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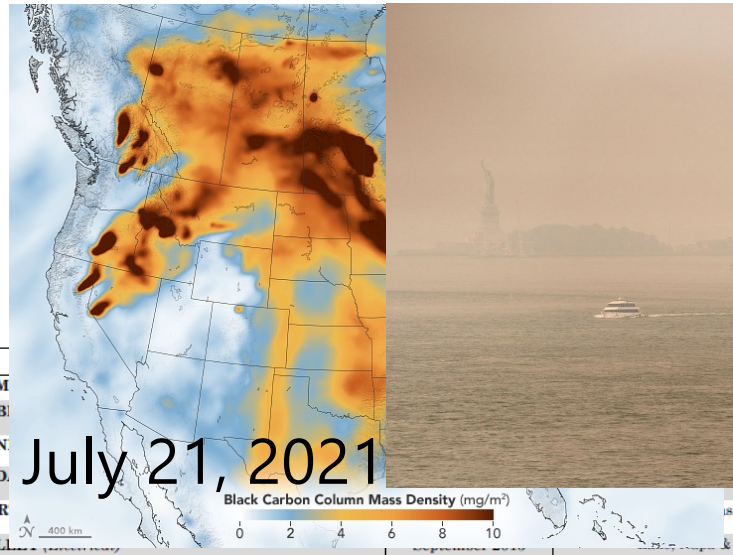
Integrated Systems Architectural Modeling with Architectural Trade Study of a UAV Surface-less Flight Control Systems for Wildfire Detection and Communication utilizing MBSAP

Introduction

Wildfire and UAV Research - Systems Thinking

Wildfires are a Growing Complex Problem



1	CAM				
2	TUB				
3	TUN				
4	CED				
5	NOR		s, & Yuba		
6	VALL		& Sonoma		
7	**WITCH** *(Powerlines)*	October 2007	San Diego		
8	**WOOLSEY** *(Electrical)*	November 2018	Ventura		
9	**CARR** *(Human Related)*	July 2018	Shasta County, Trinity	229,	
10	**GLASS** *(Undetermined)*	September 2020	Napa & Sonoma	67,484	
11	**LNU LIGHTNING COMPLEX** *(Lightning/Arson)*	August 2020	Napa, Solano, Sonoma, Yolo, Lake, & Colusa	363,220	6
12	**CZU LIGHTNING COMPLEX** *(Lightning)*	August 2020	Santa Cruz, San Mateo	86,509	**1,490** 1
13	**NUNS** *(Powerline)*	October 2017	Sonoma	44,573	**1,355** 3
14	**DIXIE** *(Under Investigation)**	July 2021	Butte, Plumas, Lassen, & Tehama	963,309	**1,311** 1
15	**THOMAS** *(Powerline)*	December 2017	Ventura & Santa Barbara	281,893	**1,063** 2
16	**CALDOR** *(Human Related)*	September 2021	Alpine, Amador, & El Dorado	221,835	**1,005** 1
17	**OLD** *(Human Related)*	October 2003	San Bernardino	91,281	**1,003** 6
18	**BUTTE** *(Powerlines)*	September 2015	Amador & Calaveras	70,868	**965** 2
19	**JONES** *(Undetermined)*	October 1999	Shasta	26,200	
20	**AUGUST COMPLEX** *(Lightning)*	August 2020	Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, & Colusa	1,032,648	

"Structures" include homes, outbuildings (barns, garages, sheds, etc) and commercial properties destroyed.
This list does not include fire jurisdiction. These are the Top 20 regardless of whether they were state, federal, or local responsibility.
*Numbers not final

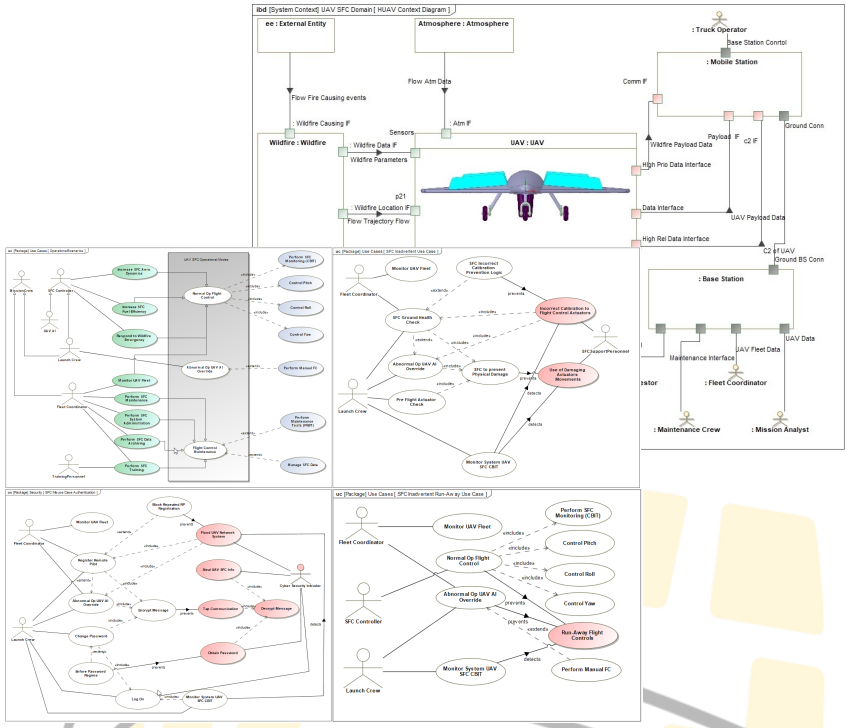
Increasing Severity (2018)
- # fires 8527 fires
- 1 893 913 acres
- 18804 structures Butte County 2018
- ~ %4-6 of US GHG Emissions

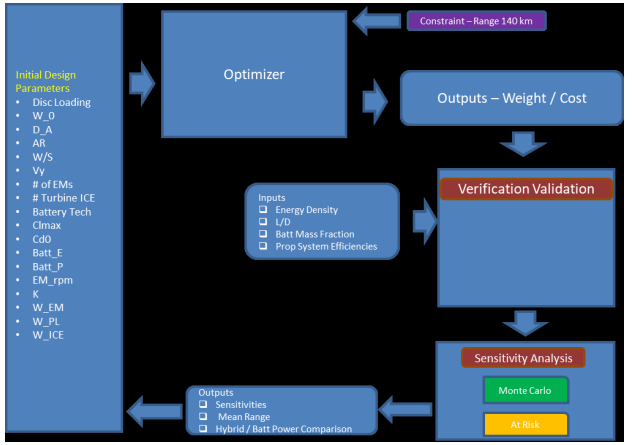
Increasing Jurisdictions/ Organizations/
- Emergency Services
- Wildfire Mitigation & Control Services
- Local, state, Federal & International Boundaries
- Many loosely coupled system of systems

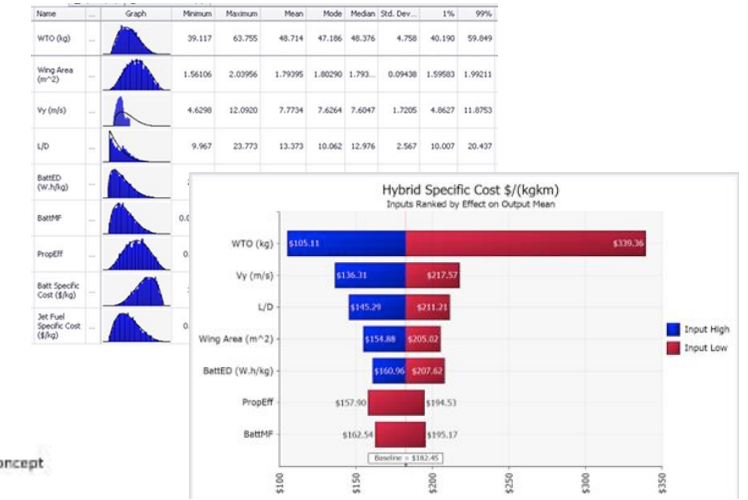
New Technologies Not Cost Effective
- UAV's
- Geosynch Sats
- Hosted Payload Sats
- Awareness Techs
- Navigation Techs

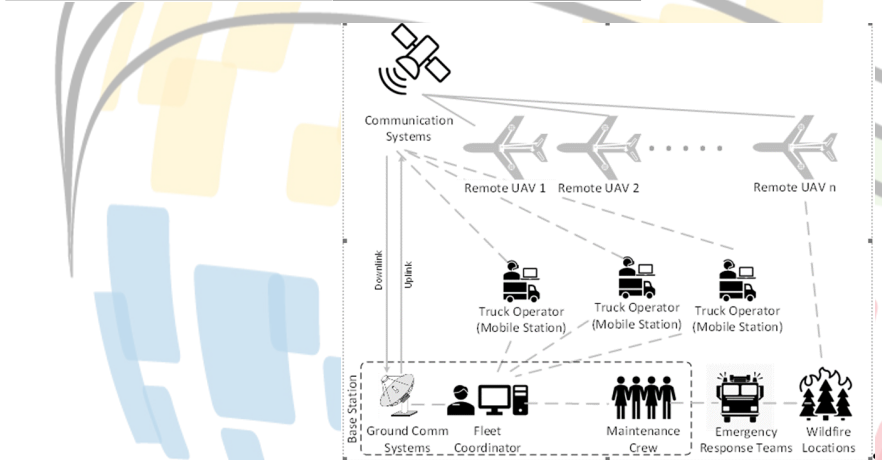
Existing Solutions are costly, difficult to manage and Ineffective

