Prognostics As A Service (PaaS) Advisory Working Group

Initial Meeting
January, 2018

PaaS Team

Chris Teubert (NASA ARC): Project PI, Group Lead Diagnostics and Prognostics

Nelson Brown & Otto Schnarr (NASA AFRC): Autonomy, Large UAS/UAM

Patrick Quach (NASA LaRC): Small UAS

Mark Muha (NASA GRC): Security Expert

Robert Kerczewski (NASA GRC): Communications Expert

Jason Watkins (NASA ARC, SGT Inc.): Software Engineer

Agenda

1. Background PaaS Idea
2. Project Timeline
3. Working Group
4. Introductions

Meeting objectives:

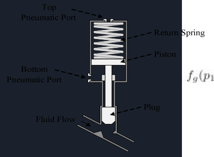
1. Establish a common understanding of the PaaS project and concept
2. Establish a common understanding of the purpose of the working group
3. Introduce PaaS team members & WG members
4. Provide initial feedback and guidance to the PaaS Team

Prognostics

Prognostics uses sensor data to provide real-time assessment of

1. *Current Health State*
2. *Future Health States*
3. *Future Performance*
4. *Failure Prediction*

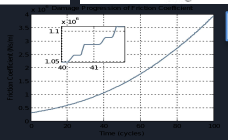
For systems, vehicles, airspaces



$$f_g(p_1,p_2)=\begin{cases} C_sA_sp_1\sqrt{\frac{\gamma}{ZR_gT}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}}, & p_1\geq p_2 \wedge p_1/p_2\geq\left(\frac{\gamma+1}{2}\right)^{\gamma/(\gamma-1)}\\ C_sA_sp_1\sqrt{\frac{2}{ZR_gT}\left(\frac{\gamma}{\gamma-1}\right)\left(\left(\frac{p_2}{p_1}\right)^{2/\gamma}-\left(\frac{p_2}{p_1}\right)^{(\gamma+1)/\gamma}\right)}, & p_1\geq p_2 \wedge p_1/p_2<\left(\frac{\gamma+1}{2}\right)^{\gamma/(\gamma-1)}\\ C_sA_sp_2\sqrt{\frac{\gamma}{ZR_gT}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}}, & p_1<p_2 \wedge p_2/p_1\geq\left(\frac{\gamma+1}{2}\right)^{\gamma/(\gamma-1)}\\ C_sA_sp_2\sqrt{\frac{2}{ZR_gT}\left(\frac{\gamma}{\gamma-1}\right)\left(\left(\frac{p_1}{p_2}\right)^{2/\gamma}-\left(\frac{p_1}{p_2}\right)^{(\gamma+1)/\gamma}\right)}, & p_1<p_2 \wedge p_2/p_1<\left(\frac{\gamma+1}{2}\right)^{\gamma/(\gamma-1)} \end{cases}$$

$$f_t(t)=f_g(p_t(t),u_t(t))$$
$$f_b(t)=f_g(p_b(t),u_b(t))$$

$$f_v(t)=\frac{x(t)}{L_s}C_vA_v\sqrt{\frac{2}{\rho}|p_{fl}-p_{fr}|}\mathrm{sign}(p_{fl}-p_{fr})$$

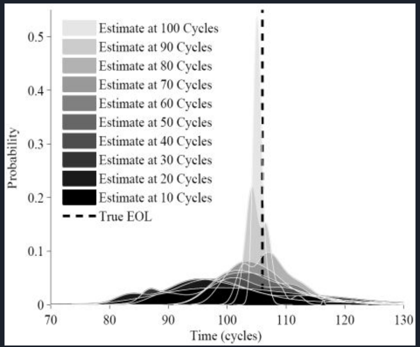


$$\dot{r}(t)=w_r|F_f(t)v(t)|$$

$$EOL(t_P)\triangleq\inf\{t\in\mathbb{R}:t\geq t_P\wedge T_{EOL}(\mathbf{x}(t),\boldsymbol{\theta}(t))=1\}$$

Algorithm 2 EOL Prediction

Inputs: $\{(\mathbf{x}^i_{k_P},\boldsymbol{\theta}^i_{k}),w^i_{k_P}\}^N_{i=1}$
Outputs: $\{EOL^i_{k_P},w^i_{k_P}\}^N_{i=1}$
for $i=1$ **to** N **do**
  $k\leftarrow k_P$
  $\mathbf{x}^i_k\leftarrow\mathbf{x}^i_{k_P}$
  $\boldsymbol{\theta}^i_k\leftarrow\boldsymbol{\theta}^i_{k_P}$
  while $C_{EOL}(\mathbf{x}^i_k,\boldsymbol{\theta}^i_k)=0$ **do**
    Predict $\hat{\mathbf{u}}_k$
    $\boldsymbol{\theta}^i_{k+1}\sim p(\boldsymbol{\theta}_{k+1}|\boldsymbol{\theta}^i_k)$
    $\mathbf{x}^i_{k+1}\sim p(\mathbf{x}_{k+1}|\mathbf{x}^i_k,\boldsymbol{\theta}^i_k,\hat{\mathbf{u}}_k)$
    $k\leftarrow k+1$
    $\mathbf{x}^i_k\leftarrow\mathbf{x}^i_{k+1}$
    $\boldsymbol{\theta}^i_k\leftarrow\boldsymbol{\theta}^i_{k+1}$
  end while
  $EOL^i_{k_P}\leftarrow k$
end for



Prognostics- Utility

- Pilots
- Remote Operators
- Air Traffic Control
- UAS Traffic Management (UTM)
- Airline Dispatch
- Autonomy
- Maintainers

