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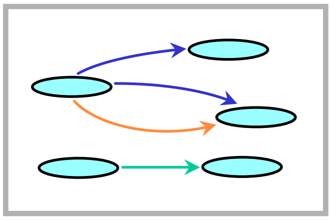

Method and Tool For Virtual Flight Testing and Evaluation Of Aircraft

Presentation Slides

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Definitions, Acronyms, Abbreviations

n-D - *n*-dimensional, n=2, 3, 4
ABC - automatic bank control
AC - Advisory Circular
AoA - angle of attack
C.G. - center of gravity
FAR - U.S. Federal Aviation Regulations
FL - flap
FNN - fuzzy-neural network
HSCT - high-speed civil transport
JAR - Joint Airworthiness Requirements (EC)
km/h - kilometers per hour
m/s - meters per second
M&S - modeling and simulation
MAC - mean aerodynamic chord
MAGE - 3-D graphics program, freeware (ref. http://kinemage.biochem.duke.edu/website/kinhome.htm)
MFS - manned flight simulation
NEH - “north-east-height” [axes]
NB - *nota bene* (Lat.)
Pfe - Programmer’s File Editor (freeware, ref. http://www.lancs.ac.uk/ people/cpaac/pfe)
r.p.m. - revolutions per minute
s.f.c. - specific fuel consumption
SCAS - stability and controllability augmentation system
T&E - test and evalution
VATES - Virtual Autonomous Test & Evaluation Simulator [6]
VEF - engine failure airspeed
VFT&E - virtual flight test and evalution (certification)
VLA - aircraft landing approach speed
VR - aircraft rotation speed
A - “atmospheric condition” type process
B - branch
B - blowing coefficient
C - aerodynamic coefficient, $C \in \{C_X, C_Y, C_Z, C_l, C_m, C_n\}$
E - flight event
F - “onboard system failure” type process
H - altitude of flight
I - initial conditions (initial state) of flight
O - “system state observer” type process
P - “control procedure” type process
Q - “pre-defined time-history” type process
R - “rain” type process
S - flight [situation] scenario, $\mathbf{S} = \Omega(\mathbf{E}) \cup \Omega(\mathbf{\Pi})$
T - “piloting task” type process
W - “wind” type process
x - model variable, $\boldsymbol{x} \in \Omega(\mathbf{X})$
Y - “runway surface condition” type process
АП - Авиационные Правила - Russian Aviation Regulations
$\Im$ - flight situation tree
$\Omega(\boldsymbol{n})$ - set of values of model objects of type $\boldsymbol{n}$, $\boldsymbol{n} \in \{\mathbf{X}, \mathbf{E}, \mathbf{\Pi}\}$
Π - flight process, $\mathbf{\Pi} \in \{\mathbf{A}, \mathbf{F}, \mathbf{O}, \mathbf{P}, \mathbf{Q}, \mathbf{R}, \mathbf{T}, \mathbf{W}, \mathbf{Y}, ...\}$
Φ - operational factor

Research Task Formulation

Subject

Behavior of the «operator (pilot/automaton) - flight vehicle - operational environment» system in complex flight situations - dynamics, logic, control, safety, effectiveness

The problem

Lack of systematic information on the anomalies in the system behavior in complex flight situations for a new vehicle during the design, flight test and certification (evaluation) phases of the vehicle's R&D cycle. Insufficient use of modern computers, modelling and simulation techniques for predicting flight safety standards of a new vehicle

The solution: Virtual Flight Test & Evalution (VFT&E)

Studying complex (multi-factor) flight domains in computer simulation experiments using a generalized autonomous flight situation model

Objectives

Thoroughly study the system behavior in complex flight situations <u>before</u> manned flight simulations (MFS) and flight tests (FT), ideally - before a test article is built ⇒ Reduce risk, cut R&D time and cost, focus and increase the efficiency of flight test and manned simulation programs ⇒ Examine and enhance flight safety standards of a new vehicle <u>in advance</u>, i.e. <u>not</u> based on statistics of flight accidents/incidents

Main steps

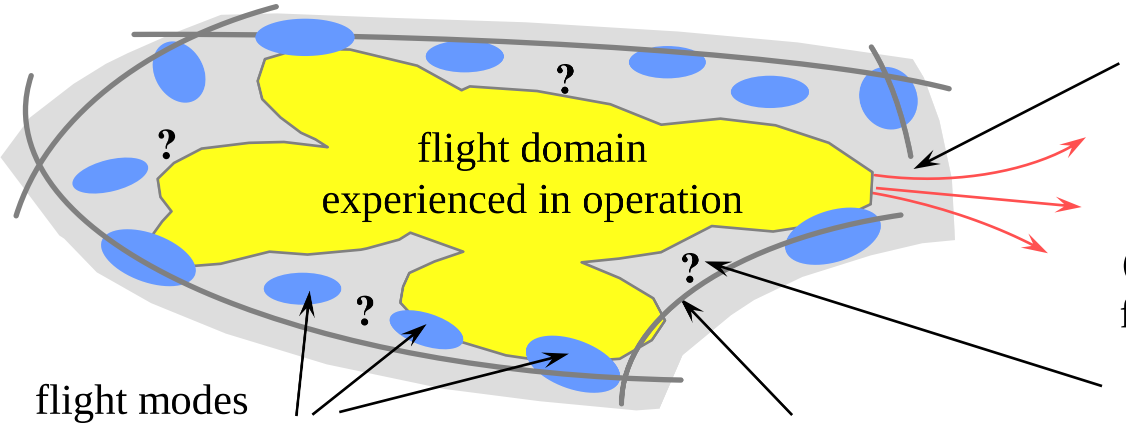
Develop the vehicle's model «parametric definition». Formalize airworthiness requirements or other problem pertinent requirements in the form of flight scenario library. Plan and carry out VFT&E computer experiments. Build, process and analyze output database of «flights». Identify peculiarities in the system behavior. Prepare feedback recommendations for designers, pilots

Methods and tools

Applied aerodynamics, flight dynamics and control principles, numeric techniques, situational control and artificial intelligence models, flight analysis tool VATES (proprietary software [6]), Programmer's File Editor Pfe (freeware), MS Office, Fortran, Tcl, 3-D graphics program MAGE (freeware), PC (Pentium III, 500 MHz, 96 RAM)

Two Methods of Defining Aircraft’s Flight Operation Envelope

Exemplified flight envelope (MFS+FT)



“hole” in flight envelope

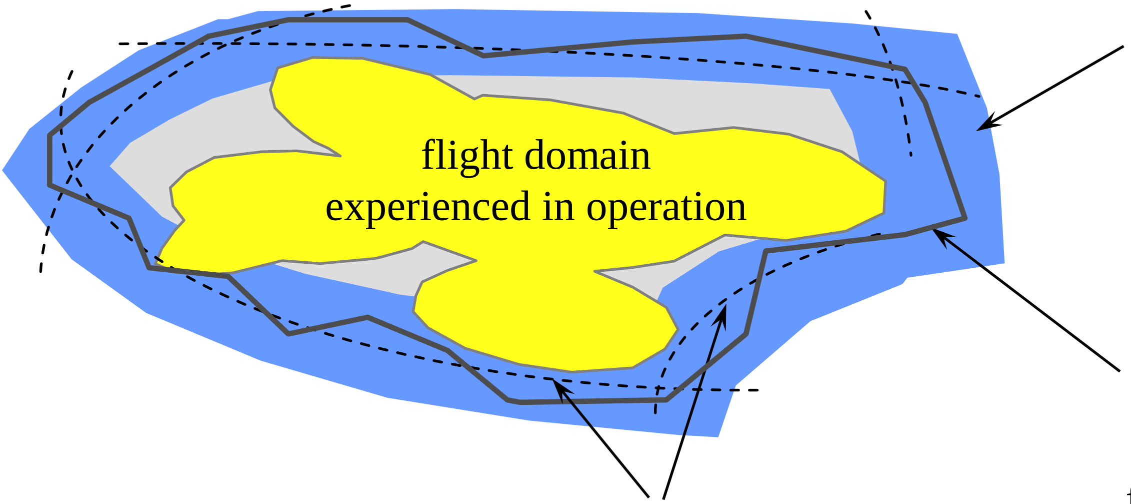
“irreversible trajectories (chain reaction” flight accidents)

non-examined (unknown) sub-domains

flight modes checked in flight tests or/and manned simulations

“exemplified” flight envelope (present practice)

“Intelligent” flight envelope (VFT&E+MFS+FT)

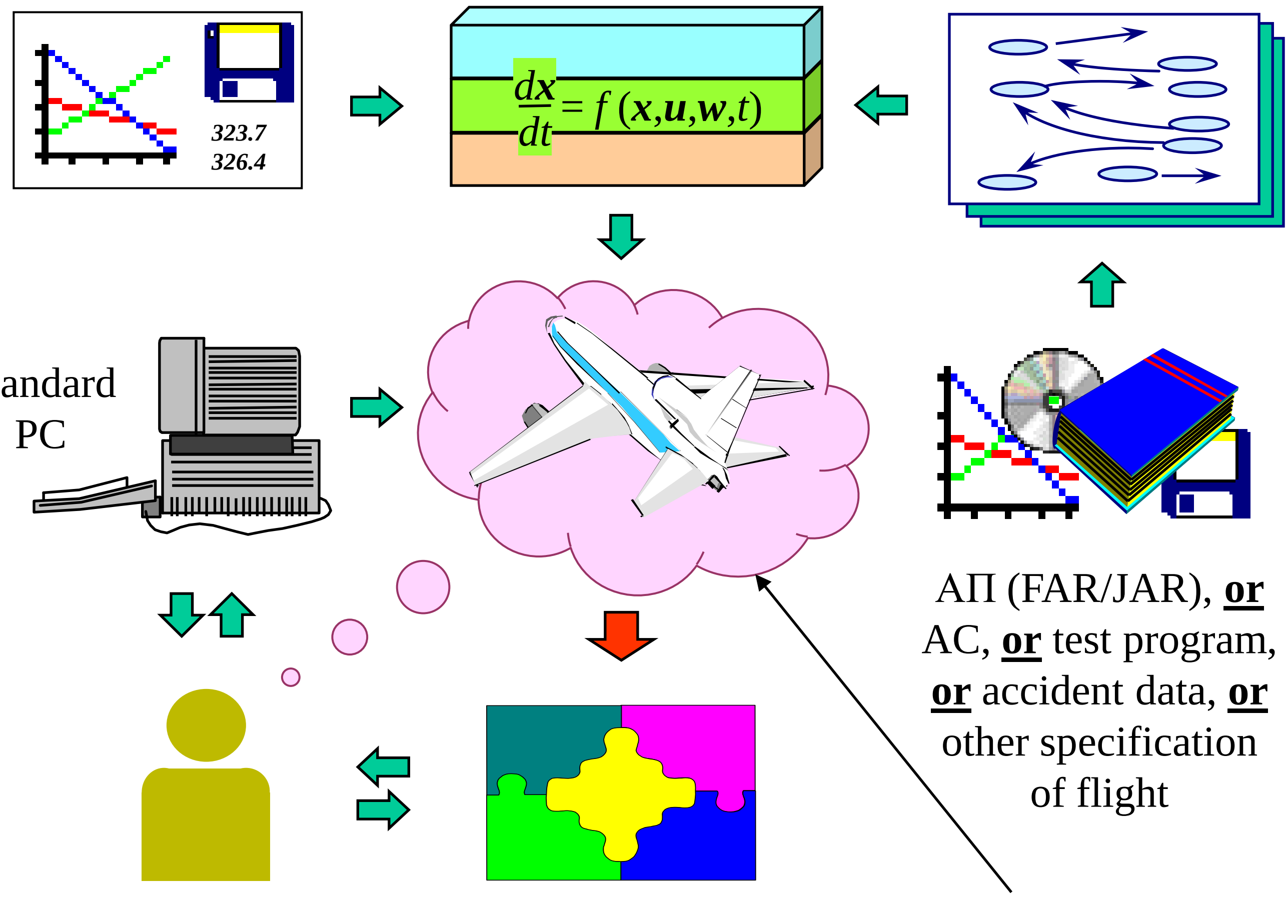


systematically examined complex “domain-ring”

“intelligent” (close to actual) flight envelope - VFT&E-based approach

“exemplified” flight envelope

Virtual Flight Test & Evaluation (Certification) Complex



$$\frac{d\mathbf{x}}{dt} = f\,(\mathbf{x},\mathbf{u},\mathbf{w},t)$$

Vehicle parametric definition (model input data base)

Autonomous situational model of the “pilot - vehicle - operational environment” system behavior (VATES)

Library of formalized flight test scenarios

Standard PC

АП (FAR/JAR), **<u>or</u>** AC, **<u>or</u>** test program, **<u>or</u>** accident data, **<u>or</u>** other specification of flight

Aerodynamicist, designer, test pilot/engineer, safety analyst, etc.

Database of “flights” - systematic information on the system behavior in complex FS

Virtual “flight test article”

Examined Flight Situation Types

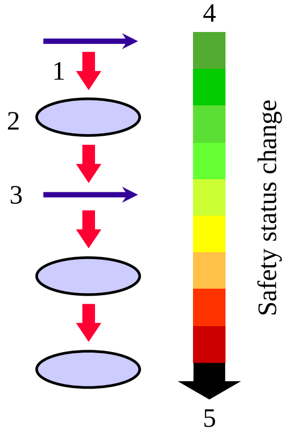
A. Complex (multi-factor) flight situation

- Logically completed segment of flight
- Normally 15-120 s long
- Several interrelated operational factors are involved
- May result in a “chain reaction” type flight accident/ incident or mission failure
- Building block in the ‘pilot - vehicle - operational environment’ system behavior
- Examples:
  - • *A400M prototype takeoff with two right-hand engines out*
  - • *A320 landing in heavy rain and windshear conditions, Warsaw, 09/14/93*
  - • *Sukhoj-37 flight accident at Paris Air Show’99*

At present, a limited subset of (1-2 factor) complex flight situations are being studied in advance, due to the ‘curse of dimensionality’, lack of available resources (budget, time, manpower), etc.

B.“Chain reaction” type flight accident

- A rarely observed complex flight situation
- Action of strong cause-and-effect links (1) between events (2) and processes (3)
- Fast (spontaneous), irreversible transition from a safe state (4) to a catastrophe (5)
- Graphic representation:



At present, a few (if at all) “chain reaction” type cases are studied, and only <u>after</u> the event (e.g., after a severe flight accident), this is mainly due to lack of suitable methods

<u>Note</u>: **B ⊂ A**

Flight Dynamics Model Summary

Equations of motion

System of ordinary first-order differential equations of motion in the form of quaternions with non-linear right parts

Input characteristics

Aerodynamics, moments/products of inertia, engine thrust and s.f.c data, etc. - represented as lookup tables or approximation functions of one to three arguments (model variables)

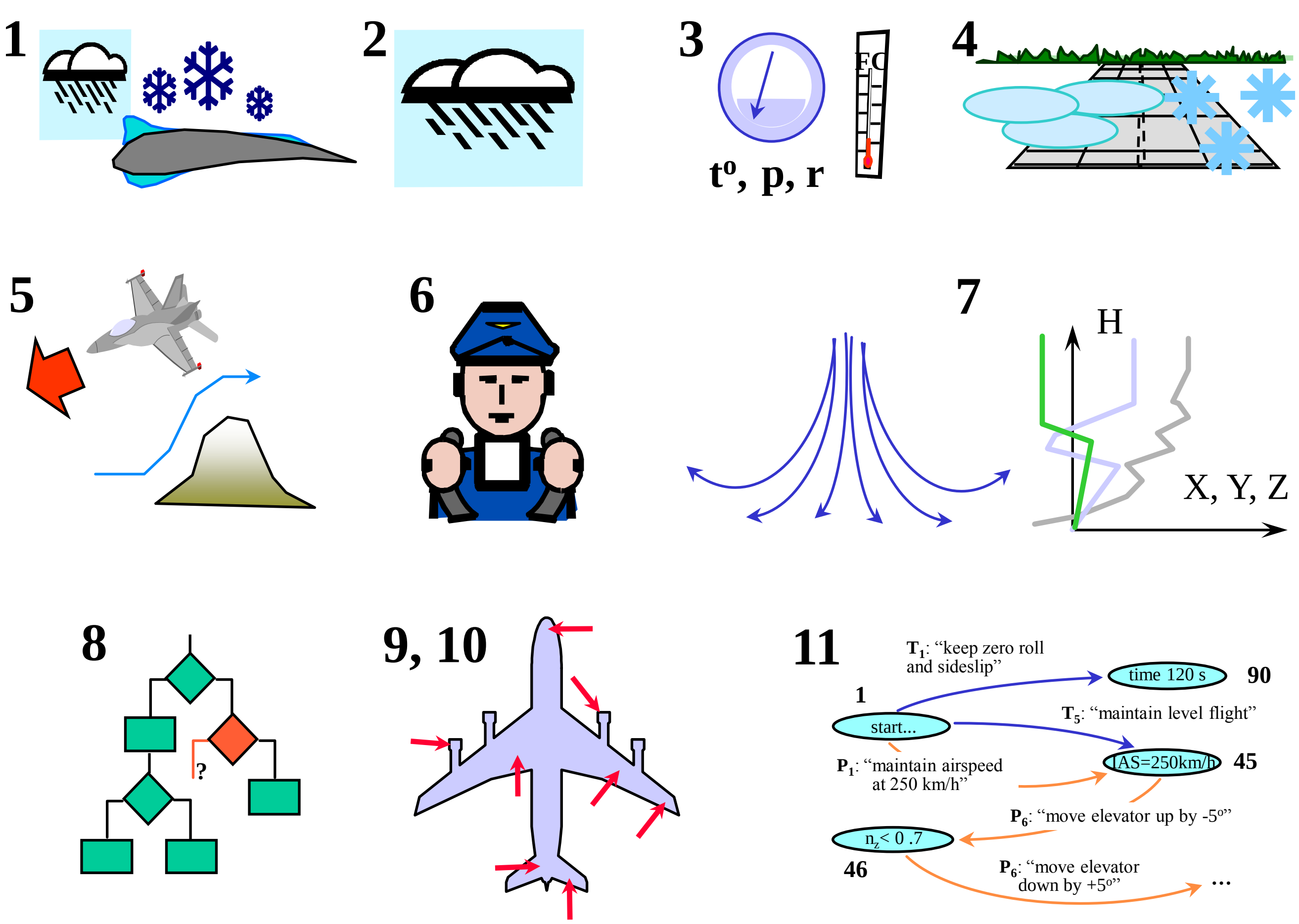
Arguments of input characteristics

Mach number, AoA, sideslip, AoA and sideslip rates, altitude, airspeed, bank, pitch, and yaw angles and their rates, control surface/lever positions (aileron, rudder, elevator, flaps, spoilers, stabilizer, throttles, undercarriage, etc.)

