Accelerator Award Final Update

Project Title: Data Security Measures and User-Layer Development for a Prognostics Use Case

Reporting Period
June 01, 2020 – April 30, 2021

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April 26, 2021

Accelerator Award Final Update

Outline

1. Summary of milestones and progress: 5 minutes

2. Detailed milestone updates: 20 minutes
    a. Milestone outcomes
    b. Contractor work
    c. Industry expert contributions

3. Project Impact and Next Steps: 10 minutes

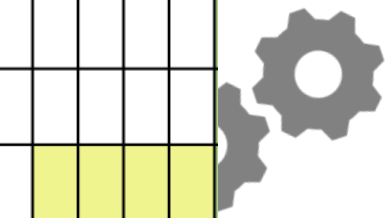
4. Commercialization update: 15 minutes
    a. Team
    b. Grants
    c. Path Forward

Pitch Day Milestone Plan

The project has two objectives:

1. **Build Demo for Pilot Use Case: Jet Engine Prognostics**
2. **Develop User-Interface for deployment**

Goal	Milestone/Task Detail	Timeline (month-wise)											
		M1	2	3	4	5	6	7	8	9	10	11	12
1 PILOT USE CASE	1.1. Establish physics-based engine models [Kumar, VanFossen]												
	1.2. Establish data format for inputs, State of Health [Kumar, VanFossen]												
	1.3. Establish Quantities of Interest and Performance Thresholds [Kumar, VanFossen]												
	1.4. Prescriptive analytics, Code Optimization, Integration [Kumar, VanFossen, Infoscitex]												
2 USER INTERFACE	2.1. UI Layers: Front and Backends [Kumar, Infoscitex]												
	2.2. AWS (Web) Deployment [Kumar, Infoscitex]												
	2.3. Communication protocols for data security [Kumar, Infoscitex]												



Milestone Progress: Final

Milestone #	Milestone Name	Status	Deliverables	% Completion
1-1	Identify and encode physics-based models for engine failure	*Completed*	*Successfully Achieved*	*100*
1-2	Identify data format for current state of engine health	*Completed*	*Successfully Achieved*	*100*
1-3	Identify and encode meaningful quantities of interest (QoI)	*Completed*	*Successfully Achieved*	*100*
1-4	Algorithm tuning and delivery of actionable intelligence	*Completed*	*Successfully Achieved*	*100*
2-1	Create an illustrative, responsive and intuitive user interface (UI) layer	*Completed*	*Successfully Achieved*	*100*
2-2	Deploy software as a web-based tool	*Completed*	*Successfully Achieved*	*100*

Vendor Milestone Progress: Q2 End

Detailed Milestone Plan for the Vendor (InfoScitex): Status at End of Q2

Item	Task	Start	End
1	Prototyping: 2.1	06/01/2020	06/20/2020
2	Data Input: State: 2.1	06/21/2020	07/01/2020
3	Data Input: Dynamics (ODE, Parameters): 2.1	07/01/2020	07/20/2020
4	Data Input: Initial Conditions: 2.1	07/01/2020	07/20/2020
5	Data Input: QOI, Thresholds: 2.1	07/21/2020	07/31/2020
6	Integration with Excel Sheet Input: 2.1	08/01/2020	08/10/2020
7	Testing: Data Input: 2.1	08/01/2020	08/10/2020
	Q1 Report Due	**08/17/2020**	**08/17/2020**
8	Integration with MATLAB Code: Transfer data: 1.4	08/11/2020	08/31/2020
9	Integration with MATLAB Code: Pull Data from Code: 1.4	08/16/2020	09/01/2020
10	Testing: Integration with MATLAB Code: 1.4	08/15/2020	09/15/2020
11	Analytics: Visuals: QOI, time evolution: 2.1	08/16/2020	9/15/2020
12	Analytics: Visuals: System Graphs: 2.1	09/15/2020	9/30/2020
13	Analytics: Report Generation: 2.1	10/01/2020	10/15/2020
14	Testing: Analytics: 2.1	10/15/2020	10/31/2020
	Q2 Report Due	**11/16/2020**	**11/16/2020**
15	Web Deployment: Input end: 2.2	12/01/2020	12/31/2020
16	Web Deployment: Integration with MATLAB Code: 2.2	01/01/2021	01/15/2021
17	Web Deployment: Display and data transfer to user: 2.2	01/16/2021	02/10/2021
18	Testing: Web Tool: 1.4, 2.2	01/25/2021	02/10/2021
	Q3 Report Due	**02/15/2021**	**02/15/2021**
19	Security Measures: Input data: 2.3	02/16/2021	03/15/2021
20	Security Measures: Data Transfer to Backend: 2.3	03/16/2021	03/31/2021
21	Security Measures: User data deletion: 2.3	04/01/2021	04/30/2021
22	Integrated Testing: 1.4, 2.1, 2.2, 2.3	05/01/2021	05/30/2021
	Final Report	**06/15/2021**	**06/15/2021**

Vendor Milestone Progress

Detailed Milestone Plan for the Vendor (InfoScitex): Status at End of March,2021

Item	Task	Start	End
1	Prototyping: 2.1	06/01/2020	06/20/2020
2	Data Input: State: 2.1	06/21/2020	07/01/2020
3	Data Input: Dynamics (ODE, Parameters): 2.1	07/01/2020	07/20/2020
4	Data Input: Initial Conditions: 2.1	07/01/2020	07/20/2020
5	Data Input: QOI, Thresholds: 2.1	07/21/2020	07/31/2020
6	Integration with Excel Sheet Input: 2.1	08/01/2020	08/10/2020
7	Testing: Data Input: 2.1	08/01/2020	08/10/2020
	Q1 Report Due	**08/17/2020**	**08/17/2020**
8	Integration with MATLAB Code: Transfer data: 1.4	08/11/2020	08/31/2020
9	Integration with MATLAB Code: Pull Data from Code: 1.4	08/16/2020	09/01/2020
10	Testing: Integration with MATLAB Code: 1.4	08/15/2020	09/15/2020
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13	Analytics: Report Generation: 2.1	10/01/2020	10/15/2020
14	Testing: Analytics: 2.1	10/15/2020	10/31/2020
	Q2 Report Due	**11/16/2020**	**11/16/2020**
15	Web Deployment: Input end: 2.2	12/01/2020	12/31/2020
16	Web Deployment: Integration with MATLAB Code: 2.2	01/01/2021	01/15/2021
17	Web Deployment: Display and data transfer to user: 2.2	01/16/2021	02/10/2021
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19	Security Measures: Input data: 2.3	02/16/2021	03/15/2021
20	Security Measures: Data Transfer to Backend: 2.3	03/16/2021	03/31/2021
21	Security Measures: User data deletion: 2.3	04/01/2021	04/30/2021
22	Integrated Testing: 1.4, 2.1, 2.2, 2.3	05/01/2021	05/30/2021
	Final Report	**06/15/2021**	**06/15/2021**

Milestone Progress: Task 1-1

100%

[Engine Model]

- NPSS® stands for Numerical Propulsion System Simulation®

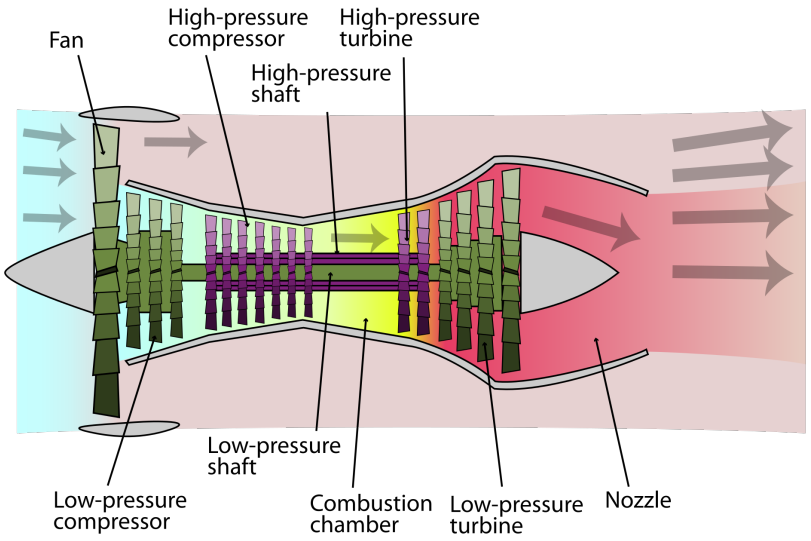
- It is an advanced object-oriented, non-linear thermodynamic modeling environment used by the aerospace industry for modeling turbomachinery, air-breathing propulsion systems, liquid rocket engines, engine control systems, and system model integration
- It can also be used for modeling refrigeration cycles, multi-phase heat transfer systems, vehicle emission analyses, or supercritical carbon dioxide (sCO2) power cycles

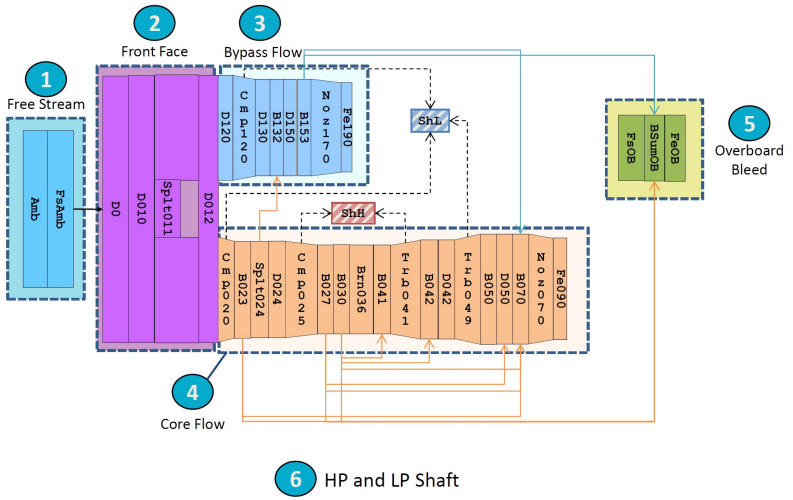
Milestone Progress: Task 1-1

100%

[Engine Model]

- NPSS [Numerical Propulsion System Simulation]
  - Common Development Model (CDM) Turbo Fan 01 (TF02)
  - Close to GE GE9X engines: Contributed by GE
  - Continued integration with software, with representative flight profiles, e.g., JFK-LAX cycles





Milestone Progress: Task 1-1

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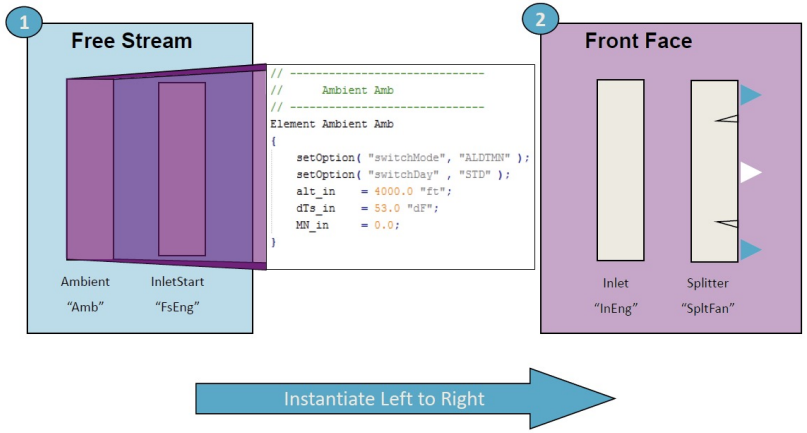
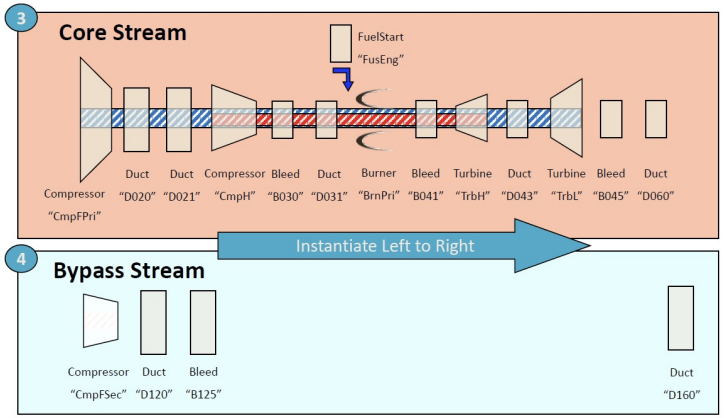
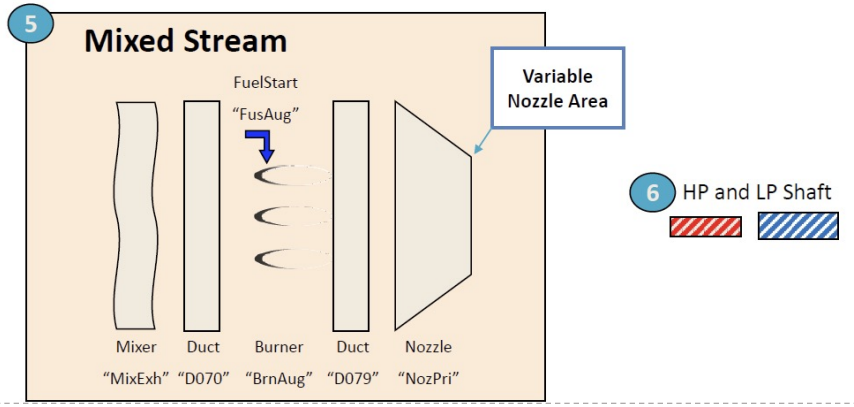
[Model Structure: Order of Instantiation]