Prognostics- Utility

Pilots

Remote Operators

Air Traffic Control

UAS Traffic Management (UTM)

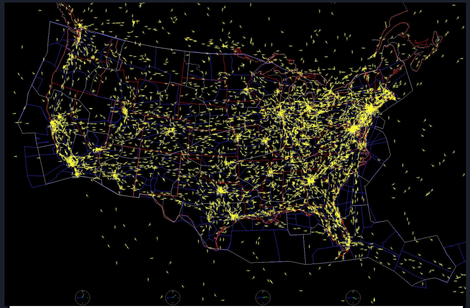
Airline Dispatch

Autonomy

Maintainers

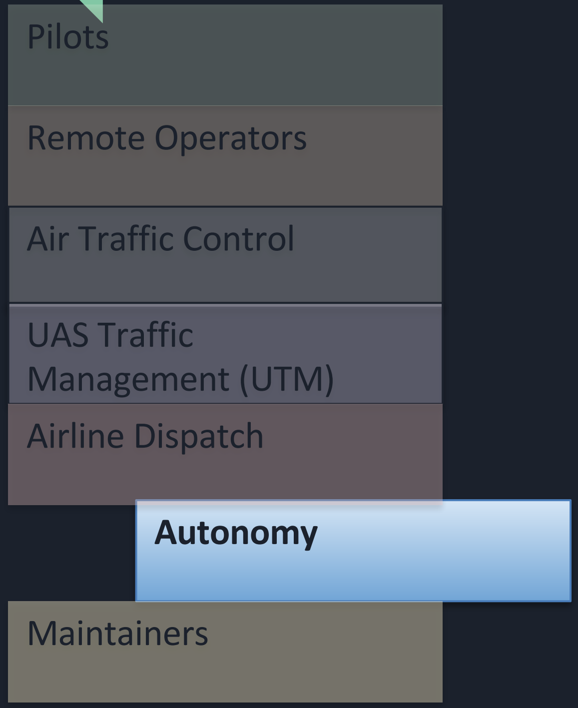
Provide health information for components, vehicles, airspace

Reduced Risk of failure of critical systems



Reduced System Delays

Prognostics- Utility



Impact: Enabling Robust Autonomous Systems

Autonomous Systems that:

1. **Monitor** health in-flight
2. **Predict** failures in-flight
3. **Understand** how performance degrades
4. **Autonomously** make decisions based on this

