
Release Approval PENDING
DECO: Digitally Enabled Cooperative Operations
Exploring a New Digitally Enabled Operating Mode to Complement VFR and IFR
April 2024
Graphic by R. Neale

What is an Operating Mode?

Regulatory, procedural, and technical means for aircraft to *operate safely* within the airspace

aka "*flight rules*" as defined in regulations, policies, procedures, training materials, …

Routine Operating Modes	Specialized Operating Modes
Widespread use in most airspace classes *Routine for pilots & controllers*	*Limited to certain operations and/or airspace incompatible with VFR & IFR* *Routine for pilots who use them; Nonroutine for controllers and other pilots*
● Visual Flight Rules (VFR) ● Instrument Flight Rules (IFR)	● State/Military Aircraft ● Moored Balloons / Kites / Amateur Rockets / Unmanned Free Balloons ● Ultralight Vehicles ● Parachute Operations ● Small Unmanned Aircraft Systems

Key Points:

An Operating Mode is a "must have" for all flights (safety requirement)

All existing Operating Modes depend on human situation awareness and procedures

"Traffic Management" and "Operating Mode" are not the same thing

Coming Soon to an Airspace Near You

What Innovations are Coming?

- New Types of Propulsion
- New Missions and Business Models
- Flight Operations in New Locations
- Remotely Piloted Aircraft
- Increasingly Automated (e.g., m:N)
- Unknown Future Innovations

What Operating Modes Can Be Used?

Increasing Ops Tempos, Volume, Density, Complexity →

Existing Operating Modes

Existing Operating Modes w/ waivers & special procedures at low operational tempos

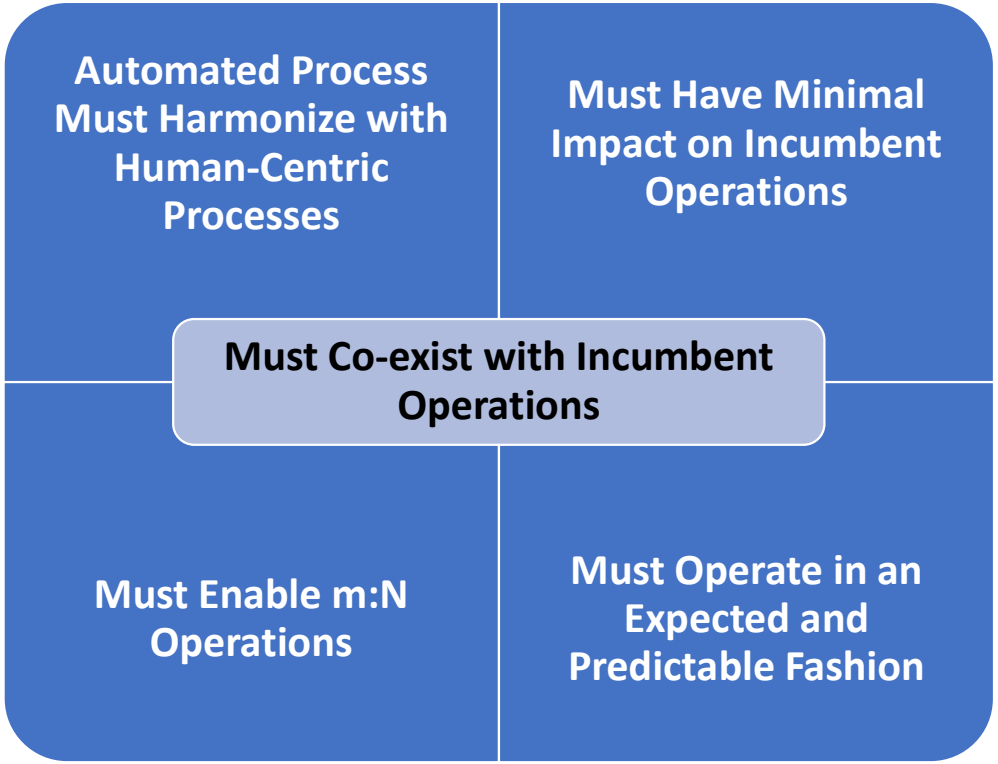
Existing Operating Modes May Be Insufficient

Community Awareness:

*"**New and adapted flight rules and procedures will be required** to efficiently manage these increasingly dynamic operations of differing priority and types."* Airbus and Boeing, 2020

Airspace Integration Challenges with Increasingly Automated Flight

- **Situation awareness**
  - See and avoid other aircraft
  - Localization and navigation
  - Obstacle/Terrain avoidance
  - Remaining clear of clouds
  - Visual approaches
- **Ability to follow airspace procedures**
  - Visual and instrument procedures
  - Traffic Patterns
  - Interaction with Air Traffic Control (Vectors / Clearances)
- **Contingencies**
  - Weather
  - Aircraft emergencies
  - Novel situations
- **Technology Maturity and Ability to Qualify Automation**



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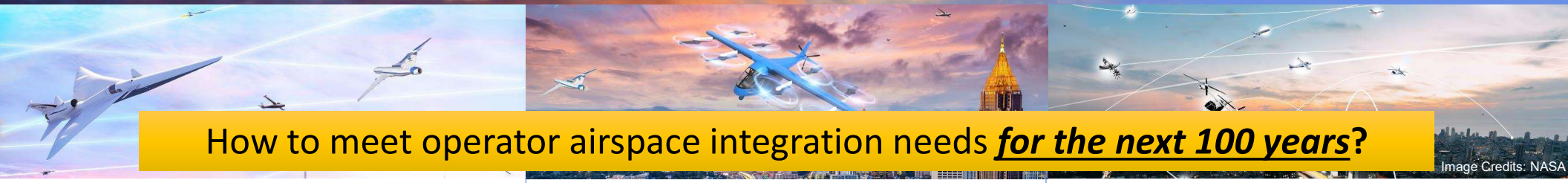
Operating Mode Options for 21st Century Aviation



How to meet operator airspace integration needs ***for the next 100 years***?

Image Credits: NASA

Do Nothing

Operating Modes of the 20th Century are

- Not adaptable to increasing flight diversity
- Not scalable to high tempos and density
- Not suited to self-piloted aircraft
- Not sufficiently predictable
- Not conducive to regional growth

Cannot be solved by Traffic Management alone

Not really an option

Add to Specialized Modes

Specialized Operating Modes

- State/Military Aircraft
- Moored Balloons etc. (Part 101)
- Ultralight Vehicles (Part 103)
- Parachute Operations (Part 105)
- sUAS (within visual) (Part 107)
- sUAS (beyond visual) (Part 108?)
- Another (Part 109?)
- And another
- And yet another

Proliferation of Solutions

- Divergent?
- Incompatible?
- Segregated?

Starting to happen

Converge to One New Routine Mode

Routine Operating Modes

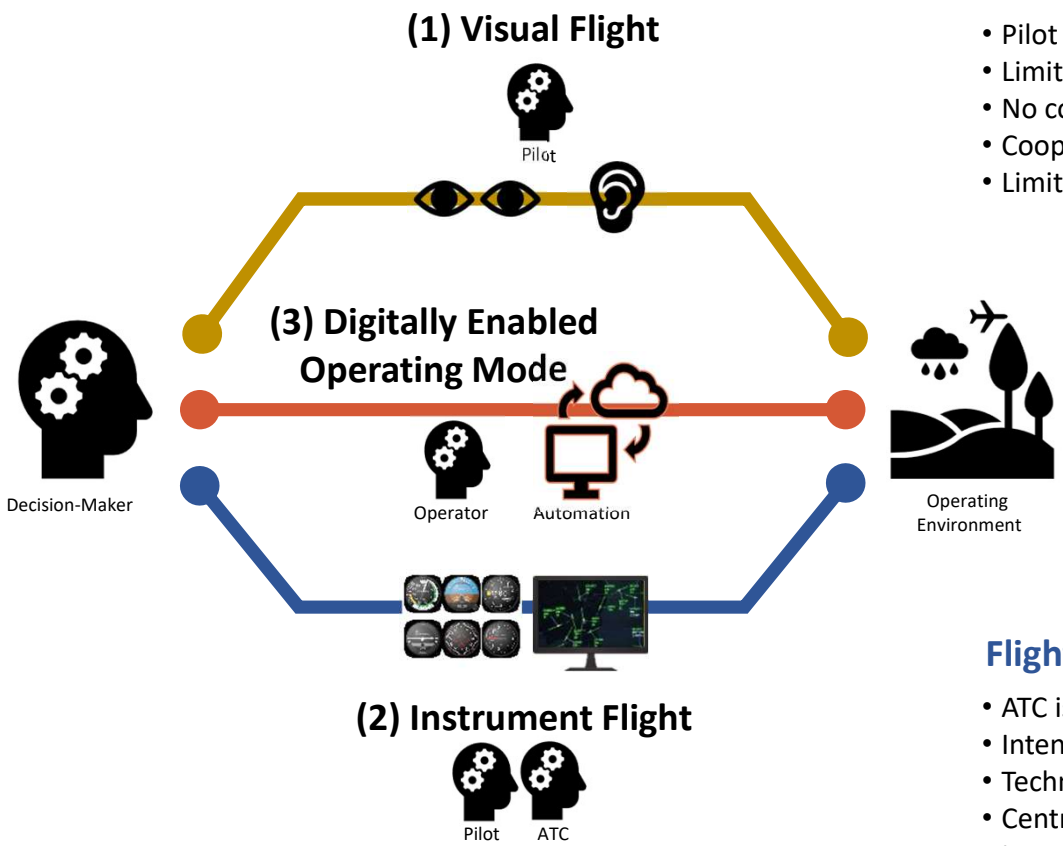
- **Visual Flight Rules (VFR)**
- **Instrument Flight Rules (IFR)**
- **New Routine Operating Mode (digitally native & cooperative)**

Convergent Aeronautics Solution

- Unifying
- Compatible
- Integrated
- Flexible
- Adaptable

Needs to happen!

