Validation of Dynamic Simulation Models using Metamorphic Testing and Given-When-Then Patterns

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Motivation

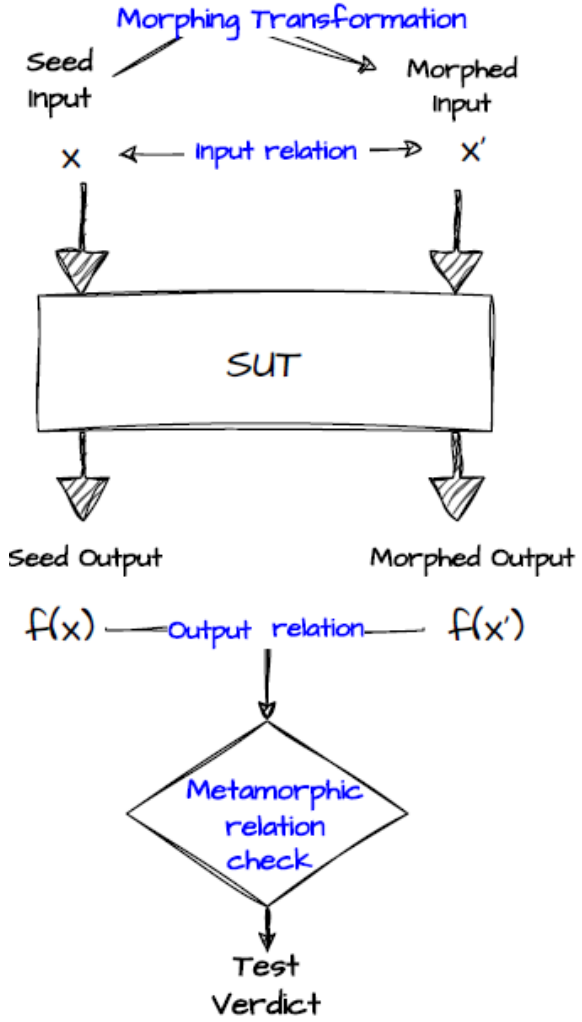
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- Efficient validation of simulation models at an early stage of development life cycle
- Integration of Behavior-Driven Development(BDD) with metamorphic testing
- Improved test automation and coverage to assure quality

Metamorphic testing

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- A testing technique based on properties/functional behavior of the system
- Proposed as a solution for
  - test oracle problem
  - automated test-case generation problem



Metamorphic testing

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- Uses metamorphic relations composed of an
  - Input relation
    - Transforms seed input -> morphed input
  - Output relation
    - Used to compare seed output and morphed output

BDD testing

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- Behavior-driven development (BDD)
  - Uses features & scenarios representing desired functional behavior as **acceptance criteria**
  - Uses **Given-When-Then** format to define tests

Overview of the approach

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- Metamorphic BDD test generation for simulation models based on user-defined:
  - Scenarios
  - Metamorphic I/O relations
  - Given-When-Then format

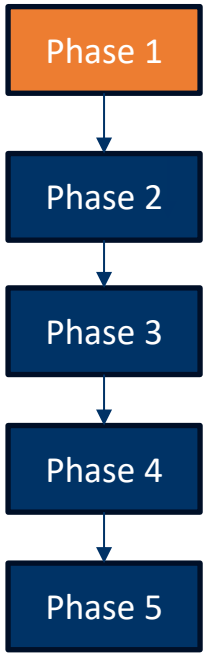
Import Interface specification

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FMU

io_specification.json

```
{
    "inputs": {
        "temperature_cooling_liquid_in": {
            "description": "The temperature of the cooling water entering the lube oil cooler.",
            "value range": {
                "min": 0,
                "max": 100
            },
            "unit": "C"
        },
        "mass_flow_cooling_liquid_in": {"description": "The mass flow rate of the cooling water through the circuit.
        "setpoint_temperature_oil": {"description": "The setpoint temperature of the lube oil entering the engine.".
        "engine_load": {"description": "The current load on the engine, which can influence the heat generated."...}
    },
    "outputs": {...},
    "parameters": {...}
}
```



