

NPAS Physics Pump Models for Autonomous Monitoring

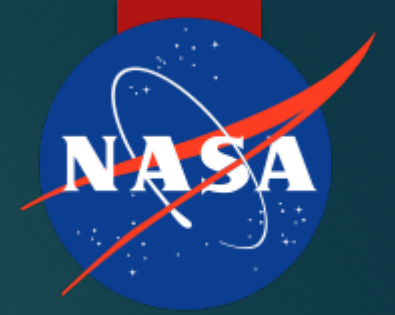
PREPARED BY PETTE JOSEF RAMOS

ELGIN COMMUNITY COLLEGE

FERNANDO FIGUEROA, MENTOR

AUTONOMOUS SYSTEMS LABORATORY

Overview

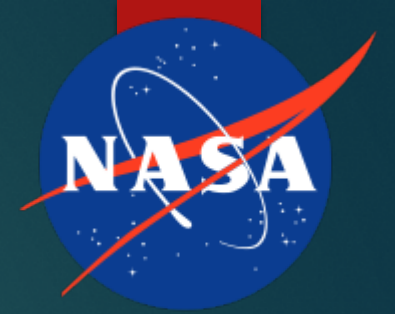


- ▶ Introduction
- ▶ Background
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- ▶ Future Plans
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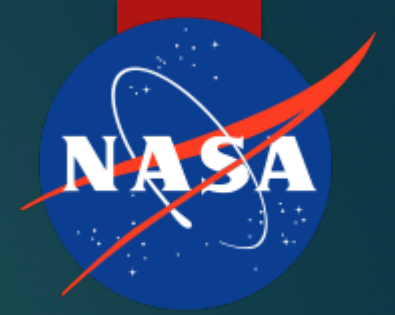


Introduction

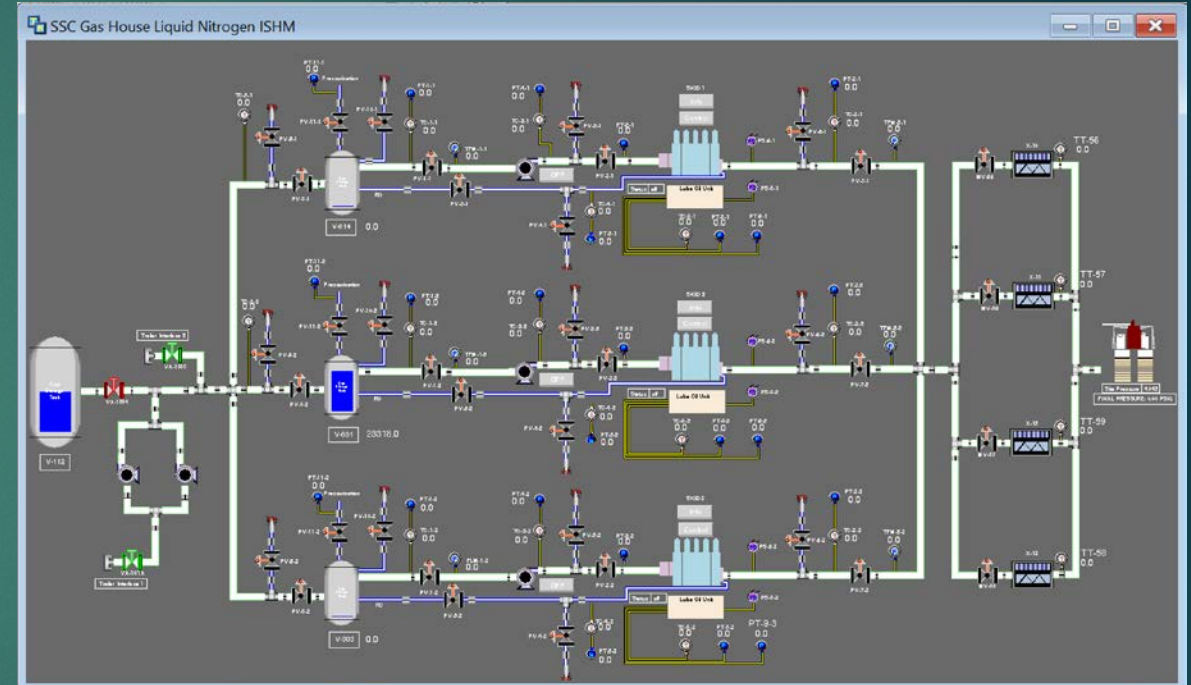
- ▶ Major: Biomedical Engineering
- ▶ College: Elgin Community College in Elgin, Illinois
- ▶ Prior to Internship:
 - ▶ NASA Community College Aerospace Scholar
 - ▶ Biomedical Engineering Volunteer
 - ▶ Taekwondo Instructor