Prognostics- Utility

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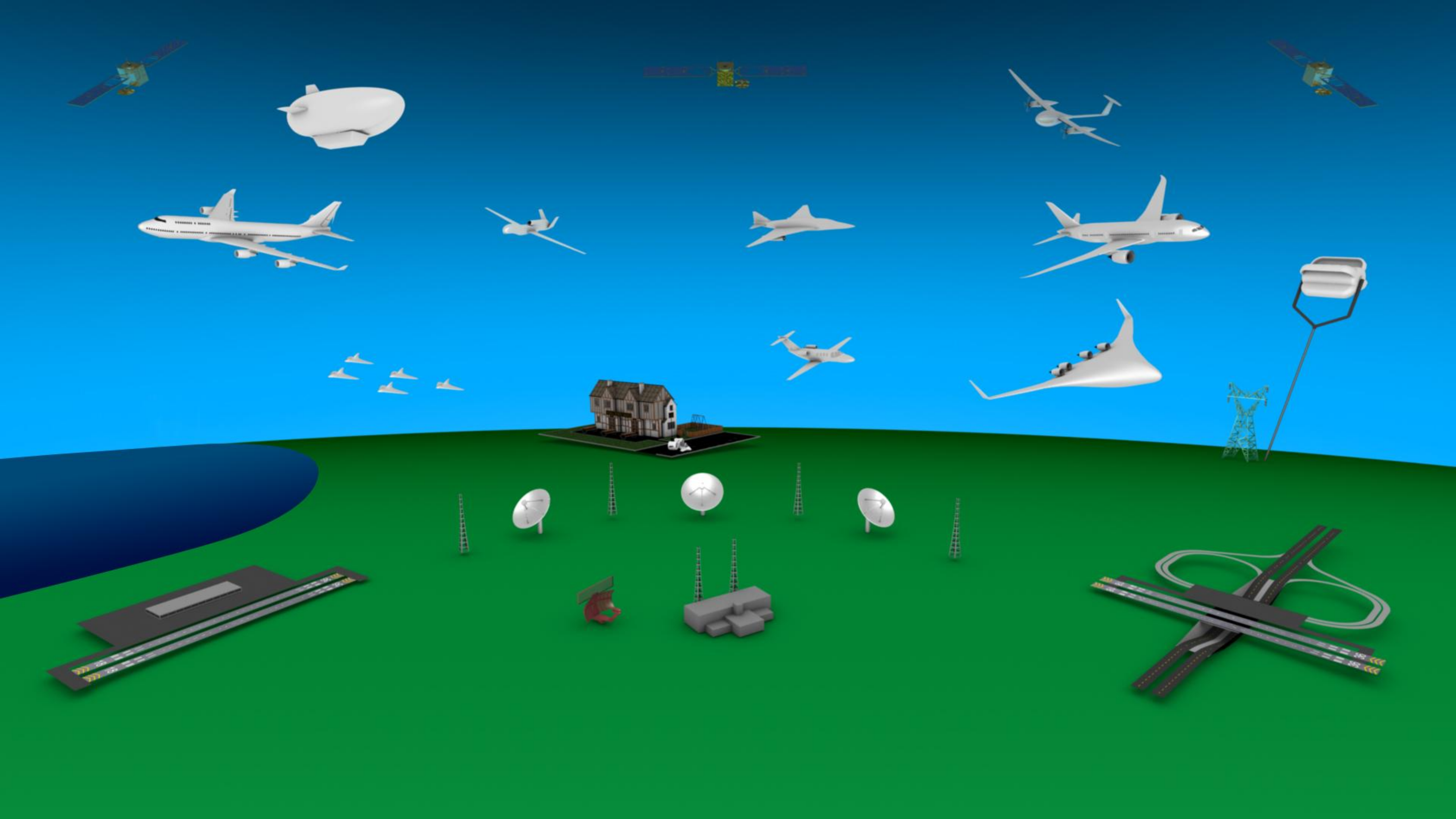
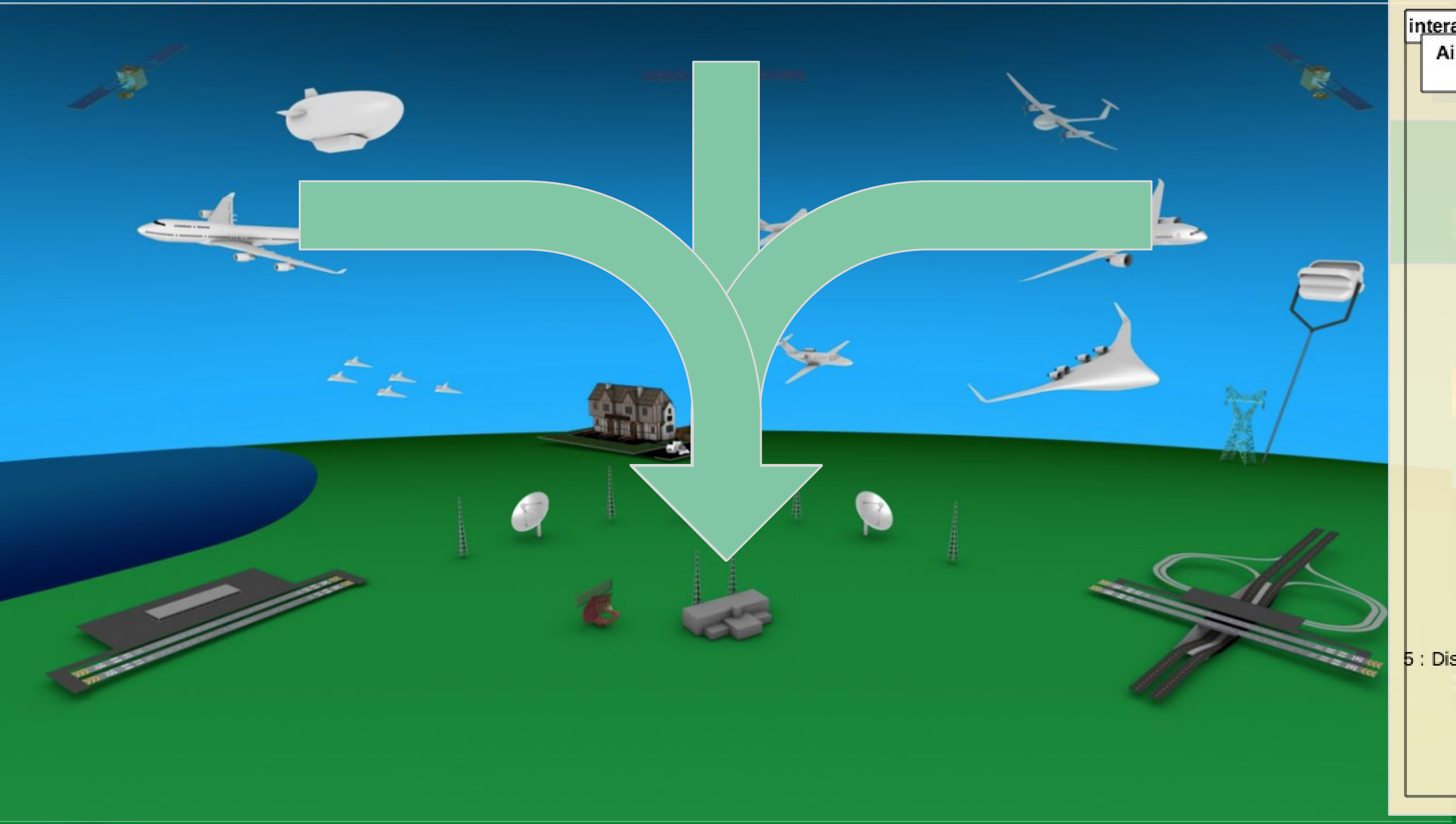
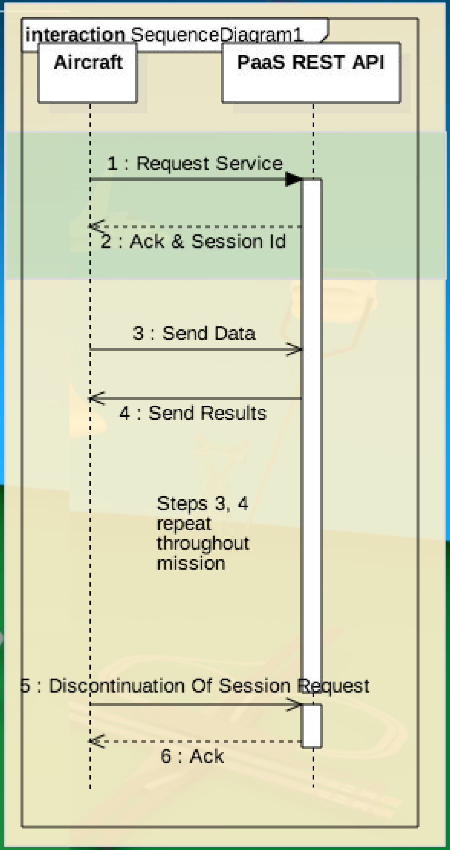
- Airline Dispatch
- Autonomy
- **Maintainers**