Exploring a Third Routine Operating Mode



Flight by Reference to Visual Cues

- Pilot is the separator (see and avoid)
- Limited to no intent sharing
- No conflict management technology required
- Cooperative through human interpretation & judgment
- Limited to no dependence on traffic management

Flight by Reference to Digital Capabilities

- **Operator is the separator**
- **Required intent sharing**
- **Technology-dependent separation function**
- **Encoded cooperative practices**
- **Collaborative with traffic management**

Flight by Reference to Instruments and ATC Services

- ATC is the separator
- Intent sharing with ATC, not with other IFRs
- Technology dependence (communications, navigation, surveillance)
- Centralized control
- Integrated with traffic management

Detailed Framework for a Digitally Enabled Operating Mode

Information Services

Maintains a digital model of the operating environment for use by decision-making automation

Cooperative Practices

Governs the behavior of DF operations to ensure harmonized use of the airspace

CP-A: Share and Update Intent	**CP-B:** Take Timely Action	**CP-C:** Respect Intent When Changing Intent	**CP-D:** Respect VFR and IFR Aircraft
CP-E: Navigate with Intended Precision	**CP-F:** Apply Pair-Appropriate Separation	**CP-G:** Respect Right-of-Way Among DF Aircraft	**CP-H:** Coordinate Maneuvering Among DF Aircraft
CP-I: Coordinate with ATC in Controlled Airspace	**CP-J:** Join in Appropriate Flow Management	**CP-K:** Avoid Active Protected Airspace	**CP-L:** Respect Established Operating Procedures

Essential Elements

- **EE-1: Info Services & Connectivity**
- **EE-2: Shared Traffic & Intent Awareness**
- **EE-3: Cooperative Practices**
- **EE-4: Automated Conflict Management Capabilities**

Shared Traffic & Intent

Maintains awareness of relevant traffic information for use in conflict management

- **SI-1:** Aircraft State
- **SI-2:** Shared Operational Intent (Near, Intermediate, Destination)
- **SI-3:** Intended Navigation Performance

Principal Capabilities

Automates the critical functions in conflict management

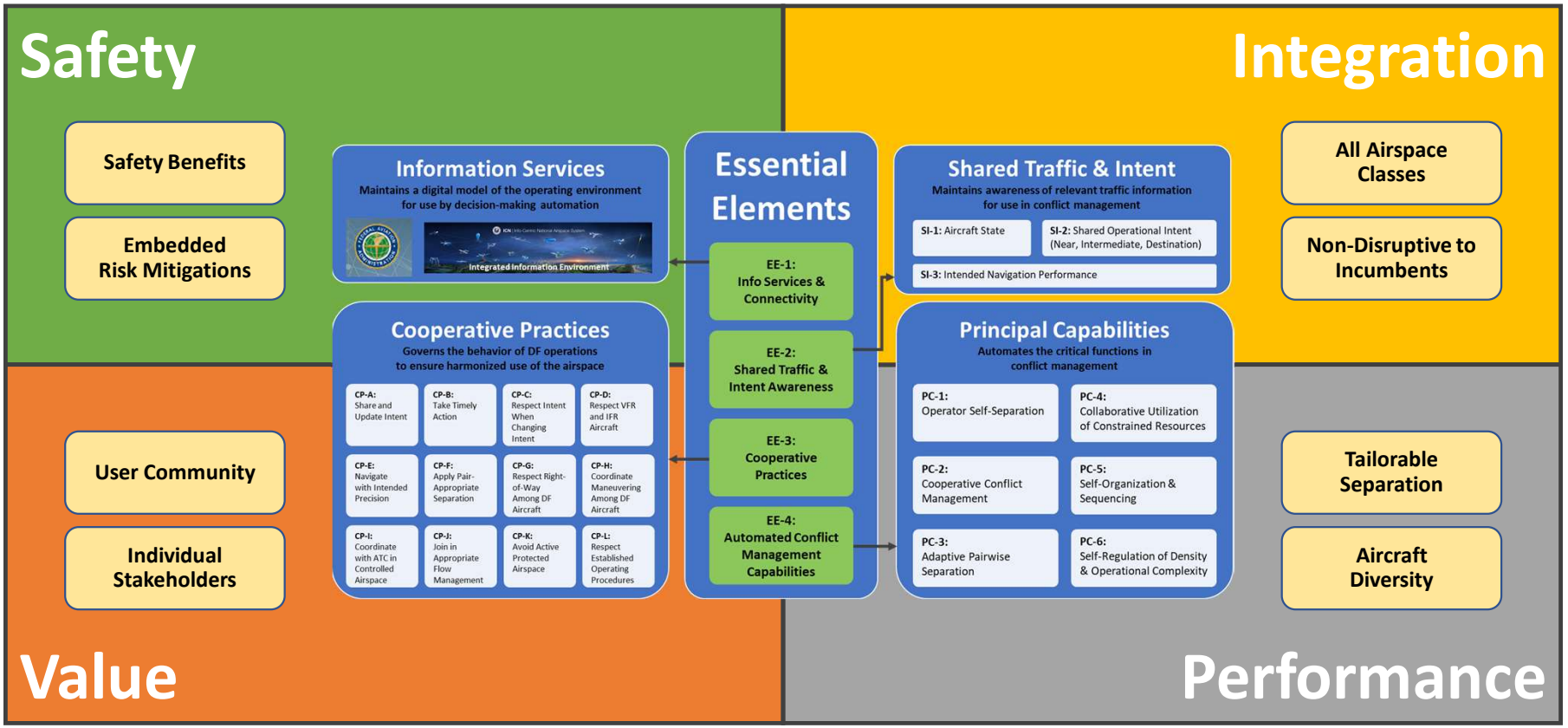
PC-1: Operator Self-Separation	**PC-4:** Collaborative Utilization of Constrained Resources
PC-2: Cooperative Conflict Management	**PC-5:** Self-Organization & Sequencing
PC-3: Adaptive Pairwise Separation	**PC-6:** Self-Regulation of Density & Operational Complexity

ICAO Layers of Conflict Management

ICAO Conflict Management[1]	Visual Flight	Instrument Flight (ATM Services)	Digital Flight
Strategic Conflict Management *"Achieved through the airspace organization and management, demand and capacity balancing and traffic synchronization components; Aim to reduce the need to apply the second layer — separation provision."*	**Procedures, Practices, and Airspace Structure** • Traffic Pattern • Ordinal Altitudes • Routes, Flyways	**Traffic Flow Management & Airspace Structure** • Executed via ATC	**Traffic Flow Management & Airspace Structure** • Cooperative compliance (PC-4) • Self organization (PC-5) • Self limiting (PC-6)
Separation provision *"Tactical process of keeping aircraft away from hazards by at least the appropriate separation minima; Only used when strategic conflict management cannot be used efficiently."*	**Remain well-clear** Airspace user is the separator for its activity in respect of one or more hazards Visual separation, assisted by technology • CDTI • FLARM	**Separation Services** • Radar separation • Procedural separation	**Self-Separation** Airspace user is the separator adhering to a defined minima in respect of one or more hazards • Operator self-separation (PC-1) • Cooperative conflict management (PC-2) • Adaptive pair-wise separation (PC-3)
Collision avoidance *"Must activate when the separation mode has been compromised; Not part of separation provision; Must be compatible with separation provision mode."*	**"See" and Avoid** • Pilot vision • CDTI – Traffic Alerting • TCAS (in some cases)	**"See" and Avoid** • Pilot vision • TCAS/DAA (in most cases)	**"See" and Avoid** • Pilot vision (optional) • TCAS/DAA (in all cases)

1: International Civil Aviation Organization, ICAO Doc 9854, *Global Air Traffic Management Operational Concept*, First Edition-2005.