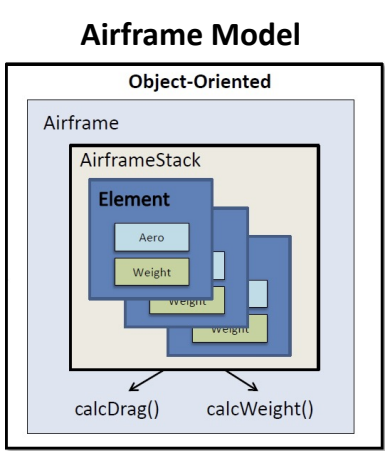


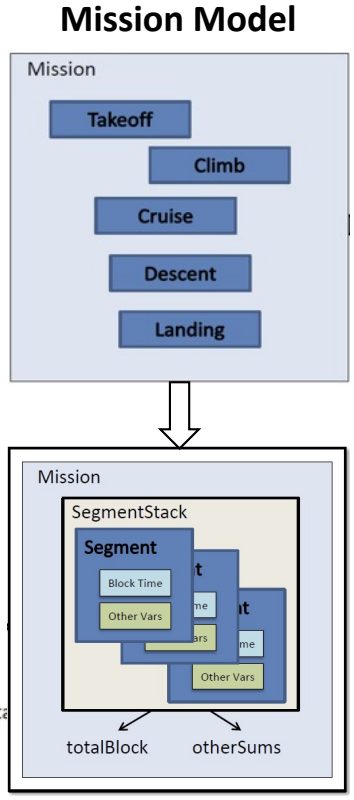
Milestone Progress: Task 1-1

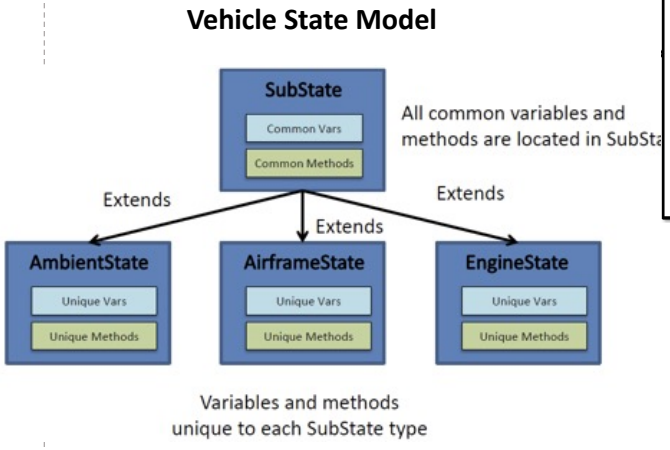
100%

[Mission Requirements]

- Ambient atmospheric properties model
  - Provided by AirBreathing/Ambient element
- Airframe specification of airframe weight and drag properties including the effects of droppable stores
- Engine performance model
  - CDM01_TF02 model is used as an example, but any model with the appropriate interface can be used
- Mission model of total aircraft performance over fixed mission segments

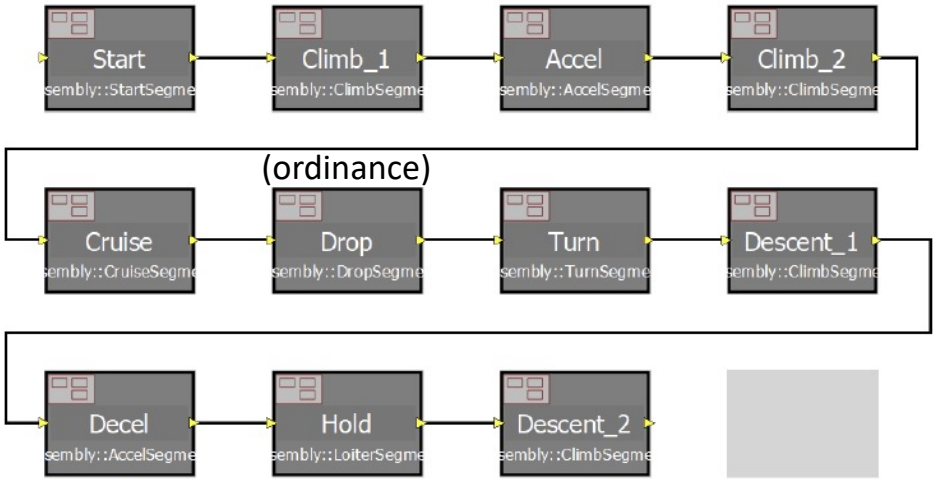






Milestone Progress: Task 1-1/1-2 100%

[Mission Overview]



Example Summary File

MISSION ANALYSIS

SUMMARY OUTPUT DATA

TOGW	Total_Range	Total_Fuel_Burn	Total_Time
46458	265.45	6953.90	1.11

MISSION SEGMENT DATA

	Initial_Weight(LB)	FUEL(LB)	PLA	TIME(HR)	RANGE(NM)
Base.Segments.Start	46458	0.00	100.00	0.00	0.00
Base.Segments.Climb_1	46458	1016.44	100.00	0.06	10.51
Base.Segments.Accel	45441	335.70	100.00	0.02	7.74
Base.Segments.Climb_2	45105	634.15	100.00	0.06	28.85
Base.Segments.Cruise	44471	1811.58	46.35	0.41	200.00
Base.Segments.Drop	42660	0.00	44.65	0.00	0.00
Base.Segments.Turn	41908	93.12	102.43	0.01	4.90
Base.Segments.Descent_1	41815	37.31	10.00	0.01	4.33
Base.Segments.Decel	41777	53.59	10.00	0.01	4.49
Base.Segments.Hold	41724	2812.58	26.15	0.50	0.00
Base.Segments.Descent_2	38911	159.42	10.00	0.03	4.63

Milestone Progress: Task 1-1/1-2 100%

[Integration with AMC]

SIMULATION INPUTS

Mission Segment	Uncertainty Input	Units
Climb_1	Ending Altitude	ft.
Acceleration_1	Ending Mach Number	unitless
Climb_2	Ending Altitude	ft.
Cruise_1	Total Distance	nmile.
Descent_1	Ending Altitude	ft.
Deceleration_1	Ending Mach Number	unitless
Hold_1	Time Duration	hr.

INITIAL UNCERTAINTY

$$\boldsymbol{\mu}_0 = [20000 \quad 0.8 \quad 40000 \quad 200 \quad 20000 \quad 0.3 \quad 0.5]^T$$

$$\boldsymbol{\Sigma}_0 = \mathrm{diag}[150^2 \quad 0.005^2 \quad 150^2 \quad 2^2 \quad 150^2 \quad 0.005^2 \quad 0.02^2]$$

with $\boldsymbol{\mu}_0$ and $\boldsymbol{\Sigma}_0$ directly related to each mission segment above

Milestone Progress: Task 1-2 100%

[Data Format: System Variables]

- Taxonomy document developed codifies input data format
- Serves as User Guide V1.2
- UI output generated in JSON (key-value pairs) format
- JSON format integrated with backend (MATLAB software)

[Taxonomy document]

1 Taxonomy of UI Inputs

UI Version 1.0 is designed to handle the following inputs related to the system behavior and analytics. Input is to be arranged in six separate csv sheets as described in various sections below. These sheets are to be named as below:

1. System Preamble: **CS-SP**
2. System Parameters: **CS-SR**
3. System Dynamics: **CS-SD**
4. Initial Conditions: **CS-SI**
5. Simulation Performance: **CS-SF**
6. System Analytics: **CS-SA**

[Input Data Sheet]

	A	B	C	D	E	F	G
1	SysType	HBOX					
2	NS						
3	NU	7					
4	NY	1					
5	NN						
6	SName						
7	TName	t					
8	UName	C1_altFinal_in	ACC_MNfinal_in	C2_altFinal_in	CRS_dist_in	D1_altFinal_in	DCC_MNfinal_i
9	YName	SMH					
10	NonDimS						
11	NonDimT						
12	NonDimU	0					
13	NonDimY	0					
14	TDunit	hour					
15	TAunit	hour					
16	TSmax	inf					
17	TSmin	0					
18	param_c	C1_altFinal_in	ACC_MNfinal_in	C2_altFinal_in	CRS_dist_in	D1_altFinal_in	DCC_MNfinal_i
19		1	1	1	1	1	
20	param_sd						
21							
22	param_f						
23							
24	param_tab						
25							
26	param_rand						

CS-SP | CS-SR | CS-SD | CS-SI | CS-SF | CS-SA

Milestone Progress: Task 1-3 100%

[Quantities of Interest: Engine Model]

- Received feedback from GE to use following potential variables as QOI:
  - HPT speed
  - LPT speed
  - Specific fuel consumption ratio
  - Stall Margin inside the compressor (SMH)

$$SMH = \frac{\text{WcMap}/\text{WcMapSMH}}{\text{PRmap}/\text{PRmapSMH} - 1} * 100$$

- SMH is a function of incoming corrected weight flow (WcMap: lbm/sec), corrected weight flow at the stall line (WcMapSMH: lbm/sec), total-to-total pressure ratio (PRmap) , and the total-to-total pressure ratio at the stall line (PRmapSMN)
- The inputs to SMH are also functions of the corrected speed (rpm) and engine maps
- Prescribed Accuracy Bounds:

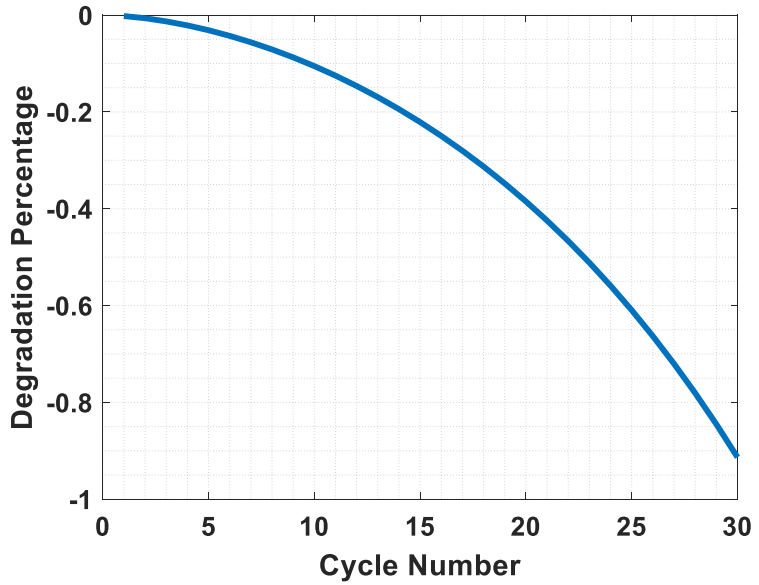
$$\varepsilon_t^{U^*} = 0.22 \text{ (SMH)}$$

$$\varepsilon_t^{L^*} = 0.0 \text{ (particle removal disabled)}$$

Milestone Progress: Task 1-1/1-3

100%

[Engine Model: *Degradation*]



Component	Maximum Efficiency Degradation Δ_{max}
CmpFSec	0.03
CmpFPri	0.0173
CmpH	0.0227
TrbH	0.0193
TrbL	0.034

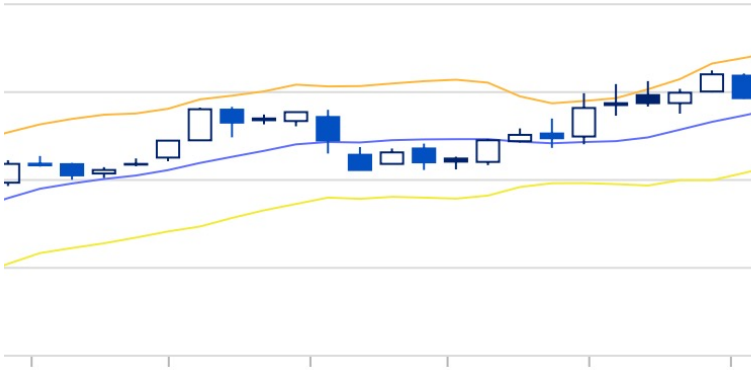
- A rudimentary efficiency degradation model was implemented within NPSS to modify engine efficiency (health) parameters.
- This was required due to system health parameters being an input to NPSS and not degrading from cycle to cycle.

