraft power levers were retarded" raises the questions "by whom?" and "was this the normal power setting?" Certainly the aircraft was not the actor, nor did the levers retard themselves. The 'mental movie' is incomplete at this point. (It would be reasonable to infer that the Captain retarded the throttle levers, as he was the handling pilot, and he gave no instruction to the co-pilot to do so).

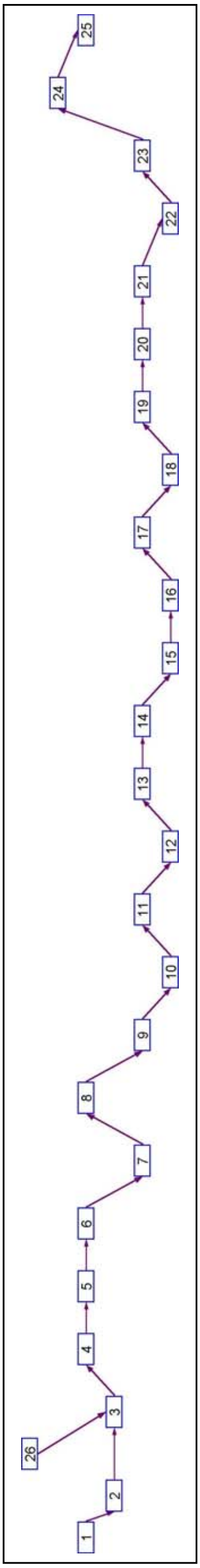
Constructing the graph also brings to light out-of-sequence statements in the report: 1.1.3 (p. 7) "The aircraft…intercepted the final approach track." "During the… turn … the aircraft's power levers were retarded ". While there is no ambiguity, out of sequence statements make the report harder to read.

However, the principle limitation of section 1.1 of the report, 'History of the Flight' (pp. 7, 8), which is intended to provide the reader with an understanding of what happened, is seen when the links between events are examined. Take for example, the final sequence

- First officer pulled release handle
- GPWS warning sounded
- Aircraft collided with terrain

There are no logical links between any of these events. The action of pulling the release handle did not cause the GPWS warning to sound, and the GPWS warning did not cause the aircraft to collide with the terrain. The links, as drawn, serve only to show sequence, and do not comply with the MES requirements for logical links, i.e. that the linkages should show that preceding actions were *necessary* and *sufficient* for those following. Clearly, more information must be sought before the reader can understand the sequence of events.

Where logical links cannot be drawn, the gaps between unlinked EBBs point to potential unknowns in the understanding of what happened (Benner, 1994). More information may be found in other sections of Part 1 of the report. Information on the GPWS is provided at 1.6.65-1.6.82 (pp. 19-23).



Key:
1 Aircraft departed from Auckland (1.1.1)
2. Pilots briefed themselves for 07 approach (1.1.2)
3. Pilots re-briefed for 25 approach (1.1.2)
4. Aircraft was flown to join 14 DME arc (1.1.3)
5. Aircraft turned right (1.1.3)
6. Aircraft power levers were retarded to flight idle (1.1.3)
7. First officer advised captain '12DME looking for 4000' (1.1.3)
8. Aircraft intercepted 25 approach track at 13 DME (1.1.3)
9. First officer advised ATC 'established inbound' (1.1.3)
10. Captain called 'Gear down' just before 12 DME (1.1.4)
11. First officer responded 'Selected [low on profile] (1.1.4)
12. Captain called 'Flap 15' (1.1.4)
13. First officer noticed undercarriage warning
14. First officer proposed alternate landing gear extension (1.1.4)
15. Captain ordered alternate extension during approach (1.1.4)
16. Captain stated He would fly the aircraft during alternate extension (1.1.5)
17. First officer began reading checklist (1.1.6)
18. Captain told First officer to skip some checks (1.1.6)
19. First officer resumed checks (1.1.6)
20. First officer performed checks, up to opening alternate release door (1.1.7)
21. First officer inserted pump handle (1.1.7)
22. Captain advised First officer to pull release handle first (1.1.9)
23. First officer pulled release handle (1.1.10)
24. GPWS sounded alarm 1.1.10)
25. Aircraft collided with terrain about 5 seconds after GPWS alarm (1.1.11)

Miscellaneous
26. ATC specified 25 approach (1.1.2)

Figure 2. Events from 1.1 (History of the flight)

The Ground Proximity Warning System (1.6.65-1.6.83, pp. 19-23).

The GPWS operated in a variety of modes depending on the aircraft configuration, using inputs from the air data computer and radio altimeter, and if applicable the glidepath indication (not relevant in this case) (1.6.67, 68 (p. 20)). The mode applicable in this case was Mode 2A, excessive rate of closure with terrain, and 17 seconds of warning should have been provided in the particular circumstances (1.6.81, p. 23). The cockpit voice recorder (CVR) showed that terrain warning occurred about 5 seconds before impact (1.6.69, p. 21), and the digital flight data recorder (DFDR) showed that 3 1/2 seconds before impact there was a nose-up elevator input and corresponding change of pitch attitude (1.6.70, p. 21).

The captain was the handling pilot, and in view of the very rapid response to the GPWS warning it may be inferred that it was he who applied the nose-up input. So the final section of the MES graph may be re-drawn as in Figure 3.

These linkages meet the test of necessity and sufficiency. If the aircraft was closing with terrain and the GPWS sensed this, the warning would sound. If the warning sounded, the handling pilot would commence avoiding action by raising the nose. If raising the nose resulted in a flightpath change insufficient to avoid terrain, the aircraft would strike the terrain. Without further evidence, it is not possible to include information on why the GPWS did not sound earlier: in MES, the emphasis is on what *did* happen. However, the graph does flag the need to seek such further information.

One limitation is that 'aircraft closed with terrain' is not strictly an *event*; it is a continuing state of affairs, i.e. a *state*,[2] as Ladkin terms it (Ladkin and Loer 1998). For this reason, it has been flagged with a different symbol.

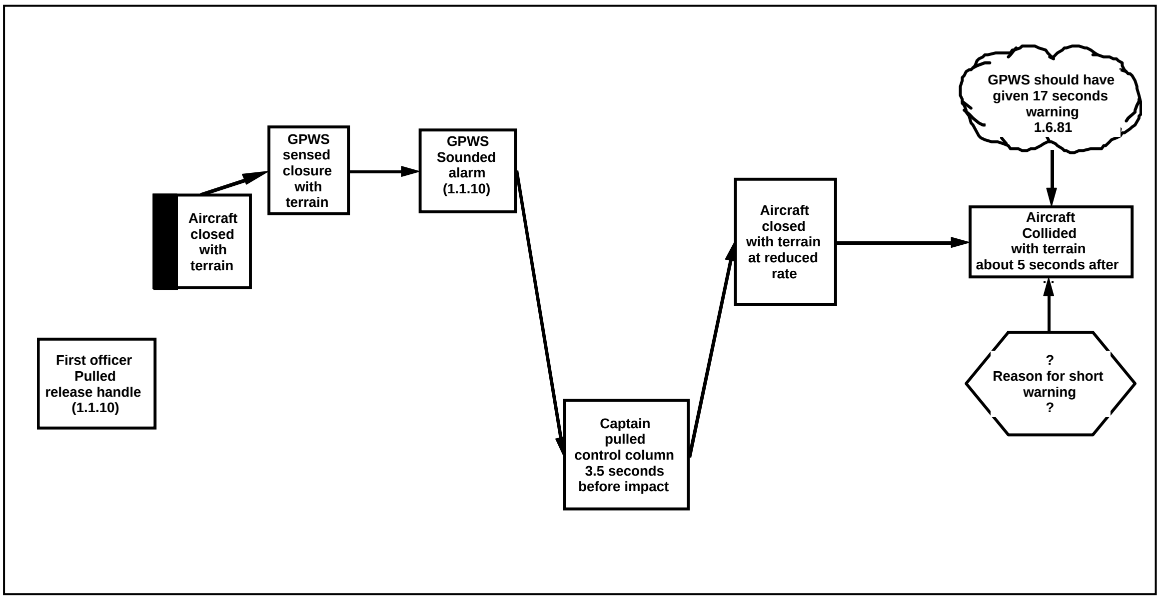


Figure 3. Ground proximity warning.

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[2] Strictly, this is a *state-event*, i.e. a state which is initiated and terminated by events. A state, per se, is of longer duration, for example the existence of a hill.

Having completed one section of the MES graph from information in the report, the next stage will be to examine the sequence in Figure 2 involving the undercarriage, from 'Captain called "gear down" ' to 'First officer pulled release'.

The Undercarriage

In the sequence relating to the undercarriage malfunction, the Captain's call of 'gear down' did not result in the First Officer's warning 'low on profile', and the Captain's call for 'flaps 15' did not cause the First Officer to notice an undercarriage warning (refer Figure 2). As with the section relating to the GPWS, additional information must be sought. The nosewheel was down at impact (1.12.11, p. 35), indicating that the First Officer not only responded to the Captain's call, but also selected the undercarriage lever to the down position. However, the First Officer's warning 'low on profile', was unrelated to his action of lowering the undercarriage.

It implies that he was monitoring the approach path, and that the aircraft had descended below the optimum descent path at this point. The Captain's call for 'flaps 15' was the logical consequence of the First Officer's response to the 'gear down' call, because this was the next action required to configure the aircraft for landing. But again, the detection of the undercarriage warning by the First Officer is unrelated to the 'flaps 15' call; it is a consequence of the right undercarriage leg remaining retracted after the undercarriage had been selected down. This section of the graph is shown in Figure 4.

From Figure 4, it can be seen that there were four streams of events going on in parallel: hence '*Multilinear* Events Sequencing'. Although 'left and nose wheels' is a compound actor, this does not give rise to any ambiguity. The EBBs and linkages now meet the logical requirements.

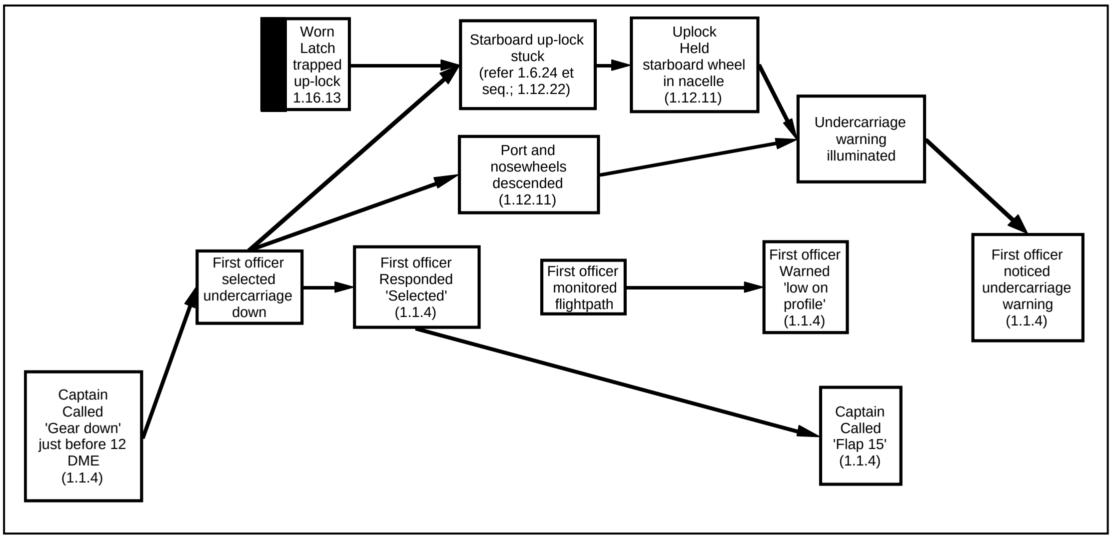

Figure 4. Undercarriage malfunction.

The First Officer's comment 'low on profile' appears 'out of the blue', and will need to be linked to some other events. The actual comment was

"On profile, ten sorry hang on ten DME we're looking for four thousand aren't we, so a fraction low" (TAIC, 1995, Appendix C, 0920:14, p. 128; the transcript of the Cockpit Voice Recorder).

However, according to the vertical profile shown in the Report (Fig. 3, p. 28) the aircraft was at 3100 feet at ten miles DME. According to the Palmerston North Approach Plate (Figure 5) the optimum height at 10 DME was 3420 feet, so the aircraft had just crossed the optimum descent path. 3120 feet was the optimum height at 9 DME. While the First Officer was correct in saying the aircraft was 'a fraction low', the reference to 4000 feet had the potential to be confusing. (The consequences of this would be discussed at a later stage; for example, when examining the Why-Because Analysis of this accident). The next stage in the accident sequence was the attempt to lower the right wheel by means of the alternate procedure.

Alternate Undercarriage Extension

While the EBBs in the sequence relating to the use of the alternate undercarriage extension method follow logically from one to the next in Figure 2, some additional information is necessary. It is necessary to know why the Captain ordered the First Officer to omit some checks, and why the First Officer performed actions out of sequence. Also, it would be helpful to know why the Captain decided to attempt to rectify the problem while continuing the approach (see Figure 6).

The first and third boxes in the time sequence have no paragraph references; they are necessary inferences from the material in the report, rather than direct references. However, supporting evidence should be available in the CVR transcript, Appendix C. Appendix C (p. 128; 09:20:30 et seq.) shows that the sequence in 1.1.4 (p. 7) is misleading. It was the captain who observed the undercarriage warning ("Oh #") and then whistled, before the First Officer noticed it. So the MES graph must be modified as in Figure 7.

