

# Asset Analysis and Operational Concepts for Separation Assurance Flight Testing at Dryden Flight Research Center

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**A preliminary survey of existing separation assurance and collision avoidance advancements, technologies, and efforts has been conducted in order to develop a concept of operations for flight testing autonomous separation assurance at Dryden Flight Research Center. This effort was part of the Unmanned Aerial Systems in the National Airspace System project. The survey focused primarily on separation assurance projects validated through flight testing (including lessons learned), however current forays into the field were also examined. Comparisons between current Dryden flight and range assets were conducted using House of Quality matrices in order to allow project management to make determinations regarding asset utilization for future flight tests. This was conducted in order to establish a body of knowledge of the current collision avoidance landscape, and thus focus Dryden's efforts more effectively towards the providing of assets and test ranges for future flight testing within this research field.**

## I. Introduction

UNMANNED aircraft systems (UAS) represent a significant advancement in the state of the art of civil and military aviation. This is most readily seen in the decision by the Department of Defense (DOD) and Federal Aviation Administration (FAA) to use the term “unmanned aerial system” as a replacement for the more familiar “unmanned aerial vehicle” (UAV) in order to signify that there is more at work than merely “hardware with wings”: a full UAS consists of an aircraft (or several aircraft), a ground control station, data links, and related support equipment.

Recently, several market opportunities have been identified for using unmanned vehicles as commercial transports and surveillance platforms operating within the national airspace system (NAS). However, while these operational concepts capitalize upon the unique advantages of UAS – specifically, long endurance and reduction of pilot risk – several hurdles remain before UAS can be integrated with manned air traffic. The essential question remains: how can UAS be safely integrated into the NAS? This question encompasses a lack of regulation concerning manned and unmanned vehicles attempting to coexist within the same airspace, a need for testing separation assurance and collision avoidance (SACA) concepts and technologies, and a need to establish standards of operation with respect to the communications technologies and frequencies to be used by unmanned systems. Policies and procedures for handling off-nominal events – such as link loss and multiple collision risks in a mixed-traffic environment – still need to be established.

For unmanned systems to be successfully integrated into the NAS with manned air traffic, it must be demonstrable that neither aircraft type will pose a hazard to the other, and that unmanned systems are able to operate in both airborne and terminal environments. For testing purposes, the aircraft under test may be a “real” or “surrogate” UAS, the latter referring to an aircraft that has been outfitted with autonomous SACA technology but still retains a pilot in the cockpit as backup; this pilot in the loop (PITL) redundancy ensures that a collision can be safely avoided irrespective of the performance of the SACA technology. Aircraft must also be able to detect and avoid one another both in cooperative (“friendly”) scenarios, where both aircraft are equipped with transponders, or non-cooperative (“threat” or “intruder”) scenarios, where one or both aircraft lack transponders.

This paper addresses previous fields of SACA research, including previous flight tests of SACA concepts and technologies, visual sensing and detection technologies, data transmission standards, and current federal mandates and restrictions on UAS use. An asset analysis of Dryden Flight Research Center's (DFRC) test vehicle fleet and test ranges was conducted to provide project managers with an easy to use tool for the selection of test aircraft and ranges. The operational characteristics of several vehicles from the DFRC test fleet and Airborne Science fleet are compared and examined to determine each aircraft's suitability for use as a test UAS, surrogate UAS, cooperative aircraft, or intruder aircraft.

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## II. Literature Search

To avoid duplicating previous research, a preliminary literature search was first conducted to establish a “market landscape” of sorts, identifying previous SACA efforts, previously-employed technologies and testing methodologies, and relevant lessons learned. This literature search revealed research papers – some dating back to 2005 – which describe the various approaches to UAS integration into the NAS. These previous research efforts were used to develop some preliminary operational concepts to test SACA concepts for a variety of programs, including the Air Force’s Fighter Risk Reduction Project (FRRP) and the Sense and Avoid Flight Test (SAAFT) project headed by Northrop Grumman. It is important to note that a great deal of work has already been done with the collision avoidance portion of SACA; therefore, it is the goal of DFRC to focus on the “separation assurance” side of the problem – including establishing standards for development flight instrumentation, pilot-aircraft interface (PAI), and frequencies ranges to be reserved for SACA data traffic. This is done to ensure that previous and subsequent collision avoidance efforts are able to use established standards that will expedite the integration of their technology into UAS deployed in the NAS.

The literature search also served to establish the current state of the art of the various technologies needed for further SACA work. These technologies include electro-optical systems, transmission profile characteristics for the H.264/Part10 standard, and satellite communications technology. This portion of the literature search was necessary to establish a baseline of available technology – some of which may be useful to SACA efforts even though they were not specifically developed for aircraft – and to raise the technology readiness levels of desirable technologies through flight testing.

