The HAL 9000 Planning Engine Design and Operational Requirements

Howard K Stetson
Dr. Michael D Watson Ph.D
Ray Shaughnessy
June 2012

TELEDYNE BROWN ENGINEERING, INC.
A Teledyne Technologies Company

MSFC

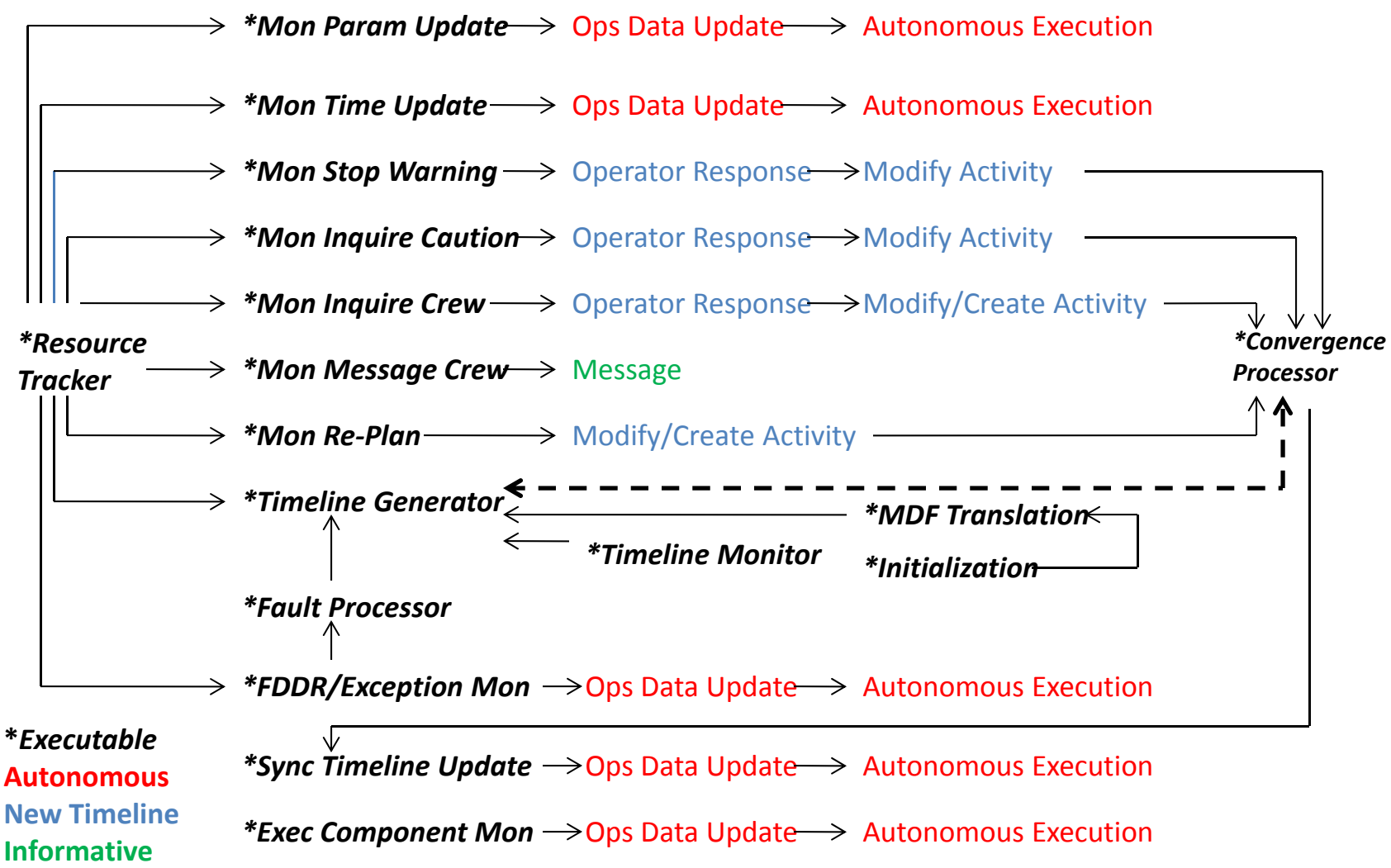
MOL THE MISSION OPERATIONS LABORATORY

HAL 9000 Design Influences

- Command Procedure Transfer to On-Board Execution only
- System Monitoring Transfer to Autonomous On-Board Monitoring
- Procedure Development Transfer to On-Board Development
  - Procedure Test and Qualification Transfer to On-Board
- Planning Development and Implementation Transfer to On-Board
- Crew Autonomy Enabler
- Comm to Earth Light Time Delay Risk Mitigation
- Permanent Loss of Comm Risk Mitigation
- Assured Crew Return Enabler
- Safety Integration Transfer to On-Board Operations and Planning
- Increase Crew Time for Science
- Single Crew Command Functionality
  - Functions
  - Activities