Other modeled effects and phenomena

“Ground cushion”, autopilot/SCAS (if present), instruments, actuators, aeroelasticity effects (static), undercarriage dynamics, engine (thrust, moment, r.p.m.) effects, and other

Models of Key Operational Factors

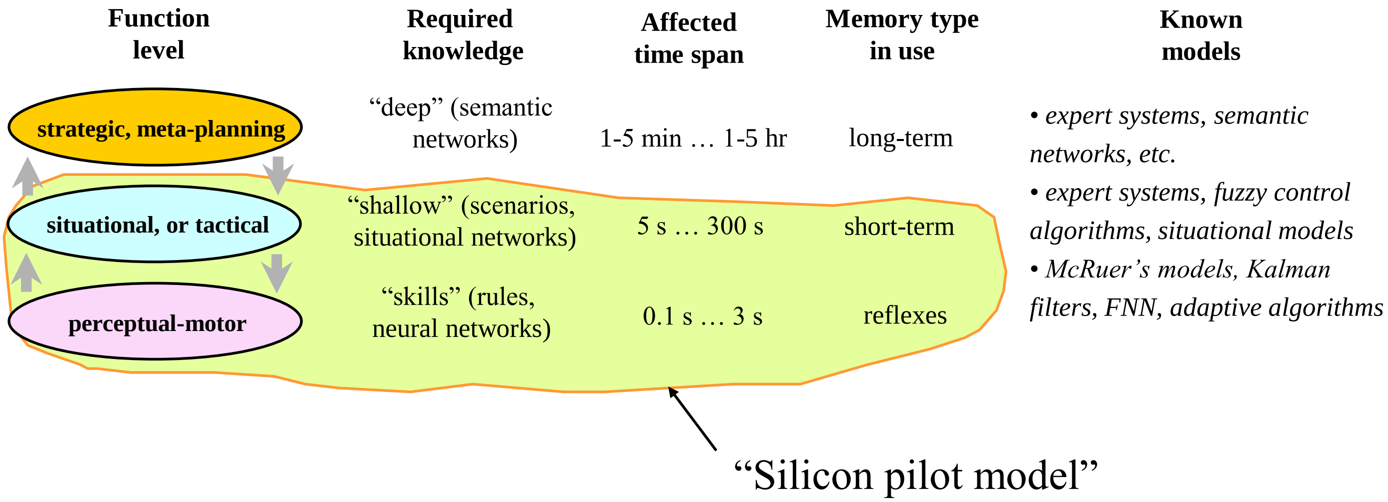


1 - icing (effect on aerodynamics of wing, fuselage, and tail)
2 - rain (effect on vehicle aerodynamics)
3 - non-standard atmospheric conditions (temperature, pressure)
4 - demanding runway condition (dry/wet/iced), geometry, dynamics
5 - obstacles (moving, stationary) or other safety threats
6 - pilot errors/inattention/tactics (objectives, observers, gains, etc.)
7 - wind (∀3-D profile: gusts, crosswind, tailwind, microburst, etc.)
8 - onboard systems' logic errors
9 - mechanical system failures (engines, control, undercarriage, etc.)
10 - variations in aircraft configuration, weight, C.G., and inertia
11 - variations in operational flight scenario

NB: any meaningful combination of above-listed factors can also be modeled

Pilot Decision-Making Model

Three levels of human pilot decision-making



Function level	**Required knowledge**	**Affected time span**	**Memory type in use**	**Known models**
strategic, meta-planning	"deep" (semantic networks)	1-5 min … 1-5 hr	long-term	• *expert systems, semantic networks, etc.*
situational, or tactical	"shallow" (scenarios, situational networks)	5 s … 300 s	short-term	• *expert systems, fuzzy control algorithms, situational models*
perceptual-motor	"skills" (rules, neural networks)	0.1 s … 3 s	reflexes	• *McRuer's models, Kalman filters, FNN, adaptive algorithms*

"Silicon pilot model"

Work definition

The situational model of the human pilot (the 'silicon pilot model') is a discrete-continuous deterministic scenario-based model of a human operator's decision-making processes in a particular flight situation, i.e. at the 2nd and 3rd levels

Assumptions and limitations

- human's limb motion, visual and audio sensoring are not modeled
- strategic functions are modeled in the form of a preset scenario
- perceptual-motor and tactical decision making levels are modeled deterministically

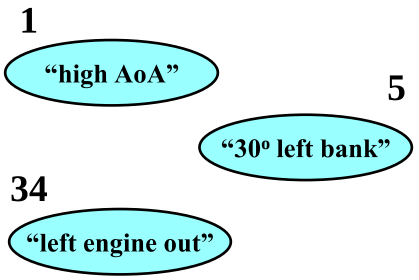
Flight Situation Model: Basic Concepts

Basic concepts

These are: flight event (**E**), flight process (**П**), and flight scenario (**S**).

The flight event

This is a special state of the system, which is important to the pilot, designer or safety expert and stands for a substantial change in the flight situation under study, e.g.: *"left engine out", "speed VR achieved", "altitude 360 ft and speed 180 kt", "on the runway", "high angle of attack", "30^o left bank", "go-around decision*"



1

"high AoA"

5

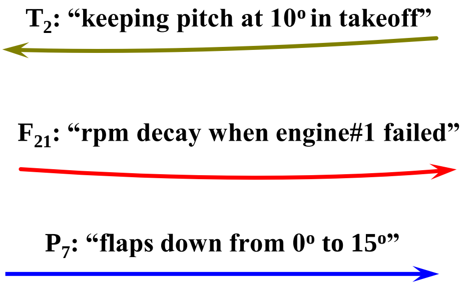
"30^o left bank"

34

"left engine out"

The flight process

This is a time-history of one or several flight parameters (variables), which characterize a certain aspect of the system behavior (dynamics, control, weather, etc.), e.g.: *"steering runway's centerline", "keeping pitch at 10^o in takeoff", "windshear 10 ft/s per 30 ft of H", "rpm decay when engine#1 failed", "flaps down $0^o \rightarrow 15^o$", "turn at 20^o bank and 0^o sideslip", "wet runway*" *condition.*



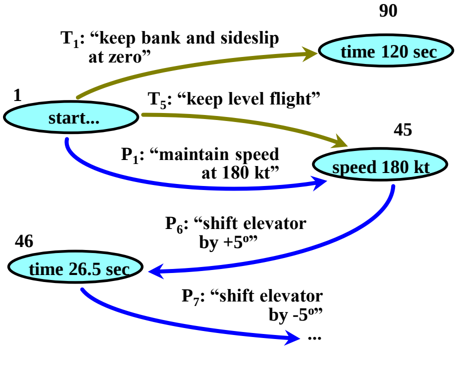
T_2: "keeping pitch at 10^o in takeoff"

F_{21}: "rpm decay when engine#1 failed"

P_7: "flaps down from 0^o to 15^o"

The flight scenario

This is a plan of the flight situation under study. It specifies this situation content and the control tactics associated with it. Flight scenarios are depicted as directed graphs and named after related situations. Examples are: *"normal takeoff", "aborted takeoff with engine#1 out" - "landing in crosswind conditions", "groundroll on wet runway", "coordinated turn at 15^o bank", "stall in takeoff configuration", "cruise mode at 500 kt & 30000 ft"*



90

T_1: "keep bank and sideslip at zero"

time 120 sec

1

start...

T_5: "keep level flight"

45

P_1: "maintain speed at 180 kt"

speed 180 kt

P_6: "shift elevator by $+5^o$"

46

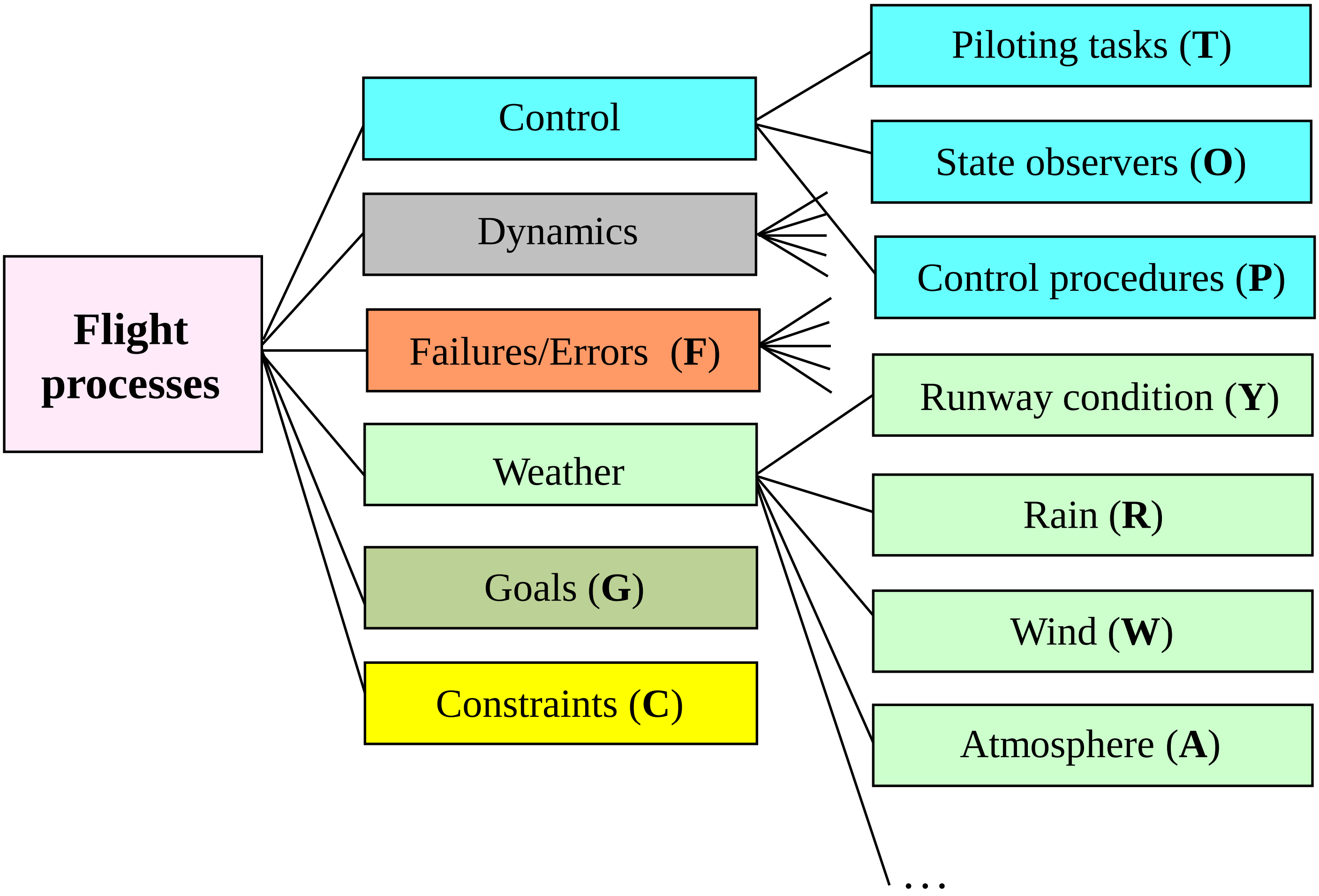
time 26.5 sec

P_7: "shift elevator by -5^o"

...

Main Types of Flight Process

Classification scheme



Flight processes

Control

Dynamics

Failures/Errors (**F**)

Weather

Goals (**G**)

Constraints (**C**)

Piloting tasks (**T**)

State observers (**O**)

Control procedures (**P**)

Runway condition (**Y**)

Rain (**R**)

Wind (**W**)

Atmosphere (**A**)

…

United list of flight processes

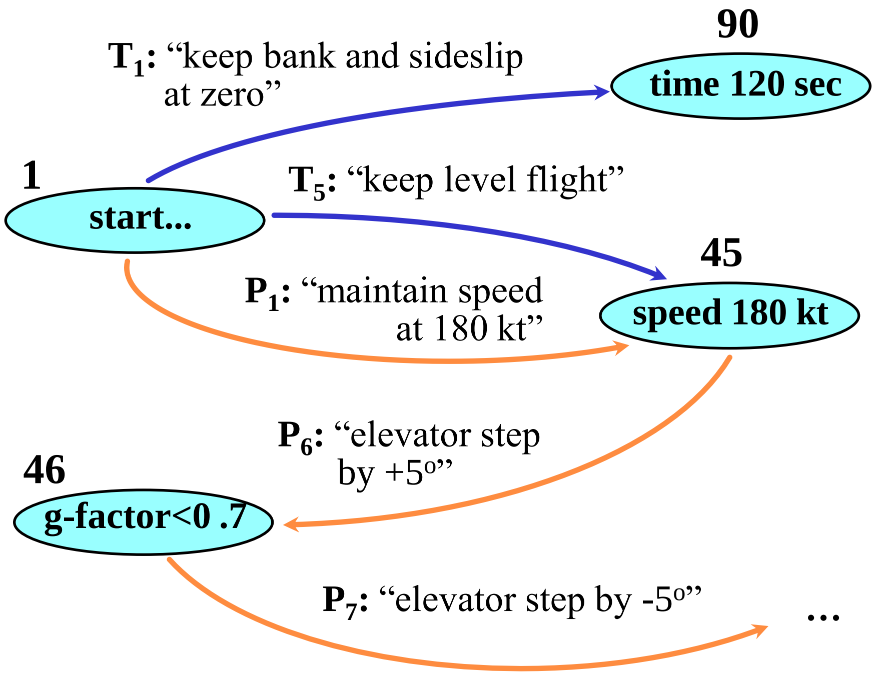
$$\Omega(\Pi) = \Omega(\mathbf{T}) \cup \Omega(\mathbf{P}) \cup \Omega(\mathbf{O}) \cup \ldots \Omega(\mathbf{B}) \cup \Omega(\mathbf{F}) \cup \ldots$$

$$\ldots \cup \Omega\,(\mathbf{W}) \cup \Omega(\mathbf{R}) \cup \Omega(\mathbf{Y}) \cup \Omega(\mathbf{A}) \ldots$$