Milestone Progress: Task 1-4

100%

[Algorithm Tuning + Actionable Intelligence]

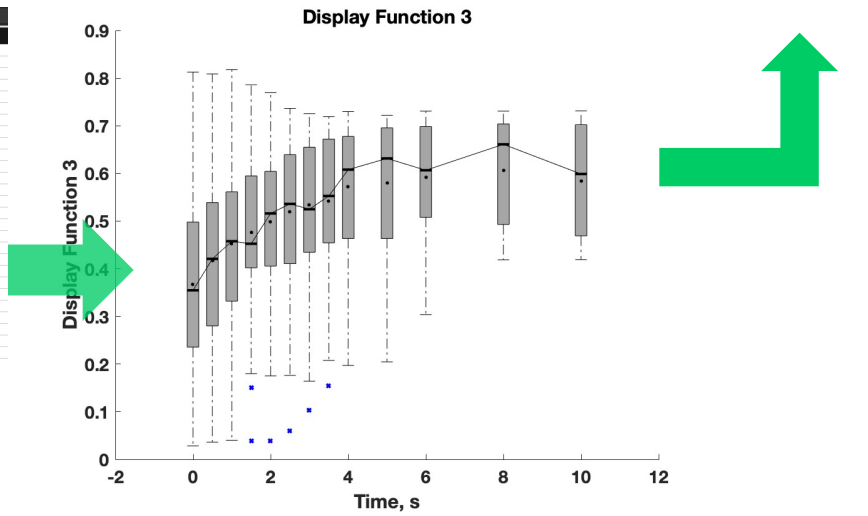
- Output data created in Excel format
- COTS graphing package: *SyncFusion*
- Compatible with Blazor, JS & ASP .NET Core



A1 Time_1

Time_1	Time_2	Time_3	Time_4	Time_5	Time_6	Time_7	Time_8	Time_9	Time_10	Time_11	Time_12	Time_13
-0.750790442	-0.695926898	-0.516847767	-0.208925684	0.306417379	0.854376402	0.978274232	0.877577817	0.699553931	0.034657053	-0.981059046	-0.327903362	0.928785991
0.146498442	-0.120481777	-0.492794441	-0.754718324	-0.770718886	-0.636263959	-0.392998661	0.013774805	0.619756041	0.946404283	0.59058545	-1.002740168	-0.128164407
-0.135872299	0.010684925	0.245649436	0.509119551	0.65353561	0.62471206	0.462553214	0.161388904	-0.343587876	-0.956465888	-0.666940749	0.994151062	0.272924631
0.666565708	0.81761986	0.749739768	0.567634745	0.269714408	-0.227984821	-0.817554856	-0.990831308	-0.90354003	-0.492977422	0.483048649	0.663625767	-0.998263353
-0.289610138	-0.605247417	-0.73971648	-0.679865579	-0.496253424	-0.179110334	0.348499602	0.874126283	0.973388066	0.682990781	-0.006138782	-0.814876766	0.819314665
0.468595327	0.430456957	0.269882874	-0.041665284	-0.511364292	-0.848270208	-0.865876442	-0.731749417	-0.509202196	0.41589791	0.985343858	-0.018780909	-0.811243065
0.371874164	0.079071225	-0.40217546	-0.839662777	-0.914407805	-0.801339719	-0.604142309	-0.304456916	0.190055419	1.000641024	0.754548627	-0.93254199	-0.419174085
-0.59022016	-0.354703806	0.0506435	0.639553387	0.960679499	0.928737734	0.780372199	0.561910294	0.230885405	-0.883733305	-0.894356288	0.540511494	0.644052933
0.03685876	-0.10487539	-0.29792222	-0.47772036	-0.55193595	-0.490815864	-0.300482585	0.052155236	0.572965147	0.892448144	0.525732047	-0.990396029	-0.009090972
-0.112112007	0.378216032	0.844009087	0.931259685	0.82177021	0.630082263	0.342743785	-0.128451978	-0.754672181	-0.933152125	-0.549787856	0.997108682	0.049143346
0.232662645	0.272202229	0.248755825	0.139370406	-0.077803027	-0.396800093	-0.67113341	-0.73519275	-0.631689379	-0.034763556	0.947264527	0.304233047	-0.9201755
-0.411162498	-0.500404301	-0.468824711	-0.311989176	-0.00482629	0.476025342	0.852047565	0.887913851	0.76108596	0.219145959	-0.885025993	-0.457592315	0.97267044
0.296377439	0.4831686	0.562294265	0.503249531	0.314851177	-0.034555947	-0.558455542	-0.901281472	-0.899271304	-0.538921718	0.358801261	0.701509598	-0.981941843
-0.036177673	-0.560516696	-0.901926024	-0.899029942	-0.758167357	-0.538047745	-0.197576836	0.361008795	0.904617828	0.881824772	0.442623932	-0.967932525	0.159711574
-0.473328165	-0.278922721	0.07982652	0.596101534	0.900875039	0.882246114	0.734652794	0.505199632	0.145230369	-0.935389565	-0.8634704	0.664963711	0.595875397
0.925203619	0.80526087	0.605710142	0.304681111	-0.191467089	-0.804875164	-1.001517179	-0.919699745	-0.754831694	-0.163065192	0.932332358	0.419536075	-0.960390087
-0.230327535	-0.198161966	-0.087860318	0.118335434	0.403711904	0.636049276	0.684480135	0.576836191	0.345648129	-0.637575667	-0.923852252	0.329172102	0.712925282
0.099055793	0.626850715	0.914518886	0.884036727	0.732190151	0.49973703	0.135074733	-0.452867886	-0.941379161	-0.860250163	-0.397359377	0.952886367	-0.247259841
0.561805067	0.202532838	-0.380153812	-0.928579955	-1.004564633	-0.889707722	-0.709063583	-0.453550767	-0.050343918	0.97842404	0.833944135	-0.767192439	-0.54791578
-0.956309928	-0.922055259	-0.772333452	-0.55119133	-0.21419887	0.339230258	0.896469598	0.996771537	0.888450408	0.45561835	-0.566189768	-0.634737197	1.00340758
-0.003130032	0.294419903	0.610253372	0.74181319	0.67962231	0.494375958	0.175153905	-0.355126254	-0.877763574	-0.864390541	-0.415249707	0.958722266	-0.212349496
-0.337207067	-0.55020832	-0.623147164	-0.544590439	-0.33730273	0.034972886	0.588694643	0.928672746	0.914932648	0.552910556	-0.330342342	-0.711745775	0.975342269
0.760165012	0.744811565	0.592556168	0.326017175	-0.123031969	-0.727333355	-0.982545711	-0.922026901	-0.764055985	-0.189110747	0.915515604	0.43785647	-0.966413711
-0.200992604	0.155636916	0.629622508	0.874399078	0.837558962	0.679292928	0.429301156	0.024507855	-0.592343606	-0.961784512	-0.61653755	1.00409885	0.17584913
0.261786153	0.036256	-0.335655219	-0.711287555	-0.825887566	-0.738105755	-0.543219819	-0.227234997	0.298016485	0.989148312	0.712545115	-0.973618092	-0.348921372
-0.656227903	-0.55027124	-0.317588673	0.089639833	0.66229655	0.952140585	0.911218285	0.758272392	0.531916294	-0.385084613	-0.992648096	-0.017605056	0.823052105
0.186750685	-0.329411944	-0.859758822	-0.970837046	-0.866796742	-0.685633988	-0.42267035	-0.001625225	0.627713766	0.961165032	0.609966052	-1.004226394	-0.163140863

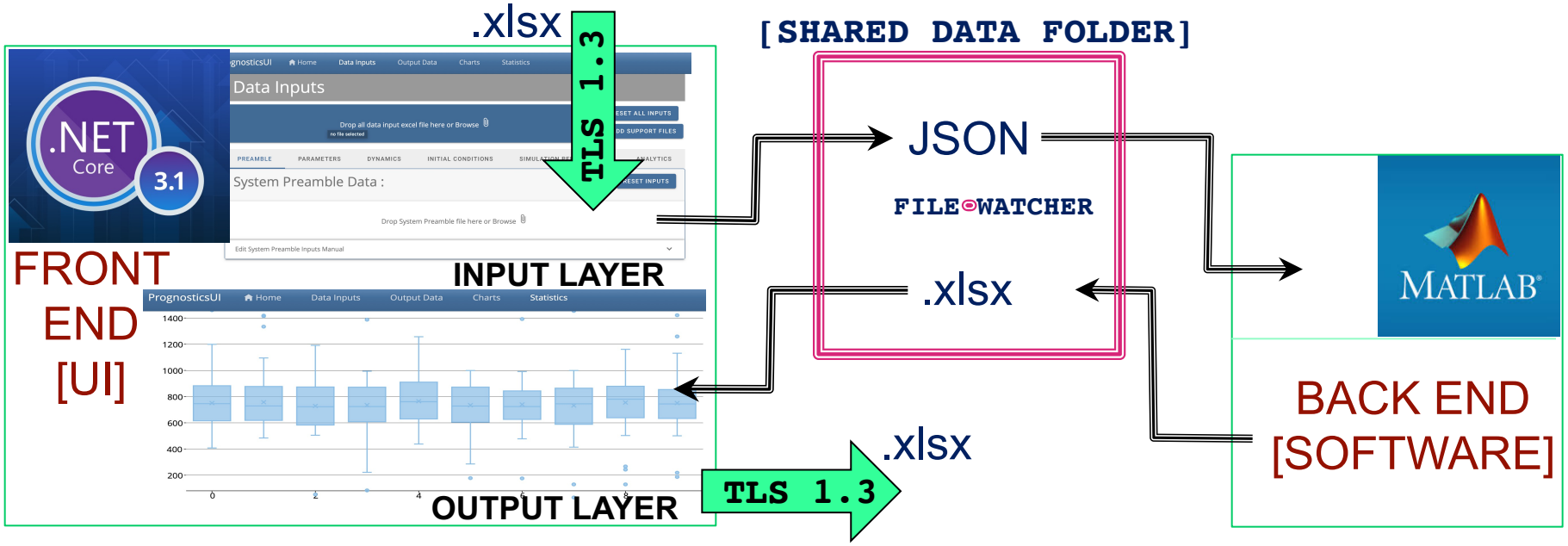
[Output Data]



Milestone Progress: Task 2-1 100%

UI Development

- .NET Web-based application (AWS)
- Multi-platform (Win, Linux, Mac, etc)
- Input Layer: Data inputs follow Taxonomy
- Output Layer: Integrated with SyncFusion
- File Share System: File Watcher