Defining features and scenarios

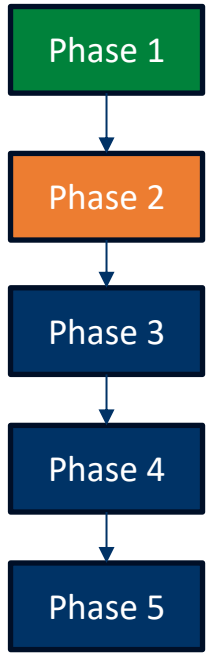
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Domain Expert

Feature ID: F6

Feature : LOC system temperature control check

Scenario: When engine load increases, input temperature of cold circuit increases, and mass flow increases the lube oil temperature eventually increases and stays within limits



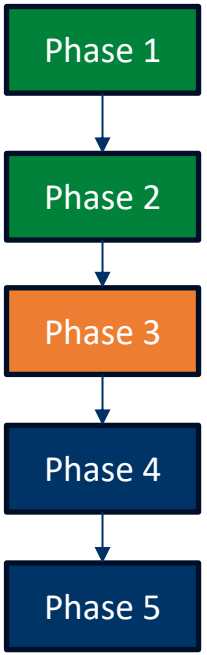
Defining Initial Conditions (Given)

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GIVEN WHEN THEN

(Select Initial condition for inputs)

Input Variable	Initial Value	Lower Limit	Upper Limit
temperature_cooling_liquid_in	30	0	100
mass_flow_cooling_liquid_in	15	0	50
setpoint_temperature_oil	55	30	90
engine_load	0	0	1



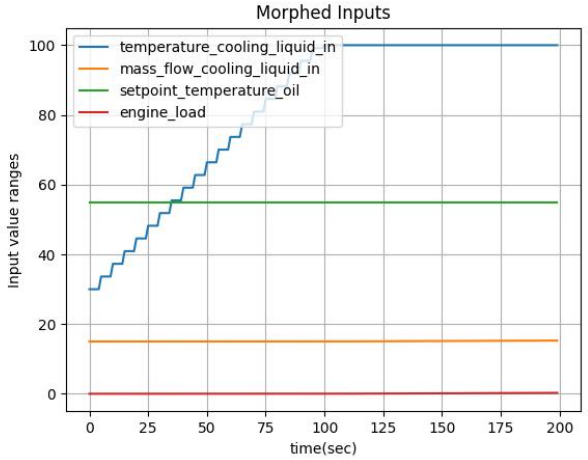
Morphing Transformation for inputs (When)

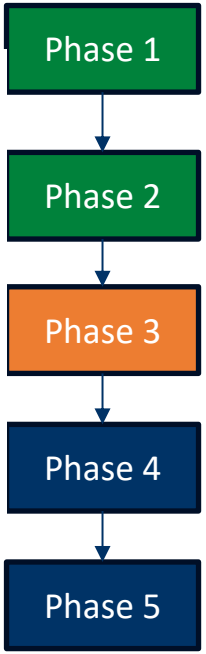
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GIVEN **WHEN** THEN

(Select transformation for inputs)