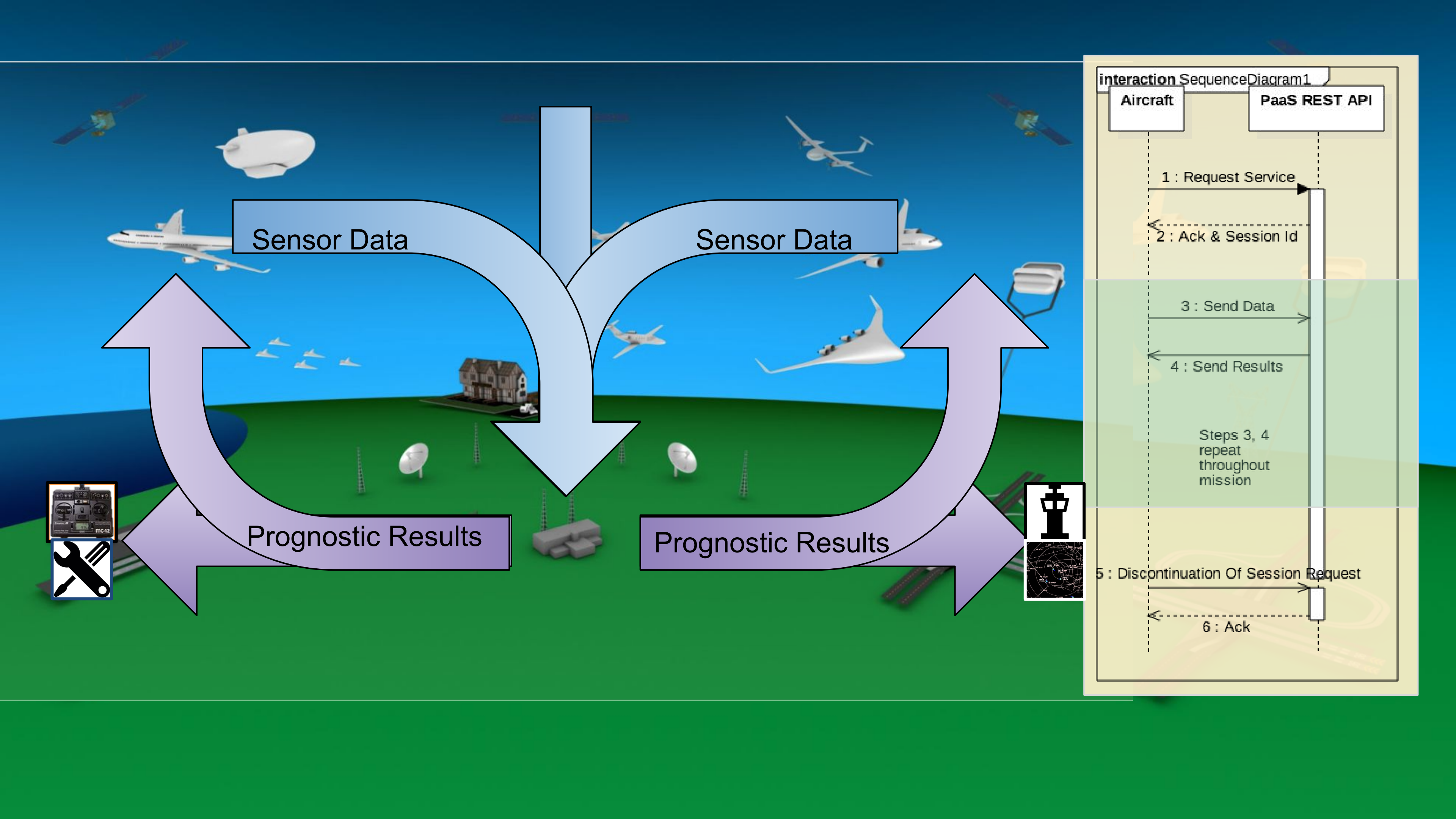
Reduced Maintenance Costs







Request PaaS Services



Sensor Data
Sensor Data
Prognostic Results
Prognostic Results
interaction SequenceDiagram1
Aircraft
PaaS REST API
1 : Request Service
2 : Ack & Session Id
3 : Send Data
4 : Send Results
Steps 3, 4 repeat throughout mission
5 : Discontinuation Of Session Request
6 : Ack

PaaS Users

Pilots

Air Traffic Control

Maintainers

Remote Operators

UAS Traffic Management (UTM)