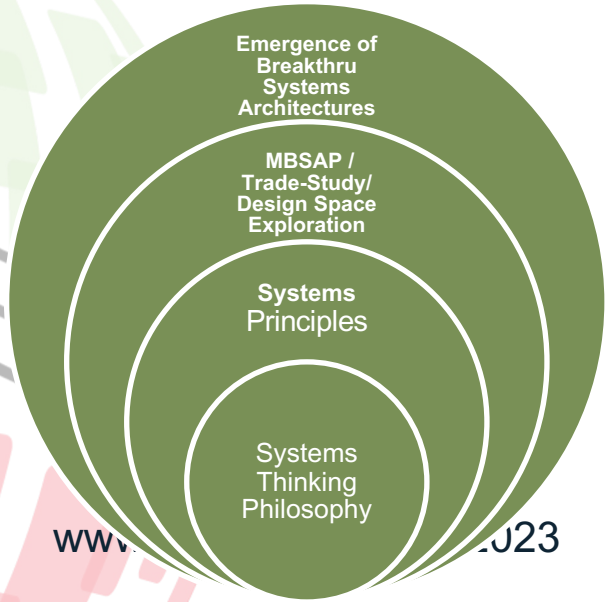
Approaching Complex Problem of Affordable Wildfire Detection + Communication

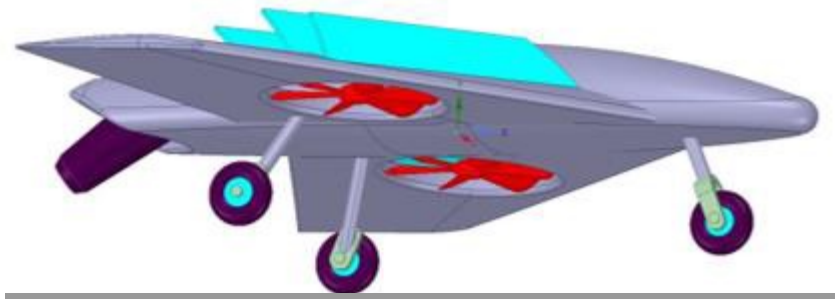










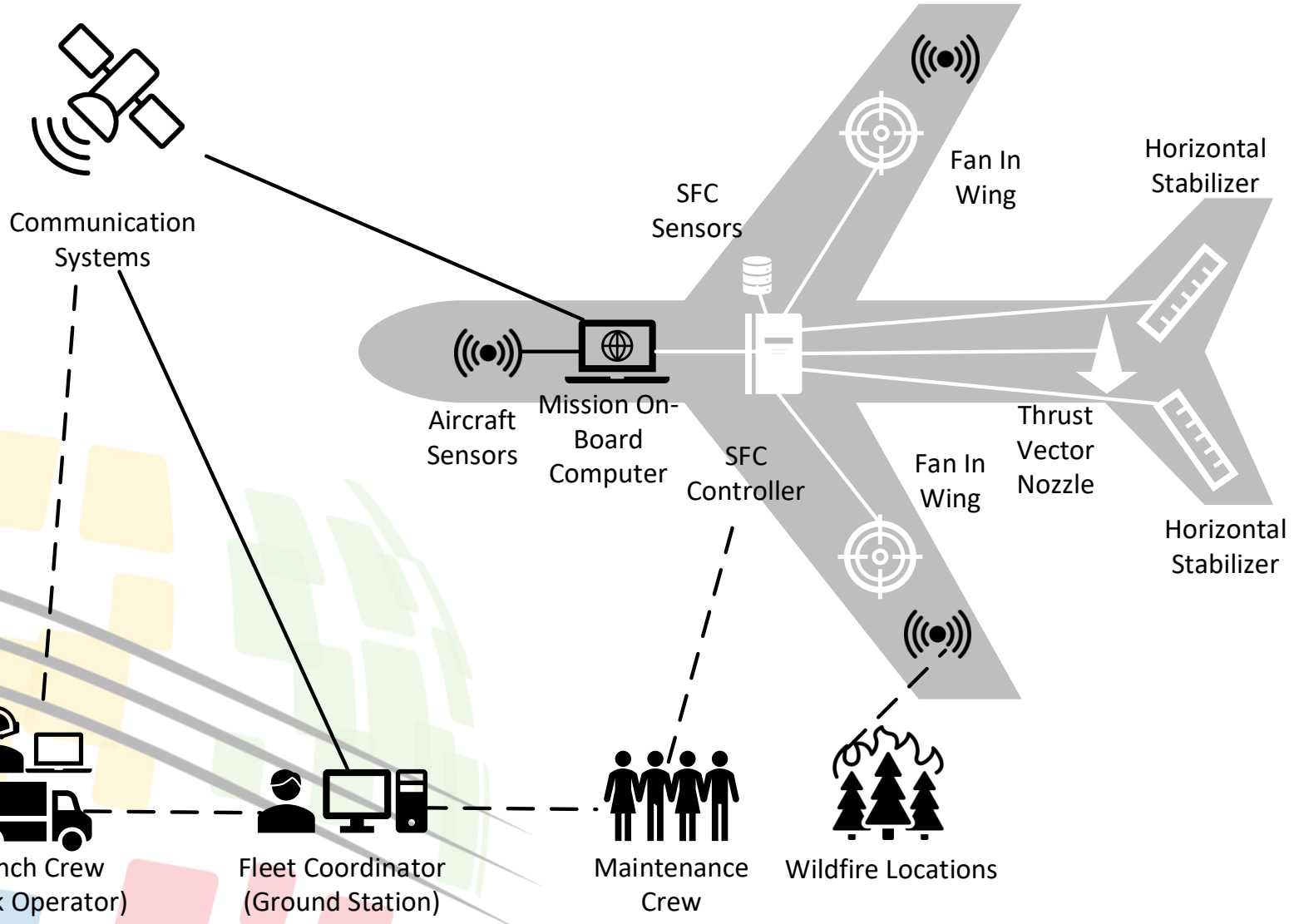


Emergence of a Potential Gamechanger: Surface-Less Flight Controls

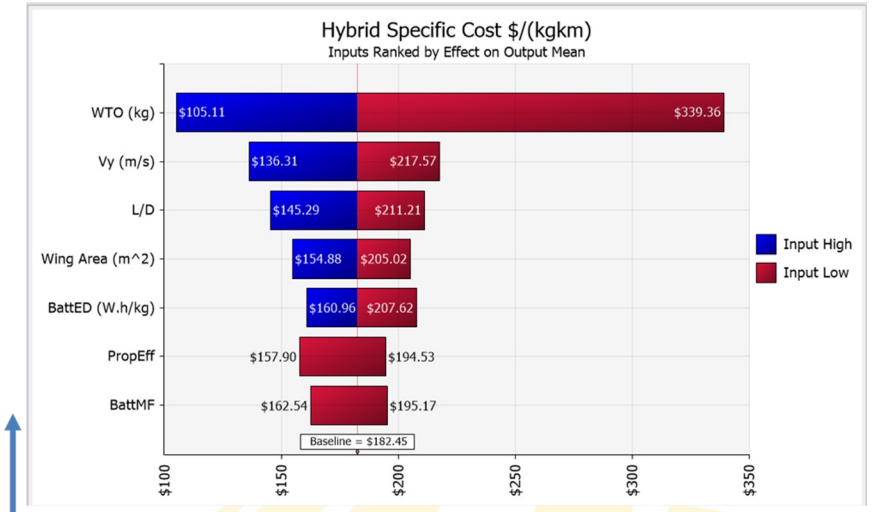
Wildfire UAV

Enterprise System and UAV Specifications

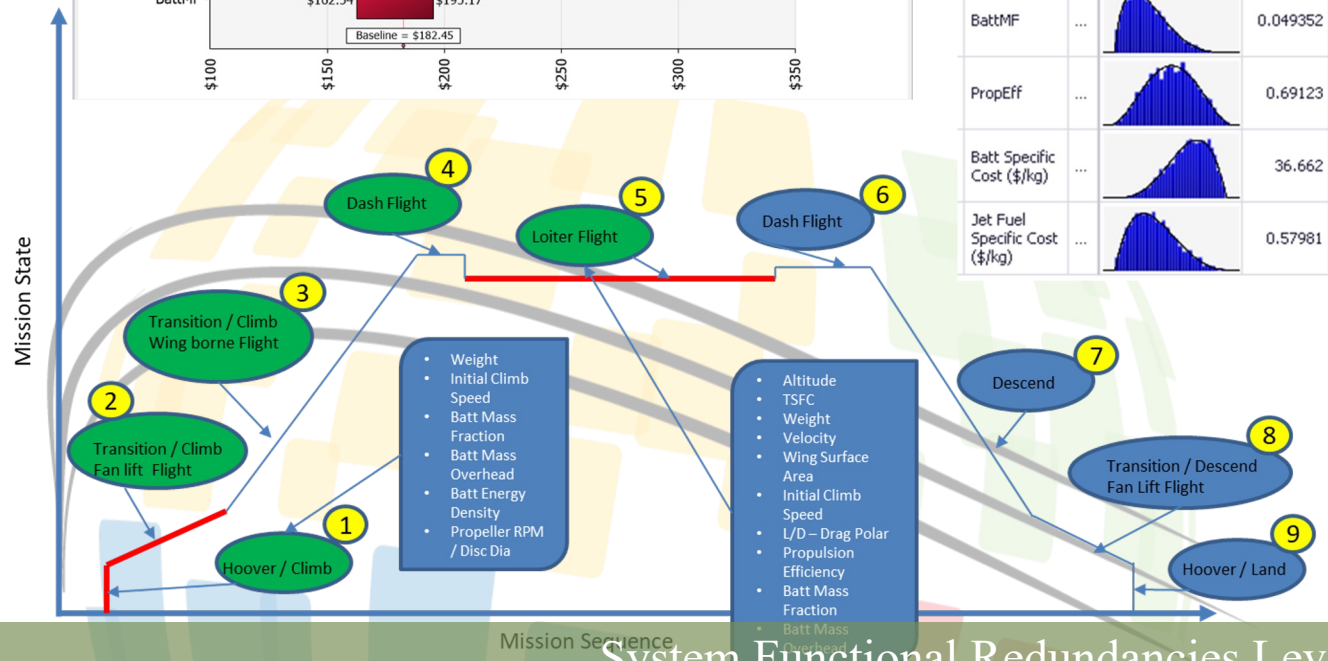
Wildfire UAV Flight Mission of the Context System