} Procedures

Planning Engine (HAL 9000 Executive) Architecture

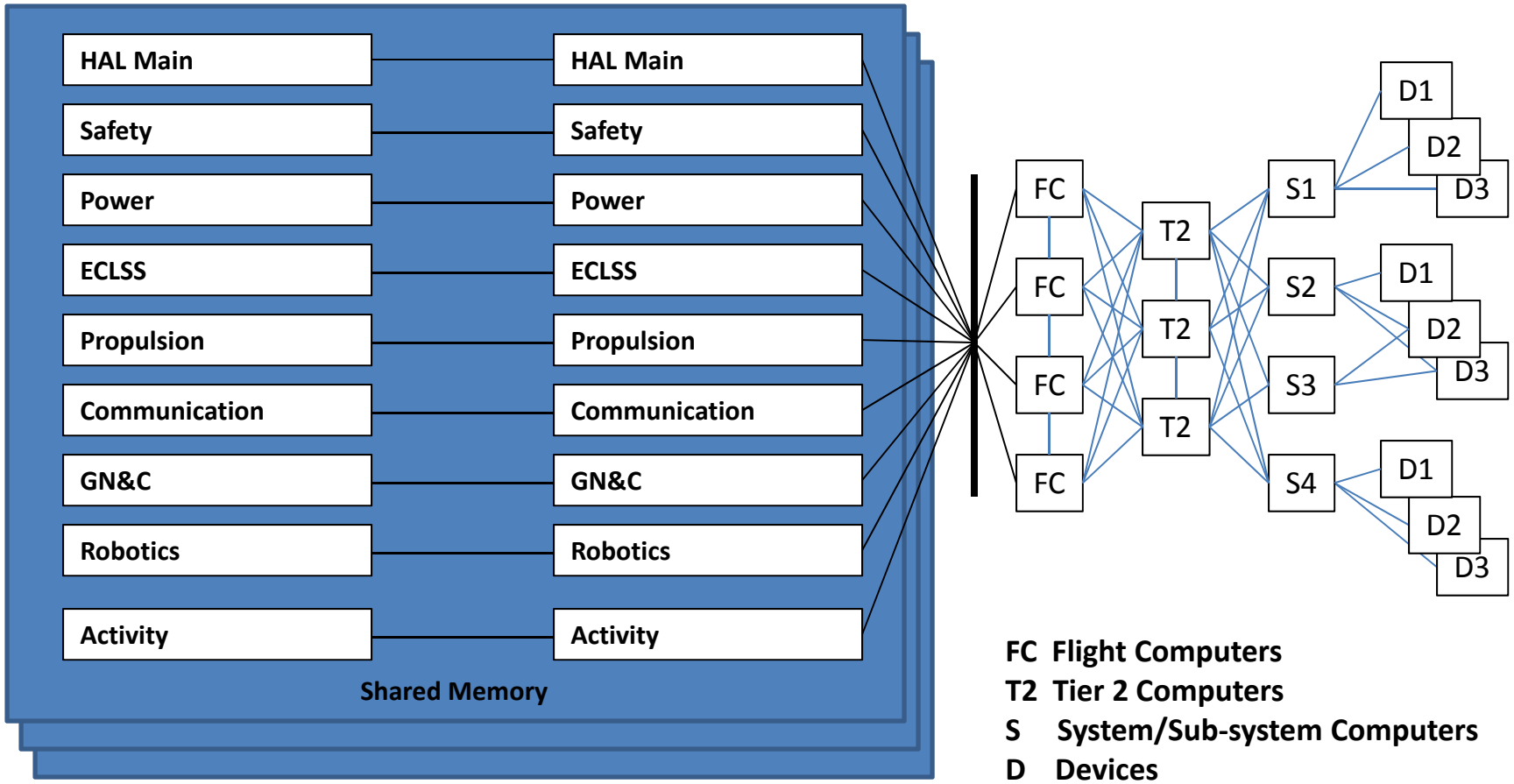


HAL 9000 Real Time Architecture

Executive Component (Planning Engines)

Execution Component (Timeliner-TLX™ Engines)

Vehicle Component (Notional Avionics)



FC Flight Computers
T2 Tier 2 Computers
S System/Sub-system Computers
D Devices

Planning Executives Key Points

- Divides operations planning into their respective disciplines
- Employs an iterative plan approval process that is configurable and autonomous
- Each Executive contains specific “intelligence” about planning its subsystems
  - Planning Logic Modules can be modified in flight
- Flight Rule, Regulations and Condition check insertion into real-time planning
- Safety integrated as a planning discipline (also integrated into execution)
- The Planning Executive becomes the operator in most cases
- Crew self planning
  - Crew Procedure Authoring
- Monitors and Reacts to unplanned events autonomously (re-plan)
- Priority definitions can vary depending upon the targeted system to operate
  - Adjustable granularity in priorities (Priority Leveling)
  - Relaxed Crew environment (anytime priority)
- Continuous Resource Verification
- Embedded real-time operations restrictions (Flight, Safety and Condition Rules)