Airline Dispatch

All could potentially be human or autonomous

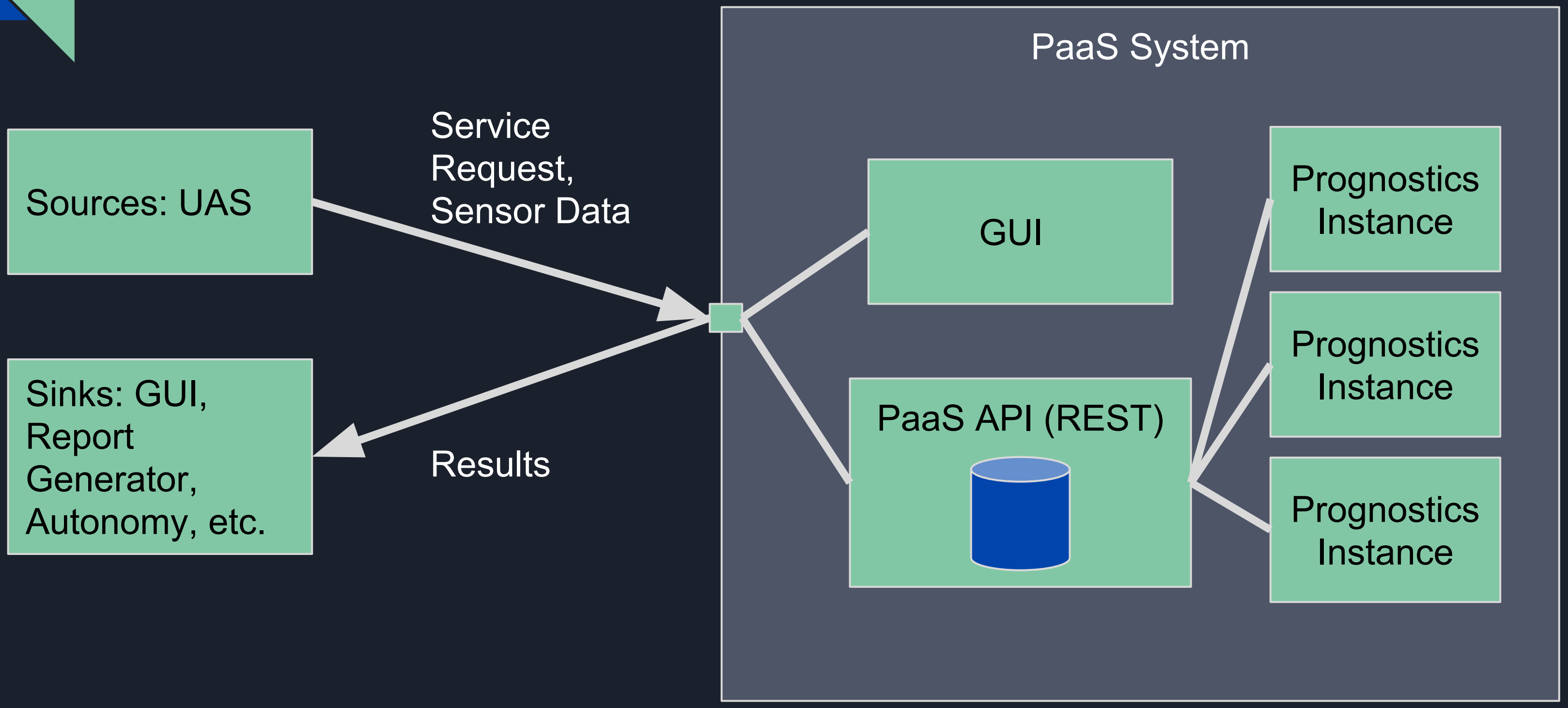
Prognostics As-A-Service (PaaS)

Identify, explore, and develop solutions to mitigate the technical barriers and design decision space for performing prognostics remotely, as-a-service at a large scale

Challenges

Generalizatio n	Can a single PaaS system support the wide variety of aircraft classes and configurations?
Env Complexity	Can a PaaS system provide accurate predictions in complex environments?
Usefulness	Can the PaaS results be provided in such a way that they can inform significant action to maintain safety and efficiency?
Security	Can existing security solutions help PaaS operate in a way so as to protect Confidentiality, Integrity, and Availability?
Comms	Can PaaS handle the communication complexity involved with the architecture: including bandwidth constraints, dropout, etc.?
Trust	Can PaaS be designed so that the results will be trusted?

Prognostics As-A-Service Prototype



Timeline

April 2017

Project Formation

Identify the challenges of the PaaS architecture, formulate a project plan

April 2018

Prototype Development

Design, develop, and test prototype PaaS System

October 2018

CASTInG Gate & Further Development

Present PaaS at CASTInG Gate, pitch for integration with other projects.

Meanwhile continue to mature the PaaS prototype

April 2020

Feasibility Study

Study to establish the feasibility of overcoming the 6 primary challenges of the PaaS Architecture, and identify solutions to these

Release, integrate into NASA projects

PaaS Working Group

Working Group Purpose

To advise in the identification and investigation of feasibility challenges for the PaaS Architecture, and on how feasibility can be established in a manner meaningful to industry and academia

Working Group Membership

24 individuals from across government, industry, and academia

- Academia
- Urban Air Mobility
- Government
- Unmanned Aircraft Systems (UAS)
- Intelligent Data Providers

Discussion

Please say name and company/organization before speaking

Questions

- Why are you interested in prognostics as-a-service?
- What challenges do you see for this architecture?
- What would you need to feel that this technology is mature enough to use?