## III. Asset Analysis

An asset analysis was conducted in order to identify the unique characteristics and testing opportunities that are to be found at DFRC. These assets are not limited to the Center’s test and research aircraft fleet, but also to the ground facilities, work space, engineering and simulation resources, and climate – all of which contribute to the Center’s ability to conduct integrated flight testing. These assets are classified as follows:

### A. Geography and climate

Geography and climate are vital but often-overlooked assets of DFRC. The close proximity to Los Angeles- and San Fernando-based original equipment manufacturers and subcontractors allows for design iterations to be quickly integrated into test aircraft as needed, and the distance is short enough to allow flight data to be analyzed at the company’s office, if needed. The location of DFRC is also sufficiently remote to ensure that electromagnetic interference is minimal, especially when compared to test sites in an urban setting; Dryden’s remote location also minimizes flight risks, as unproven technologies can be safely tested with comparably fewer structures in danger than would be found in an urban setting. Minimal rainfall – less than six inches per year and an average of 360 days per year without precipitation<sup>1</sup> – also contribute to making DFRC an ideal flight test location.

The key constraint presented by the climate is the area’s winds, which can reach speeds of up to 75mph during the springtime, with most wind activity peaking during the early morning and late afternoon periods<sup>2</sup>. This creates a “golden time” to test, between mid-morning to mid-afternoon (approximately 0900 – 1500); thus, the wind creates a scheduling constraint upon flight testing, as it causes the testing of smaller and more fragile aircraft to be conducted during times when the demand for airspace, frequencies, and test equipment increases.

### B. Research aircraft fleet

DFRC operates and has access to a wide variety of research and test aircraft. These include:

- High-speed, high-agility fighter jets; 1- and 2-place variants.
- High-altitude, long-endurance (HALE) reconnaissance aircraft, manned and unmanned.
- Medium-altitude, long-endurance (MALE) unmanned aircraft.
- Medium-altitude conventional aircraft.
- Low-altitude “low and slow” observation and chase aircraft.

Additionally, other aircraft from the National Test Pilot School are available as needed, including QF-4 and QF-16 (F-4 Phantom and F-16 Falcon aircraft reconfigured for use as surrogate UAS). Additionally, the maintenance and engineering personnel at DFRC are already experienced in retrofitting the aircraft fleet with sensors as required by various projects.

Key fleet constraints are operating costs and aircraft availability. While aircraft availability is highly dependent upon the needs of the project, baseline operating costs can be estimated from the aircraft’s “wet rate” (the rate charged by Dryden to cover all operating costs of the aircraft) or “proficiency rate” (the rate charged by Dryden for fuel only), which again depends on availability. This is demonstrated by Table 1.

**Table 1. DFRC Research and test fleet cost and general characteristics.**

Aircraft	Type	Duration (hrs)	MTOW (lbs)	Useful Payload (lbs)	Max Alt. (ft)	Airspeed (kts)	Power Available	Ops Stations [Crew]	Wet Rate (\$/hr)	Proficiency Rate (\$/hr)
Beechcraft King Air #801	Conventional	6.75	12,500	4,100	35,000	260	3x 50A circuits 28VDC; 120VAC inverters planned.	5 [2]	997.00	325.00
Beechcraft T-34 Mentor	Conventional	3	4,300	-	30,000	214	-	1 [1]	163.00	163.00
DC-8	Transport Jet	12	340,000	30,000	41,000	450	115VAC 40Hz, 40kVA; 115VAC 60Hz, 40kVA; limited 220VAC	42 [8]	6,500.00	-
ER-2	HALE Jet	12	40,000	2,550	70,000 +	410	30kVA (115VAC @ 400Hz); 10kVA @ 28VDC	[1]	3,700.00	-
F-18 #843	Fighter Jet	2.32	51,550	TBD	40,000	775	28V; inverters available	0 [1]	7,732.00	3,250.00
F-18 #846	Fighter Jet	2.32	51,550	TBD	40,000	775	28V; inverters available	1 [1]	7,732.00	3,250.00
F-18 #850	Fighter Jet	2.32	51,550	TBD	40,000	775	28V; inverters available	0 [1]	7,732.00	3,250.00
F-18 #852	Fighter Jet	2.32	51,550	TBD	40,000	775	28V; inverters available	1 [1]	7,732.00	3,250.00
Global Hawk	UAS Jet	11	25,600	1,500	65,000	335		0 [1]	3,500.00	-
Gulfstream G2	Business Jet	7	45,000	2,610	45,000	459	120VAC	11 [2]	3,596.00	1,950.00
Ikhana	UAS Turboprop	24	10,000	2,000 +	40,000	171	6kW @ 28VDC	0 [1]	3,500.00	-
TG-14 (Ximango)	Motorglider	5	~1500	22	10,000	128	35A @ 28V	1 [1]	130.00	60.00

Typically speaking, it is more cost-effective to “piggyback” test equipment and procedures onto an aircraft that is being used for proficiency training, as the necessary tests may be conducted during a given pilot’s checkride. However, there is no guarantee that a given pilot will be due for a proficiency checkride at the time that a test needs to be conducted; hence, both operating rates are given. Additionally, some aircraft which might otherwise be ideal for the UAS in the NAS project – such as Global Hawk and Ikhana, which are representative of the most likely types of unmanned MALE and HALE systems – feature proprietary software and flight controls, which cannot be changed without great expense.

