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**N91-17576**

Formally specifying the logic of an automatic  
guidance controller

David Guaspari

Odyssey Research Associates

Truth arises more readily from error  
than from confusion.

Francis Bacon  
*Novum Organum*

## The Penelope project:

- Interactive, incremental, tool for formal verification of Ada programs (Larch/Ada specifications).
  - Structure or ordinary text editor
  - Permits development of program and proof in concert, “reuse by replay”
- Covers large subset of sequential Ada.
- Mathematically based.

Problem: specify “logic” of experimental Automatic Guidance Control System for a 737

- Pilot requests kind and degrees of automatic assistance
- Requests may be honored, disallowed, “put on hold
- Responses must be displayed

## Work-in-progress: Larch/Ada specification

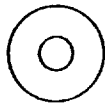
- Formal specification of Ada code
- Goals: precise; intelligible to designers and implementors
- Currently wrong, but clear

## Related work

- Original code (CSC)
- Experiment in redesign (NASA)

19500

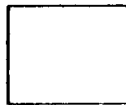
2.3



ALT  
ENG

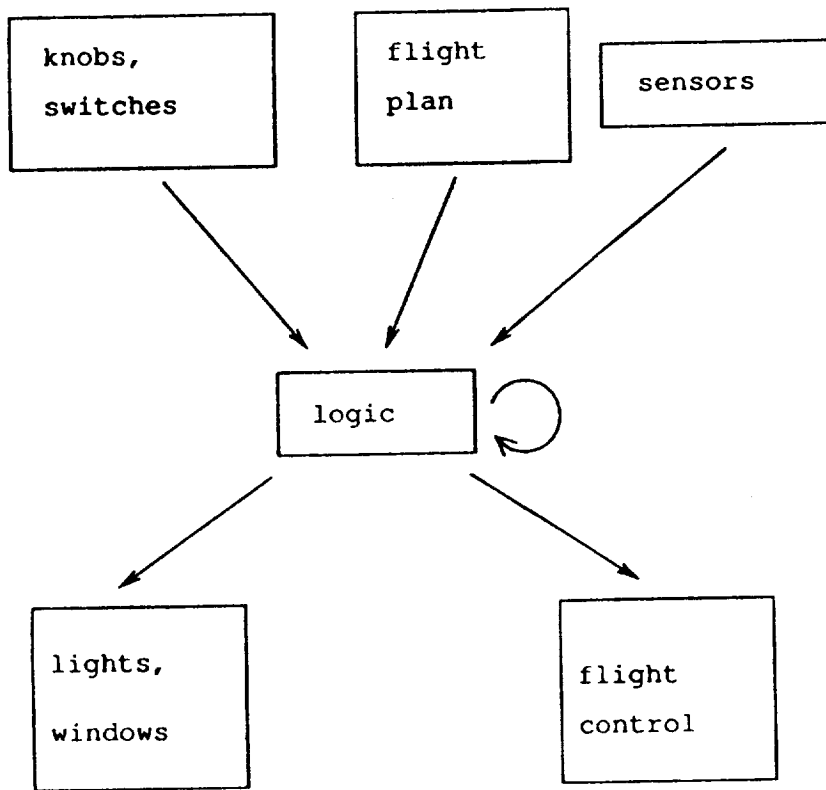


FPA  
SEL



VERT  
PATH





## Some failures of informal description

1. Ambiguous: “Select” a switch vs. “select” a mode.
2. Incomplete: “CAS ENG may be engaged independent of all other AGCS modes except TIME PATH.”
3. Contradictory:
  - FPA ... cannot be deselected directly.
  - [if] ... appropriate selection of the FPA SEL ... switch returns the mode to the off state ...



Larch/Ada specifications: “two-tiered”

- Mathematical part (Larch Shared Language):  
defines vocabulary
- Interface part (Larch/Ada): uses vocabulary to specify code

Example: specifying executable addition

Mathematical part: defines mathematical  $+$  on *Int*, the (infinite) domain of mathematical integers

Interface part: Specifying evaluation of  $x+y$

- Type integer is “based on” *Int*.
- Return value  $(x + y)$  if

$$\min \leq (x + y) \leq \max.$$

No side effects.

- Otherwise, raise `numeric_error`. No side effects.

The mathematical part

States: AGCS\_state, Sensor\_state, etc.

