Why-Because-Analysis Tools and The Concorde Accident

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- Why-Because-Analysis - A short Introduction
- Causal System Analysis - An Extension of WBA
- Text-based Tools for WBA/CSA
  - wb2dot
  - cid2dot
  - cid2ft
- Graphical Tools for WBA/CSA
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Part II - The Concorde Accident

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  - Finding "Why-Because" Pairs
  - Making the Graph
- Analysis
  - Interesting Observations / Discrepancies to the Official Conclusions
  - Recommendations by Authorities
  - Conclusions

Part I

Why-Because-Analysis Tools

Why-Because-Analysis

- Formal, yet easy to understand approach
  - Why did A happen? Because B happened!
- Counterfactuality Test
  - "Had A not happened, then B would not have happened"
- Direct causes need to satisfy "INJS" criterium
  - "Individually Neccessary, Jointly Sufficient"
- When to Stop?
  - How do you know when not to go into further detail?
  - One possibility: use the information from the Official Report, e. g. from the NTSB (USA) or BEA (France)

Why-Because-Analysis

- Advantages
  - Easy to find Root Causes: leaf nodes
  - More powerful than Fault Trees

- Disadvantages
  - Only suitable for accidents that already happened
  - Only discrete influences are considered

Why-Because-Analysis

- Remedy
  - Extend the WBA to be suitable for analyses of systems that have not yet failed
- Leads to Causal System Analysis
  - Includes ways to take discrete and fluent influences into account
  - Possibility to handle delayed influences

Text-based WBA/CSA-Tools

- wb2dot
  - Creates nicely layed-out graphs from textual "WB-Script" input
- cid2dot
  - The counterpart to wb2dot for CSA
- cid2ft
  - Create fault trees from Causal Influence Diagrams

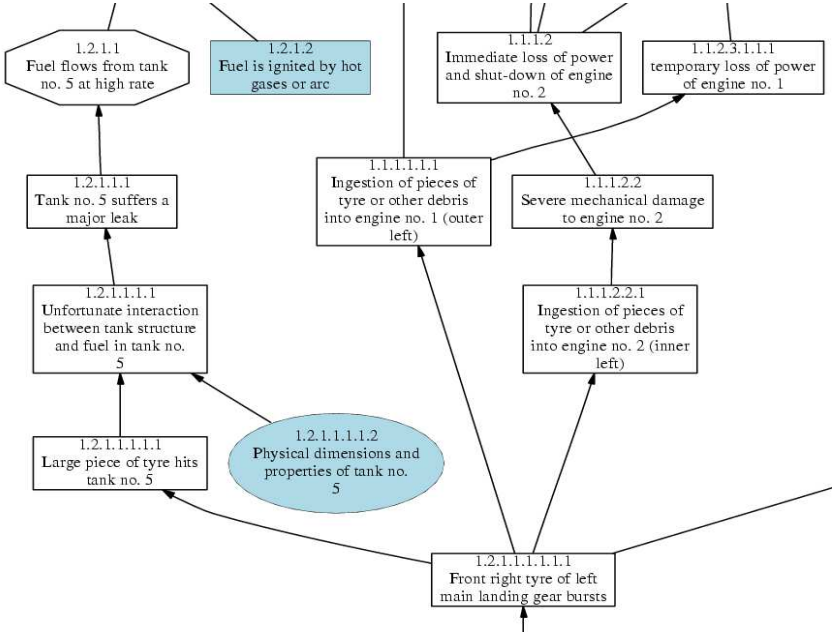
Examples of the Text-based Tools

- WB-Script (to be edited in a text editor)

```
[0] /* Impact */
 /\  [1] /* Loss of control of aircraft */

[1] /\ {-.1} /* Control surfaces ineffective */
    /\ {-.2} /* Deformation of left wing by fire */
    /\ [-.3] /* Loss of power of engines no. 3 and 4 */

[1.1] /\ {-.1} /* Unusually high angle of attack and banking
                  angle */
      /\ {-.2} /* Too low airspeed */

[1.1.2] /\ <-.1> /* Landing gear would not retract */
        /\ [-.3] /* Too early Takeoff because of
                    approaching left RWY edge */
```

Example of the graphical output

- Run the Perl script wb2dot on the WB-Script text file
  - wb2dot creates a .dot input file and then creates a Postscript rendering of the WB-Graph



Shortcomings of the Text-based Tools

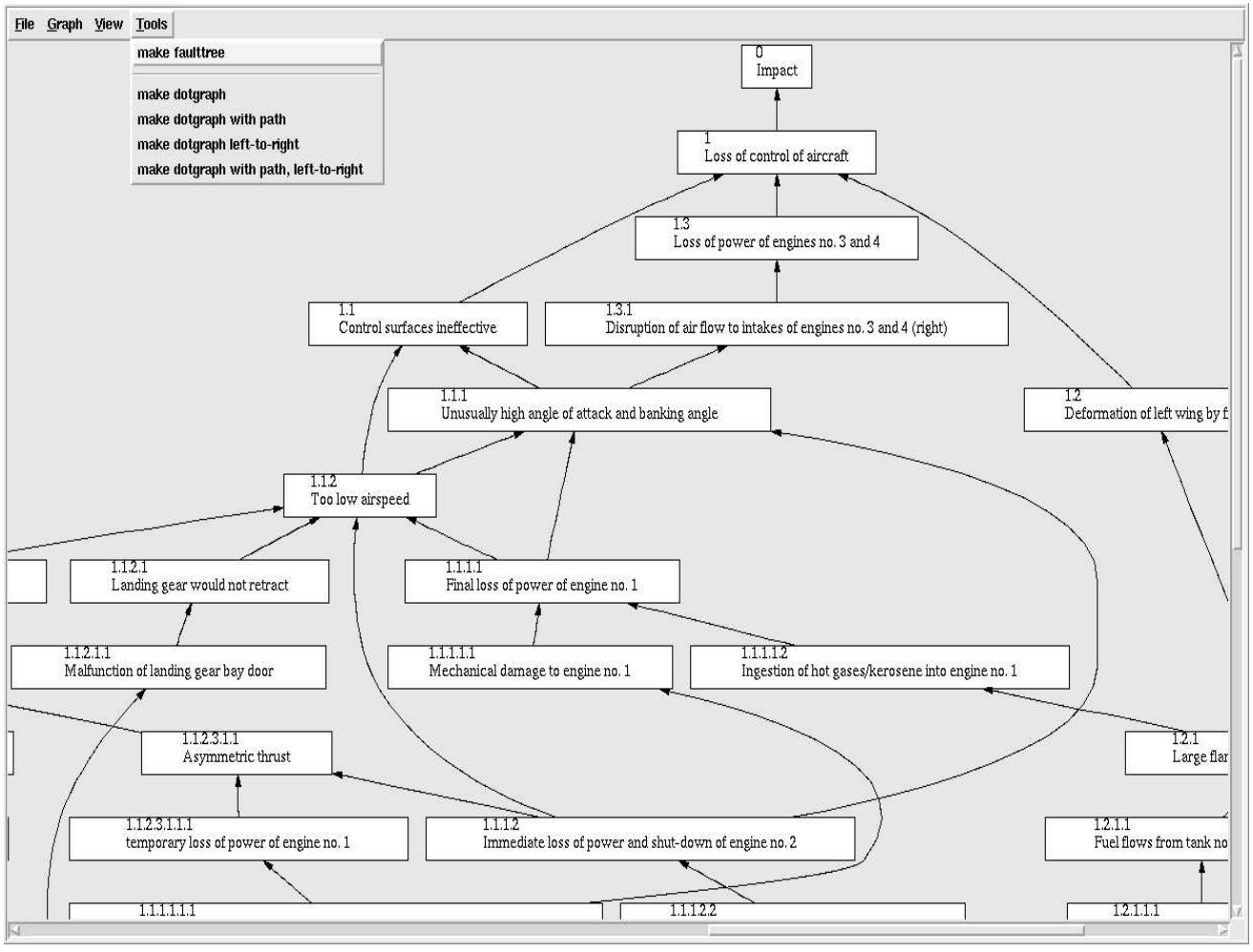
- No immediate Visual Feedback
- Node numbering has to be maintained manually
- Very prone to input errors
- Very tedious procedure to add nodes (May require renumbering large sub-graphs)