Asserted Attributes of the Framework

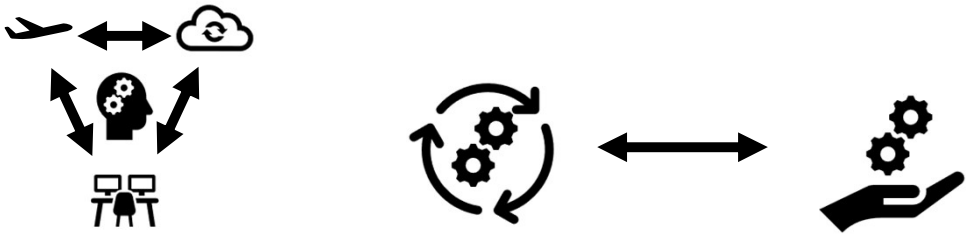


Essential Elements

Essential Elements	Role
Information Services and Connectivity	Maintains a digital model of the operating environment for use by decision-making automation
Shared Traffic & Intent Awareness	Maintains awareness of relevant traffic for use in conflict management
Cooperative Practices	Governs the behavior of digital flights to ensure harmonized use of the airspace
Automated Conflict Management Capabilities	Automates the separation function through dynamic path planning

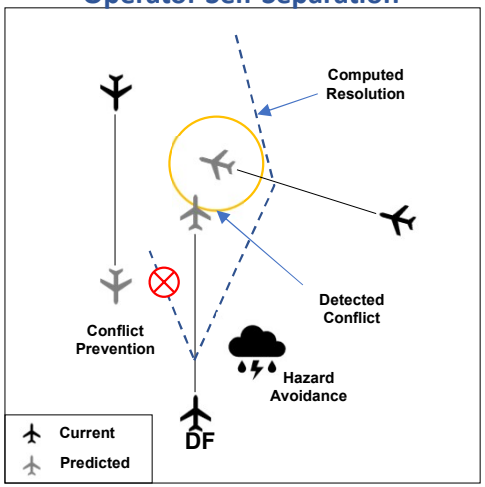
https://www.faa.gov/sites/faa.gov/files/Charting-Aviations-Future-Operations-in-ICN_0.pdf

Operator Flexibility in Implementation:

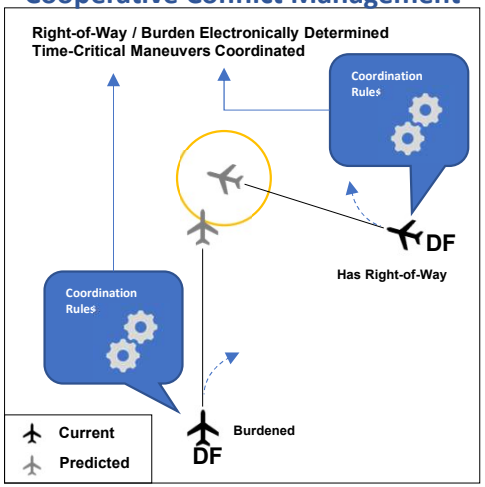


Envisioned Principal Capabilities

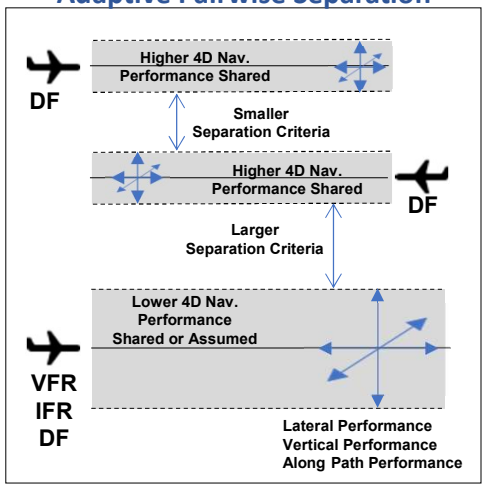
Operator Self-Separation



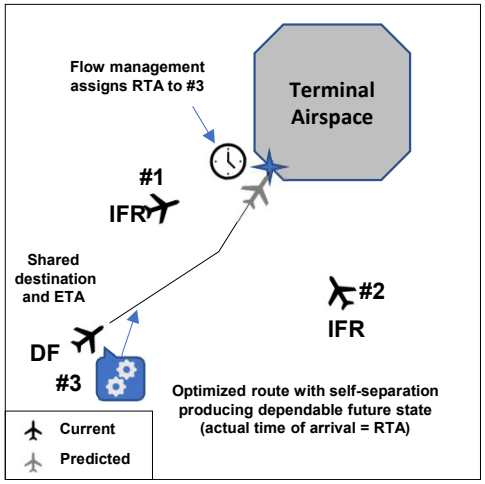
Cooperative Conflict Management



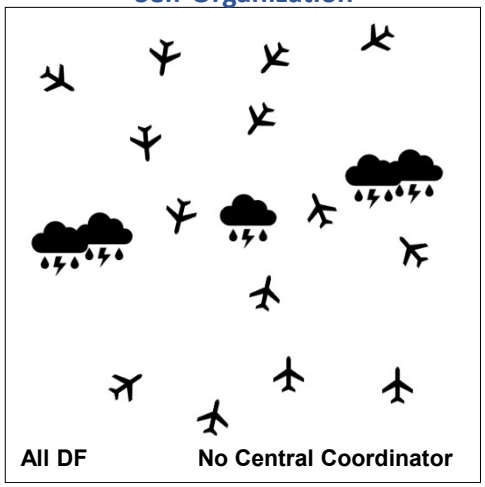
Adaptive Pairwise Separation



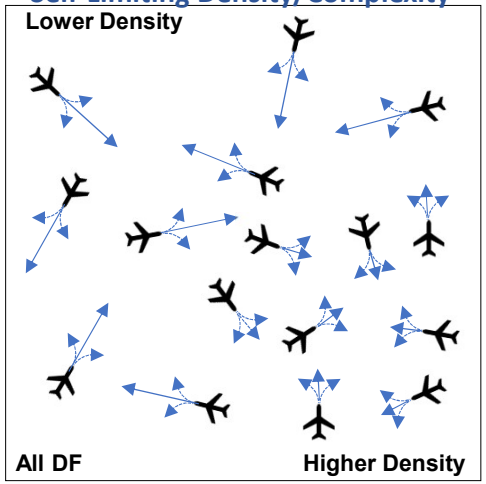
Constrained Resource Collaboration



Self-Organization

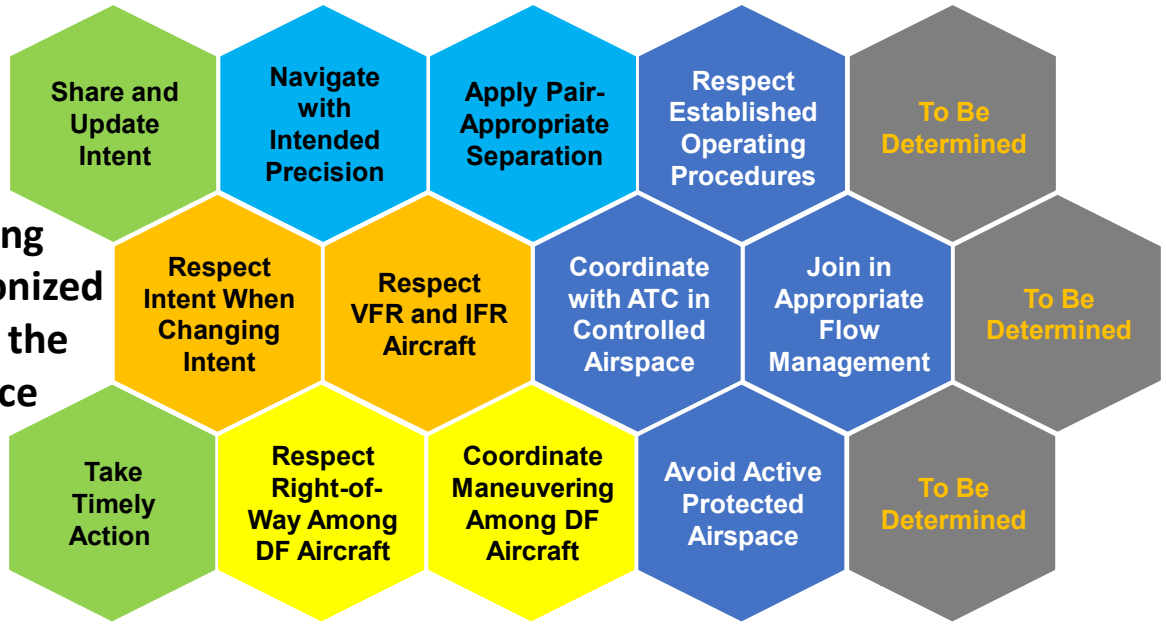


Self-Limiting Density/Complexity



Candidate Cooperative Practices

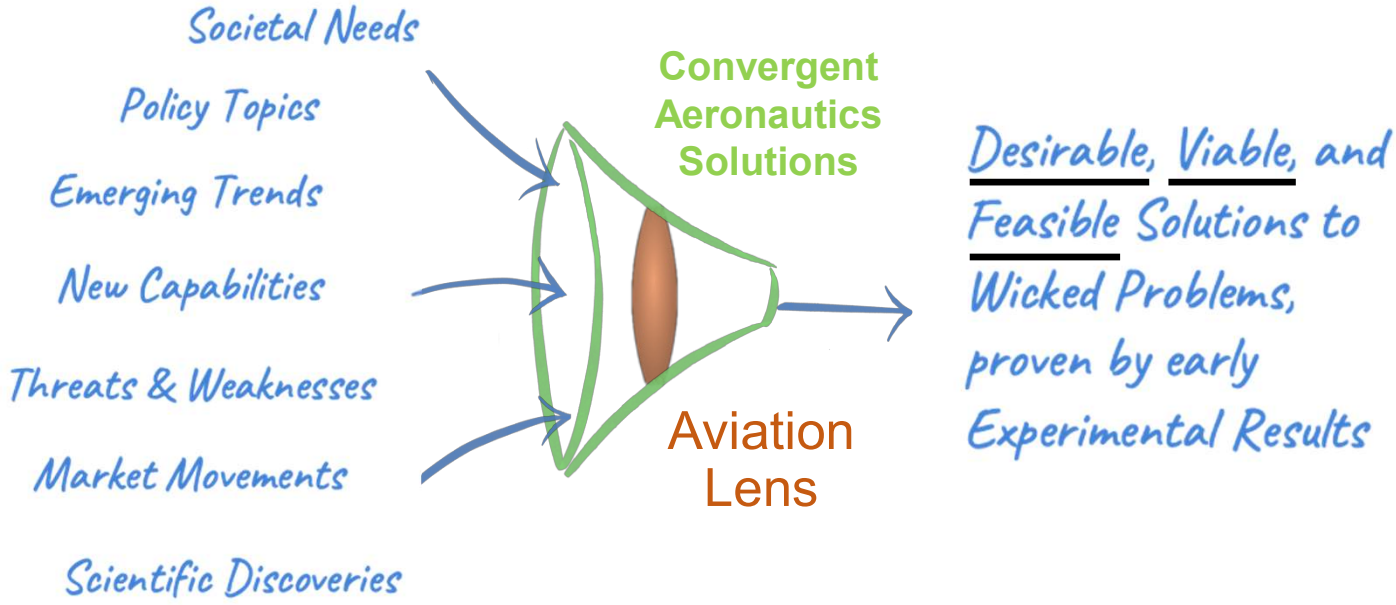
Ensuring harmonized use of the airspace



Intended Effect
Increase predictability, efficiency, stability, and safety
Minimize disruption to existing operations
Increase airspace capacity Reduce actionable conflicts
Distribute separation burden Increase safety
Facilitate airspace integration Minimize controller workload Minimize disruptions

Convergent Aeronautics Solutions (CAS) Project
Thinking differently to revolutionize aviation

Explores the unknown – Converges disciplines & industries – Advances disruptive concepts



CAS Project is sponsoring exploratory research on Desirability, Viability, and Feasibility

- ***Imagine*** desirable aviation futures
- ***Explore*** the most difficult problems of aviation
- ***Discover*** pathways to overcoming barriers
- ***Test*** these pathways via vanguard experiments
- ***Incubate*** transformative change in aviation
- ***Emerge*** new strategic thrusts in ARMD

CAS Execution Strategy Based on DVF

- **Desirability**
  - Community evidence shows a desire for new operating modes
  - **Does framework meet diverse community needs? What must change to achieve convergence?**
- **Viability**
  - DF must be regulatorily and economically achievable, sustainable, and adaptable
  - **Is the framework sufficiently applicable to diverse operators and environments?**
- **Feasibility**
  - We're building on substantial prior R&D into digitally enabled operations
  - **Will new operations be safe and efficient when integrated with existing operating modes?**

No shortage of barriers to achieving a paradigm-shifting new operating mode!

CAS DECO Research Portfolio

	Activity	Framework Focus	Attributes Focus	D	V	F
CR-1	Boeing	All aspects	All aspects	◉	◉	○
CR-2	FAA & NATCA	Essential elements	Integration	◉	○	○
CR-3	Flight Safety Foundation	PC6 - complexity	Safety	◉	◉	○
CR-4	Broad Community	All aspects	All aspects	◉	◉	○
MS-1	Lower E Airspace	Select PCs and CPs in different airspaces	Safety, Integration		○	◉
MS-2	Upper E Airspace	↓	Value, Performance	○	○	◉
MS-3	Terminal Airspace	↓	Integration		○	◉
FE-2	Non-Towered Airport	PC5 – self-sequencing	Integration, Value	○	○	◉

CP – Cooperative Practices
PC – Principal Capabilities
NATCA – National Air Traffic Controllers Association

D – Desirability Barriers
V – Viability Barriers
F – Feasibility Barriers

◉ Significant focus
○ Contributing focus

Concept Refinement (CR) Activities

Engage with key stakeholders to clarify and refine the DF framework to achieve convergence

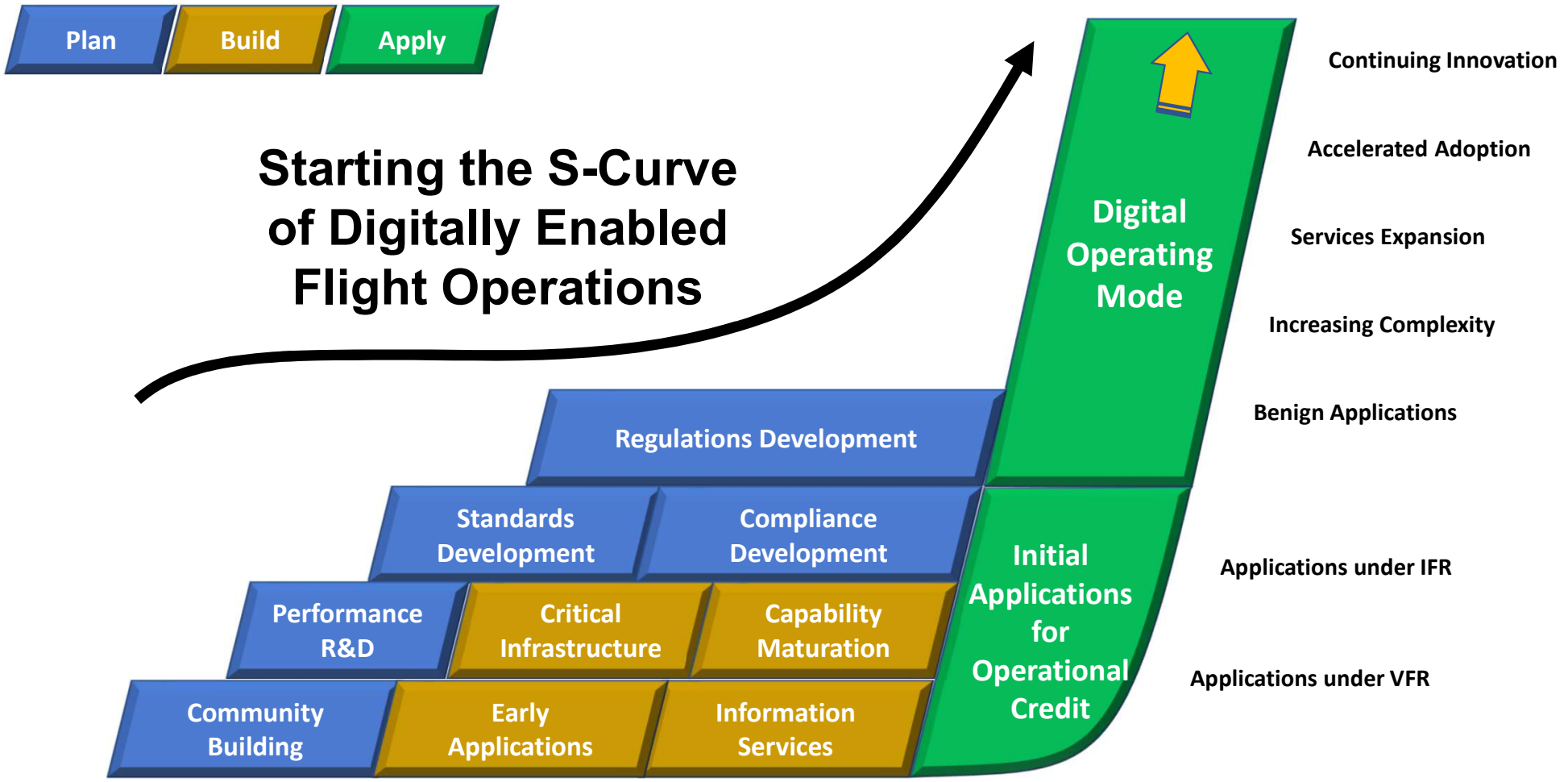
Modelling and Simulation (MS) Activities

Conduct studies to assess technical feasibility and to substantiate or refine the DF framework and attributes

Flight Evaluation (FE) Activity

Conduct real-world evaluations of select DF capabilities to assess operational feasibility

A Path Forward



DECO: Digitally Enabled Cooperative Operations

Exploring a New Digitally Enabled Operating Mode to Complement VFR and IFR

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Thank You!