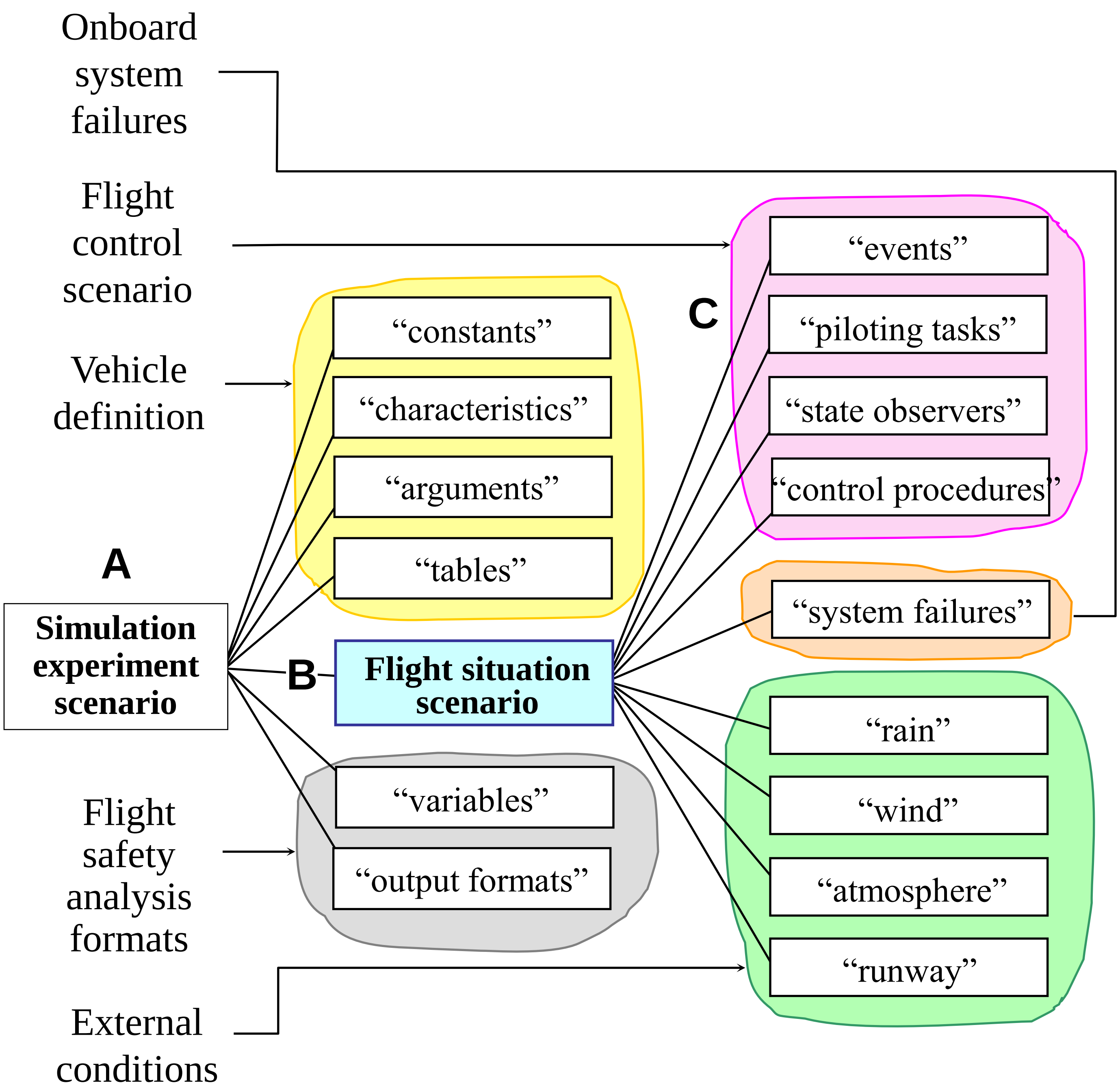
Flight Scenario Definition

Flight [situation] scenario

- Concise plan-structure of flight situation
- Defines combined logic of flight and control
- Captures cause-and-effect links between events and processes
- Named by the flight situation which it specifies:
  - *“normal takeoff”*
  - *“aborted landing”*
  - *”level flight at 400 km/h and 1 km”*
  - *“coordinated turn at 75º bank”*
  - *“stall in takeoff configuration”*
  - *Cobra maneuver*
- Depicted and formalized as a directed graph, $\mathbf{S} = \Omega(\mathbf{E}) \cup \Omega(\mathbf{\Pi})$:



Computer Simulation Experiment Scenario


Onboard system failures

Flight control scenario

Vehicle definition

A

Simulation experiment scenario

Flight safety analysis formats

External conditions

“constants”

“characteristics”

“arguments”

“tables”

B

Flight situation scenario

“variables”

“output formats”

C

“events”

“piloting tasks”

“state observers”

“control procedures”

“system failures”

“rain”

“wind”

“atmosphere”

“runway”

Note: $\mathbf{A} \supset \mathbf{B} \supset \mathbf{C}$

Specification of Model’s Main Objects [9]

“[Model variable” (x)

$R[\boldsymbol{x}^i] = \quad \{ i,\ x_{\text{min}}, x_{\text{max}}, N, U, S, D, \ \dots \}$

“Flight event” (E)

$R[\mathbf{E}_i] = \quad \{ i, j^{\text{IF}}, N, (x_1, \dots, x_{\text{n}}), (x \square R), \text{t}, \Delta t, \ldots \}$

“Piloting task” (T)

$R[\mathbf{T}_i] = \quad \{ i, j(\mathbf{E}_*), j(\mathbf{E}^*), \xi, N, (j(u_1), \dots, j(u_{\text{n}})), (\Delta_1, \dots, \Delta_{\text{n}}), \ldots \}$

“System state observer” (O)

$R[\mathbf{O}^i_k] = \quad \{ j(\mathbf{T}), j(u), j(x), N(x), G, k, x_1, x_2, \Delta_{\text{o}}, \dots \}$

“Control procedure” (P)

$R[\mathbf{P}_i] = \quad \{ i, j(\mathbf{E}_*), j(\mathbf{E}^*), \xi, N, m, (j(u_1), \dots, j(u_4)), G, \tau, k_{\text{du/dt}}, \dots \}$

“Onboard subsystem failure” (F)

$R[\mathbf{F}_i] = \quad \{ i, j(\mathbf{E}_*), j(\mathbf{E}^*), \xi, N, m, (j(u_1), \dots, j(u_4)), G, \tau, k_{\text{du/dt}}, \dots \}$

“Rain” (R)

$R[\mathbf{R}_i] = \quad \{ i, N, j(\mathbf{E}_*), j(\mathbf{E}^*), (RT, x_{arg}, r_*, r^*, n), \Delta J, \dots \}$

“Wind” (W)

$R[\mathbf{W}_i] = \quad \{ i, N, j(\mathbf{E}_*), j(\mathbf{E}^*), (WT, x_{arg}, r_*, r^*, n), \dots. \}$

“Parameter time-history” (Q)

$R[\mathbf{Q}_i] = \quad \{ i, (j(x_1), \ldots, j(x_n)), N, \xi, j(\mathbf{E}_*), j(\mathbf{E}^*), (HT, r_*, r^*, n), \Delta t, \Delta x, \dots \}$

These data structures are unified within each object class, for all problems studied (40+), all vehicle types and projects (22), all phases and modes of normal and test flight, and all flight scenario types (over 400). They remain unchanged since 1984 ⇒ the “events-processes” model is sufficiently universal flight specification language - ref. [6-11]

VATES-Based Flight Analysis Process [6]

Phase 1. Develop vehicle «parametric definition» database:
- form data tables containing vehicle's input characteristics
- form file-description of the vehicle's input characteristics tables
- fill out a file containing the vehicle model 'constants'

Phase 2. Formalize airworthiness requirements or flight content requirements in the form of flight scenario library:
- select operational factors for studying (pilot errors, failures, weather)
- develop normal flight scenarios
- develop complex flight scenarios

Phase 3. Plan and conduct computer simulation experiments (form a database of virtual test «flights»):
- select a subset of variables for recording and analysis
- select tabular and graphic formats for output representation and analysis
- define flight situation tree structure (genotype)
- develop a program of VFT&E experiments
- assess model's sensitivity to the operational factors under testing
- run computer simulation experiments.

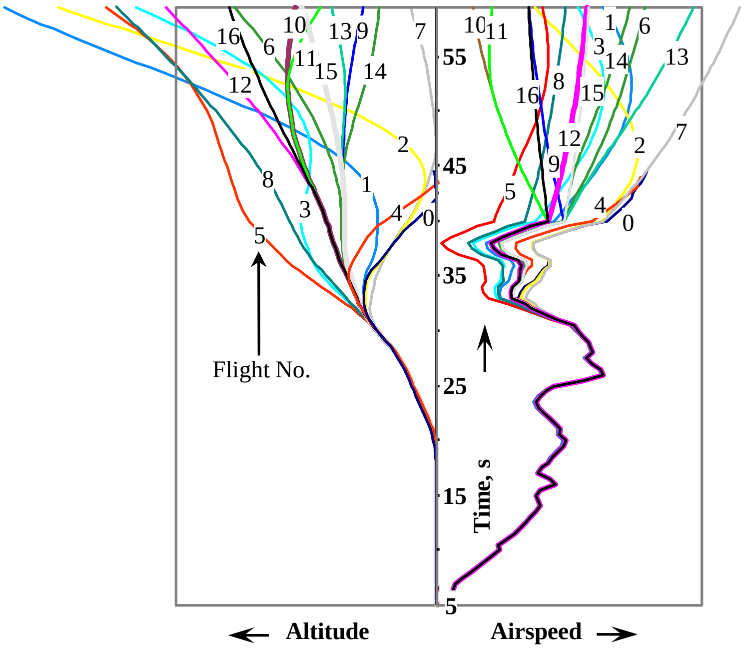
Phase 4. Process, document and analyze «flight» data:
- check-in resulting «flight» in database
- record «flights» on PC in the form of a situational tree
- conduct analysis of each «flight» data
- compare the results with data obtained by other methods if available
- conduct analysis and make generalizations/sections over a set of «flights»
- prepare a subset of «flights» and output formats for technical report

Phase 5. Identify anomalies/irregularities in the system behavior:
- characterize unsafe situations, describe their scenarios, and primary causes (events and processes)
- identify key operational factors and their critical combinations

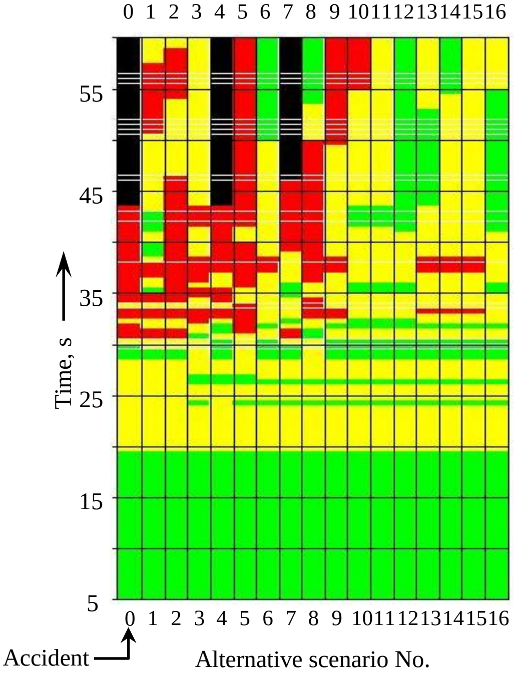
Phase 6. Develop recommendations/feedback to designers, pilots:
- describe potentially unsafe scenarios, their development and consequences
- suggest constraint refinement under multiple/extreme conditions
- prepare recommendations (new/modified piloting tactics, control laws, changes to design)
- develop proposal to refine/expand vehicle's 'parametric definition' database

VFT&E Output Format Examples

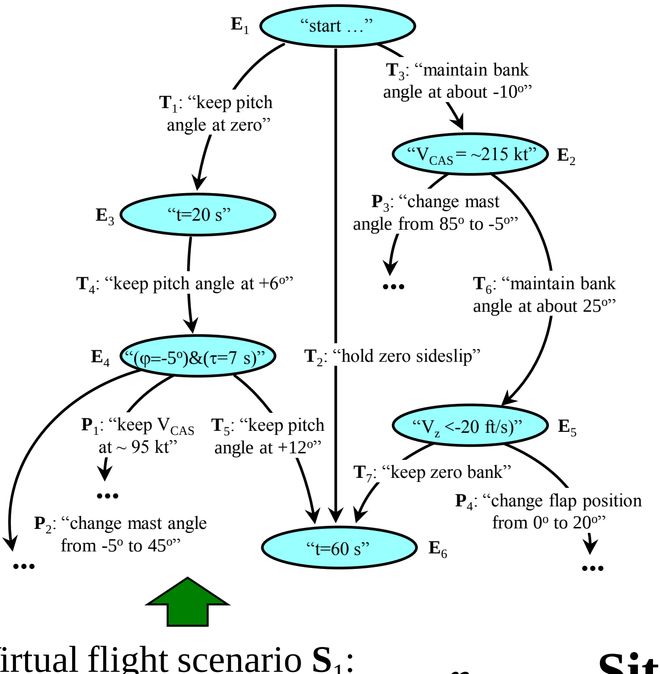
Situational tree [8]



Flight safety spectrum[8]



Flight scenario graph



E$_1$ "start …"

T$_1$: "keep pitch angle at zero"

T$_3$: "maintain bank angle at about -10°"

"V_{CAS} = ~215 kt" **E**$_2$

E$_3$ "t=20 s"

P$_3$: "change mast angle from 85° to -5°"

…

T$_4$: "keep pitch angle at +6°"

T$_6$: "maintain bank angle at about 25°"

E$_4$ "(φ=-5°)&(τ=7 s)"

T$_2$: "hold zero sideslip"

P$_1$: "keep V_{CAS} at ~ 95 kt"

…

T$_5$: "keep pitch angle at +12°"

"V_z <-20 ft/s)" **E**$_5$

T$_7$: "keep zero bank"

P$_4$: "change flap position from 0° to 20°"

…

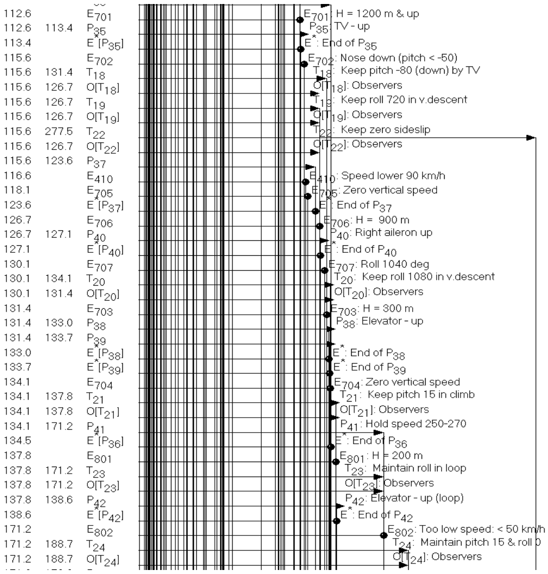
P$_2$: "change mast angle from -5° to 45°"

…

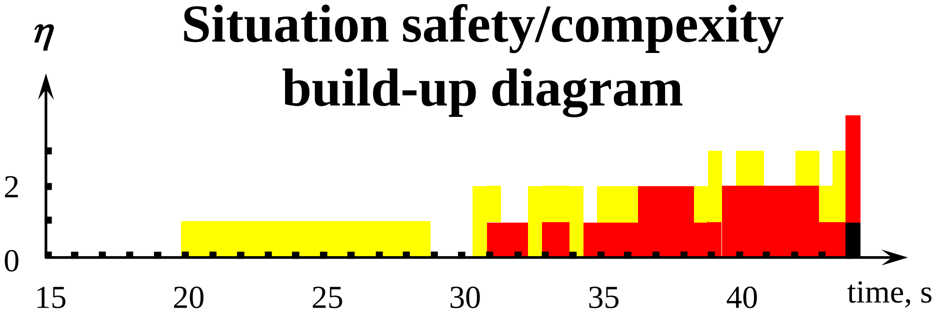
"t=60 s" **E**$_6$

Virtual flight scenario **S**$_1$: "Transition from airplane mode to tilt-rotor mode via helicopter mode under multiple control inputs (XV-15 tilt-rotorcraft [7])"

Scenario time-history [10]

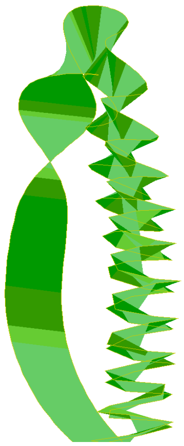


Situation safety/compexity build-up diagram

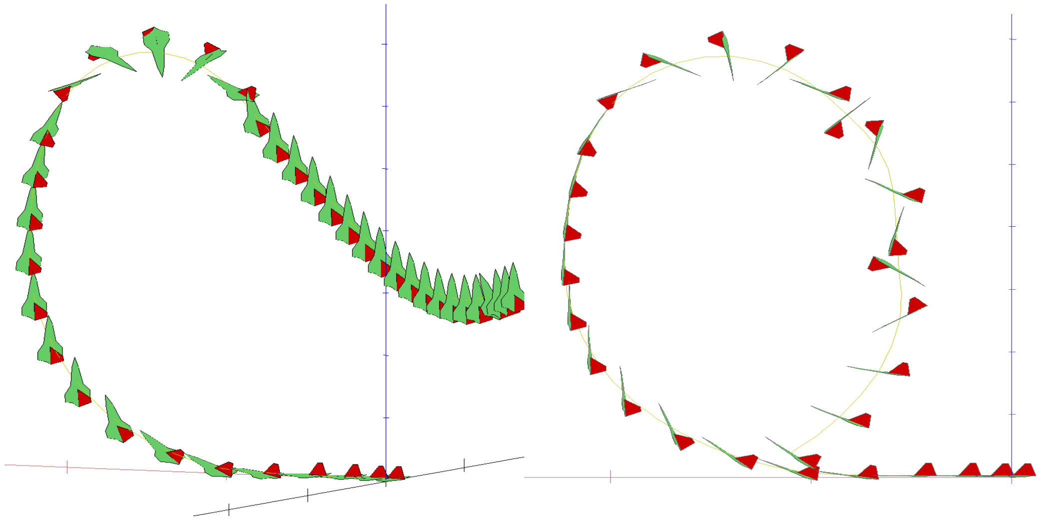


VFT&E Output Format Examples[1]

