Overview of the PLEXIL Plan Execution Technology and its Applications in Autonomous Piloting Projects at NASA

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Proud history, bright future.

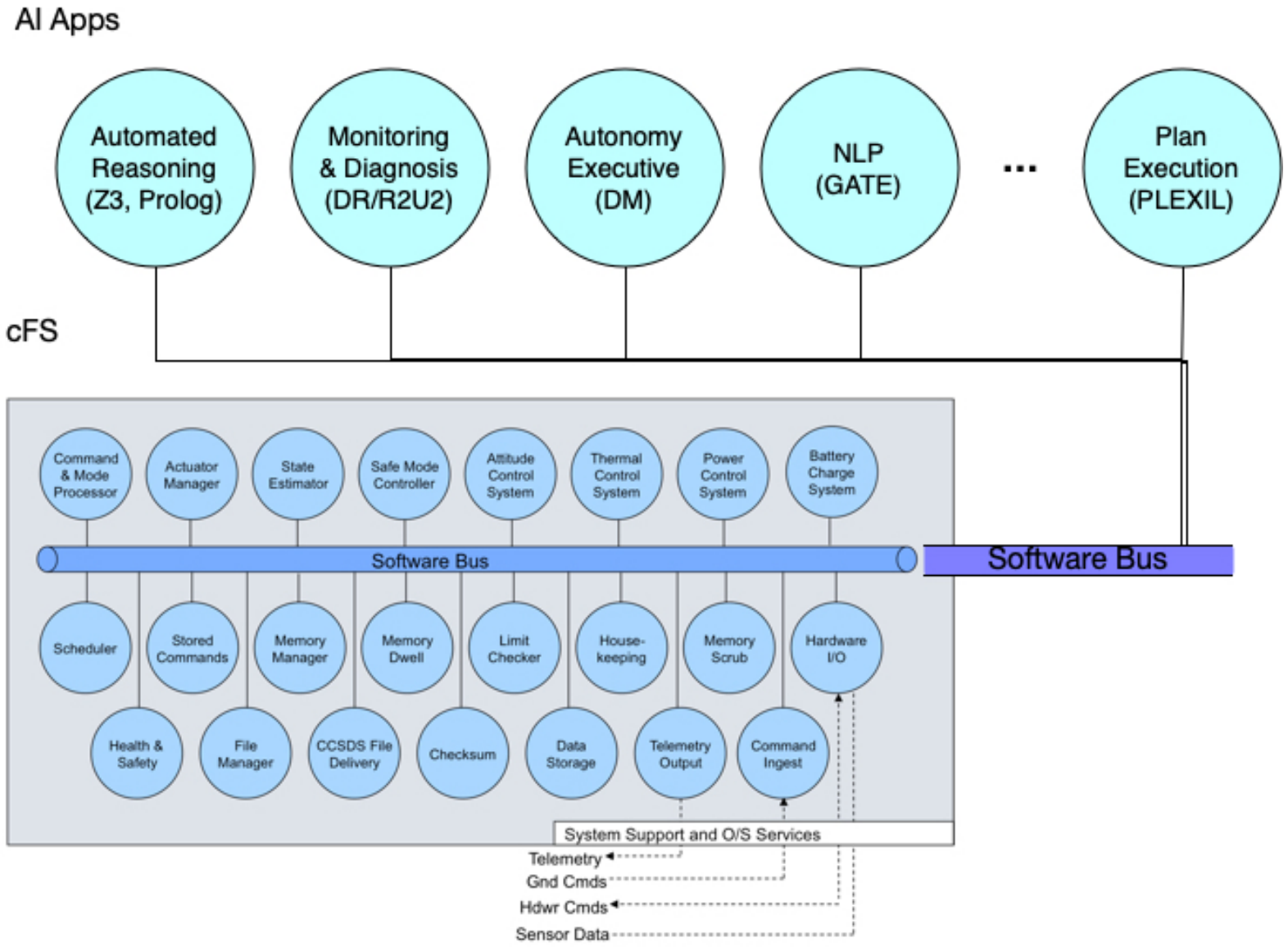
Autonomy Operating System (AOS) for UAS

- AOS software is NASA's Core Flight System (cFS) + AI engines
- AOS project is a feasibility study. Can AOS…
  - be an open standard for verifiable, certifiable UAS flight software?
  - be a reusable software platform, with associated verification technology, for UAS autonomy app development?
  - enable UAS to safely and reliably fly themselves in the National Air Space, behaving as a certified pilot? ("Pilot in a Box")