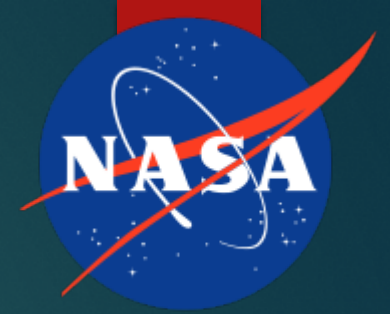
Background



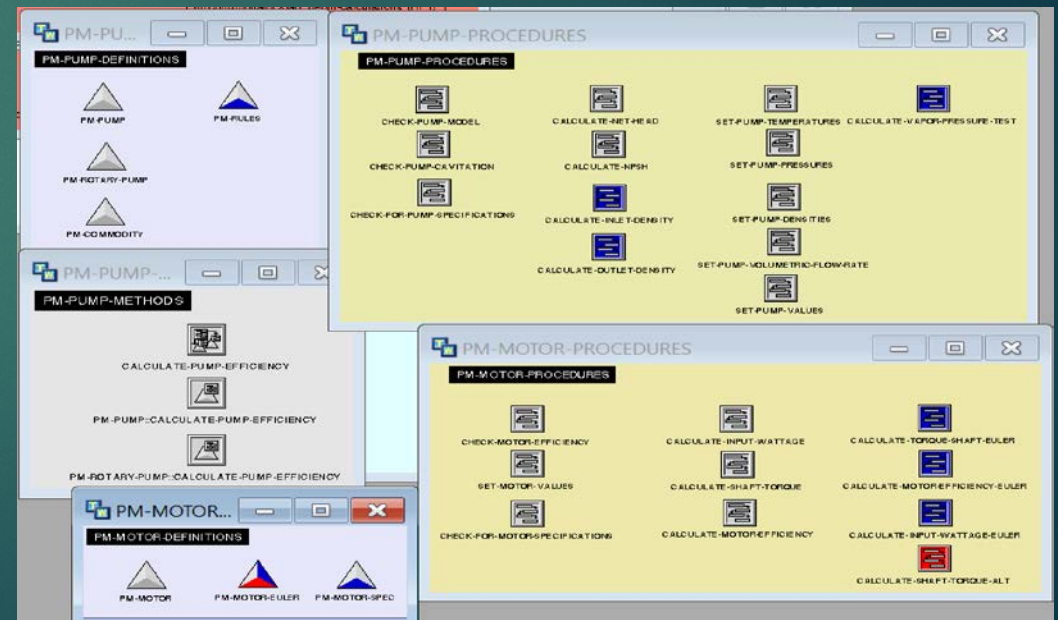
- NPAS is a platform for autonomous operations developed at SSC's Autonomous Systems Laboratory (ASL)
- The Intelligent Stennis Gas House Technology (INSIGHT) is a project that uses NASA Platform for Autonomous Systems (NPAS) to implement autonomous operations at the Gas House
- Initially INSIGHT is implementing autonomous operations of the Nitrogen system



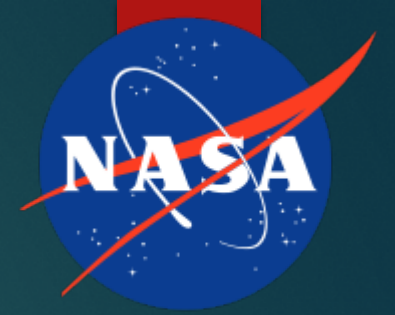
Background From Previous Interns



- ▶ Andrew Yeo, a former NASA intern, provided the theory of how the centrifugal pump should work and left behind equations and parameters to begin coding in NPAS
- ▶ Former Interns Kyle Bentain and Wilson Barce laid the groundwork for reasoning using the physics pump model