Challenges

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Backup Slides

Potential Strengths/Weaknesses of PaaS Architecture

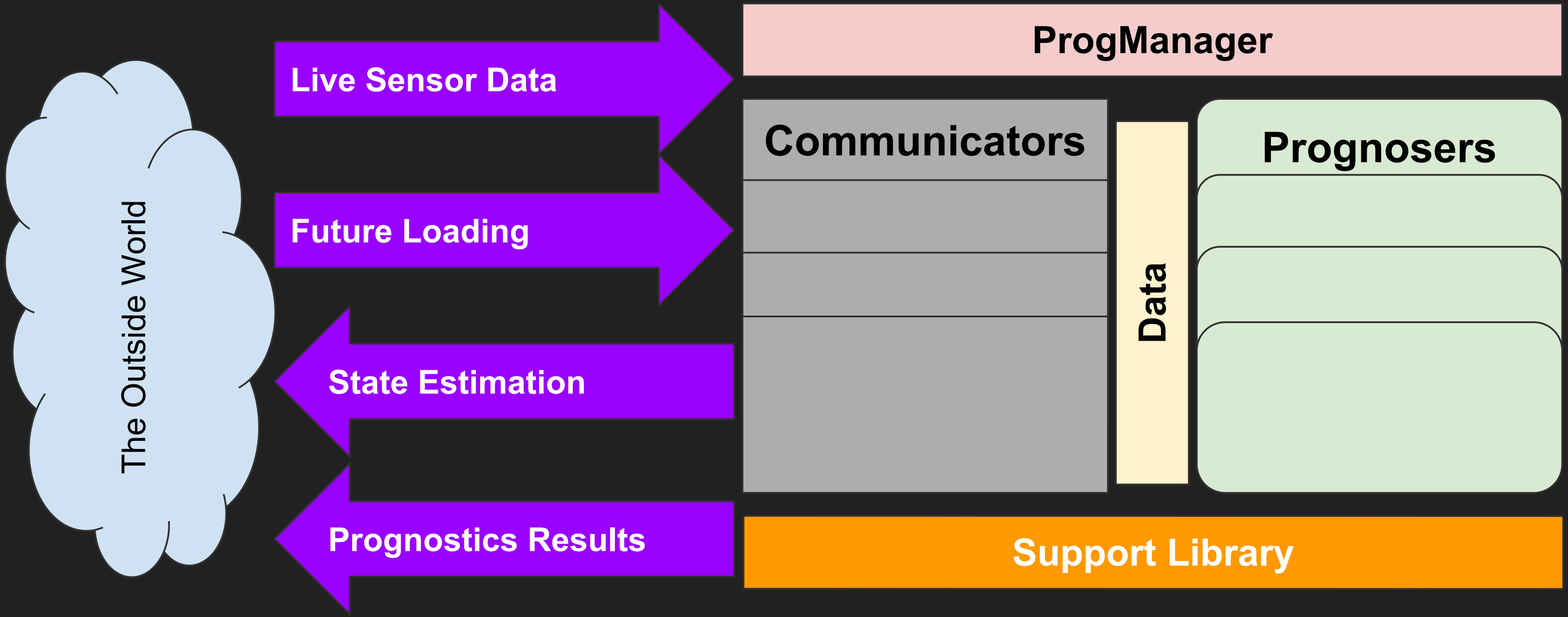
Strengths

- Computational constraints
- Access to external data
- Ease of integration, maintenance
- Ease of extension
- Size, Weight, and Power (SWaP)
- Efficiency of resource sharing
- Data collection/learning

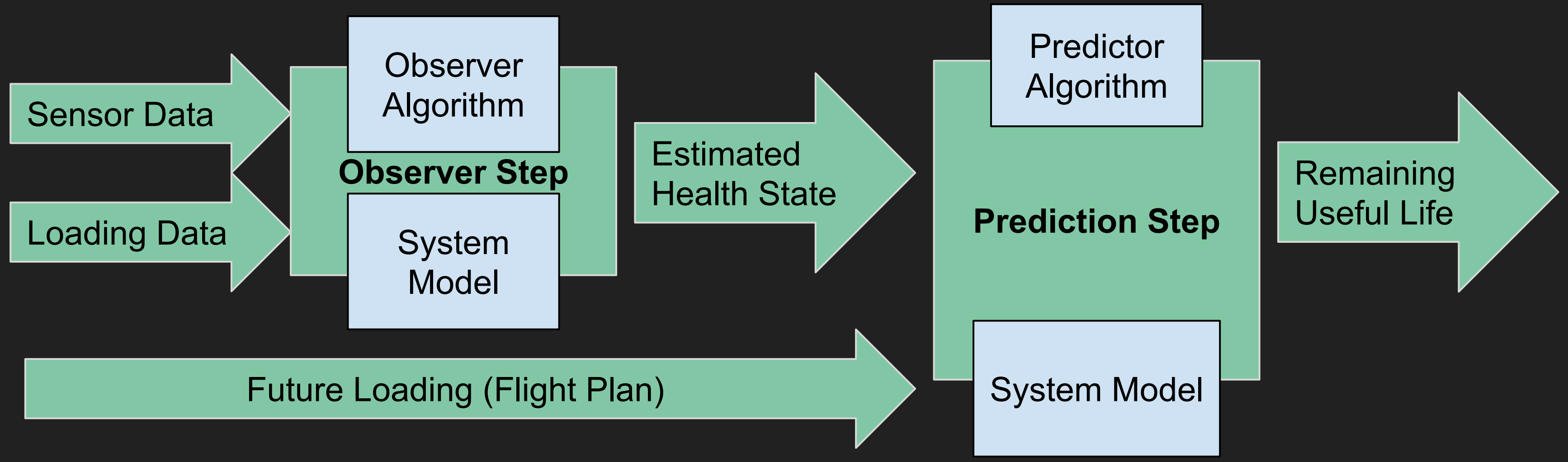
Weaknesses

- Communication security concerns
- Communication stability/availability
- Latency/bandwidth constraints

GSAP


The Outside World
Live Sensor Data
Future Loading
State Estimation
Prognostics Results
ProgManager
Communicators
Data
Prognosers
Support Library