Milestone Progress: Task 2-1 100%

UI Development

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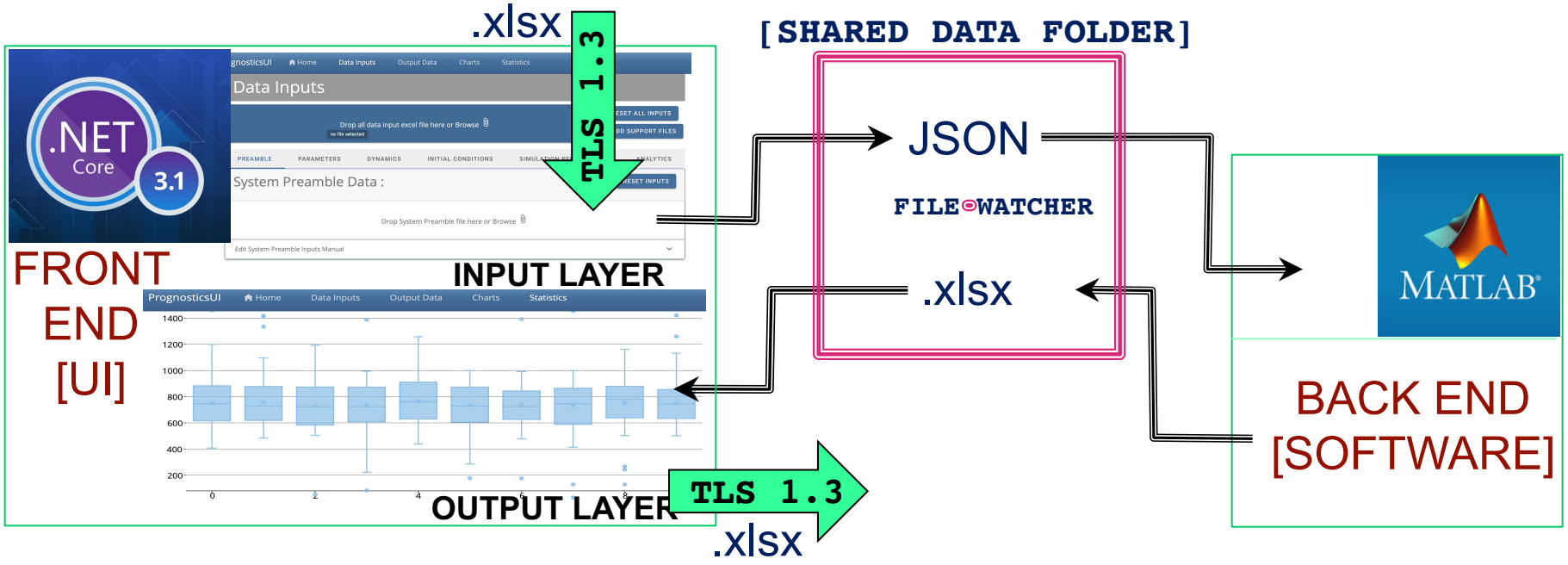
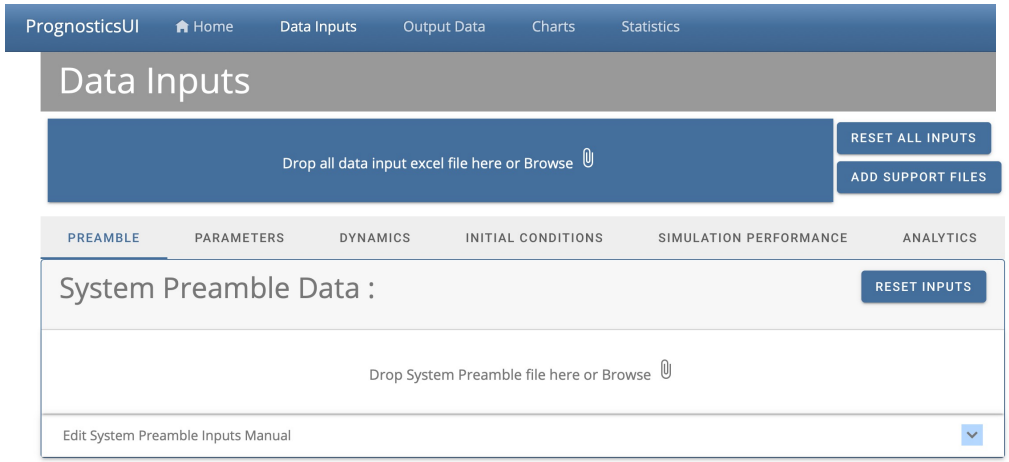


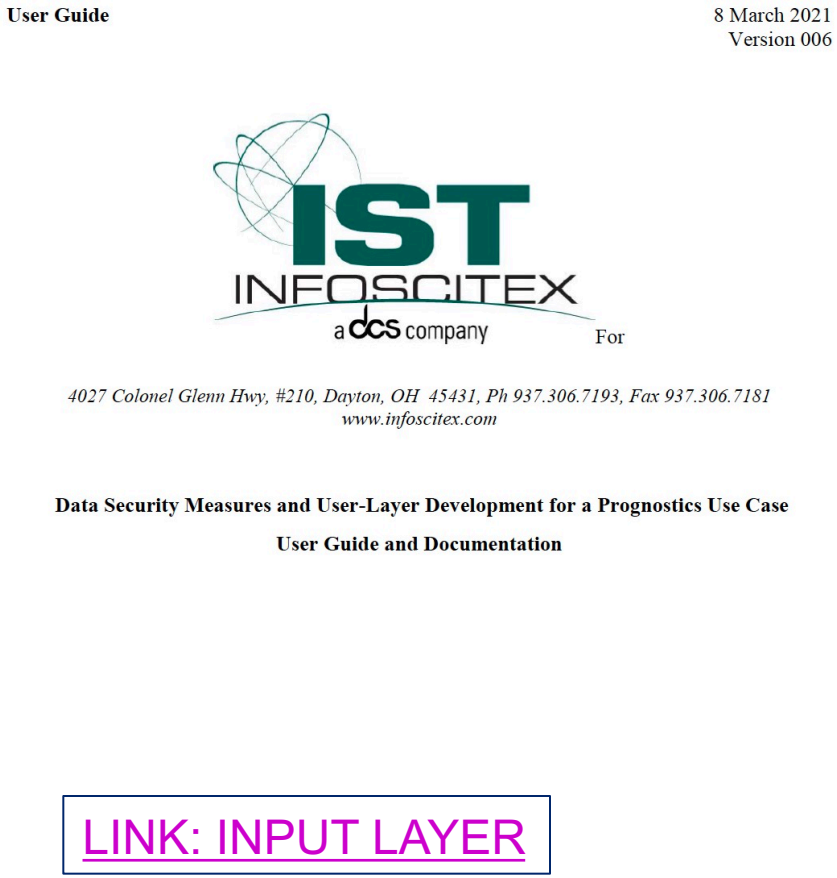
Milestone Progress: Task 2-1

100%

UI Development: Input Layer

- .NET Web-based application
- Works online (AWS) and offline (Docker)
- Individual user login
- Manual entry or File Uploads
- User Guide Developed by IST (vendor)



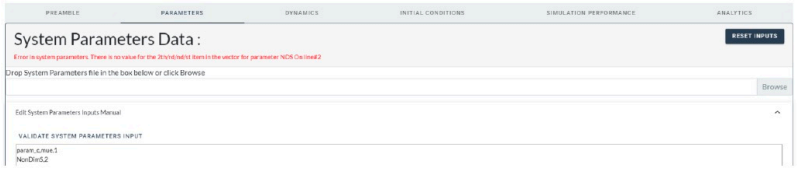


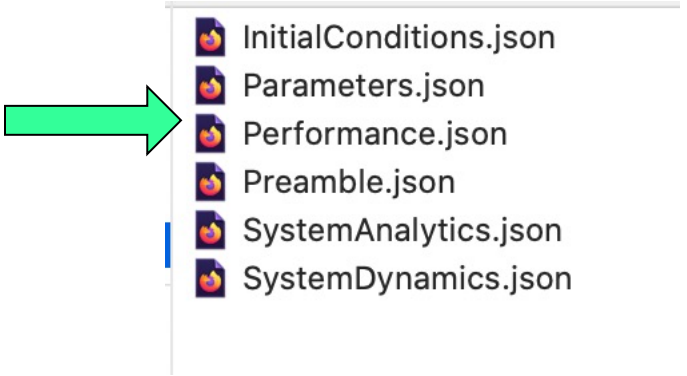
LINK: INPUT LAYER

Milestone Progress: Task 2-1 100%

UI Development: Input Layer

- Workflow
  - Upload Support Files
  - Upload all Input Data (Per Taxonomy)
  - Alternate: Type in Input Data
  - Hit "Run Model"
    - Each Section Validated (Per Taxonomy)
    - Data Displayed on Screen for Validation
    - Data Translated to JSON key-value pairs
    - Data Sent to Share Folder
    - (Available for Download in Demo)
    - If Errors Encountered
      - Errors Messages Displayed in Red

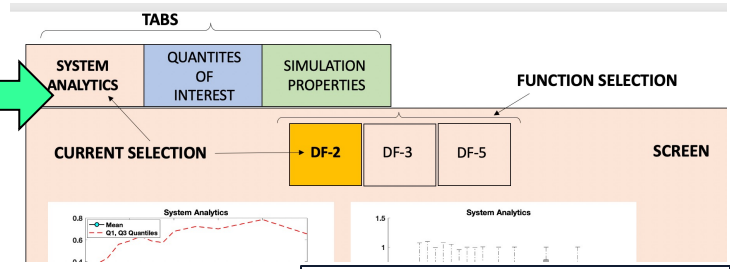




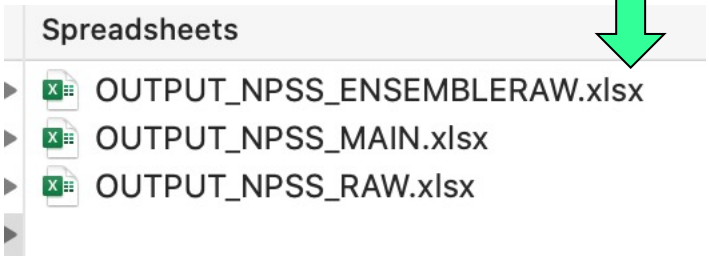
Milestone Progress: Task 2-1 100%

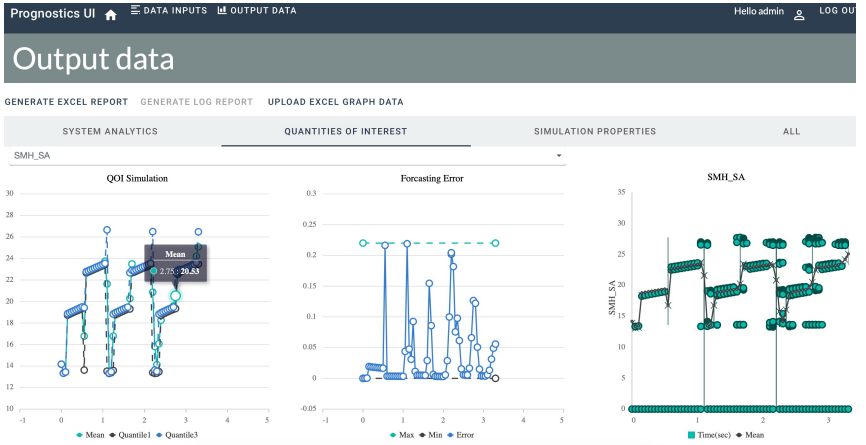
UI Development: Output Layer

- .NET Web-based application
- Integrated with SyncFusion Graphics Software
  - Annual License
- File Watcher monitors Shared Folder
- Live Results Displayed as data becomes available
- Display Separated into Groups (per Taxonomy)
- Interactive Plots (add/subtract charts)
- Upload Data Sheets for Offline Displays
- All Data Sheets Returned to User