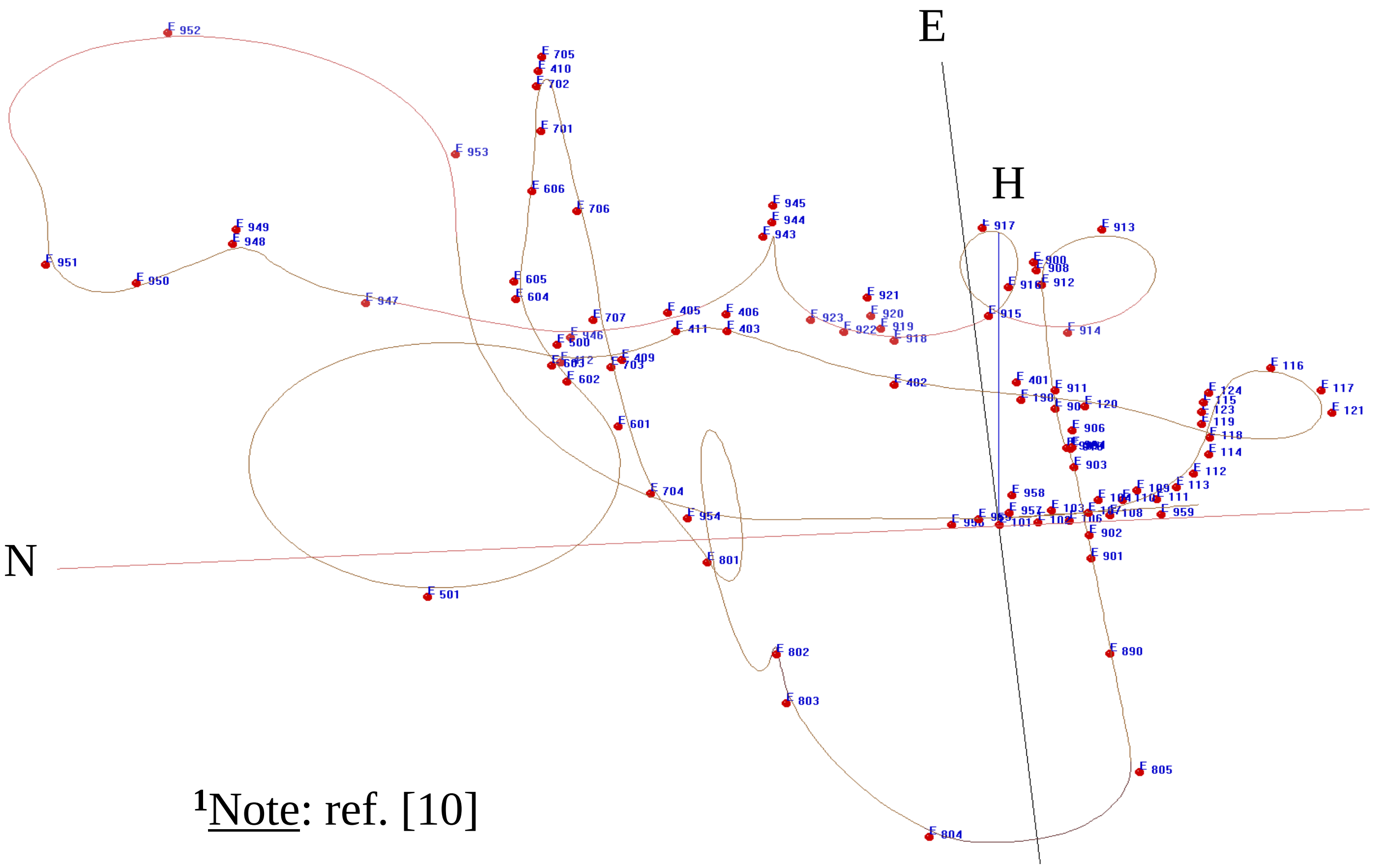
«Roll - flight path ribbon»



4-D snapshot flight diagram («movie»)



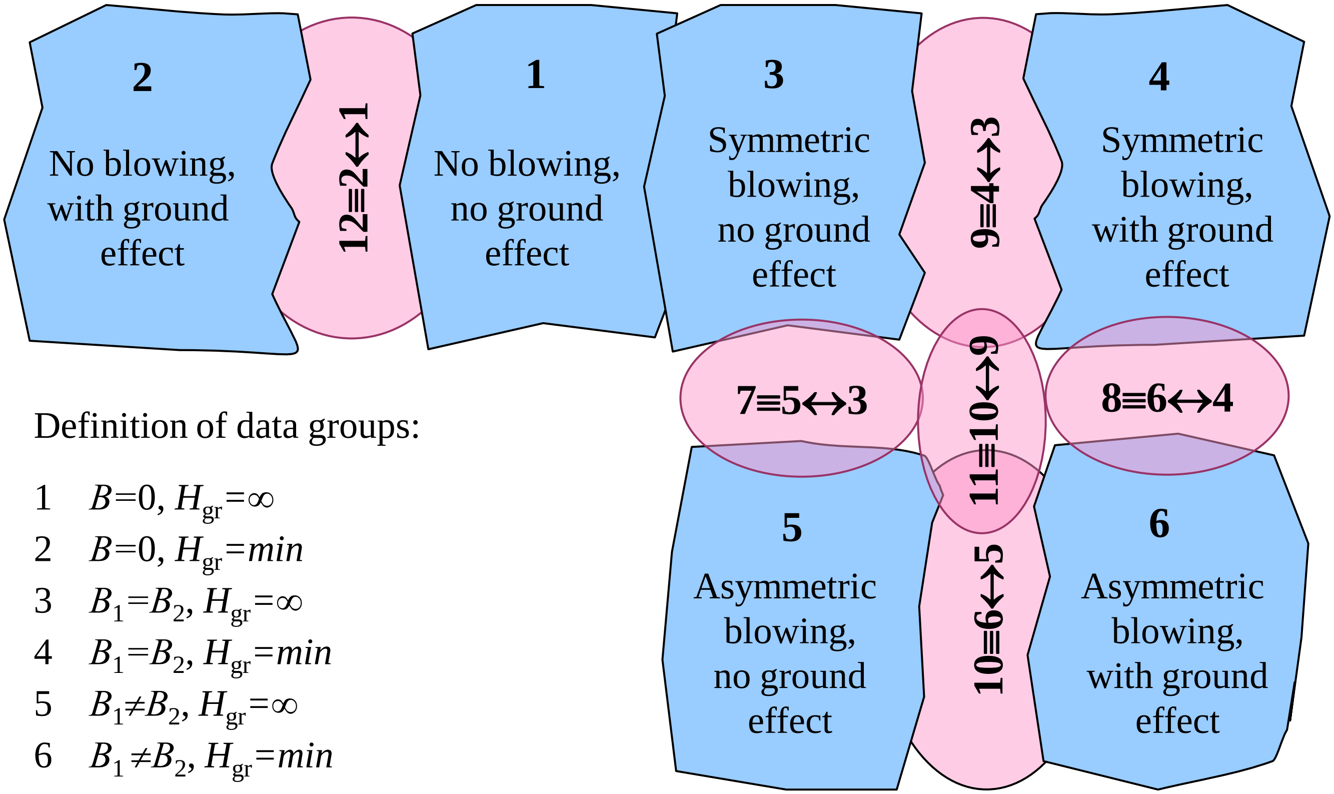
«Flight events - trajectory» diagram



[1] <u>Note</u>: ref. [10]

Aerodynamic Characteristics of Wind Tunnel Model №9612M [3-5]

Main and interim groups of source data arrays



2
No blowing, with ground effect

12≡2↔1

1
No blowing, no ground effect

3
Symmetric blowing, no ground effect

9≡4↔3

4
Symmetric blowing, with ground effect

7≡5↔3

11≡10↔9

8≡6↔4

5
Asymmetric blowing, no ground effect

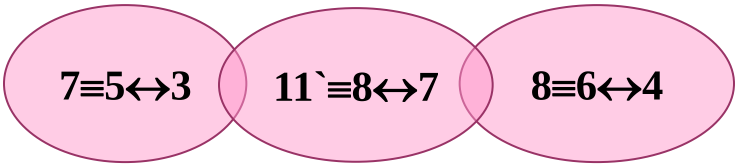
10≡6↔5

6
Asymmetric blowing, with ground effect

Definition of data groups:

1 $B=0,\ H_{gr}=\infty$
2 $B=0,\ H_{gr}=min$
3 $B_1=B_2,\ H_{gr}=\infty$
4 $B_1=B_2,\ H_{gr}=min$
5 $B_1\neq B_2,\ H_{gr}=\infty$
6 $B_1\neq B_2,\ H_{gr}=min$
7 5↔3
8 6↔4
9 4↔3
10 6↔5
11 10↔9
11\` 8↔7
12 2↔1

Alternative method of group № 11 (11\`) definition:



7≡5↔3

11\`≡8↔7

8≡6↔4

Characteristics calculation for interim group *k* ≡ *i*↔*j*

$$\Delta C_k \equiv \Delta C_{i\text{-}j} = \Delta C_i \cdot \xi \ + \Delta C_j \cdot (1 - \xi),$$

where ΔC is an aerodynamic characteristic, $C \in \{C_X, C_Y, C_Z, C_l, C_m, C_n\}$, ξ - transition parameter, $\xi \in [0\ 1]$. In the S-80GP model: $\xi \equiv \boldsymbol{x}_{178}$ - thrust asymmetry coefficient (for $C_{5\text{-}3}$, $C_{6\text{-}4}$ and $C_{10\text{-}9}$) and $\xi \equiv \boldsymbol{x}_{194}$ - model relative altitude over ground (for $C_{2\text{-}1}$, $C_{4\text{-}3}$, $C_{6\text{-}5}$ and $C_{8\text{-}7}$).

Aerodynamics Model Build-Up Matrix (S-80GP, Article №01-02 [5])

	C_X	C_Z	C_Y	C_l	C_n	C_m
Wing+body	cx_zf024_xx (40) cx_zf24_x0 (54)	cy_zf024_xx (41) cy_zf24_x0 (55)	cz_zf024_xx (42) cz_zf24_x0 (56)	mx_zf024_xx (43) mx_zf24_x0 (57)	my_zf024_xx (44) my_zf24_x0 (58)	mz_zf024_xx (45) mz_zf24_x0 (59)
Elevator	cx_ezf024_00 (1) cx_egwzf24_00 (37) cx_ezf2_xx (46) cx_ezwgf2_xx (87)	cy_ezf024_00 (2) cy_egwzf24_00 (38) cy_ezf2_xx (47) cy_ezwgf2_xx (88)	-	-	-	mz_ezf024_00 (3) mz_egwzf24_00 (39) mz_ezf2_xx (48) mz_ezwgf2_xx (89)
Rudder	cx_rzf04_00 (4) cx_rzf2_xx (49) cx_rzf2_x0 (60) cx_rzwgf4_xx (90)		cz_rzf04_00 (5) cz_rzf2_xx (50) cz_rzf2_x0 (61) cz_rzwgf4_xx (91)	mx_rzf04_00 (6) mx_rzf2_xx (51) mx_rzf2_x0 (62) mx_rzwgf4_xx (92)	my_rzf04_00 (7) my_rzf2_xx (52) my_rzf2_x0 (63) my_rzwgf4_xx (93)	mz_rzf04_00 (8) mz_rzf2_xx (53) mz_rzf2_x0 (64) mz_rzwgf4_xx (94)
R/aileron	cx_azf04_00 (9) xx_right_aileron (102)	cy_azf04_00 (10)	-	mx_azf04_00 (11)	my_azf04_00 (12)	-
L/aileron	cx_azf04_00 (9) xx_left_aileron (101)	cy_azf04_00 (10)	-	mx_azf04_00 (11)	my_azf04_00 (12)	-
Sideslip	cx_bzf0_00 (13) cx_bzf2_00 (19) cx_bzf4_00 (25)	cy_bzf0_00 (14) cy_bzf2_00 (20) cy_bzf4_00 (26)	cz_bzf0_00 (15) cz_bzf2_00 (21) cz_bzf4_00 (27)	mx_bzf0_00 (16) mx_bzf2_00 (22) mx_bzf4_00 (28)	my_bzf0_00 (17) my_bzf2_00 (23) my_bzf4_00 (29)	mz_bzf0_00 (18) mz_bzf2_00 (24) mz_bzf4_00 (30)
Wheels	cx_wzf024_00 (31)	cy_wzf024_00 (32)	-	-	-	mz_wzf024_00 (33)
Ground	cx_zwgf2_xx (71) (not used: cx_gwzf24_00 (34))	cy_zwgf2_xx (72) (not used: cy_gwzf24_00 (35)	cz_zwgf2_xx (73)	mx_zwgf2_xx (74)	my_zwgf2_xx (75)	mz_zwgf2_xx (76) (not used: mz_gwzf24_00 (36)
R/ABC flap	cx_zkf4_00 (77) cx_zkf4v2_00 (82)	cy_zkf4_00 (78) cy_zkf4v2_00 (83)	-	mx_zkf4_00 (79) mx_zkf4v2_00 (84)	my_zkf4_00 (80) my_zkf4v2_00 (85)	mz_zkf4_00 (81) mz_zkf4v2_00 (86)
L/ABC flap	cx_zkf4_00 (77) cx_zkf4v2_00 (82)	cy_zkf4_00 (78) cy_zkf4v2_00 (83)	-	mx_zkf4_00 (79) mx_zkf4v2_00 (84)	my_zkf4_00 (80) my_zkf4v2_00 (85)	mz_zkf4_00 (81) mz_zkf4v2_00 (86)
Thrust reverse	cx_tzwgf4_xx (95)	cy_tzwgf4_xx (96)	cz_tzwgf4_xx (97)	mx_tzwgf4_xx (98)	my_tzwgf4_xx (99)	mz_tzwgf4_xx (100)
$\dot{\alpha}$	-	cy_aoa_dot	-	-	-	mz_aoa_dot
p	-	-	-	mx_p	My_p	-
q	-	cy_q	-	-	-	mz_q
r	-	-	cz_r	mx_r	My_r	-
$\bar{x}_{cg}$	-	-	-	-	-	mz_x_cg
$\bar{z}_{cg}$	-	-	-	-	-	mz_y_cg
Rain	cx_rain	cy_rain	-	-	-	mz_rain
Icing	cx_ice	cy_ice	-	-	-	mz_ice

Definition of input characteristics arguments

ID (x)	x_{min}	x_{max}	Δx
AoA	-11.00	27.00	1.00
flaps	0.00	40.0	20.00
blowing	-1.25	1.50	0.25
sideslip	-22.00	22.00	1.00
rudder	-30.00	30.0	5.00
aileron	-25.00	20.0	5.00
elevator	-25.00	15.0	2.50
fuel	0.00	2400.0	600.00
payload	0.00	2400.0	600.00
wheels	0.00	1.0	1.00
ground	0.00	1.0	0.25

Total number
of input characteristics
in the S-80GP (article
№01-02) flight model:
109

Operational Flight Domain Under Study

Flight phases

Takeoff (normal, continued, aborted, non-standard situations), landing approach and landing (normal, continued, non-standard situations), go-around (normal, with engine(s) out, non-standard situations), climb and descent, level flight, groundroll.

Main groups of tested operational conditions/ factors

- Pilot erorrs, inattention, control tactic variations
- Onboard system failures/logic errors
- Demanding weather conditions (wind, rain, turbulence, runway, …)

Pilot errors, inattention, control tactic variations

Incorrect selection of VR/VLA/... speeds, variations/errors in setting command/goal states (flightpath, pitch, bank, sideslip, vertical rate, airspeed, etc.), response delay after engine/subsystem failure, current-command state error feedback sensitivity, flap setting variations, airspeed/thrust control errors/variations, piloting methods variations/errors, etc.

Onboard system failures/logic errors

Primary effectors hardover (rudder, etc.), engine failure, thrust reverse failure, brakes failure, ABC system failure, flap jam, etc.

Demanding weather conditions

Crosswind (left/right), tail- and headwind, «strong» and «very strong» windshear, «microburst», turbulence, heavy rain/shower, wet/icy runway, etc.

