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Integrating Tests of Autonomy with SW and People: Autonomy Requirements Tester (ART)

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Background: core Flight System (cFS)

- Autonomy Requirements Tester (ART) is design to be compatible with core Flight System (cFS)
- cFS architecture and software
  - Software platform developed by Goddard Space Flight Center (GSFC)
  - Reusable software framework across multiple projects
  - Set of reusable software applications
  - Dynamic run-time environment (real-time constraints)
  - Layered software
  - Component based design
  - <u>Publish-subscribe message communication</u> to make component apps independent
- ART can easily be modified to fit any pub-sub architecture

Autonomy Requirements Tester (ART): Human Centered View

- A tool to support software developers
  - Especially flight software
- People Tasks:
  - Capture autonomy requirements
  - Generate test specifications
  - Execute the test specs
  - Report results
  - Iterate for test-driven development

cFS-based Autonomy Requirements Tester (ART) project: System View

NASA Phase I SBIR sponsored by ARC & JSC

- Design eXtensible Markup Language (XML) schema to define cFS data models to support app-level testing
- Describe potential approaches for semi-autonomous test generation
- Design displays that support the management of requirements, test designs, and test results
- Develop a Concept of Operations (ConOps) with scenarios illustrating how ART supports people tasks
- Develop and demonstrate feasibility prototype

Represent Data for Progression from Requirement to Test Results

Autonomy Requirement

When a person is near the robotic arm, its movements should be reduced in speed.

Test Objective (Behavior)

When any sensor detects a range of 3 feet or less:

IF (range to human <= 3 feet)

THEN switch to slow arm motion mode (which reduces the highest arm speed to no greater than 0.5 feet per second)

Test Input

IR sensor range
IR_range <= 2.9 feet

Expected Results

Arm_Motion_Mode = slow

(Publish Msg)
IR_Range_To_Human

IR_range <= 2.9 feet

(Subscribe Msg)
Arm_Mode_Change

(expect value to be:
Arm_Motion_Mode = slow)