Dryden also has the important advantage of experienced flight operations personnel. The Center has flown a wide variety of aircraft throughout its history – including trainers, heavy transports, heavy bombers, fighter aircraft, and high-altitude manned and unmanned systems – and thus the Center’s engineering and operations personnel possess both great breadth and depth of knowledge of flight testing procedures. DFRC also has a very high sortie capacity: currently, DFRC and Edwards AFB fly a combined 20 sorties per hour, or 50 – 70 sorties per day<sup>3</sup>. Conservative estimates predict that the maximum combined flight testing capacity of the facility is 40 sorties per hour and up to 200 sorties per day<sup>4</sup>.

**C. Flight test ranges and corridors**

It is arguable that Dryden’s most valuable assets are the flight test ranges and corridors, as these encompass a total available testing area that is virtually impossible to match. R-2508, for instance, is the country’s largest supersonic test corridor<sup>5</sup>; other ranges – R-2506, R-2524, R-2509, and R-2515 – are also available, which provide both high- and low-altitude restricted airspace for testing any variety of aircraft.

The Southwest Range Complex – which covers parts of Arizona, Nevada, Utah, New Mexico, California, and the Pacific Ocean – ensures that virtually any type of aerial vehicle can be tested at DFRC.

Most importantly, from the standpoint of the UAS in the NAS project, the Predator (Ikhana) UAS has been successfully test-flown in the Dryden test ranges in the past; this demonstrates that an

unmanned aircraft of the representative type envisioned by the FAA and other stakeholders as one day operating in the NAS, can be safely tested within Dryden’s airspace. As an added benefit, DFRC also has Certificates of Authorization (COAs) on file with the FAA which allow for extensive use of unmanned aircraft, both within the test ranges and also within limited areas of the NAS – the Ikhana, for instance, has been used in the First Response Experiment (FiRE) to provide real-time fire data to ground fire management personnel<sup>6</sup>, which required operation outside of the Dryden test ranges. These COAs, while not a “file and fly” solution, allow for the creation of a wide variety of test cases and scenarios for unmanned aircraft technology.

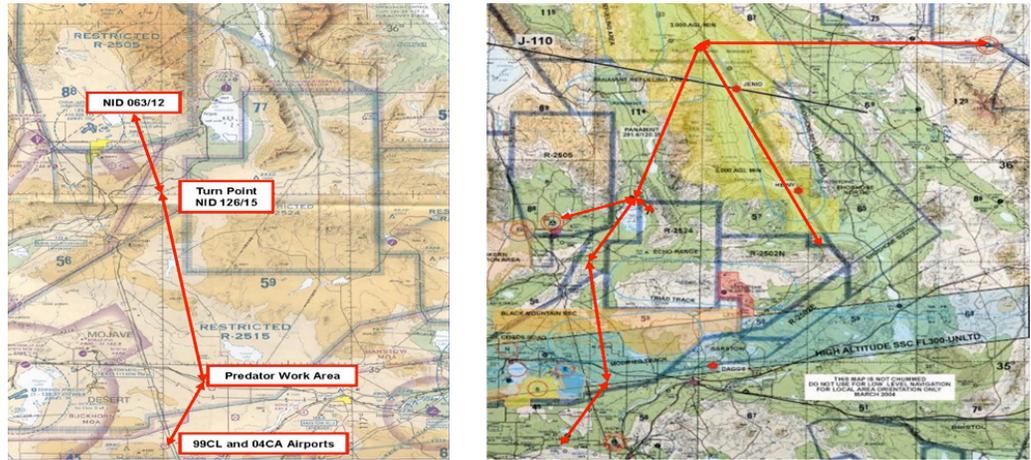


Figure 1. Predator transitions in R-2508 for LOP and LOA directives.

#### D. Ground assets

Dryden offers a large number of ground assets to facilitate testing. The facility offers over 68 miles of landing runways (combined tarmac and dry lake bed), as well as a large amount of ramp area and hangar space for aircraft handling and storage, aircraft modification, and payload integration. DFRC currently offers 385,000ft<sup>2</sup> of ramp space (with an additional 114,000ft<sup>2</sup> at the Dryden Aircraft Operations Facility)<sup>7</sup> and over 220,000ft<sup>2</sup> of hangar space. The hangar facilities at Dryden offer a wide variety of test and integration options, including thermal and cryogenic systems, fabrication facilities, and simulation capabilities. These are detailed in Table 2<sup>8</sup>:

Table 2. DFRC ground facilities capabilities.