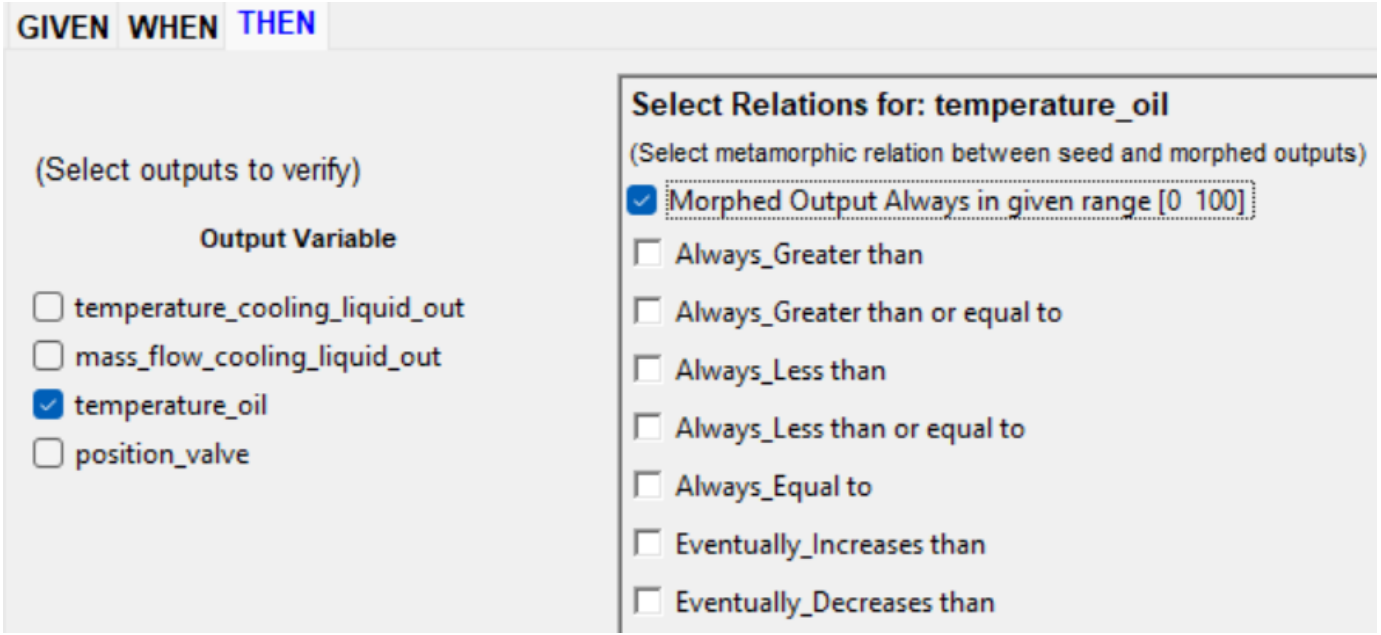
Input Variable	Transformation Relation
temperature_cooling_liquid_in	Steps_Increase
mass_flow_cooling_liquid_in	Drift_Increase
setpoint_temperature_oil	None_Constant
engine_load	Drift_Increase

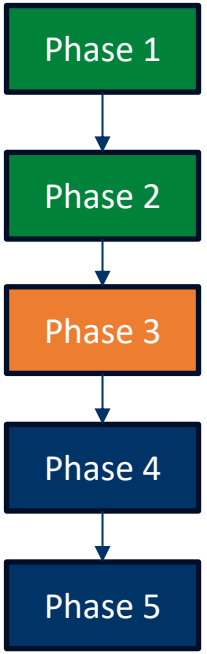




Metamorphic relation for outputs (Then)

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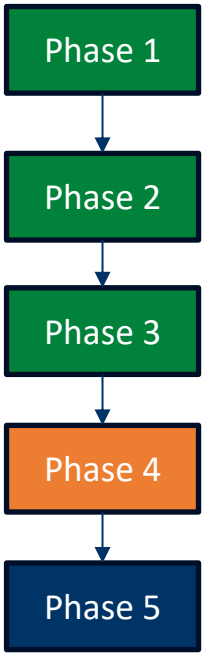
Metamorphic G-W-T test generation

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```
Feature: F6_LOC system temperature control check
  Scenario: F6_scenario When engine load increases, input temperature of cold
circuit increases, and mass flow increases the lube oil temperature eventually
increases and stays with limits
    Given 'F6_scenario' has seed_inputs with initial values '[30, 15, 55, 0]'
generating seed_outputs in '1000' time steps