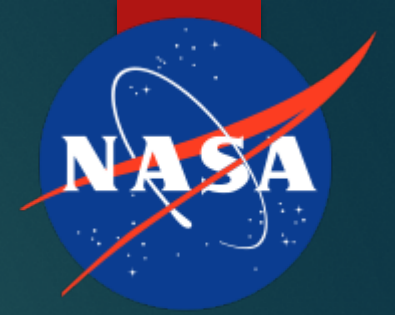


Project Objectives



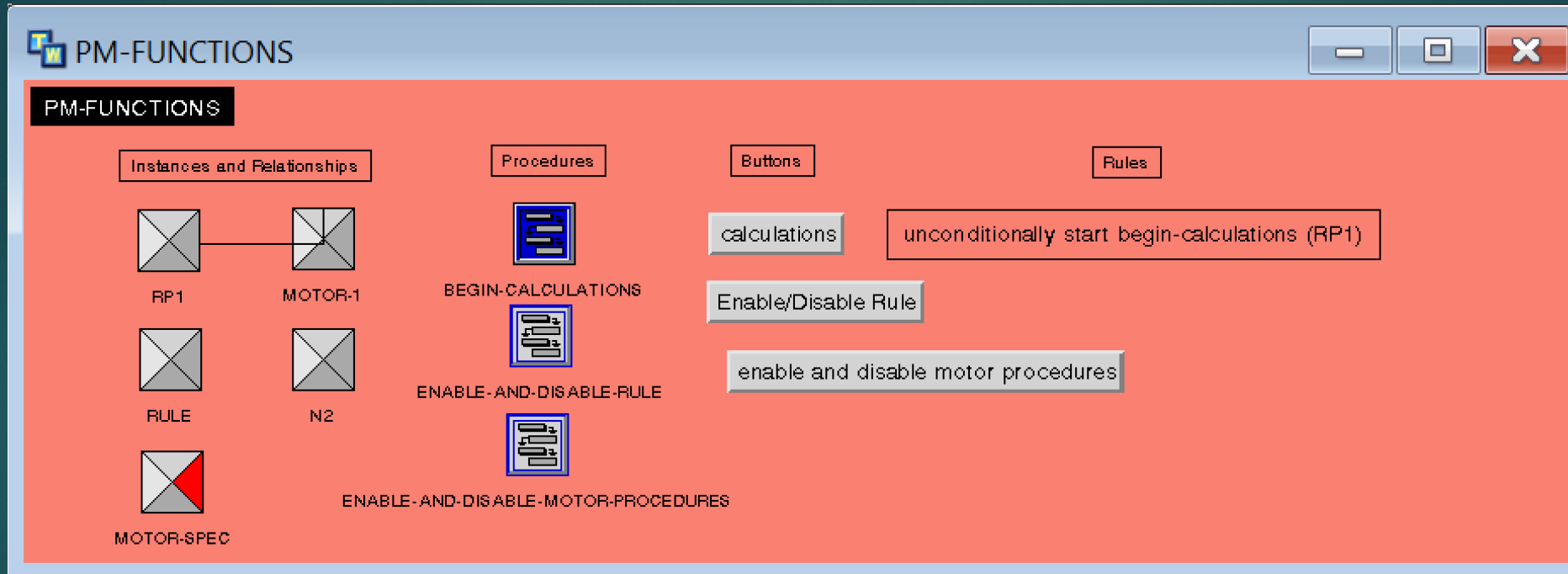
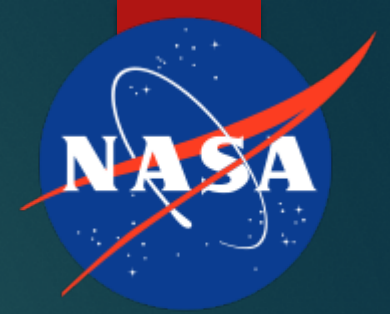
- ▶ Learn how to program using the G2 Software environment
- ▶ Create procedures and methods to detect cavitation in a centrifugal pump and other features such as efficiency
- ▶ Verify that the code and theory work by implementing test cases
- ▶ Begin implementation of the generic rotational pump model package for the High Pressure Gas Facility

Solutions

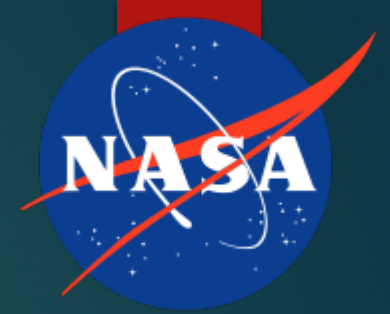


- ▶ Created a workspace to test the code of the previous interns and modified the code as needed
- ▶ Acquired data at the High Pressure Gas Facility to verify calculations
- ▶ Create rules to make relevant calculations automatically in 5 second intervals

