Chapter 25

The WB-Graph of the 1994 Nagoya Accident

On 26 April 1994, a China Airlines A300 (a non-"fly-by-wire" Airbus) crashed on landing at Nagoya in Japan. It turns out that the pilot flying had inadvertently triggered the ‘go-around’ mode, as noticed by the captain (the non-flying pilot) but did not disconnect the autopilot, despite repeated instructions from the captain to do so (the A300 Operations Manual explicitly requires the pilot to disconnect the autopilot in such circumstances) until 40 seconds after it was noticed. The pilot flying tried to force the nose of the airplane down, and the autopilot, in go-around mode, reacted to the lack of climb by trimming pitch even further up. When the pilot eventually stopped pushing and the AP was disconnected, the captain took over. However, without the forward pressure on the yoke, the nose rose sharply, due to the extreme nose-up trim, and the plane stalled in an extreme nose-high configuration, and hit the ground tail-first. There were early rumors of unusually high levels of blood alcohol in the pilots’ bodies (more than is expected as a natural by-product of death), and a complete power failure before the crash, but neither of these figured in the final report. The question, why the pilot flying did not disconnect the autopilot as he is required to and was instructed to multiple times, probably cannot be answered. As a result of this accident and other recent incidents and accidents, the US FAA started to ‘work with’ China Air on its pilot training programs.

The final accident report may be found in [Lad]. It is large. We have prepared a textual WB-Graph of the accident from the report. This WB-Graph contains roughly 100 nodes, roughly four times the size of the WB-Graph of the Northwest DC-10 incident, Figure 17.4. We would expect that a full WBA of the Nagoya accident would lead to an increase in the number of nodes in the WB-Graph, but we judge it unlikely that it would lead to, say, a ten-fold increase, a ten-fold increase in the number of nodes would make the Nagoya WB-Graph roughly forty times the size of the graph in Figure 17.4. Since the number of causal-factor edges in a WB-Graph appears to be roughly linear in the number of nodes (see
Figures 23.5 and 24.1 as well as Figure 17.4), we conclude that a complete WBA proof for the Nagoya accident would use less than (we expect in fact considerably less than) forty times the effort required for the proof in Chapter 22 of the WBA for the example whose WB-Graph is Figure 17.4. Such an effort we judge to be feasible for an accident investigation, given technical expertise with hierarchical proofs in EL.

We include the Nagoya textual WB-Graph here as the basis for our comments, above, on complexity.
/* AC crashes into landing zone near EI taxiway
   @T11:15'45" */
   {1} /* AC stalls since
   @T11:15'31"
   {2} /* CWG unable to recover stall */

   {1} {-.1} /* AOA becomes too large */

   {1.1} /\<-.1> /* AC in out of trim (nose high) condition */
   /\<-.2> /* AC climbing steeply */
   /\<-.3> /* CAS becomes too low */

   <1.1.1> /\<-.1> /* THS at -12.3 degrees (=nose-up) since: [1.1.1.1.1] */
   /\<-.2> /* Elevators in nose-down position */
   /\<-.3> /* CWG does not correct out of trim condition */

   <1.1.1.1> /\<-.1> /* AP is engaged in CMD
   @T11:14'18" */

   /\<-.2> /* AP in GA mode */
   /\<-.3> /* F/O pushing on control column */
   /\<-.4> /* AP stays engaged, although [1.1.1.1.3] */
   /\<-.5> /* CWG's hand-tuning attempts ineffective
   // ACTION# // @T11:14'20" // @T11:14'34" // @T11:14'39" */

   <1.1.1.1.1> [-.1] /* AP engaged
   // ACTION# // @T11:14'18" */
   <1.1.1.1.2> /\<-.1> /* F/O (PF) triggers GA-lever
   @T11:14'05" // inf CVR */
   /\<-.2> /* F/O (PF) does not disengage GA mode although advised to do so by CAP several times:
   @T11:14'10" // @T11:14'30" // @T11:14'45" */

   [1.1.1.1.2.1] /\<-.1> /* position of GA-lever
   // ASSUMPTION */
   /\<-.2> /* F/O moves hand on throttles
   // ASSUMPTION */

   <1.1.1.1.2.1.1> [-.1] /* Airbus Industry Cockpit Layout */

   Figure 25.1: The Nagoya WB-Graph, Part 1
(1.1.1.1.2.2) \{-1\} /* F/O (PF) tries but does not succeed in disengaging GO-AROUND mode
// #ACTION# */
\{-2\} /* F/O (PF) does not realize his actions didn’t succeed
// #PERCEPTION# */