Model-Based Prognoser



Prototype Shortcomings

- REST is not the best format for an API for streaming sensor data/results- Consider other architectures

Chosen Architecture

Architecture

Cloud Enhanced Prognostics

Reasoning for Architecture Choice

- Computational constraints
- Utilizing external data
- Ease of integration, Maintenance
- Ability to integrate new features
- Improve with use
- Size, Weight, and Power (SWaP)
- Resource Sharing (Efficiency)

Take-away

A cloud-enhanced architecture can provide prognostics technologies to all aircraft and includes additional efficiency, capability, and performance advantages

Demonstrating Feasibility

Test the ability to address the six challenges with a proof of feasibility system, for small and large UAS (UAM representative vehicles), with different end users

Generalization	Env Complexity	Usefulness
Security	Comms	Trust

Testing Communications and Environmental Complexity

Communication:

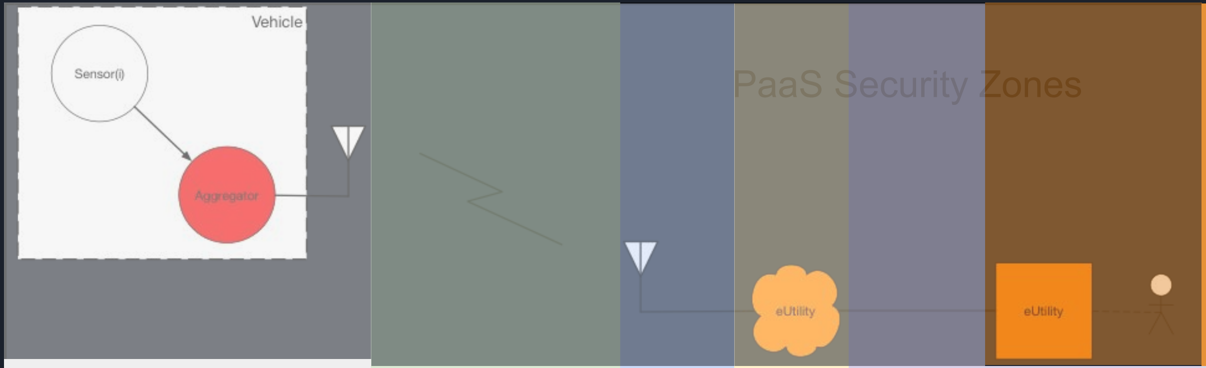
- Communications Constraints (e.g. Bandwidth, Latency)

Environmental Complexity:

- Different environmental

Experts from both of these will be involved with developing requirements, designing experiments, and final feasibility assessment

Testing Security



F
eUtility (Cloud) resource access
Cloud to data consumers

A
- Sensor Security
- Vehicle Sensor to Vehicle Aggregator Interface
- Aggregator/ Agent Security

B: Broadcast Medium Security

C

Antenna Security

D

E

Service Level Agreements (QoS, Security Levels Provided) between external receiver owners and prognostication utility.

Inter Prognostics Service Utility Information processing (cloud)

Protect Confidentiality, Integrity, and Availability (CIA Triad)

Security expert on team

Hardware-In-The-Loop FlightDeck

Leveraged for PaaS HITL

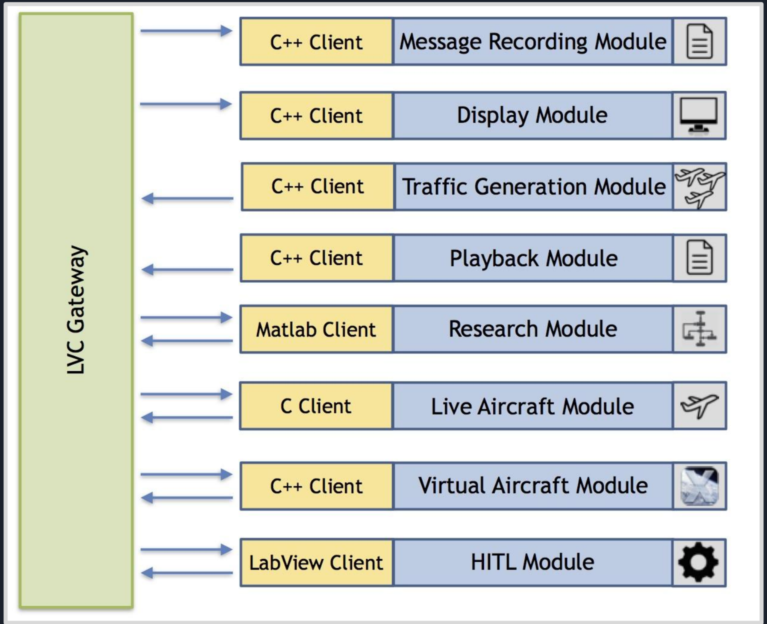
- Consists of cockpit with flight controls, autopilot, radio
- Connected to prognostics virtual lab
- Can display prognostics results on GUI on left screen

Operation Station

- Connected to prognostics virtual lab
- Controls experiment, can operate as ATC or Dispatch

Prognostics Virtual Lab

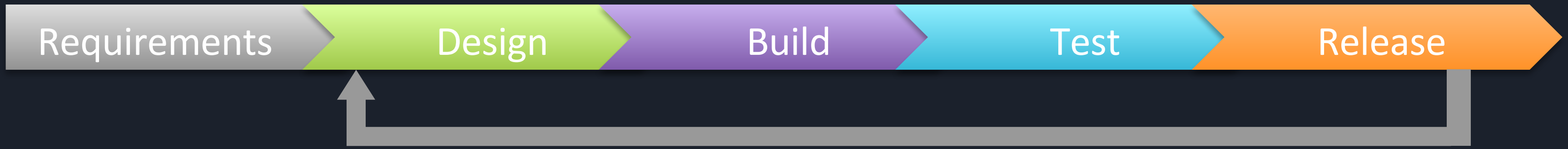
- Set of tools for distributed prognostics experiments
- LVC Gateway used to share network messages for aircraft, and systems
- Connect HITL Elements, Virtual and Real aircraft, prognostics algorithms, GUIs, etc.