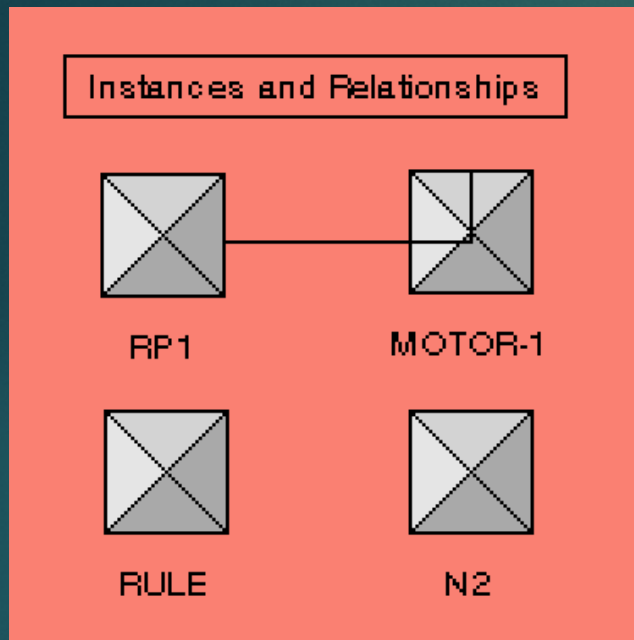
PM-Functions workspace



This workspace was used to simulate a running pump and motor

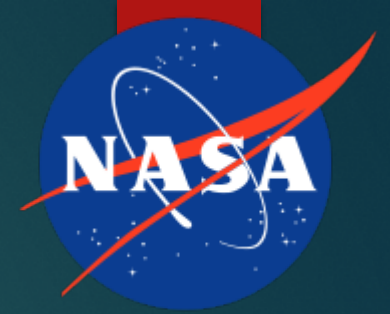


Instances/Objects



- Each instance is a representation of an object that is used at the Gas House with the exception of the "RULE" instance (more on that later)
- RP1 represents a centrifugal pump that is connected to MOTOR-1
- The connectivity automatically enables use of the linked motor and pump parameters in the modeled equations
- N2 represents the commodity that is being passed through the pump (RP1), which is Liquid Nitrogen
- RULE is used to disable and enable the use of the model when needed

Attributes



Four screenshots of software windows showing attribute data for different components:

MOTOR-1, a pm-motor

UUID	"f890fe30d95211e88139d4258bf7213b"
Notes	OK
Item configuration	none
Names	MOTOR-1
Motor torque constant	1.246
Gearbox reduction ratio	4.91
Rotational speed	3525.0
Specified operating amperage	34.4
Specified operating voltage	460.0
Specified motor efficiency	0.95
Input amperage	18.0
Input wattage	8280.0
Shaft torque	110.121
Motor efficiency	0.781

RP1, a pm-rotary-pump

UUID	"bd2afa43db8911e88139d4258bf7213b"
Notes	OK
Item configuration	none
Names	RP1
Commodity	n2
Flow order	50
Inlet diameter	2.5
Outlet diameter	1.5
Inlet height	2.0
Outlet height	6.0
Specified net positive suction head	4.6
Inlet pressure	18.5
Outlet pressure	118.7
Inlet temperature	-317.7
Outlet temperature	-313.5
Volumetric flow rate	92.3
Inlet density	0.029
Outlet density	0.025
Net head	5.031
Pump efficiency	0.627
Net positive suction head	8.451
Allowable model error	0.357

