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Beyond Pixie Dust:

A Framework for Understanding and Developing Autonomy in Unmanned Aircraft

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The Air Force must accelerate its developmental and fielding timelines for autonomous teaming aircraft

Autonomous aircraft have the potential to affordably provide:

- Increased force capacity
- Operational resiliency
- New operational concepts
- Complexity to the adversary

"It's a commitment to going forward in a direction that we have been thinking about experimenting with, but hadn't committed to before. So that's a major change, actually."

SECAF Frank Kendall

Manned and unmanned aircraft will have to collaborate closely and in ways that are effective and trusted by human warfighters

Warfighters and engineers do not share a common understanding/vision of autonomy

RISK: A lack of a shared understanding of autonomy generates serious miscommunication and mistrust between what the USAF's strategic planners envision, what its operational warfighters need, and what aerospace engineers can deliver

If these misunderstandings persist, they may lead to:

- **Delayed developmental timelines**
- **Broken acquisition programs**
- **Failure to develop CONOPS**
- **Broken expectations/trust**
- **Resistance to adoption**

To more rapidly develop and field relevant capabilities that warfighters can trust, the Air Force should adopt an autonomy framework that can facilitate a shared understanding between warfighters and engineers

What Is Autonomy??

Automated – A system whose actions result from deterministic programming

Deterministic – Programming that is highly scripted, predictable, and repeatable

Direct control – Humans are immediately causal to the actions and outcomes of the system

Supervision – Humans monitor the decisions, actions, and outcomes of the system

Autonomy – A system's ability to independently self-direct in an adaptive manner

Machine learning– Self-optimizing algorithmic systems that are able to adapt behaviors without explicit inputs by analyzing and making inferences from patterns in data

Self-direction – The system's ability to make choices and take action independently

Authority – The locus of agency in decision making and determining courses of action and taking action

Command Intent – Direction provided to a system by description of the desired outcome without dictation of specific actions to accomplish the outcome

Independence – The ability of a system to make decisions and execute operations without human intervention

There is NO commonly accepted and consistently/widely used definition of autonomy across the DOD

What Is Autonomy??

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No shared understanding of what autonomy is or how it should be applied in autonomous teaming aircraft risks confusing developmental efforts

What Is Autonomy??

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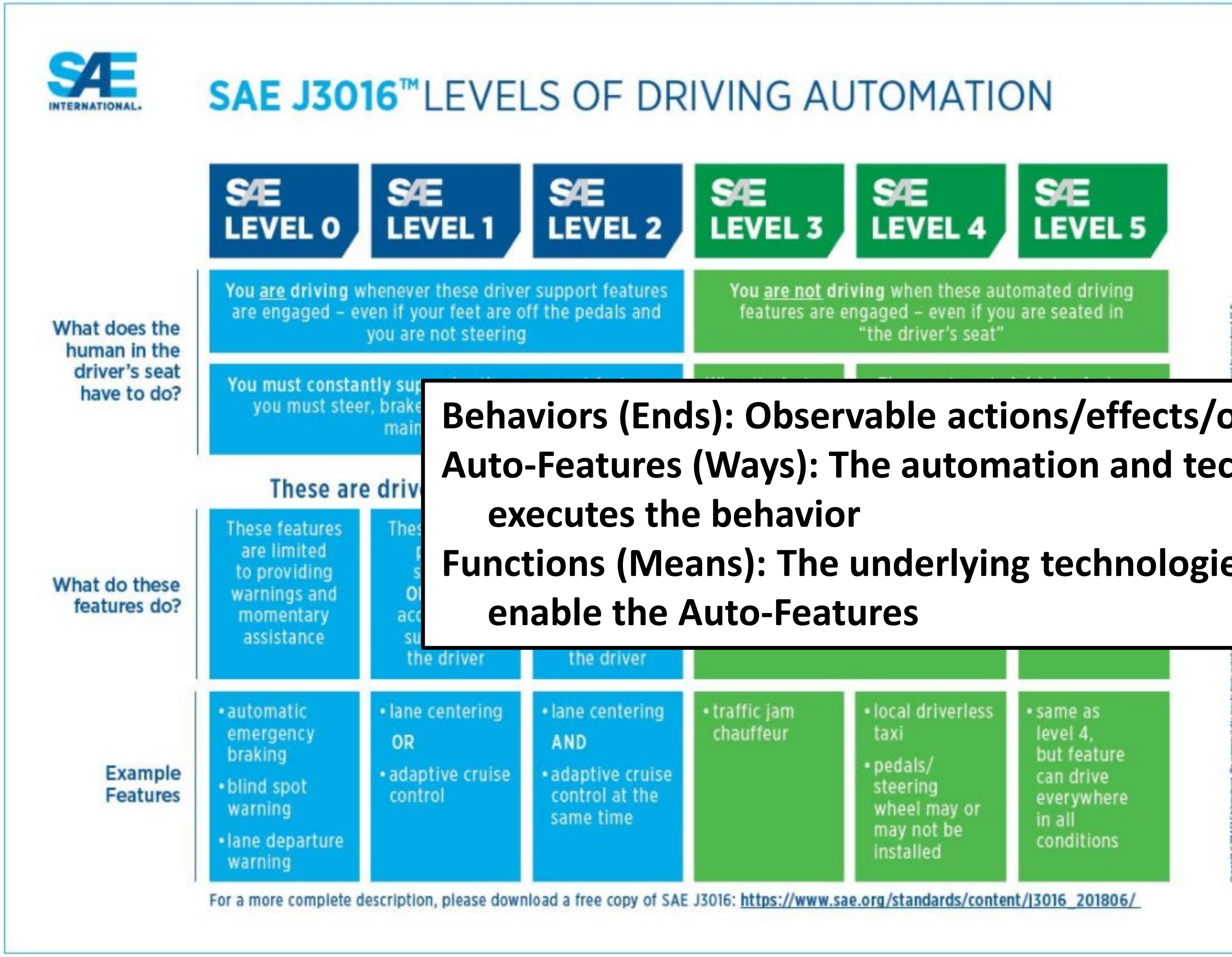
We define autonomy as the system's ability to independently self-direct in an adaptive manner – this implies some element of machine learning