Flight Situation Tree Structure Planning (Example)

Subtree B_1 fragment: “Takeoff at left-hand (critical) engine out during groundroll, variations of V_1, sideslip control, ABC-system flap failure, and crosswind”

Legend:

1. Tree branch and bud coloring:

- 🟪 Sideslip control technique
- 🟩 ABC-system right flap failure
- 🟥 Left-hand (critical) engine failure
- 🟦 Engine failure speed (VEF)
- 🟫 Crosswind

2. Airborne sideslip control technique :

№ 1 - ground: Ψ(0), β(1°), airborne: β(1°), β(1°)
№ 2 - ground: Ψ(0), ψ(0), airborne : ψ(0), β(1°)
№ 2` - ground: Ψ(0), ψ(0), airborne : ψ(0), β(4°)

3. Scenario code (‘flight’ №):

988, …, 1008

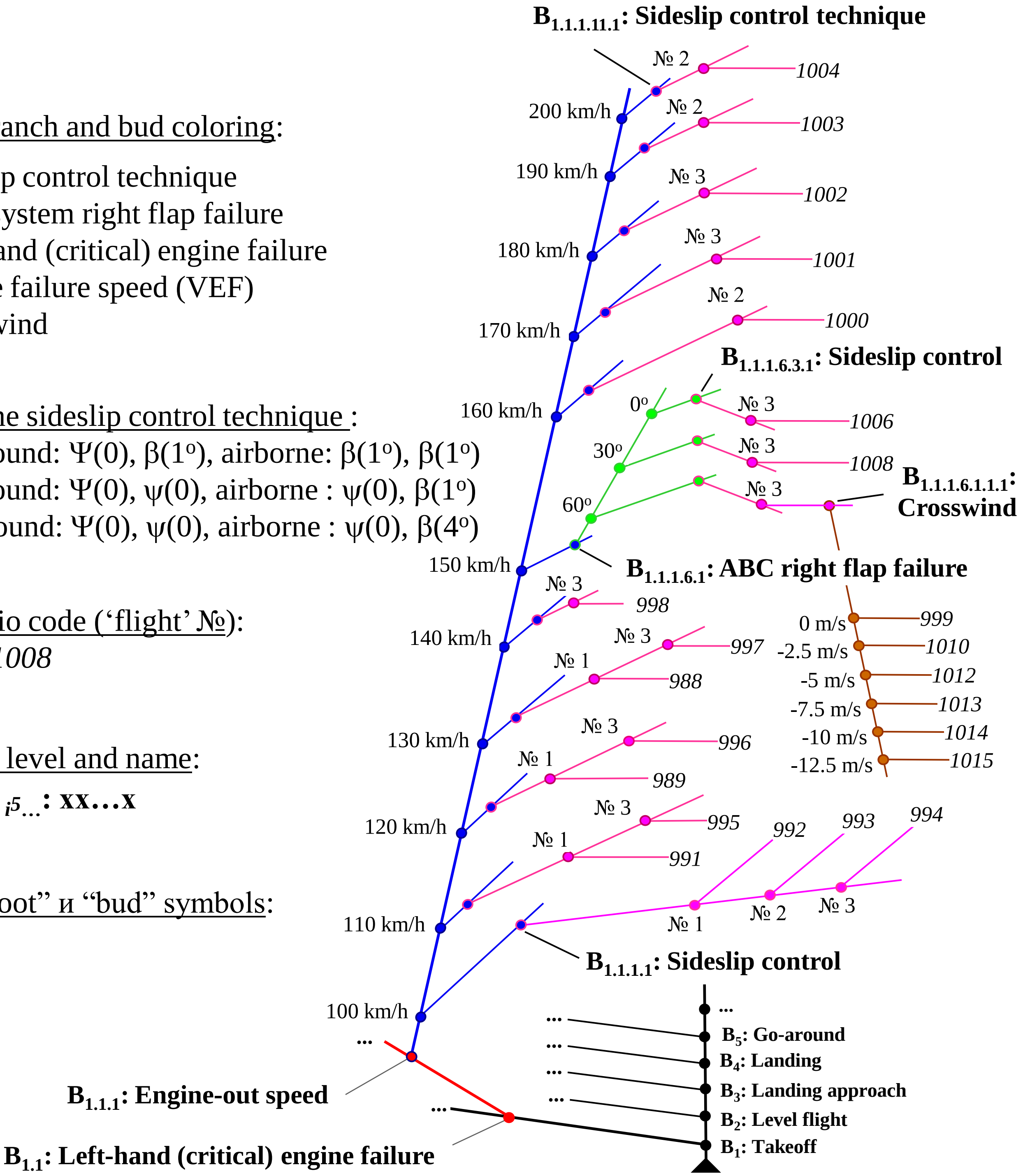
4. Branch level and name:

$B_{i^1.i^2.i^3.i^4.i^5...}$: xx…x

5. Tree “root” и “bud” symbols:

▲

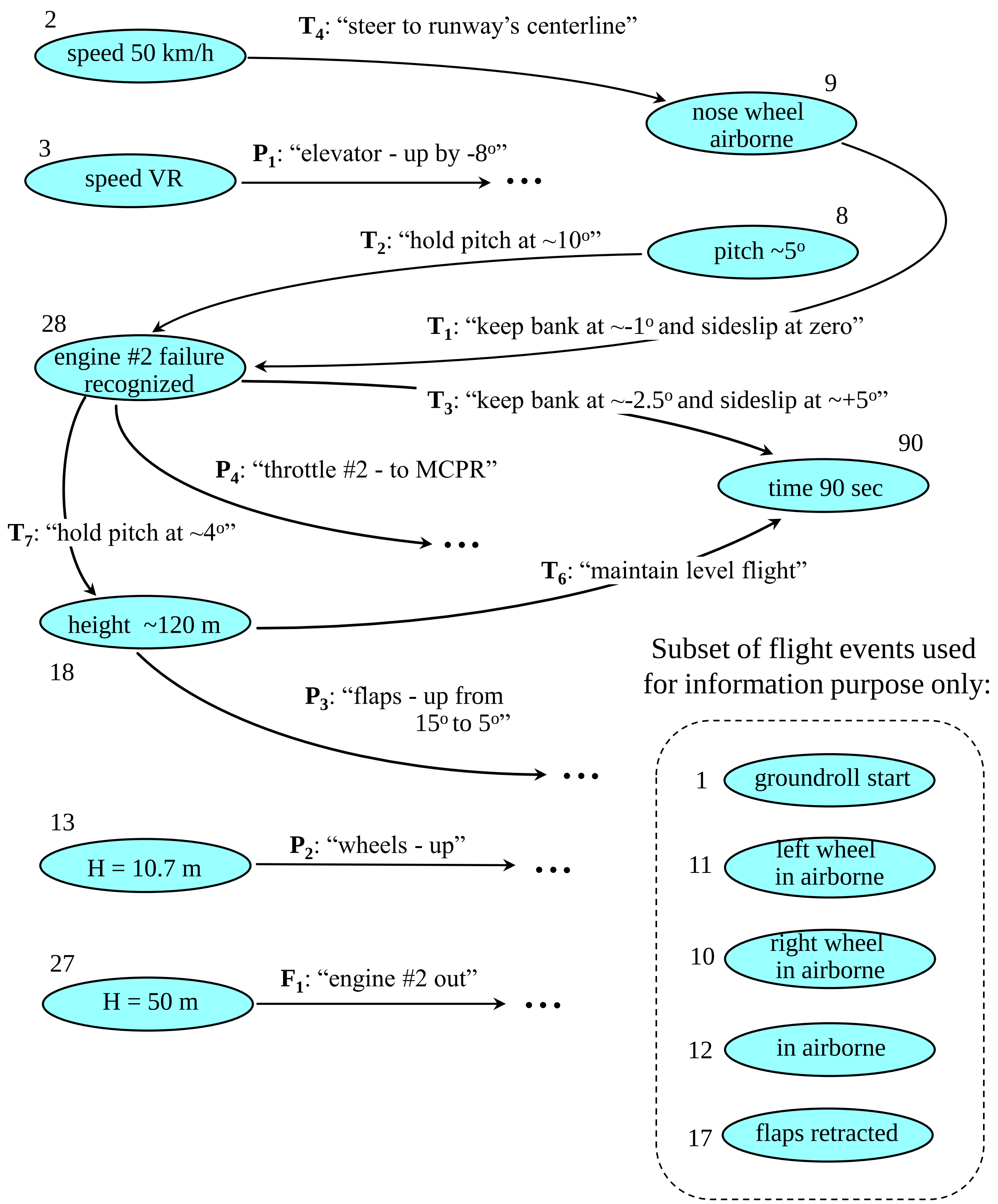
●



VFT&E Experiment Statistics (S-80GP, Input Database v.S-80GP.1.1)

Flight code	Experiment №
Number of flight events in a scenario	10...20
Number of piloting tasks	3...6
Number of control procedures/failures	3...15
Number of system state observers	9...18
Total number of experiments (“flights”)~2500	
Average duration of “flight”	~60…80 s
Total flight time (VFT&E “experience):	
48 = 70 x 2500 / 3600	≈48 hrs
Computer time per one 70-s long “flight”	4…10 s
VFT&E experiment speed (PIII, 500 MHz)	1:10...1:20
Number of variables recorded in one “flight”	350
Number of variables used to analyze “flight”	20…60
Number of output forms	>14

Flight Scenario Graph Example: "Airplane Takeoff With Right-Hand Engine Out At *H*=50 m"



2 speed 50 km/h

T$_4$: "steer to runway's centerline"

9 nose wheel airborne

3 speed VR

P$_1$: "elevator - up by -8^o" …

8 pitch ~5^o

T$_2$: "hold pitch at ~10^o"

28 engine #2 failure recognized

T$_1$: "keep bank at ~-1^o and sideslip at zero"

T$_3$: "keep bank at ~-2.5^o and sideslip at ~+5^o"

90 time 90 sec

P$_4$: "throttle #2 - to MCPR" …

T$_7$: "hold pitch at ~4^o"

T$_6$: "maintain level flight"

18 height ~120 m

P$_3$: "flaps - up from 15^o to 5^o" …

13 H = 10.7 m

P$_2$: "wheels - up" …

27 H = 50 m

F$_1$: "engine #2 out" …

Subset of flight events used for information purpose only:

1 groundroll start

11 left wheel in airborne

10 right wheel in airborne

12 in airborne

17 flaps retracted

Flight Scenario Data File Example

S_{373}: ”Landing approach (VLA=195 км/h), right-hand engine out (*H*=50м), ABC-system flap on (60^o), 0 s delay of response to engine failure, go-around, δ_{FL}=40^o”

```
101 Initial conditions        2  9  1  1
(i5,1x,5a4,20x,3i3,2x,f11.3,2x,a8)

* Flight No.  373 S-80GP     v.1.1       flaps=40,VLA=195km/h,righteng_out(50m),
* go-around(tau=0.0s,pitch=1.5),leftAUK=on
   83 fuel                                   0  0  0      700.000     kg
   92 payload                                0  0  0      950.000     kg
   77 instrumental speed                     0  0  0      200.000    km/h
  186 altitude (wheels)                      0  0  0      100.000      m
   76 flightpath angle                       0  0  0       -2.700    degr
   14 pitch angle                            0  0  0       -3.000    degr
   25 flaps                                  0  0  0       40.000    degr
    3 elevator                               0  0  0        5.000    degr
   63 throttle 1                             0  0  0       17.000      %
   64 throttle 2                             0  0  0       17.000      %
  260 left engine operativ                   0  0  0        1.000      -
  261 right engine operati                   0  0  0        1.000      -
  251 runway-wheels adhesi                   0  0  0        0.700      -
   89 wheels on                              0  0  0        1.000      -
  250 duration of flight                     0  0  0       60.000      s
  213 aero prt mode                          0  0  0        1.000      -
  201 table formation step                   0  0  0        0.250      s
------------------
```

$\Omega(I)$

```
  102 Flight events             0 17  3  0
(i4,1x,i4,1x,6a4,1x,4i3,i5,1x,a2,a4,i3,i2,f8.2,f4.1,f5.1)

   1    0 situation start          106 92 83 78   41 GT  0   0 0   -1.00 0.0  0.0
   2    1 height  5m /wheels        14 19 31 32  186 LE  0   0 0    6.00 0.0  0.0
  20    1 time 20 s                 14 19 31 32   41 GE  0   0 0   20.00 0.0  0.0
  21    1 H < 50 m                  14 19 31 32  186 LE  0   0 0   50.00 0.0  0.0
  22    1 engine failure recogn     14 19 31 32  261 LE  0   0 0    0.10 0.0  0.0
   3    1 height 5 m /wheels        14 19 31 32  186 LE  0   0 0    5.00 0.0  0.0
   4    3 flightpath angle -1 deg   14 19 31 32   76 GE  0   0 0   -1.00 0.0  0.0
   5    1 left leg contact r/way    12 32 36 21   86 LT  0   0 0    0.00 0.0  0.0
   6    1 right leg contact r/w     12 32 36 21   85 LT  0   0 0    0.00 0.0  0.0
   7    1 nose wheel contact r/w    12 32 36 21   84 LT  0   0 0    0.00 0.0  0.0
  77    2 NY > 1.15                 12 32 36 21   36 GT  0   0 0    1.15 0.0  0.0
   8    1 airspeed < 50km/h         20 14 76 32   77 LT  0   0 0   50.00 0.0  0.0
  88    1 airspeed < 150m/h         20 14 76 32   77 LT  0   0 0  150.00 0.0  0.0
   9    6 on the runway ...         12 32 36 21  120 LT  0   0 0    0.00 0.0  0.0
  89    1 airspeed < 100m/h         20 14 76 32   77 LT  0   0 0  100.00 0.0  0.0
  11    4 load factor > 1.5         12 32 36 21   36 GT  0   0 0    1.50 0.0  0.0
  12    4 load factor > 2.0         12 32 36 21   36 GT  0   0 0    2.00 0.0  0.0
  13    4 load factor > 2.5         12 32 36 21   36 GT  0   0 0    2.50 0.0  0.0
  14    3 height 3m /wheels         14 19 31 32   20 LE  0   0 0    7.00 0.0  0.0
  15    4 vertical speed -1.5 m/s   12 32 36 21   32 AE  0   0 0   -1.50 0.0  0.0
  16   15 positive vert. Speed      12 32 36 21   32 GT  0   0 0    0.00 0.0  0.0
 190    0 Time 200 sec             186 77 14 12   41 GE      0 0  200.00 0.0  0.0
------------------
```

$\Omega(E)$

```
  104 Piloting tasks            0 16  4  0
(i2,2i5,i2,8a4,4i3,2(1x,f4.3),2(1x,f3.2))

 1    1   21 0 maintain glide slope by elev.    3  0  0  0 .050 .000 .00 .00
 2    1   21 0 keep zero roll by ailerons       4  0  0  0 .050 .000 .00 .00
 3    1   21 0 keep zero sideslip by rudder    10  0  0  0 .050 .000 .00 .00
 6   22  190 0 maintain pitch to go around      3  0  0  0 .050 .000 .00 .00
 6   22  190 0 keep zero roll by ailerons       4  0  0  0 .050 .000 .00 .00
 6   22  190 0 keep zero sideslip by rudder    10  0  0  0 .050 .000 .00 .00
------------------
```

$\Omega(T)$

```
103 Control procedures        0 17  3  0
(i3,2i5,1x,i2,1x,5a4,1x,a3,4i4,a4,2i3,f8.2,f5.1,f6.2)

  1    1   21   0 holding speed 195    THR  63  64   0   0      0  0  195.00 -5.0  0.10
 15   21    0   0 right engine out     ABS 261   0   0   0      0  0    0.00  0.0  1.50
 26   22    0   0 Thrust --> max       ABS  63   0   0   0      0  0  100.00  2.0  1.00
 17   21    0   0 left  AUK on         ABS 174   0   0   0      0  0   60.00  2.0  0.50
```

$\Omega(P)$

$\Omega(F)$

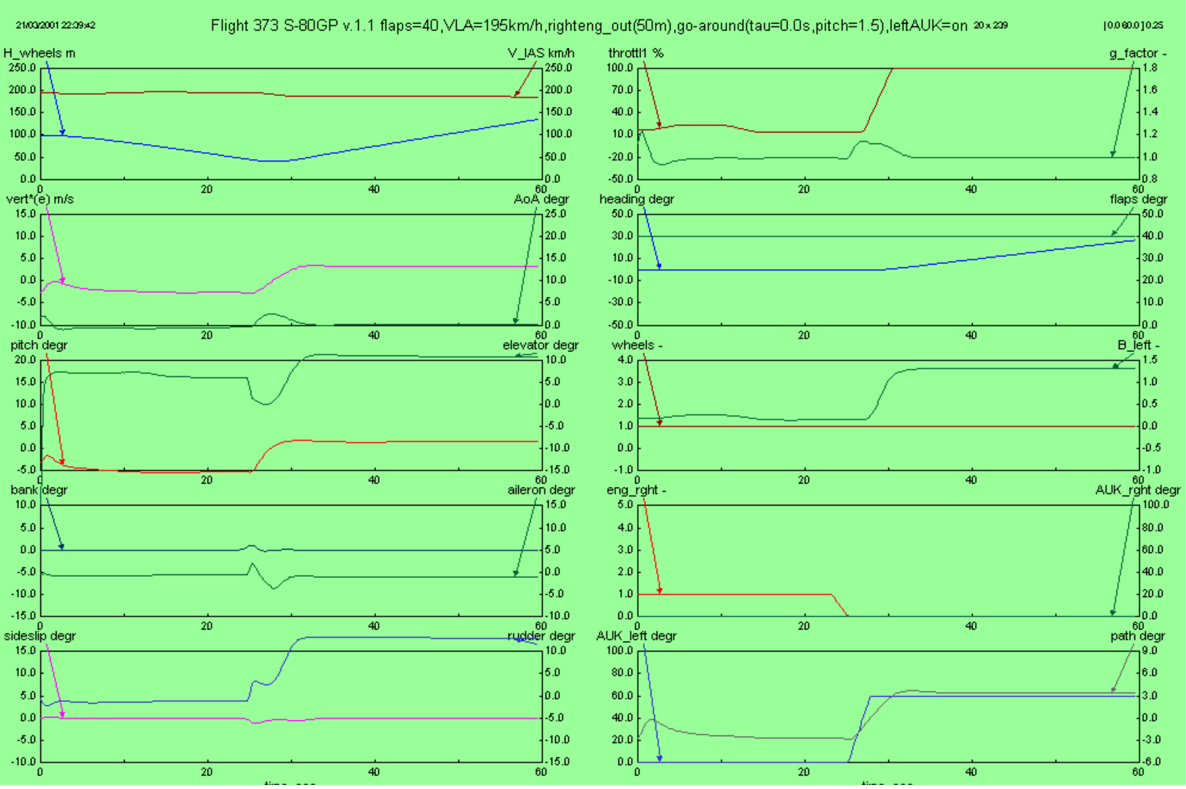
Typical Subset of Flight Variables Depicted on Time-History Plots