N2, a pm-commodity

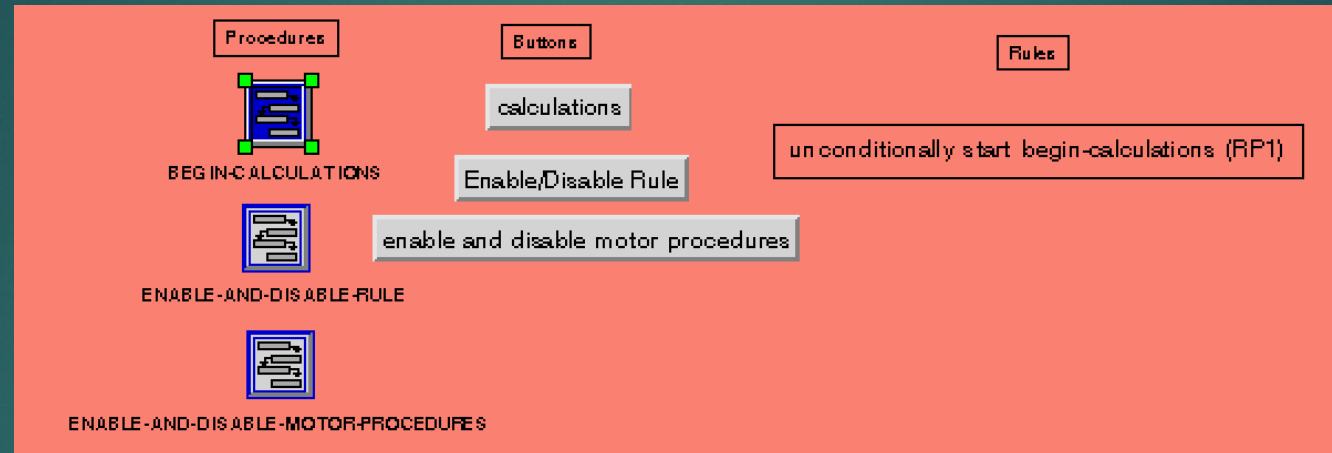
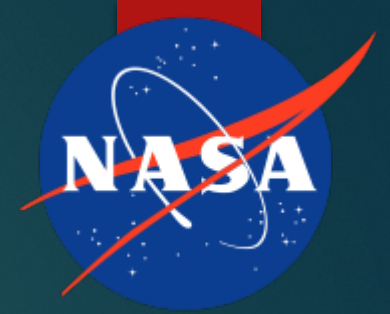
UUID	"c3572739c68611e88136d4258bf7213b"
Notes	OK
Item configuration	none
Names	N2
Isothermal coefficient	13.98
Specific heat capacity	0.486
Vapor pressure	0.057

RULE, a pm-rules

UUID	"781d99afde0611e8813ad4258bf7213b"
Notes	OK
Item configuration	none
Names	RULE
X	0

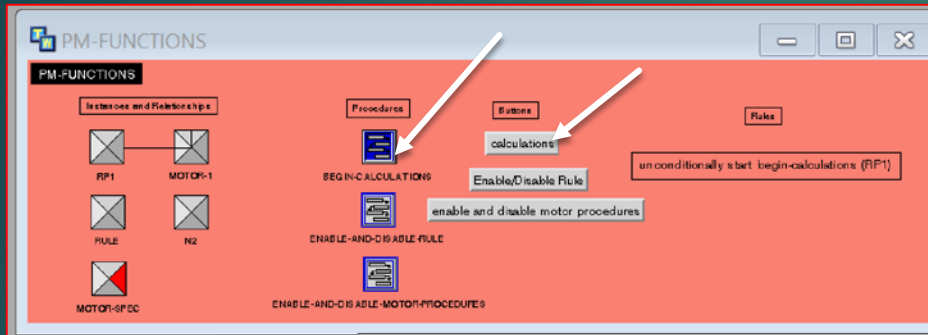
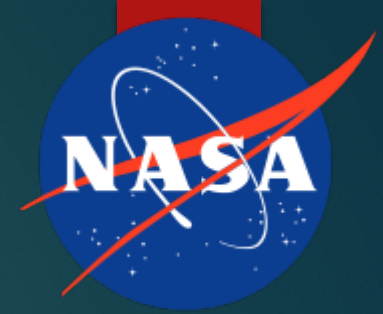
- Each instance contains a set of attributes
- The attributes in this case hold raw data and calculations
- These calculations are made through procedures and methods
- Raw data was collected by reading pressure, temperature, and flow rate sensors at the HPGF

Procedures, Rules, and Buttons



- The following procedures have different functionalities:
 - Begin-calculations calculates all attributes of a class through the use of a button
 - Enable-and-disable-rule turns a rule on/off when in administrator mode
- Buttons trigger these procedures to begin
- Rules were used to have the procedures run automatically

Procedures, Rules and Buttons (cont.)