Building	Ft <sup>2</sup>	Availability	Current Use	Unique capabilities
4801	24,300	365 days	F-15 maintenance	Office, conference rooms, and laboratories. In-floor heating and evaporative cooling. Aircraft air-conditioning system in middle of hangar, AFFF fire system
4802	56,230	365 days	Support/service small & medium aircraft	3000 psi hydraulic system, AFFF fire system, in-floor heating and evaporative cooling.
4820	19,680	As needed	Load and heat testing of structural components and complete flight vehicles. Calibrate and evaluate flight loads instrumentation under conditions expected in flight.	High bay test area with adjacent laboratory, office, and storage area. Data acquisition and test control room overlooking test area. 5-ton rail crane, 39' max height. Carbon-carbon and titanium test capabilities. Thermal and cryogenic systems. Power output range from 1,000 to 20,000 kW and testing temperature range from -100 to 3,000 °F.
4823	6,620	As needed	Aircraft modification	Machine shop, weld shop, sheet metal shop, fluids shop, composites facility, NDI.
4826	36,430	365 days	Avionics and electronics laboratories, model shop; houses inactive aircraft	AFFF fire system, hush houses for aircraft hydraulics and cooling units
4833	26,010	Space Shuttle-dependent	Shuttle Processing Hangar	Water deluge fire system, 25t crane (x2), explosive blowout panels, exhaust fans, mission control center, communications room, office and laboratory space, floor drains.
4840	52,675	365 days	High-bay test area (x6)	Aircraft-in-the-loop simulation, secured simulation laboratory, remotely augmented vehicles systems, simulators, and laboratories; ground vibration testing.
<b>Total</b>	<b>221,945</b>			

Dryden's ground assets also include dynamic mission planning tools such as JUMPS and FalconView, and the facility offers a streamlined flight approval process for unmanned systems. Because DFRC has several COAs on file with the FAA, customers can literally save months' worth of time and money by using Dryden as a test facility.

#### **E. Equipment and technology**

Dryden has six discipline branches that provide research and project support. These branches offer expertise that covers software, hardware, data analysis, aircraft modeling, flight and ground test development, mission planning, and flight test operations. The six DFRC discipline branches are:

- Aerodynamics & Propulsion
- Aerostructures
- Dynamics & Controls
- Flight Instrumentation
- Flight Systems
- Systems Engineering & Integration

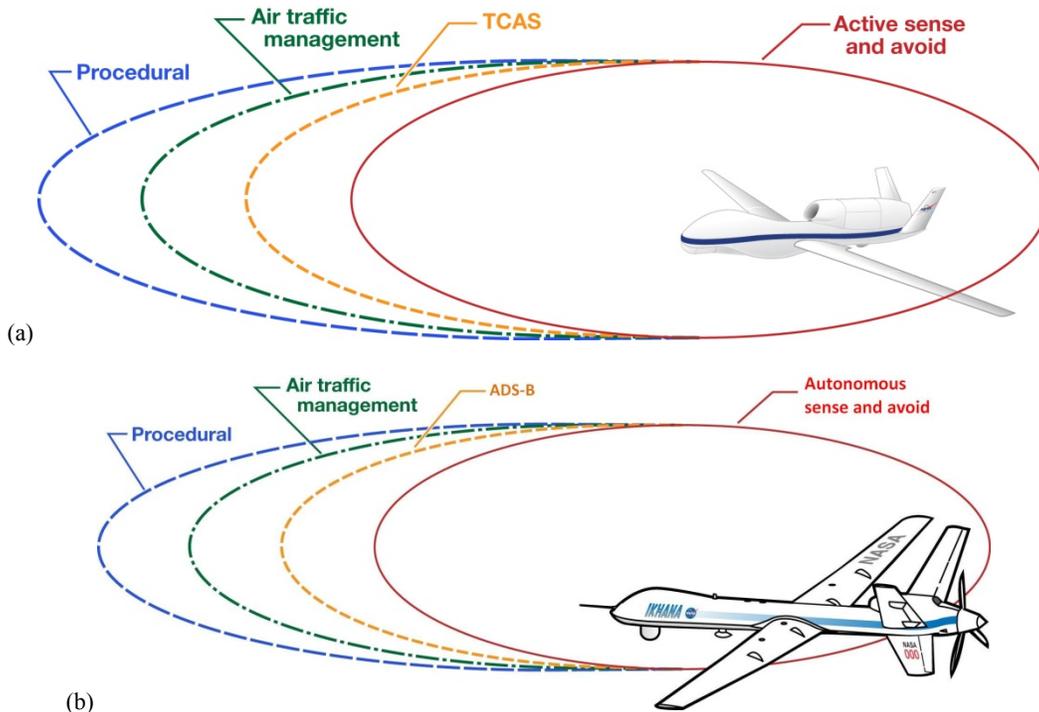
Dryden also has several technological advantages that are critical to the success of the UAS in the NAS project. Proper separation assurance in the NextGen NAS is heavily dependent upon aircraft being able to identify one another quickly and accurately once airborne; this NextGen system is based on the Automatic Dependent Surveillance-Broadcast (ADS-B) system architecture, which the FAA has required to be installed by 2020 on all aircraft operating in Class A, B, and C airspace<sup>9</sup>. This system allows air traffic controllers to know an aircraft's position with much higher accuracy than using ground-based radar (using "ADS-B out" in conjunction with a transponder)<sup>10</sup>, and represents a critical enabling technology for automated separation assurance. Currently, DFRC has two ADS-B units purchased under Access 5, which are able to be installed and operated on both manned and unmanned aircraft.