Wildfire UAV Flight Mission Profile



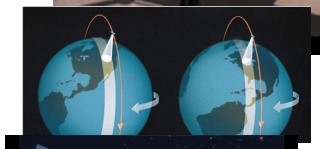
Name	...	Graph	Minimum	Maximum	Mean	Mode	Median	Std. Dev...	1%	99%
WTO (kg)	...		39.117	63.755	48.714	47.186	48.376	4.758	40.190	59.849
Wing Area (m^2)	...		1.56106	2.03956	1.79395	1.80290	1.793...	0.09438	1.59583	1.99211
Vy (m/s)	...		4.6298	12.0920	7.7734	7.6264	7.6047	1.7205	4.8627	11.8753
L/D	...		9.967	23.773	13.373	10.062	12.976	2.567	10.007	20.437
BattED (W.h/kg)	...		245.56	697.17	369.16	309.52	353.11	85.24	250.34	608.49
BattMF	...		0.049352	0.089123	0.061049	0.055900	0.059...	0.007148	0.050064	0.0799...
PropEff	...		0.69123	0.81020	0.75033	0.76153	0.750...	0.02424	0.70040	0.80097
Batt Specific Cost ($/kg)	...		36.662	65.972	55.173	58.006	55.777	5.923	40.443	65.100
Jet Fuel Specific Cost ($/kg)	...		0.57981	1.30453	0.83658	0.81141	0.821...	0.14187	0.59856	1.20111

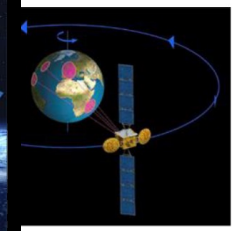


Total Weight (kg)	46.64
Fuselage Mass (kg)	2.17
Wings Mass (kg)	3.86
Empenage Mass (kg)	0.342
Landing Gear (kg)	4.77
Airframe Mass (kg)	**11.14**
Fuel Mass (kg)	7.08
Battery (kg)	1.87
Storage Total	**8.96**
Gasturb Mass (kg)	2.29
Lift EM (kg)	1.44
Lift Props (kg)	0.19
Ducting (kg)	4.00
Propulsion Mass (kg)	**7.92**
Flight Controls Mass (l	**12.62**
Payload Mass (kg)	**6.00**

System Functional Redundancies Leveraged to increase performance

Systems Level: Hybrid Propulsion/ Battery/Range





synchronous earth orbit satellite

Trade Study

Affordability
Response time

UAV

Operation flexibility

VTOL UAV

Speed
Duration
Operations Flexibility

Wing Embedded
EM Fan
Articulating
Nozzle ICE

Power application
Thrust efficiency
Clean energy

EM Fan

Propulsive flexibility
Packaging
Battery energy density

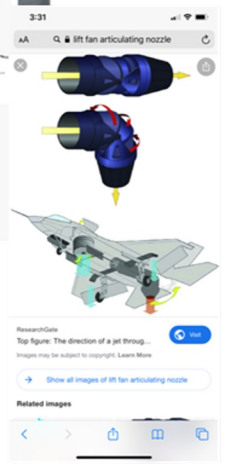
Power density
Fuel Energy density

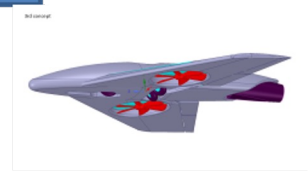
Turbine ICE

Parallel hybrid
propulsion

AWHERO (2)

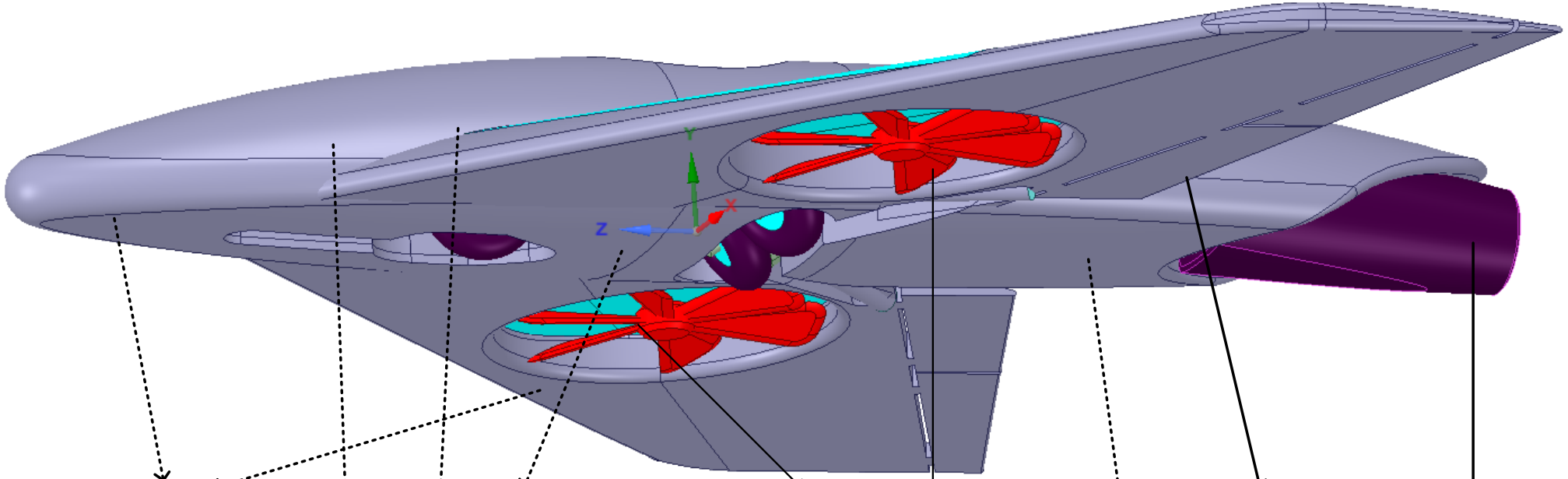
Bell eagle (1)





Vector Nozzle Turbine ICE with Embedded Wing mounted EMs - Mission Phase Optimized Functionality

External View of SFC SOI at Loiter Configuration of the UAV (3D rendering)



SFC Sensors including Dual LiDAR sensing packages
(Not externally visible)

Surface-less Flight Control (SFC) Controller
(Not externally visible)

Fan In Wings (FIW)
(Lift Fans that are BLDC EM driven and with Counter Rotating Propellers)

Horizontal Stabilizer

Small Turbine ICE
(Not externally visible)

Thrust Vector Nozzle (TVN)

Li-ion Battery
(Not externally visible)

Conformal Fuel Cell
(Not externally visible)

Legend:
(shaded items) Surface-Less Flight Control (SFC) System of Interest (SOI)

Surface-less Flight Controls (SFC) Architecture

Integration of UAV Flight Controls Trade Study with MBSAP

Surface-less Flight Controls (SFC)

Architectural trade study applied to flight control systems

Wildfire UAV vs. Surface-less Flight Controls

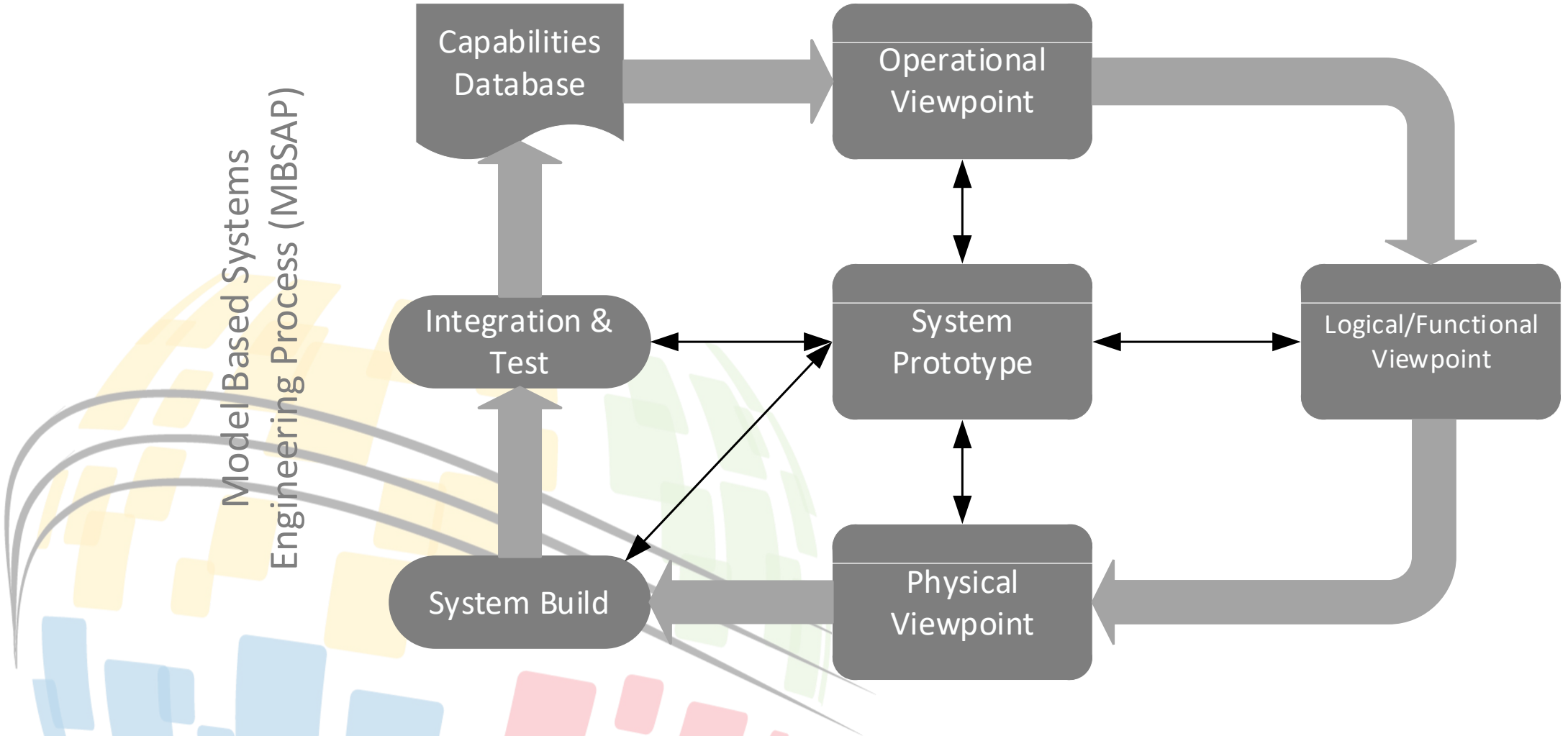
Classical FC architecture vs. Novel SFC architecture(s)