Graphical WBA/CSA-Tools

- CiEdit
  - Graphical Editor for creating/modifying WB/CS-graphs
  - Automatic Generation of Postscript renderings of Why-Because-Graphs and Causal Influence Diagrams
  - Automatic Conversion of Why-Because-Graphs or Causal Influence Diagrams into Fault Trees
  - Automatic Renumbering of the whole Graph
- GraphViz
  - Toolkit by AT&T to make graph layouts

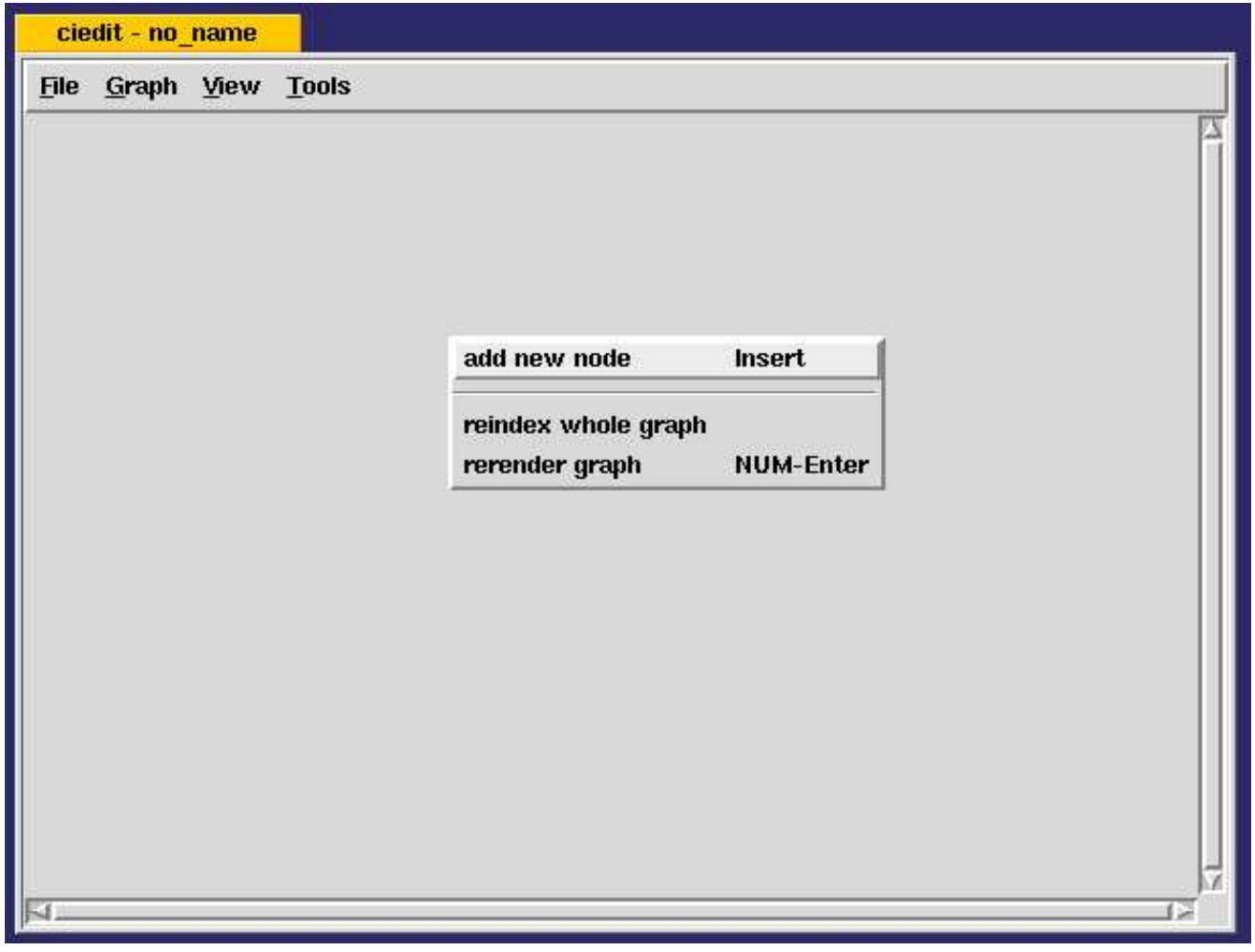
CiEdit ("Causal Influence EDITor")

- Based on Tcl/Tk and the TclDot plugin



CiEdit ("Causal Influence EDITor")

- Creating a new node



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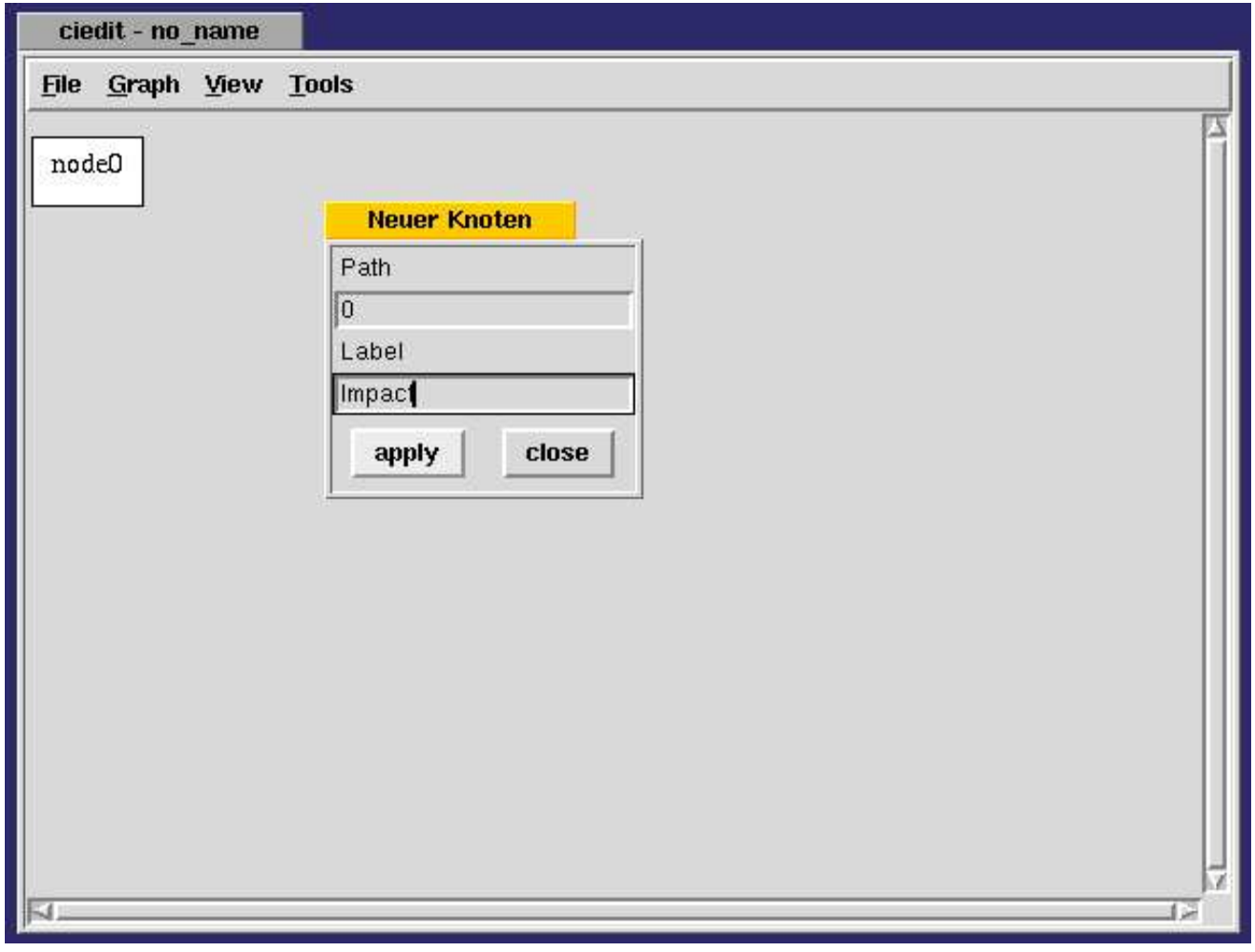
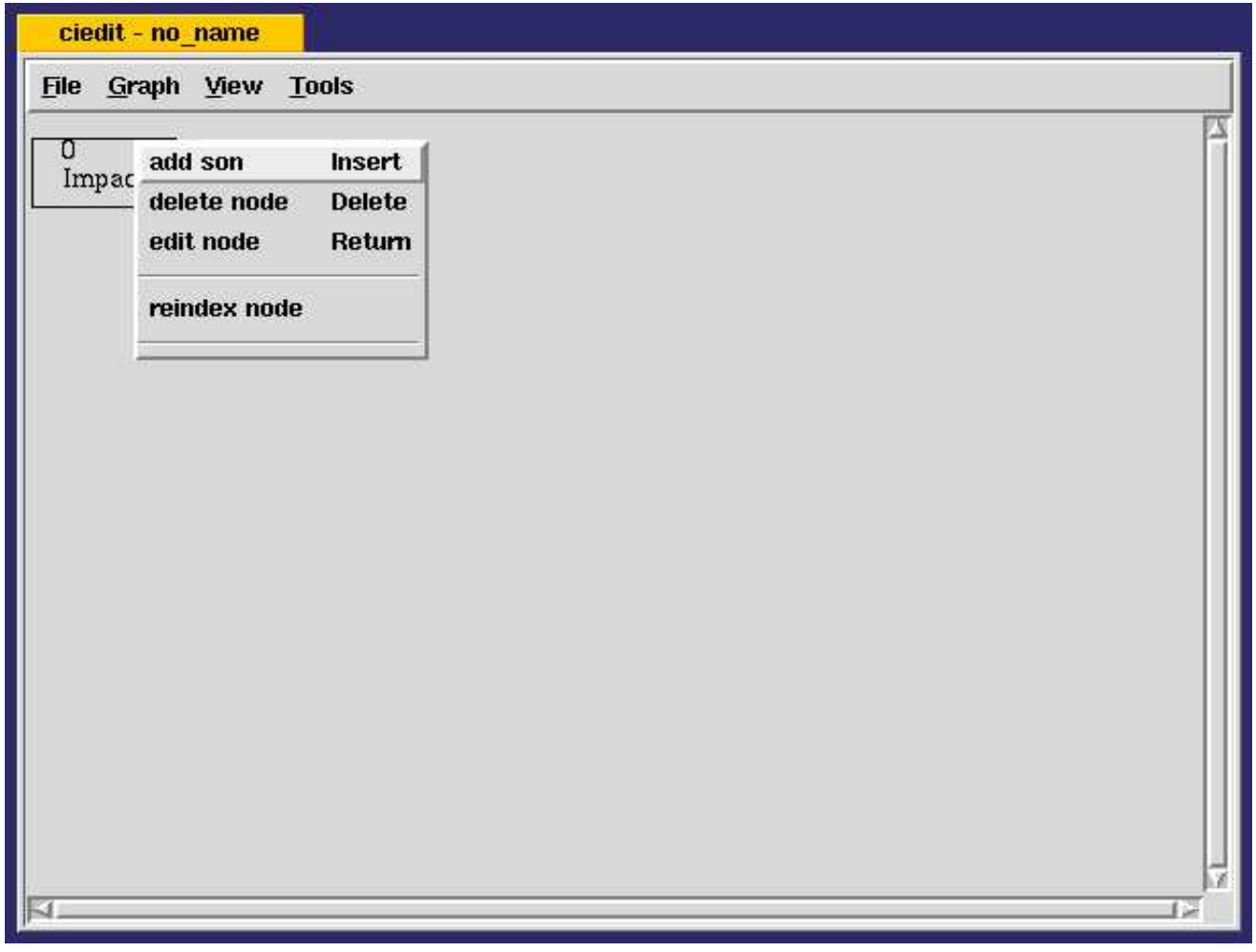