This change illustrates the use of MES as a quality control measure for checking an existing report. MES would function in exactly the same way if used to check the work during the preparation of a draft. Although a minor matter, such a discrepancy would provide ammunition should the report come under criticism during litigation.

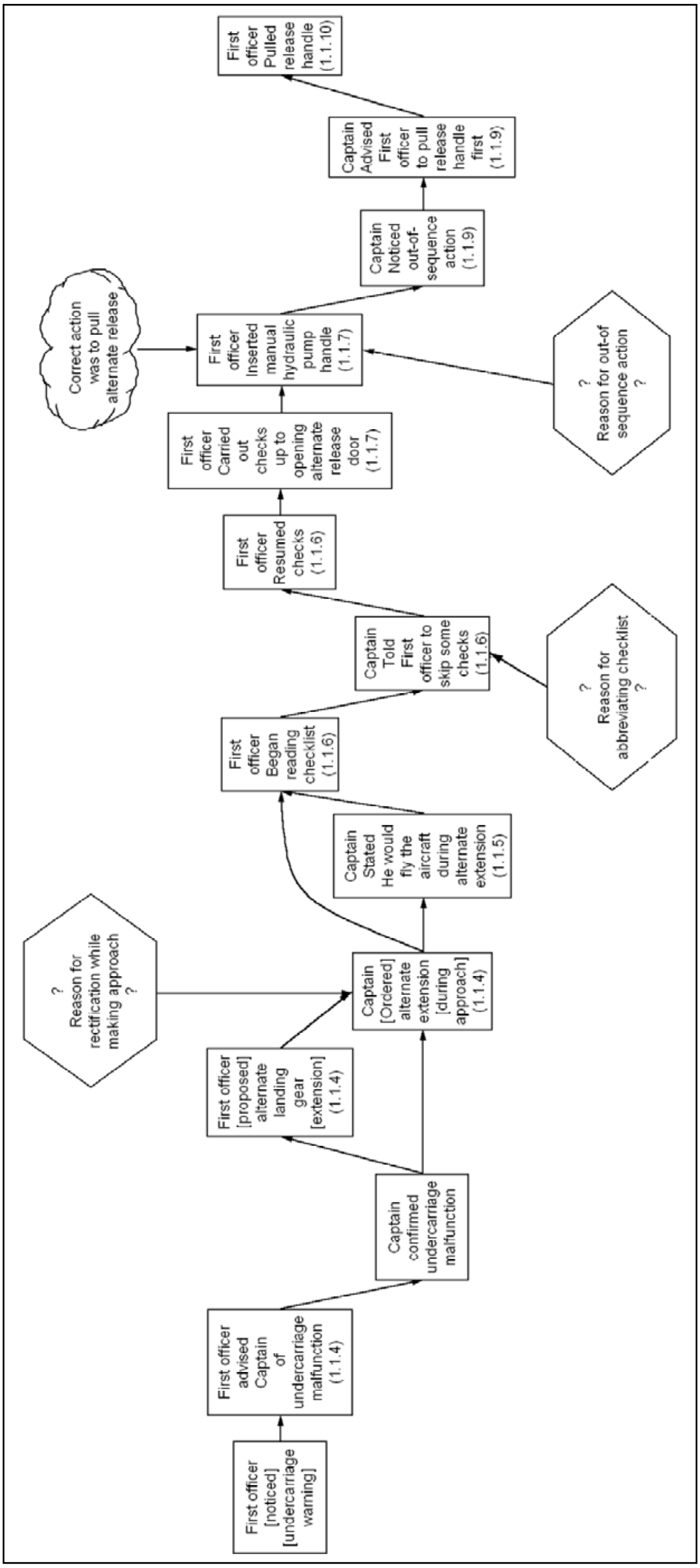

Figure 6 Alternative Undercarriage Selection.

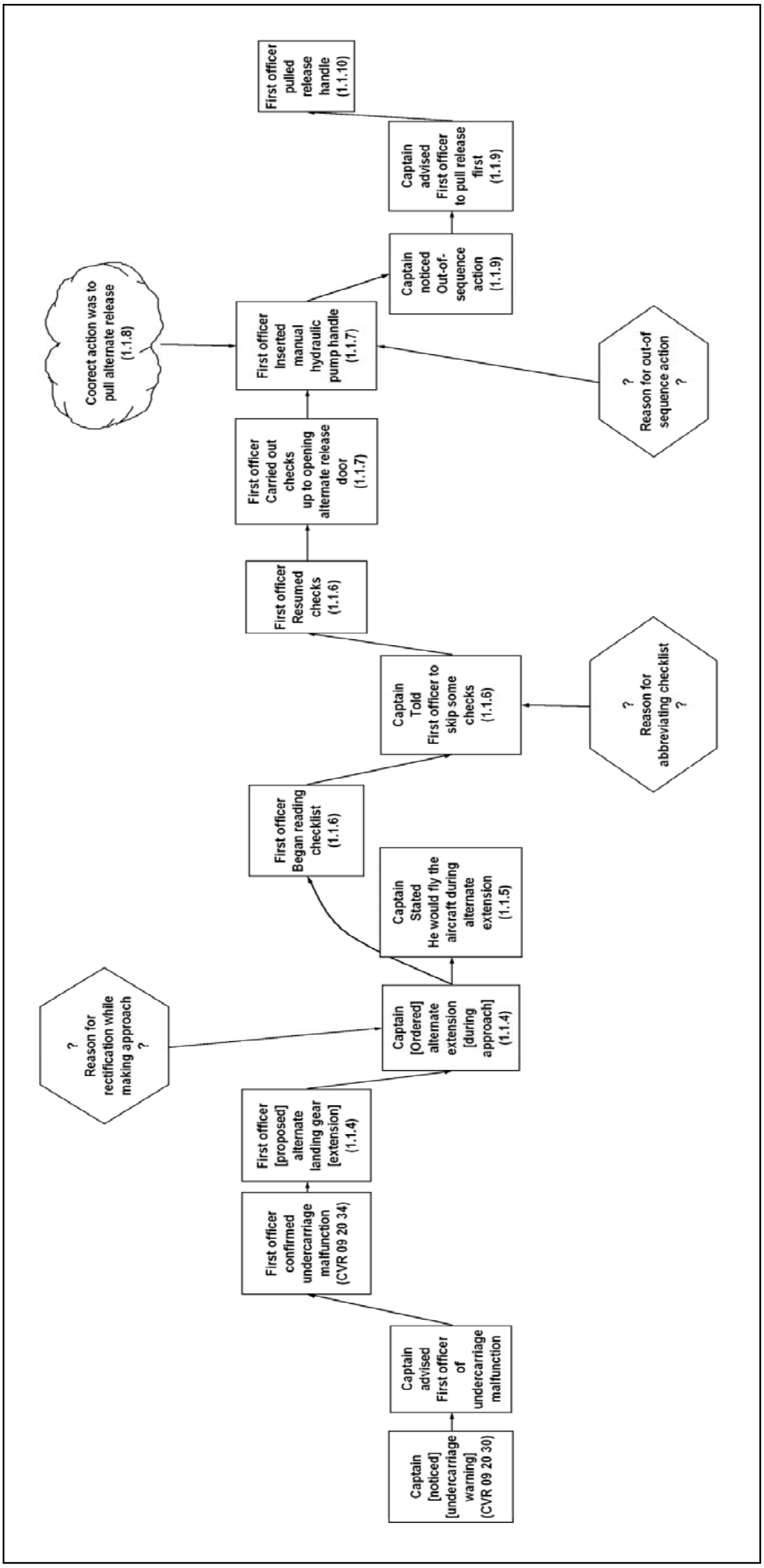

Figure 7. Alternate undercarriage selection (modified).

The approach to Palmerston North

The initial section of Figure 2 now requires logical linkages. 'Aircraft departed from Auckland', though only remotely related to 'Pilots briefed themselves for the 07 approach', sets the scene, and does not need elaboration. The initial perturbation has not yet been reached, and the flight is proceeding routinely. The initial perturbation was the specification by ATC of the 25 approach. This was a recently introduced approach (1.10.6, p. 31), which the Captain had flown only once before (1.18.35, p. 64; Appendix C, p. 111). MES does not provide a means to display this information, which would be considered later, e.g. in 'Why-Because Analysis'. The crew had briefed themselves for the usual 07 approach, and so had to re-brief themselves, and this in turn led to them flying the required 14 mile radius arc about the Palmerston North DME beacon. Notwithstanding some misunderstanding with ATC as to the heights to fly around the arc, the aircraft reached the lead-in radial at the correct height, and then turned right, onto the final approach to Palmerston North (Report, Figures 3 and 4, pp. 28; 30).

The right turn did not cause the power levers to be retarded to flight idle. This action was needed because the aircraft had become high on the glidepath by the time it completed the turn, and this excessive height was the result of the descent being interrupted during the turn (Report, Figure 3, p. 28). MES flags the need to examine *why* the aircraft had become high on the glidepath; again, this would be discussed later in the Why-Because Analysis.

This initial section of the MES graph is shown in Figure 8.

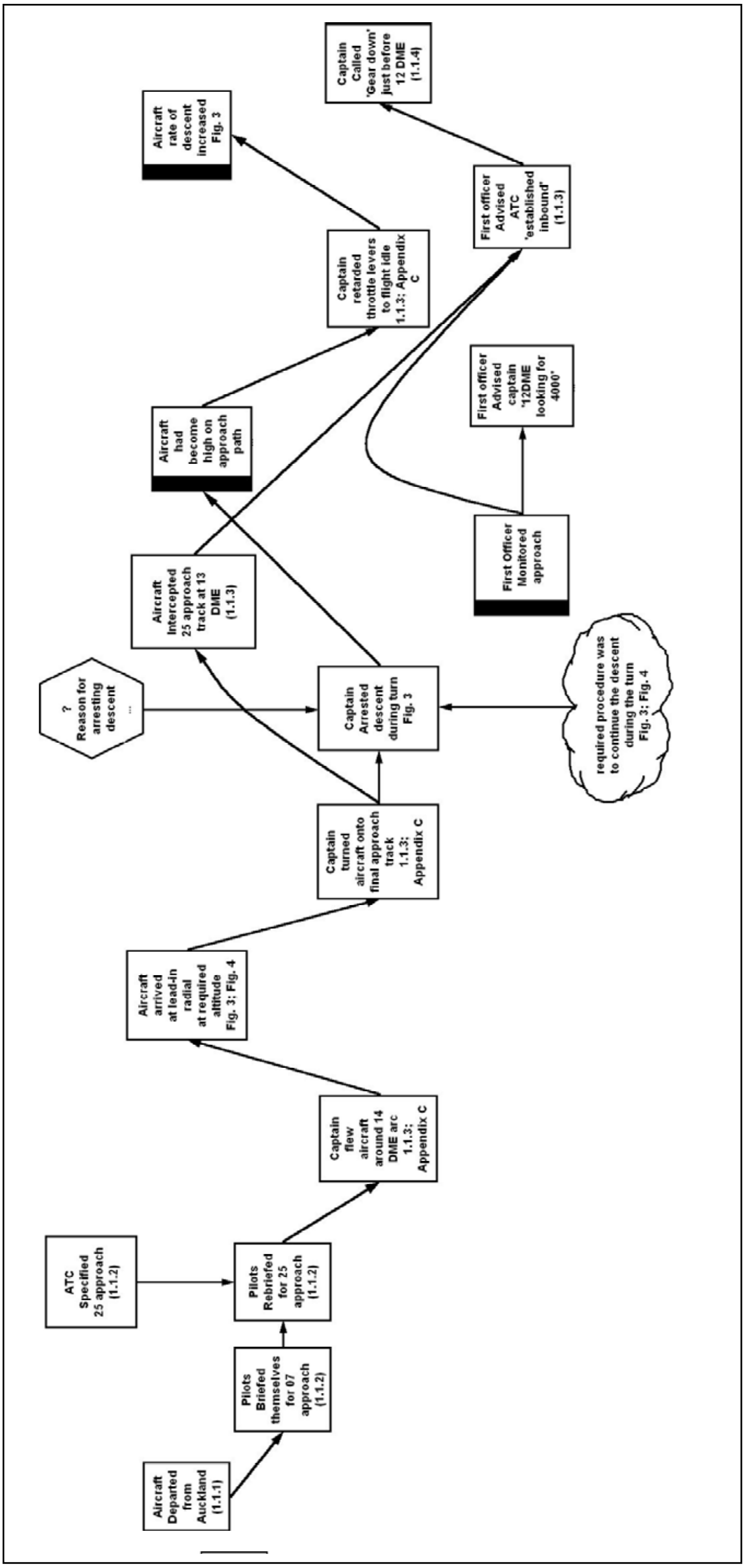

Figure 8. Initial approach to Palmerston North.