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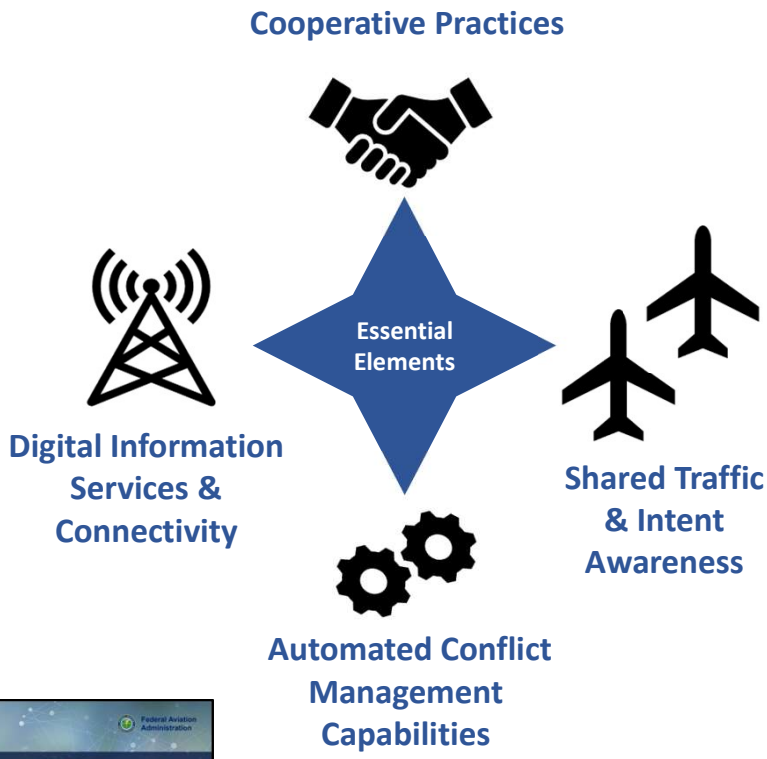
Use this QR code to access a 2022 NASA publication describing the concept framework in greater detail.

Detailed Material

Essential Elements



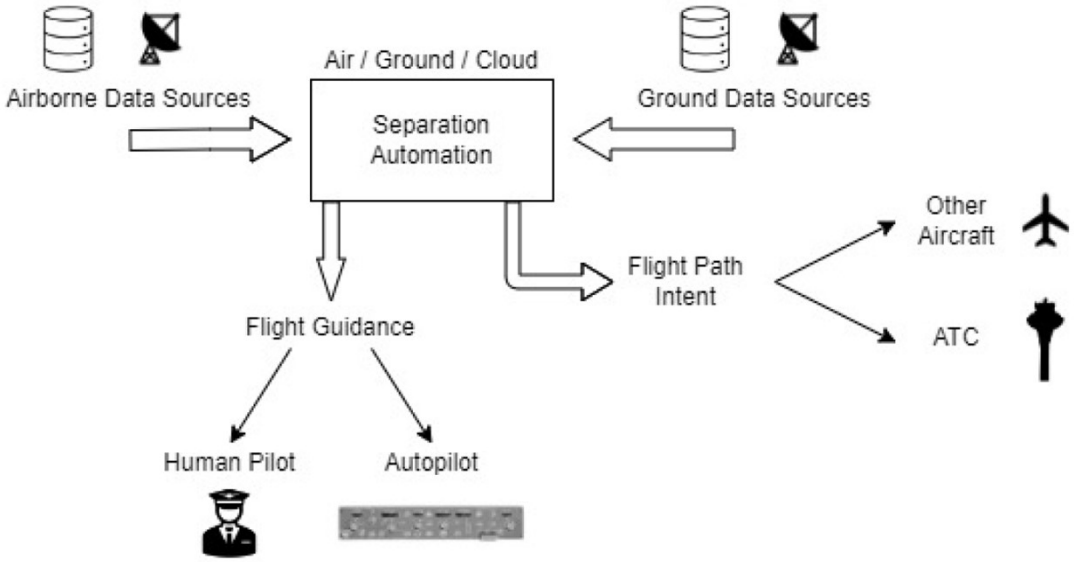
Essential Elements	
Information Services and Connectivity	Maintains a digital model of the operating environment for use by decision-making automation • Shared situation awareness • Current and future states • Traffic, environment, constraints • Must meet integrity criteria
Shared Traffic & Intent Awareness	Maintains awareness of relevant traffic for use in conflict management • Aircraft state, flight path intent, navigation performance
Cooperative Practices	Governs the behavior of digital flights to ensure harmonized use of the airspace
Automated Conflict Management Capabilities	Automates the separation function through dynamic path planning • Tool for detecting and resolving conflicts while conforming to constraints

https://www.faa.gov/sites/faa.gov/files/Charting-Aviations-Future-Operations-in-ICN_0.pdf

Envisioned Architecture Flexibility

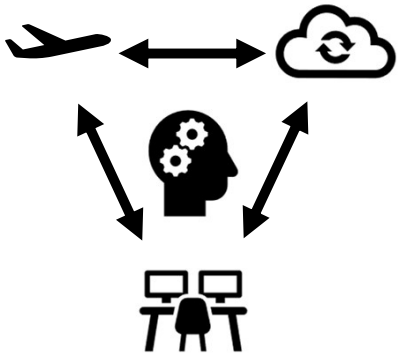
Automated Conflict Management may be

- Provided by the operator or by a third party
- Based in the air, ground, the cloud, or a combination