CiEdit ("Causal Influence EDITor")

- Creating a new Causal Factor



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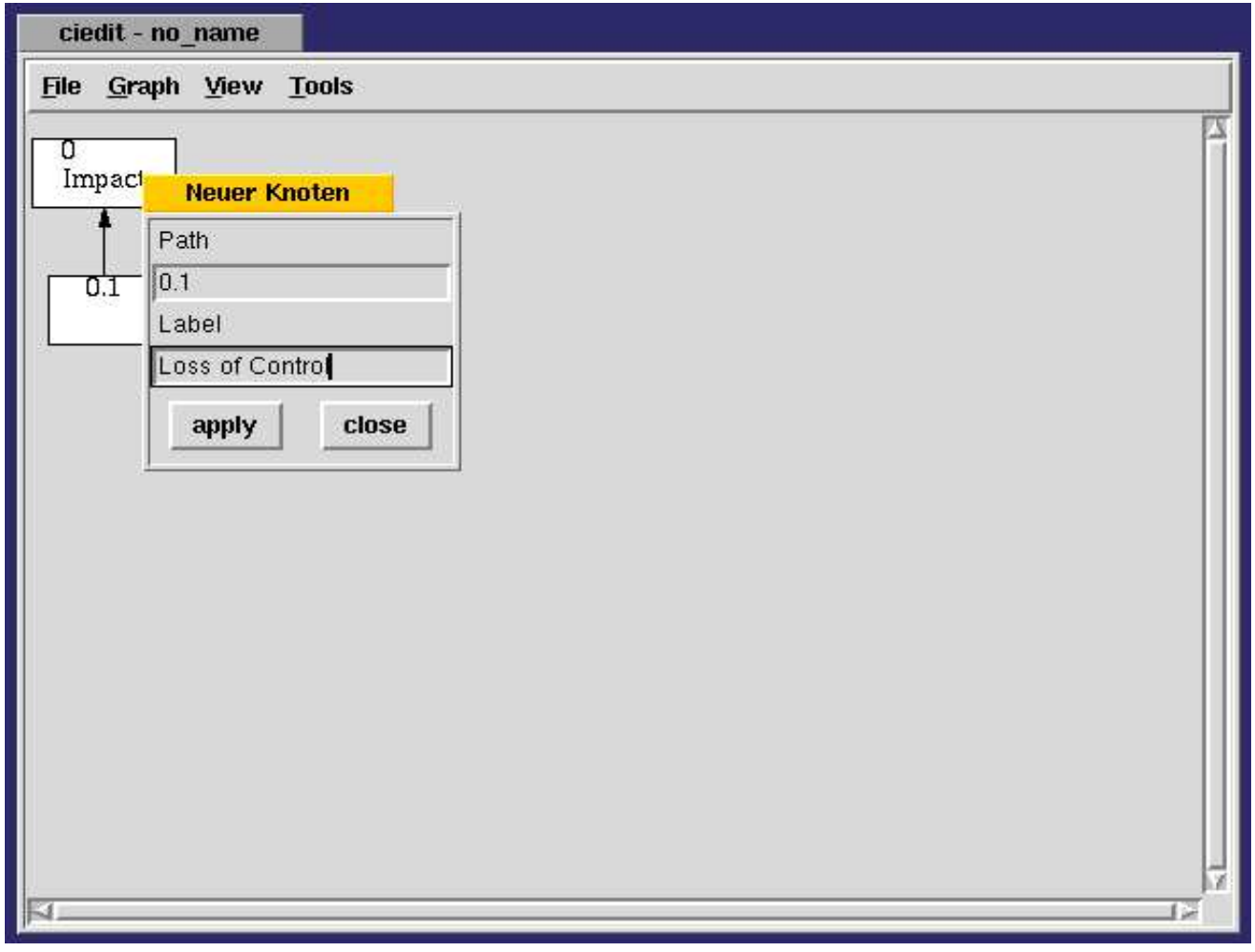
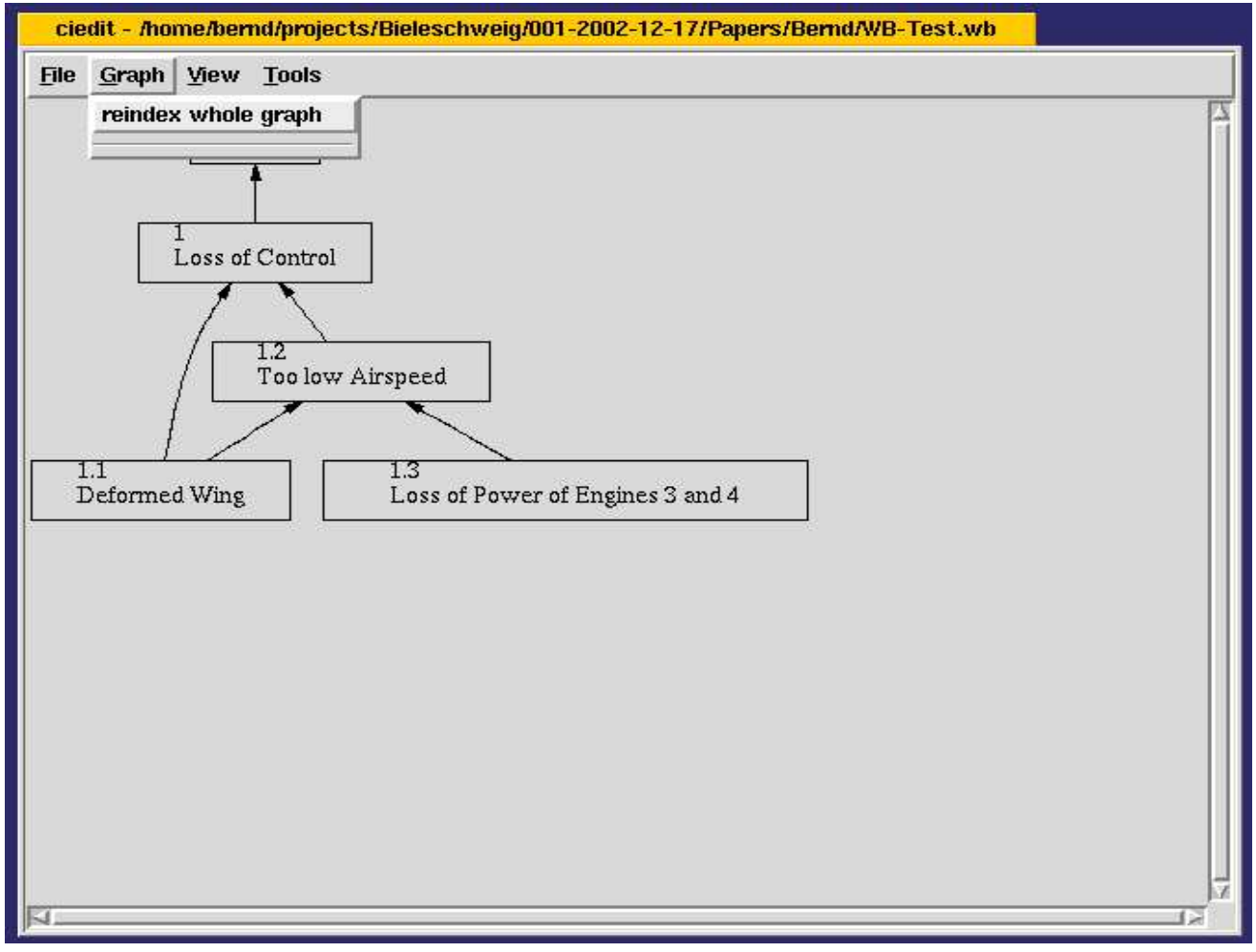
- Creating a new Causal Factor