MES Graph from Initial Approach to Impact

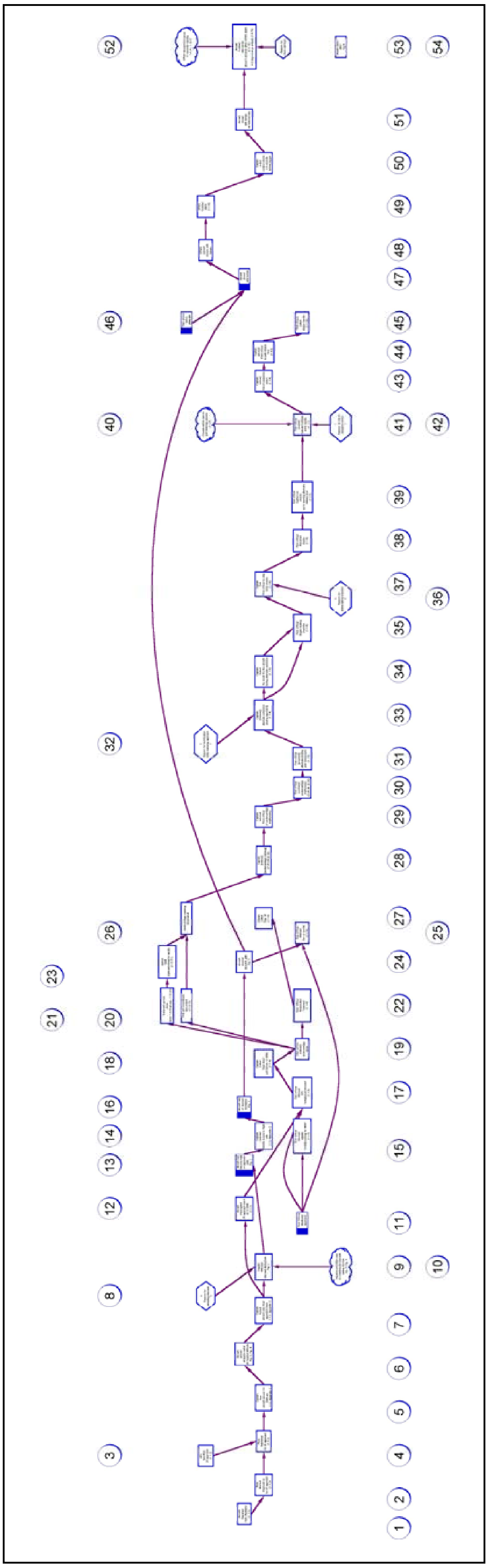

Figure 9. MES Graph from initial approach to impact

Key to Figure 9:

1 Aircraft departed from Auckland (1.1.1)
2 Pilots briefed themselves for 07 approach (1.1.2)
3. ATC specified 25 approach (1.1.2)
4 Pilots re-briefed for 25 approach (1.1.2)
5 Captain flew aircraft around 14 DME arc (1.1.3; Appendix C)
6 Aircraft arrived at lead-in radial at required altitude (Fig. 3; Fig. 4)
7 Captain turned aircraft onto final approach track (1.1.3; Appendix C)
8 Reason for arresting descent?
9 Captain arrested descent during turn (Fig. 3)
10 Required procedure was to continue the descent during the turn (Fig. 3; Fig. 4)
11 First officer monitored approach
12 Aircraft intercepted the 25 approach track at 13 DME (1.1.3)
14 Captain retarded throttle levers to flight idle (1.1.3; Appendix C)
15 First officer advised Captain ’12 DME looking for 4000’ (1.1.3)
16 Aircraft rate of descent increased (Fig. 3)
17 First officer advised ATC ‘established inbound’ (1.1.3)
18 Captain called ‘Gear down’ just before 12 DME (1.1.4)
19 First officer selected undercarriage down
20 Port and nose wheels descended (1.12.11)
21 Starboard up-lock stuck (1.16.24 et seq.; 1.12.22)
22 First officer responded ‘selected’ (1.1.4)
23 Up-lock held starboard wheel in nacelle (1.12.11)
24 Aircraft crossed descent path (fig. 3)
25 First officer warned ‘low on profile’ (1.1.4)
26 Undercarriage warning illuminated
27 Captain called ‘Flap 15’ (1.1.4)
28 Captain noticed undercarriage warning (CVR 0920:30)
29 Captain advised First officer of undercarriage malfunction
30 First officer confirmed undercarriage malfunction (CVR 0929:34)
31 First officer proposed alternate landing gear extension (1.1.4)
32 Reason for rectification while making approach?
33 Captain ordered alternate extension during approach (1.1.4)
34 Captain stated he would fly aircraft during alternate extension (1.1.5)
36 Reason for abbreviated checklist?
37 Captain told First officer to skip some checks (1.1.6)
38 First officer resumed checks
39 First officer performed checks up to opening alternate release door
40 Correct action was to pull alternate release (1.1.8)
41 First officer inserted manual hydraulic pump handle (1.1.7)
42 Reason for out-of-sequence action?
43 Captain noticed out-of-sequence action (1.1.9)
44 Captain advised First officer to pull release first (1.1.9)
45 First officer pulled release handle (1.1.10)
46 High ground below glidepath
47 Aircraft closed with terrain
48 GPWS sensed closure with terrain
49 GPWS sounded alarm (1.1.10)
50 Captain pulled control column 3.5 seconds before impact
51 Aircraft closed with terrain at reduced rate
52 GPWS should have given 17 seconds warning (1.6.81; 1.16.17)
53 Aircraft collided with terrain about 5 seconds after GPWS alarm (1.1.11) in 8 degree nose-up attitude (1.16.70)
54 Reason for short warning?

Figure 9, showing the overall picture from initial approach to impact, is constructed by amalgamating the individual sections previously discussed.

There is an important deficiency in the presentation so far. Just as a landing is not complete until the aircraft has reached the end of its landing roll, so the accident sequence is incomplete until the final loss-inducing event has occurred. It is therefore necessary to seek information relating to the impact sequence.

Ground Impact Sequence

Section 1.1 (pp. 7, 8) is silent on the impact sequence, though as injuries and some fatalities occurred, the impact sequence is of importance in understanding the accident. Some information is contained in 1.12 (pp. 33-37), 'Wreckage and Impact Information', and the events are displayed in Figure 10.

As with the information from History of the Flight, not all events can be joined by logical linkages: there is essentially a catalogue of events, in sequence, but additional information must be adduced before a 'mental movie' can be formed. For example, 'left wing and engine and undercarriage assembly broke away from fuselage' did not, without more, cause 'left wing (assembly) slid inverted along hillside', and there is no obvious reason why 'fuselage assembly struck bank on hillside' should cause 'fuselage assembly was slewed 150 degrees (to right)'.

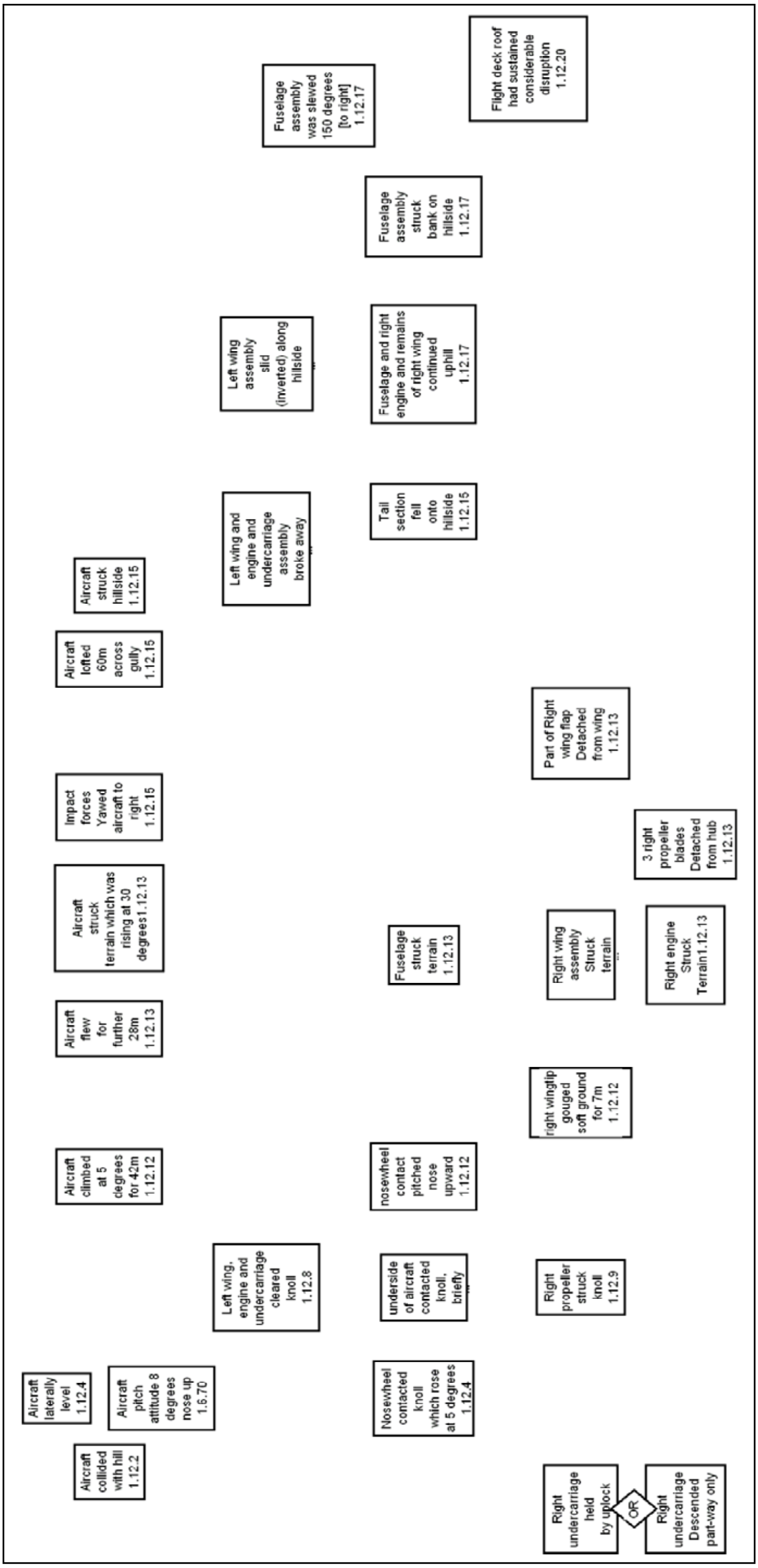

Figure 10. Events from Section 1.12

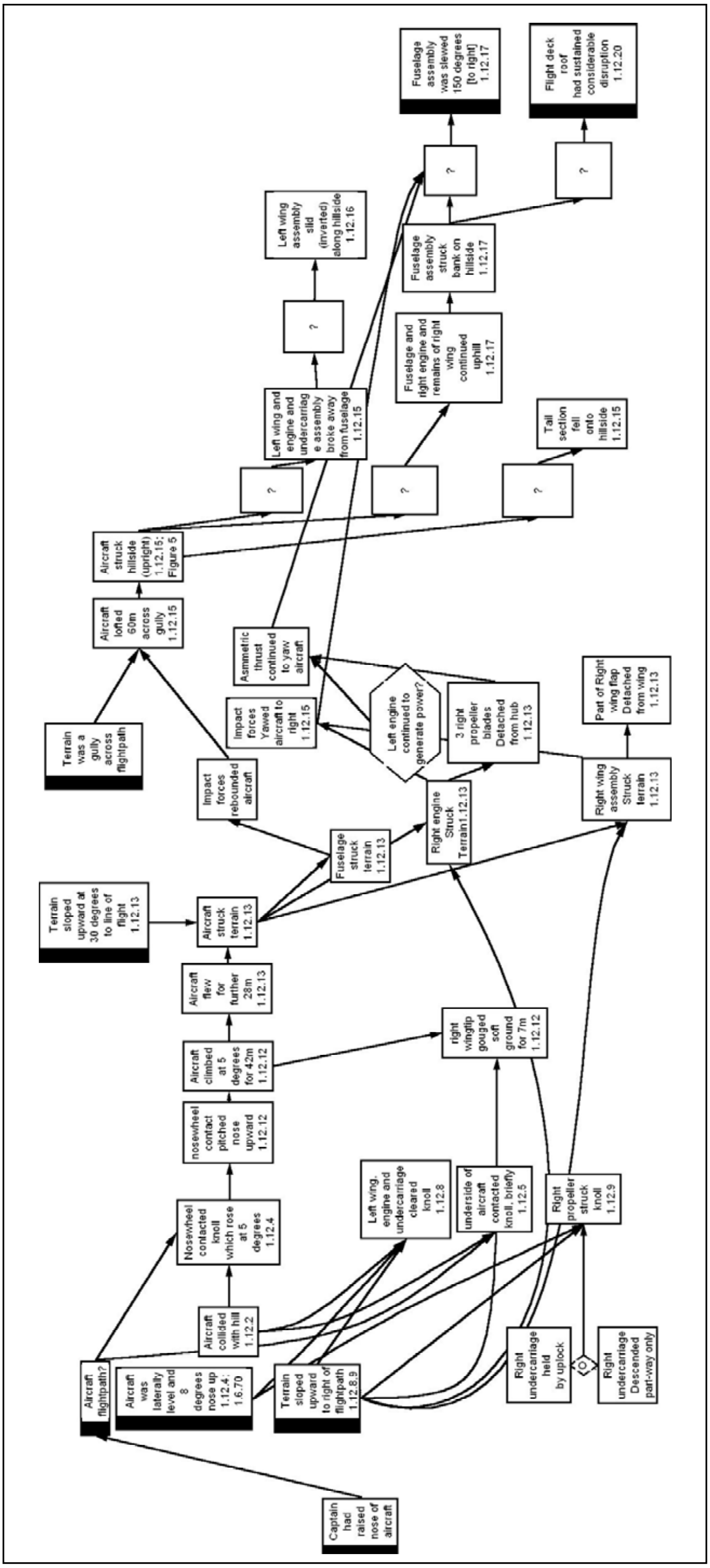

Figure 11. Impact sequence MES graph.