LINK: OUTPUT LAYER

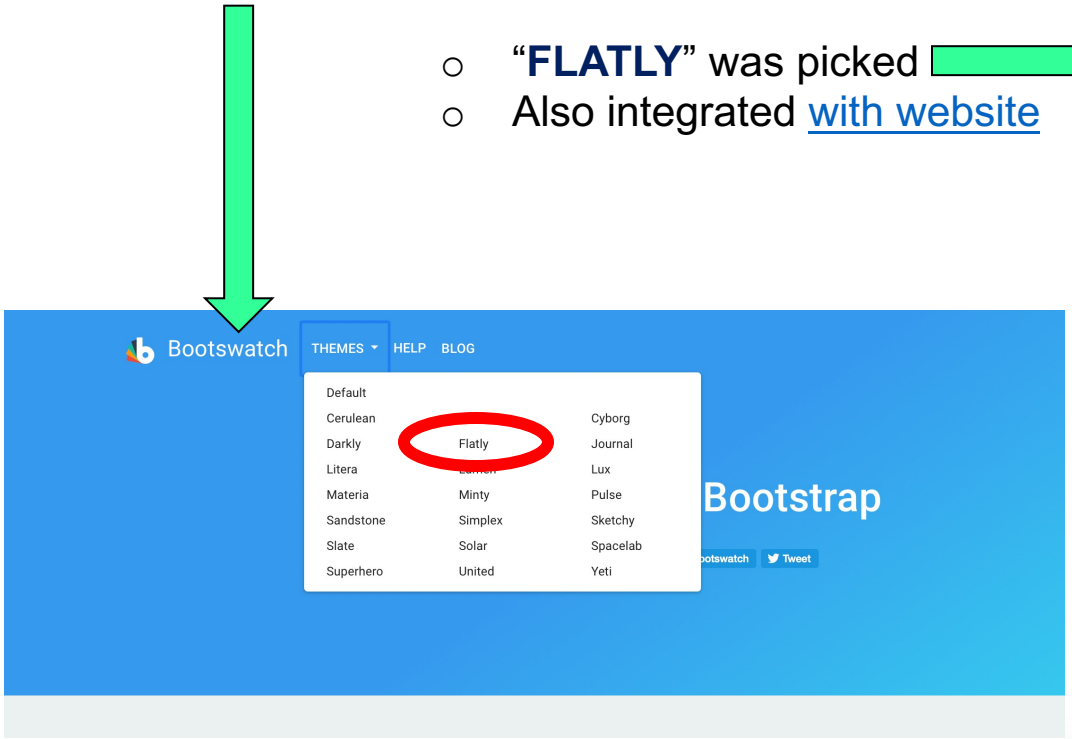


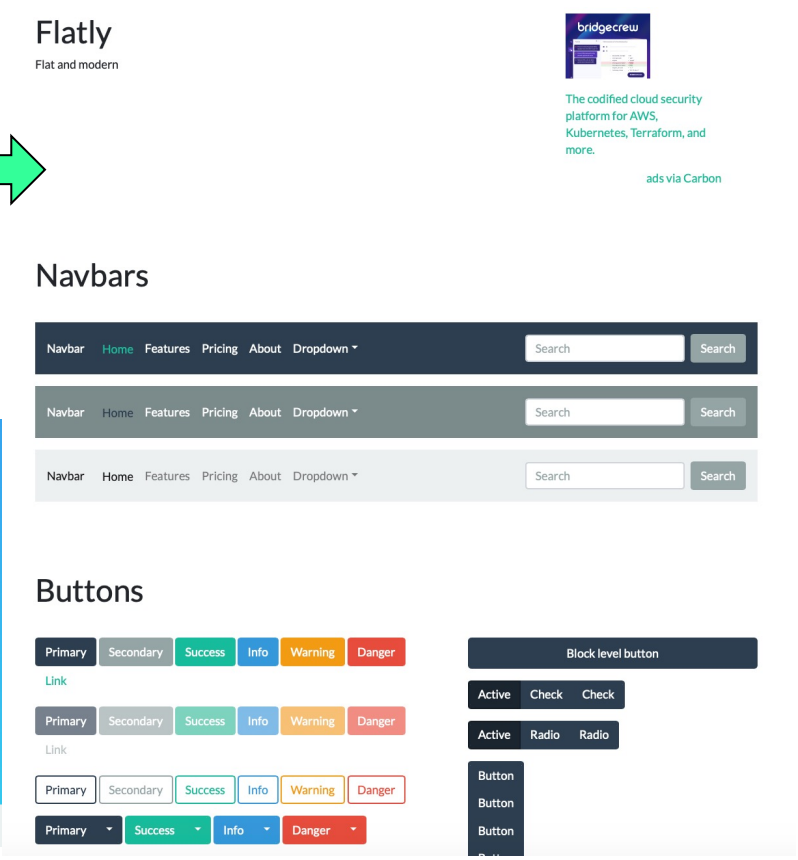


Milestone Progress: Task 2-1 100%

UI Development: Look and Feel

- Vendor provided free compatible themes on Bootswatch.com
  - "**FLATLY**" was picked
  - Also integrated with website

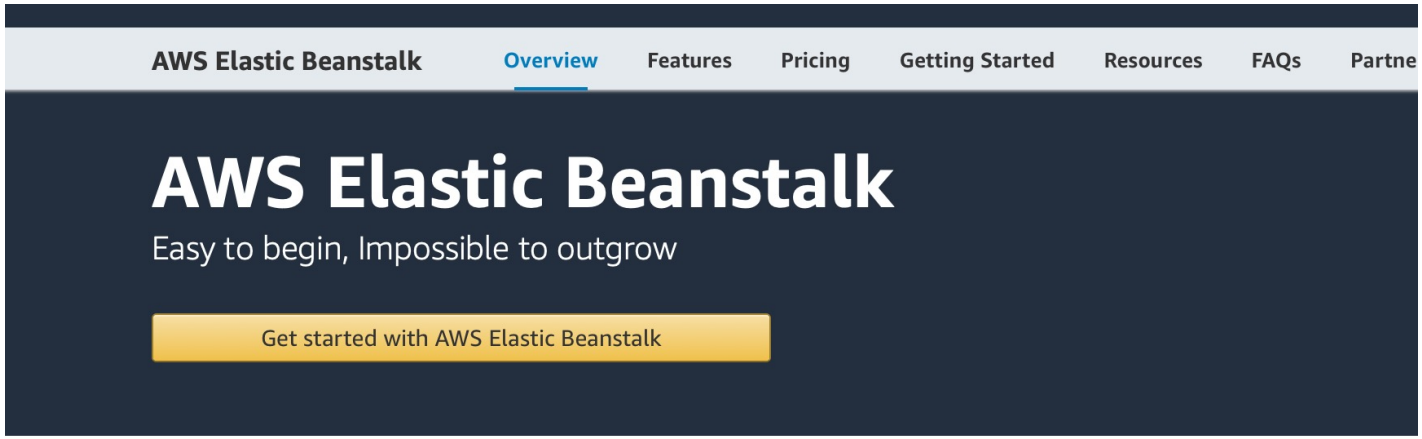




Milestone Progress: Task 2-2 100%

UI: Web Deployment

- Launched as a web-based application
- AWS Beanstalk Platform

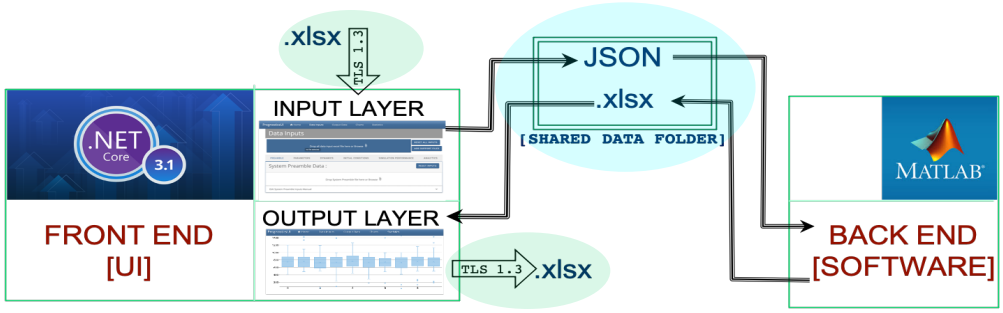


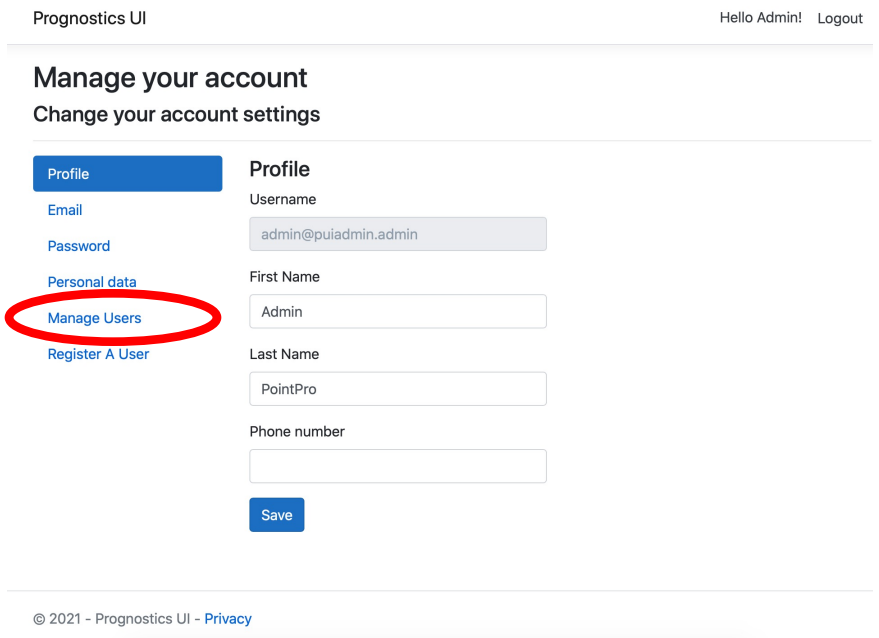
AWS Elastic Beanstalk is an easy-to-use service for deploying and scaling web applications and services developed with Java, .NET, PHP, Node.js, Python, Ruby, Go, and Docker on familiar servers such as Apache, Nginx, Passenger, and IIS.

Milestone Progress: Task 2-3 100%

Security

- Access restricted to secure user-accounts
- All live-wire data protected under TLS 1.3 protocols:
- For all internal (non-live) data, use secure file sharing folder along with file-watcher system





Milestone Progress: Learnings

- Vendor Initiative
  - Bittersweet experience working with large government contractor
  - Junior staff
  - Limited time, commitment and drive
  - “Lack of imagination” at conceptualization stage: wanted direct instructions
  - Must look for development alternatives
  - May return to them but will not work with the same team

- Student Work
  - Reliable resource
  - Limited time due to grad program commitments
  - Need a dedicated resource

Grant Impact

- Product
  - Integrated NPSS and associated literature with forecasting software
  - Understanding of shortcomings of NPSS and need for better models
  - Beta UI ready
  - Significant discovery about interface strengths and weaknesses
- Teams and Outreach
  - Established extensive contacts at GE (work still in progress towards pilot)
  - Established contacts at Lockheed
  - Expanded team (Saha): crucial for continuity of software work
  - Air Force, APEX, AFRL contacts
- Grants
  - Applied for NSF/AF grants on basis of progress
  - Won AF STTR Phase I
  - NSF awards in review

Immediate Next Steps: UI

- Testing, Evaluation and Upgrades
  - Expert testing: functionality and interaction: Saha and Rev1 helping with this
  - Enumerate weak points
  - Fix holes and make UI robust
  - Add features:
    - Additional display functionality
    - Offline results processing
    - Building parameter sweeps
    - Link studies
  - Develop detailed documentation for Software and UI use
  - Project being maintained on GitHub

Commercialization Status (1/3)

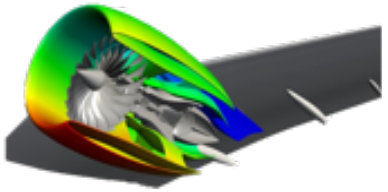
1. Incorporation
   - Formed Delaware Corporation (09/22/2020): **POINTPRO, INC.**
   - Registered with SAM and acquired DUNS number
   - Built company website (wordpress): www.pointprousa.com
   - Integrated with Hubspot for CRM

2. Team Building
   - Current Team:
     - Matthew Bell: CEO
     - Mrinal Kumar: CTO
     - Bill Thoet: Member, Advisory Board
     - Alex Brown (Dickinson-Wright PLLC): Legal Counsel
     - David Bergeron and Matt Chimes: Rev1 Advisors
     - Roshmik Saha [full stack developer]
   - Future:
     - Lead Technical Architect (to be hired)
     - Developers (to be hired)

Commercialization Strategy (2/3)

Strategy for Commercializing – Preparation for Launch

- Significant positive from customer research and conversations with firms in industry (e.g., GE Aviation) led to explore commercialization
- While PointPro has a wide variety of applications, our strategy is to first identify a single high-potential industry use case and tailor our software offering to meet it.
- Condition prognostics of jet engines was chosen based on market size, likelihood of customers adoption, and our own domain expertise.
- With completion of TVSF grant from the Ohio Third Frontier, we have a demo-ready user interface for feedback and potential customers
- Receiving industry **subject matter expert (SME) feedback is needed** to identify specific use cases and to inform our next software refinement steps. The workplan steps described on the Workplan slide is our path to gain that feedback to tightly tailor our software to the needs of the end user.
- Following a successful STTR Phase I we will have all the elements needed to tell the value creation story and a path to make software refinements desired by users: user feedback, a workplan of necessary additions for specific AF use cases, and documentation of the economic value created with each use case.