{1.1.1.1.2.2.1} \{-1\} /* F/O (PF) tries to go direct into LAND mode
// #INTENTION# // inf OVR */
\{-2\} /* direct access to LAND mode button cannot disengage GO AROUND mode */

<1.1.1.1.2.2.1.1> <1.1.1.1.5.3.1>

<1.1.1.1.2.2.1.2> <1.1.1.1.4.1>

<1.1.1.1.2.2.2> \{-1\} /* F/O (PF) overextended with situation
// ASSUMPTION */
\{-2\} /* high workload
// #ATTENTION# */

<1.1.1.1.4> \{-1\} /* Airbus Industry AP logic */
\{-2\} /* modification to AP prescribed in Service Bulletin SB A300-22-6021 had not been incorporated into the aircraft
// 3rd party Information */

(1.1.1.1.4.2) \{-1\} /* The aircraft manufacturer did not categorise the SB A300-22-6021 as "Mandatory"
// 3rd party Information */
\{-2\} /* The airworthiness authority of the nation of design and manufacture did not issue promptly an airworthiness directive pertaining to implementation of the SB.
// 3rd party Information */

Figure 25.2: The Nagoya WB-Graph, Part 2
{1.1.1.3} /\{-.1\} /* F/0 (PF) tries to recover optimal glide path */
/\{-.2\} /* F/0 (PF) believes nose-down elevator commands will
achieve nose-down state
// ASSUMPTION */

{1.1.1.3.1} /\{-.1\} /* AC left optimal glide path */
/\{-.2\} /* AC should return to optimal glide path */

{1.1.1.3.1.1} [1.1.1.2.1]
// inf CVR */

<1.1.1.3.2> <1.1.1.5.3.1>

{1.1.1.5} /\{-.1\} /* CRW attempts to hand-tune */
/\{-.2\} /* when active, AP doesn’t allow THS override */
/\{-.3\} /* CRW doesn’t realize <1.1.1.5.2>
// #PERCEPTION# */
/\{-.4\} /* CRW lacks experience and knowledge with A300 AP
// ASSUMPTION */

[1.1.1.5.1] {1.1.1.3.1}

<1.1.1.5.2> <1.1.1.4.1>

(1.1.1.5.3) <1.1.1.5.4>

<1.1.1.2> {1.1.1.3}

Figure 25.3: The Nagoya WB-Graph, Part 3
(1.1.1.3) (\textsuperscript{-.1}) /* CRW does not recognize COT condition */
// #PERCEPTION# // inf CVR */

(1.1.1.3.1) /\textsuperscript{-.1} /* optical systems for the purpose of THS motion awareness do not provide effective information at night */
/\textsuperscript{-.2} /* optical/acoustical warning device, capable of actively alerting THS motion inactive */
/\textsuperscript{-.3} /* CRW does not pay attention */
// #ATTENTION# // inf CVR */

<1.1.1.3.1.1> <1.1.1.1.2.1.1.1>

<1.1.1.3.1.2> /\textsuperscript{[-.1]} /* Airbus Industry eliminated function from AP in CMD mode design */
// 3rd party information */
/\textsuperscript{-.2} /* Airbus Industry did not establish another warning and recognition function */
// 3rd party information */
/\textsuperscript{1.1.1.1.1}>

<1.1.1.3.1.2.1> (\textsuperscript{-.1}) /* Airbus Industry followed suggestion from UK CAA */

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Figure 25.4: The Nagoya WB-Graph, Part 4
<1.1.2> /\<.1> /* high engine thrust */
/\<.2> /* F/O releases control wheel */
/\<1.1.1>
/\<1.1.1.1>

<1.1.2.1> [-.1] /* EPR increased from 1.04 to > 1.6 */
[1.1.2.1.1] /\[-.1] /* THR levers moved forward */
/\[-.2] /* Alpha Floor Function activated */
/\<11:15'11" */
/\<11:14'57" */
/\<11:14'57" */
/\<11:14'57" */

[1.1.2.1.1.1] [-.1] /* CAP(PF) decides to initiate GO-AROUND manoeuvre */
/\<11:15'03" */

<1.1.2.1.1.2> /\<.1> /* AOA exceeded threshold AOA of 11.5 degrees */
/\<.2> /* pitch angle increased */
/\<.3> /* AP disengaged */
/\<11:14'50" */
/\<11:14'50" */
/\<.4> /* Airbus Industry Logic */

<1.1.2.1.1.2.1> /\<1.1.1>
/\{1.1.3}

<1.1.2.1.1.2.2> /\<1.1.1>
/\<1.1.2.1>
// causal feedback loop !! = alpha floor //