Figure 11 shows the construction of a MES Graph for the impact sequence. The first step is to change the format of the events to that permitted for EBBs: primarily, this involves changing to active voice. As before, it is necessary to incorporate a number of states (i.e. continuing states of affairs) in order to make the sequence of events comprehensible. Consider the group at the beginning of the time sequence in Figure 11, representing the initial contact with the hill. In order to make sense of the points of contact, additional information is needed. For the nosewheel to make rolling contact, which was able to pitch the nose upward (1.12.12, p. 35), it is not sufficient that the aircraft collided with the hill. It is also necessary that the flightpath and the terrain profile were not greatly different. The report advises that the terrain sloped upward to the right of the flightpath (1.12.8, p. 35) - a state - and that the aircraft was laterally level (1.12.4, p. 35) - likewise a state, not an event. These two states account for the absence of contact with the left undercarriage (1.12.8, p. 35). Also, the slope together with the absence of the right undercarriage accounts for the right propeller contacting terrain (1.12.9, p. 35). The states are necessary to understanding the impact, and are included, suitably flagged to show that they are not EBBs.

Although 1.12.4 (p. 35) gives the terrain slope of 5º, it is necessary to refer to 1.6.70 (p. 21) to discover the pitch attitude (8º nose-up). The dispersion of information makes the official report harder to follow, and this dispersion is readily evident from the MES graph. Accordingly, had this graph been constructed during the investigation, the information could have been re-arranged or duplicated to assist the reader in visualising the occurrence. There is no information in the report on the aircraft flightpath immediately before impact. The pitch attitude alone is insufficient information to assess the impact without knowledge of the flightpath (USAAMRDL 1971)Additional states are needed to help explain the second and third impacts. Like the initial states mentioned above, they are also incorporated and flagged.

There is a significant omission (not readily determined from the construction of the MES graph) in that the effect of the loss of the right propeller blades is not discussed. It is suggested that the impact of the right engine with terrain would have yawed the aircraft to the right (1.12.5, p. 35), but this yaw would have been damped by the fin and rudder during the rebound. A more prolonged rotation in yaw could have resulted from asymmetric thrust, if the left engine continued to generate power. The report is silent on this point. In view of the subsequent comment that the fuselage had yawed through 150 degrees (1.12.17, p. 36), with no discussion as to how this happened, the effect of asymmetric thrust should not have been ignored.

A major factual omission in the official report is the lack of reference to the detachment of the outboard section of the right wing, shown in Report Figure 1, the wreckage distribution diagram. The significance of this will be discussed later.

The series of queries after the second major impact also points to deficiencies in the report. It proceeds directly from 'aircraft struck hillside' (1 12.15, p. 36) to 'left wing assembly broke away' (1.12.15) and 'tail section fell onto hillside' (1.12.15) without saying how these things happened. Also, there is no obvious reason why the left wing assembly should have slid inverted (1.12.16, p. 36). Especially significant is the unexplained damage to the flight deck roof (1.12.20, p. 36), which will be discussed in relation to pilot injuries and additional evidence.

Further events during the impact sequence are contained in 1.14, Fire (pp. 39, 40), and 1.13, Medical Information (pp. 37-39).

The Fire Sequence

The fire sequence is shown, in MES format, in Figure 12. Three weaknesses in the report are evident from Figure 12 relating to weakening of the structure, burns to a passenger, and the second flash fire.

There is an attempt to explain the detachment of the empennage, and of the left wing which broke off at the centre section. However, the comments as to the initial impact weakening the structure of the left wing assembly and empennage (1.14.5, p. 39) are unsupported by any evidence, and must be considered speculative in the absence of further information.

The disconnected group at the end of the time sequence, events leading to fatal burns to a passenger (1.14.9, p. 40), indicates an absence of linkage to the rest of the report. There is no information as to the source of the fuel, nor why this fire suddenly flared up. A small slow fire in the neighbourhood of an engine could well have been an oil fire, ignited by the hot section of the engine. However, this would not account for the way in which the fire suddenly flared up, which is characteristic of a kerosene fire where the kerosene has soaked into the ground. The report speaks of 'residual fuel', without saying where this originated (1.14.7, p. 40). Since the left wing with its fuel tank had departed, and the right fuel tank had completely ruptured (see Figure 22, later), the only remaining source of fuel would have been the small quantity contained in the cross-feed lines in the wing centre section. Accordingly, the linkages to the remainder of the fire information are rupture of the cross-feed lines, draining of fuel from these lines, and ignition by a small engine fire. This matter will be addressed when the post-impact diagrams are amalgamated.

No evidence is adduced as to the origin of the second flash fire (1.14.5, p. 39). There was no significant loss of fuel from the left wing, and no indication of fire around the left wing or engine (1.14.6, p. 40), so the source of fuel had to be either the right wing or engine nacelle. As the fuel tank, contained in the outer panel of the right wing, had already separated, the only source of fuel was residual fuel in the fuel lines in the nacelle, or perhaps fuel which had leaked and accumulated in the nacelle (1.6.6, p. 10). It is difficult to envisage either source being a sufficient supply of fuel for a flash fire. Also, there is little evidence as to whether the second flash fire occurred. The alternative, that there was fuel adhering to the empennage which was still burning, is canvassed in the report (1.14.5, p. 39). Further information is needed on this point.

Figures 22 and 23, later, show that the sooting patterns around the rivets are consistent with a static fire. (There was also evidence of in-flight fire, consistent with the first flash fire). Since the static fire could only have occurred after the empennage came to rest, and there was no source for this fuel other than droplets already on the tailplane, it may be inferred that this second fire was a static fire rather than a flash fire. This matter will also be addressed when the post-impact diagrams are amalgamated.

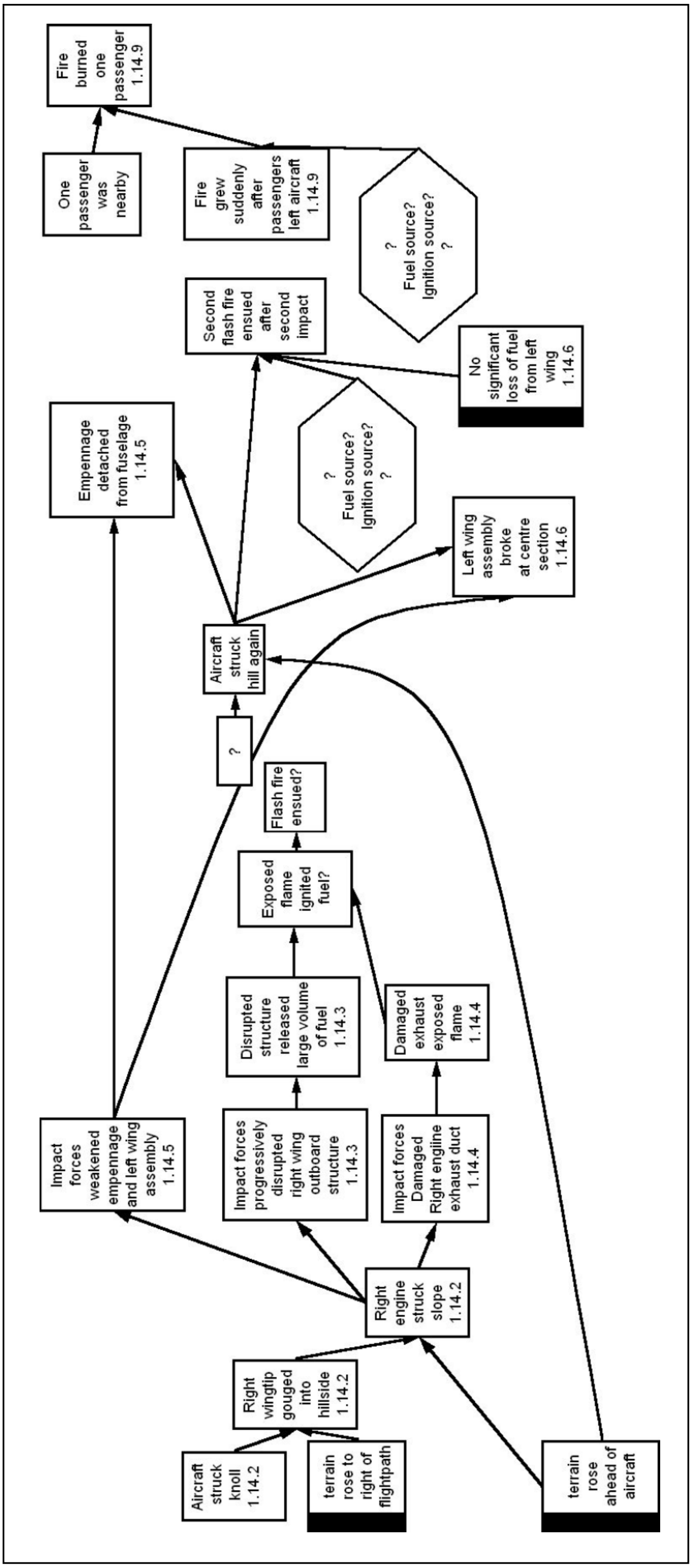

Figure 12. Fire sequence

A further limitation in the report is shown by the inconsistency between Figures 11 (the impact sequence) and 12 (the fire sequence). Figure 11 indicates that, for a short period after rebounding from the knoll, the right wing tip scraped the ground, and then the aircraft struck the ground again with the fuselage and the right engine. This is not at all the same as the progressive impact described in Figure 12 - right wing tip, right wing and engine - producing the progressive disruption of the right wing structure alluded to in 1.14.3 (p. 39). While the impact description in section 1.14 would account for the disruption of the integral tanks and so the flash fire, Figure 5 in the report (the wreckage diagram – see Annex A) shows that the description in Figure 11 is accurate.

Accordingly, the impact sequence in Figure 12 is wrong. The scrape by the right wing was a transient affair; loads on the wing would have been minor and in-plane, and unlikely to have caused significant damage. The subsequent impact was taken by the right engine, and the belly of the aircraft. Although the engine struck the ground sufficiently hard to damage the engine, the underside of the outer right wing, found further along the wreckage trail, did not display evidence of a major impact. The detachment of the wing, and the fire, remain to be explained. Further evidence must therefore be sought. This will be discussed later, in 'evidence from the wreckage'.

While the discrepancy in the descriptions of the impact sequence might have been detected by diligent reading of the official report, neither the original authors of the report, nor the Commissioners whose task it is to vet reports, detected the inconsistency. The graphical presentation of MES makes the detection of such a discrepancy more probable.

Medical Information

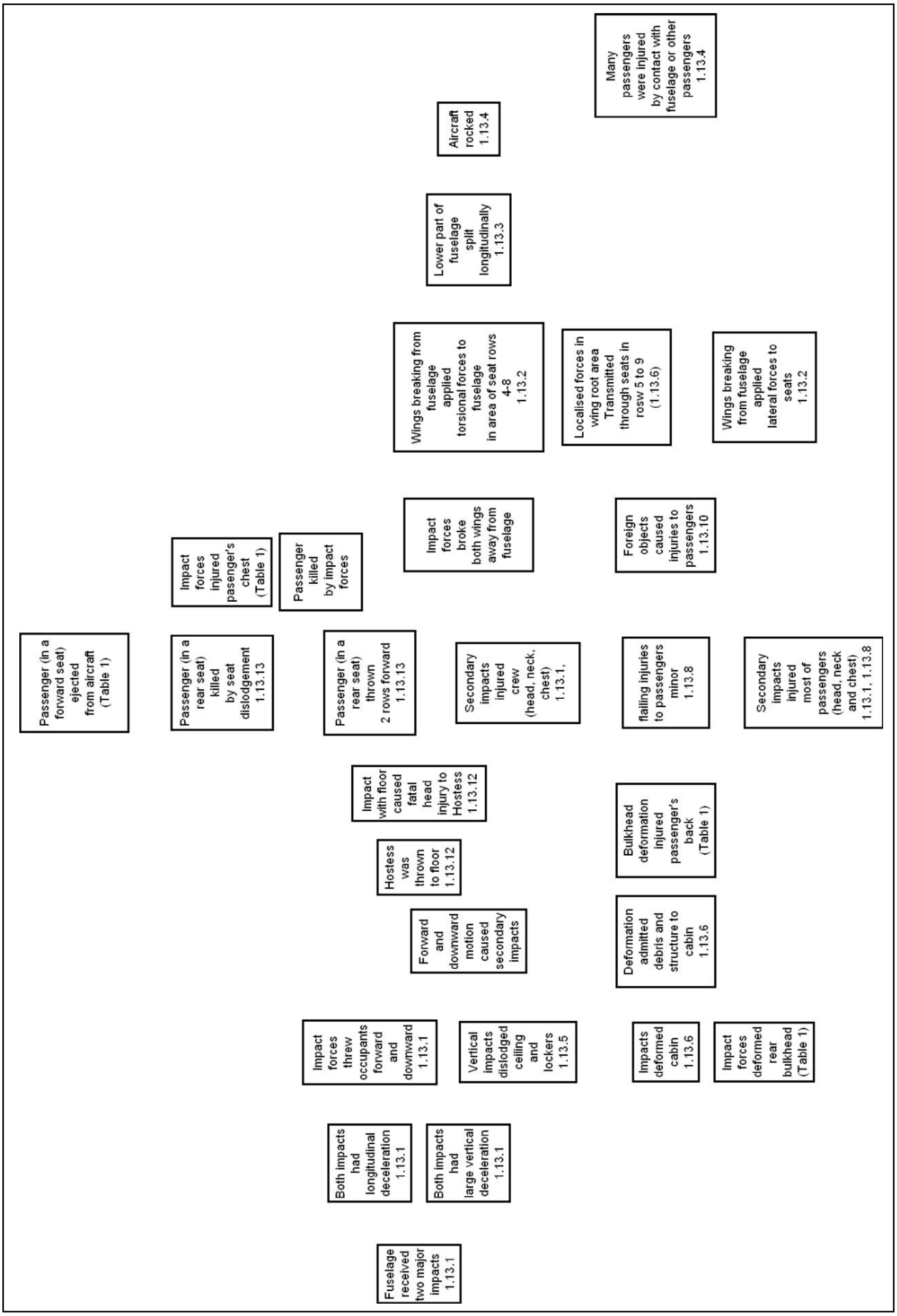

Figure 13. Events in medical information.