MOTOR-1, a pm-motor	
UUID	"f890fe30d95211e88139d4258bf7213b"
Notes	OK
Item configuration	none
Names	MOTOR-1
Motor torque constant	1.246
Gearbox reduction ratio	4.91
Rotational speed	3525.0
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RP1, a pm-rotary-pump	
UUID	"bd2afa43db8911e88139d4258bf7213b"
Notes	OK
Item configuration	none
Names	RP1
Commodity	n2
Flow order	50
Inlet diameter	2.5
Outlet diameter	1.5
Inlet height	6.0
Outlet height	16.0
Specified net positive suction head	4.6
Inlet pressure	18.5
Outlet pressure	118.7
Inlet temperature	-317.7
Outlet temperature	-313.5
Volumetric flow rate	92.3
Inlet density	0.029
Outlet density	0.025
Net head	5.523
Pump efficiency	0.692
Net positive suction head	8.441
Allowable model error	0.357

```

BEGIN-CALCULATIONS, a procedure
  UUID "636198e0d0a611e88138d4258bf7213b"
  Notes OK
  Authors pjramos (28 Nov 2018 1:45 p.m.)
  Change log 0 entries
  Item configuration none
  Tracing and breakpoints default
  Class of procedure invocation none
  Default procedure priority 6
  Uninterrupted procedure execution limit use default

  (This is a test procedure and should not be used in the final code unless told otherwise. This procedure will attempt to call all calculation procedures and post on the message board any activity that occurs)

  begin-calculations (RP: class pm-rotary-pump)

  //In a change, this procedure will also call all check procedures

  begin
    {calling all pump calculations}
    start calculate-net-head (RP1);
    start calculate-npsh (RP1);
    start pm-rotary-pump::calculate-pump-efficiency (RP1);
    //start calculate-inlet-density (RP1);
    //start calculate-outlet-density (RP1);

    {calling motor calculations}
    start calculate-input-wattage (MOTOR-1);
    start calculate-motor-efficiency (MOTOR-1);
    start calculate-shaft-torque (MOTOR-1);

    //commodity equations
    start calculate-vapor-pressure-test (N2);

    //calling all check procedures
    start check-motor-efficiency (MOTOR-1);
    start check-pump-model (RP1);
    start check-pump-cavitation (RP1);
    start check-for-pump-specifications (RP1);
    start check-for-motor-specifications (MOTOR-1);

  end
  
```

Message Board Wednesday, November 28,...

of 0.0 for SKID-3-MOTOR

#353 1:44:21 p.m. The pm-motor MOTOR-1 is operating below the minimum efficiency.

#354 1:44:21 p.m. The rotary pump RP1 fits the pump model

#355 1:45:54 p.m. The pm-motor MOTOR-1 is operating below the minimum efficiency.

#356 1:45:54 p.m. The rotary pump RP1 fits the pump model

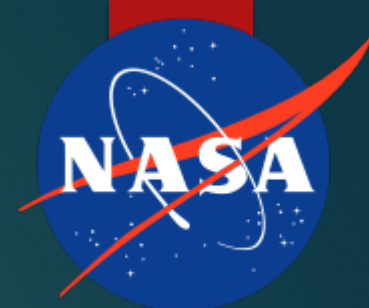
#358 2:49:12 p.m. The pm-motor MOTOR-1 is operating below the minimum efficiency.

#359 2:49:12 p.m. The rotary pump RP1 does not fit the pump model.

#360 2:55:21 p.m. The pm-motor MOTOR-1 is operating below the minimum efficiency.

#361 2:55:21 p.m. The rotary pump RP1 does not fit the pump model.

Programmatically Disabling and Enabling a Rule



```

ENABLE-AND-DISABLE-RULE, a procedure
  UUID "da9c33e3de0711e8813ad4258bf7213b"
  Notes OK
  Authors pjrmos (2 Nov 2018 2:04 p.m.)
  Change log 0 entries
  Item configuration none
  Tracing and breakpoints default
  Class of procedure invocation none
  Default procedure priority 6
  Uninterrupted procedure execution limit use default

//This procedure attempts to enable and disable a rule when a button is pressed
enable-and-disable-rule (R: class pm-rules)

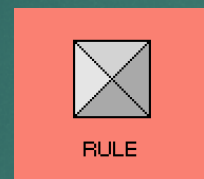
//Note: To allow procedure to run, you need to be in administrator mode

ThisWindow.class G2-Window = sequencer-1-window; //initializing the window
required for the procedure

x: integer = the x of RULE;
begin

conclude that the may-refer-to-inactive-items of the evaluation-attributes of
enable-and-disable-rule is true;
//conclude that the x of RULE = 1;
//conclude that the x of RULE = 0;

case (x) of
1:
begin
conclude that the x of RULE = 0;
call g2-system-command (the symbol enable, ThisWindow, pump-rule,
the symbol none);
post "Calculation Rule has been enabled"
end;
0:
begin
conclude that the x of RULE = 1;
call g2-system-command (the symbol disable, ThisWindow, pump-rule, the
symbol none);
post "Calculation Rule has been disabled"
end;
end;
end
  
```



RULE, a pm-rules	
UUID	"781d99afde0611e8813ad4258bf7213b"
Notes	OK
Item configuration	none
Names	RULE
X	1

Message Board Wednes...