JET ENGINE FAILURE & PROGNOSTICS

Current Product Development

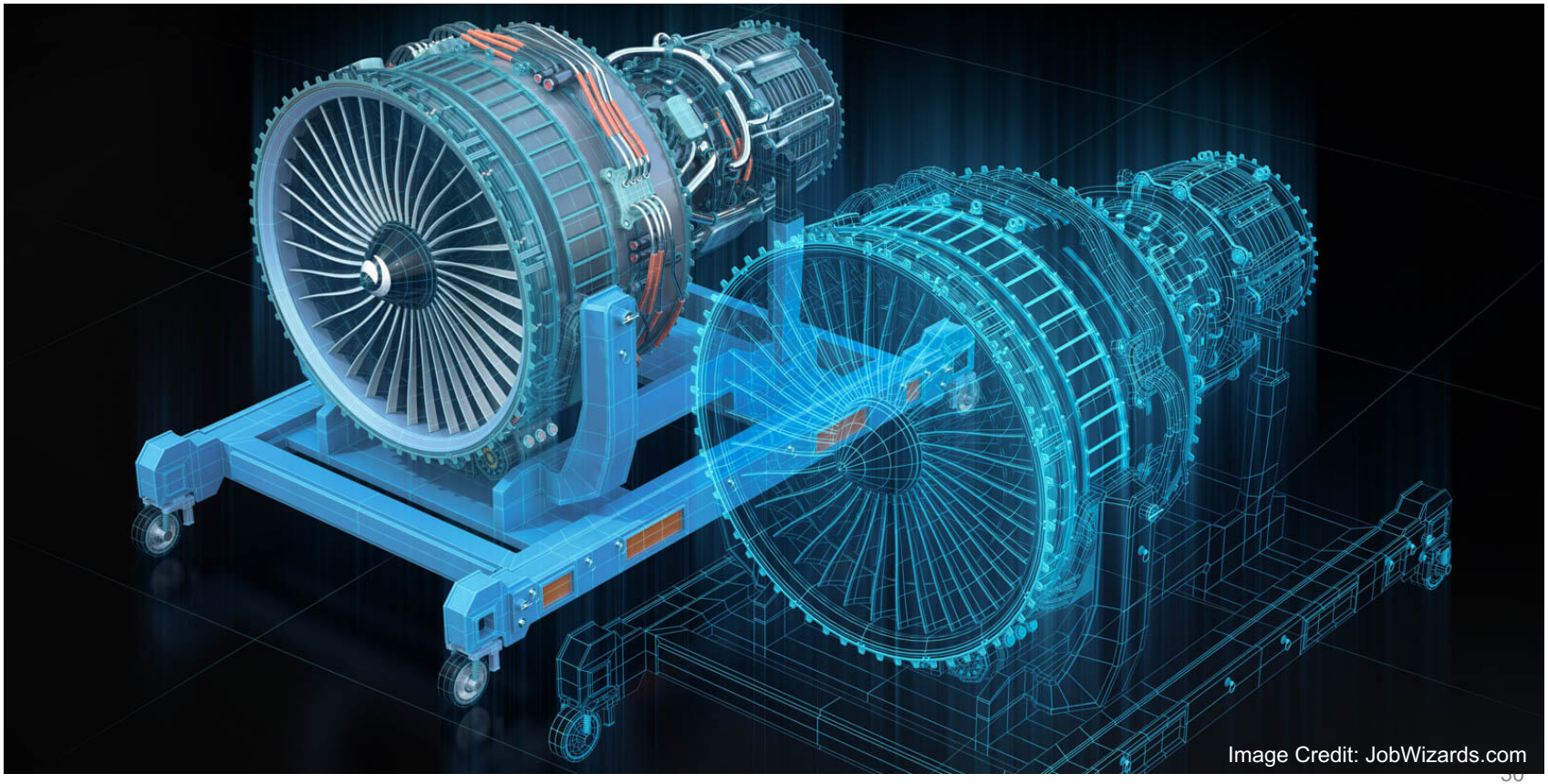
Commercialization Partners

The Ohio State University has invested resources in the commercialization of the PointPro technology through the Corporate Engagement Office.

Rev1 Ventures provides commercialization 1:1 coaching and resources to PointPro. Rev1 is a selective startup studio in Columbus, Ohio.

Commercialization Path (3/3)

The nonstandard term "Digital Twin" is used in a variety of ways and in a different contexts making market sizing difficult. Nonetheless, there are many signs pointing toward the continued growth of this market.



Commercialization Path (3/3)

The nonstandard term "Digital Twin" is used in a variety of ways and in a different contexts making market sizing difficult. Nonetheless, there are many signs pointing toward the continued growth of this market.

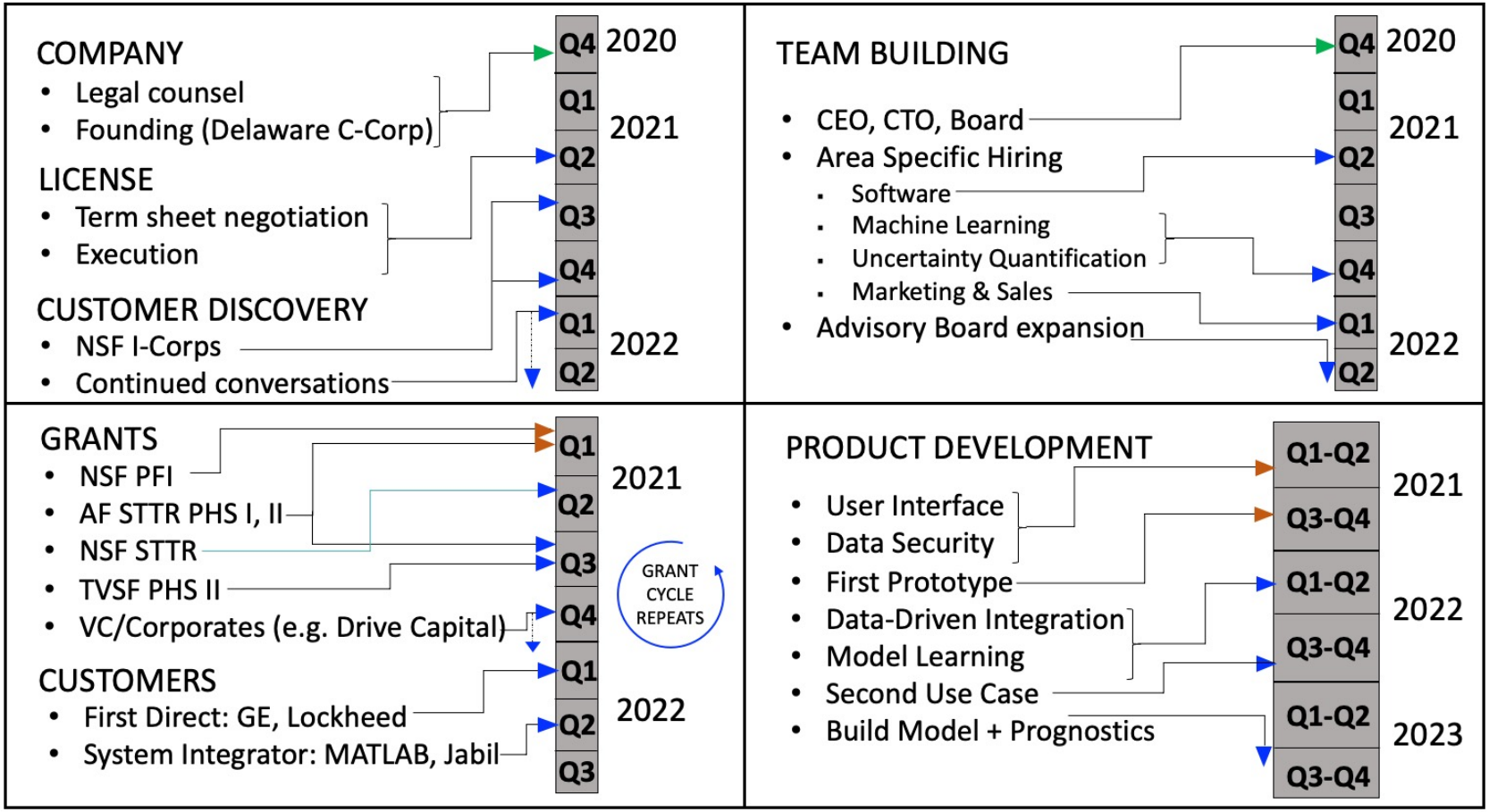
The AF is ramping up adoption of Digital twins for predictive maintenance: "All Air Force platforms should be using some form of predictive maintenance by the end of fiscal 2022… The RSO plans to add predictive maintenance for 10-20 platforms per year for the next five years. – *AF spokesman Daryl Mayer*

Digital Twin adoption in Manufacturing: "Typically, at the manufacturing plant, the OEE [a measure of operating efficiency] may be 60%. Through the use of digital twins, you can raise that up to maybe 80% and that transfers to real productivity improvement." – *Ansys CTO*

A large quickly growing market: "The Digital Twins market is projected to reach US$ 26B by 2025 with CAGR or 38%." – *Grand View Research*

Growth of digital twins is occurring in the design, operations, and maintain lifecycle phases: "Of the expanding digital twin market projected to reach $26 billion by 2025, two-thirds is estimated to focus on assets' operational phase. About $5.8 billion is estimated for the design phase, and about $2 billion for the analysis and maintenance phase.– *Ansys CTO*

Commercialization Path (3/3)



PointPro Commercialization Path

Commercialization Path (3/3)

PointPro Commercialization Path: AF/DOD

SME Feedback is the next planned iteration in the commercialization process

Origin — **Refinement** — **User Interface** — **Commercialization**

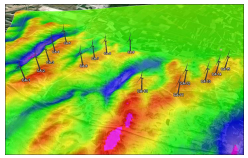
2013 — 2020 — 2021

Tech Origin

- Demonstrated fundamental limits of standard Monte Carlo forecasting for nonlinear systems

NSF Funding (CAREER)

Use Case: Wind Forecasting



WIND FORECASTING

- Developed first adaptive Monte Carlo forecasting platform
- Successful demonstration of trustworthy SSA forecasts

AF Funding (OSR-YIP)

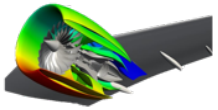
Use Case: Space situational awareness

SPACE ASSET DEFENSE

- OSU Files for IP Protection

TVSF Funding

Funded: Build product demo for jet-engine use case nested in an interactive user interface (UI)



ENGINE PROGNOSTICS

- Follow-on AFOSR Funding (Rem. Sensing)

STTR Phase I: SME Feedback

- Identify specific use cases and end users
- Create workplan for Phase II
- Identify and quantify benefits

- Engine Beta Demo Ready

STTR: Phase II Integrate Feedback

- Execute workplan to prepare software for end users
- Begin marketing to Industry
- Engage investors and Corporates

Product Launch: AF/DoD and Industry

Next Steps: Technology

- Funding for tech development
  - Objectives: speed, new vertical, data-driven capabilities
    - AF STTR: Won Phase 1 (period: 05 – 07 2021)
    - NSF: STTR: Phase 1 (June 2021)
    - NSF PFI: 2021 cycle
    - TVSF Phase II: Summer - 2021
    - AF STTR: Phase 2 (July 2021)
  - Hiring needs: tech and software specialist