CiEdit ("Causal Influence EDITor")

- Re-Index whole Graph



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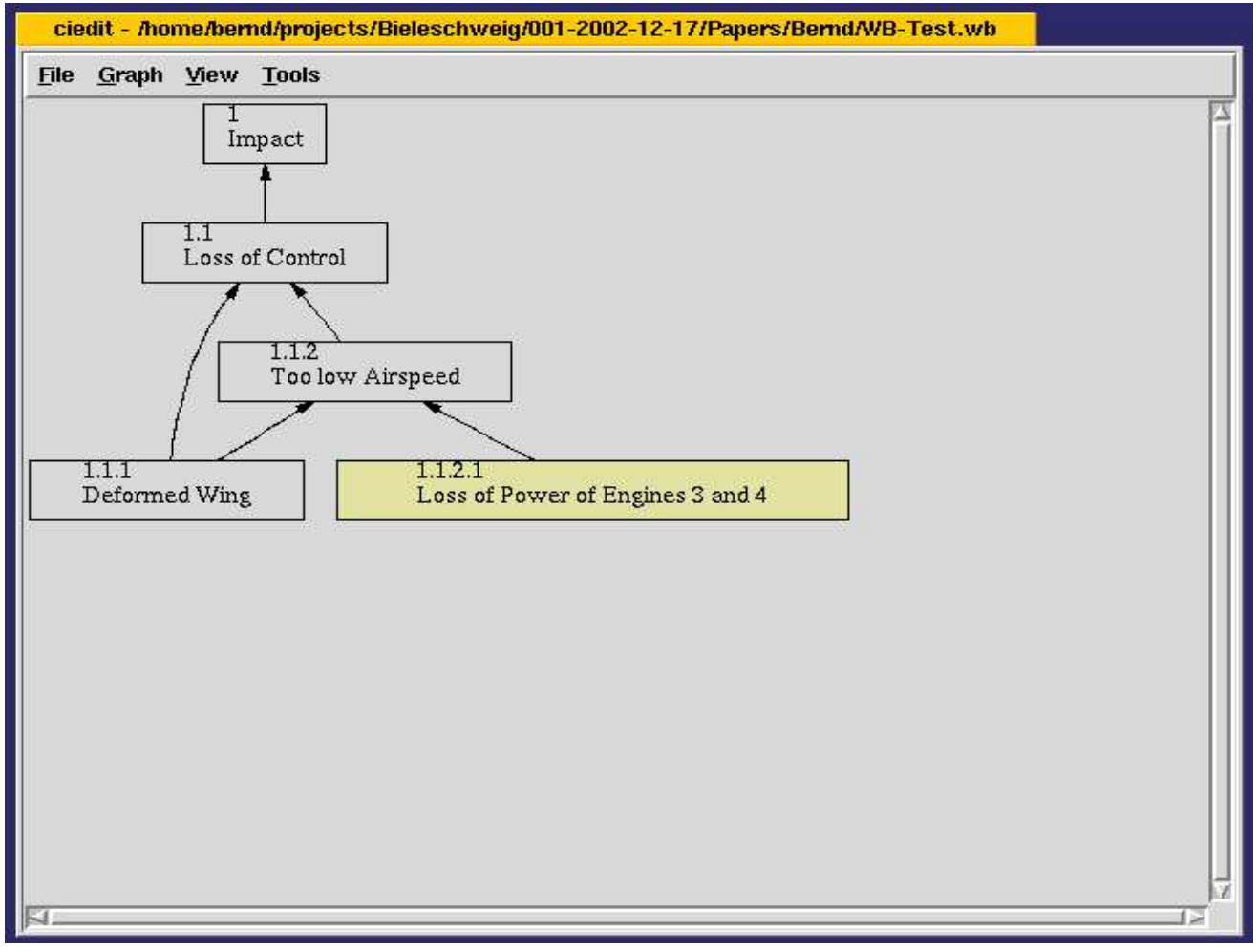
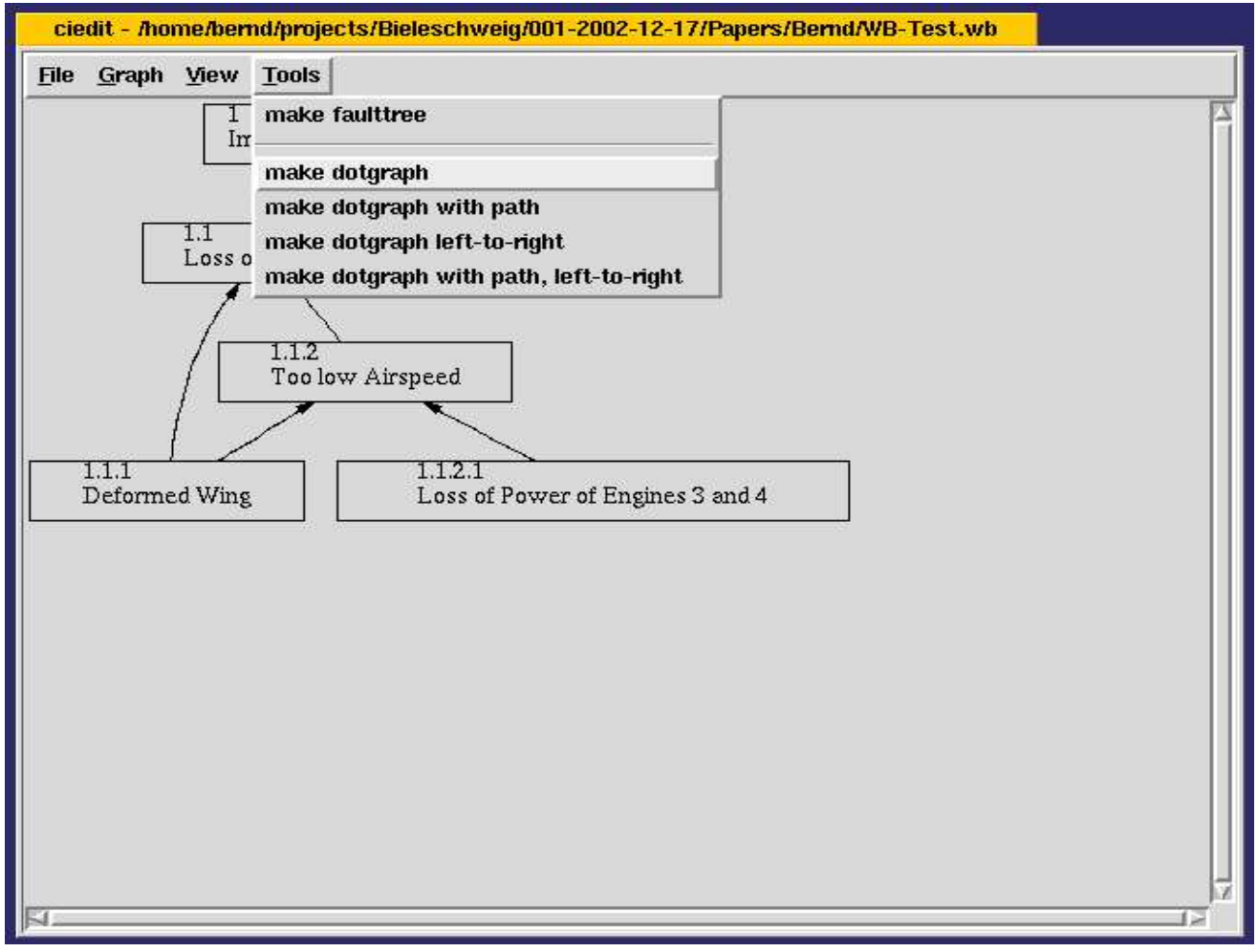