Code	Name	Unit	ID
186	Flight altitude measured at main wheels bottom	M	Altitude
77	IAS	Km/h	V_IAS
32	Vertical velocity	M/s	Vert*(e)
1	Angle of attack	Deg	AoA
14	Pitch angle	Deg	Pitch
3	Elevator position	Deg	Elevator
12	Bank angle	Deg	Bank
4	Right aileron deflection	Deg	aileron
11	Sideslip angle	Deg	Sideslip
10	Rudder deflection	Deg	Rudder
25	Flap setting	Deg	Flaps
44	Right undercarriage unit shocker move	m	S_shck2
171	Left propeller blowing coefficient	-	B_left
36	Normal load factor at C.G.	-	G-factor
71	Left propeller thrust	KN	Thrust_1
63	Left engine lever setting	Deg	Thrott_1
19	North coordinate	M	North
78	Longitudinal C.G. position on MAC	%	X_c.g.
21	East coordinate	M	East
192	Rate of climb	%	R/Climb

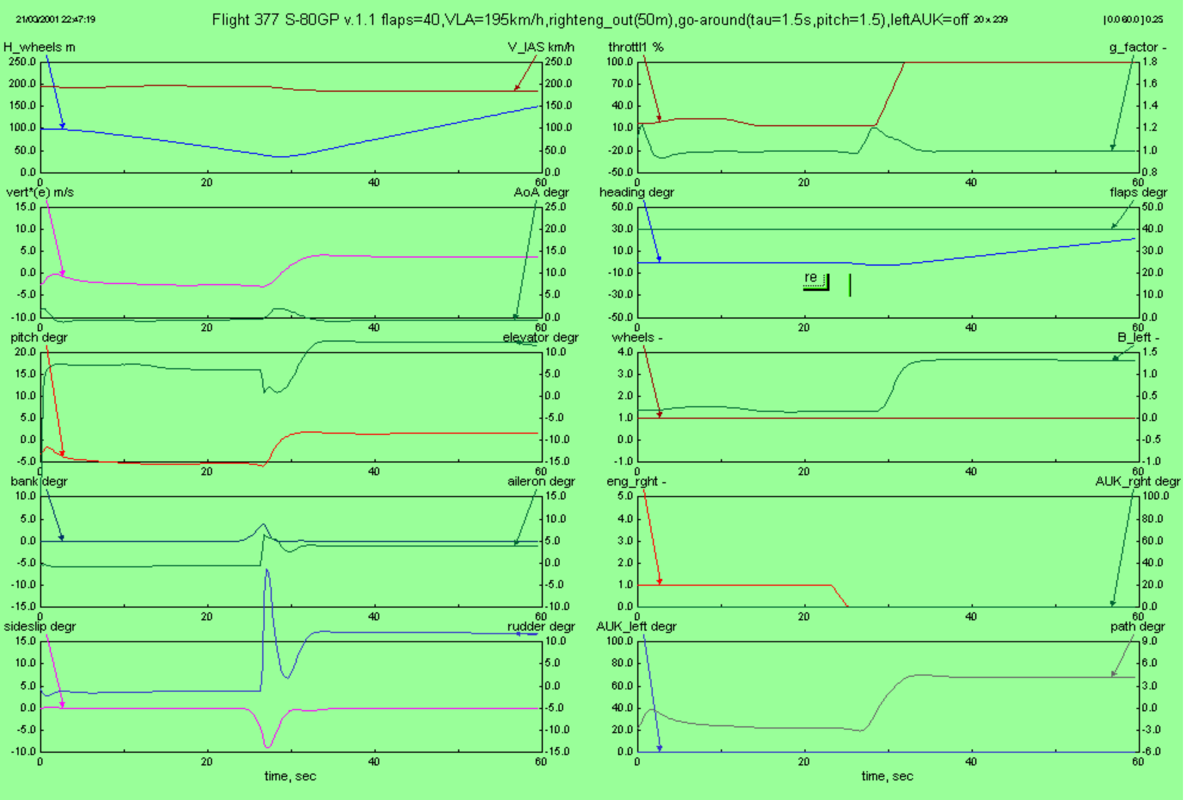
Note: codes of the flight variables in the table above correspond to the S-80GP flight model's vocabulary, $\Omega(\mathbf{X})$ [5]

Simulation Examples (S-80GP, 01-02)

S_{373}:”Landing approach (VLA=195 км/h), right-hand engine out (*H*=50м), ABC-system flap on (60°), engine failure response delay 0 s, go-around, δ_{FL}=40°”

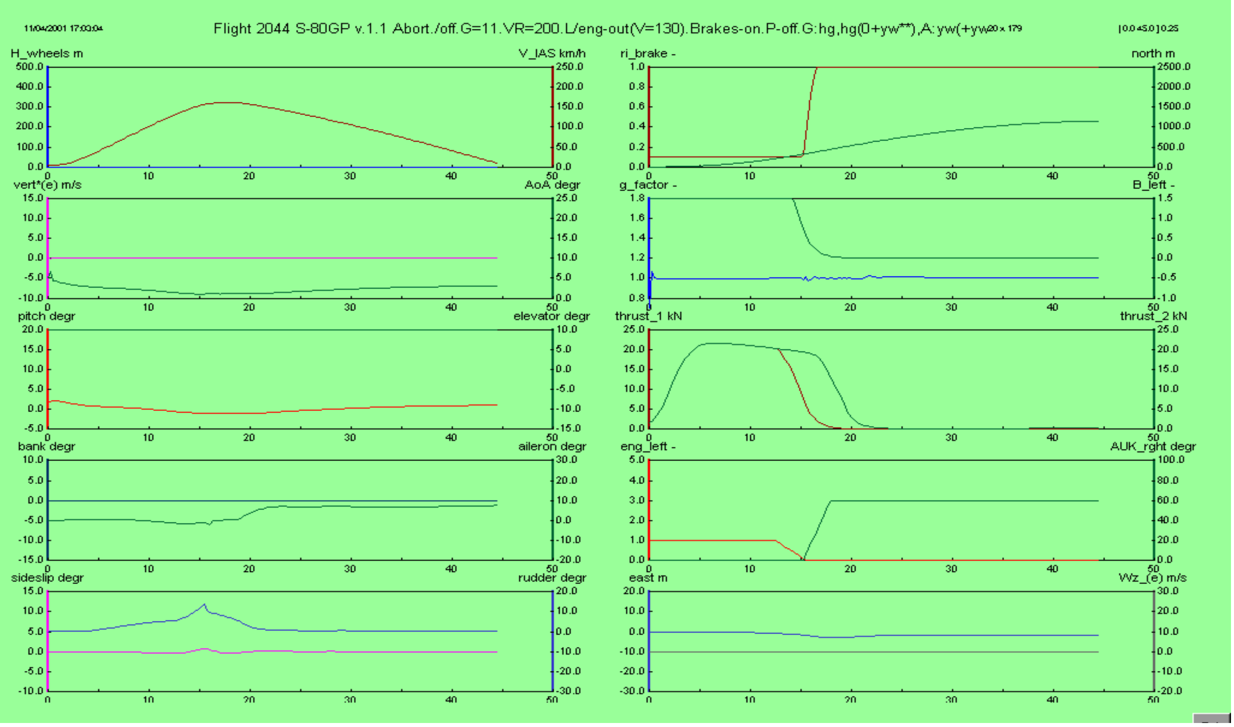


S_{377}: ”Landing approach (VLA=195 км/h), right-hand engine out (*H*=50м),ABC-system flap on (60°), engine failure response delay 1.5s, go-around, δ_{FL}=40°”

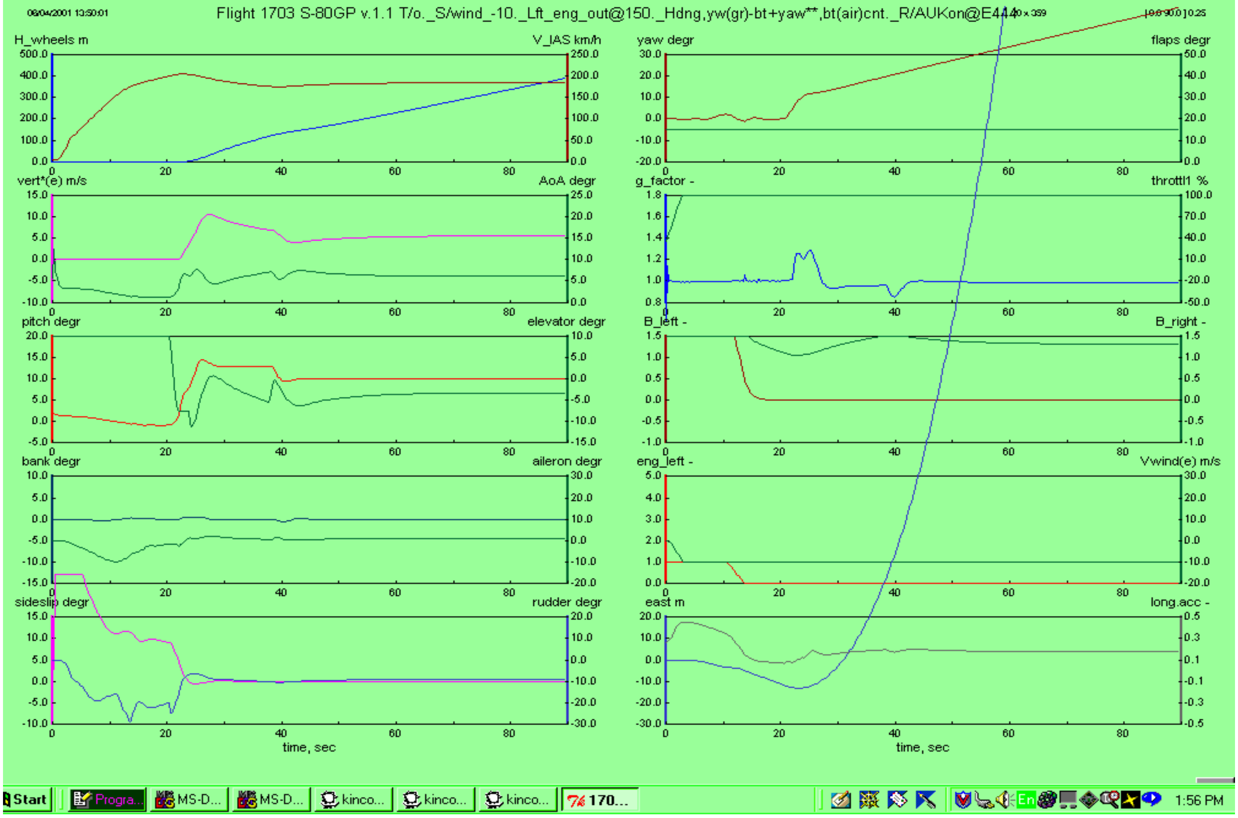


Simulation Examples (Continued)

S_{2044}: ”Aborted takeoff, left-hand engine out at VEF=130 km/h, δ_{FL}=15^o)”

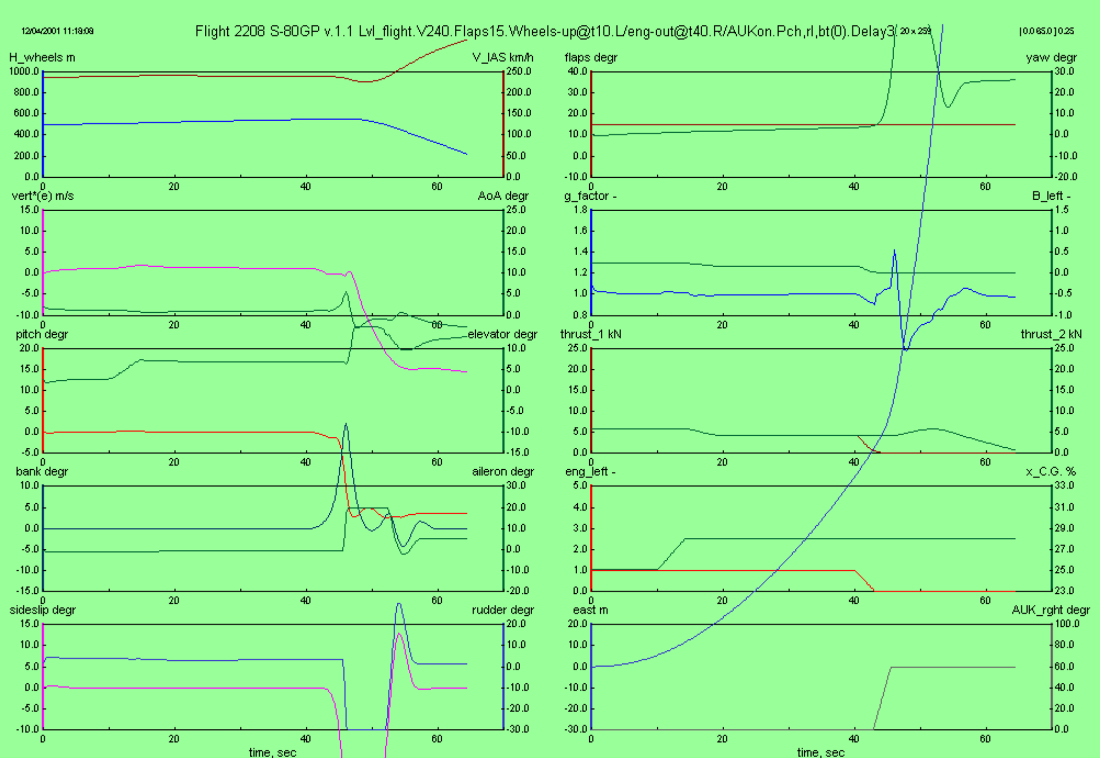


S_{1703}: ”Continued takeoff, left-hand engine out at VEF=150 km/h, δ_{FL}=15^o, right-to-left crosswind (-10 m/s)”

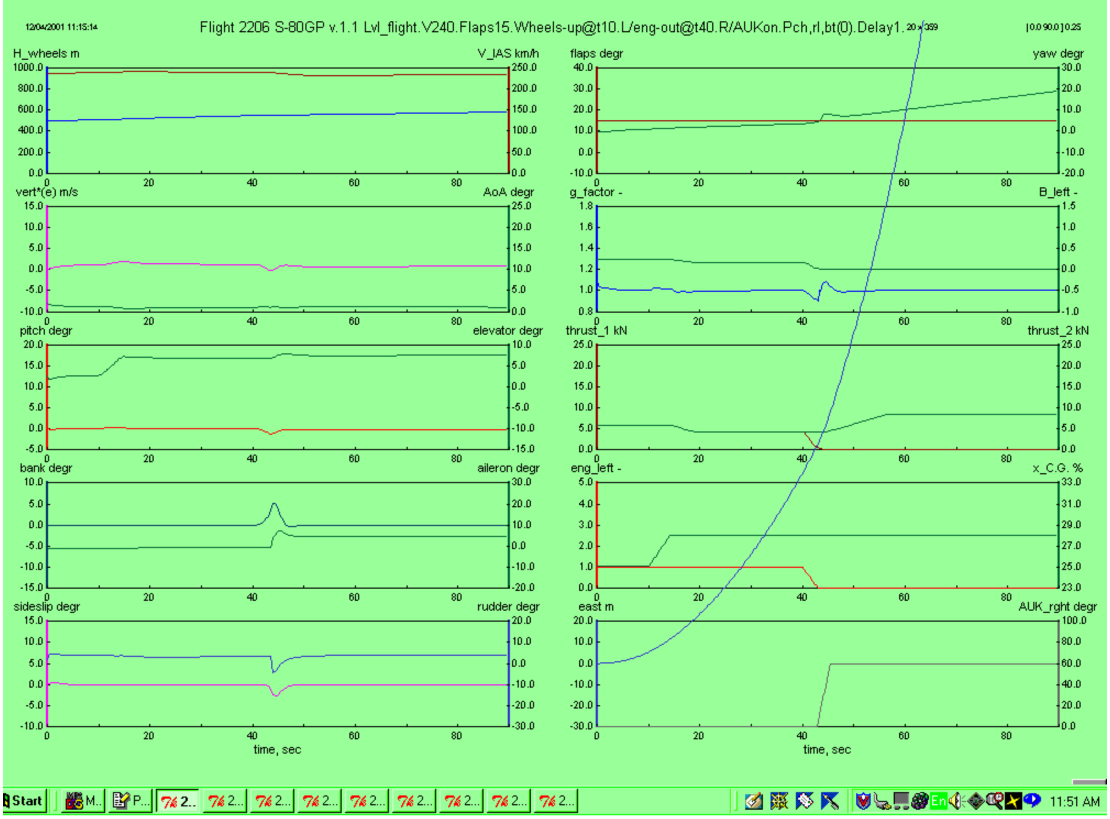


Simulation Examples (Continued)