Turning now to the crew and passenger injuries, the sequence is shown in Figure 13. As with the section on fire, there is also information on the impact sequence, in this section.

A difficulty arises in trying to determine what events are described in the section on medical information, because of missing and conflicting information.

- While the report states that impact forces have been calculated for the impact sequence (1.13.7, p. 37), these calculations are not shown, and the forces are not stated.
- 1.13.7 refers to Table 1 in the report (p. 38), which details the damage to seats and injuries to passengers by seat location. However, there is some conflict between the written report and Table 1. Section 1.13.13 (p. 39) states that a passenger was thrown two rows forward and fatally injured, while Table 1 states that the only fatally injured passenger in a detached seat (in seat 6G) was ejected from the aircraft. Unmentioned in the written report is another passenger ejected from the aircraft (in seat 3G), who suffered non-fatal chest injuries (Table 1, p. 38).

- Paragraph 1.13.8 (p. 39) states that "most of the occupants' injuries... were to the head, neck and chest". Table 1 indicates that there were 3 head injuries, 1 neck injury, and 5 chest injuries. Taken together (9 injuries), these were commonest overall, but in general these injuries did not happen to the same occupants, e.g. those who suffered head injuries did not generally suffer chest injuries. After chest injuries, the commonest injury among the passengers was back injury (4 injuries).

- Table 1 (p. 38) is silent on the injuries said to have been caused by the entry of foreign objects (1.13.10, p. 39).

To produce the MES graph for the events relating to injury, the events described in Figure 13 are first converted to EBBs, and then linkages are made where possible. The MES graph of this section is shown in Figure 14.

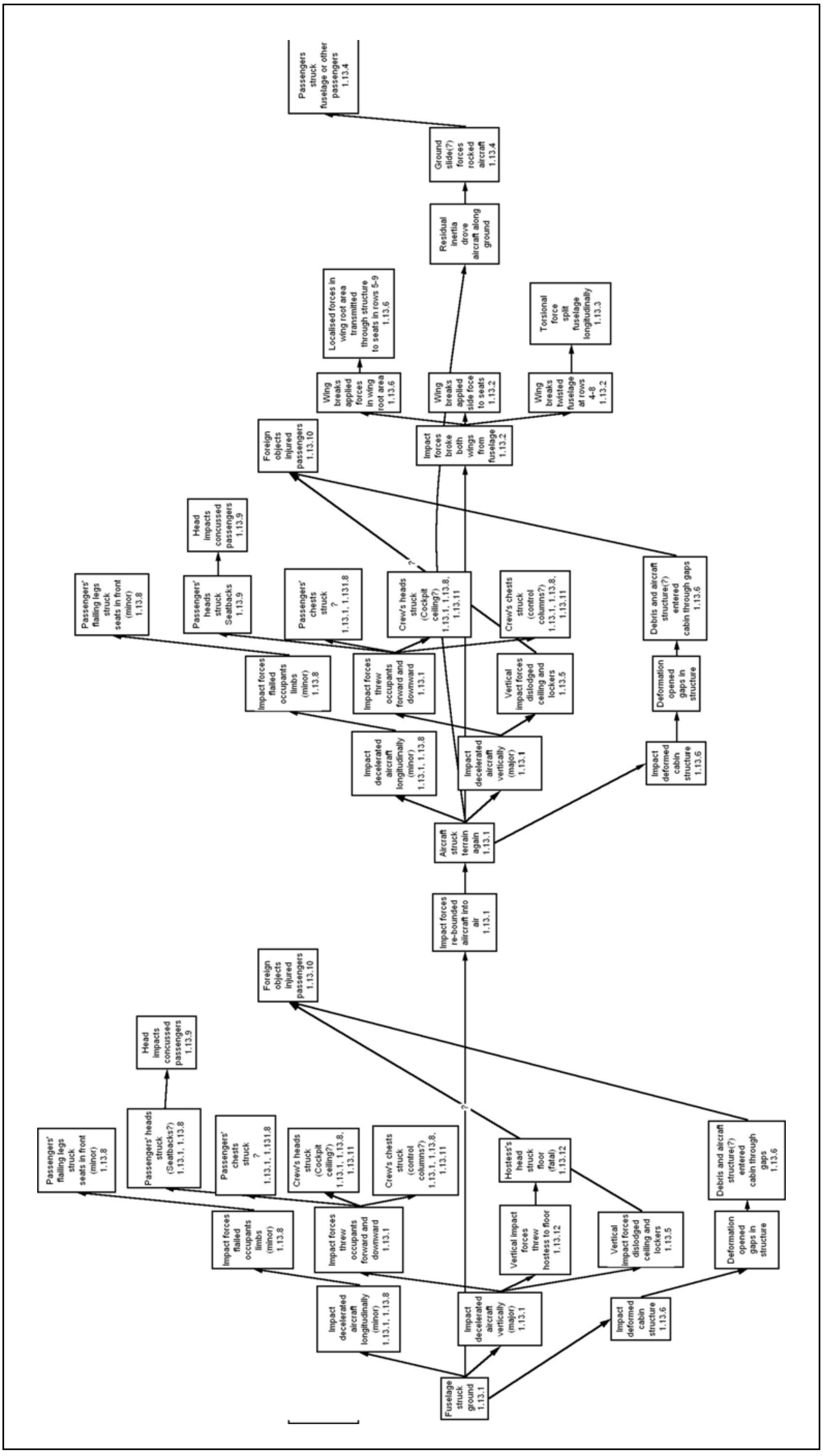

Figure 14. Injuries MES graph.

The pilots' head injuries (1.13.11, p. 39) are attributed to forward and downward motion on impact (1.13.1, p. 37), but this lacks face validity, since the pilots would have been restrained by inertia reel seat harnesses. Figure 6b in the report (p. 42) (shown at Annex A) shows that there was disruption of the cockpit roof in way of the pilots' heads, and the photograph on p. 4 in the report (also at Annex A) shows that this disruption was due to external impact. Since the report implies that both major impacts were upright (Figure 1; 1.12.13, 1.12.15, pp. 35, 36) this disruption must have occurred, not at the major impacts, but during or at the end of the ground slide. (This matter is addressed when the graphs are amalgamated, as discussed below).

The split in the cabin floor appears to be attributed to torsional forces (1.13.2, 1.13.3; p. 37) but this attribution also lacks face validity. Supposing that the wing breakage could cause torsional forces in the fuselage (and this is difficult to visualise, since the rotational inertia of the fuselage about its longitudinal axis is low) the expected mode of failure of a cylinder (the outer fuselage skin) would be a spiral twist. There was no evidence of this. An internal diaphragm (the floor) would be subject to diagonal loading, and would tend to tear at 45° to the fore-and aft axis, and this did not happen. (The split in the floor will be discussed later, in considering other evidence).

The EBBs as shown have the multiple actors used in the report's terminology. While multiple actors are not permitted in EBBs (Benner, 1994) it does not introduce ambiguity to say that 'passengers' or 'crew' were affected by impact forces, unless there were material differences in the forces experienced by different persons. It is possible to visualise all passengers being thrown forward and downward at the same time, for example. Also, the general term 'impact forces' is unavoidable, absent information on these forces.

However, both the written report and Table 1 (p. 38) indicate that there were material differences in the forces experienced: 1.13.1 (p. 37) indicates that seats in the forward area did not break free, while those further aft did so (Table 1). This implies that forces along the fore-and-aft axis (expressed in multiples of the force of gravity, in that axis, Gx) were greater, towards the tail of the aircraft. This is unusual, since forces within the aircraft are attenuated by the distortion of crushable structure further forward (see, for example, USAAMRDL, 1971). Likewise, the presence of vertical deceleration (Gz) at the rear bulkhead, sufficient to distort it and so injure the back of a passenger in a rear seat, is abnormal. Such an unusual state of affairs merited explanation.

The imprecise language used in the report caused some difficulty. Thus, where 1.13.1 (p. 37) speaks of the impact forces from two major impacts, it is difficult to visualise what occurred separately on each. In general, the forces at first impact are likely to be more severe than those after a rebound, because energy is absorbed during the initial impact. However, this is not necessarily so: if for example, the initial impact is a glancing blow and the second deceleration is more sudden, then more severe forces could be experienced during the second impact. Also, if seats or structure are damaged in the initial impact, there may be less occupant protection during a subsequent impact. Although the report states (1.13.7, p. 37) that the impact forces were calculated (and so the investigators were presumably aware of the severity of each impact) the absence of this information has led to the duplication seen in Figure 14. Nevertheless, it can reasonably be inferred that the unrestrained hostess fell to the floor at the first impact: she could hardly have fallen far enough to suffer a fatal head injury (1.13.12, p. 39) in the second impact if she was already on the floor.

Where there was insufficient information in the report to construct valid EBBs and linkages, the missing information has been shown by question marks. These indicate areas where further information should have been sought during the investigation, for a full understanding of the impact sequence. Presumably, it was the lack of full understanding which led to the use of imprecise language. If a MES graph had been used when this section of the report was being drafted, the ambiguities introduced by imprecise language should have been evident, and they could have been addressed. The inconsistencies between the written report and Table 1 (p. 38) might also have come to light.

Figure 14 shows a number of loose ends. Although it is stated that structure and debris entered the cabin (1.13.6, p. 37) and injured passengers (1.13.10, p. 39), these injuries are nowhere detailed, so it is not known whether they were serious or minor. More importantly, the report's authors considered the forces transmitted to the seats in rows 5-9 (1.13.6, p. 37), and the split in the floor (1.13.3, p. 37) worthy of mention, but these events are not followed up. Likewise, the event of the passengers striking each other or the fuselage side (1.13.4, p. 37) was no doubt material, but it is left hanging in the report.

These lapses are apparent from the MES graph, and had the authors used such a graph, it should have brought the lapses to their attention. In summary, the use of an MES graph while compiling the section on injuries, or when subsequently reviewing the text, would have shown where information was missing, or logical connections needed to be made, or further information needed to be obtained.

The Complete MES Graph for the Impact Sequence

The complete MES graph for the impact sequence, shown in Figure 16, is produced by combining the impact, fire and injury graphs, Figures 11, 12 and 14. Where it has been possible to resolve inconsistencies from the report, this has been done.

First, the 'impact' and 'fire sequences are combined (Figure 15). (The detail in this graph is too small to be visible at this scale, but is essentially the same as in the individual sectors). Then, the 'injuries' sequence is combined with the already amalgamated information in Figure 15, to form the overall picture of the impact sequence shown in Figure 16[3].

(The anomaly, between 'left wing assembly broke off' (1.12.15, p. 36) and 'both wings broke away' (1.13.2, p. 37) is a matter of loose phrasing in 1.13.2; in fact the right engine and remains of the right wing remained loosely attached (1.12.17, p. 36)).

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[3] Figures 15 and 16 show the overall arrangement of the MES graph at this stage. Figure 24 shows the finalised MES graph for the impact sequence, and has a complete key.

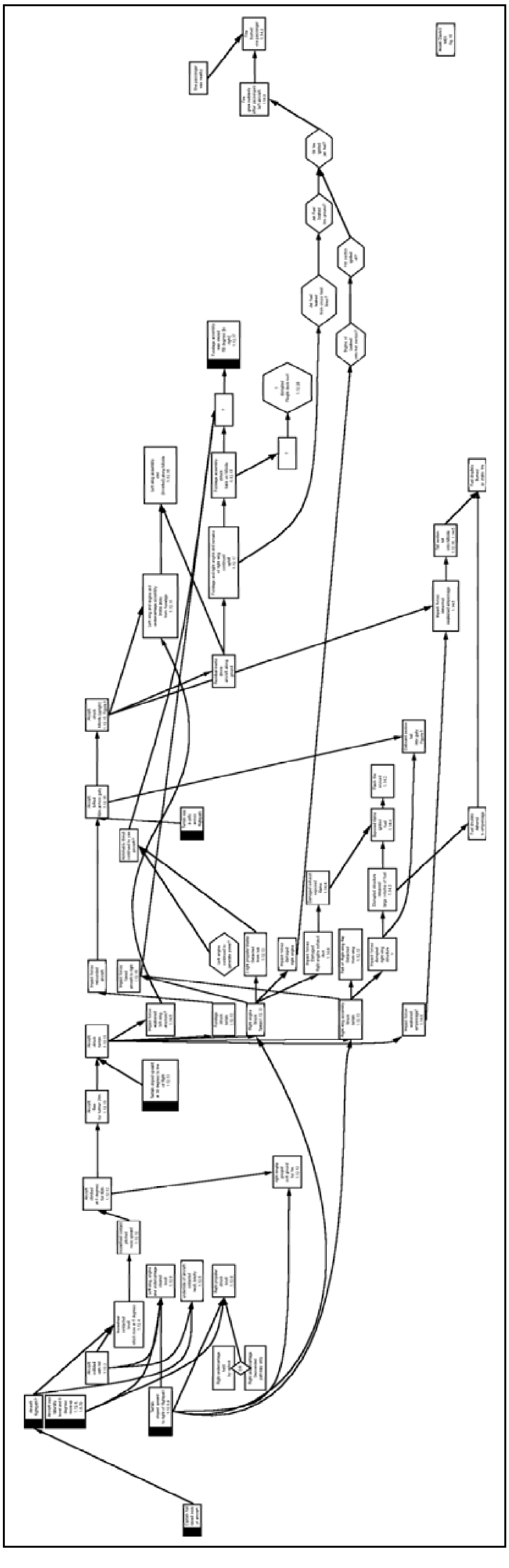

Figure 15. Ansett Dash 8 MES, combining the Impact and Fire sequences.