Increased availability & improved effectiveness

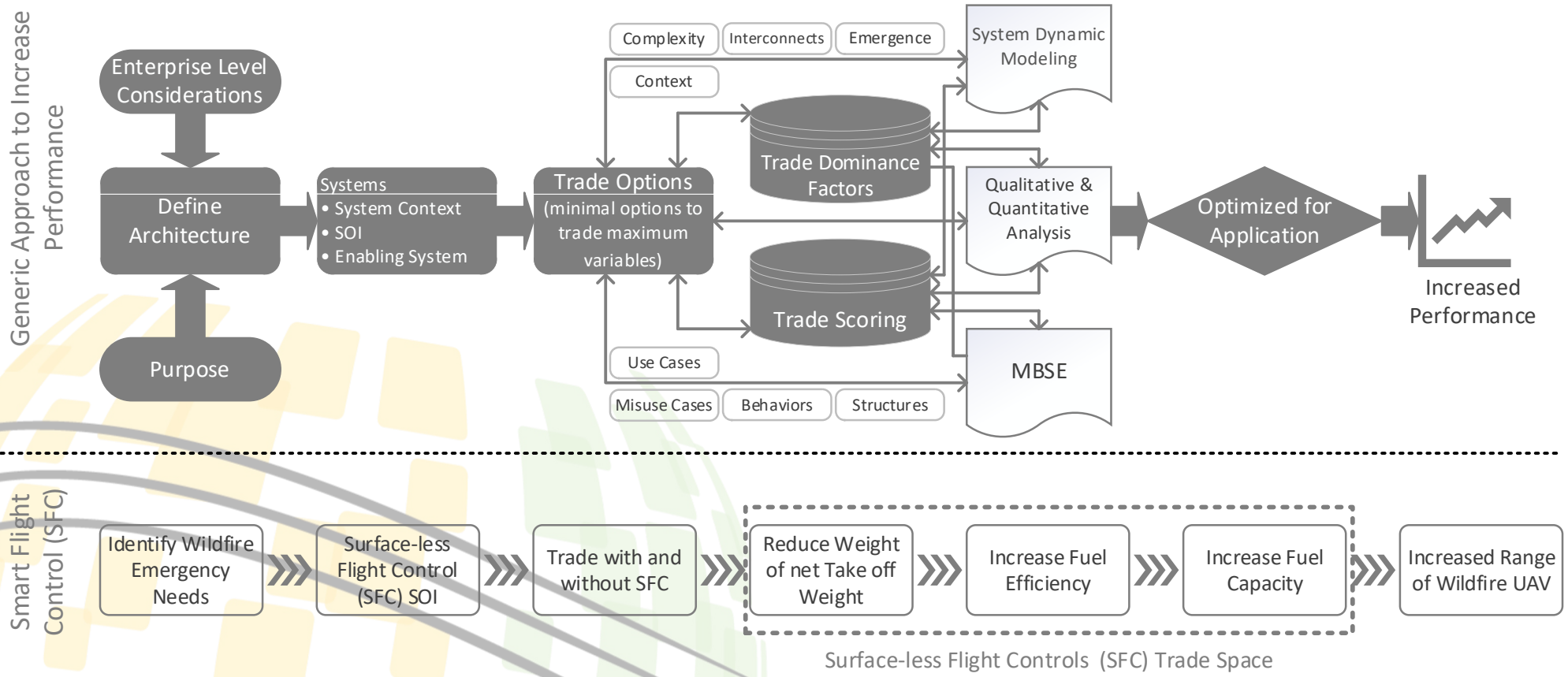
Integrated Systems Architectural Modeling with Architectural Trade Study of a UAV Surface-less Flight Control Systems for Wildfire Detection and Communication utilizing MBSAP

Wildfire UAV | Surface-less Flight Controls (SFC)

Integrating MBSAP Methodology into flight controls Trade Study



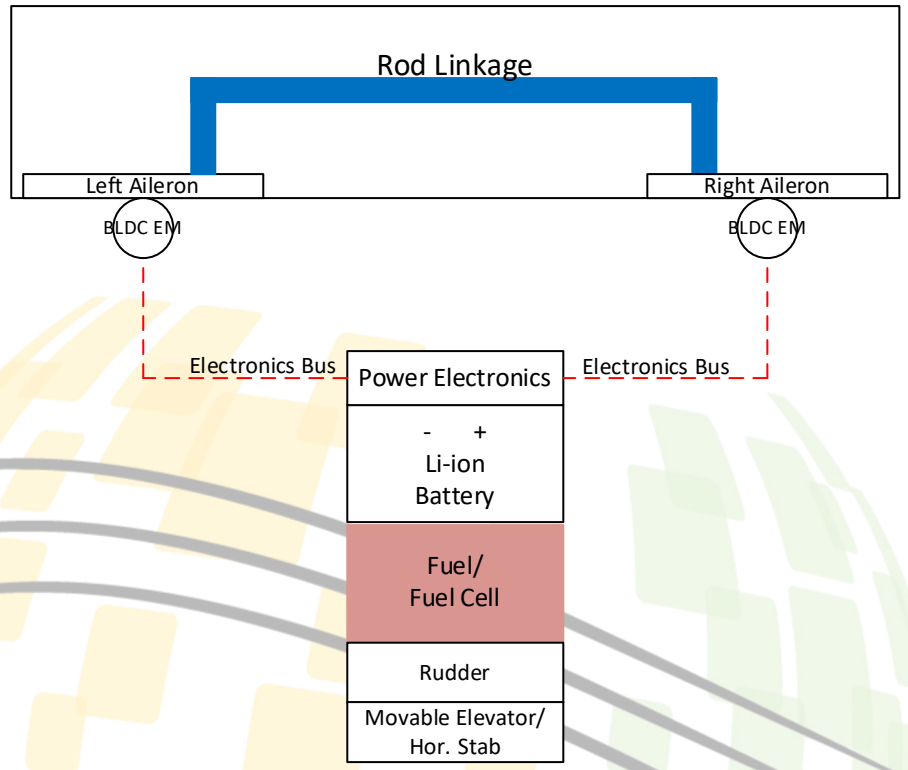
Development Process Utilizing the concepts of MBSAP to Increase Performance



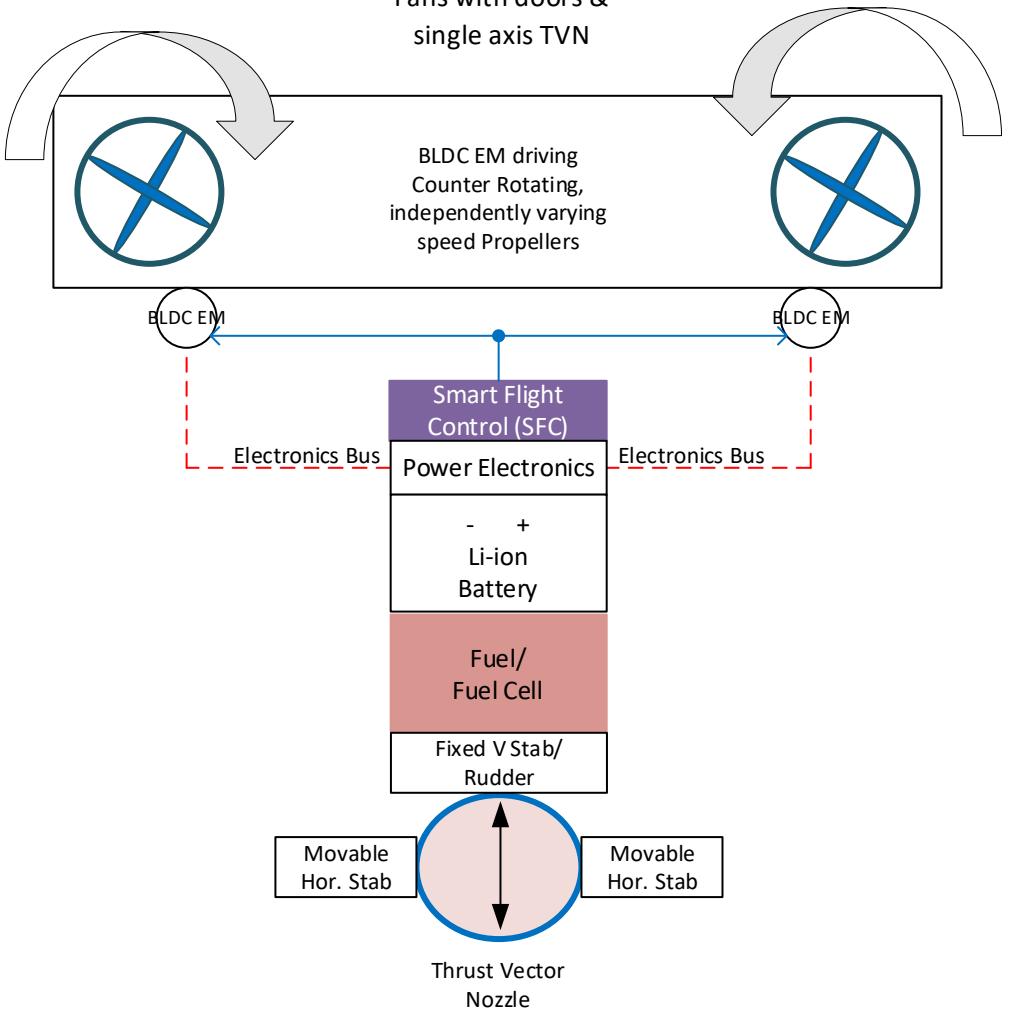
- Approach to increase performance consistent with MBSAP
  - Smart Flight Control (SFC) implementation of the generic approach / development process utilizing the concepts of MBSAP to increase range of the UAV.