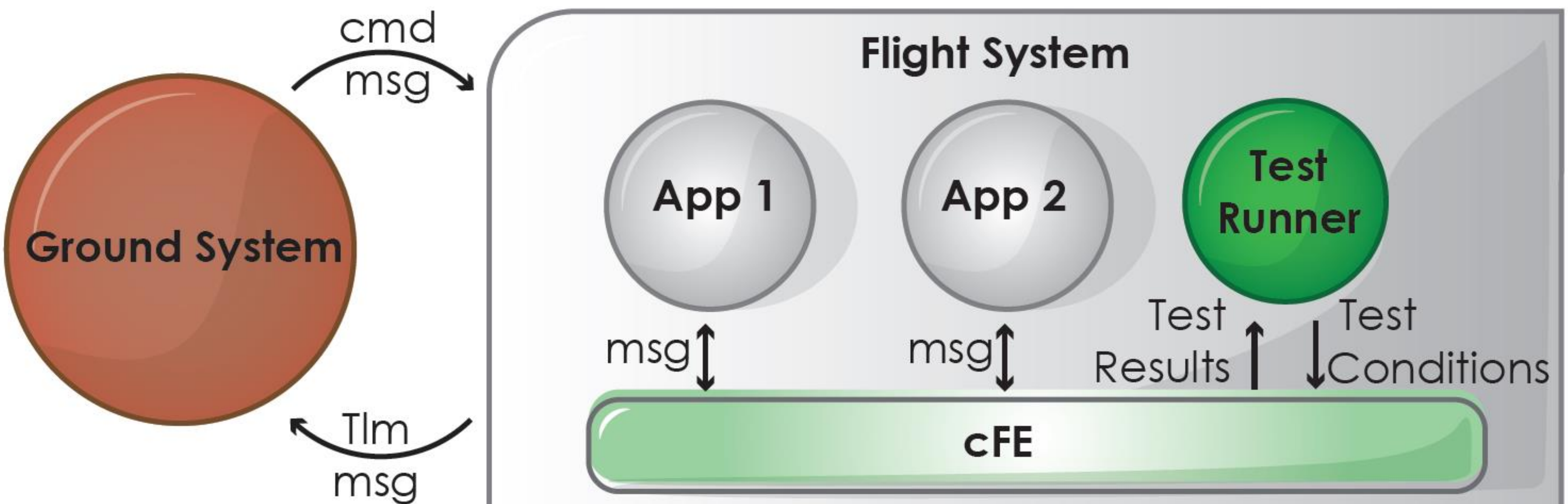
Test Input

Camera estimated range
Camera_Est_Range = 2.9 feet

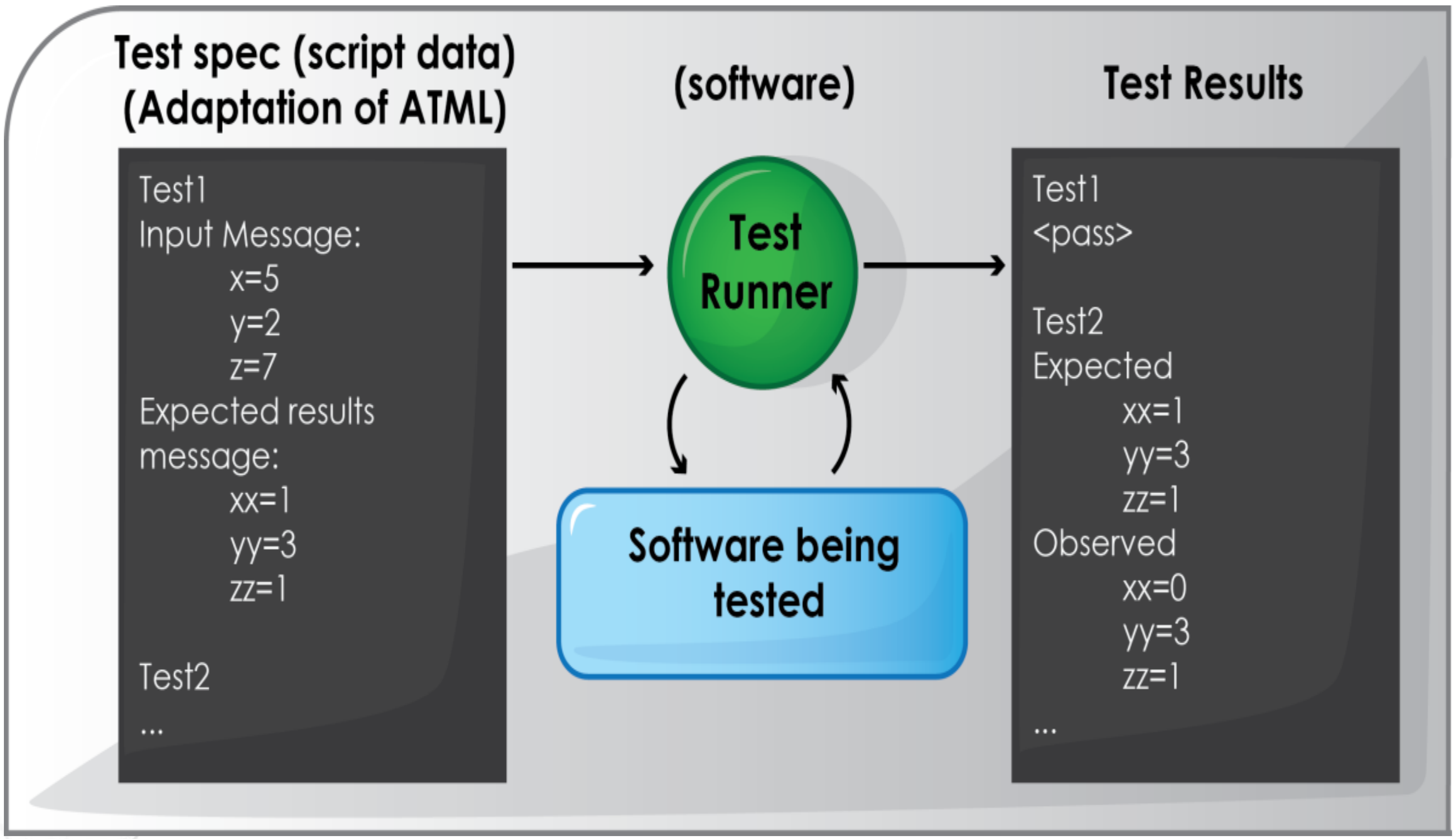
Expected Results

Expect values of
Arm_Motion_Mode = slow

Test Runner Uses CFS Pub/Sub Architecture

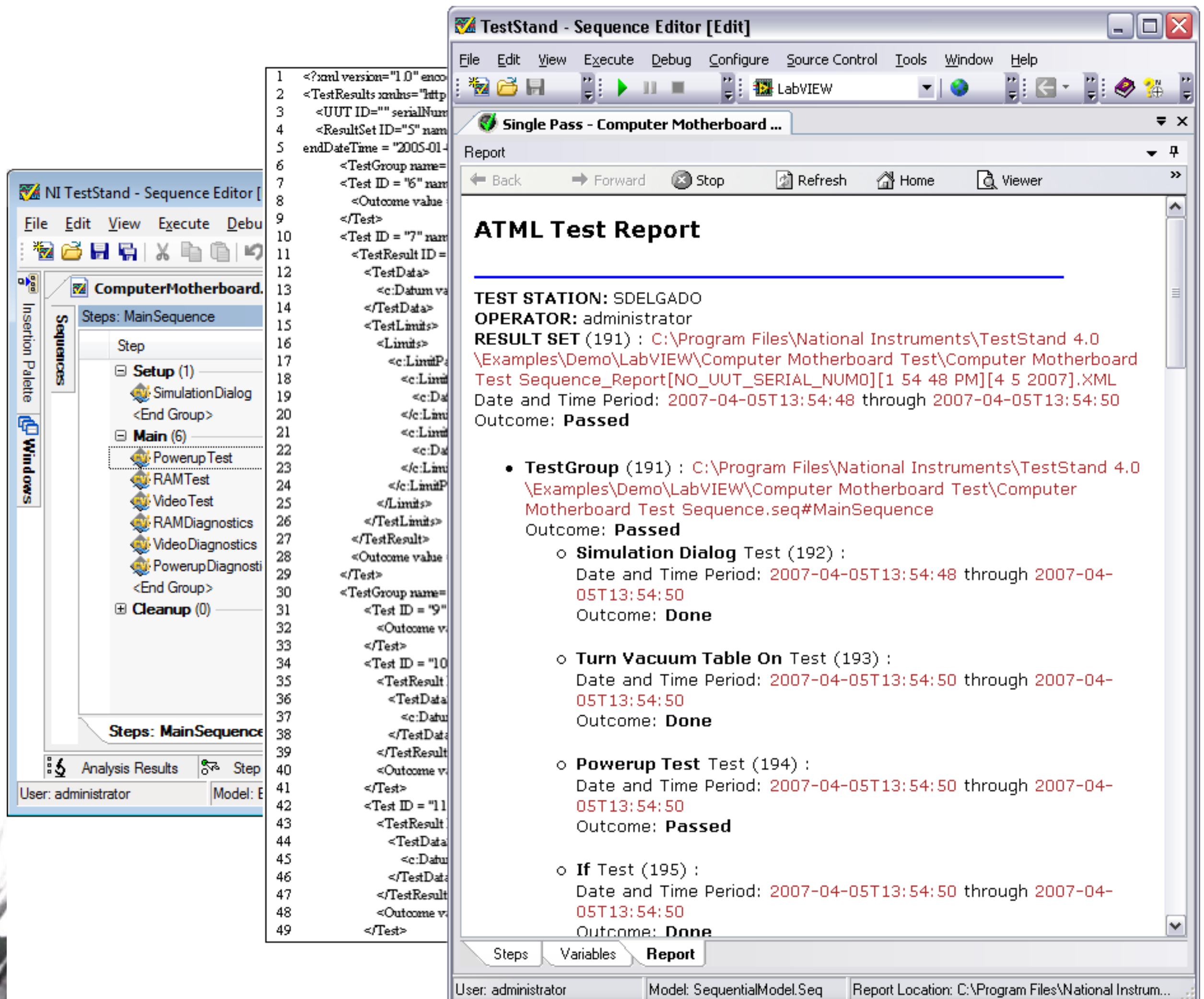


Test Runner Reads Test Spec, Produces Test Results



Data Model Based on IEEE Standards

adopted by the Institute of Electrical and Electronics Engineers (IEEE) as a standard (IEEE Std 1671-2010)

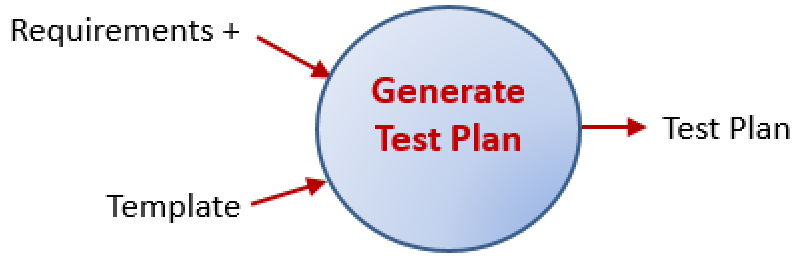


Generating the Test Plan from Requirements

Observation from Phase I exercise with APL Solar Probe Plus type autonomy requirements

- Similarities from one requirement to the next
  - Often a tiered response, when first tier doesn't correct the issue, go to the next tier
  - Rule based behavior: If {condition} then {response}
- Similarities enable the formation of a template (illustrated on next page) for generating the test
- Some additional parameters are needed in addition to the template (illustrated on the page after that)

Generating Detailed Test Plans



- Detailed test plan can become tedious to specific in every detail
- Templates for a given set of requirements can remove some of the tedium
- Can encourage test-driven development

Parameter Entry to Enable Test Generation from Template

Enter Design Values To Construct Initial Test

AUT-3	Monitor Battery Temperature	Autonomy shall perform the following tiered response if the battery temperature is above a pre-defined limit: A) Soft-reset the PSC B) Power-cycle the PSC C) Switch the PSC (via a CIM side switch)

Enter values from design file ...