The rotary pump RP1 does not fit the pump model.

#840 4:03:41 p.m.
The pm-motor MOTOR-1 is operating below the minimum efficiency.

#841 4:03:41 p.m.
The rotary pump RP1 does not fit the pump model.

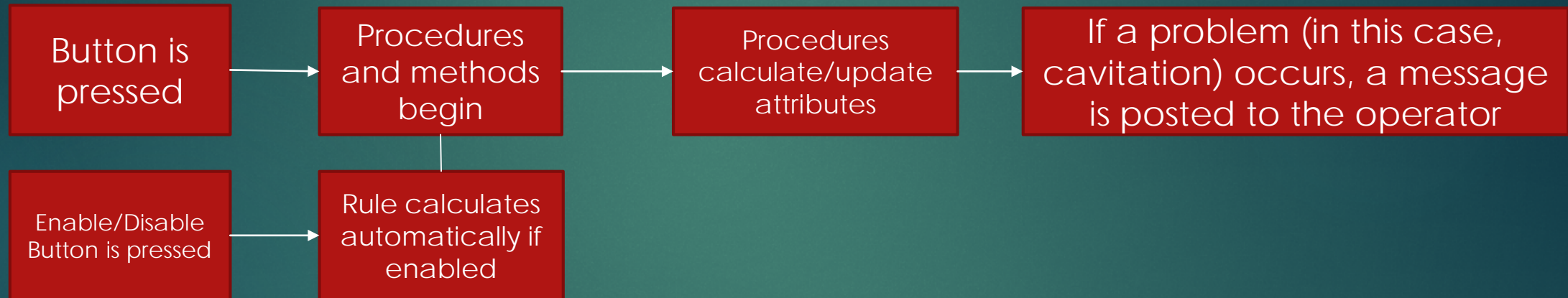
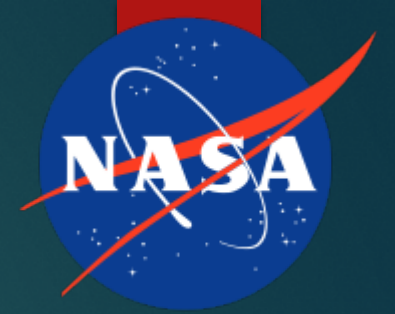
#842 4:03:46 p.m.
The pm-motor MOTOR-1 is operating below the minimum efficiency.

#843 4:03:46 p.m.
The rotary pump RP1 does not fit the pump model.

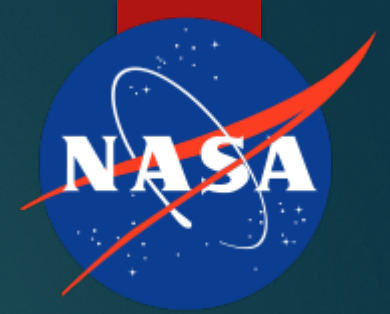
#844 4:03:48 p.m.
Calculation Rule has been disabled



Logic



Common Problems



- ▶ One of the biggest problems when running a procedure lied within the units being used for each equation
- ▶ As a way to distinguish the required units, documentation and comments were made for each procedure to keep all units uniform to the equations
- ▶ Miscellaneous equation errors

UNITS:

Length/Distance: Inches (in)

Weight: Pounds (lbs)

Time: Minutes (min)

Volume: Gallons (G) * {in³ for calculations} [conversion factor: *231]

Pressure: Pounds per square-inch (psi)

Density: Pounds per cubic inch (lbs/in³)

Rotational Speed: Revs/Minute (rpm) {rev/s for calculations} [conversion factor: * 1/60]

Linear Speed: Inches per second (in/s)

