IMPACT DYNAMICS IN ACCIDENT INVESTIGATION
- AN INVESTIGATOR'S VIEWPOINT

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Abstract

Following the accident to a B737-400 in January 1989, AAIB commissioned a studyof the impact, using computer-based dynamics. The structural code KRASH wasused for the airframe and MADYMO for the occupant. The results were publishedin the accident report

This led to the development, principally at the Cranfield Impact Centre(CICL), of a 'user-friendly' (now PC-Windows based) tool, facilitating theinvestigator's interaction with the impact codes. This has become known as AAIT(Air Accident Investigation Tool). During its development, the components ofAAIT have been used in accident investigations, including the accident to anMD-81 near Stockholm in December 1991.

The paper discusses the lessons learned, from AAIB's viewpoint. Theselessons include usefulness of the results, the need for timely response,co-operation with the aircraft manufacturer and the need for teamwork betweenthe investigator and impact analyst.

Introduction

In common with other accident investigation bodies around the world, AAIBhas taken an increasing interest in the crashworthiness and survivability issuesin aircraft accidents. This interest, now taken for granted, contrasts with theearlier days when the investigators concentrated almost entirely on theprevention of recurrence of the accident itself. For instance, there was acivil C47A Dakota crash in Kent in 1947 in which 8 of the 16 occupants sustainedfatal injuries but the comprehensive AIB (as it was then) accident reportcontained the simple statement that: "The passengers' seats had torn away at thefloor anchorages. The safety belts were found still fastened and were probablybeing worn at the time of the crash" and made no further comment on what wewould, from our current perspective, regard as being a largely survivableimpact!

For AAIB, crashworthiness and survivability investigations have centred in3 areas:

- i) survival in the deceleration of accident impacts,
- ii) survival and evacuation around aircraft fires,
- iii) evacuation and survival at sea after helicopter ditchings.

AAIB has conducted significant investigations into accidentsinvolving all three categories: notably the investigation into the 737-200 fireat Manchester Airport in August 1985 and a number of North Sea helicopterditchings. This paper concerns the first category (i), impact crashworthinessand survivability.

Accident to Boeing 737-400, G-OBME, at Kegworth on 8January 1989

The accident which, for AAIB, provided the impact corollary to the Manchesterfire was the accident to Boeing 737-400, G-OBME, near Kegworth, Leicestershireon 8 January 1989. At the Manchester accident there was cabin fire and noimpact; at Kegworth there was massive impact and, very fortunately, no cabinfire.

G-OBME was a 737-400 aircraft and was making a single-engine approach intoEast Midlands Airport following a major problem with the No. 1 engine in flightand the shut-down by the crew of the No 2 engine. About 2.4 nautical miles fromthe runway the fan of the No. 1 engine began to break up and, with the crewunable to restart the No. 2 engine, the aircraft sank below the glideslope

The aircraft's first impact was in a level field adjacent to the easternembankment of the M1 motorway: it then suffered a severe impact on the westerncarriageway and on the western embankment of the motorway. Of the 126occupants, 47 died as a result of the accident and a further 74 suffered seriousinjury.

There were a number of crashworthiness and survivability issues in theaccident, principally:

the structural failure of seats on the flight deck and in the cabin,

the structural failure of the cabin floor in two distinct areas,

damage and injuries caused by the failure of the overhead binattachments.

Central to each of these issues was the necessity of understanding thedynamics of the aircraft's impact and, in particular, the shape and magnitude ofthe pulse in the second, major, impact. For determining the deceleration pulsetransmitted to the cabin floor in the second impact AAIB considered severalsources of information, including calculation of the basic kinematics, thedamage to the passenger and pilot seating related to previous dynamic testingand comparison of airframe damage with previous calibrated tests. These werethe conventional approaches but, in addition, it was decided to attempt acomputer-based modelling of the impact dynamics of the aircraft and a typicaloccupant. The primary objective was to refine the deceleration levels at thecabin floor throughout the impact sequence. Secondary objectives were todetermine the efficacy of such a computer-based model and whether such a studycould achieve useful results within the time-scale of the overall accidentinvestigation.

Because of its simpler modeling, and the availability of full-scale testdata from previous FAA full-scale impact tests, Cranfield Impact Centre Limited(CICL) was commissioned to perform the impact study, using the KRASH program. KRASH is a ‘hybrid’ program and had been developed in the UnitedStates for the numerical analysis of aircraft impact problems. By contrast, itwas considered that use of a 'full' finite element program, which would model avehicle structure in detail using geometric and material-properties input data,would not provide answers within the timescale of the accident investigation.

A further, and crucial, advantage of the 'hybrid' modeling approach wasthat the requests, for structural and inertia data to be provided by theaircraft manufacturer, were reasonable and the figures already existed withinthe loads and inertia documentation of the aircraft design and certification. AAIB and CICL were greatly assisted by the aircraft manufacturer in this case.