CiEdit ("Causal Influence EDITor")

- Making a Postscript Representation



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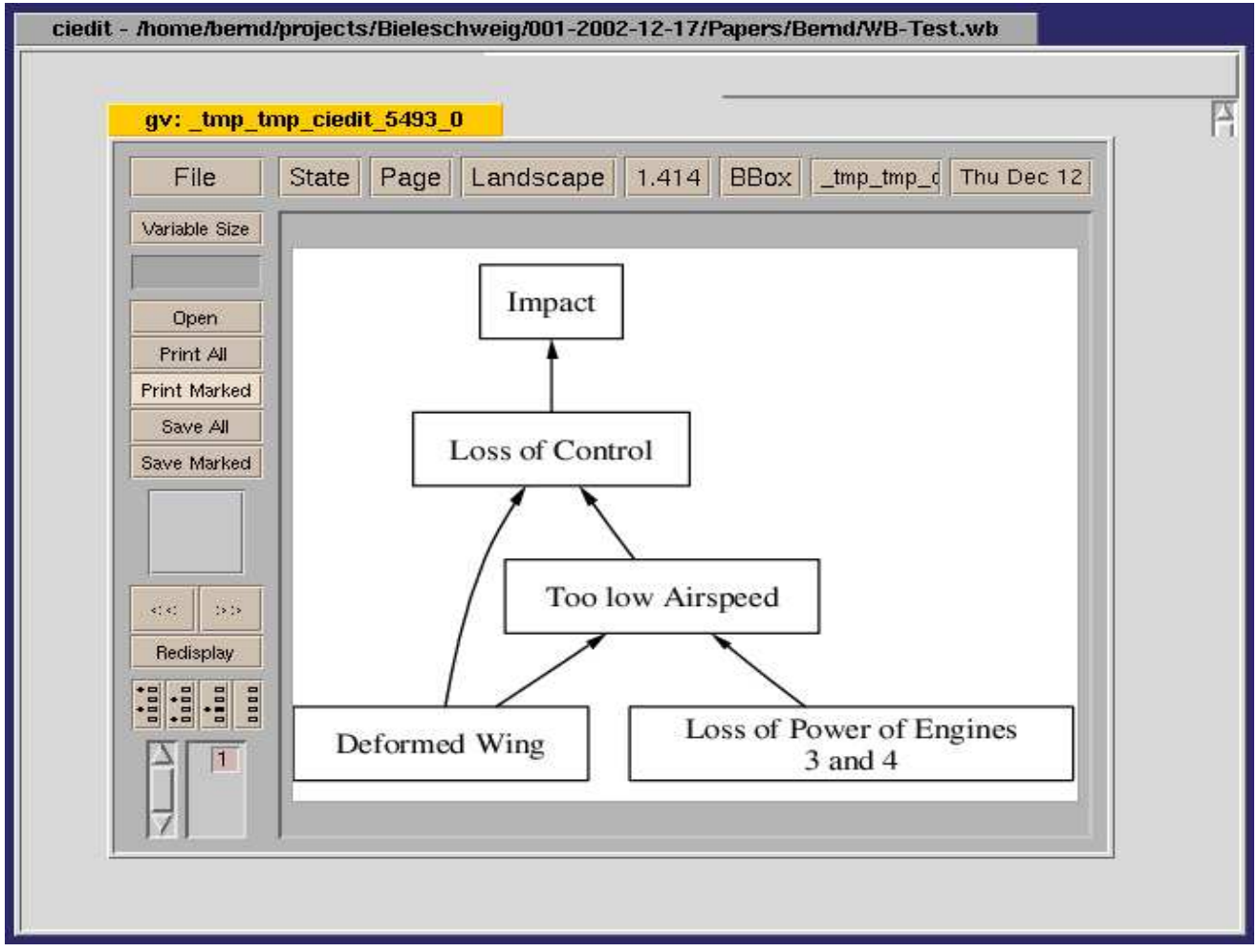
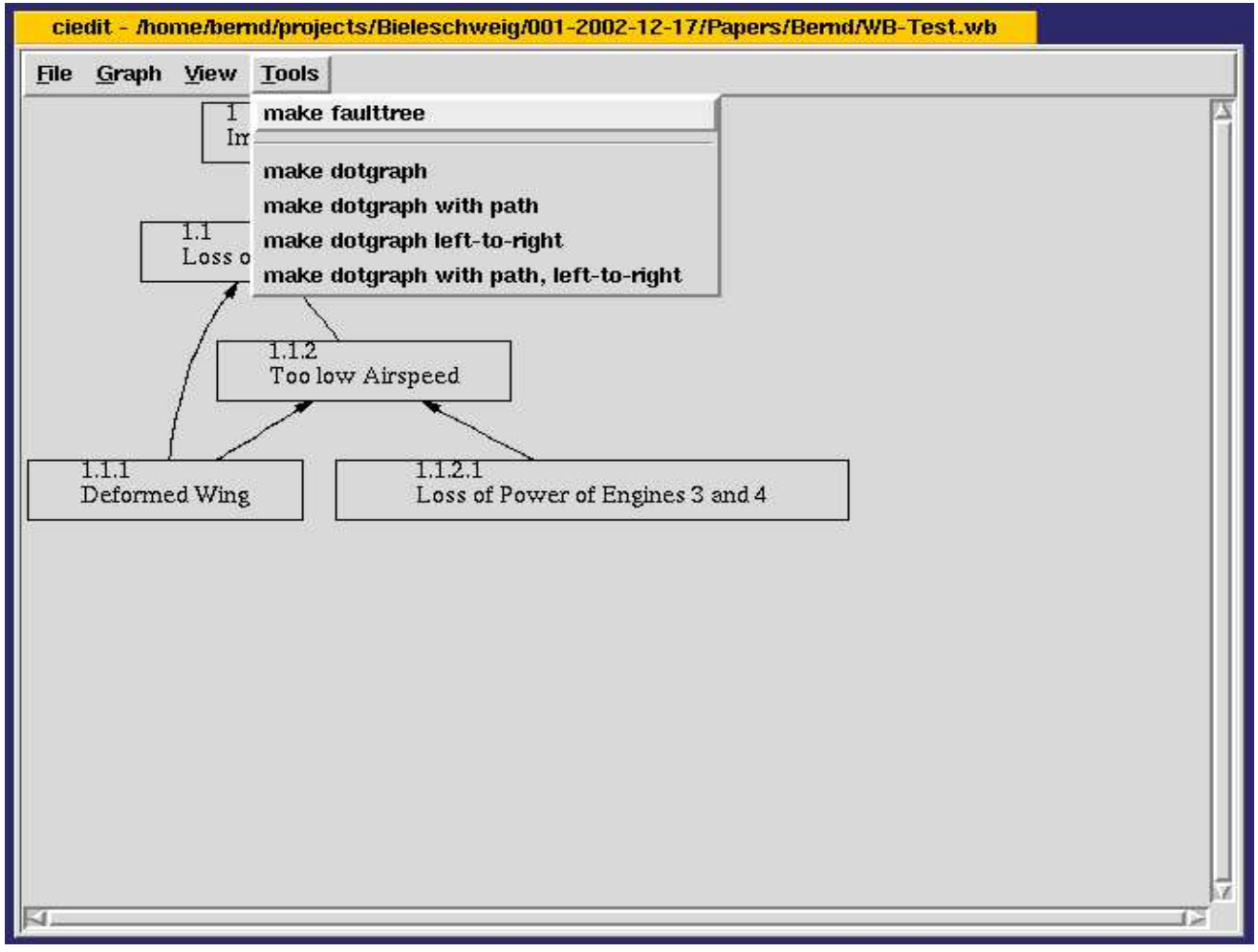