M 5 N 6	Persistence (m of n)
9	Max fire count
2	Priority
Enabled	Initial rule state (enabled/disabled)
battery_temp	Battery temperature variable name (default from rqts xml)
160	pre-defined limit
PSC_reset_cmd	Soft-reset the PSC command name (default from rqts xml)
PSC_pwr_cycle_cmd	Power-cycle the PSC command name (default from rqts xml)
change_CIM_side_cmd	Switch CIM side command name (default from rqts xml)

Template Contents for Generating Details of Test Specification

AUT-3	Monitor Battery Temperature	Autonomy shall perform the following tiered response if the battery temperature is above a pre-defined limit: A) Soft-reset the PSC B) Power-cycle the PSC C) Switch the PSC (via a CIM side switch)

1. Set nominal spacecraft system state
2. Verify autonomy takes no action
3. Inject fault
4. Verify faulted state (optional, especially level 0)
5. Verify autonomy response
6. Repeat steps 3-5 through all possible iterations
7. For tiered rule:
    1. Inject fault corrected by 1st action
    2. Inject fault corrected by 2d action
    3. Inject fault corrected by 3d action
    4. Inject unrecovered fault

1st Part of Detailed Test Plan

Initialize

1. Set nominal spacecraft system state
   - set rule_fire_count(AUT3) to 0
   - set battery_temp = 159, every second
2. Verify autonomy takes no action
   - Wait 12 sec (m*2)
   - Verify rule_fire_count(AUT3)=0

Succeed on Tier 1 Response

1. Inject fault
   - set battery_temp = 161, every second
2. Verify tier 1 autonomy response
   1. Wait 7 sec (n+1)
   2. Verify PSC_reset cmd
   3. Verify rule_fire_count(AUT3) = 1
3. Success
   1. set battery_temp = 159, every second
   2. Wait 15 sec (m * 3)
   3. Expect rule_fire_count(AUT3) = 1
   4. Verify that there is no:
      1. PSC_reset_cmd
      2. PSC_pwr_reset_cmd
      3. change_CIM_side_cmd

Succeed on Tier 2 Response

Succeed on Tier 3 Response

Unrecovered Function

Initialize

Succeed on Tier 1 Response

Succeed on Tier 2 Response

1. Inject fault
   - set battery_temp = 161, every second
2. Verify tier 2 autonomy response
   1. Wait 7 sec (n+1)
   2. Verify PSC_pwr_reset_cmd
   3. Verify rule_fire_count(AUT3) = 2
3. Success
   1. set battery_temp = 159, every second
   2. Wait 15 sec (m * 3)
   3. Expect rule_fire_count(AUT3) = 2
   4. Verify that there is no:
      1. PSC_reset_cmd
      2. PSC_pwr_reset
      3. change_CIM_side

Succeed on Tier 3 Response

Unrecovered Function

For Browsing Requirement

Autonomous Rule System Requirements Overview

Requirements | Test Plans | Test Results

Requirement ID	Title
AUT-1	Detect Loss of Telemetry
AUT-2	Detect Invalid Telemetry
AUT-3	Monitor Battery Temp
AUT-4	Monitor Battery State of Charge
AUT-5	Detect Critically Low State of Charge
AUT-6	Battery Heater Power On
AUT-7	Battery Heater Power Off