Figure 25.5: The Nagoya WB-Graph, Part 5
{1.1.3} \(\langle -.1 \rangle\) /* THR not engaged continuously */
\(\langle -.2 \rangle\) /* THR decreased temporarily */
\(\langle 1.1.2 \rangle\)

\(\langle 1.1.3.1 \rangle\) \(\langle -.1 \rangle\) /* CAP (PF) uncertain about situation */
// #ATTENTION# */
\(\langle -.2 \rangle\) /* CRWs actions interfere with AP operation */

\(\langle 1.1.3.1.2 \rangle\) \(\langle -.1 \rangle\) /* F/O (PF) interrupts execution of Alpha Floor function */
\(\langle -.2 \rangle\) /* A300 AP 'intended to permit pilots to apply small manual control inputs to assist the AP'
// cite from FODM */
\(\langle -.3 \rangle\) /* CRW unaware that A300 AP does not allow permanent manual override */
// #ATTENTION# */

[1.1.3.1.2.1] \(\langle .1 \rangle\) /* F/O (PF) counteracts against resulting pitch-up movement from [1.1.2.1.1.2] */

\(\langle 1.1.3.1.2.1.1 \rangle\) \(\langle -.1 \rangle\) /* F/O (PF) doesn’t realize [1.1.2.1.1.2] */
// #ATTENTION# */

\(\langle 1.1.3.1.2.2 \rangle\) \(\langle 1.1.1.1.4.1 \rangle\)

\(\langle 1.1.3.1.2.3 \rangle\) \(\langle -.1 \rangle\) /* CRW unable to gain this information from FODM */
\(\langle -.2 \rangle\) /* CAP’s (PF) action would be appropriate for Boeing AP */
// ASSUMPTION */
\(\langle 1.1.1.1.5.3.1 \rangle\)

\(\langle 1.1.3.1.2.3.1 \rangle\) \(\langle -.1 \rangle\) /* FCOM design not suited for handling alert situations */
// ASSUMPTION */

\(\langle 1.1.3.1.2.3.1.1 \rangle\) \(\langle -.1 \rangle\) /* Airbus Industry FODM layout */

\(\langle 1.1.3.2 \rangle\) \(\langle -.1 \rangle\) /* THR levers retarded temporarily */
\(\langle -.2 \rangle\) /* surges occurred in both engines */

[1.1.3.2.1] \(\langle -.1 \rangle\) /* CAP (PNF) intends to continue approach */
// inf CVR */
\(\langle 1.1.3.1.2.1 \rangle\)

\(\langle 1.1.3.2.2 \rangle\) \(\langle -.1 \rangle\) /* high AOA of inlets */

\(\langle 1.1.3.2.2.1 \rangle\) \(\langle 1.1.2 \rangle\)
\(\langle 1.1.3.1 \rangle\)

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Figure 25.6: The Nagoya WB-Graph, Part 6
{2} \(-.1\) /* CRW doesn't take appropriate action to recover stall */
\(-.2\) /* AC systems in unusual modes */
\(-.3\) /* time and altitude for recovery operations short to insufficient */

(2.1) \(-.-1\) /* CRW not aware of AC systems states */
// #ATTENTION# */

\(<-1.1> /* situation is unusual */
\(<-2.2> /* no THS motion warning */
\(<-3.3> /* none of the CRW is able to keep track of the situation */
// #ATTENTION# */
\(<1.1.3.1.2.1.1.1>"

\(<-1.1> /* transition 'GO-AROUND \(\rightarrow\) LAND' is no flight manoeuvre according to Standard Operating Procedures */

\(<1.1.3.1.1>"
\(<1.1.3.1.2>"

\(<2.1.3> \[-.1\] /* CAP (PNF) takes over controls against duty assignment */
// #ACTION# // 0T11:15'03" */
\(<-2.2> /* CAP (PNF) doesn't grasp flight conditions */
// inf CVR */
\(<-3.3> /* F/O (PF) looses his autonomy, since he follows a series of instructions given by CAP (PNF) instead of acting on his own */
// 0T11:14'26" to T11:15'03" */

\(<2.2> \<.1> /* complex control situation at stall */

\(<2.2.1> \<-.1> /* trying to transit GO-AROUND \(\rightarrow\) LAND */
\(<1.1.2.1.1.2>"
\(<1.1.1>"

\(<2.3> \<-.1> /* nose-up attitude is 43.8 degrees */
\(<-2.2> /* altitude is 1,730ft */
\(<-3.3> /* AS is less than 50kts */

(88 nodes)

Figure 25.7: The Nagoya WB-Graph, Part 7
Semantics:

[X.X] Event
[Y.Y] State
[Z.Z] Process
[U.U] Non-Event

/* comment on node */

additional information on comments:

// @T... T=Time (hh:mm:ss" UTC)
// @H... Predicates: H=Heigh (pressure altitude in ft)
// @P... P=Position (2D)

// #<classification_of_failure>#: where
// <classification_of_failure> ::= perception | attention | reasoning |
//                               decision | intention | action

is the classification of failures according to the extended
information-processing model introduced in [GLL96]

// 3rd party information
// inf CVR any information judged as required
// ...