Design Reference Missions

- Assists in the analysis of the HAL 9000 planning and execution capabilities
  - How do you relocate ground operations to on-board?
  - What additional tools are needed to drive inputs to planning?
  - What level of autonomy is appropriate for the crew?
  - What embedded functionality is missing?
  - What changes to crew skill sets are required?
  - How much mitigation can be achieved for communication light time delays?
  - How much mitigation can be achieved for permanent loss of communications?
  - How do you integrate Safety to be a real-time player?
  - What impacts to the Execution Component will be realized from un-converged plan execution?
  - Just a few of the questions we are asking ourselves

Re-Supply Design Reference Mission

Key Points from Operations Flow

* Guidance Navigation and Control requires trajectory data for course, speed and vehicle orientation (external system provision)
* Propulsion Executive requires translation intelligence (Thruster firings)
* Crew modified an existing GNC Activity (auto-procedure) and added it to the plan
    - New GNC Activity generated a new Propulsion Plan
    - New Propulsion Plan generated a new Power Plan
    - New GNC Activity generated a new Communications Plan (Vehicle re-orientation)
    - New Communications Plan generated a new Power Plan
    - Activity resources identified in real-time from Knowledge Pack data within the core link list structures
* Communication Executive requires intelligence for vehicle/transponder selection during vehicle maneuvers

Jupiter Assured Crew Return Design Reference Mission

- Key Points from Operations Flow

- Candidate new plan contains the added GNC Activity
- Candidate new plan contains the Maneuvering Arm Activity

- Safety, HAL Main and Propulsion Executives reject the new plan encountering resource constraints specified in the Flight Rules and Safety Rules
  - Mission restrictions implemented in real-time for planning and execution
  - Programmatic Safety and Flight Rule implementation (3 separate annunciations)

- Flight Rules and Safety Rules can be modified during flight or……
- Crew can override and implement the Candidate New Plan (emergency)
  - Non-Converged Plan will generate ECW Messages and potential stop of execution (requires further investigation for auto-procedure inhibits that are available in the system)
- Maneuvering Arm Activity added successfully

DRM Summary

- Predefined Activities (auto-procedures), with known resource allocations ease the planning convergence
- Activities that have unknown resource allocations (an initial estimate by the developer and an activity that has not been executed before), only has the duration time of the activity for resource utilization estimates until it has been executed at least once (Activity History)
  - Requires detailed resource utilization intelligence for vehicle maneuvering activities
  - Different Maneuver's will require different resource allocations
  - Could have pre-planned maneuver's, giving more accurate resource use
- Operations restrictions can be pre-planned and embedded (Rules & Conditions)
- Adding 1 activity may cause several plan updates in a cascading fashion.
  - Candidate plans are held back until the initial activity is approved.
  - Could promote all plans at one time, but it is not the way it works.
    - Forces Validation of each edit against the current complete plan
    - Re-Check of Flight, Safety and Condition rules and resources for each edit

Future Work

- No plans to enhance or expand development of the HAL 9000 Executives
- Continue utilization of the Timeliner-TLX™ System for ISS and other projects automated command and control requirements
- Lack of a target vehicle and mission for application of the complete HAL 9000 System
  - Continue to proof design as opportunities arise or HAL System capabilities are needed for other projects
- Currently developing methods for crew procedure authoring and verification/validation of these procedures during flight.

Conclusion

- Concepts for the HAL 9000 System design have never been directly funded
  - Proof of concept leveraged on other projects and private development
- Autonomous operations is viable and ready
  - Current Operations paradigms are not ready
- Can be applied in other command and control operations with a scaled down system
  - Execution Component Only (HAL 3)
  - Executive Component Only (HAL 1000)
  - De-scaled combination Executive and Execution components (HAL 2000 and above, such as for Habitats)
- Vehicle design and development must be driven by HAL 9000 requirements
  - HAL 9000 Development Methodology is required
  - All Systems, sub-systems and devices must be automated
  - Cannot fully automate a system that is not designed for such
- Safety is employed during design, build-up and operations
  - They must make their decisions up front and available during real-time
- External systems and simulations are required to assist the crew in HAL9000 operations
  - Critical areas are in Guidance, Navigation, Prognosis and Diagnosis
- Crew Autonomy, Relaxed Crew Ops, On-board Procedure development/Implementation
  - Is anybody ready?


Questions?
Copyright 1997 by Calvin J. Hamilton