CiEdit ("Causal Influence EDITor")

- Making a Fault Tree



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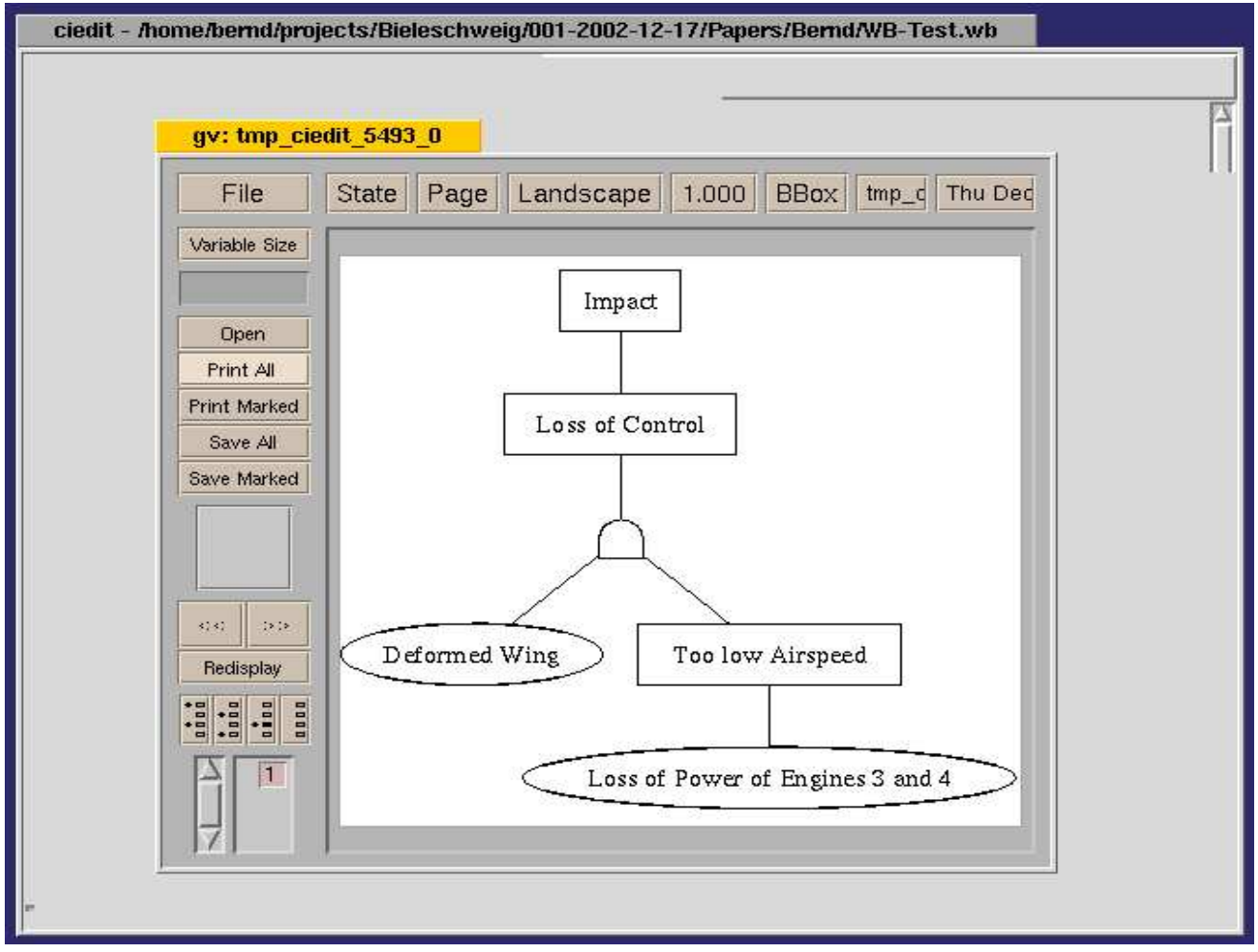


Part II

The Concorde Accident

What Happened?

On July 25, 2000 a Concorde supersonic airliner operated by Air France (F-BTSC) crashed onto a hotel shortly after take-off from Paris Charles-de-Gaulle, killing all 109 passengers and crew on board and 4 people on the ground, injuring another 6 people on the ground.

Official Investigation

The Bureau Enquetes Accidents (BEA) launched an extensive investigation into the accident and published a preliminary report, two interim reports with updates and a final report.

The reports cover many aspects of the accident flight, the aircraft’s previous record, the crew’s certificates, maintenance procedures, weather conditions, runway condition, the origin of pieces found at the runway, the accident site, and in-between.

Sequence of events

- Aircraft runs over a metal strip
  - (Lost by another aircraft)

- Tyre bursts
- Debris hits landing gear bay, and a wing fuel tank
- Debris gets ingested into engines 1 and 2
- Engines 1 and 2 lose thrust, engine 1 recovers, engine 2 is shut down

Sequence of events (cntd.)

- Tank ruptures, fuel flows out
- Arcs in gear bay ignite fuel/air mixture
- Aircraft takes off, burning intensely
- Landing gear does not retract
- Engine 1 fails, Angle of Attack increases

- Engines 3 and 4 fail
- Aircraft stalls and crashes

Creating a WB-Analysis

- Only source of information: the BEA-Reports
- Finding Why-Because-Pairs
  - To start a WB-Analysis, it can be useful to read through the report, writing down all direct causal influences mentioned.
- Re-read the reports
  - See if any causal factors have been forgotten

Create the WB-Script

- Write the WB-Script in a text editor
  - Write down all direct why-because pairs
  - Be sure to include all other direct causes as well

- Alternatively, use the graphical tool, CiEdit
  - Enter all the nodes and link the appropriate cause/consequence pairs
  - Have the program re-index the graph if neccessary
  - Save the WB-Script to a file

Create the Postscript Representation of the WB-Graph

- Use the text based tools
  - Call the wb2dot Perl script from a shell
    - wb2dot Concorde.wb
  - Call a Postscript viewer to view the result
    - gv Concorde.ps
- Alternatively, use CiEdit
  - Select the menu option "Make Dotgraph"

Check the resulting WB-Graph

- Do all influences satisfy the requirements?
  - Counterfactuality
    - E. g. Had the tyre not run over the metal strip, then it would not have burst
    - or, had the fuel not been ignited by an arc, there would not have been a flame under the wing
  - INJS
    - Are really all of the causes neccessary causal factors?
    - Are they sufficient to cause the event?
- Identify Root Causes
  - Leaf nodes, i. e. nodes that have no further causes in the graph, are Root Causes
  - The source material for the anlysis defines, what a root cause is.

Root Causes

- Leaf node events might have further causes, but we do not consider them if they are not mentioned in the Official Report.

- Other sources of information that go into more detail could be used.
  - Here e. g.: What led to the violation of the maintenance procedures?
  - This would probably involve management/engineer interaction, etc.