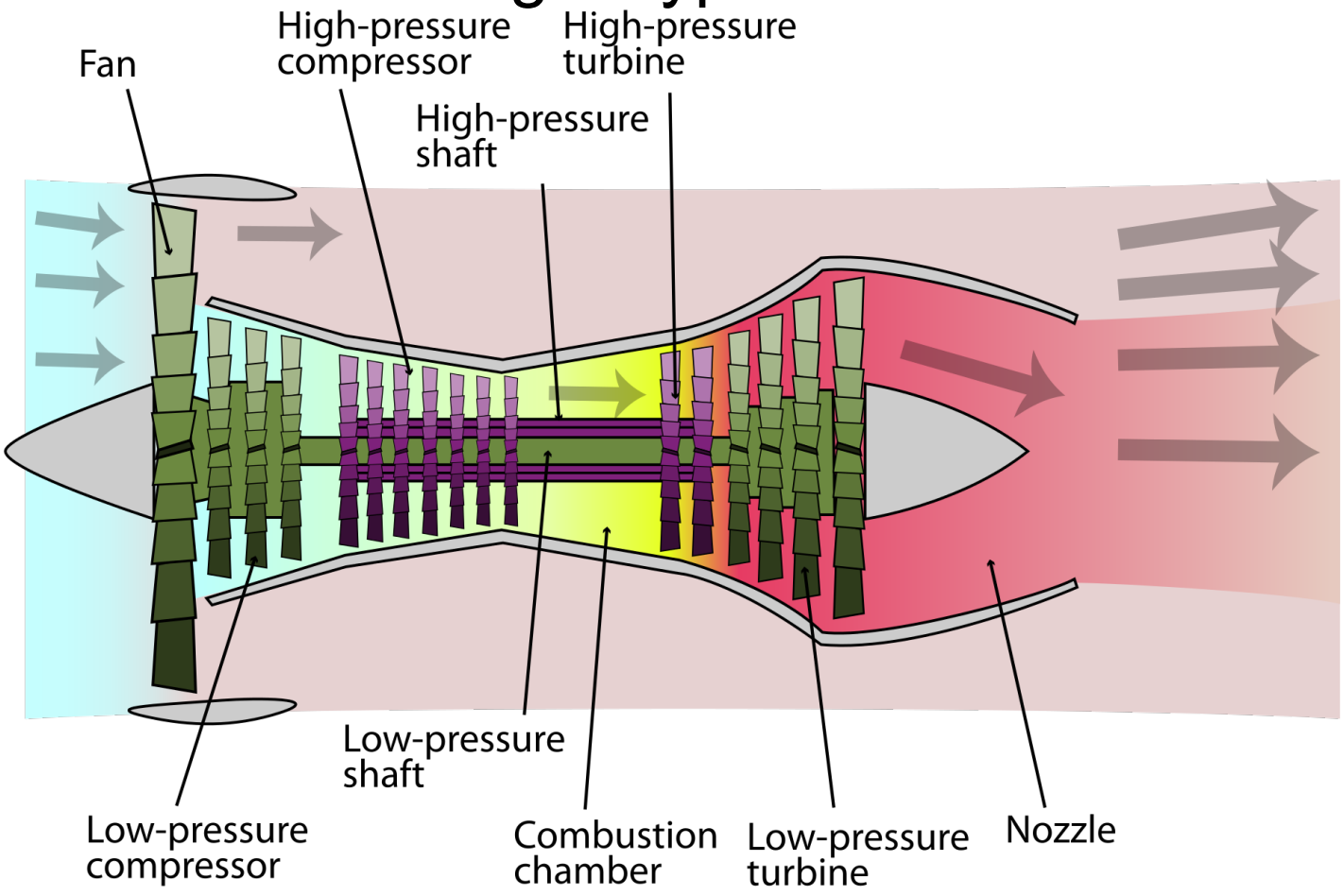
Action Items: Commercialization

- Pilot Study
  - Engage with GE/Boeing to work towards pilot study
- Non-Dilutive Funding
  - AF, NSF, State Funding
- Venture Capital
  - After winning AF Phase II
  - Build Investor Deck
  - Engage with local and national firms (expected Q1’21 end)
- Continue Customer and Partner Conversations
  - Leverage contact base

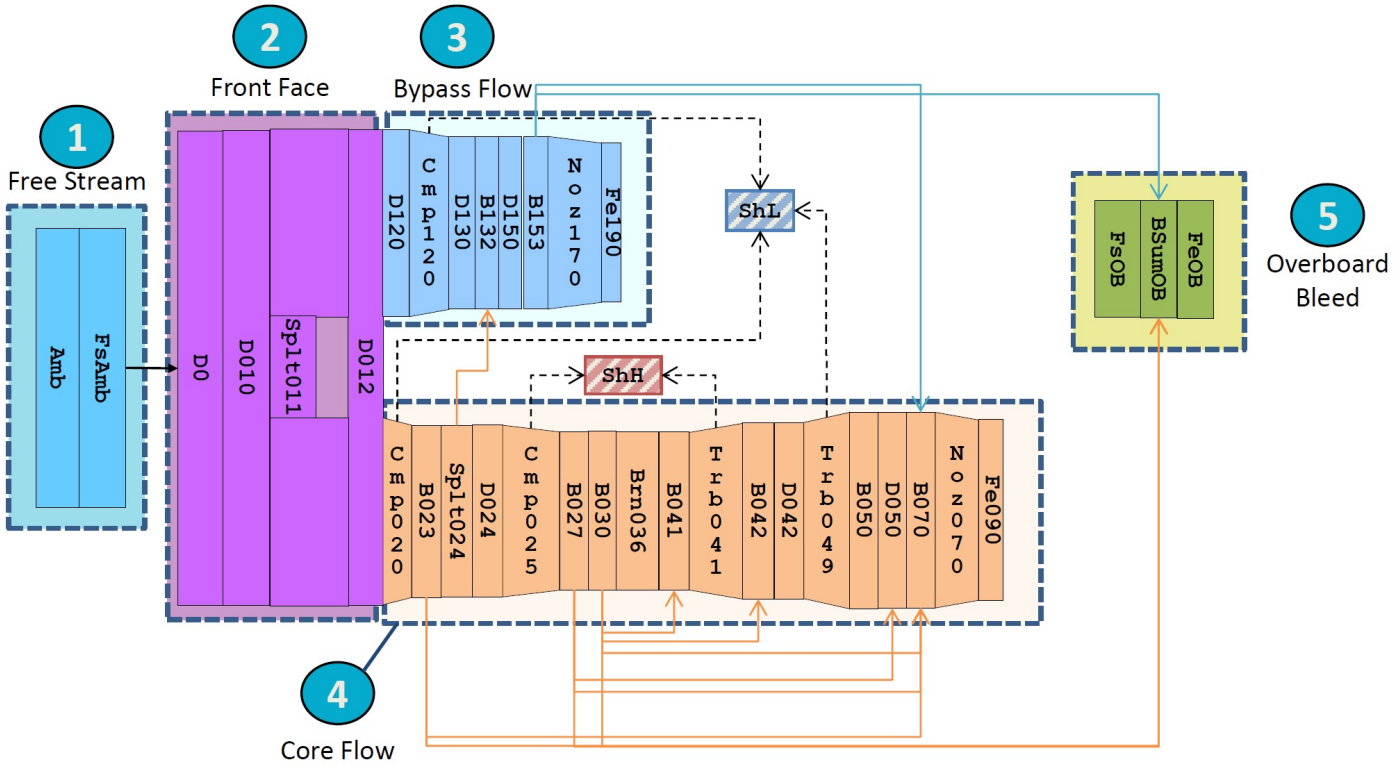
Backup Slides

NPSS Example Engine

- Baseline engine model provided by GE / NPSS known as Generic NPSS High-Bypass Turbofan



NPSS Model Structure



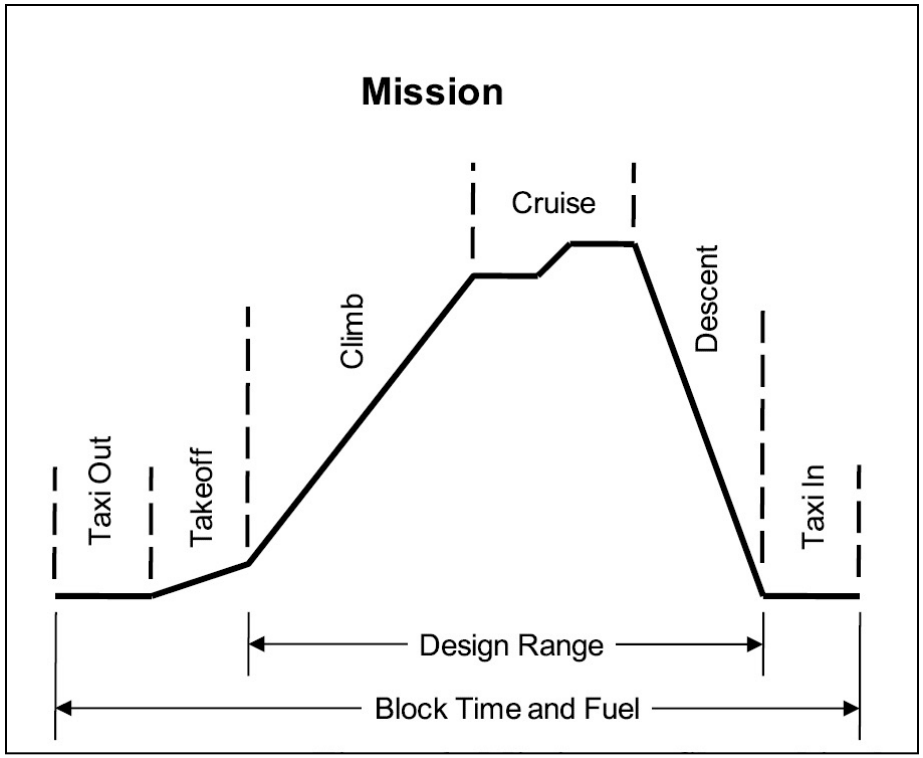
Expanded views of each group are presented in the following slides

Order of Instantiation

Image by NPSS/SwRI "Common Development Model (CDM) Turbo Fan 01 (TF01).pdf"

Flight Profile

- Typical flight profile for commercial aviation aircraft
- Mission uncertainty can be quantified using software such as FlightAware
  - Flight altitude variations
  - Aircraft weight
  - Weather conditions
  - Flight time, etc…



Engine Parameters

- **Operating Conditions:**
  - **Altitude: 0 – 35,000 ft (varied)**
  - **Mach Number: 0 - 0.8 (varied)**
  - **Pressure Ratios:**
    - **Cmp020: 2.7**
    - **Cmp120: 1.3**
    - **Cmp025: 20**
    - **Trb041: 5.42**
    - **Trb049: 3.48**
  - **Exhaust Gas Temperature: 2,300 Rankine**
  - **Engine Thrust: 95,000 lbf at rest, sea level**

Input/Output Variables

Inputs

```
Cmp120.S_map.S_MPSize.s_dpq = 0.958566;
Cmp120.S_map.S_MPSize.s_eff = 0.982426;
            Cmp120.NcDes = 4629.99;
 Cmp120.S_map.S_MPSize.s_wr = 0.154213;

Cmp020.S_map.S_MPSize.s_dpq = 0.969321;
Cmp020.S_map.S_MPSize.s_eff = 0.991199;
            Cmp020.NcDes = 4629.99;
 Cmp020.S_map.S_MPSize.s_wr = 0.157126;

Cmp025.S_map.S_MPSize.s_dpq = 0.985347;
Cmp025.S_map.S_MPSize.s_eff = 1.00656;
            Cmp025.NcDes = 11699.8;
 Cmp025.S_map.S_MPSize.s_wr = 0.204563;

         Trb041.S_map.dhqT = 0.0871399;
Trb041.S_map.S_MPSize.s_eff = 1.41645;
 Trb041.S_map.S_MPSize.s_wr = 1.39153;
Trb041.S_map.S_NpSize.s_dhqT = 0.936423;
 Trb041.S_map.S_NpSize.s_Np = 0.976956;

         Trb049.S_map.dhqT = 0.066681;
Trb049.S_map.S_MPSize.s_eff = 0.933704;
 Trb049.S_map.S_MPSize.s_wr = 1.41716;
Trb049.S_map.S_NpSize.s_dhqT = 1.13015;

 Trb049.S_map.S_NpSize.s_Np = 0.805857;
            Brn036.Wfuel = 0.654269;
               FsAmb.Wc  = 168.488;
```