Trade Study Comparisons for Flight Control Options

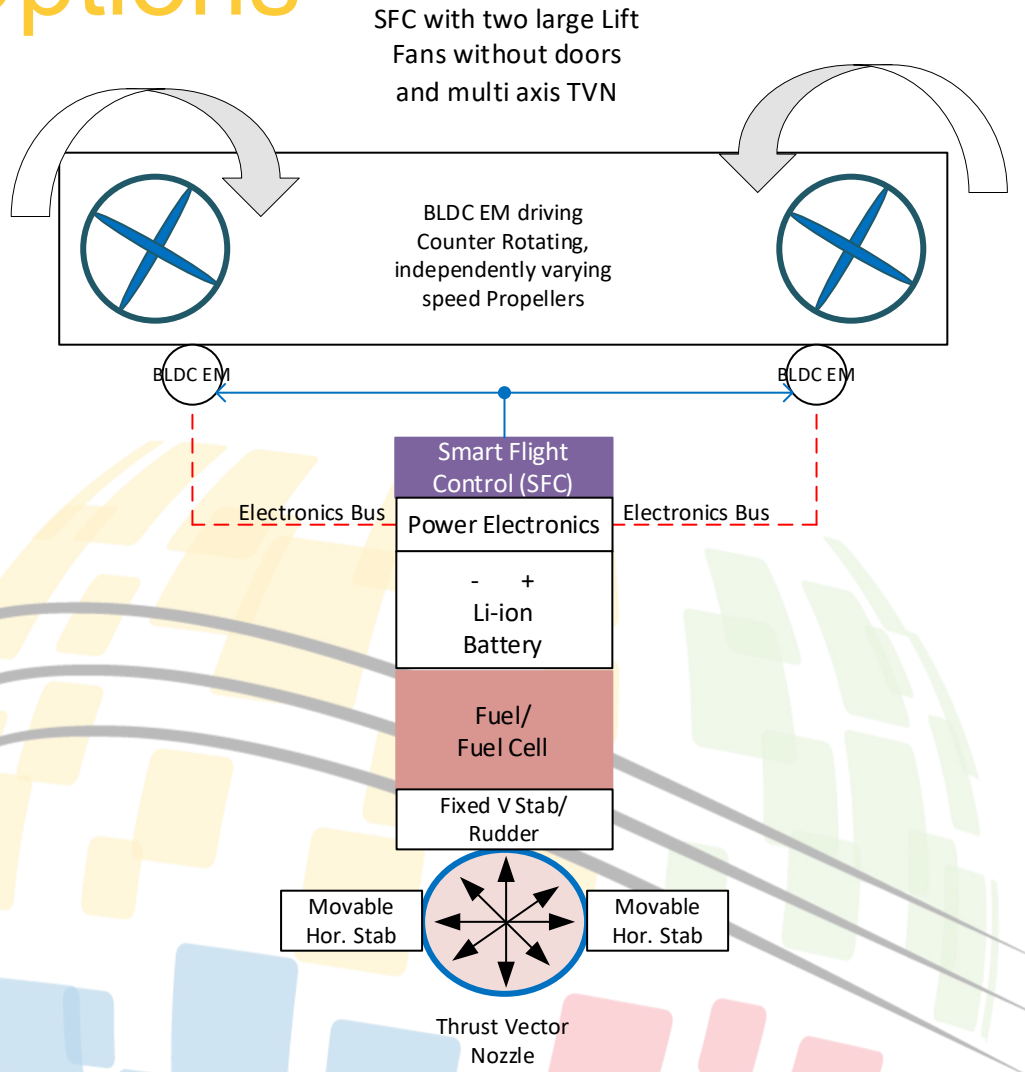
Tradition Flight Controls (TFC) with ailerons, rudder and elevators