The need for an autonomous teaming aircraft framework



Behaviors (Ends): Observable actions/effects/outcomes

Auto-Features (Ways): The automation and technology that executes the behavior

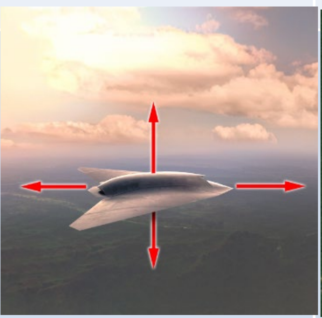
Functions (Means): The underlying technologies needed to enable the Auto-Features

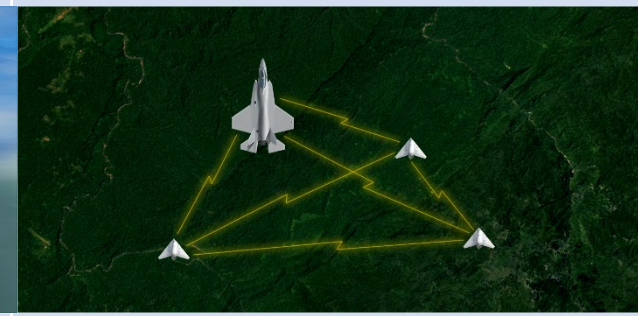
To create a shared understanding, the Air Force needs an autonomy framework that marries both unmanned aircraft and autonomy levels

Two View Autonomy Framework

Warfighter View

Core		Mission	Teaming
flight control inputs and navigation functions that are necessary for aircraft to fly without direct human control		**functions necessary to accomplish mission-related tasks such as managing sensor operations, releasing weapons on targets, and performing other tactics**	**functions and features necessary for autonomous UAVs to conduct collaborative operations with other aircraft, both manned and unmanned**
Aviate	**Navigate**		