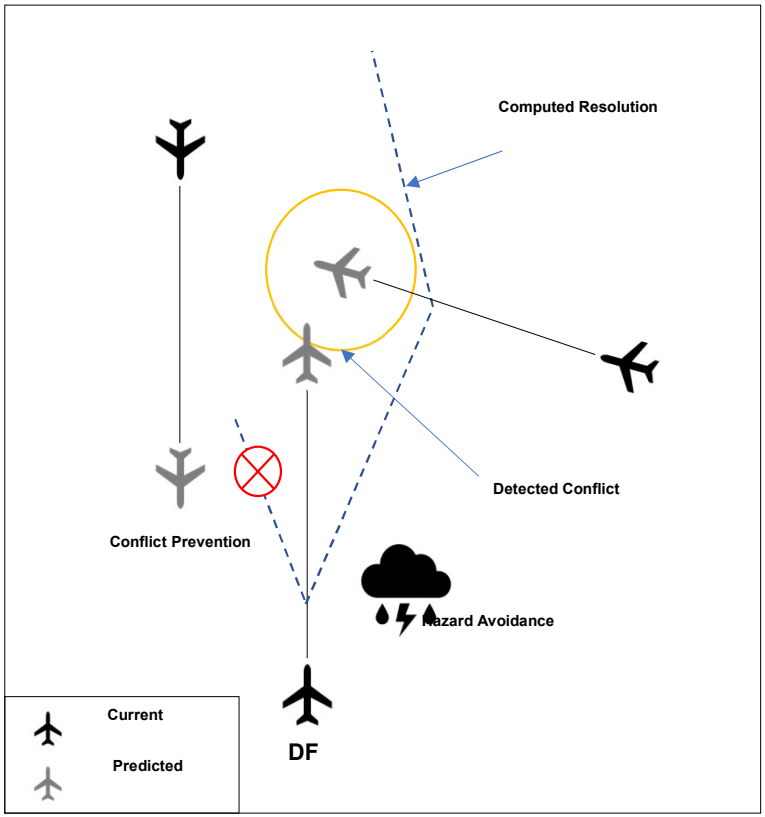
Self-Provision

Services Provision



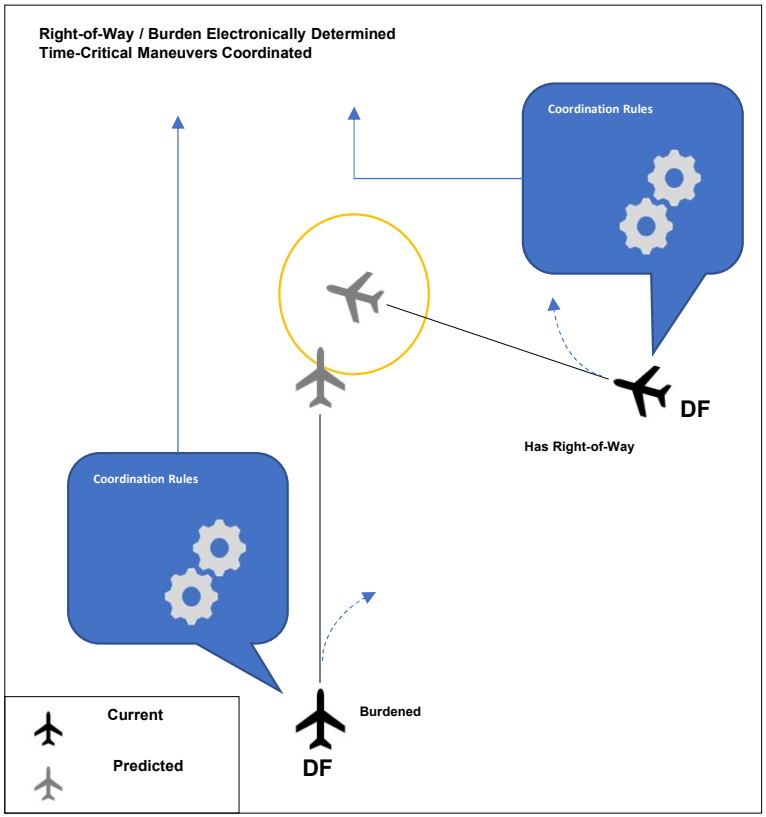
Location of automation and decision-making

Operator Self-Separation



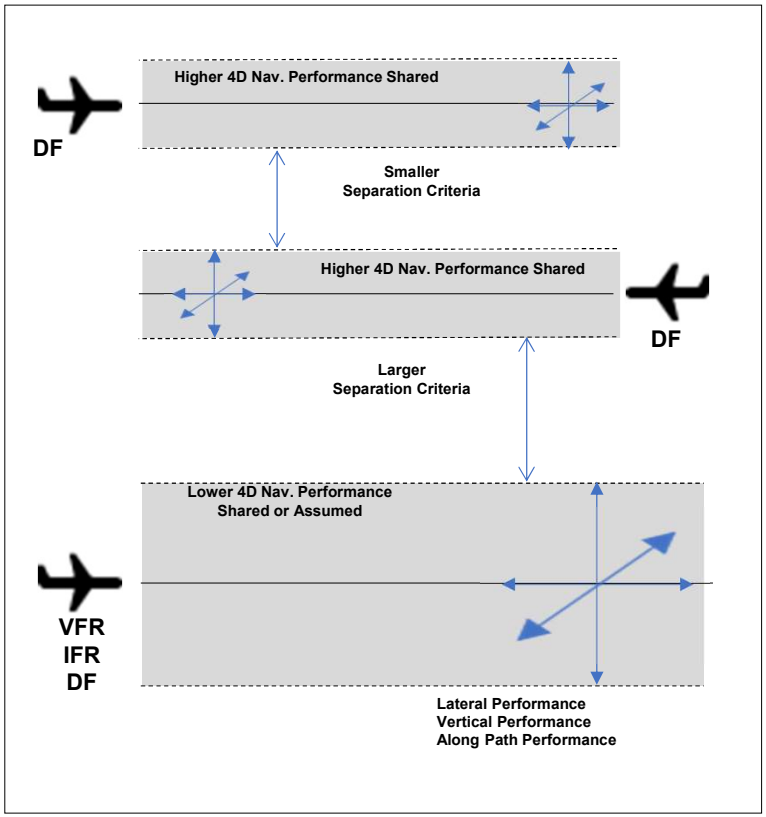
- Primarily focuses on traffic separation but includes all hazards
  - E.g., Weather, terrain, obstructions, protected airspace
- Applies cooperative practices
- Remains “well clear” from VFR (digitally)
- Remains greater than IFR separation mins from IFR traffic
  - Communicates intent to ATC

Cooperative Conflict Management



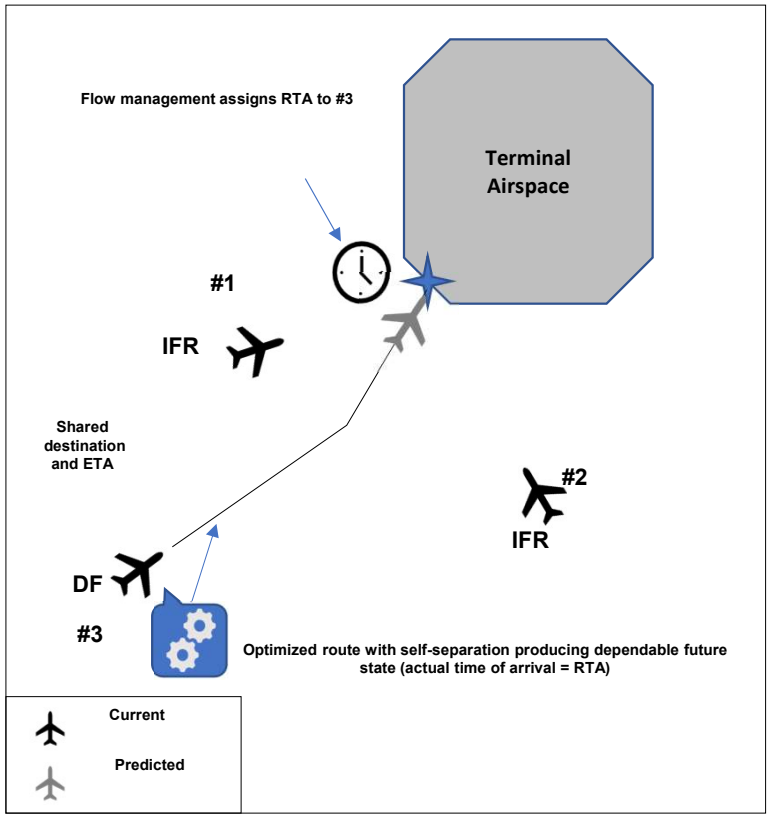
- Distributes the burden of separation provision among themselves
- Shares airspace with minimal impact
- Applies cooperative practices
- Shares intent with other DF operations
  - Enables early detection of potential conflicts
  - Reduces unnecessary maneuvers
- Avoids creating conflict when changing intent
- Follows DF right-of-way rules
- Coordinates maneuvers when appropriate
  - Explicit maneuvers require communications

Adaptive Pairwise Separation



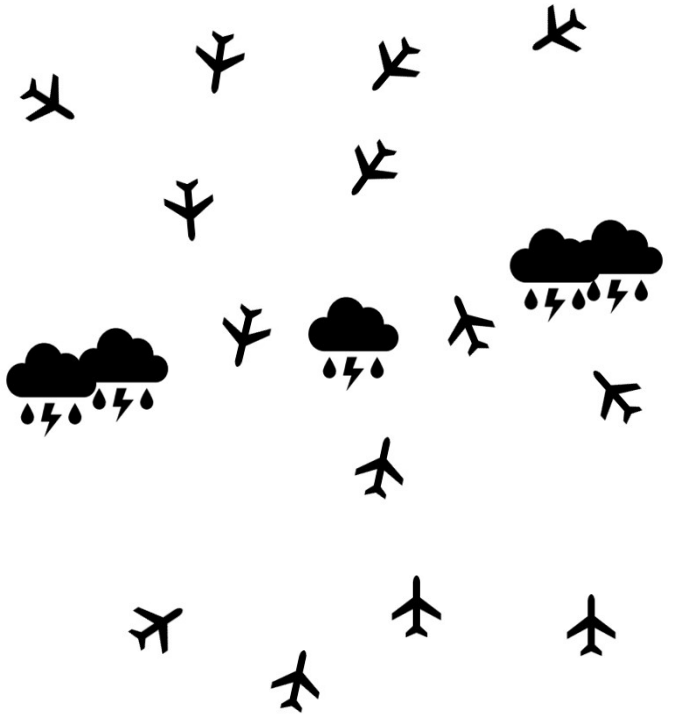
- Automation enables tailoring separation criteria to specific situation
  - VFR – Well clear
  - IFR – IFR separation standards
  - DF – Pair-specific separation standards
- Derived from information sharing
  - Intent
  - Navigation precision (self-proclaimed commitment to intent)
- Enables reduced DF v DF separation
  - Higher traffic density