Dryden also has differential GPS (dGPS) and Joint Precision Approach and Landing System (JPALS) resources available. dGPS uses fixed, ground-based stations which broadcast corrections between an aircraft's GPS system and a known ground reference (typically, the dGPS tower); this increased the accuracy of GPS, and is essential for UAS autonomous landing. Several UAS test-flown at DFRC – including Global Hawk – have demonstrated the successful use of dGPS on unmanned systems. Similarly, JPALS uses differential-corrected GPS to serve as an all-weather instrument landing system (ILS); this system allows for autonomous precision landing of multiple aircraft, and can even vector multiple aircraft to the same runway using different approaches. JPALS can also implement an "approach of the day," based upon terrain and current weather conditions, to ensure an optimal approach path for unmanned aircraft. These technologies ensure that an unmanned aircraft is able to land safely and reliably after each flight.

#### **IV. Dryden Research Aircraft Fleet House of Quality Matrix**

A house of quality (HOQ) matrix was used to define the relationships between the project requirements and the capabilities of the DFRC research aircraft fleet. This effort was done to present the capabilities of each aircraft in the research fleet relative to each other as well as to the requirements of the project. The aircraft were ranked *relative to each other* for the Competitive Analysis portion of the HOQ matrix, rather than to an idealized set of capabilities. The HOQ for the research aircraft fleet is shown in Fig. 2.





**Figure 3. Levels of deconfliction operational concepts - NowGen (a) and NextGen (b) NAS.**

The two main differences between the separation assurance procedures and protocols between NowGen and NextGen are found in the two innermost regions. Currently, the Traffic Alert and Collision Avoidance System (TCAS) are used to resolve separation issues not directly covered by the Federal Aviation Regulations (Procedural) or Air Traffic Control (Air Traffic Management). The procedures set forth in the FAR establish minimum separation clearances between aircraft; currently, these separation minimums are 2,000 feet vertically and up to 90 miles laterally, depending on the flight situation<sup>11</sup>.

However, in response to increasing air traffic density (especially around large metropolitan areas), an initiative within the FAA to reduce vertical clearance minimum to 1,000 feet was enacted in 2005<sup>12</sup>. This allowed aircraft to fly more optimum profiles, and increased air traffic capacity. With global demand for airspace continuing to grow – especially with the increasing viability of operating UAS in the NAS – air traffic management technology must also evolve. Thus, TCAS will need to be replaced or integrated with the ADS-B system mandated by the FAA. Additionally, “active” sense and avoid (which could be as straightforward as visual detection by a human pilot or a radar/electro-optical suite deployed on a UAS) will need to be replaced by *autonomous* sense and avoid so that UAS are able to avoid collisions even in link-loss and comm.-loss scenarios.

**A. PAI subgroup**

The pilot-aircraft interface (PAI) on UAS presents several important issues which must be resolved if UAS are to safely operate with manned air traffic. A majority of these issues center on the loss of situational awareness experienced by the UAS pilot – i.e. loss of auditory, vestibular, and olfactory cues, combined with a very restricted field of vision (typically 30°)<sup>13</sup>. Additionally, several issues with the ground control station (GCS) exist; namely, most GCS are designed without applying over 70 years of experience designing manned cockpits, are usually proprietary and very difficult to modify, and are rarely designed with UAS use in the NAS in mind<sup>14</sup>. These designs typically also fail to account for UAS-specific concerns, such as loss of link, vehicle speed and maneuverability, and contingency operations.

The PAI subgroup’s efforts will mainly focus on large, Predator-style UAS, as their operators (DHS, USAF, and US Army<sup>15</sup>) will likely be the first users of UAS in the NAS. The key deliverable will be a NAS-compliant GCS, which will be demonstrated in flight in FY2015<sup>16</sup>. Flight test objectives (FTOs) for the PAI subgroup are given in Table 3.

