Accelerating Technology Maturity via Rapid Debug and Redeployment

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Issue

- Recent studies/audits cite use of immature technology during E&MD as a leading cause of program failure
  - GAO, DAU, Rand, National Academy of Sciences & Air Force Studies Board, OUSD/AT&L
  - WSARA requires mechanisms that allow for deferral of technologies that are not yet mature
- Simultaneously, government & industry need to accelerate delivery of capabilities that rely on emergent technologies
- Data point: Phase IIB GPS program, where the same T&E plan/method produced different technology maturity results
  - Each receiver type had functional/performance qual, SIL, OT
  - Their contributions to maturity were radically different

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Developing 1st Generation GPS Receivers (1979-1984)

- Accelerating maturity was a result of increasing the information flow among planners, developers, testers
  - Increasing the bandwidth, reducing the latency
- This increased the number of experiments, observations (failures, anomalies) per test …
- … which increased the error/weakness detection rate for the architecture, design, algorithms, components
- Enabled by facilities & process that increasingly allowed information to move along the fastest/easiest path

Facilities: 5-Channel Prototype Receivers

- Five types for fixed wing aircraft & submarine
  - Each had common positioning hardware & software, but vehicle-unique external interface hardware & software
  - Each type was tested on a different representative vehicle – F-16, B-52, A-6, C-130, SSN-688 (class)
- Lab receivers were RAM-based & edge-connector reprogrammable, allowing machine code patching
  - Accelerated root-cause analysis – e.g., via breakpoints in the code
  - Allowed evaluation of alternative approaches to signal acquisition, satellite selection, multipath rejection, time-aided acquisition, etc.

Facilities: Contractor Simulation & Evaluation System (SEVS)

- Hardware-in-the-loop simulator & signal generator
  - Fed receiver time-correlated satellite signals, onboard sensor inputs under user-defined host vehicle velocity/acceleration/jerk scenarios
  - Time-correlated truth data for receiver error determination

- Processor controller/monitor
  - Monitor memory, stop/start processor local bus, capture/store processor local bus traffic, insert patches, install new load module

- JPO, IV&V contractor helped define scenarios that reproduced & explored observed pathologies
  - Run scenario, monitor receiver's real-time behavior, collect instrumentation data for post-test analysis

Facilities: Tracking Center at Yuma Proving Grounds (YPG)

- Laser tracking system established and recorded time-tagged, second-by-second ground truth
- Telemetry link received & recorded receiver's time-tagged instrumentation data – e.g., position, velocity, acceleration
- Ground system time-correlated receiver's data with ground truth & identified errors & anomalies from the differences
- Post-flight debriefs identified anomalies not obvious in the recorded data

Facilities: System Integration Labs

- RAM receivers connected to development rack were integrated with onboard systems
  - Used sensors, cables, connectors, protocols identical to the host vehicle's – e.g., INS over 1553, NTDS
- Developers could patch software, define experiments, add & change tests on-the-fly
  - Software was heavily instrumented, data was instantly available
- Significantly accelerated the maturity of receiver's host vehicle interface hardware & software
  - Exposed many errors & weaknesses
- Had little impact on positioning hardware/software maturity

Operational Test: C-130 (1980/81)

- Process
  - Test plan/procedure was formal & allowed little deviation
  - Field Service Engineer (FSE) accompanied missions, monitored receiver performance via Control-Display Unit (CDU)
  - FSE post-processed instrumentation data, provided oral summary to developers same/next day; provided data 2-7 days later
  - No accurate time-correlation of instrumented data with flight profile, engineer observations (via CDU), or IRCC data
  - IRCC telemetry data & ground truth mostly unavailable to developers; developer data mostly unavailable to testers, planners
  - No redeployments

- Positioning failures/anomalies observed, but few errors & weaknesses identified & fixed
  - Testing confirmed basic positioning capability

Operational Test: SSN (ca.1982/83)

- Process
  - Allowed deviation from formal test plan to explore failures & anomalies: altered condition testing to increase observations
  - Contractor FSE accompanied missions, monitored receiver performance via CDU - testing became an ad hoc collaboration
  - No instrumentation - observations from tests available to developers when sub returned to port
  - No ground truth – positioning “errors” estimated by deviation from inertial solution
  - 1 redeployment

- Little increase in observed failures & anomalies or identified positioning errors & weaknesses
  - Confirmed unique capabilities – e.g., time-aided signal acquisition
  - Reduced latency of some information, but also reduced bandwidth

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Operational Test: F-16 (summer 1984)

- Process
  - Developers could observe missions at YPG & suggest impromptu tests to increase amount of information collected from each flight
  - Immediate developer access to YPG time correlated data
  - Developer access to aircraft at Nellis AFB for *in situ* static test & debug (e.g., development rack under nose of aircraft)
  - Used instrumentation, YPG ground truth, pilot debrief to reproduce pathologies & confirm hypotheses in SEVS
  - Used 3 receivers for sometimes daily redeployment (1 in aircraft, 1 in SEVS, 1 in transit) on a 24-hour ship-install-fly cycle

- Significant increase in observed failures & anomalies, in identified positioning errors & weaknesses
  - Significantly increased information bandwidth, reduced latency
  - Design, algorithmic changes made to all software functions
  - Cuts/jumps, firmware changes made to nearly all circuit boards

Results & Observations

- JPO found formal/informal, authorized/unauthorized ways to increase information bandwidth, reduce latency
  - Maturity rate = $dm/dt \approx f(\text{bandwidth}/\text{latency})$
  - Acceleration ($d^2m/dt^2 > 0$) required more information, faster

- Phase III (ca. 1985-1989) maturity comparison
  - RFP redefined external interfaces, requiring redevelopment of interface hardware & software
  - Required 184 mid-development ECPs, mostly against the interfaces
  - At T&E outset, interface hardware & software were still volatile
  - Phase III changed few positioning requirements, resulting in stable hardware & software
  - Residual positioning errors & weaknesses were primarily in areas where Phase II dm/dt was low – e.g., jamming resistance

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