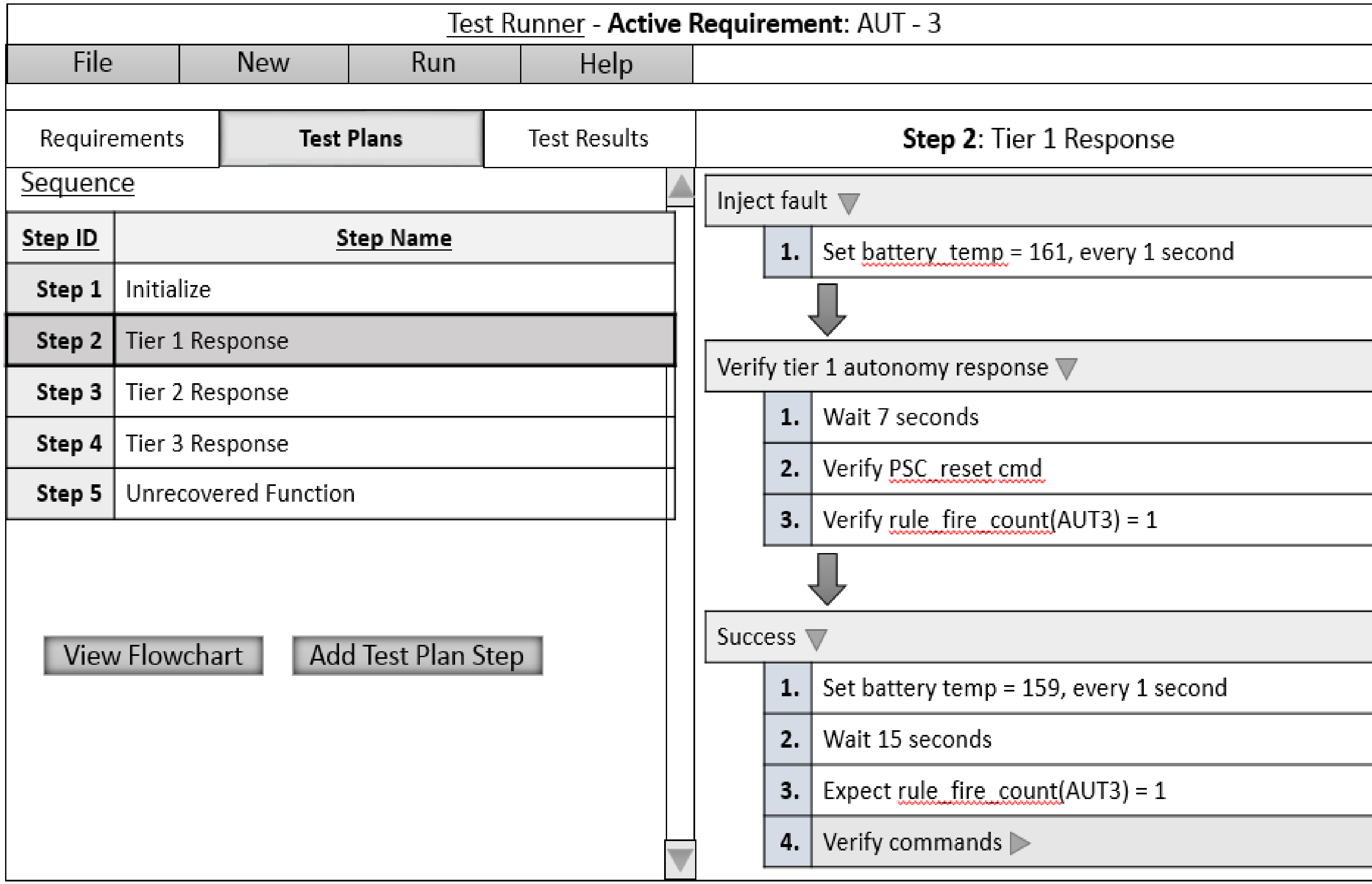
Requirement AUT-3 Monitor Battery Temp

ID	AUT-3
Name	Monitor Battery Temp
Categories	Device Health, Thermal Monitoring
Parents	SC-1
Rationale	Protects against a potential PSC control fault that could cause excessive battery temperature.