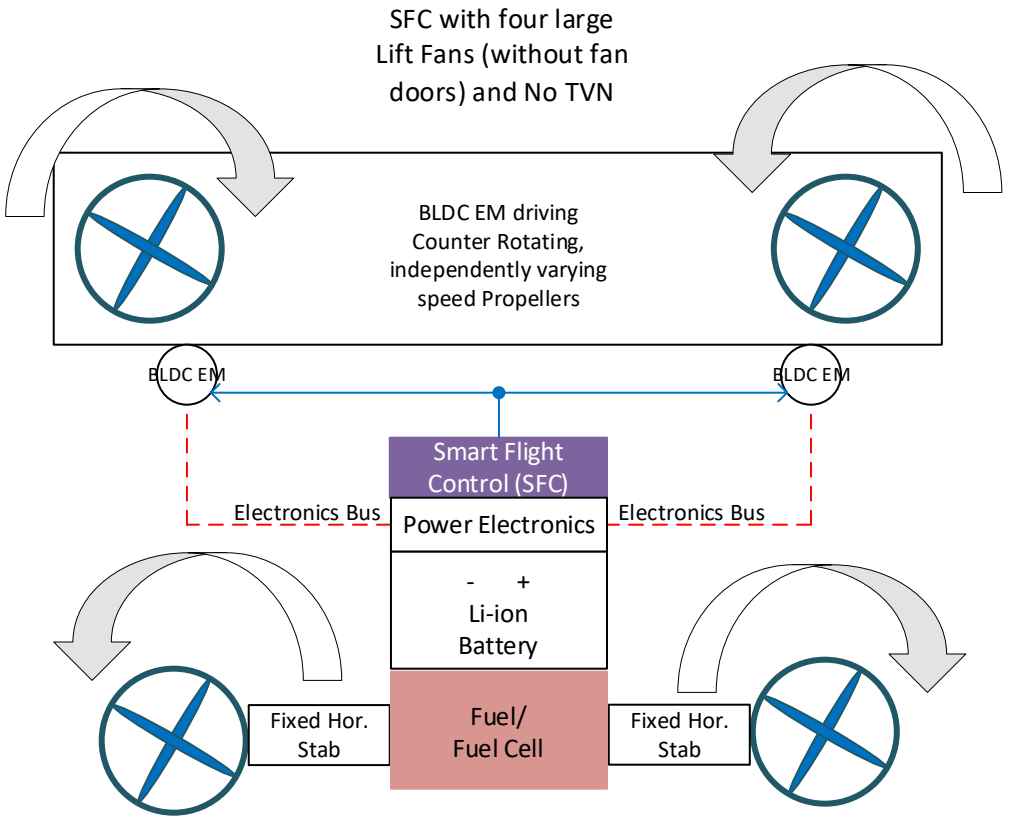


SFC with two large Lift Fans with doors & single axis TVN



Trade Study Comparisons for Flight Control Options

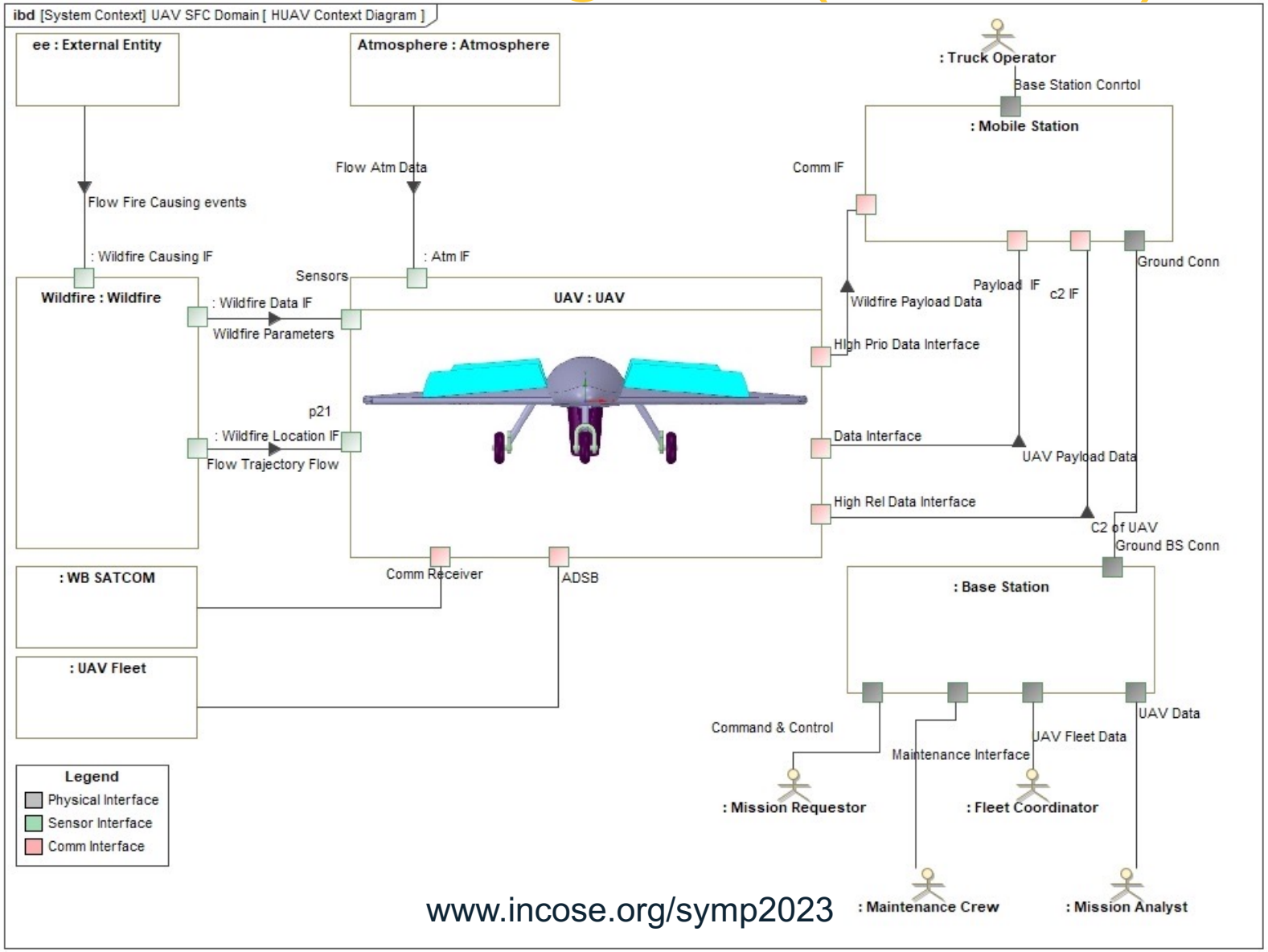




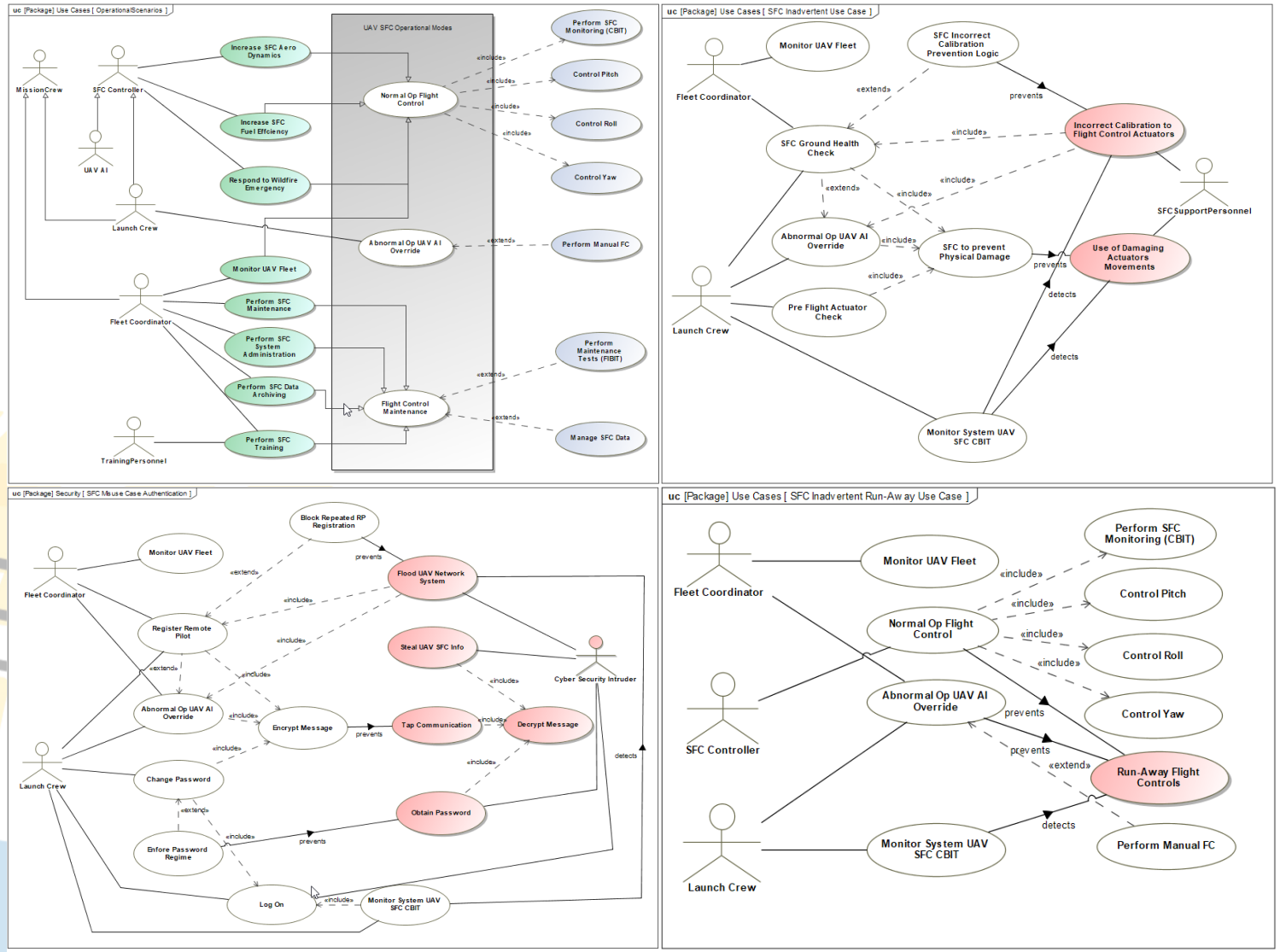
Trade Study Comparisons for Flight Control Options

Class of Parameters	Parameters to Trade	Dominance Factor (DF) (1 to 5)	OPTION-1 Traditional Flight Control (TFC)	OPTION-2 SFC with 2 FIWs with Doors	OPTION-3 SFC with 2 FIWs without Doors	OPTION-4 4 Lift Fans & No TVN	OPTION-1 Traditional Flight Control (TFC) SUBTOTAL	OPTION-2 SFC with 2 FIWs) SUBTOTAL	OPTION-3 SFC with 2 FIWs without Doors SUBTOTAL	OPTION-4 4 Lift Fans & No TVN SUBTOTAL
Weight	Take off Weight	5	2	4	5	4	10	20	25	12
	Battery Weight	1	3	2	2	2	3	2	2	6
	Fuel Weight	1	3	2	2	2	3	2	2	6
Technical Feasibility	Signal Architecture Complexity	2	4	2	2	3	8	4	4	9
	Power Architecture Complexity	2	3	3	4	3	6	6	8	9
	Complexity of Control Laws	1	4	2	1	3	4	2	1	9
	Aircraft Sizing	3	3	3	3	3	9	9	9	9
Performance	Horizontal Speed	3	3	4	4	1	9	12	12	3
	Verticle Speed	2	3	4	4	3	6	8	8	9
	L/D (Drag/Aero Dynamic)	2	3	4	4	3	6	8	8	9
	Battery ED/Energy Efficiency	1	3	4	4	3	3	4	4	9
	Flight Range	5	3	5	4	4	15	25	20	12
Cost	Initial Cost	4	4	2	3	3	16	8	12	9
	Final Unit Cost	4	3	3	4	3	12	12	16	9
	Per Square Mile Cost	4	3	4	4	3	12	16	16	9
Operational Parameters	Maintainability	3	3	3	3	3	9	9	9	9
	Reliability (MTBF)	3	4	2	3	3	12	6	9	9
	Producibility	3	3	3	3	3	9	9	9	9
	Security/Cybersecurity	5	3	4	4	4	15	20	20	12
	Harsh Environmental Tolerance	4	3	4	4	4	12	16	16	12
	TOTAL SCORE						179	198	210	180

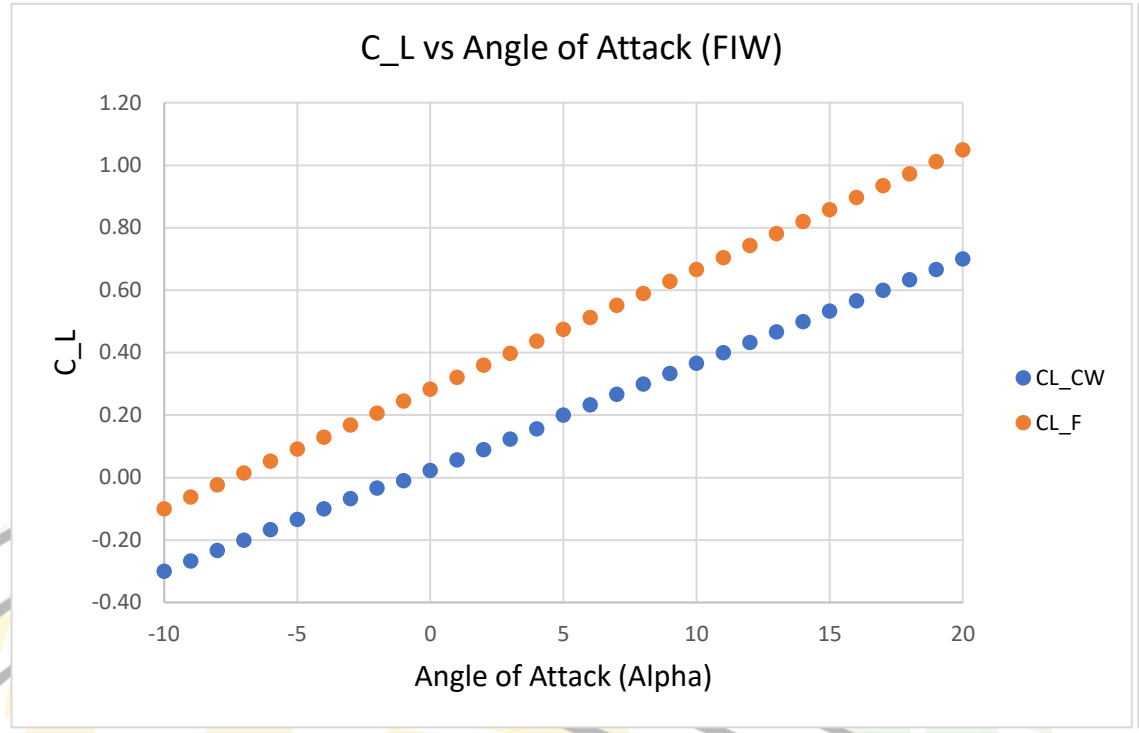
System Context Diagram (Cameo)