**Table 3. FTO mapping, PAI subgroup (P = primary objective; S = secondary objective).**

ID	Title	FY 11 Flight 1	FY 12 Flight 2	FY13 Flight 3	FY14 Flight 4	FY15 Flight 5
PAI-001	Evaluate NAS-compliant GCS.				S	
PAI-002	Demonstrate prototype GCS / display suite.					P

## B. Communications subgroup

Communications with unmanned aircraft is currently managed via exception, with VHF and UHF frequencies for line-of-sight (LOS) operations, Ku-band satellite equipment for beyond-line-of-sight (BLOS) operations, as well as low-power LOS links in amateur bands or unlicensed Instrument/Scientific/Medical (ISM) bands<sup>17</sup>. However, none of the frequencies currently used are designed for safety and regularity in flight; furthermore, no frequency spectrum has been specifically designated by the International Telecommunications Union for UAS command and control links for either LOS or BLOS communications<sup>18</sup>.

The scope of the communications subgroup is first and foremost to obtain appropriate frequency allocations for UAS operation in both national and international airspace; secondly, it must develop and validate a candidate command and non-payload communication (CNPC) system that is compliant with national and international UAS frequency regulations. Security protocols must also be established to prevent frequency vulnerabilities and tampering when UAS are operating in the NAS. The CNPC suite will be tested on a Beechcraft T-34C owned by NASA Glenn Research Center, and will be tested in both minimal- and mixed-traffic environments. The FTO mapping for the communications subgroup is given by Table 4.

**Table 4. FTO mapping, communications subgroup (P = primary objective; S = secondary objective).**

ID	Title	FY 11 Flight 1	FY12 Flight 2	FY13 Flight 3	FY14 Flight 4	FY15 Flight 5
COM-001	Evaluate effective airborne range of ADS-B systems and ad-hoc networking capabilities.	P	S	S	S	S
COM-002	Demonstrate the performance of the CNPC suite on T-34C.				P	
COM-003	Demonstrate the performance of the CNPC suite in mixed-traffic environment.					P

## C. SACA subgroup

The SACA subgroup focused on four areas of research<sup>19</sup>:

- Tactical separation assurance safety systems
- Off-nominal procedures and automation
- System-level effects of UAS inclusion on the NAS
- Required collision avoidance system performance

The SACA subgroup’s separation assurance model leaves primary responsibility for separation assurance with ATC, with the tactical separation assurance systems providing an additional layer of safety and monitoring. This creates a redundancy in the system, as both ATC and the SACA system are both able to ensure proper separation between aircraft; this is vital in off-nominal situations, such as when a UAS has lost a communications link. Current operating procedures for a UAS in a link-loss scenario mandate that it either circle back and attempt to regain communications, or simply return to base; however, if UAS are to operate in the NAS alongside manned air traffic, they must have the capability to continue their mission without posing a danger to other aircraft. This is complicated by the fact that UAS have performance capabilities that are vastly different from conventional aircraft: relative to a commercial transport, a UAS will often be smaller and significantly slower, leading to UAS being a “turtle on the highway”<sup>20</sup> relative to conventional air traffic and therefore posing a possible collision risk. UAS will also typically fly different routes than manned aircraft, leading to increased air traffic management concerns.

The core safety concern with unmanned systems is that there is no pilot onboard to handle emergency situations, which represents a sizeable barrier to UAS integration with regular air traffic. For off-nominal events, such as link loss, the UAS must execute emergency decision-making procedures automatically as the situation dictates; this represents a crucial area of research for the SACA subgroup, as NASA will be able to leverage its vast contingency-management experience to provide tools for UAS safety in off-nominal conditions. This will be shown in a series of flight demonstrations that will demonstrate not only separation assurance systems, but also the automation of contingency decision-making in off-nominal scenarios. The FTO mapping for the SACA subgroup is given by Table 5.

**Table 5. FTO mapping, SACA subgroup (P = primary objective; S = secondary objective).**

ID	Title	FY11 Flight 1	FY12 Flight 2	FY13 Flight 3	FY14 Flight 4	FY15 Flight 5
SACA-001	Demonstrate tactical separation assurance safety systems; evaluate operation of safety tools with real latencies and trajectory uncertainties.				P	S
SACA-002	Determine off-nominal procedures and automation to assure safety of other aircraft and infrastructure in the event of a UAS off-nominal event such as loss of communication					P

## D. Integrated test and evaluation (IT&E)

The IT&E subgroup will provide integrated concepts at the systems level which address barriers to routine UAS access to the NAS, and through simulation and flight testing will address integration issues such as separation assurance, communications requirements, and human factors issues in relevant environments<sup>21</sup>. Because a great deal of tactical separation assurance depends on ADS-B technology, the feasibility of using this technology for separation assurance will first be demonstrated on Ikhana (Predator-B); these demonstration flights will determine the accuracy of ADS-B and serve to evaluate the performance of the flight management system (FMS) in response to simulated air traffic.

