Predicting and Managing Multifactor Unknowns in Flight[1]

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A critical situation can suddenly develop in the 'pilot/ automaton – aircraft – operating environment' system dynamics as the result of a spontaneous mixing and unfavorable cross-coupling of several risk factors – demanding operational conditions (**Fig. 1**). The latter include adverse weather effects, pilot/ automaton errors and onboard mechanical failures. 'Troubles never come alone'... At present, multifactor (off-normal, complex, compound, etc.) operational situations represent a major challenge both for pilots and for flight control automata. In spite of a negligibly small theoretical probability of occurrence, multifactor scenarios do happen in flight operations, often leading aircraft to irreversible 'chain reaction' accidents – regardless of the proficiency level of pilots and sophisticated logic of automata.

In order to be avoided or safely resolved, a broad spectrum of potentially dangerous multifactor scenarios must be known in advance and timely recognized onboard during flight. At present, the volume and the quality of a priori knowledge on complex operational domains (embedded into flight automation or described in pilot manuals) may be insufficient. The main difficulty is combinatorics ('the curse of dimensionality') which determines technical, time and budget constraints.

A knowledge-centered solution approach to flight automation has been developed to address the problem of accident prediction and prevention in multifactor/ unknown situations. High-fidelity mathematical modeling, fast-time computer simulation (M&S), artificial intelligence (AI) and self-organization techniques should be harnessed to a broader extent beginning from the early phases of a life cycle. The goal is to fill the gaps on complex system dynamics in a pilot's (automaton's) 'internal knowledge base' to help de-materialize unsafe flying experience in multifactor conditions from the outset.

Using the system dynamics model as a virtual fast-time test and operation article, potentially unsafe multifactor operational hypotheses can be screened more reliably in advance. The proposed technology enables users to automatically explore, analyze and map very large sets of realistic off-normal scenarios in the form of a situational tree (**Fig. 2**). It is a collection of branching 'what-if' flight situations that are 'planted' around a baseline case to thread a complex operational domain of interest.

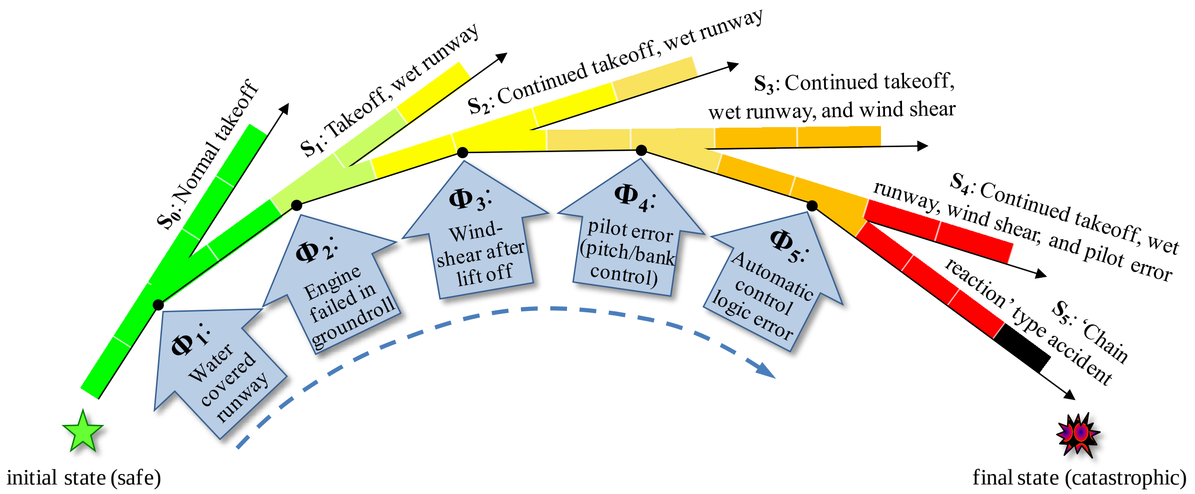
Special techniques are employed to 'mine' system-level safety knowledge from virtual accidents. Situational trees are used to retain comprehensive information on potential anomalies in the system behavior, quantify critical combinations of risk factors (accident precursors), derive available recovery options and depict optimal control tactics using 'a bird's eye view' knowledge maps (**Fig. 3**). The output is a knowledge base which can be used onboard. The objective is to predict flight paths and implement safety protection control of aircraft under complex or uncertain conditions for 10…30 s ahead (**Fig. 4**).

In this paper, the main concepts of the developed technology are introduced. Key research avenues are outlined for prototyping a backup 'AI pilot' model aimed at real-time prediction and management of multifactor 'alternative futures' in the system dynamics. Discussed are major challenges to be overcome during the main phases of a life cycle on the way towards knowledge-centered flight automation.