“Pilot in a Box” – Technical Challenges

- Perform reasoning and decision-making needed for aviation
  - Aviate, Navigate, Communicate
- Communicate with Air Traffic Control (ATC)
  - Process clearances: understand, validate, readback, execute
- Formalize pilot procedures and execute them autonomously
  - Selected en-route, VFR/IFR approach procedures
  - Lost communication procedures

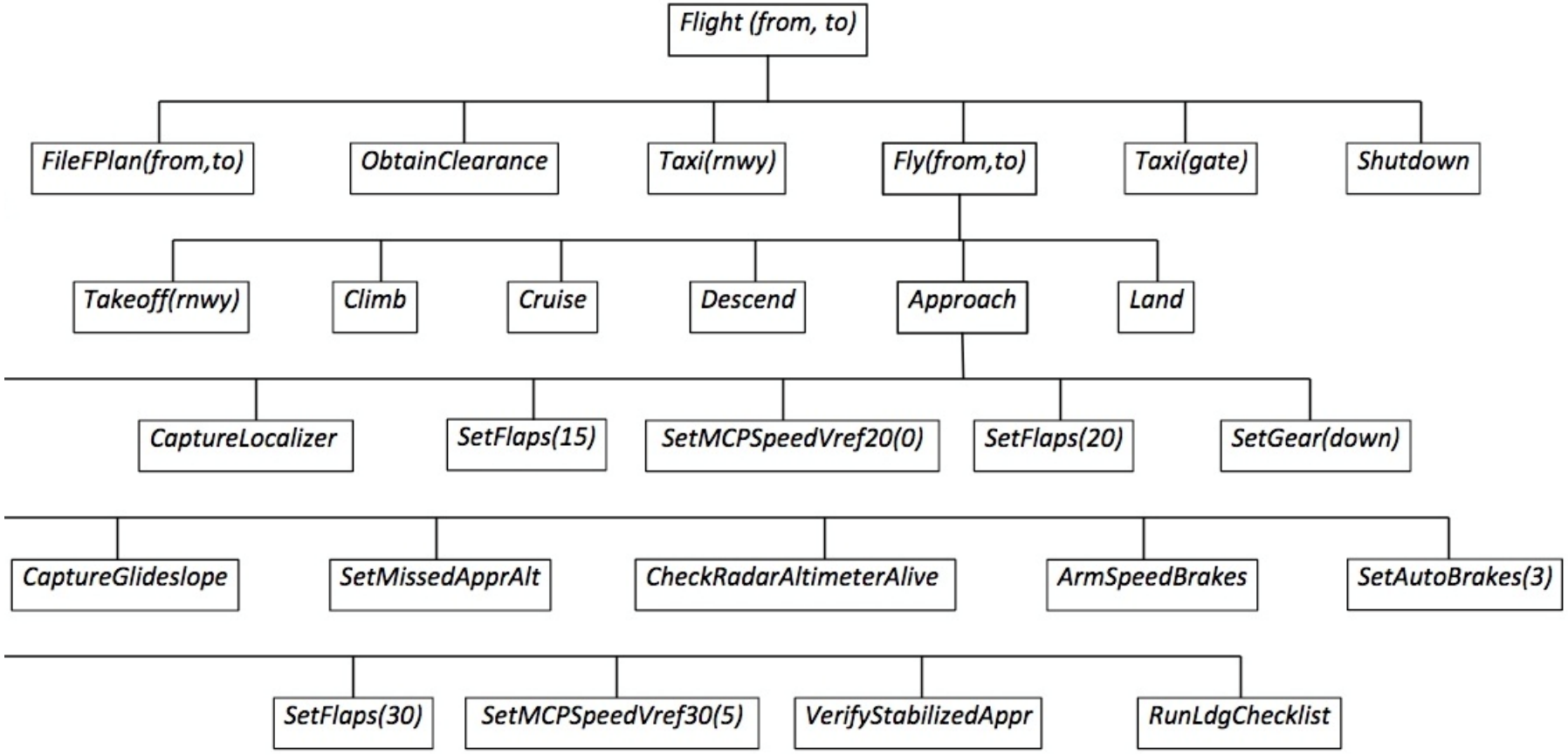
AOS Architecture



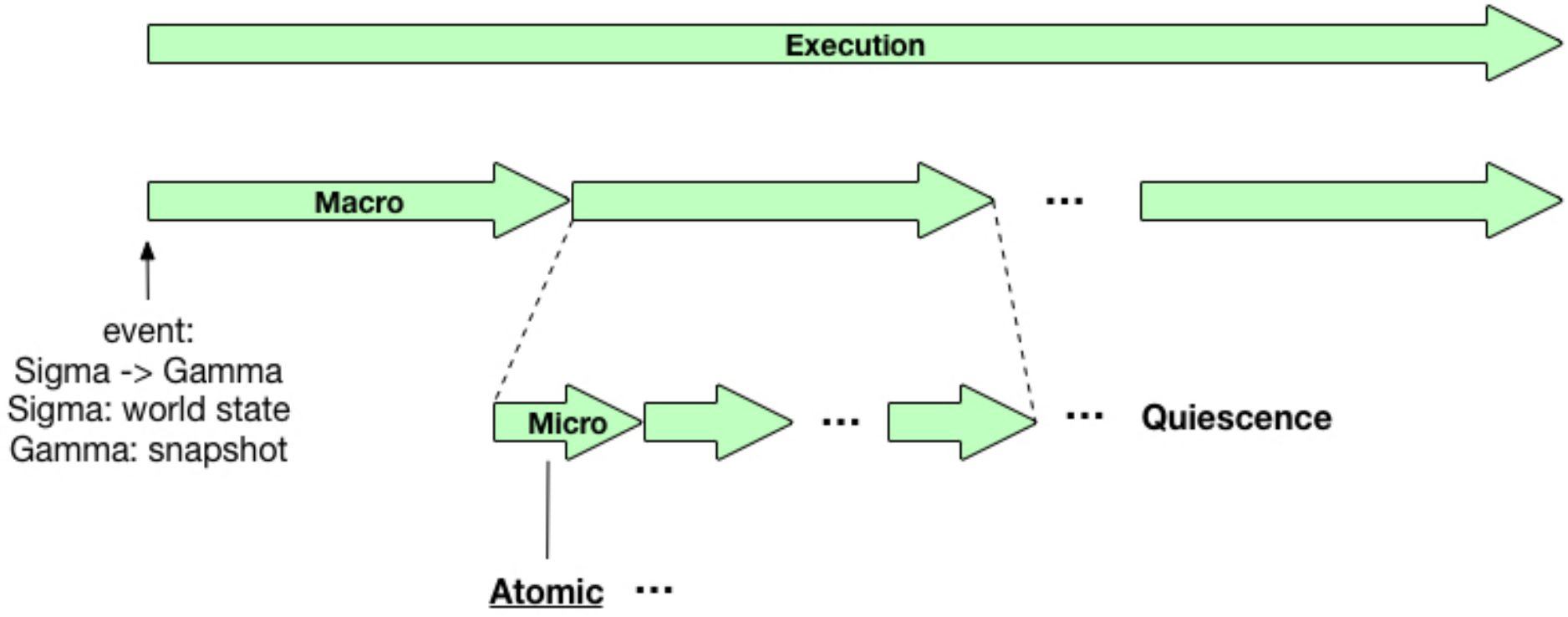
PLan EXecution Interchange Language (PLEXIL)

1. **Language** for encoding plans for automation
   - Synchronous, reactive
   - Hierarchical, partially ordered plans
   - Condition and event-driven logic
   - Variety of control: concurrency, conditionals, loops
   - Formal semantics with proven properties
2. **Software** for executing plans on real or simulated systems
   - Executive (runs under Unix, Linux, embedded systems)
   - Tools: GUI, translators, checkers

Hierarchical Plans



PLEXIL Formal Semantics : layered relations



$$\frac{(\Gamma,\pi) \vdash \texttt{A.start} \rightsquigarrow \mathit{true} \quad (\Gamma,\pi) \vdash \texttt{A.pre} \rightsquigarrow \mathit{true} \quad \texttt{A.status} = \mathit{Waiting}}{(\Gamma,\pi) \vdash \texttt{Node A} \longrightarrow \texttt{Node A with [status = } \mathit{Executing} \texttt{]}}$$