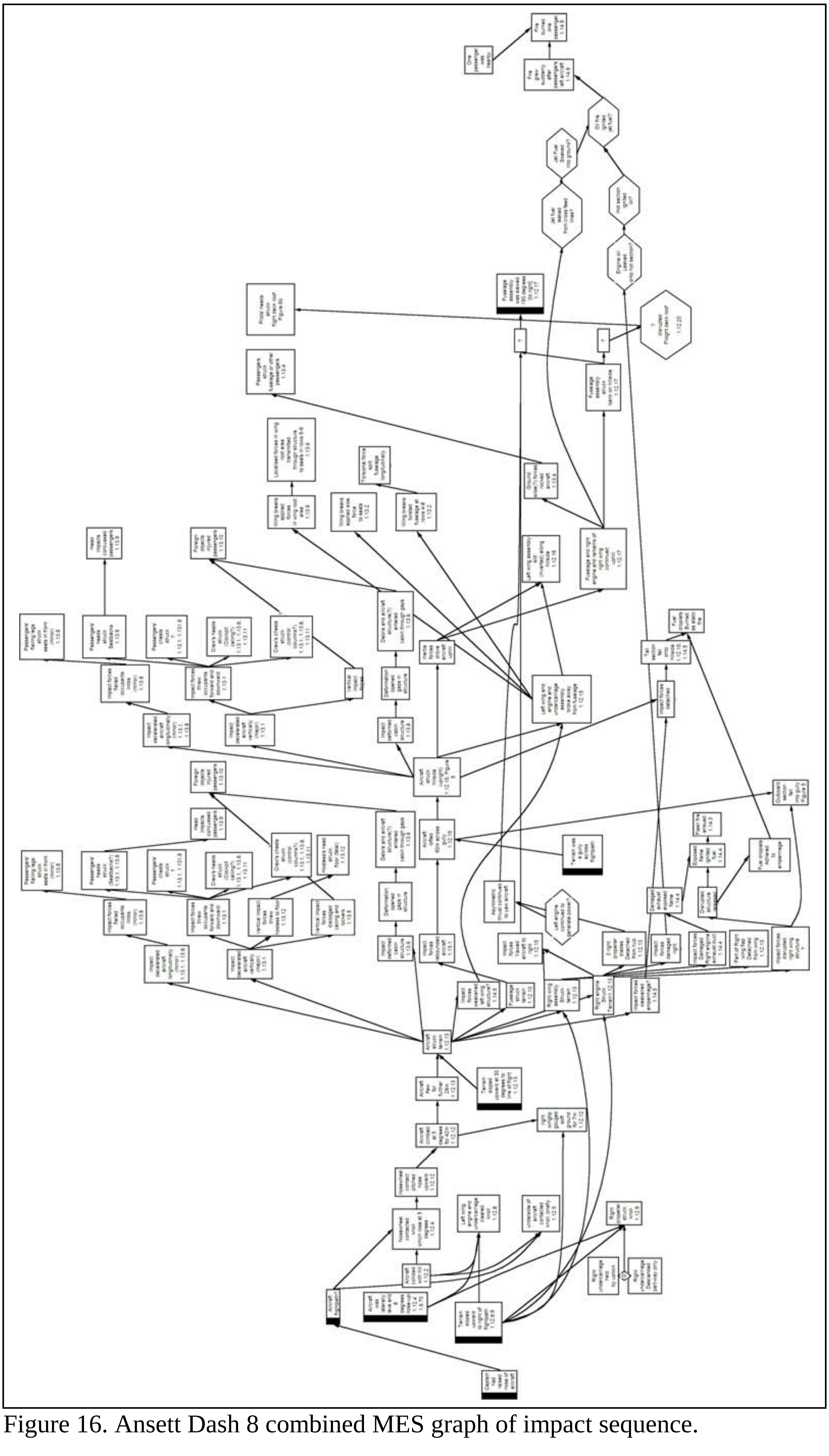

Figure 16. Ansett Dash 8 combined MES graph of impact sequence.

Evidence from the Wreckage

Evidence from the wreckage was used to resolve some of the queries raised by the development of the MES graph. The photographs in the following section, taken by the author and his students while the wreckage was stored in a hangar at Palmerston North aerodrome, illustrate the various points discussed.

The first unresolved point on the MES graph of the impact sequence is whether the right hand undercarriage was unlatched or not. The question is relevant in determining whether the indentation on the undercarriage latch was entirely due to wear, or whether it might have been, in part, due to impact from the retaining roller during the impact sequence. This point should be easily resolved by examination of the undercarriage doors, since immediately after release of the undercarriage the wheel would pass between the doors; subsequently the undercarriage leg would be between the doors. If the undercarriage had started to descend, there should be witness marks on the doors, i.e. marks made by contact between the doors and the undercarriage, showing what position the undercarriage was in relative to the doors when the marks were made.

Figure 17 shows part of the interior of an undercarriage door, alongside a tyre. The tyre manufacturer's name is embossed on the side of the tyre, and the witness mark is a mirror image of that name, impressed on the inside of the door by contact between the tyre and the door. To make the mark in this position, the wheel had to be partly descended, its sidewall being parallel to the door, at the moment of impact. Accordingly, the uncertainty is resolved: the undercarriage was unlatched, and the wheel had partly descended, when the engine nacelle struck the ground.

The report by the manufacturers of the undercarriage, Messier-Dowty (cited at 1.16.13, p. 46), stated that it was not possible for the manufacturer to determine whether all of the depression measured in the uplock hook was due to wear, or whether some might have been due to impact loading (1.16.13). Since the leg was partly extended, the uplock roller was not in proximity to the hook, and all of the measured depression was due to wear. The MES graph shows that there was an unresolved issue here. Had the investigators been using this method of data display and manipulation, their attention could have been drawn to the deficiency, and the matter resolved.

Figure 17. Witness mark on part of right hand undercarriage door.

The next question to be considered is the injuries to the pilots' heads. As already discussed, this came about because of exterior damage to the roof of the cockpit, but the question is, how did this damage come about? It could not have occurred during an upright impact, and it is hard to envisage it happening during the ground slide, or resulting from the impact with the small bank at the end of the ground slide.

The photograph on p. 4 of the report shows the aircraft looking from the front (shown in Annex A, for convenience). The upper part of the cockpit roof has been flattened. Figure 18 shows that this crushing is continued as a line along the aircraft skin, along the cabin roof and more or less parallel to it. This line is termed a 'crush line': it shows where structure has been crushed in, and has then rebounded to something like its original form. Earth is ingrained in the roof area. The only way to produce such crushing is for the aircraft to strike the ground or other solid object, with the part which has been deformed. In other words, the evidence from the photograph on p. 4, and figure18, is that *the aircraft struck the ground inverted, in a slightly nose-down attitude.*

Figure 18. View from front of fuselage, showing crush lines and ingrained dirt.

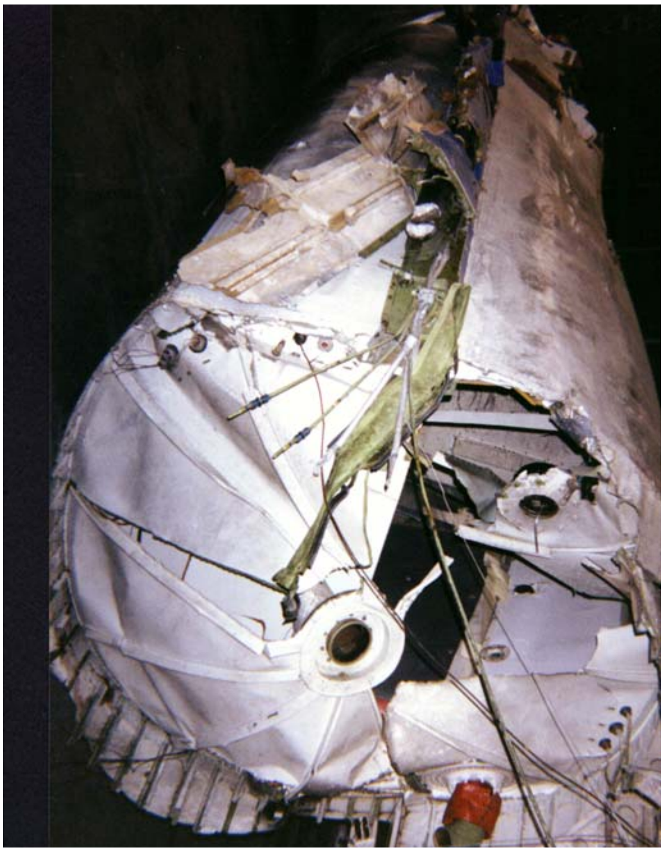

Figure 19. View from rear of fuselage, showing crush line, and torsional damage to rear bulkhead.

Evidence supporting the inverted impact is the lack of damage to the left undercarriage leg, which remained intact and extended throughout (photograph of the accident site, report p. 2 and Annex A), and the absence of damage to the underside of the left engine nacelle (Figure 20). Further supporting evidence is the crush damage to the front top of the engine nacelles made (like the damage to the cockpit roof) by an inverted impact in a somewhat nose-down attitude. Figure 21 emphasises the pronounced flattening on the top of the rear fuselage.

Figure 20. Left engine nacelle, showing lack of damage to underside, and inverted ground contact. Damage to the propeller shows that it was in this position, and rotating, when the nacelle struck the ground.

Figure 21. View from bottom rear of fuselage. Impact damage is ahead of rear bulkhead. Note flattening at top of rear fuselage.

Clearly, the first major impact (after the touch on the grassy knoll) was upright: there was nothing which could have caused the aircraft to roll inverted. This initial upright impact is consistent with crush damage to the belly of the aircraft (Figure 21). There was little structural damage likely to detach the empennage, and had it become detached at this point its subsequent flight path would have been random, because its weight in relation to its area was low. It would have been unlikely to have come to rest in the vicinity of the second impact, because its weight in relation to its area would have been much lower than that of the fuselage and wings.

A potential cause of roll after the first impact was asymmetric thrust, which would have caused both yaw-roll coupling, and asymmetric lift due to the flow of slipstream over one wing but not the other. However, this cannot account for the rate of roll. The distance between the first and second major impacts was 60 metres, and at 122 knots (the groundspeed of initial contact) the aircraft would have covered this distance in 0.96 seconds. Even allowing for reduction of speed during ground contact, the rate of roll required to go from upright to inverted would have been about 180 degrees per second. The answer to the achievement of the high roll rate lies in the removal of the right wing, outboard of the engine nacelle (Figure 5 in the report; Annex A). The nose was rising before the first major impact (perhaps because of the initial nosewheel impact) so the wings would have been at a larger than normal angle of attack, and lifting strongly. Removal of the outboard part of one wing would have left the lift from the other wing unbalanced, so the aircraft would have rolled at a rate constrained only by the roll damping of the remaining wing.

How did the right wing come to be removed? There were gouges in the ground from the right wingtip, but these alone do not indicate that the wing was torn off backwards. Wings of airliners form a shallow box structure, which is strong in-plane, and so unlikely to be torn off at part span by contact at the tip. Were the wing to have been torn off by tip contact, it would probably have failed at the point of highest stress, i.e. at the root, but this did not happen. Also, if the outer portion was torn off by ground contact it seems unlikely that it would have finished on the centreline of the wreckage path (Figure 5 in the report): it would have been expected to have been somewhat to the right of track.

Was the structure critically weakened by bending normal to the plane, as the result of ground impact, thus leading to failure? There was no evidence of bending of the spar before failure when the author examined the wreckage in the hangar at Palmerston North. The spar shear web showed no deformation due to shear loading, in the region of separation. Besides, contact between the ground and nacelle would have alleviated the load.

However, what *was* visible were two indications of in-flight explosion: the wing skins had been forced outward on both sides of the break; and belling of the spar web, where pressure has forced the web rearwards between the stiffened areas. This suggests that an explosion must have been initiated while the structure was still intact, as otherwise the pressures necessary to deform and tear the metal could not have been generated. (The best photograph available is Figure 22. Unfortunately, attempts to photograph these features were unsatisfactory: they were black features against a black background, in a dimly lit hangar, and no special lighting was available. Ansett Airlines were permitted to destroy the wreckage before this evidence could be properly documented).

Figure 22. Starboard wing outboard of nacelle. Downward deflection of lower surface; spar web pulled away from spar caps. There has been no loading of the web in shear.

One possible way for ignition to have occurred while the structure was intact would have been via a tank vent. If there was a flame trap in the vent, it would have had to have been ineffective, for ignition by this means to have occurred. However, the evidence was destroyed before the matter could be further investigated. Another possibility could have been an electrical spark from elements such as the fuel contents sensors, or the pump. The wreckage having been destroyed, there is no way of knowing.