S_{2208}: ”Level flight (wheels - up, left engine out (t = 40 s), 3 s delay of pilot response (in roll and sideslip control) to engine failure”

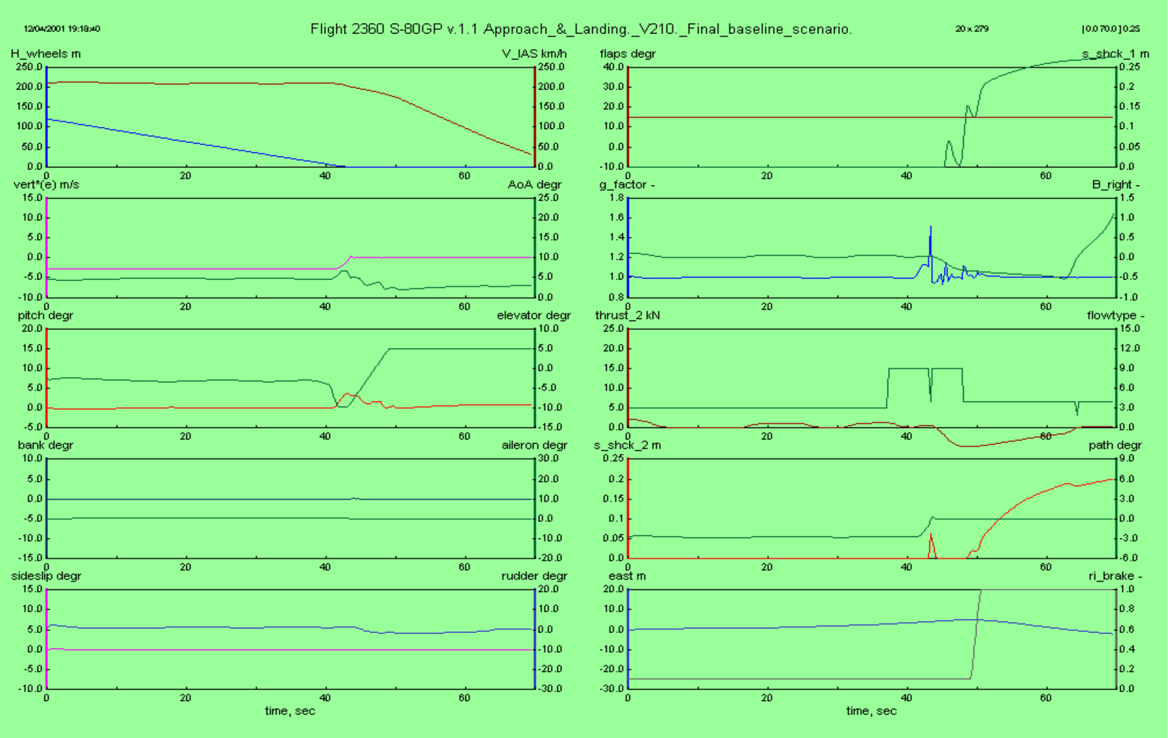


S_{2206}: ”Level flight (wheels - up, left engine out (t = 40 s), 1 s delay of pilot response (in roll and sideslip control) to engine failure”

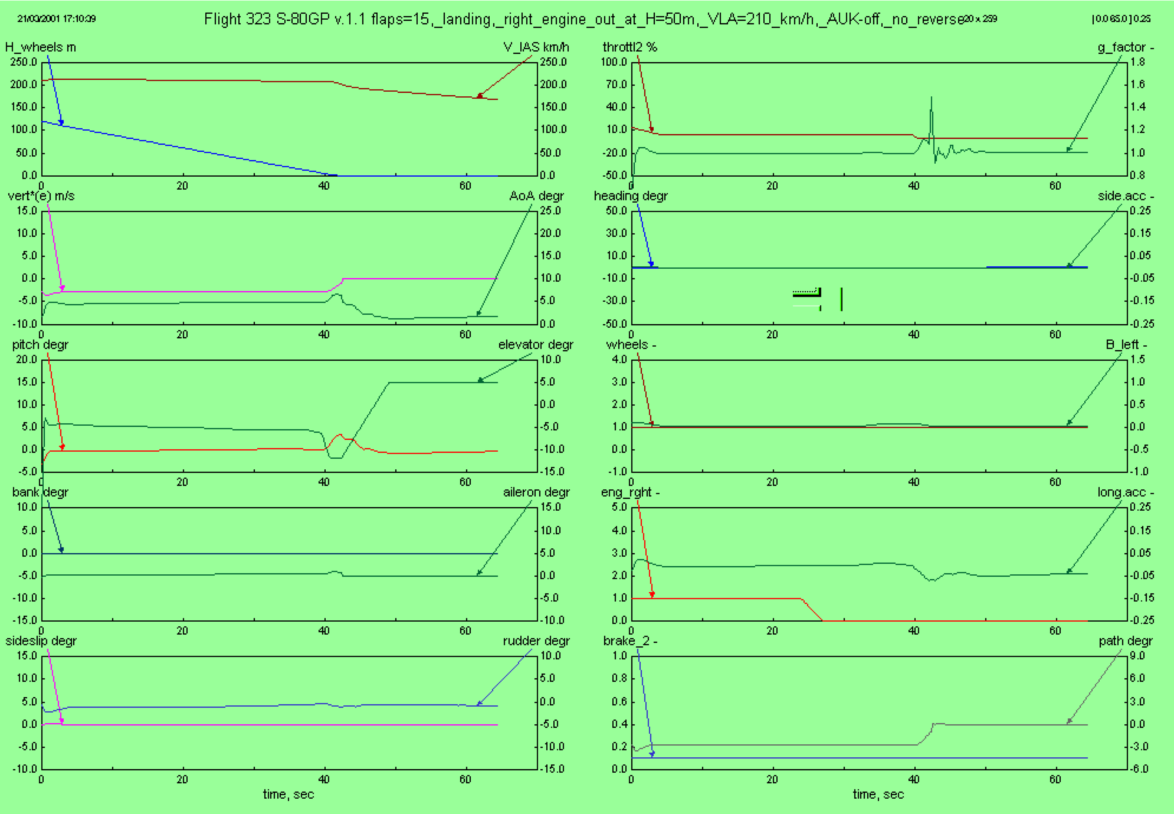


Simulation Examples (Continued)

S_{2360}: ”Landing approach (VLA=210 km/h, δ_{FL}=15^o), normal landing, thrust reverse on and wheel brakes on”

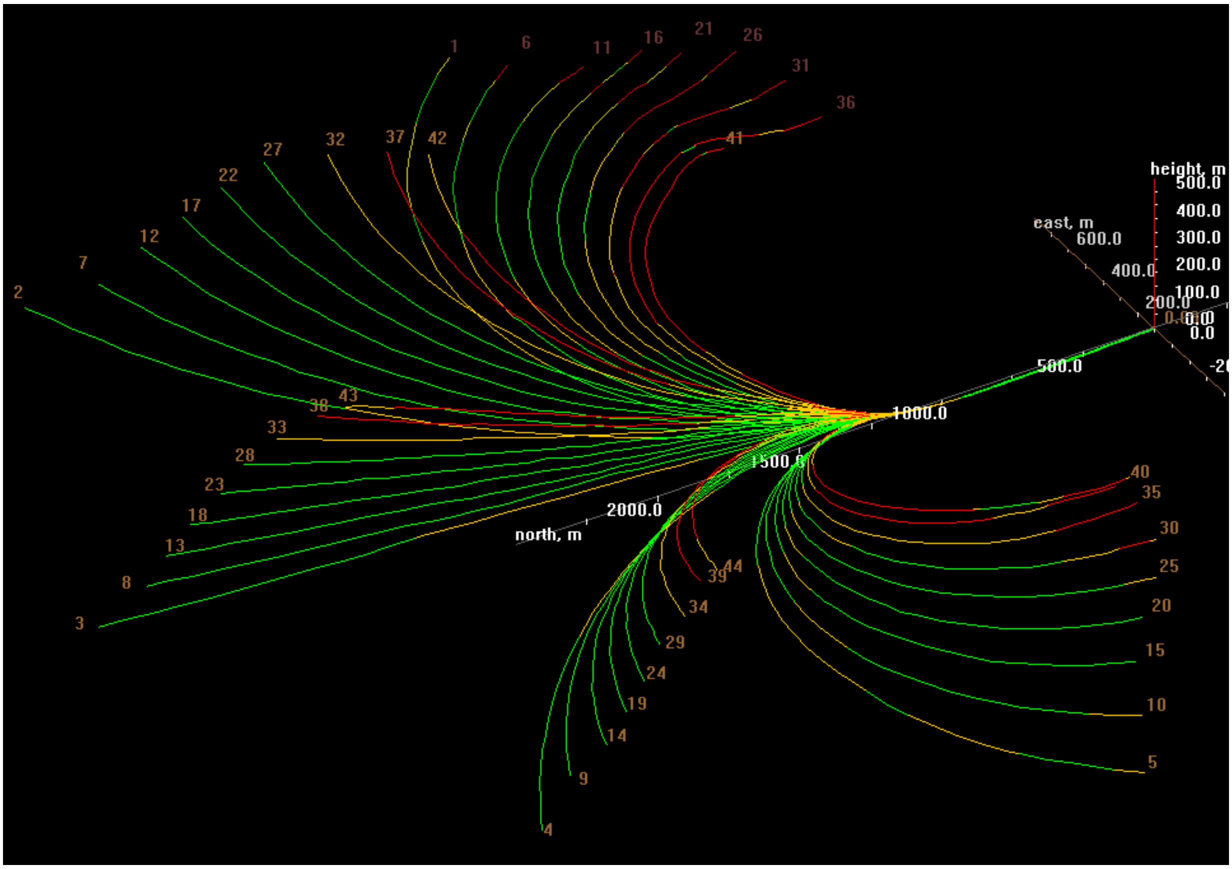


S_{323}: ” Landing approach (VLA=210 km/h, δ_{FL}=15^o), normal landing, right-hand engine out (H=50m), ABC-flap off, thrust reverse off, wheel brakes on”

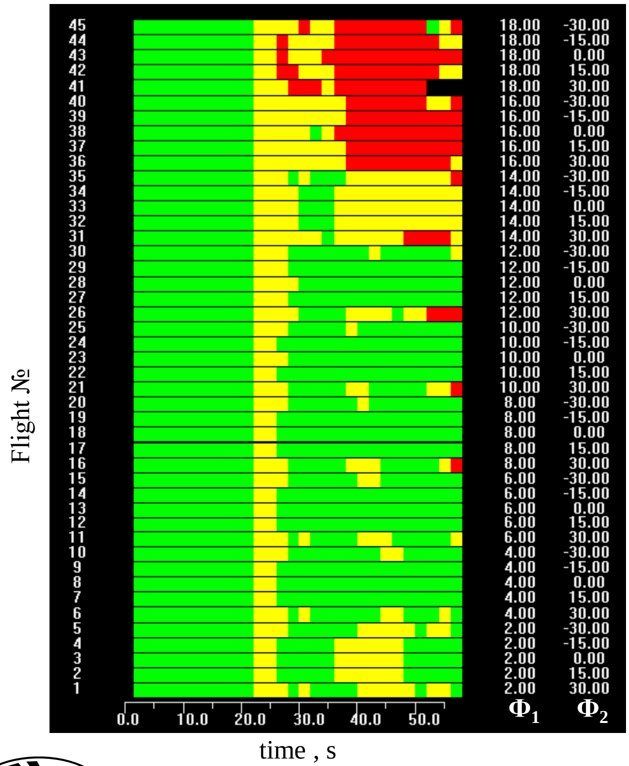


Parallel Analysis of Flight Safety

Situational tree $\mathfrak{I}_{45}$: “Normal takeoff, VR=200 km/h, errors/ variations of climb path and bank angles” (NEH-axes)



Flight safety spectra ($\mathfrak{I}_{45}$)



$\mathfrak{I}_{45}$ statistics and analysis

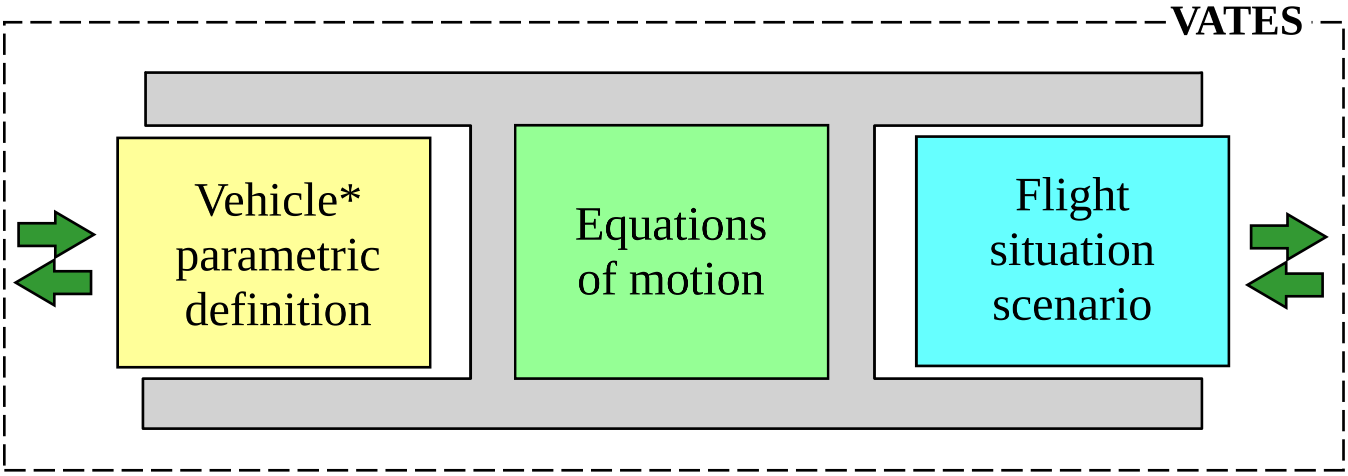
1. Total number of “flight”-branches in $\mathfrak{I}_{45}$ - 45.
2. Number of operational factors under testing - 2, $\mathbf{\Phi_1}$ and $\mathbf{\Phi_2}$.
3. OF $\mathbf{\Phi_1} \equiv$ “variations/errors of flight path angle”, $\Omega(\mathbf{\Phi_1}) = \{2^o, 4^o, \ldots, 18^o\}$.
4. OF $\mathbf{\Phi_2} \equiv$ “bank angle variations”, $\Omega(\mathbf{\Phi_2}) = \{-30^o, -15^o, \ldots, 30^o\}$.
5. Certainly unsafe (prohibited) scenarios: $\mathbf{S_{36}}$, …, $\mathbf{S_{45}}$ - initial climb at flight path angle of 16^o...18^o and with any bank angle.
6. Potentially unsafe scenarios: $\mathbf{S_{16}}$, $\mathbf{S_{21}}$, $\mathbf{S_{26}}$, $\mathbf{S_{31}}$ - climb path angle within 8^o...14^o and right bank of 30^o, $\mathbf{S_{35}}$ - climb angle of 14^o and left bank of -30^o.
7. Conditionally safe scenarios requiring pilot enhanced attention (as flight proceeds close to constraints): $\mathbf{S_{32}}$, ..., $\mathbf{S_{34}}$ - climb path angle of 14^o, bank angle within -15^o... 15^o, $\mathbf{S_1}$, ..., $\mathbf{S_5}$ - climb path angle of 2^o, and bank within -30^o...30^o.
8. Safe scenarios: $\mathbf{S_6}$, ..., $\mathbf{S_{15}}$ - flight path angle of about 4^o… 6^o, and bank angle within -30^o...30^o, $\mathbf{S_{17}}$, ..., $\mathbf{S_{20}}$, $\mathbf{S_{22}}$, ..., $\mathbf{S_{25}}$, $\mathbf{S_{27}}$, ..., $\mathbf{S_{30}}$ - flight path angle within 8^o…12^o, and bank angle within -30^o…15^o.