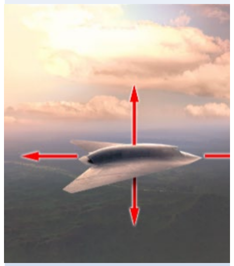


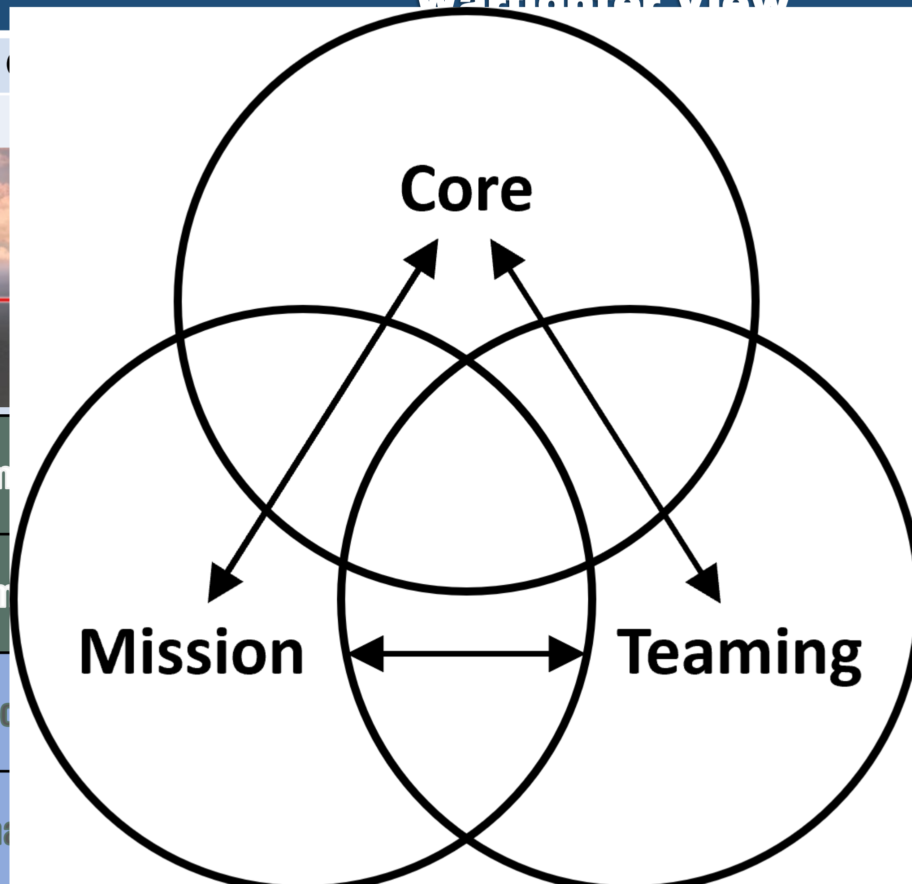
Autonomy Feature Level (1-5)

Engineer View

- Function: What do the Automated or Autonomous features need to accomplish?
- Technology: What hardware and software are needed to deliver these functions?
- Data: What inputs – training and real-world data – are needed to deliver these functions?

Warfighter View

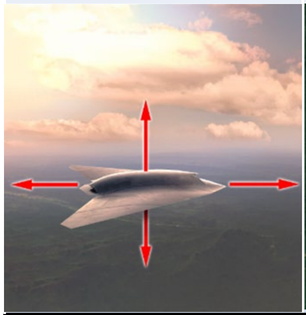
Autonomy Levels	Warfighter View	
	Aviate 	Teaming 
5	Fully Autonom	d Supervision
4	Semi Autonom	nd Supervision
3	Full Automatic	ol by Exception
2	Partial Automa	Supervision
1	Low Automation (Deterministic) – Significant Human Direct Control and Supervision	



The Warfighter View is based on combat pilots' cognitive tasks

Engineer View

Engineer View

Core		Mission	Teaming
Aviate	Navigate		
			

Function – What do the Automated or Autonomous Features need to accomplish, and to what level?
Technology – What hardware and software are needed to deliver these functions?
Data – What inputs – training and real-world data – are needed to deliver these functions?

The Engineer View enables engineers to functionally decompose the behaviors and autonomy levels described by the warfighter

Notional "missile truck" example

Two View Framework: Core

Applying the Two-View Framework on a Notional Missile Truck			
	Warfighter View		**Engineer View**
Core Aviate	Must be able to handle all phases of flight from takeoff to landing without any need for direct control from a remote pilot or the flight lead.	Autonomy Level: Level 3 Full Automation to Level 5 Autonomous (desired)	Full autonomy may be beyond the capabilities of current technologies, and thus increase time and cost of development. Pursuing Level 3 could help speed a minimum viable capability to the field while work on incremental software or hardware upgrades to increase autonomy continues.
Core Navigate	At a minimum, must be able to maintain designated formation positions without hitting the ground, its flight lead, or other aircraft. At more advanced levels, might be able to fly dynamic tactics and conduct threat avoidance and defeat maneuvers.	Autonomy Level: Level 3 Full Automation to Level 5 Autonomous	Level 4 Semi-autonomous may be faster to develop and train than a Level 3 system. Engineers can discuss the tradeoffs in development and fielding of pursuing higher or lower levels of autonomy.

Warfighters describe ATA required behaviors with the level of self-direction and adaptation needed (autonomy levels) in collaboration with engineers

Two View Framework: Mission

Applying the Two-View Framework on a Notional Missile Truck			
	Warfighter View		**Engineer View**
Mission	The human flight lead selects which ordinance to use, when, and on which target. Additional autonomy may provide extra options that increase lethality and mission effectiveness.	Autonomy Level: Level 1 Low Automation to Level 3 Full Automation at a minimum	The benefit to the warfighter of a higher level of automation may be initially outsized by increased cost and impact on a ATA's development. Conversely, higher levels of mission autonomy may eventually provide even more benefit, to the point where the missile truck truly becomes a smart teammate. This depends on increasing warfighter trust in autonomy.