Using data derived from the impact analysis conducted at the CranfieldImpact Centre (CICL) a further computer analysis of the occupant response wascarried out. This further study was undertaken by H W Structures Ltd using thecrash victim simulation program, MADYMO.

Results

The results of the computer-based simulations in this accident wereencouraging and the work was fully represented in the AAIB accident report. Ofthe 29 Safety Recommendations in the report, 11 concerned crashworthiness andsurvivability issues. The simulation data was used to support a number of theseRecommendations though, in each case, there was also independent supportingevidence and analysis.

The use of the KRASH computer program as a part of the impact study inthe G-OBME investigation was judged by AAIB to have been successful. This waslargely due to the helpful attitude of both the airframe manufacturer and theFAA, under whose auspices the KRASH code was developed.

The study was not ideal, however, and did highlight a number of areas forimprovement of the simulation process, both in the operation of the crashdynamics codes themselves and in the creation of the aircraft model. Theseimprovements would enable impact simulations to be run in a more timely andcost-efficient manner.

Following proposals from Cranfield Impact Centre, therefore, the MOD(Ministry of Defence) and AAIB decided to fund a development programme, spreadover 3 years, to provide a usable tool for the analysis of aircraft impacts,provisionally called the 'Aircraft Accident Investigation Tool' (AAIT). FAAprovided advice during this initial development and, in later development, havealso provided a level of funding.

Accident to McDonnell Douglas MD-81, OY-KHO, on 27 July December 1991

During AAIT development, there was an opportunity to use portions of theAAIT. The aircraft, OY-KHO, was an MD-81 operated by Scandinavian AirlineSystems (SAS). On 27 December

1991 OY-KHO suffered failure of both enginesshortly after take-off from Stockholm/Arlanda airport; the engine failures wereinduced by the ingestion of ice shed from the wings. The crew attempted aforced landing in a field roughly in the direction of flight. In the groundimpact the fuselage broke into three sections and slid for some 110 metresbefore stopping. There was no fire and, of the 129 occupants, eight sufferedserious injuries and 84 suffered minor injuries. With high verticaldecelerations in the forward passenger cabin there was, again, the problem ofoverhead bins descending onto the passengers and seatbacks.

AAIB offered assistance to the Swedish Board of Investigation (SHK) in anumber of technical areas, including a possible computer-based analysis of theimpact dynamics. This offer was accepted and, following an AAIB survey, AAIBand SHK jointly commissioned a study of the impact dynamics. In this case CICLperformed an AAIT structural analysis based on a KRASH model derived from datahelpfully provided by the airframe manufacturer and the resulting pulse was usedin a MADYMO occupant simulation.

Results for MD-81, OY-KHO

1) The combination of the KRASH structural simulation and theMADYMO occupant simulation was successful but highlighted the need for closeco-operation between the agencies responsible for the various aspects of theprogramme.

2) The KRASH code produced acceptable structural simulations of theimpact and these extended for a sufficient length of time for the impactsequence to be simulated, from initial ground impact until the aircraft came torest.

3) The results of the various KRASH runs highlighted some of the areasstill under development within AAIT, such as the principle of varying thecoefficients affecting interaction between the airframe and the ground withtime. This led to the development, within AAIT, of 'soft ground' and waterimpact modules.

4) The MADYMO simulation runs produced injury indices which appeared tobe in agreement with the injuries reported to the medical investigators. TheKRASH signals indicated that the decelerations generated in cockpit, and withinthe forward portion of the passenger cabin, were higher than the levels used forcertification of the MD81 and similar passenger aircraft. This applied to thecrew seats, the passenger seats and the overhead stowage bins and the pulseswere also above those specified in the newer "16g dynamic" certificationcriteria (FAR/JAR 25.561 & 562).

Lessons learned

AAIT has developed further and is now based on the PC platform, with aWindows user interface version now making it much easier for use by users whoare not impact dynamicists.

From an AAIB viewpoint, there are a number of general lessons which we havelearned through experience and development of AAIT. These would seem to applyto the use of any computer-based impact tools applied in an accidentinvestigation:

1) For appropriate accidents, the use of these analytical tools**does** add real value to the accident investigation as a whole, as asupplement, and **not** a substitute, for other means of analysis. **But** -

2) The process **must** fit into the timescale of the accidentinvestigation, seeming to preclude the use of extensive 'finite element'modeling and favouring the use of 'hybrid' models, such as in KRASH.

3) For successful building of airframe structural models, there is nosubstitute for the helpful co-operation of the manufacturer which, in general,is forthcoming after an accident. For impact analysis, this co-operation islikely to extend readily to the provision of, for instance, data on design loads- the co-operation is unlikely to extend to provision of a full 'finite element'model.

41944240 And, finally, it is imperative that the accidentinvestigator remains closely in touch

investigator needs the specialist'sknowledge in setting up the impact model and 'keeping

investigator toensure that the impact analysis remains firmly wedded to the physical

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Effective aircraft accident investigation is a highly collaborativeactivity. AAIB readily

order and amongst others!) the CICL,MOD, FAA, CAA, SHK and the aircraft manufacturers.

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