REFERENCES

1. http://aixtree.mcdir.ru/publ/18_Paper_SAE_2011-01-2659_manuscript_v-2.pdf.
2. http://aixtree.mcdir.ru/publ/15_ICAS_2010_723_updated.pdf.
3. http://aixtree.mcdir.ru/publ/AUVSI_USE_2007_v-2.pps
4. http://aixtree.mcdir.ru/publ/13_SICPRO_Paper_2009.pdf (in Russian).
5. http://aixtree.mcdir.ru/publ/04_SAE_1998_Paper_Number_981223.pdf.

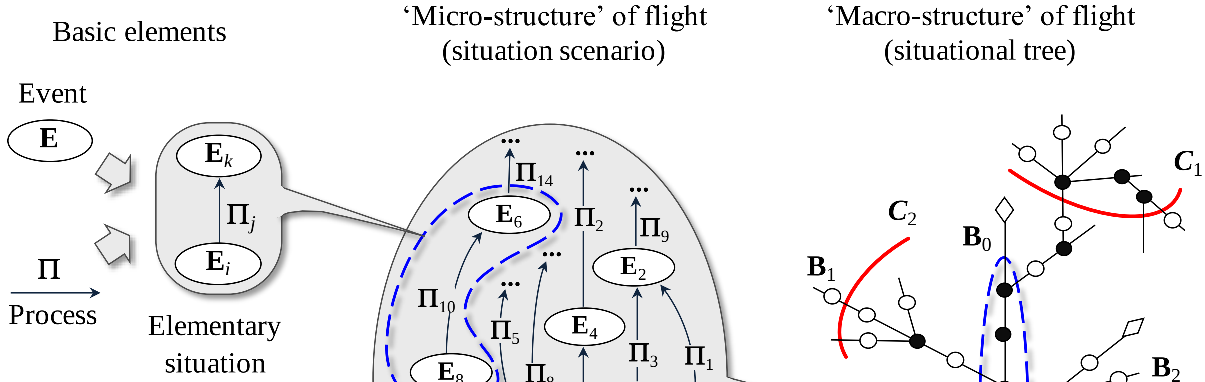
[1] http://skybrary.aero/bookshelf/content/bookDetails.php?bookId=3133



Legend:

- – time axis of an 'alternative future' (a 'what-if' situation).
- – a situational tree of 'alternative futures' – 'what-if situations'.
- Φ – an operational/ design (safety risk) factor used to generate complex 'what-if' operational hypotheses to 'plant in advance a multifactor situational tree of virtual test and operation domain.
- • – an event when a new (additional) operational factor is 'grafted' into the situational tree.
- $S_0, \ldots, S_5$ – alternative ('what-if') situation scenarios in the order of increasing complexity and risk: S_0 – normal (zero-risk, benign) scenario, …, S_5 – highly complex catastrophe-prone (five-factor) scenario.
- – an anomalous mix of safety risk factors, which can trigger an irreversible 'chain reaction' accident.
- – safety colors.

Fig. 1 – Multifactor 'chain reaction' flight accident build-up mechanism – takeoff example



Legend:

E_i – event

Π_j – process

C – fuzzy constraint

○ – reference state ('node')

● – branch grafting state ('bud')

◇ – branch target state ('leaf')

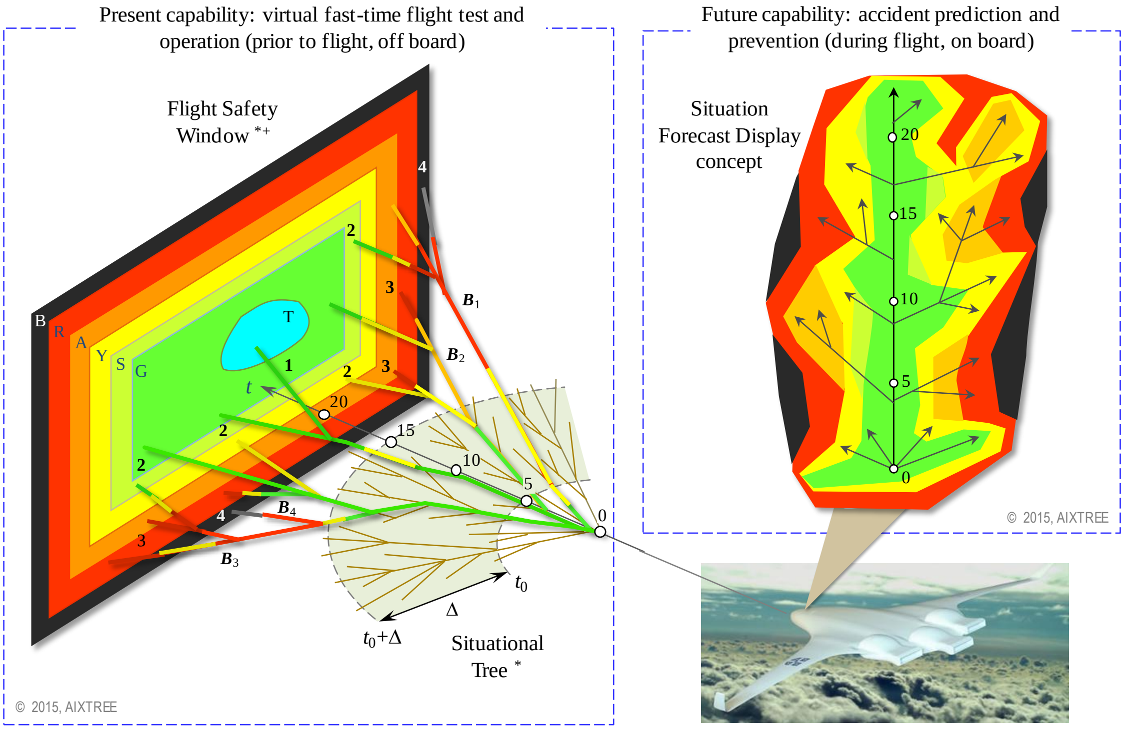
△ – branch source state ('root')