The position of the outer wing portion in the wreckage trail can be accounted for if the wing panel was loosely retained by a small portion of the structure, until it was finally torn off as the aircraft rolled. Such a portion, distorted in a manner consistent with such action, is visible in Figure 22, and some of the damage to the right tailplane is consistent with impact from the wing (Figure 23).

Figure 23. Damage to upper skin of starboard tailplane. The square hole has extensive sooting inside; the deflection damage has very little sooting.

Figure 24. Damage to leading edge of fin and upper surface of tailplane. There was no corresponding damage on the outer portion of the right wing. Soot deposits around rivets are fairly even, suggesting static fire.

The next point to consider is the split in the lower fuselage. Rupture of the floor because of torsional forces has already been discounted. However, inverted impact could account for the split in the floor: the inverted impact would set up severe hoop stresses in the fuselage formers, tending to cause tensile overload failure of the floor beams, simultaneously at a number of stations. This would lead to the floor splitting longitudinally.

When the aircraft struck the ground inverted, the empennage would also have struck the ground. The aircraft had a 'T' tail, and it would be expected that the entire empennage would separate at the fin root. It separated at the former just ahead of the fin root. Supporting evidence is impact damage to the upper surface of the tailplane (Figure 24). Together with the juxtaposition of the empennage, this is evidence that the inverted impact removed the empennage.

Evidence from the Injuries

The pilots suffered head injuries. They were restrained by full harnesses. How, then, could their heads come into contact with the cabin structure? The photograph from the front of the aircraft (report, p. 4 and Annex A) shows that the top of the cockpit was crushed in by the inverted impact, to an extent greater than subsequently found when the wreckage was examined. Since the occupiable space in the cockpit was significantly reduced as found (report Figure 6b, p. 42 – see Annex A), it may be concluded that the pilots' head injuries were due to transient lack of occupiable space, while the structure was crushed in by the inverted impact.

The Flight Attendant was not restrained at the time of the accident. She was leaning over the back of a seat in the front row, talking to the passenger behind. This passenger had previously noticed that the right wheel had not extended, and had notified her of this; she had gone into the cockpit to ensure that the pilots were aware of the malfunction, and came back to explain to the passenger that the pilots were dealing with it. She died from head injuries. Lack of flailing injuries to the passengers' limbs (1.13.8, p. 39) shows that longitudinal deceleration was low, and there was little room for her to accelerate relative to the structure, if she was thrown against the bulkhead behind her. Such an impact is therefore unlikely to have been the cause of death. The report attributes her death to falling to the cabin floor, in an upright impact. Injuring one's head while falling to the floor is perhaps less likely than injuring it by being thrown against the inverted ceiling, which would be forced inward as the aircraft struck the ground inverted. The pathologist's report did not indicate a contre coup incident, which might have explained a fatal head injury in a fall to the floor.[4]

Two passengers towards the rear of the cabin (seats 6G and 7B) suffered fatal head, and neck or back, injuries. The bases of their seats were broken, even though the bases of most of the seats forward of them were undamaged (Table 1 in the report, p.

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[4] A contre coup injury is related to head injuries where the brain is propelled forward and then back. The skull is a rigid outer vault that houses the jelly-like organ, the brain. When subject to a sudden jolt, the protective cushioning fluid is no longer effective, allowing sudden acceleration/deceleration.

Primary injury to the brain in blunt trauma as in Ansett is caused by the acceleration/ deceleration of the brain within the skull. What is seen in the brain can be either haemorrhage, contusion or laceration.

In the Ansett case, the Flight Attendant was standing at the time of the crash, unrestrained, and leaning across the back of the seat in the first row, and the distance from the ceiling of the aircraft and the front bulkhead could not have caused her injuries, in an upright impact.

The source of information is photographic evidence and the description of injuries from the St John Medical Director’s talk, and the ICU Specialist on duty at the time of the crash, at Palmerston North Hospital.

38). In an upright impact with relatively low forward deceleration, it would be unusual for passengers to suffer fatal head and spinal injuries, especially towards the rear of the cabin. Some facial injuries might occur as the passengers were thrown against the seatbacks in front, but seatbacks are made frangible in order to avoid more serious injury in such circumstances. However, an inverted impact would impose loads for which the seats were not designed, which could account for the structural failure. If the passengers' heads struck the cabin roof in the course of an inverted impact, fatal head and spinal injuries might be expected. The severity of the impact at the rear of the aircraft could be explained by a whiplash effect, as the rear fuselage was slammed into the ground following the nose-down inverted contact. Such an event is demonstrated by the flattening of the roof at the rear bulkhead (figure 21). This flattening was also the cause of the distortion of the rear bulkhead, which caused back injury to the passenger in 10F (Table 1 in the report, p. 38).

It has been shown that

- The inverted impact was responsible for some of the injuries
- The aircraft became inverted because of the loss of the right wing
- The right wing came off because of an explosion in an intact fuel tank

Accordingly, the explosion and inverted impact were significant factors in the survivability of this accident: they should have been addressed as a safety concern. It is unfortunate that this deficiency in the report was not recognised and addressed before the evidence was destroyed, after the wreckage had been released by the Commission. Discovering such deficiencies *during the course of an investigation,* while there is still time to rectify them, is an important function, and one which Multilinear Event Sequencing seeks to address.

Evidence from Crown v Sotheran

The Captain of the Dash 8, Captain Sotheran, was charged with manslaughter, in relation to the deaths of the passengers[5]. At the trial, evidence was given as to the failure of the GPWS to provide the expected warning, by the designer of the warning system. The official report did not note that the radome for the radio altimeter aerial had been painted over, contrary to instructions. Nor was there any information on the condition of the aerial. At the trial, evidence was given by the designer of the GPWS system, that the aerial was seriously corroded. In the designer's opinion, the corrosion of the aerial (which would have had an adverse effect on the signal strength available to the radio altimeter) would explain the shorter than expected warning time. The paint on the radome could also not be ruled out as a contributory factor (Morgan 2001). Had the warning time been the expected 17 seconds, there is no doubt that the response by the crew would have averted the accident, so the corrosion of the aerial was a causal factor in the accident. It would therefore have been appropriate to consider how the aerial came to be so corroded, without the corrosion being detected during normal maintenance. The use of an MES graph would have flagged to the investigators the deficiency in their investigation, and so directed their attention to the additional evidence that was available

Complete MES Graph with All Available Information

The completed MES graph, showing the overall picture of the impact sequence, is shown in Figure 25. It is formed by correcting the various boxes with the information derived from the evidence already discussed. For example, the box containing ‘upright impact’ in Figures 14 and 16 is amended to ‘inverted impact’ in Figure 25, and concomitant changes to the causes of injuries follow.

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[5] Captain Sotheran was acquitted.

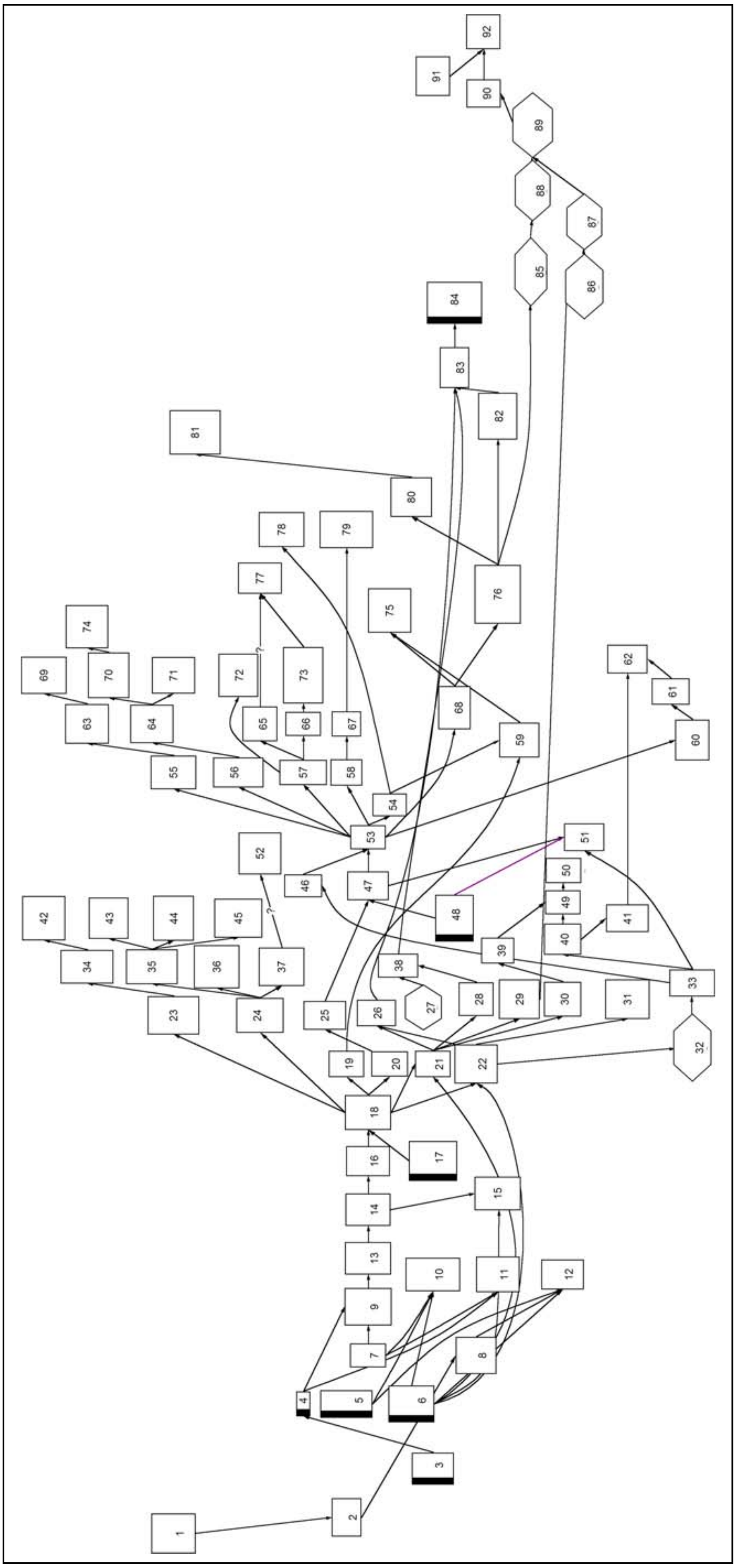

Figure 25. Complete MES Graph using all available information.

Key to Figure 25

1. Co-pilot pulled emergency undercarriage release
2. Undercarriage latch opened
3. Captain had raised nose of aircraft
4. Aircraft flightpath?
5. Aircraft was laterally level and 8 degrees nose-up 1.12.4; 1.6.70
6. Terrain sloped upward to right of flightpath 1.12.8,9
7. Aircraft collided with hill 1.12.2
8. Right undercarriage Descended part-way only
9. Nosewheel contacted knoll which rose at 5 degrees 1.12.4
10. Left wing, engine and undercarriage cleared knoll 1.12.8
11. Underside of aircraft contacted knoll, briefly 1.12.5
12. Right propeller struck knoll 1.12.9
13. Nosewheel contact pitched nose upward 1.12.12
14. Aircraft climbed at 5 degrees for 42m 1.12.12
15. Right wingtip gouged soft ground for 7m 1.12.12
16. Aircraft flew for further 28m 1.12.13
17. Terrain sloped upward at 30 degrees to line of flight 1.12.13
18. Aircraft struck terrain 1.12.13
19. Impact forces weakened left wing structure? 1.14.5
20. Fuselage struck terrain 1.12.13
21. Right engine Struck Terrain 1.12.13
22. Right wing assembly Struck terrain 1.12.13
23. Impact decelerated aircraft longitudinally (minor) 1.13.1, 1.13.8
24. Impact decelerated aircraft vertically (major) 1.13.1
25. Impact forces rebounded aircraft 1.13.1
26. Impact forces Yawed aircraft to right 1.12.15
27. Left engine continued to generate power?
28. 3 right propeller blades Detached from hub 1.12.13
29. Impact forces damaged right engine
30. Impact forces Damaged Right engine exhaust duct 1.14.4
31. Part of Right wing flap Detached from wing 1.12.13
32. ? Ignited fuel vapour/droplets in right tank
33. Fuel explosion blew off outer part of wing
34. Impact forces flailed occupants limbs (minor) 1.13.8
35. Impact forces threw occupants forward and downward 1.13.1
36. Vertical impact forces threw Flight Attendant to floor? 1.13.12
37. Vertical impact forces dislodged ceiling and lockers 1.13.5
38. Asymmetric thrust continued to yaw aircraft
39. Damaged exhaust exposed flame 1.14.4
40. Fuel tank disruption released large volume of fuel 1.14.3
41. Fuel droplets Adhered to empennage
42. Passengers' flailing legs struck seats in front (minor) 1.13.8
43. Passengers' heads struck (Seatbacks?) 1.13.1, 1.13.8
44. Passengers' chests struck? 1.13.1, 1.131.8
45. Crew's chests struck (control columns?) 1.13.1, 1.13.8, 1.13.11
46. Asymmetric lift rolled aircraft inverted
47. Aircraft lofted 60m across gully 1.12.15
48. Terrain was a gully across flightpath