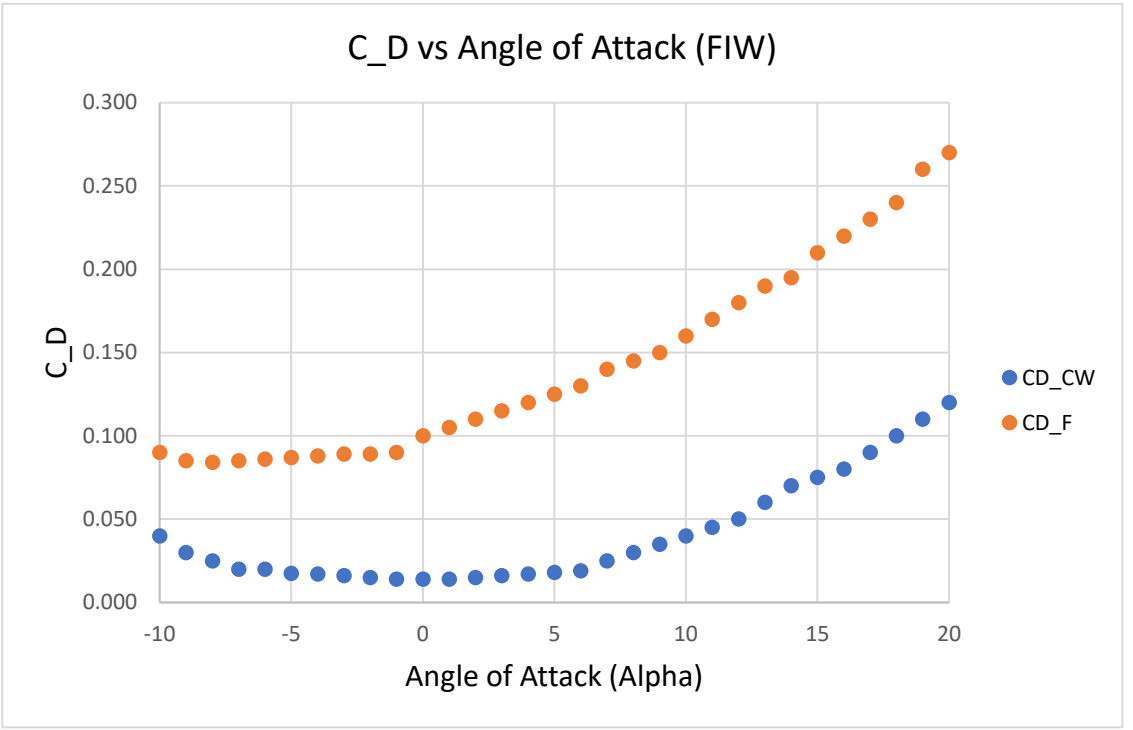


SFC Use Case vs. SFC Inadvertent/Misuse Case



Future Work for Surface-less Flight Controls

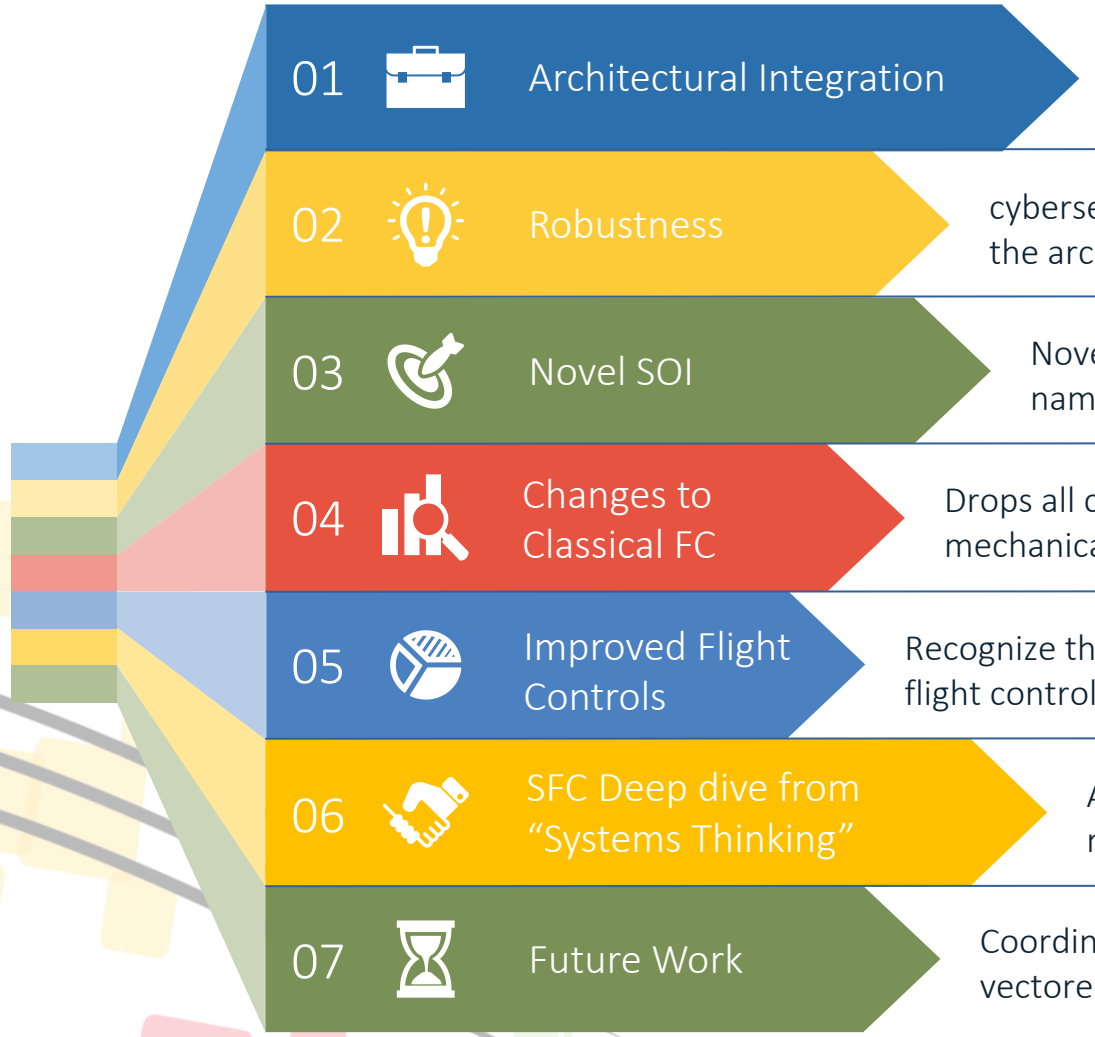




The future work revolves around Flight-In-Wings (FIW) in order to even further optimize the architecture increase the range.

Discussion of Surface-less Flight Controls Process

Wildfire UAV SFC
Using MBSAP



01	Architectural Integration	Integration of architectural trade study into a MBSAP using MBSE
02	Robustness	cybersecurity misuse cases to ensure robustness of the architecture of SOI
03	Novel SOI	Novel architecture for the system of interest, namely the SFC
04	Changes to Classical FC	Drops all classical flight control surfaces, actuators, and mechanical linkages
05	Improved Flight Controls	Recognize the potential of the lift systems to also serve flight controls: The Fan-In-Wing & Thrust Vectoring Nozzle.
06	SFC Deep dive from "Systems Thinking"	Anticipated issues, potential unknowns, and risks associated with the SFC
07	Future Work	Coordinated intelligent control of Fan-In-Wing (FIW), vectored thrust and MEA

We discovered that there is SFC is the game changer to increase the range of the Wildfire UAV

Discussion of Wildfire Topic

- **Wildfire problem is increasingly complex**:
  - Increasing scale & severity, number of loosely coupled systems and range of technologies utilized to manage them
  - Yet an affordable locally owned and operated solution to detect and communicate them does not exist
- **Integrated MBSAP, MBSE Tools, Trade Study, DSE & Monte Carlo Sensitivity Analysis**
  - Enabled the application of systems thinking philosophy and systems principles to approach this complexity
  - Found an optimal feasible point in the design space for a truck launched UAV-based detection and communication solution
  - Found the sensitivity of affordability and performance parameters to technology factors and design choices
- **Key results**
  - A feasible truck launched Hybrid Electric/ICE Propelled VTOL UAV would cost 140 km range and has an affordability of ~180 $/(kg.km) with identified directions for significant improvement
  - Battery cost and energy density needs to improve by ~ 2 to 3 for the purely electric UAV to break even
  - Flight control architecture has the potential to more than double the range or halve the $/(kg.km)
  - Several surface-less flight control architectures are currently being traded against the classical aileron, rudder, elevator architecture

Conclusions

The focus of the research project is to assist with recent uptick of the wildfire problem

Wildfire

UAV designed with the purpose of detection and communication

MBSAP (MBSE)

SFC Architectural Trade Study

Flight Controls design is not only about sizing but also prove to be a game changer to increase the range of the aircraft.