B_{-1} – parent branch

B_0 – main branch ('trunk') – baseline flight situation scenario

B_n – n-th order derivative branch, multifactor situation scenario with n contributing risk factors, $n = 1, 2, 3, \ldots$

Fig. 2 – Two-level knowledge model of a multifactor flight domain



Legend: Not to scale. Flight path categories: optimal (**1**), safe (**2**), dangerous (**3**), catastrophic (**4**). t – relative time of safety prediction, $t \in [t_0; t+\Delta]$ (t = 0 – current flight time, Δ – depth of safety prediction). Notional examples of situational tree's branches: 'stuck aileron' ($\boldsymbol{B}_1$); 'engine out' ($\boldsymbol{B}_2$); 'adverse weather': 'strong wind shear' ($\boldsymbol{B}_3$), 'heavy rain' ($\boldsymbol{B}_4$). ■ ■ ■ ■ ■ ■ ■ – flight path safety levels (T/ G/ S/ Y/ A/ R/ B safety colors). The source of notional passenger transport aircraft image: http://www.treehugger.com/aviation/blended-wing-concept-3000-times-quieter-35-more-efficient.html. (*) – see example in Fig. 4. (+) – implementation of NASA's 'performance window' concept.

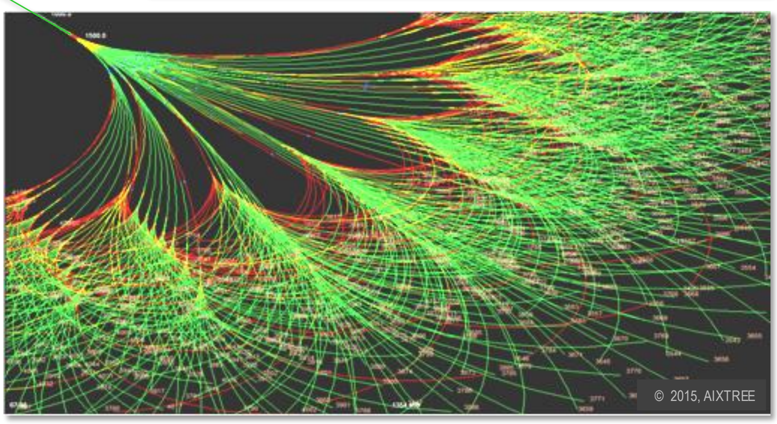
Fig. 3 – Present and future capabilities for flight accident prediction and prevention in complex/ unknown operational situations

Notional future civil transport aircraft

Flight safety window: 'Takeoff and initial climb, aircraft front C.G., hypotheses of wind shear intensity, variations (or errors) of commanded flight path angles in 1st and 2nd phases of initial climb' (notional four risk factor domain)

$S_4 \cdot \Gamma_7$		Φ_7 and Φ_8: Commanded flight path angles (1st and 2nd phases of climb), deg.												
	Φ_8	0	1	2	3	4	5	6	7	8	9	10	11	12
	Φ_7	2	3	4	5	6	7	8	9	10	11	12	13	14
Φ_9: Wind-shear intensity, -	2													
	1.8													
	1.6													
	1.4													
	1.2													
	1													

'What-if' situational tree example: Initial two-stage climb maneuvering, 'strong' wind-shear conditions, variations (or errors of selecting) of commanded flight path angle and commanded bank angle (notional four risk factor operational domain)



Legend: Notional multifactor flight situation domain is presented for technique illustration only. ■ ■ ■ ■ ■ ■ – safety levels (G/S/Y/O/R/B safety colors). Not to scale. Source of notional aircraft image: http://www.technik-welten.de/luft-und-raumfahrt/wie-funktionierts/luftfahrt/radikale-konzepte.html.

Fig. 4 – Examples of implementation of 'Situational Tree' and 'Flight Safety Window' knowledge maps for realistically complex flight domains using the system dynamics model