The IT&E flights will become increasingly complex as the project continues, increasing the number of UAS and “surrogate” UAS used in increasingly crowded airspace, in order to demonstrate the validity of the tactical separation assurance systems. The final demonstration flight will show how SACA technologies will most likely work in the NextGen NAS: an integration of both flight- and ground-based SACA systems that allow for tactical separation assurance in a dense, mixed-traffic environment consisting of both manned and unmanned aircraft. The FTO mapping for the IT&E subgroup is shown in Table 6.

**Table 6. FTO mapping, SACA group (P = primary objective; S = secondary objective).**

ID	Title	FY11 Flight 1	FY12 Flight 2	FY13 Flight 3	FY14 Flight 4	FY15 Flight 5
	<b>Demonstrate ADS-B and FMS on Ikhana.</b>					
ITE-001	Obtain SACA data related to the performance and accuracies of ADS-B information for UAS applications. Evaluate FMS performance in a number of simulated-traffic scenarios.  1 UAS Simulated traffic 20 flight hours	P	S	S	S	S
	<b>Use two UAS to demonstrate available flight- and ground-based UAS technologies in preparation for the fully integrated flight demonstration.</b>					
ITE-002	Obtain SACA data relating to performance of tactical SA algorithms in a relevant environment; obtain PAI data relating to the validation of NAS-compliant GCS in a relevant environment.  2 UAS Real UAS traffic 30 flight hours per aircraft			P		
	<b>Demonstrate available flight- and ground-based UAS technologies to build up to final flight demonstration.</b>					
ITE-003	Obtain SACA data pertaining to the performance of SACA algorithms; obtain data pertaining to validation of CA requirements; obtain PAI data pertaining to validation of NAS-compliant GCS; obtain communications data pertaining to performance of CNPC and security protocols.  2 UAS 2 manned aircraft 30 flight hours per aircraft				P	
	<b>Demonstrate available flight- and ground-based UAS technologies.</b>					
ITE-004	Obtain SACA data pertaining to the performance of SACA algorithms; obtain data pertaining to validation of CA requirements; obtain PAI data pertaining to validation of NAS-compliant GCS; obtain communications data pertaining to performance of CNPC and security protocols.  3 UAS 1 surrogate UAS 2 manned aircraft 30 flight hours per aircraft					P

**E. Measures of Performance**

Measures of Performance (MOPs) are “base” objectives that a system or architecture must meet in order for a testing program to move forward, but are not given as target objectives for a specific subgroup. These include basic system evaluations, such as datalink connectivity, which form the foundation for subsequent testing. A notional FTO mapping of the project MOPs is shown in Table 7.