VFT&E Technique Development History

Functionality evolution

	years	Generalization and/or automation of key functions				
		Vehicle's parametric definition	Equations of motion	Flight situation scenario	Flight safety analysis	Link to other methods
	1977-1983	No	No	No	No	No
	1984-1987	No	No	Yes	No	No
	1988-1992	No	No	Yes	No	No
VATES v.7.1	1993-1996	No	No/Yes	Yes	No	No
	1997-1998	No/Yes	Yes	Yes	No/Yes	No
	1999-2000	Yes	Yes	Yes	Yes	No/Yes
	2001-2002	Yes	Yes	Yes	Yes	Yes

Model current status [6]


VATES

Vehicle* parametric definition

Equations of motion

Flight situation scenario

Legend:	Yes	- fully automated and/or fully generalized function
	No/Yes	- partially automated and/or partially generalized function
	No	- not automated and not generalized function
	⇨ ⇦	- loadable component (unified input data specification)
	*	- fixed-wing aircraft class

Overview of VATES Functionality [10]

Purpose	Autonomous modeling and simulation of the “operator (pilot, automaton)-vehicle-operational environment” system behavior in complex (multi-factor) flight situations
Vehicle class	Fixed-wing aircraft
Modeled motion modes	6-DOF motion, including ground and airborne phases of flight, aerobatic maneuvers, flight test and non-standard situations
Equations of motion	First-order ordinary equations of motion with non-linear right parts in the form of quaternions (permit all attitude flight simulation)
Numeric integration methods	4-th order fixed-step predictor-correctors (four options), 2-nd order Euler variable step (one), and 4-th order fixed-step Runge-Kutta (one)
Simulated aircraft types	22 aircraft and projects in total, including 18 airplanes, two helicopters, one tilt-rotorcraft, and one hypersonic vehicle
Input specification of flight	Any one option from the following list is sufficient: Airworthiness requirements (АП/FAR/JAR, etc.); verbal description of a flight situation; flight test program; flight accident records; Flight Manual instructions; flight test data, flight graph diagrams
Modeled flight phases and modes	Take-off (normal, aborted and continued); landing (normal, continued, go-around); climb, descent and landing approach (any profile); en-route flight modes (any profile); groundroll; aerobatic, special, and test maneuvers
Confirmed application areas	Aircraft virtual flight test and certification, planning and rehearsal of flight test programs, flight incident/accident reconstruction and its neighorhood analysis, checking Pilot’s Manuals under multi-factor conditions, exploration of flight envelope topology under complex conditions, research into automatic flight control, pilot physics-based training, education and PhD research
Modeled operational conditions (factors)	Normal and demanding flight conditions and attitudes, vehicle weight, C.G. travel, moments/products of inertia, onboard system failures (engines, control, undercarriage, etc.) and system logic errors, piloting tactics and pilot errors, atmospheric conditions (air density and pressure), wind (any 3-D profile: wind shear, gusts, sidewind, microburst, etc.), air turbulence (two models), rain (effects on vehicle aerodynamics), wet, dry, water-covered runway, dynamic and uneven runway surface, any required combinations of the these factors
Solved problems	Over 40 problems in the areas of applied aerodynamics, flight dynamics, flight control and flight safety
Input characteristics	Fully loadable (generalized input data format), 1-, 2-, and 3-dimensional lookup tables, up to 500 input characteristics
Flight situation model	Discrete-continuous model; up to 100 events and 200 processes per scenario; any combination of flight dynamics, flight control and demanding operational conditions, including pilot errors, mechanical failures, demanding weather, etc.
Type of “silicon pilot” model	Discrete-continuous multi-step situational (tactical) decision making at three levels: (1) scenario-based flight situation planning contour; (2) situational control contour using “piloting tasks”, “system state observers”, and “control procedures”; the system state observer model includes: observed state variables, gains, goals, errors, insensitivity of state observations, and other parameters, and (3) automatic response (stimulus-response) control contour
Examined scenarios	Over 400 standard and non-standard flight scenario types
Output data/ knowledge visualization formats	Flight time history tables (up to 20 variables per table), flight time history plots (up to 20 variables per plot), flight scenario time history, flight experiment statistics, flight scenario time history diagram, 2-D/3-D phase diagram, 2-D/3-D flight path profile, 4-D “flight movie” diagram, 3-D “flight path-roll ribbon” diagram, 3-D “flight path-events” diagram, 3-D “flight path-roll ribbon-events” diagram, situational tree diagram, flight safety/operational effectiveness spectrum, flight situation complexity diagram, multiple constraint violation dynamics/logic diagram, etc.
Required equipment and user qualification	PC; programming and piloting skills are not required; manned flight simulator is not required; general knowledge of flight dynamics and flight control principles is required

VATES Technical Characteristics

Number of equations	13-40
Programming language	FORTRAN (MS DOS, VMS, VM/CP, OS/360, NDP)
Flight simulation speed (on PIII 500 MHz PC)	~4-10:1 (groundroll motion) ~20-50:1 (airborne modes)
Time to develop a flight scenario "from scratch"	20-30 min
RAM requirements	480-1500 Kbytes
Disk memory per scenario	10-30 Kbytes
Number of input characteristics	~20-50: Il-62M, Tu-134, HSCT ~120-350: Tu-204, Il-96-300, XV-15, Boeing-737
Max size of input characteristics table	practically unlimited
Maximum number of model objects	200-500 (flight variables), 100 (flight events), 50 (piloting tasks), 100 (state observers), 100 (control procedures and failures), 25 (time-histories), 10 (wind, rain, icing for each)
Applications:	
- number of aircraft	22 (16 flying, 6 projects, fixed- and rotary wing)
- number of problems	> 40 (applied flight dynamics and flight safety)
- number of scenarios	> 400 (operational, test, aerobatic, accidental,etc.)

Flight Testing and Manned Simulation
Vs.
Autonomous Modeling & Simulation

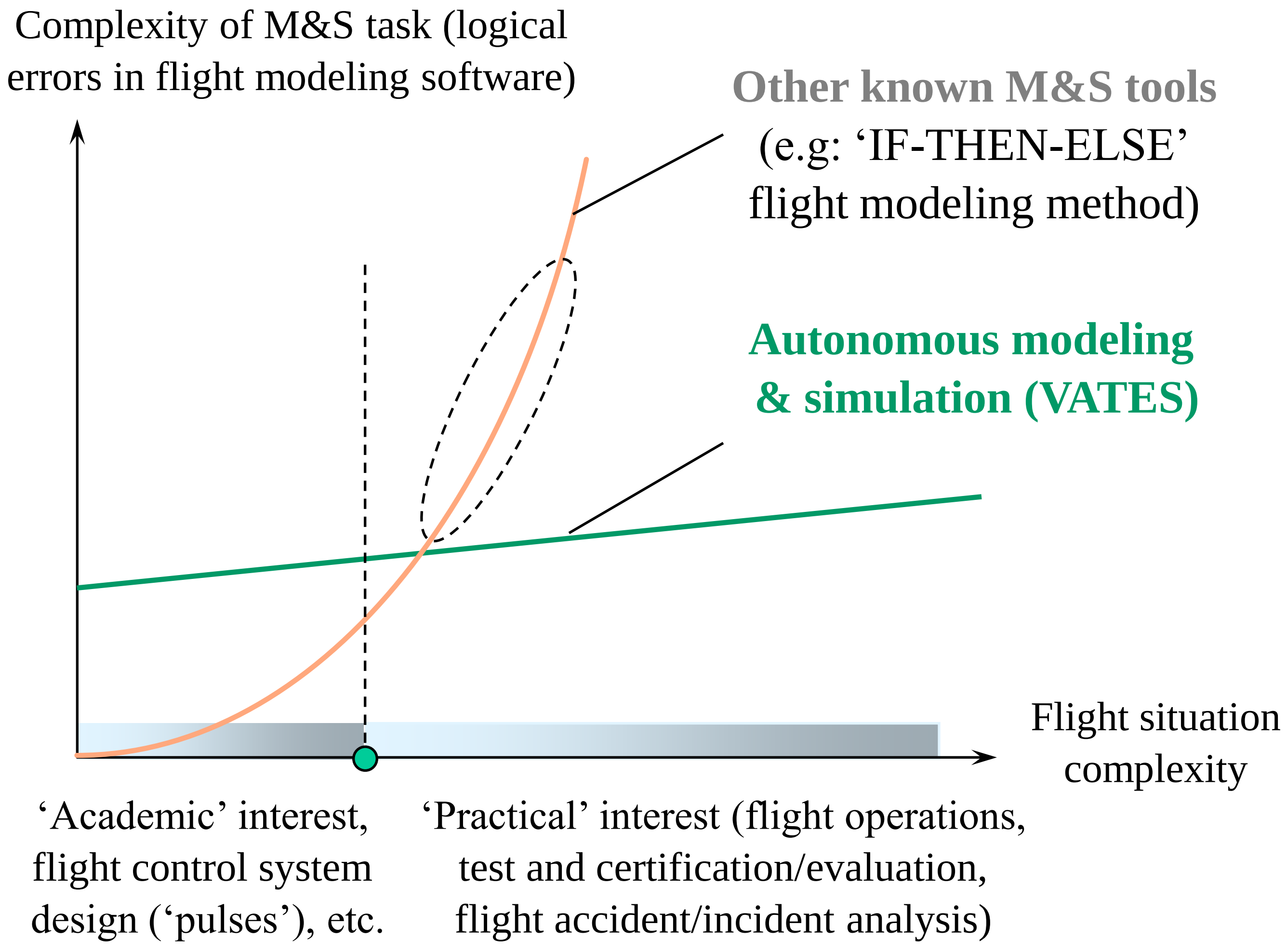
Comparison criterion	**flight test**	**manned simulation**	**autonomous M&S**
• addressing extreme/rare flight conditions	NO	YES*	YES*
• systematic exploration of broad flight domains	NO	NO	YES
• affordability to set up and run experiments	NO	NO	YES
• thorough check of combined effects	YES**	NO	YES*
• broad use in aerospace research & education	NO	NO	YES
• accuracy and fidelity of output results	YES	YES*	YES*
• “what-if” experimentation capability	NO	YES**	YES
• autonomy, independence (of pilot/equipment)	NO	NO	YES
• scenario repeatability/automation/preservation	NO	YES**	YES
• fast-time performance of flight	NO	NO	YES
• safety of experimentation	YES**	YES	YES
• suitability for pilot training	YES**	YES	YES**

Note: (*****) depends on the fidelity of the flight dynamics model
(******) limited capability

VFT&E technique is complementary to flight test and manned flight simulation techniques when studying complex (multi-factor) flight domains

VFT&E: Main Advantage (1) and Main Limitation (2)

(1) The complexity of the flight scenario planning and simulation task does not depend on the complexity of a flight situation under examination



Complexity of M&S task (logical errors in flight modeling software)

Other known M&S tools (e.g: ‘IF-THEN-ELSE’ flight modeling method)

Autonomous modeling & simulation (VATES)

Flight situation complexity

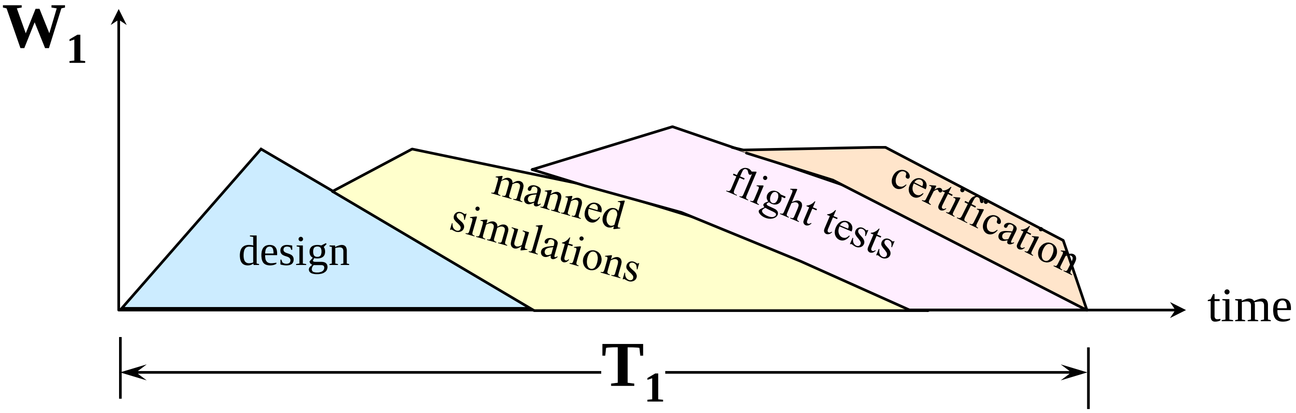
‘Academic’ interest, flight control system design (‘pulses’), etc.

‘Practical’ interest (flight operations, test and certification/evaluation, flight accident/incident analysis)

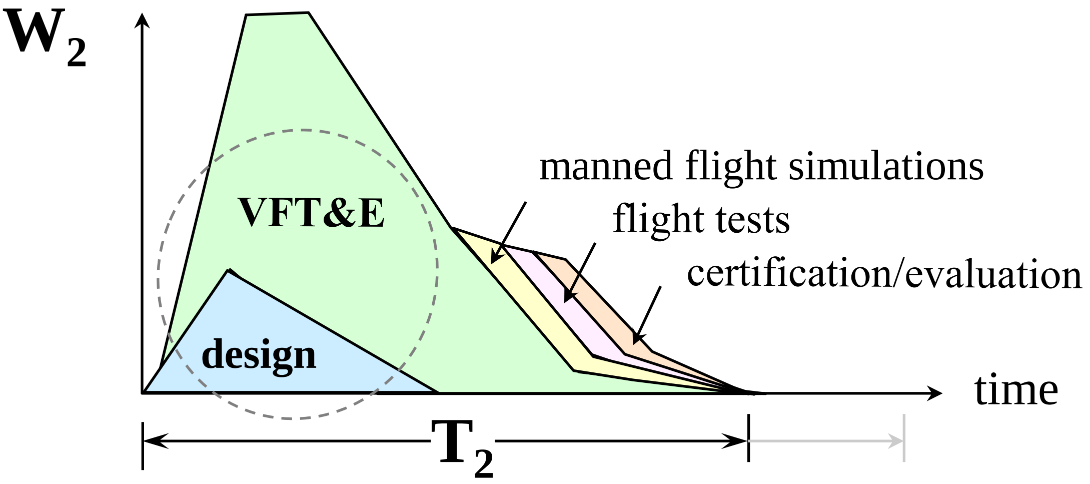
(2) However, in order to obtain reliable engineering results from the autonomous flight situation model it is required to have a complete “parametric definition” (input characteristics database) of the vehicle/project and its subsystems for all examined values of AoA and sideslip, other parameters, and similarity criteria

Present Vs. Proposed Flight T&E Cycle

Existing cycle - extensive and separated



VFT&E-based cycle - intensive and integrated



W - knowledge obtained in advance with respect to vehicle flight safety

T - overall R&D cycle time

C - T&E/C cost

Goal: $W_2 >> W_1$, $T_2 < T_1$, and $C_2 << C_1$

Conclusions

1. VFT&E is a new applied technique designed to study the «operator (pilot, automaton) - vehicle - operational environment» system behavior in complex flight situations. The technique demonstrates a set of important properties: systematic character (thoroughness), productivity, flexibility, affordability, sensitivity, capability of performing up-front analysis of flight safety, etc.

2. VFT&E can be used for a large-scale advanced numeric analysis of various non-standard flight situations - hypothetical, real and mixed cases. This technique allows to rehearse flight test programs, examine unknown and potentially unsafe maneuvers and flight modes, conduct reconstruction and ‘what-if’ analysis of flight accident/incident ‘neighborhood’, reveal topology of a complex flight domain at operational constraints

3. Simulation experiments with the autonomous flight situation model (the VATES tool) run 10-50 times faster than real flight time (on a standard PC). Piloting and programming skills are not needed for model users

4. Formalization of flight scenarios in the form of oriented graph (the “events-processes“, discrete-continuous, flight specification language) helps study system’s cause-and-effect links, which determine operational safety and mission effectiveness of flight under complex (multi-factor) conditions. Such scenarios can be derived from various sources, including: airworthiness requirements (АП, FAR, JAR), AC, flight test programs, flight accident/ incident records, verbal/graphic descriptions of flight, and Flight Manuals

5. The VATES tool allows to accumulate compact, yet comprehensive libraries of flight scenarios on computer. These libraries can be arranged by various criteria, such as: airworthiness requirements sections, Fight Manual chapters, flight accident/incident types, training program syllabus. Once having being designed and tested, they can be re-played for the same or other vehicle type in the future, in exact detail or modified as needed. Output sets of “flights” can be automatically depicted and further analyzed on PC in the form of situational trees, flight safety spectra, and other knowledge mapping formats specially developed to map key physical, logical, and safety (mission effectiveness) relationships in the system behavior

6. The vehicle’s aerodynamics database and mathematical models of flight are used most efficiently through the VFT&E process. The tool helps focus manned simulation and flight test scenarios. By adding the VFT&E phase to the R&D cycle it is expected to substantially increase the volume and quality of predictive information on the vehicle flight safety before maiden flight

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