Systems Thinking

This drives improved utilization and integration of MBSAP/MBSE tools and classical methods

Systemic thinking applied along with various systems engineering tools to achieve aiding solution for the Wildfire topic

33rd Annual INCOSE international symposium

hybrid event

Honolulu, HI, USA
July 15 - 20, 2023

www.incose.org/symp2023

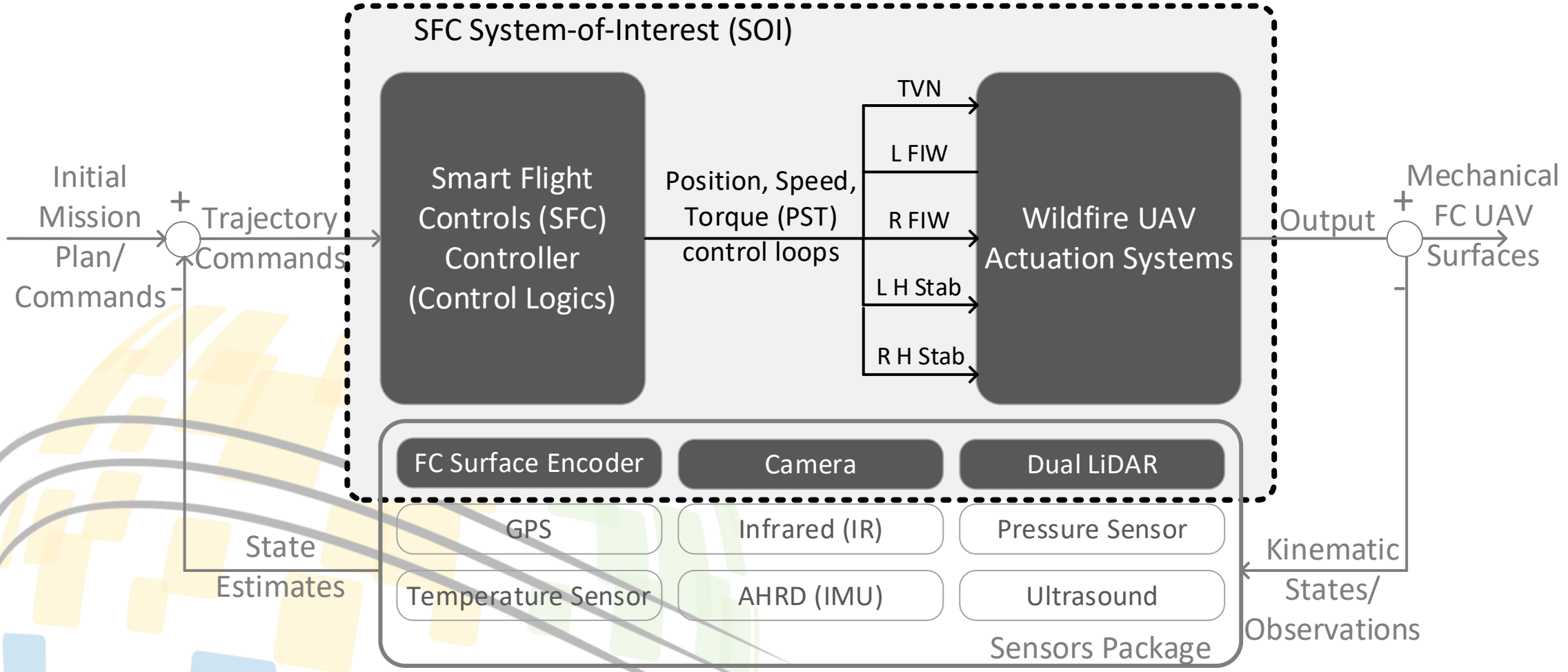
Backup

Backup Slides

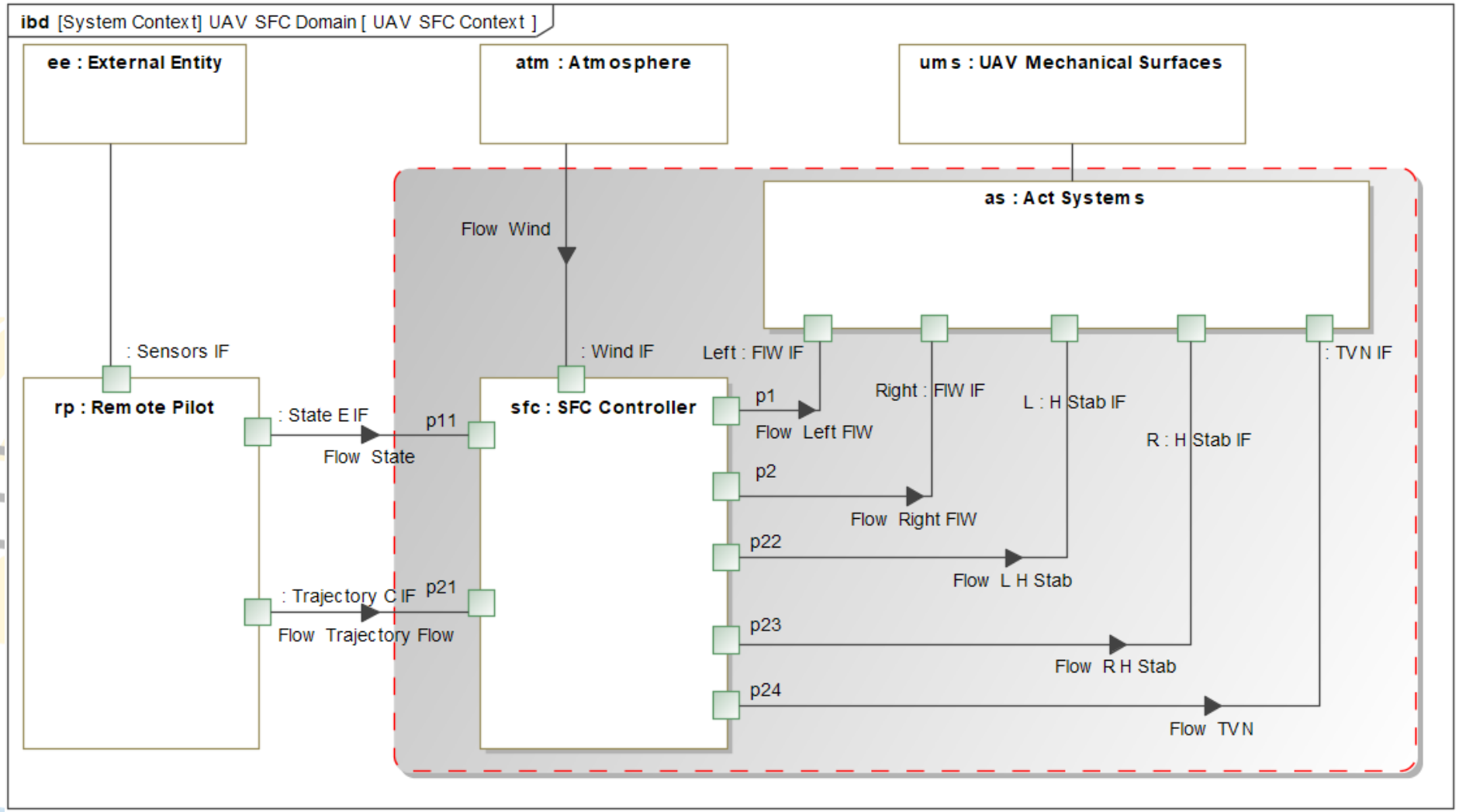
Stakeholder Diagram (Cameo)

#	Name	Need/Concerns	SFC Viewpoints
1	Fleet Coordinator	Ground Station Fleet Coordination performed by the Fleet Coordinator. Communication systems is an enabling system that allows Fleet Coordinator to access SFC if needed. Fleet coordination include calculation of fleet waypoint, integration/fusion with satellite and other detecting and firefighting assets.	Operational Viewpoint
2	Launch Crew	Launch crew, the truck operator assembles the 3 major pieces of the UAV pre-launch, fuels the UAV and does a pre-launch check, sets up retrieval coordinate, retrieves and reload the UAV after vertical landing.	Operational Viewpoint
3	Maintenance Crew	Maintenance System operated by the maintenance crew	Operational Viewpoint
4	Mission Crew	"Mission Crew" consists of "Launch Crew" and "Fleet Coordinator".	Operational Viewpoint
5	UAV AI	UAV AI is the logic for the entire flight management system that potentially resides in On Board Computer that interfaces with SFC Controller.	Logical/Functional Viewpoint
6	SFC Controller	Both UAV AI and Launch Crew (Truck Operator) are considered to be able to control SFC as "SFC Controller".	Logical/Functional Viewpoint and Physical Viewpoint
7	Training Personnel	Training Personnel are knowledgeable on the System of Systems and performs training on the SOI.	Operational Viewpoint
8	Fleet Owner	The Fleet owner of the fleet operator are the Neighborhood/Local Community or Local Fire Department)	Operational Viewpoint
9	General Public	General Public or Social Media is a vital but indirect stakeholder. It is important to generate awareness to general public and social media as devasted community and local fire department may be overloaded	Operational Viewpoint

Wildfire UAV SFC Systems Logical Architecture



Wildfire UAV SFC System of Interest (SOI) Context Diagram



SFC Asset consideration for security assessment

Critical Asset	Potential Impact if Compromised	Criticality	Potential Value	Asset Score
UAV	Loss of UAV causing fire instead of assisting mitigating wildfire	Catastrophic (5)	High (300 unit)	1500 unit
Surface-less Flight Control	Loss of SFC causing fire instead of assisting mitigating wildfire	Hazardous (4)	High (300 unit)	1200 unit
Network and Networking Equipment	Loss of network causing UAV to contribute to fire instead of assisting mitigating wildfire	Hazardous (4)	Medium (200 unit)	800 unit
Payload Data (Write)	Wildfire data being falsified, and resources being misguided	Major (3)	Medium (200 unit)	600 unit
Payload Data (Read)	Wildfire data being for other non-mission-oriented purposes	Minor (2)	Low (100 unit)	200 unit