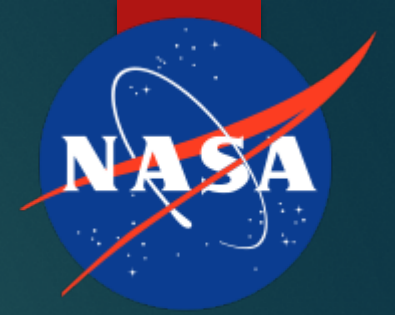
Volumetric Flow Rate: Gallons per minute (GPM) {in³/s for calculations} [conversion factor: * 3.85]

Gravitational Constant: inches per second² (in/s²)

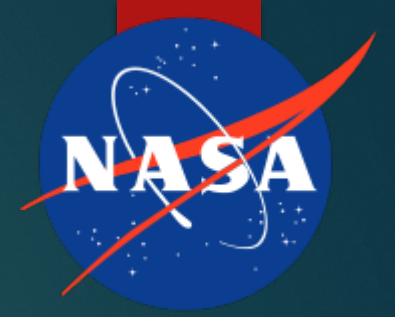
Power: in-lbs/s

** Note: When doing calculations, convert all units to pounds, inches, and seconds

Importance of ISHM



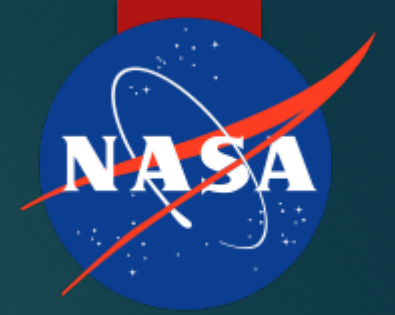
- ▶ The Integrated System Health Management (ISHM) is a component of NPAS that utilizes 4 functionalities:
 - ▶ Anomaly Detection
 - ▶ Diagnostics
 - ▶ Prognostics
 - ▶ Integrated Awareness
- ▶ Each of these functionalities work hand in hand to detect a problem in a system and to predict possible outcomes.



Moving Forward

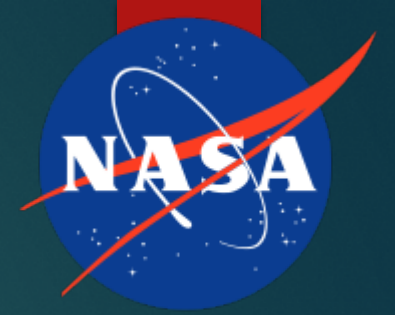
- ▶ Further develop symcure functionalities for root-cause analysis
- ▶ Implementation to the Gas House
- ▶ Implementing a saturation table that include temperature, pressure, and density

Lessons Learned



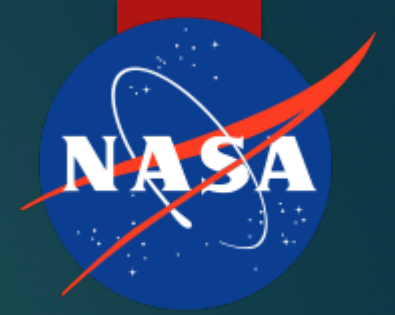
- ▶ How to program in the G2 Software environment
- ▶ Familiarity and coding for NPAS
- ▶ Application of physics in real world situations
- ▶ The properties of cryogenics and liquid nitrogen and their affects in the operations at Stennis Space Center
- ▶ How the Gas House system functions

Skills Acquired

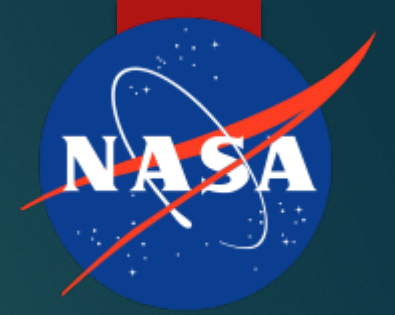


- ▶ Programming for the first time
- ▶ Coding using object-oriented programming
- ▶ Project management using scrum
- ▶ Root cause analysis
- ▶ Physics models for rotary pumps and motors

Future Plans



Acknowledgements



- ▶ Fernando Figueroa, NASA Mentor
- ▶ Andrew Tidwell, D2K Contractor
- ▶ Mark Turowski, NASA- High Pressure Gas Facility
- ▶ Wilson Barce, Former NASA Intern
- ▶ Lauren Underwood, NASA
- ▶ D2K Technologies (Mark Walker, Jon Morris, Neal Gross, Joshua Broberg, Brian Rey)



Thank You NASA!