Warfighters describe ATA required behaviors with the level of self-direction and adaptation needed (autonomy levels) in collaboration with engineers

Two View Framework: Teaming

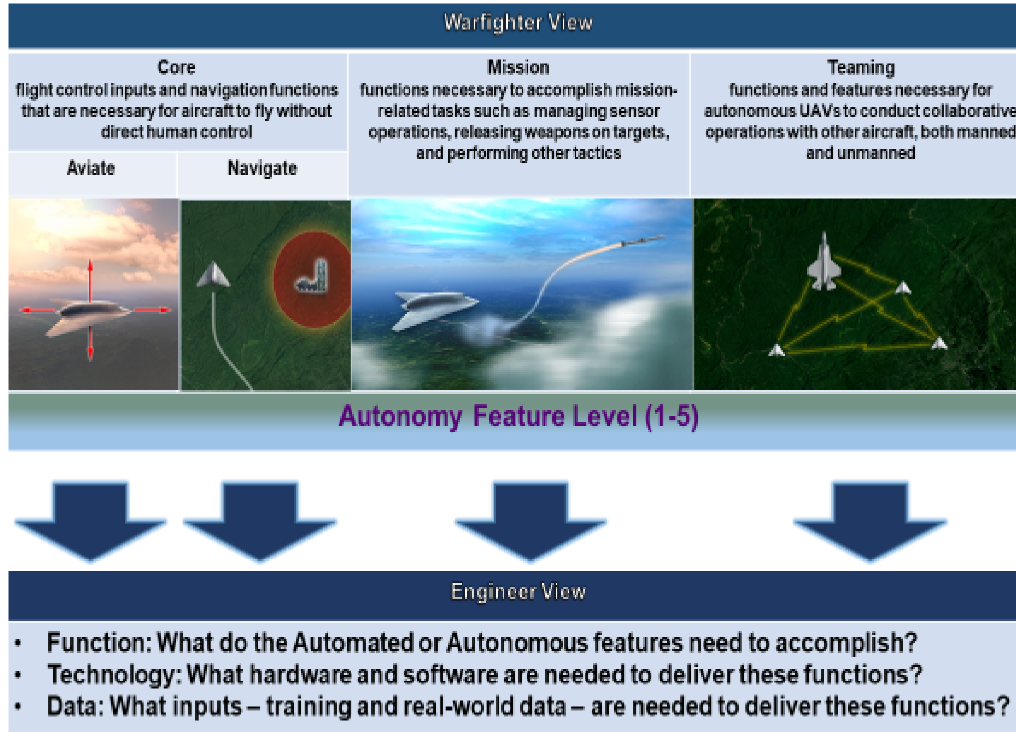
Applying the Two-View Framework on a Notional Missile Truck			
	Warfighter View		**Engineer View**
Teaming	Partial automation is sufficient to merely exchange data directly to a flight lead, assuming little need for onboard data processing or data fusion.	Autonomy Level: Level 2 Partial Automation at a minimum	Teaming at higher levels of autonomy would increase focus on processing and machine decision-making capabilities, which would also increase the need for real-time data. Increasing warfighter trust in autonomy will be key to maturing teaming capabilities and operations.

Warfighters describe ATA required behaviors with the level of self-direction and adaptation needed (autonomy levels) in collaboration with engineers

Benefits of the Two View Autonomy Framework

A shared framework that connects warfighter expectations of autonomous teaming aircraft behaviors to engineer's technological perspective:

- **Common language and perspective aligns effort to need**
- **"Right-sizes" developmental efforts**
- **Allows informed tradeoff decisions**
- **Accelerates "minimum viable product" to field**
- **Enables tacticians and planners to understand the potential and limitations of systems**
- **Increases warfighter trust**



This framework demystifies autonomous teaming aircraft in operational terms and establishes a shared understanding and language that translates across other stakeholder communities

Adopting this Two-View Framework can accelerate the development and fielding of autonomous teaming aircraft to the warfighter

Summary

1. The Air Force needs an Autonomy Framework to guide its next-generation UAV requirements definition, acquisition programs, and CONOPS and TTP development.
2. The Two-View Autonomy Framework for Unmanned Aircraft offers a model that the Air Force can use to facilitate greater collaboration between warfighters, technologists, and aerospace engineers.
3. The Air Force Deputy Chief of Staff for Strategy, Integration, and Requirements (AF/A5) should have formal ownership of the framework, in close collaboration with the Deputy Chief of Staff for Operations (AF/A3), Air Combat Command, and Global Strike Command.
4. Stakeholders across the enterprise should embrace and broadly use this two-view framework to guide autonomy research, development, and experimentation, as well as to inform the development of new tactics, techniques, procedures, and operational concepts.

The Air Force should adopt and use an autonomy framework for unmanned aircraft that facilitates the shared understanding of warfighters and engineers

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