Root Causes

The BEA identified the burst tyre as the only cause of the accident. The WB-Analysis shows 8 Root Causes.

Different categories of Root Causes

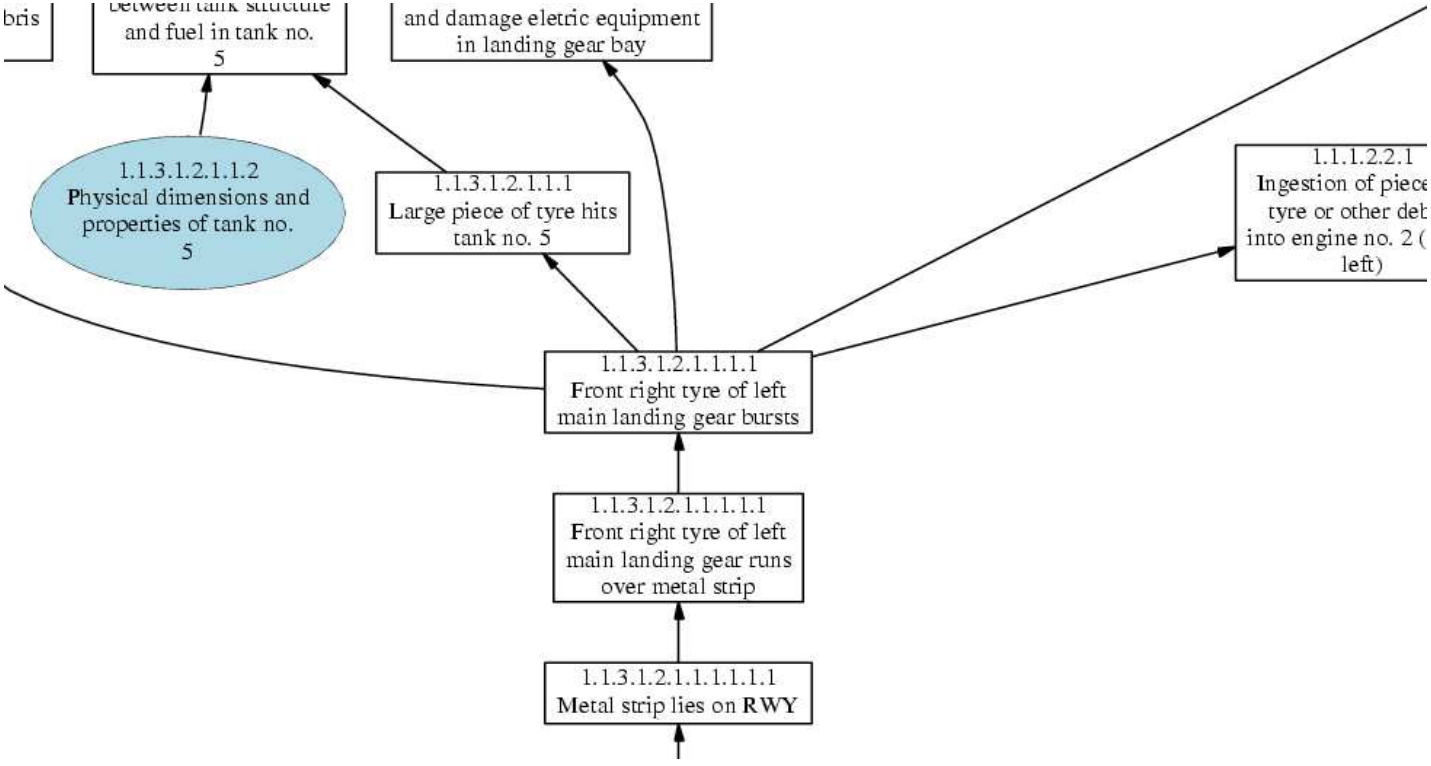
- Global design decisions, physical properties
  - Cannot be easily changed, often hard to identify as potential problems a-priori
    - 1. Physical dimensions of Tank No .5
    - 2. Layout of the Concorde fuselage and wings
- Other things beyond our control
  - Cannot be changed, but sometimes workarounds are possible
    - 3. Location of the fire
    - 4. Cockpit Crew becomes aware of the fire only after V1

Root Causes

- Operating procedures, correctly followed
  - Can be changed, but not always advisable
    - 5. Continue takeoff with only 3 operating engines after V1
- Local design decisions
  - Can be changed, often should be changed
    - 6. Fire detection sensors in wings not deemed neccessary
- Violation of Operating Procedures
  - Can be changed, usually should be changed
    - 7. Violation of procedures at Air France
    - 8. Violation of procedures at Continental Airlines

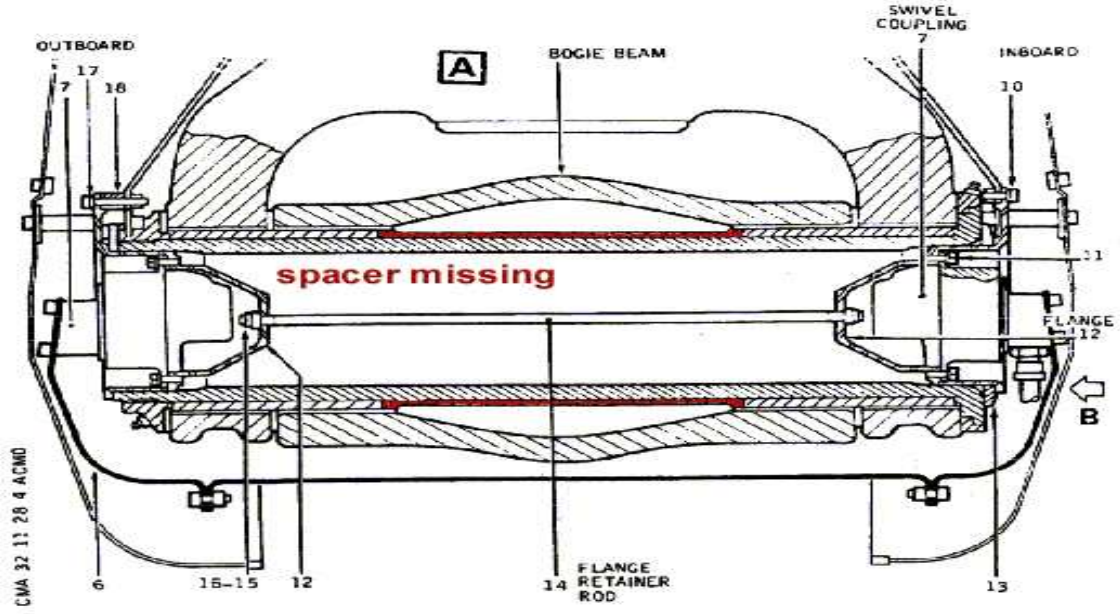
Interesting observations

- Single Point of Failure / Fan-Out
  - The tyre exploding is a single point of failure, which fans out to cause 5 further events, all of which eventually contribute to the accident.



Interesting observations

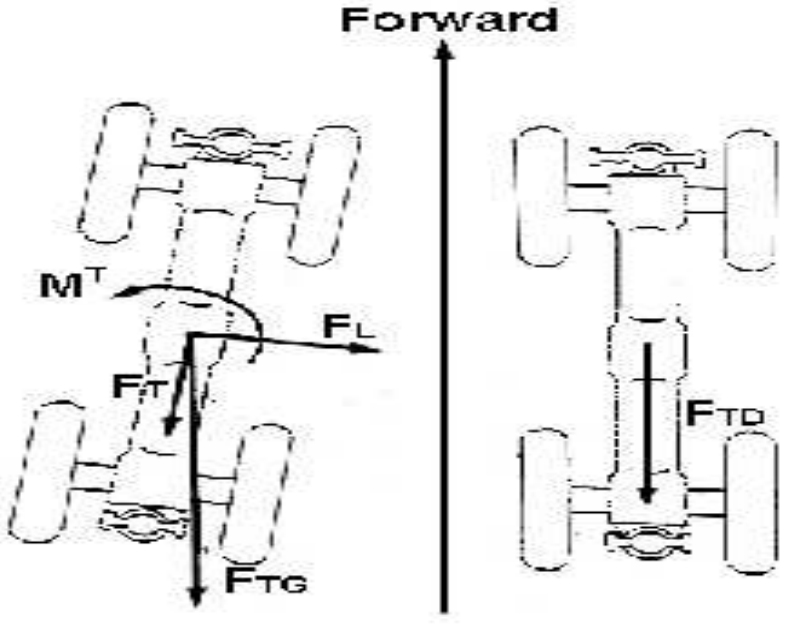
- The bogie of the left main leanding gear had been incorrectly assembled at a scheduled maintenance.