49. Exposed flame ignited fuel 1.14.4
50. Flash fire ensued 1.14.3
51. Outboard section fell into gully (Figure 5)
52. Foreign objects injured passengers 1.13.10
53. Aircraft struck hillside inverted
54. Left wing (striking ground) stopped roll abruptly
55. Impact decelerated aircraft longitudinally (minor) 1.13.1, 1.13.8
56. Impact decelerated aircraft vertically (major) 1.13.1
57. Impact deformed cabin structure 1.13.6
58. Impact deformed cockpit roof
59. Left wing and engine and undercarriage assembly broke away from fuselage 1.12.15
60. Empennage struck ground (inverted)
61. Tail section fell onto hillside 1.12.15; 1.14.5
62. Fuel droplets Burned as static fire
63. Impact forces flailed occupants’ limbs (minor) 1.13.8
64. Impact forces detached some passenger seats
65. Deformation of cabin roof dislodged ceiling and lockers 1.13.5
66. Deformation opened gaps in structure
67. Deformation generated hoop stresses
68. Inertia forces drove aircraft uphill
69. Passengers' flailing legs struck seats in front (minor) 1.13.8
70. Some passengers' heads struck cabin roof
71. Passengers' chests struck? 1.13.1, 1.131.8
72. Crew's heads struck cockpit ceiling 1.13.1, 1.13.8, 1.13.11
73. Debris and aircraft structure (?) entered cabin through gaps 1.13.6
74. Head impacts concussed passengers 1.13.9
75. Left wing assembly slid (inverted) along hillside 1.12.16
76. Fuselage and right engine and remains of right wing continued uphill 1.12.17
77. Foreign objects injured passengers 1.13.10
78. Rolling inertia applied side force to seats 1.13.2
79. Impact stresses split fuselage longitudinally 1.13.3
80. Ground slide (?) forces rocked aircraft 1.13.4
81. Passengers struck fuselage or other passengers 1.13.4
82. Fuselage assembly struck bank on hillside 1.12.17
83. ?
84. Fuselage assembly was slewed 150 degrees [to right] 1.12.17
85. Jet fuel leaked from cross feed lines?
86. Engine oil Leaked onto hot section?
87. Hot section ignited oil?
88. Jet Fuel Soaked into ground?
89. Oil fire ignited jet fuel?
90. Fire grew suddenly after passengers left aircraft 1.14.9
91. One passenger was nearby
92. Fire burned one passenger 1.14.9

Summary of MES Analysis

The MES analysis, using information from the report, from examination of the wreckage, and from subsequent litigation, shows why it is difficult to form a coherent picture of the occurrence from the report. Information has to be collected from widely dispersed sections of the report, and put into proper order, to form a 'mental movie'. Had the investigators been using MES, this would have been self-evident, and the report could have been re-drafted accordingly. Also, as indicated by the graphs, some information is missing from the report. The use of MES during the investigation would have highlighted these deficiencies, and further data could have been gathered. A further benefit of MES during the investigation would have been the identification of conflicting information, or uncertainty of information, and these matters could also have been addressed.

Although the rules for construction of MES graphs stipulate that the graphs comprise only logically related *events*, it has been found necessary, in this case study, to use *states* (i.e. a continuing state of affairs) in order to form a complete picture. Where this has been done, a different symbol has been used in order to distinguish such states from EBBs.

Some matters have been identified as being beyond the scope of MES: it is not suited to consideration of abstractions, since its purpose is to focus on concrete matters. More abstract matters will be considered in subsequent analysis, for example in Why-Because Analysis.

Comments

Teaching

The objection is sometimes raised, that MES and similar techniques are too difficult to teach. From my own experience, I know that it is not easy, yet as we’ve seen, you can’t really afford not to use them. There are two solutions:

- In the first place, not everyone needs to be a whiz at MES. One person on the investigation team will do, though it would be a very good thing if whoever reviews reports was also familiar with it.
- There is no need to teach the whole technique as a classroom exercise. MES can be learned by starting with small accidents, and building experience before using it on a major air transport accident. This is the method by which we learn many of the other techniques we use, such as on-site investigation. This is a compelling argument for the investigating authority to investigate fatal accidents to light aircraft, aside from the air safety lessons that may be learned.

Conclusion

The MES review of the Ansett accident report has shown significant deficiencies. In the first instance, it was part of the preparation for the action by the passengers against Ansett. Since the official report, in effect, made a finding of professional negligence against the pilots, and the company sought to hide behind this, it would have been necessary for counsel to seek to destroy the credibility of the report, had the case not been settled out of court. This would not have been difficult.

The report
- did not recognise that there had been a fuel-air explosion, which blew off the outboard part of one wing;
- was unsure that the starboard undercarriage leg had been unlatched before initial impact, despite clear evidence that this was so;
- did not recognise that the principal impact was inverted, despite clear physical evidence;
- consequently, did not understand the injury mechanisms; and
- provided conflicting statements in different parts of the report.

Opportunities for safety improvements were missed:
- The FAA was about to implement the NTSB's longstanding recommendation that fuel tanks be inerted, but did not include turbo-prop aircraft because there were no records of explosions in such aircraft. Had this explosion not occurred, the long upright ground-slide should have resulted in minimal injuries. This would have been a strong argument for including turboprops in the new regime. What an opportunity missed!
- Since the latch mechanism deformation was entirely due to wear and not partially due to impact, it would have been appropriate to recommend immediate mandatory modification in New Zealand, and a recommendation to overseas authorities that they consider similar action.

The report is difficult to read, but if our reports are to be effective in promoting safety, it is first necessary that they be easy to read and understand.
- The timeline in the first part of the report lacks logic; in one case it is even wrong.
- Information is scattered throughout Part One, which should have been included in the timeline. For example, information on the fire, while it might need to be amplified subsequently, was clearly part of the accident sequence, and it is unhelpful not to include it.

MES provides a way, not only for the investigator to construct a 'mental movie' of the physical sequence of the accident, but also to impart this information to others, who can easily understand 'what the heck happened', and so may be prepared for the in-depth analysis of how and why the accident occurred – and what needs to be done to prevent future accidents.

While MES may be hard to teach, you really can't afford not to use it.

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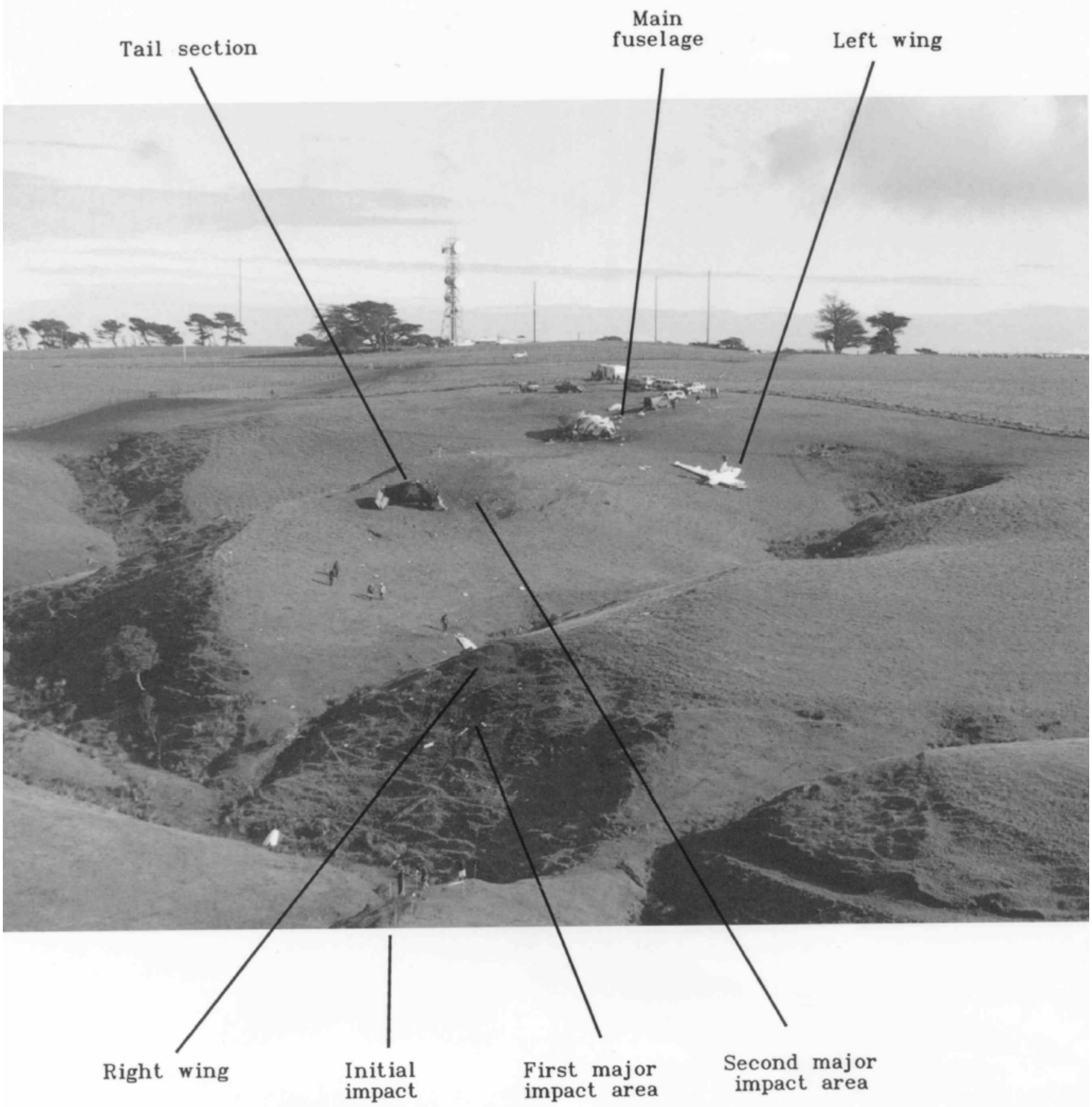
Accident Site



Accident Site - General View

Wreckage Plot

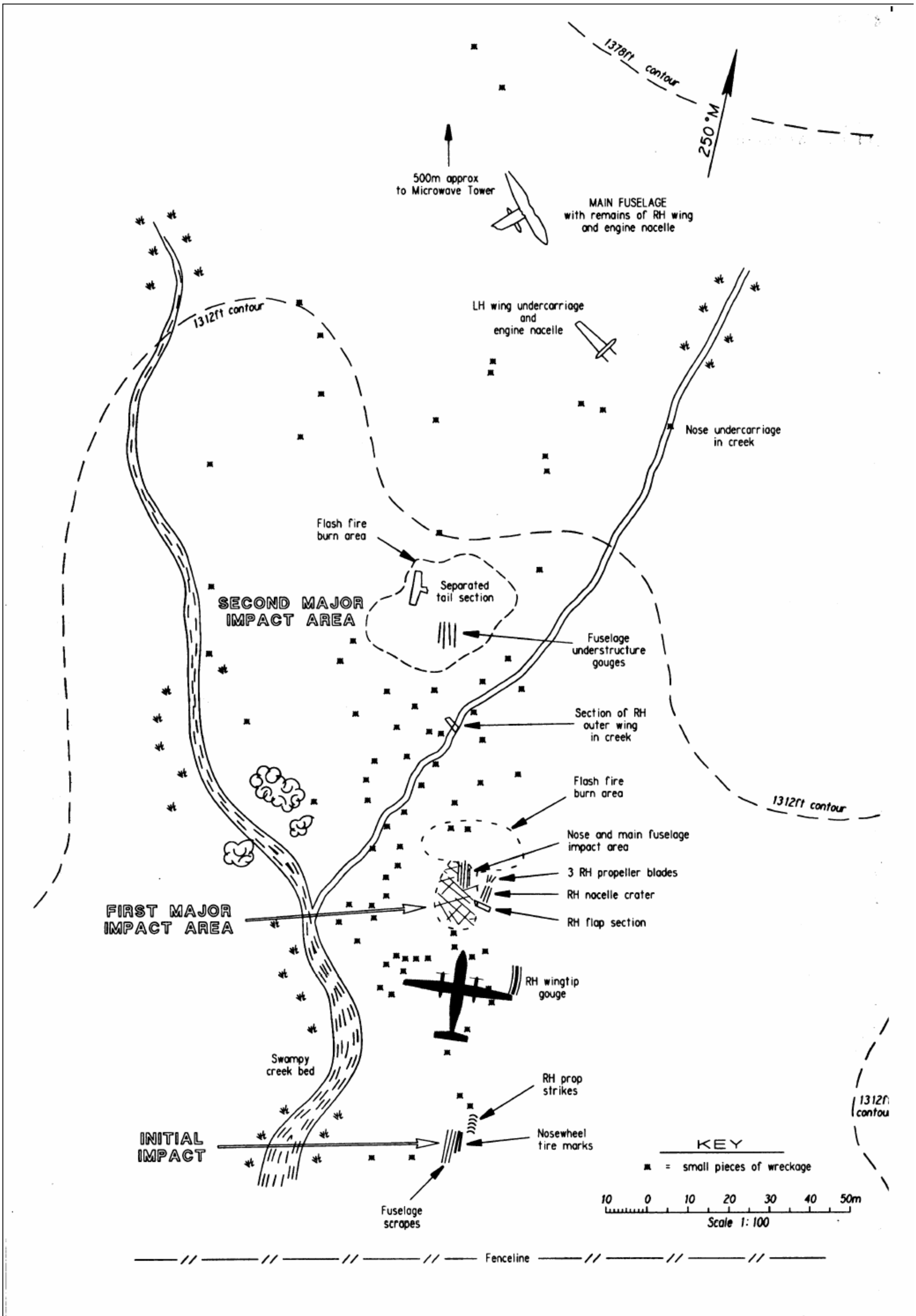


Figure 5
Impact and wreckage diagram

Cockpit Exterior

Cockpit Interior