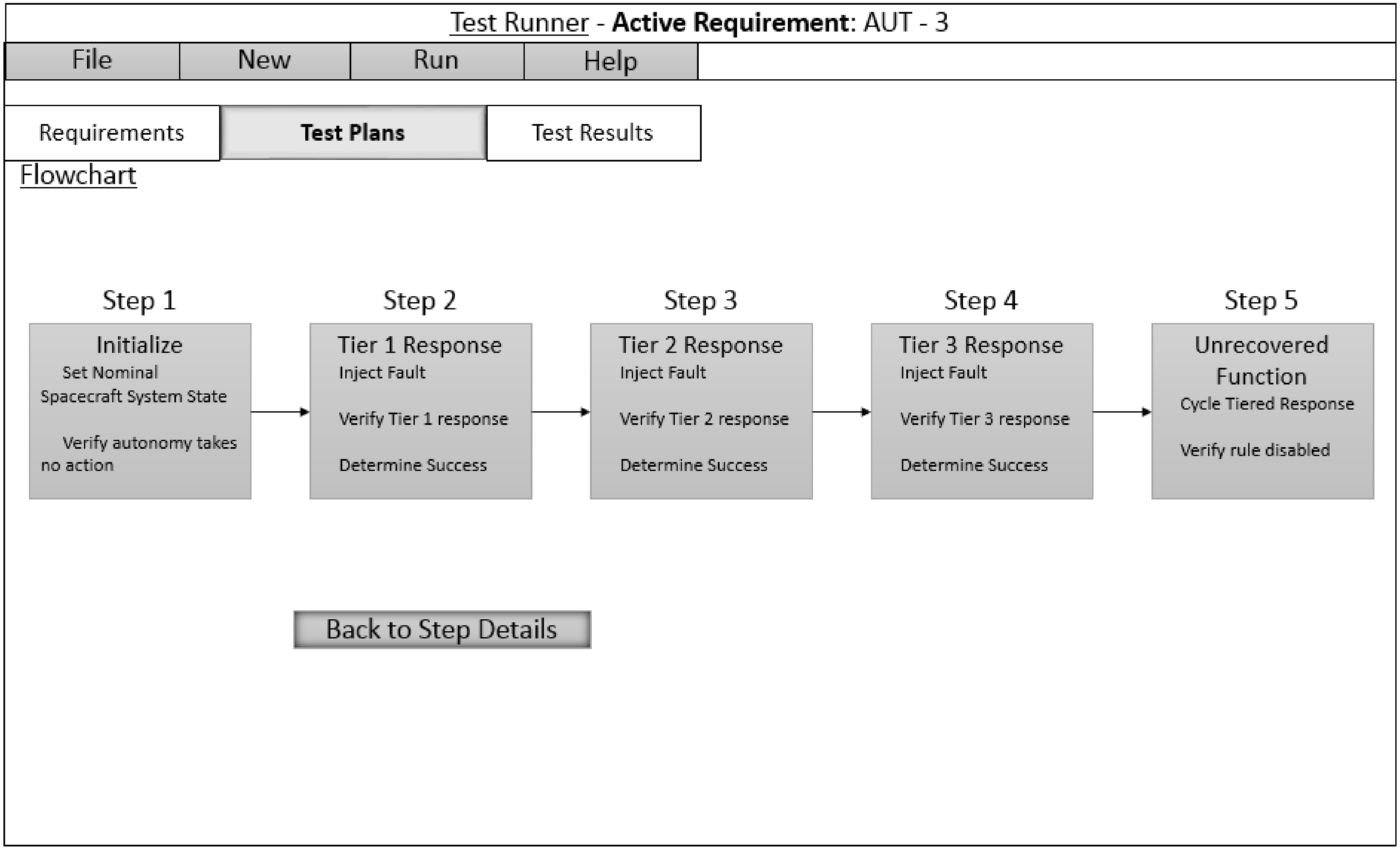
Details

Text	Autonomy shall perform the following tiered response if the battery temperature is above a pre-defined limit: A) Soft-Reset the PSC, B) Power-cycle the PSC, C) Switch the PSC (via a CIM side switch).
Condition	Battery_temp > 160
Subject	Autonomous system
Tiered Action(s)	Soft-reset the PSC, Power-cycle the PSC, Switch the PSC (via a CIM side switch)
Object	PSC
Limit Value	160
Constraint	N/A