- The problem could lead to increased drag of the left main landing gear in relation to the right one.

Interesting observations

- The BEA did not identify this as a cause, not even as a contributing cause for the accident, because the aircraft had completed several flights with the problem, and it had never caused a deviation during accelleration.



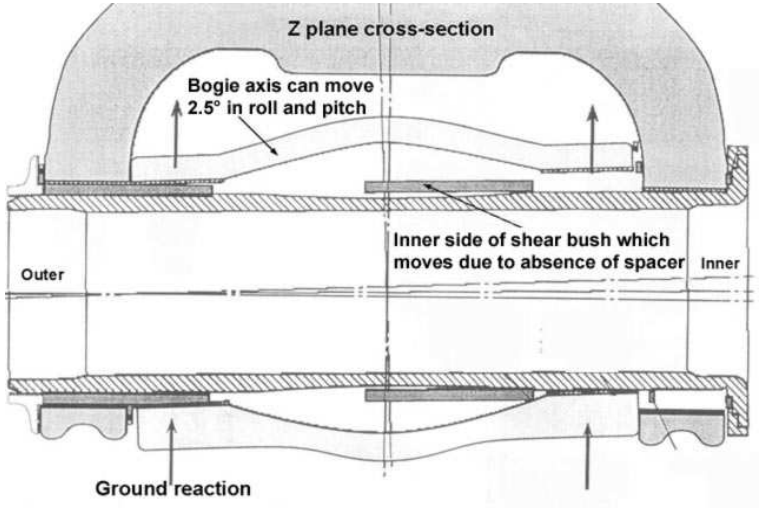
Interesting observations

But let's take a closer look:

- The aircraft had to take off early because it was approaching the left edge of the runway. This was attributed solely to the asymmetric thrust caused by the problems with engines 1 and 2.

Interesting observations

- Since the shear bushes in the landing gear bogie could now move due to the absence of the spacer, it is possible to imagine that the bogie can now be bent by several degress.
- Even if that did not happen on earlier flights the force of the exploding tyre may have bent the landing gear bogie.



Interesting observations

- It is interesting to note that we do not only see skid marks from the blown tyre, but from left and right tyres of the left main landing gear. This indicates increased drag from that gear.

Interesting observations

- After take-off the aircraft almost stabilised with 3 operating engines at around 200 kts airspeed, engines 3 and 4 running in contingency mode i. e. slightly above normal take-off power, engine 1 had recovered almost to a level of normal operation during take-off

Interesting observations

- The Concorde flight manuals provide figures for so-called zero-rate-of-climb speeds, at which the aircraft can maintain its altitude.
- The relevant zero-rate-of-climb speeds are as follows: With three engines running and the landing gear extended: 205 kts, with two engines: more than 300 kts.
- Even if the additional drag of the incorrectly assembled bogie was only small, without it the take-off might have been performed slightly later than with it, and the the aircraft might have stayed in the air slightly longer.

Interesting observations

- Even at only 215 kts it would have been manouverable with three engines running.
- An accident would probably have happened anyway, because
  - The wing was beginning to deform from the intense heat
  - engine 1 failed again, and the aircraft would not have reached the zero-rate-of-climb speed neccessary for extended landing gear and only two operational engines.
- But: it cannot be dismissed at least as a contributing factor; maybe the aircraft had not crashed onto the hotel but in the open field, sparing 4 lives.

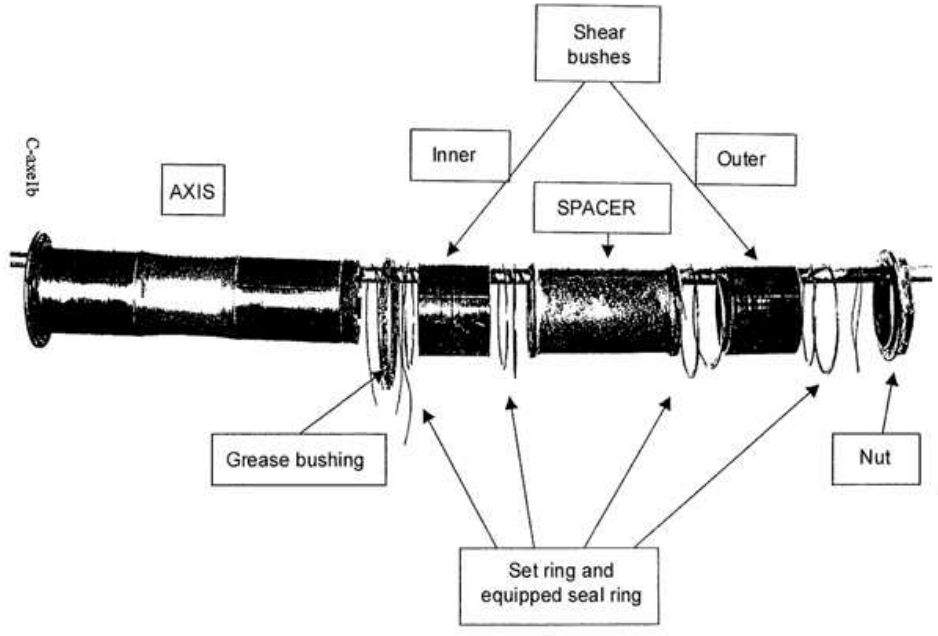
Recommendations of the Authorities

The airworthiness authorities in both the UK and France issued a number of recommendations, including

- Structural changes to the aircraft, including kevlar-lining on the inside of the wing fuel tanks
- An audit of maintenance practices at Continental Airlines

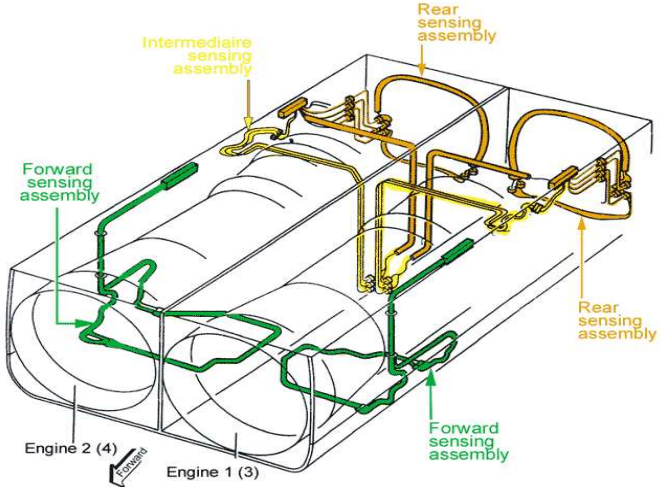
Recommendations of the Authorities

- Although the incorrect bogie assembly was not identified by the BEA as a cause, it recognized the problems and recommended an audit of maintenance practices for Concorde at Air France



Recommendations of the Authorities

- The BEA also acknowledges another problem, identified as a root cause by the WBA, but not as such by the report: That the cockpit crew were not aware of the extent of the fire. It therefore recommends that the French aviation authority study ways to visualize the hidden parts of the structure and/or install devices to detect damages.



Conclusions

- The WB-Analysis can sometimes shed new light on accidents and incidents
- WBA can help even if solely based on the official report, without using additional sources
- WBA sometimes helps discover new aspects, that the less formal approach in the official investigations miss.
  - In this case:
    - Incorrect bogie assembly
    - Unawareness of the extent of the fire by the crew

References

- Peter B. Ladkin: Why-Because Analysis: Formal Reasoning About Incidents

http://www.rvs.uni-bielefeld.de/publications/books/WBAbook/

- Peter B. Ladkin, Bernd Sieker and Joachim Weidner: How to Generate Fault Trees from Causal Influence Diagrams

http://www.rvs.uni-bielefeld.de/publications/Papers/faulttrees.pdf

- The official report by the BEA on the Concorde accident

http://www.bea-fr.org/docspa/2000/f-sc000725a/pdf/f-sc000725a.pdf

Thank You Very Much

for Your Attention