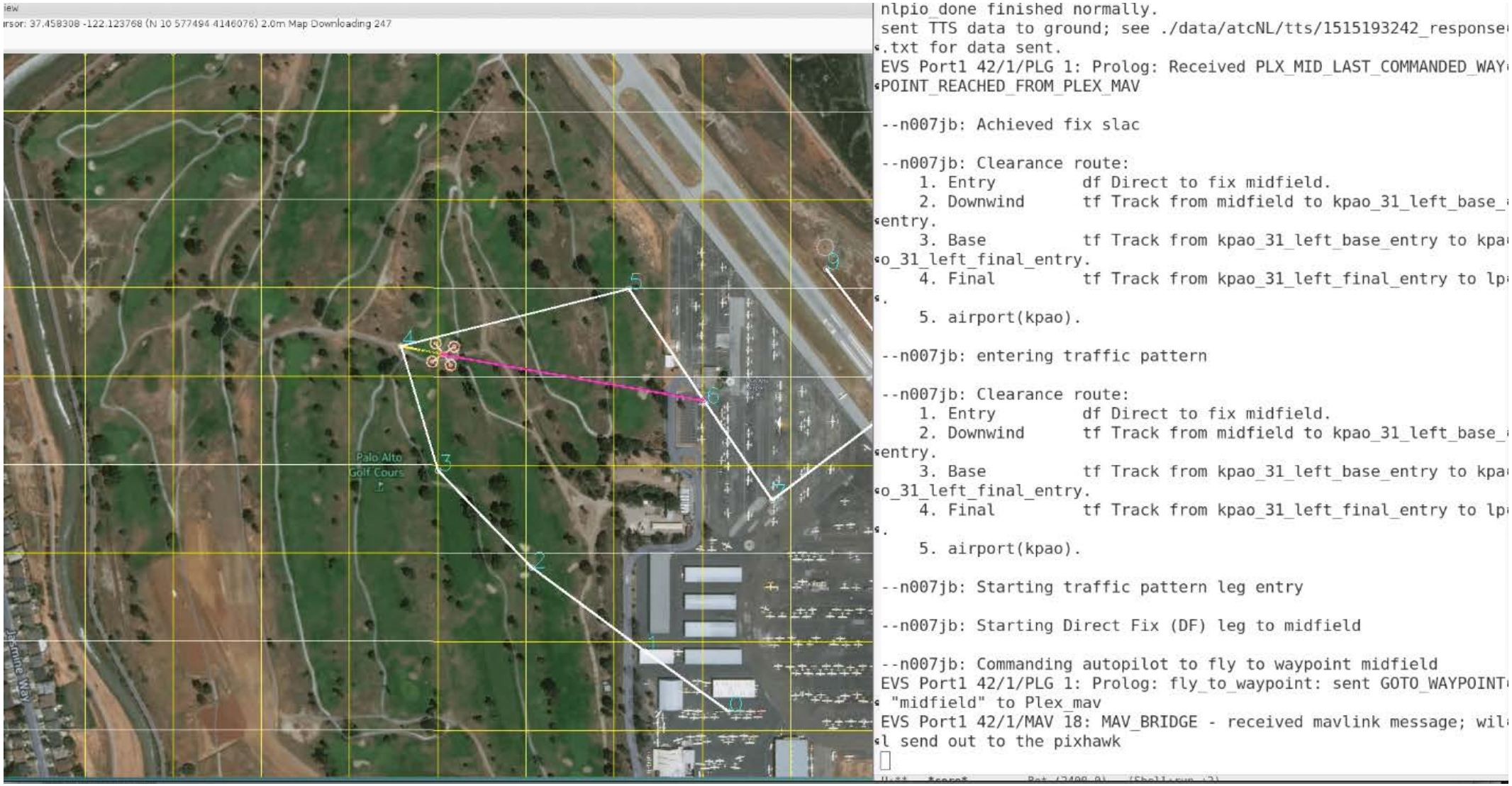
PLEXIL Example : concurrent monitors

```
MonitorLoop: {
  RepeatCondition reset;
  reset = false;
  Monitor : Concurrence {

    Off_FP:
    {
      StartCondition Nominal && !Lookup(OnExpectedFlightPath);
      SkipCondition reset;
      alert (aircraft_ID, alert_ID, Caution, "Off flight path");
      Nominal = false;
      reset = true;
    }

    On_FP:
    {
      StartCondition !Nominal && Lookup(OnExpectedFlightPath);
      SkipCondition reset;
      cancel_alert (aircraft_ID, alert_ID);
      alert_ID = alert_ID + 1;
      Nominal = true;
      reset = true;
    }
  }
}
```

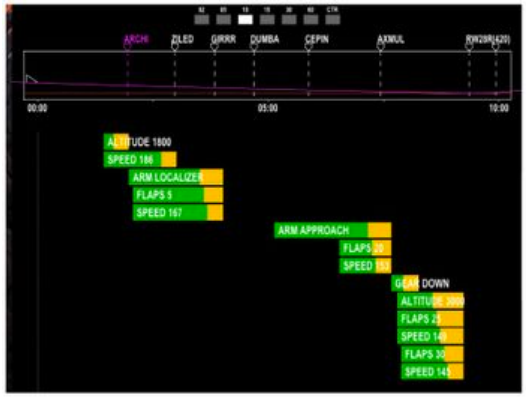
Simulated Scenario : VFR approach



Related Work

- Potential AOS follow-ons
  - Open sourcing of AOS
  - Collaboration with private industry
  - Incorporation on varied UAS

- Other aviation projects using PLEXIL
  - ICAROUS – open-sourced UAS architecture (NASA Langley)
  - Cockpit Hierarchical Activity Planning and Execution - CHAP-E (NASA Ames)



Thank you!

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PLEXIL home:

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