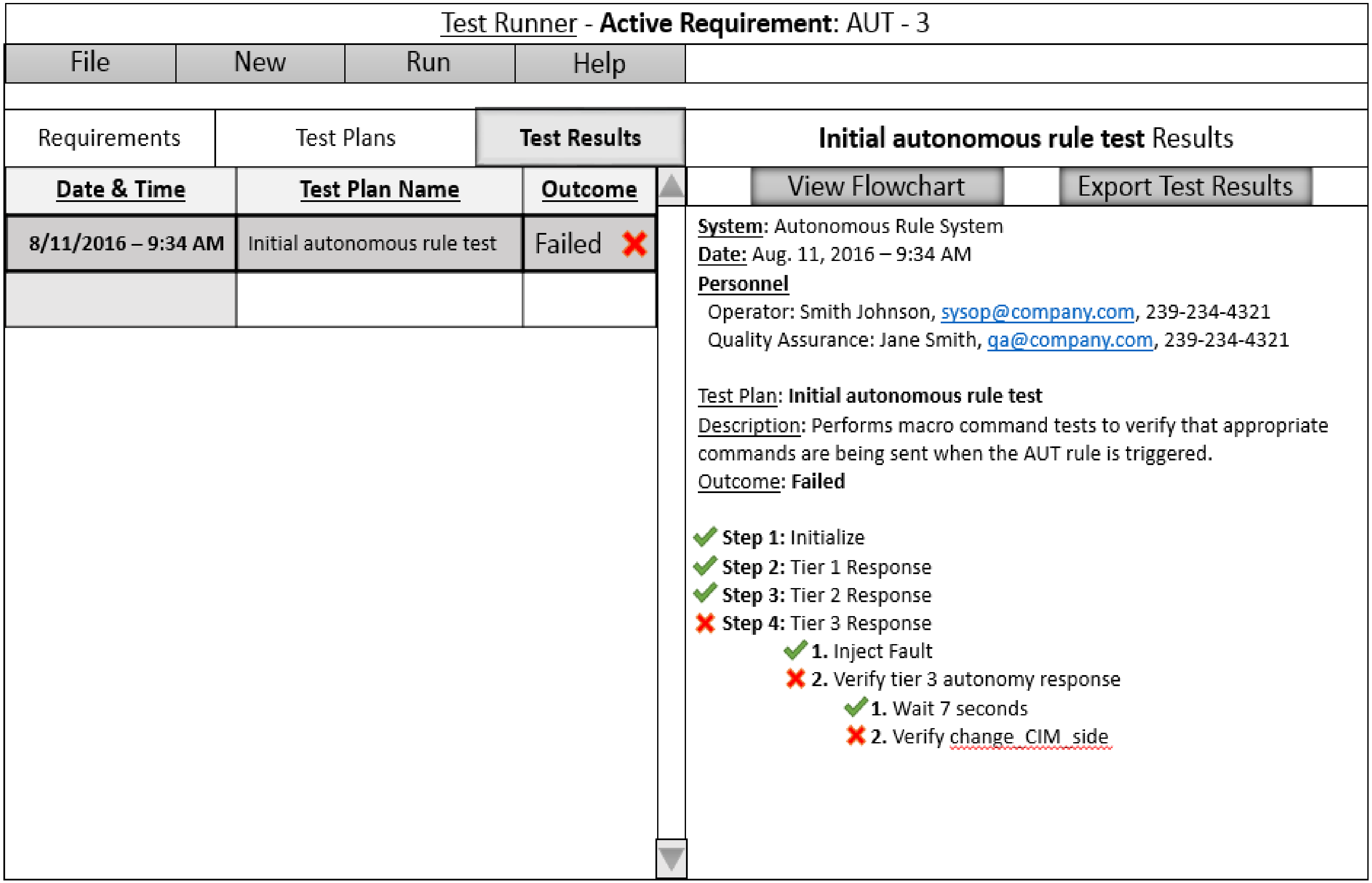
Viewing Details from Test Plan



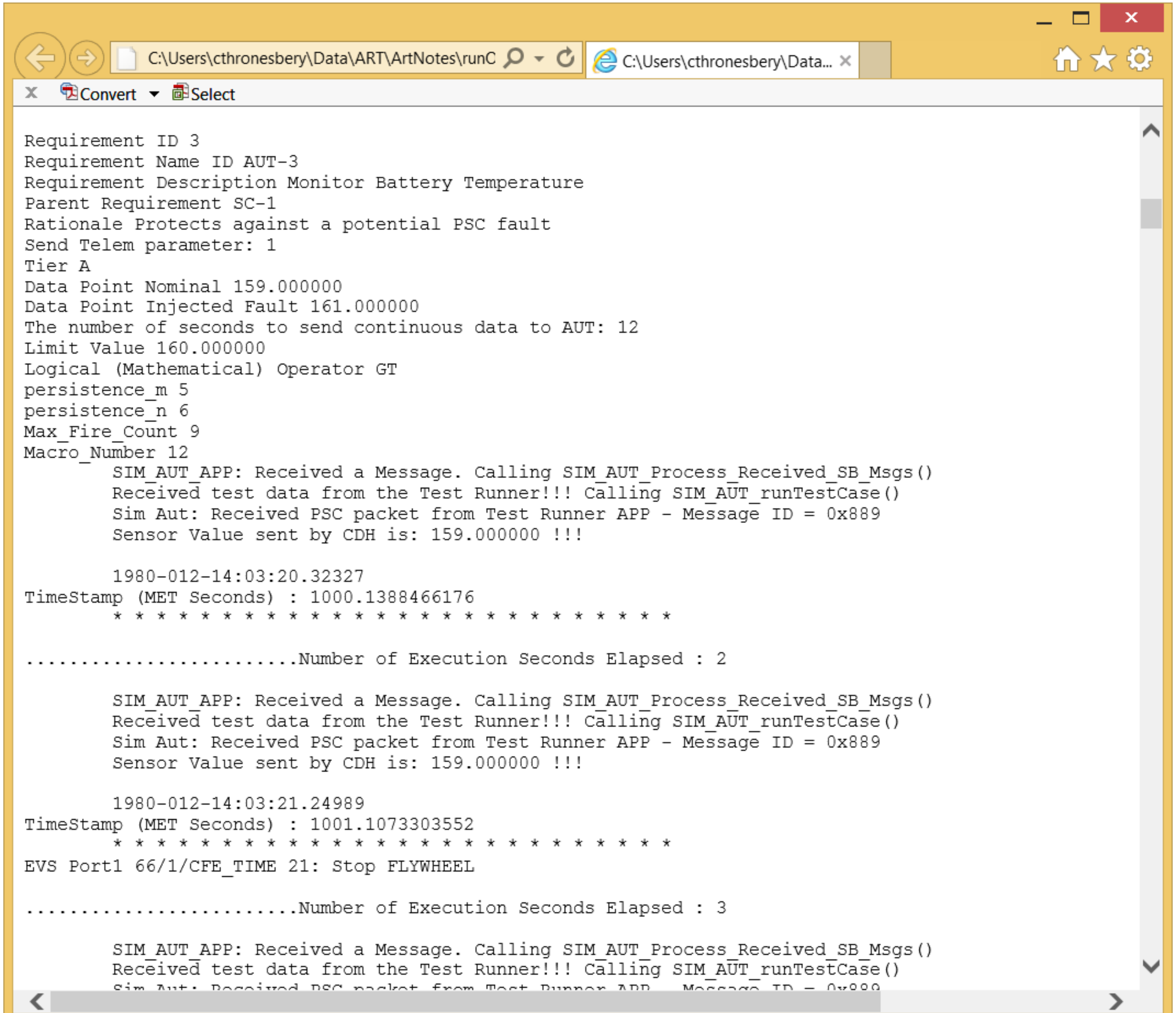
A Graphical View of the Test Plan



A View of the Test Results



TestRunner Detailed Results




```
Requirement ID 3
Requirement Name ID AUT-3
Requirement Description Monitor Battery Temperature
Parent Requirement SC-1
Rationale Protects against a potential PSC fault
Send Telem parameter: 1
Tier A
Data Point Nominal 159.000000
Data Point Injected Fault 161.000000
The number of seconds to send continuous data to AUT: 12
Limit Value 160.000000
Logical (Mathematical) Operator GT
persistence_m 5
persistence_n 6
Max_Fire_Count 9
Macro_Number 12
        SIM_AUT_APP: Received a Message. Calling SIM_AUT_Process_Received_SB_Msgs()
        Received test data from the Test Runner!!! Calling SIM_AUT_runTestCase()
        Sim Aut: Received PSC packet from Test Runner APP - Message ID = 0x889
        Sensor Value sent by CDH is: 159.000000 !!!

        1980-012-14:03:20.32327
TimeStamp (MET Seconds) : 1000.1388466176
        * * * * * * * * * * * * * * * * * * * * * * * * * *

.........................Number of Execution Seconds Elapsed : 2

        SIM_AUT_APP: Received a Message. Calling SIM_AUT_Process_Received_SB_Msgs()
        Received test data from the Test Runner!!! Calling SIM_AUT_runTestCase()
        Sim Aut: Received PSC packet from Test Runner APP - Message ID = 0x889
        Sensor Value sent by CDH is: 159.000000 !!!

        1980-012-14:03:21.24989
TimeStamp (MET Seconds) : 1001.1073303552
        * * * * * * * * * * * * * * * * * * * * * * * * * *
EVS Port1 66/1/CFE_TIME 21: Stop FLYWHEEL

.........................Number of Execution Seconds Elapsed : 3

        SIM_AUT_APP: Received a Message. Calling SIM_AUT_Process_Received_SB_Msgs()
        Received test data from the Test Runner!!! Calling SIM_AUT_runTestCase()