Actions:

{alt\_eng\_switch, ..., alt\_eng\_knob(i), ...,  
alt\_capture, ... }

Modes:

{alt\_eng, fpa\_sel, vert\_path, ... }

Transition operation:

AGCS\_state, Action, ...  $\rightarrow$  AGCS\_state

Observers: active2d, display, ...

Building mathematical part (the AGCS states)

**AgcsStructure : trait**

AGCS\_state record of

(on: Bool,

modes: Set\_of\_modes,

engaged: Engagement\_status,

setting: Value\_settings,

window: Window\_array)

**includes** Set(Mode,Set\_of\_modes)

...

**introduces**

transition:

AGCS\_state, Action, Sensor\_state,

Flight\_plan → AGCS\_state

initial\_on\_state: → AGCS\_state

**asserts**

...

## Description of mode changes caused by switches:

- Is the mode directly deselectable?
- What mode changes result?
- Under what conditions is the mode directly selectable?
- What mode changes result?

Building mathematical part (mode changes)

HorPathSwitch : **trait**

**includes** SwitchShell{hor\_path}

**asserts for all**

[agcsmodes: Set\_of\_modes,  
pl: Flight\_plan,  
sens: Sensor\_state]

hor\_path\_deselectable

hor\_path\_selectable(agcsmodes,pl) =

(auto  $\in$  agcsmodes)  $\wedge$  active2d(pl)

hor\_path\_selection\_result(agcsmodes,sens,pl) =

[hor\_path]  $\cup$  [[cas]]

hor\_path\_deselection\_result(agcsmodes) =

[tka\_sel]  $\cup$  [[cas]]

Intuitive description of window status (*chosen* vs. *current*):

- The  $w\_knob$  makes the corresponding  $w$ -window chosen.
- Any action selecting the  $w$  mode makes the  $w$ -window chosen.
- Any action deselecting the  $w$  mode makes the  $w$ -window current.
- Any other action leaves the status of the  $w$ -window unchanged.

Building the mathematical part (window changes)

StatusShell : **trait**

**imports** AgcsStructure

**introduces**

**#.component** :

Window\_array → Window\_status

md: → Mode

knob : Value → Action

**asserts for all** [agcs:AGCS\_state, ...]

**abbreviation**

agcs' == transition(agcs,act,sensor,plan)

agcs'.window.component =

**if** md ∈ agcs'.modes - agcs.modes

**then** chosen

**elsif** md ∈ agcs.mode – agcs'.modes

**then** current

**elsif** act = knob(i) **then** chosen

**else** agcs.window.component

Example: StatusShell{alt,alt\_eng,Airspeed}



## Design of the code:

- Packages `panel_logic`, `display_manager`, `sensor_data`, `flight_plan`, `flight_control`.
- State of `panel_logic` based on `AGCS_state`, etc.
- Actions  $\mapsto$  procedures of `panel_logic`:
  - read state of `panel_logic`, `sensor_data`, `flight_plan`
  - modify states of `panel_logic`, `display_manager`, `flight_control`
- Consistent with polling, interrupts, etc.

Specifying the code:

```
--| WITH TRAIT AgcsLogic, AgcsProperties,  
--|           LogicalDisplay  
--| WITH sensor_data, flight_plan,  
--|           display_manager, flight_control  
  
with sensor_data_types; use sensor_data_types;  
package panel_logic  
  --| BASED ON AGCS_state  
  --| INVARIANT  
  --| panel_logic.on -> good(panel_logic)  
  --| INITIALLY not panel_logic.on  
  ...  
  
end panel_logic;
```

```

procedure att_cws_switch;
--| WHERE
--|   GLOBALS IN   panel_logic
--|   GLOBALS OUT display_manager,
--|                 flight_control,
--|                 panel_logic

--|   IN panel_logic.on

--|   OUT panel_logic =
--|     transition(IN panel_logic,
--|                 att_cws_switch,*,*)
--|   OUT FORALL ss: Sensor_state::
--|     look(display_manager,ss) =
--|     display(panel_logic,ss)
--|   OUT FORALL md:mode ::
--|     fc_engaged(md,flight_control) =
--|     engaged(md,panel_logic)
--| END WHERE;

```

```
procedure turn_on_agcs
--| WHERE
      ...
--|   OUT panel_logic = initial_on_state
      ...
--| END WHERE;
```