- Input Descriptions:
  - Enthalpy change / inlet temperatures
  - Duct pressure drops
  - Component efficiencies
  - Speed maps
  - Incoming weight flow
  - Overall fuel flow

Note: Efficiency values are used to represent engines in various life-cycle stages

Input/Output Variables

- **In general, NPSS solves for specific station parameters during propagation. However, simulation outputs can be user defined depending on the scenario.**

Example Output File

		F041.Tt	F041.W	Trb041.Wp	Trb041.eff	F042.Pt	F042.Tt	F042.W	F049.Pt	F049.Tt	F049.W	Trb049.Wp	Trb049.eff	F050.Pt	F050.Tt	F050.W	D050.Fl_O.Pt
CASE	0	3205.7	336.37	24.448	0.90001	143.65	2277.4	352.36	143.65	2277.4	352.36	117.06	0.9	41.317	1749.2	355.97	41.317
CASE	1	3205.8	336.37	24.448	0.90001	143.64	2277.4	352.36	143.64	2277.4	352.36	117.07	0.9	41.317	1749.3	355.97	41.317
CASE	2	3097.1	247.21	24.474	0.89954	103.69	2193.9	258.98	103.69	2193.9	258.98	116.99	0.89887	29.738	1680.9	261.64	29.738
CASE	3	3204.1	217.41	24.448	0.89974	92.947	2275.9	227.74	92.947	2275.9	227.74	116.89	0.89707	26.702	1749.4	230.07	26.702
CASE	4	2841.1	171.81	24.534	0.89885	68.784	1998.6	180	68.784	1998.6	180	116.99	0.89778	19.618	1521.5	181.86	19.618
CASE	5	3006.3	172.96	24.498	0.89852	72.058	2128.5	181.2	72.058	2128.5	181.2	116.01	0.90361	20.413	1620.9	183.06	20.413
CASE	6	3280.9	161.17	24.42	0.89912	71.149	2344	168.82	71.149	2344	168.82	114.88	0.90774	20.041	1791	170.55	20.041
CASE	7	3367.8	154.03	24.398	0.89891	69.471	2415.5	161.33	69.471	2415.5	161.33	114.13	0.91087	19.452	1844.9	162.97	19.452
CASE	8	1982.6	62.88	24.734	0.89714	20.753	1362.4	65.913	20.753	1362.4	65.913	117.23	0.89242	5.8684	1015.8	66.598	5.8684
CASE	9	3994.2	381.02	23.976	0.86651	185.17	2936.8	398.91	185.17	2936.8	398.91	116.75	0.89373	54.073	2304.5	402.95	54.073
CASE	10	2018.1	62.201	24.734	0.89768	20.595	1385.1	65.198	20.595	1385.1	65.198	117.81	0.8861	5.8674	1037.6	65.875	5.8674
CASE	11	3205.8	336.37	24.448	0.90001	143.65	2277.5	352.37	143.65	2277.5	352.37	117.07	0.9	41.318	1749.3	355.98	41.318
CASE	12	3205.8	336.37	24.448	0.90001	143.65	2277.5	352.37	143.65	2277.5	352.37	117.07	0.9	41.318	1749.3	355.98	41.318
CASE	13	3205.8	336.37	24.448	0.90001	143.65	2277.5	352.37	143.65	2277.5	352.37	117.07	0.9	41.318	1749.3	355.98	41.318
CASE	14	3205.8	336.37	24.448	0.90001	143.65	2277.5	352.37	143.65	2277.5	352.37	117.07	0.9	41.318	1749.3	355.98	41.318
CASE	15	3205.8	336.37	24.448	0.90001	143.65	2277.5	352.37	143.65	2277.5	352.37	117.07	0.9	41.318	1749.3	355.98	41.318

Challenge: Connecting simulation output to degradation in engine efficiency parameters

Challenge: Overview

- ***Challenge: Identification of relevant parameters to bridge the gap between simulation outputs and degradation in engine efficiency parameters across cycles.***
  - **Model development to reflect realistic degradation**

Inputs

Name	*Symbol*
Fuel flow	W_f
Fan efficiency modifier	fan_eff_mod
Fan flow modifier	fan_flow_mod
Fan pressure-ratio modifier	fan_PR_mod
LPC efficiency modifier	LPC_eff_mod
LPC flow modifier	LPC_flow_mod
LPC pressure-ratio modifier	LPC_PR_mod
HPC efficiency modifier	HPC_eff_mod
HPC flow modifier	HPC_flow_mod
HPC pressure-ratio modifier	HPC_PR_mod
HPT efficiency modifier	HPT_eff_mod
HPT flow modifier	HPT_flow_mod
LPT efficiency modifier	LPT_eff_mod
HPT flow modifier	LPT_flow_mod

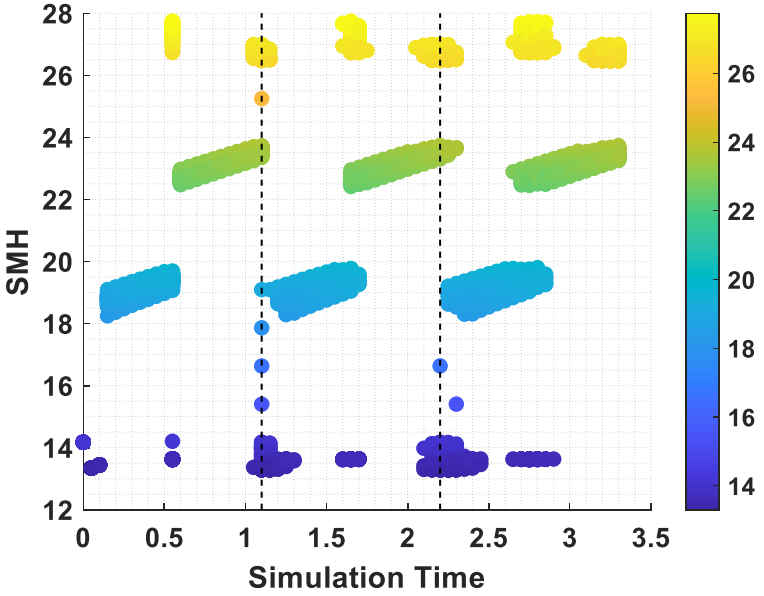
Relationship?

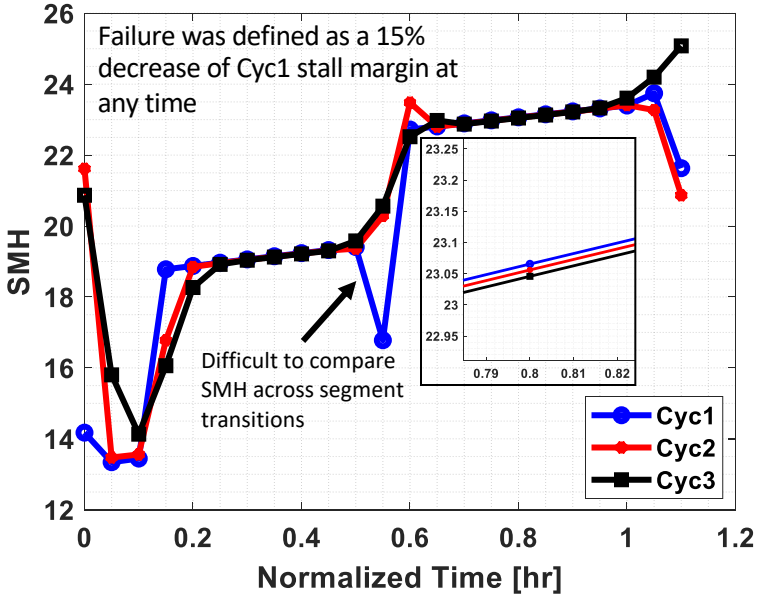
Outputs

Symbol	*Description*	*Units*
Parameters available to participants as sensor data		
T2	Total temperature at fan inlet	°R
T24	Total temperature at LPC outlet	°R
T30	Total temperature at HPC outlet	°R
T50	Total temperature at LPT outlet	°R
P2	Pressure at fan inlet	psia
P15	Total pressure in bypass-duct	psia
P30	Total pressure at HPC outlet	psia
Nf	Physical fan speed	rpm
Nc	Physical core speed	rpm
epr	Engine pressure ratio (P50/P2)	--
Ps30	Static pressure at HPC outlet	psia
phi	Ratio of fuel flow to Ps30	pps/psi
NRf	Corrected fan speed	rpm
NRc	Corrected core speed	rpm
BPR	Bypass Ratio	--
farB	Burner fuel-air ratio	--
htBleed	Bleed Enthalpy	--
Nf_dmd	Demanded fan speed	rpm
PCNfR_dmd	Demanded corrected fan speed	rpm
W31	HPT coolant bleed	lbm/s
W32	LPT coolant bleed	lbm/s
Parameters for calculating the Health Index		
T48 (EGT)	Total temperature at HPT outlet	°R
SmFan	Fan stall margin	--
SmLPC	LPC stall margin	--
SmHPC	HPC stall margin	--

Tables from A. Saxena “Damage Propagation Modeling for Aircraft Engine Run-to-Failure Simulation.pdf”

Adaptive Monte Carlo: NPSS Results

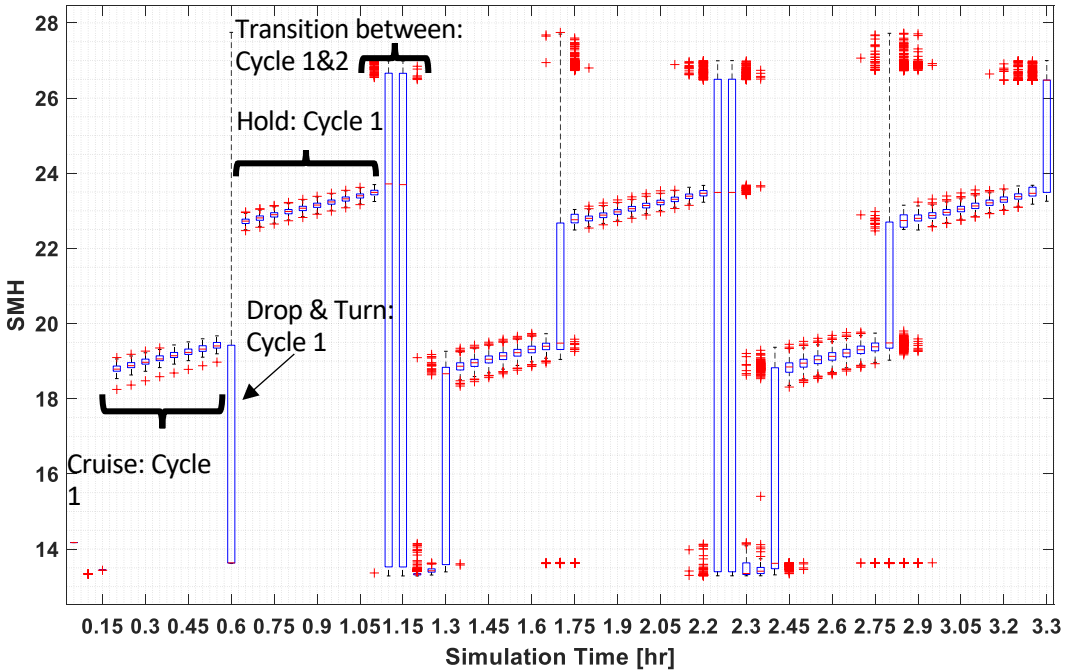




NOTE: RHS figure breaks up LHS across dashed line intervals (1.1 hrs) and computes the mean at each normalized time. SMH spikes during segment transitions (most notably cruise & hold). Begins to smooth as the cycle increases due to the increase in ensemble size

NOTE2: Time is not necessarily the independent variable within NPSS segments. This leads to individual flights during each cycle terminating at slightly different times

Adaptive Monte Carlo: NPSS Results



Increasing number of ensemble particles

NOTE: Engine degrades after each cycle (~1.1hrs)