Collaborative Utilization of Constrained Resources



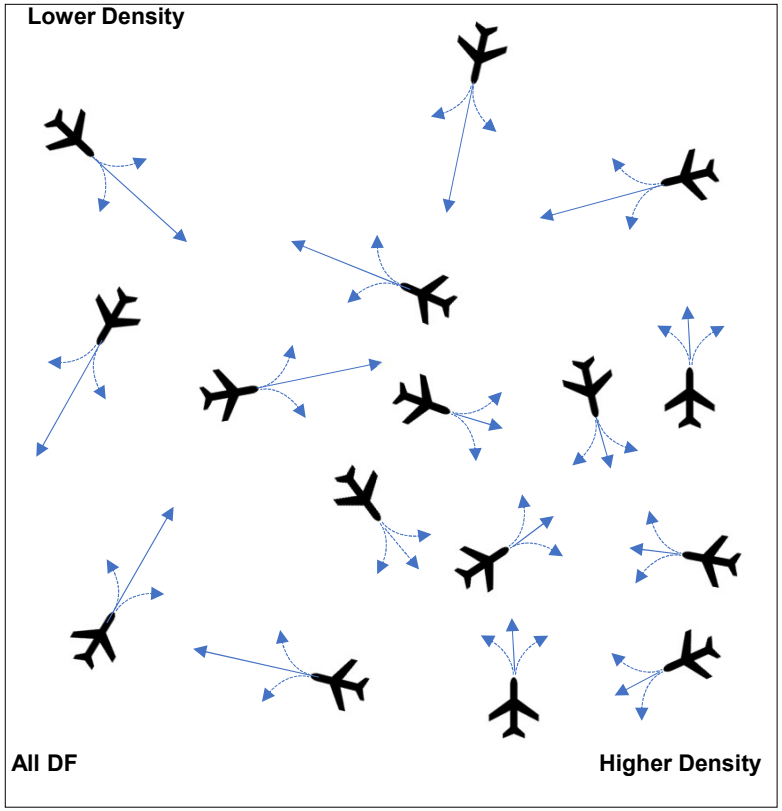
- Directly engages with strategic conflict management (e.g., demand capacity balancing, traffic synchronization)
  - Capacity-limited resources
  - Enabled by time-based flow management
- Shares and updates intent
- Conforms to scheduled times
- Continues to self-separate through cooperative conflict management

Self-Organization



- Creates order from distributed interactions
  - Shared operational objective (e.g., sequencing and spacing to land)
  - Without central authority
  - Similar to VFR at uncontrolled airfields
- Adheres to cooperative procedures which establish priority
  - Enabled by information sharing

Self-Limiting Density & Operational Complexity



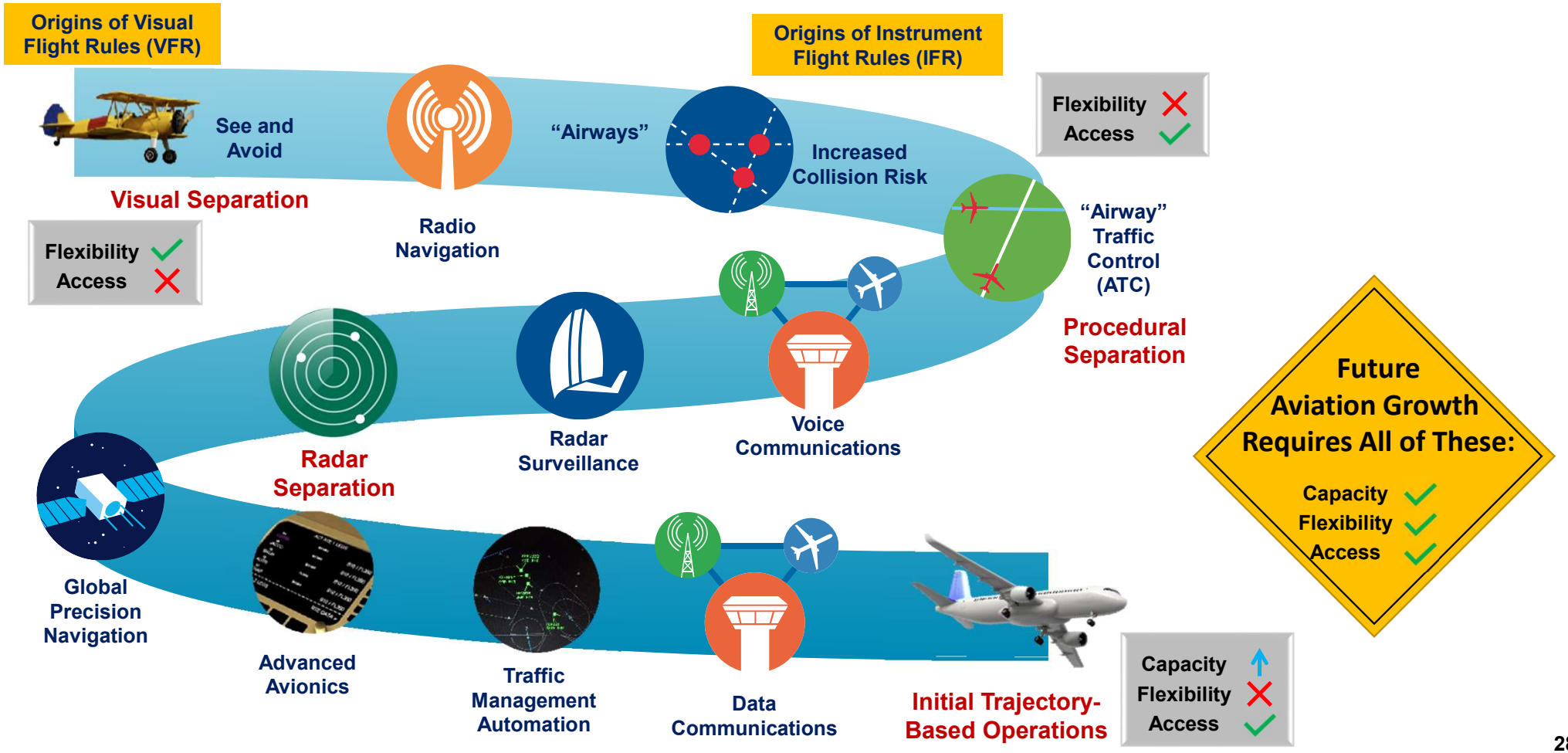
- Applies appropriate mitigations to ensure traffic volume remains at a safe scale
- Ensures that self-separation remains feasible
  - Not simply a max count of aircraft in a sector
  - Not dependent upon human workload

Regulation Basis and Separation / Avoidance Responsibilities

Civil Air Traffic					
	Enabling Regulation	Operating Modes			Separation/Avoidance Responsibility
Routine	91: General Operating and Flight Rules 121: Operating Requirements: Domestic, Flag, and Supplemental Operations 135: Operating Requirements: Commuter and on Demand Operations	IFR	VFR		Pilot / ATC based on flight rules and airspace class
Specialized	101: Moored Balloons, Kites, Amateur Rockets, and Unmanned Free Balloons	Subject to operating limitations in Part 101			None, limitations on conduct of operations
	103: Ultralight Vehicles	Operating rules as defined in Subpart B of Part 101			See and avoid
	105: Parachute Operations	Operating rules as defined in Subpart B of Part 105		Aircraft	Pilot / ATC based on flight rules
				Jumper	none
	107: Small Unmanned Aircraft Systems 108: (future)	Operating rules as defined in Subpart B of Part 107		Visual Line of Sight - VLOS	See and avoid
				Beyond VLOS (future) - BVLOS	*to be defined*

Additional Provisions available to State/Military Air Traffic				
	description		definition	Separation Responsibility
Specialized	MARSA	Military Assumes Responsibility for Separation of Aircraft	A condition whereby the military services involved assume responsibility for separation between participating military aircraft in the ATC system	Military - for aircraft engaged in MARSA ATC - between MARSA flights and non-participating aircraft
	Due Regard	Exercise of sovereign authority under provisions of ICAO treaty	A phase of flight wherein an aircraft commander of State-operated aircraft assumes responsibility to separate his/her aircraft from all other aircraft	Aircraft commander

20th Century Evolution of Operating Modes



Community Exploration

Release approval PENDING

TIM 1 – September 7-17, 2021 – Concept Maturation

50+ stakeholder

Virtual workshop - 5 sessions

- Confirmed basic premise and readiness for industry consideration

TIM 2 – February 2-23, 2022 – Capability Maturation

~200 stakeholders

Virtual workshop – 4 session

Deep Dive Assessment via vignette walk thrus

- Confirmed potential for cross-community applicability and desirability

~7200 Downloads (9/21/23)

https://ntrs.nasa.gov/api/citations/20220013225/downloads/NASA-TM-20220013225.pdf