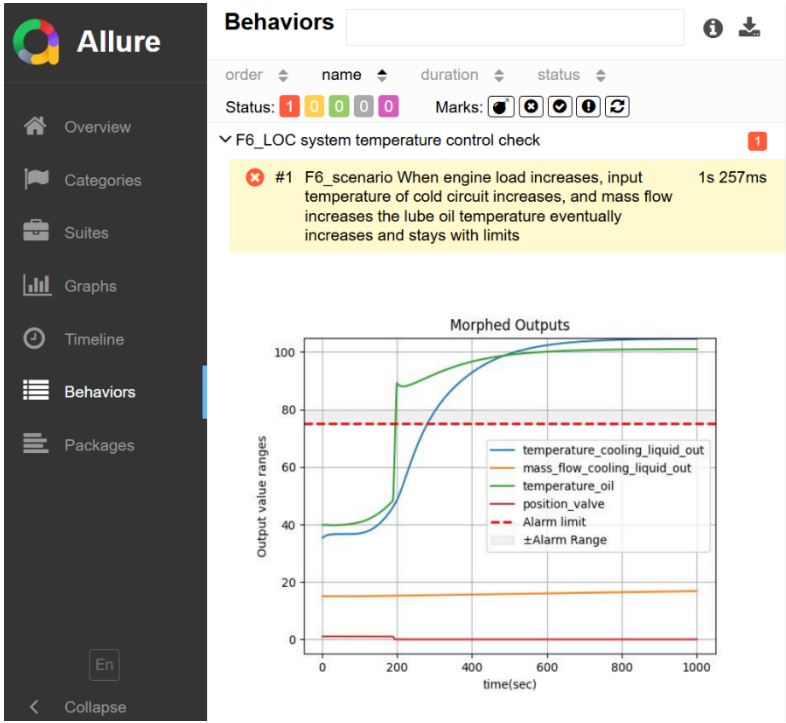
    When 'temperature_cooling_liquid_in' transform by 'Steps_Increase' with
ramp-rate '2.07'
     And 'mass_flow_cooling_liquid_in' transform by 'Drift_Increase' with
ramp-rate '0.002'
     And 'engine_load' transform by 'Drift_Increase' with ramp-rate '0.0033'
    Then morphed_outputs of 'temperature_oil' 'Always in given range [0  100]'
     And morphed_outputs of 'temperature_oil' 'Eventually_Increases than'
seed-outputs

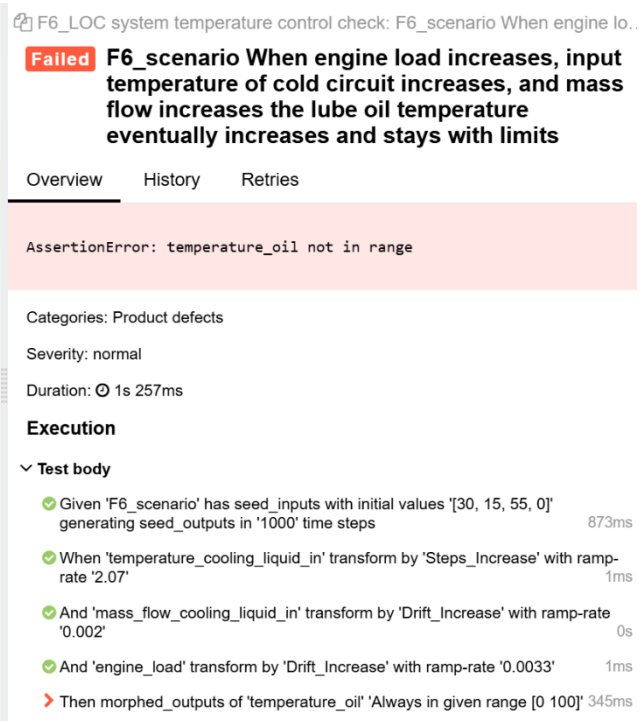
    When 'temperature_cooling_liquid_in' transform by 'Steps_Increase' with
ramp-rate '4.77'
     And 'mass_flow_cooling_liquid_in' transform by 'Drift_Increase' with
ramp-rate '0.0007'
     And 'engine_load' transform by 'Drift_Increase' with ramp-rate '0.0002'
    Then morphed_outputs of 'temperature_oil' 'Always in given range [0  100]'
     And morphed_outputs of 'temperature_oil' 'Eventually_Increases than'
seed-outputs
```

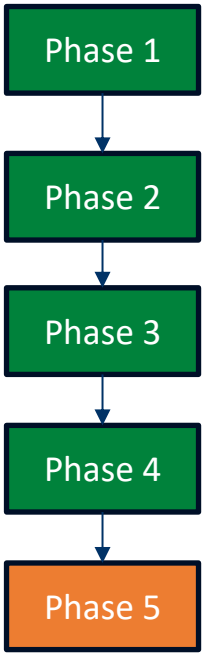


Test execution and report generation

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Future work

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- Implement domain-specific metamorphic test generation strategies
- Integrate automation workflow with tools like Jira, Git, Jenkins
- Improve automation to support both unit and integration testing

Acknowledgements

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Thank you for your attention!