        Sim Aut: Received PSC packet from Test Runner APP - Message ID = 0x889
```

ART Emphases

- Focus of Phase I (completed)
  - Hard, real-time autonomy (low level of autonomy) and cFS
  - Test-driven development
  - Unit test for app in publish-subscribe architecture
- Advantages of this approach
  - Start test driven development early
  - Ease the expression of autonomy requirements in terms of expected behavior
  - Support pre-integration testing – unit testing and regression testing
  - Make integration testing time more productive – no logic errors in software
  - During integration, if software changes are required
    - If software changes are required
    - Make the changes
    - Re-run the pre-integration test to ensure no errors were inadvertently entered
    - Resuming integration testing

Innovations

- Represent requirements and link with intended behaviors for testing the requirements
- Formal data models for requirements, behavioral expectations, test specifications, and test results
- Use of template to drive the elaboration of test specifications
- Support for test driven development
- Integration of the testing mechanism with the operational environment to support (CFS users)
  - Enabled by modular architecture w/ pub-sub communications scheme
  - No change to the unit under test between testing and operations
  - Paves the way for runtime checkout routines for selected apps (e.g., sensors for deep-space science operations)
- Reporting of test results – similar appearance to specifications, still linked to requirements

Next Steps

- Identification of how to support higher levels of integration testing:
- Identification of how to support additional types of autonomy requirements:
- Identification of additional options for semi-autonomous test generation:
- Proof-of-principle prototype of ART
- Evaluation of proof-of-principle prototype