Invited briefings

Informal meetings

Formal workshops

Momentum evidence

AOSP V2045 "Passion" Briefings

SC-228 Leadership

"Ad Hoc" Industry Group

DF TIM 1

Recal Workshop

FAA NextGen & UAS

TIM 2

Industry Pull

JARUS Auto. WG

AIA AAM WG

Collins

Wisk

SC-228 DAA OSED

AOSP / V2045 Buy-In

RTCA SC-228 Nav Gap

Sky for All Validation

AirVenture

FAA-NASA Automation WG

NASA TM

DF for Self-Piloted UAS

Wing Lacher Et al

AIA

NASA m:N Workshop

Boeing

MITRE

ADF

ASSURE

ERAU

ASTM Autonomy Symposium

Cirrus

ICAO Air Staff

Xponential Workshop

AFWERX

Zipline

EVE

RTCA DF Forum

CAS R&D Proposal Approved – June '23

Potential Partners

- Flight Safety Foundation
- Boeing
- FAA
- Mosaic ATM/GE

NASA TM

DF Motivation

Wing Levitt

2021

2022

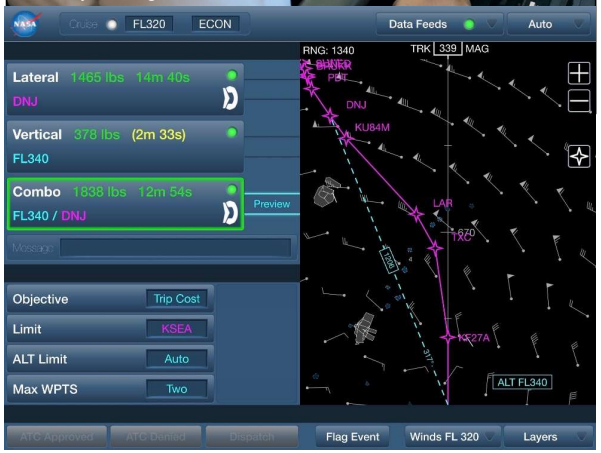
2023

October 2022
RTCA Announces Digital Flight Forum @ FAA Advanced Aviation Advisory Committee

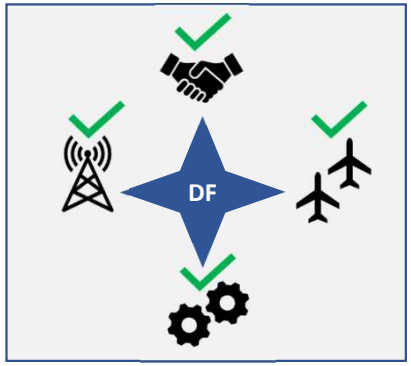
August 2022 – Reliable Robotics CEO calls for "Digital Flight Rules" in open letter to The President

Boeing, Wisk, Aura, SkyGrid, Reliable Robotics, Cirrus make a number of public statements calling for Digital Flight

NASA Tech is Already Building Toward Digital Flight



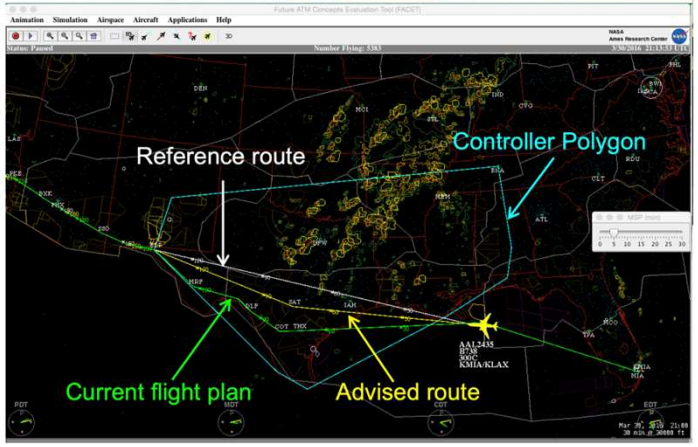
Prototyping the Building Blocks of DF Essential Elements



TASAR: Traffic Aware Strategic Aircrew Requests

NASCENT: NAS Constraint Evaluation & Notification Tool

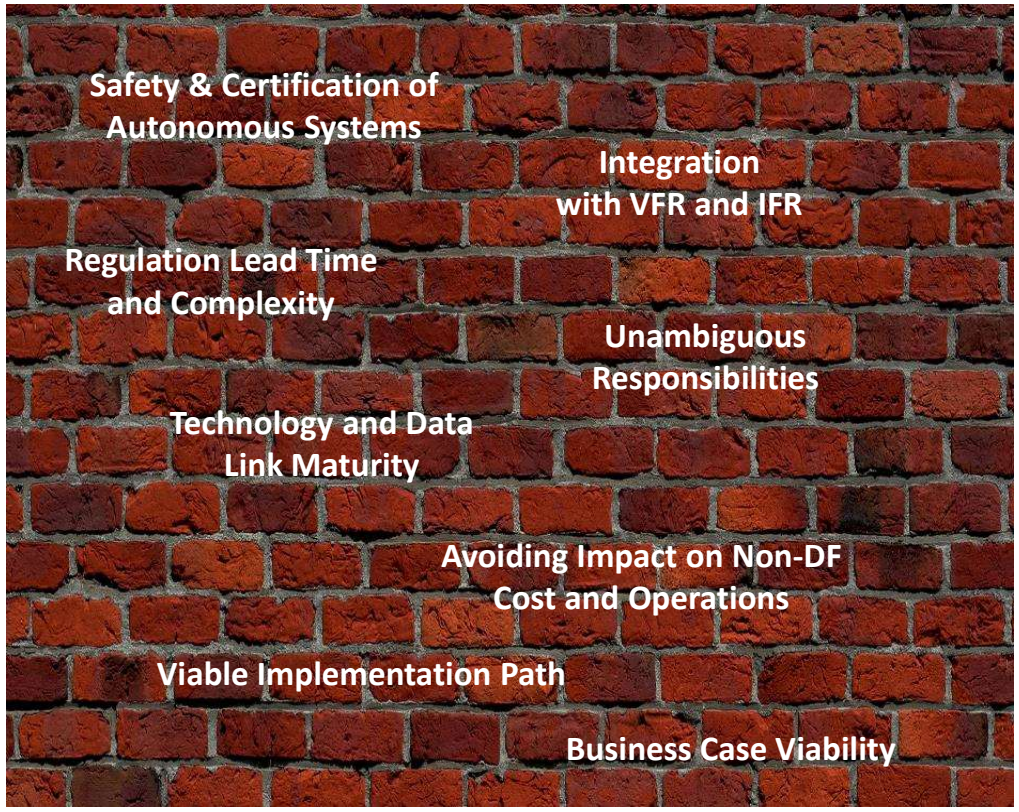
- NASA technologies for flight optimization
- Validated in airline operations
- Now commercially available



Exploring Desirability, Viability, and Feasibility

NASA Convergent Aeronautics Solutions (CAS) Project

Industry Workshops Identified Critical Barriers…



… and Paths Forward / "Chisels"

Concept Refinement and Analytics

- Describe the DF concept in greater detail to reduce identified uncertainties
- Engage with key stakeholders to get input on desired DF policy

Modelling and Simulation

- Conduct studies to quantify performance, safety impacts, and benefits resulting from DF

Flight Evaluations

- Conduct real-world evaluations of DF capabilities to assess operational feasibility

DVF Barriers

Barrier: Lack of community consensus or evidentiary data regarding Desirability

- For desirability, a new operating mode must
  - Be recognized as an indispensable component of any new “airspace operations” or “traffic management” concept.
  - Be shown to enable new operations (types, volumes, tempos) that are not otherwise achievable and sustainable by the existing operating modes.
  - Be desired by a critical mass of the operational community to overcome the emerging compartmentalization of new operations development.

DVF Barriers

Barrier: Lack of community consensus or evidentiary data regarding Viability

- For viability, a new operating mode must
  - Be regulatorily and economically achievable, sustainable, and adaptable for the long term as the industry grows and flexes in unpredictable ways.
  - Be enabled by a minimalist regulatory framework sufficient to establish the basic principles and performance-based requirements but without constraining its adaptability to novel and diverse applications.
  - Have bounded economic costs to warrant long-term industry investment far beyond normal ROI cycles.

DVF Barriers

Barrier: Lack of community consensus or evidentiary data regarding Feasibility

- For feasibility, a new operating mode must
  - Be capable of supporting significantly disparate operations with differences only in the tailoring of performance requirements.
  - Be capable of sharing airspace and airports with VFR and IFR operations without disruption (e.g., imposing inefficiencies, new equipage, undue workload, degraded safety).
  - Produce the desired system-level attributes of airspace operations (e.g., safety, efficiency, predictability, scalability).
  - Be supported by technology that exists or be able to be developed and qualified for its intended function.
  - Improve or not disrupt the “safe, orderly, and expeditious” flow of legacy air traffic.