Figure 25.8: Notational Key for the Nagoya WB-Graph
GLOSSARY:

AD : Airworthiness Directive
ADC : Air Data Computer
AFS : Automatic Flight System
ALT : Altitude
ALT SEL : Altitude Selector
AOA : Angle of Attack
AP : Auto-Pilot
APU : Auxiliary Power Unit
A/THR : Automatic Thrust
AT : Auto Throttle
ATS : Auto-Throttle System
ATT : Attitude
BEA : Bureau Enquêtes Accidents
BKN : Broken
CAP : Captain
CAS : Computed Airspeed
CGCC : Center of Gravity Control Computer
CAT : Category
CMD : Command
CN : Consigne de Navigabilité
CRW : Crew
CVR : Cockpit Voice Recorder
CWS : Control Wheel Steering
DFDR : Digital Flight Data Recorder
DGAC : Direction Générale de l'Aviation Civile
ECAM : Electronic Centralized Aircraft Monitoring
EFCS : Electronic Flight Control Unit
EFIS : Electronic Flight Instrument System
ENG : Engine
EPR : Engine Pressure Ratio
FAA : Federal Aviation Administration
FAC : Flight Augmentation Computer
FADEC : Full Authority Digital Electronic Control
FCC : Flight Control Computer
FOCM : Flight Crew Operating Manual
FCU : Flight Control Unit
FD : Flight Director
FIDC : Fault Isolation and Detection Computer
FIDS : Fault Isolation and Detection System
FL : Flight Level
FMA : Flight Mode Annunciator
FMC : Flight Management Computer
FMS : Flight Management System
F/O : First Officer
FMC : Flight Warning Computer

Figure 25.9: Glossary for the Nagoya WB-Graph, Part 1
GA : GO AROUND
GCU : Generator Control Unit
GPWC : Ground Proximity Warning Computer
GPWS : Ground Proximity Warning System
GS : Glide Slope
HDG : Heading
HDG/SEL : Heading Selector
HPC : High Pressure Compressor
HPT : High Pressure Turbine
ICAO : International Civil Aviation Organization
IGS : Instrument Guidance System
IGV : Inlet Guide Vane
IND : Indicator
ILS : Instrument Landing System
IRS : Inertial Reference System
IRU : Inertial Reference Unit
LAND : Landing
L/D : Landing
LG : Landing Gear
LOC : Localizer
LPC : Low Pressure Compressor
LPT : Low Pressure Turbine
LVL/CH : Level Change
MAC : Mean Aerodynamic Chord
MAN THR : Manual Thrust
MIC : Microphone
MTP : Maintenance and Test Panel
NAV : Navigation
NTSB : National Transportation Safety Board
OOT : Out Of Trim
OVC : Overcast
PCM : Pulse Code Modulation
PF : Pilot Flying
PFD : Primary Flight Display
P1C : Pilot in Command
PNF : Pilot Not Flying
QNH : Pressure Setting to Indicate Elevation above Mean Sea Level

Figure 25.10: Glossary for the Nagoya WB-Graph, Part 2
R ALT : Radio Altitude
RCT : Retract
RMI : Radio Magnetic Indicator
RWY : Runway
SB : Service Bulletin
SCT : Scattered
SGU : Symbol Generator Unit
SPD : Speed
SPD/MAC : Speed/Mach
SRS : Speed Reference System
SW : Switch
TCC : Thrust Control Computer
TCO : Ministry of Transport Civil Aviation Bureau Directive
THR : Thrust
THR L : Thrust Latch
THS : Trimmable Horizontal Stabilizer
TIPS : Technical Instruction Processing Sheet
TRP : Thrust Rating Panel
VAPP : Approach Target Speed
VOR : VHF Omnidirectional Radio Range
V/S : Vertical Speed
Vs : Stall Speed
VTG : Target Speed
W.STA : Wing Station

Figure 25.11: Glossary for the Nagoya WB-Graph, Part 3
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