Deliverables

- Feasibility Assessment Document
- Protocol Recommendations
- Publicly Released Proof of Concept PaaS system
- Publicly Released Data

Approach

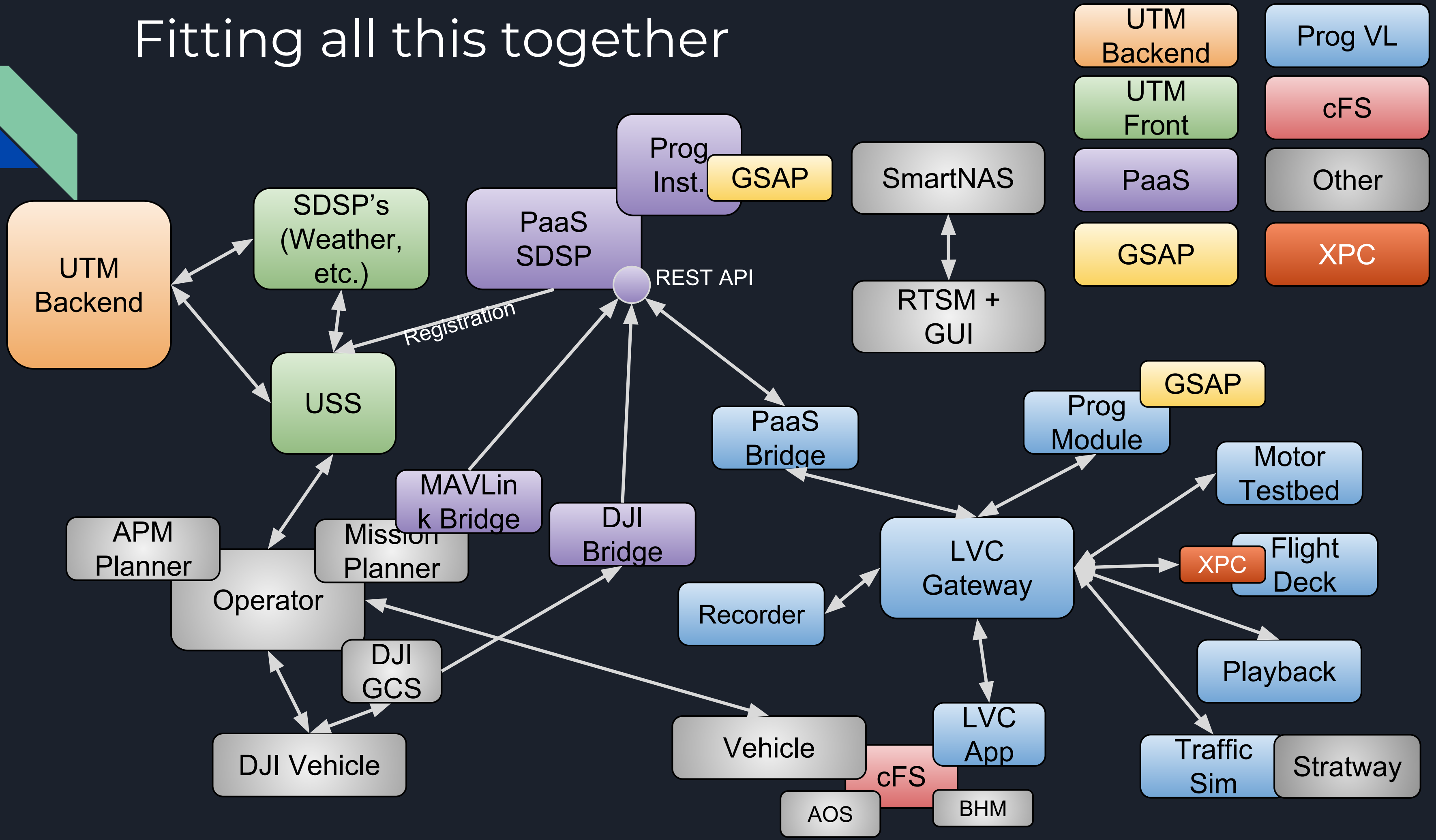


1. Requirements
2. Design and build proof-of-concept
3. **Test Early, Test Often**
4. Disseminate data, software, results
5. Transition

Deliverables

- Publicly Released Proof of Concept PaaS system
- Protocol Recommendations
- Journal/Conference Publications
- Publicly Released Data

Fitting all this together



SHARP Laboratory

- Laboratory for the development of testbeds and test systems
- Verification and validation of mathematical models
- Electric propulsion system testbed
- Flight simulation system and flight deck
- Power supplies, oscilloscopes, and data acquisition systems.

Systems Health, Analytics, Resilience and Physics modeling (SHARP) Laboratory

Factors in Choosing PaaS Targets

These factors should be considered when choosing systems to target for PaaS:

1. Criticality of system
2. Difficulty
3. Likelihood of failure
4. Ability to detect health state and predict failure
5. Utility- ability to take action based on the results of prognostics
6. Commonality- How often is this system used on aircraft

Context Diagram