**Table 7. Measures of Performance.**

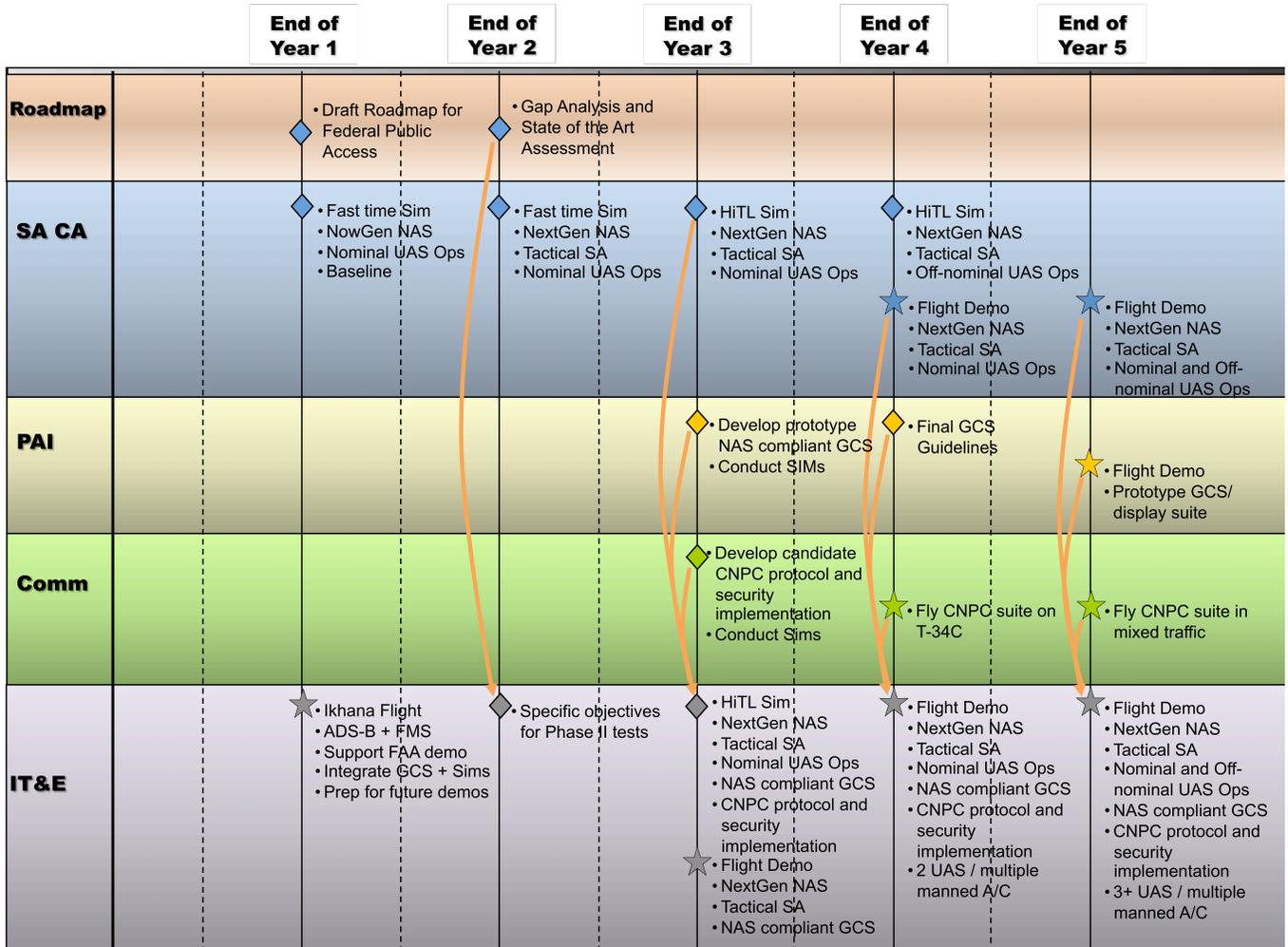
ID	Title	FY11 Flight 1	FY12 Flight 2	FY13 Flight 3	FY14 Flight 4	FY15 Flight 5
MOP-001	Evaluate datalink connectivity (telemetry, voice, and video) and bandwidth limitations.	P	S	S	S	S
MOP-002	Demonstrate ability to command and control UAS in flight.				P	S
MOP-003	Evaluate mission systems processes and vehicle performance to validate simulation model and products / processes.			P	S	S
MOP-004	Evaluate UAS RF link performance with focus on data latency and transmission of data for range safety.				P	S
MOP-005	Evaluate ADS-B network communication performance and characteristics for telemetry data including ground connectivity to Range Safety.	P	S	S	S	S

**VI. Concluding Remarks and Future Work**

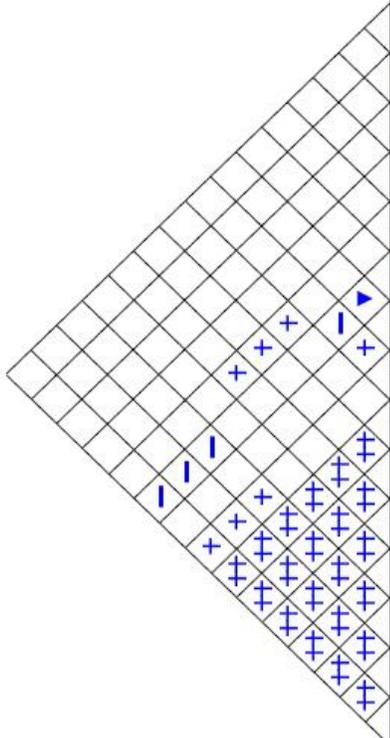
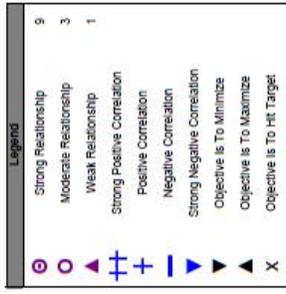
The UAS in the NAS project represents the cornerstone of aviation’s future. The desire to incorporate UAS with manned air traffic represents a practical and economic solution to many of the aviation industry’s needs; this is especially true within the industry segments concerned with logistics, law enforcement, and national security. The primary concern with UAS in the NAS is not necessarily the collision avoidance side of the problem (which has been researched and tested numerous times by various organizations) as much as the need for tactical separation assurance. In truth, the involvement of a pilot in modern aircraft operation is mostly concerned with contingency mitigation and emergency decision-making procedures; the vast majority of manned aircraft – especially commercial transports – are already capable of taking off, flying, and landing autonomously, with PITL control serving as redundancy. It would seem that modern aircraft are on the cusp of being fully autonomous – i.e. completely unmanned – as it is arguable that they are already “surrogate” automatons, however the level of sophistication required for true airborne autonomy is still beyond the current state of the art. The work done by UAS in the NAS will ensure that the NextGen NAS will operate at higher traffic densities with increased safety despite the presence of autonomous aircraft, thus leading to a more efficient and fully-utilized national airspace system.

## Appendices

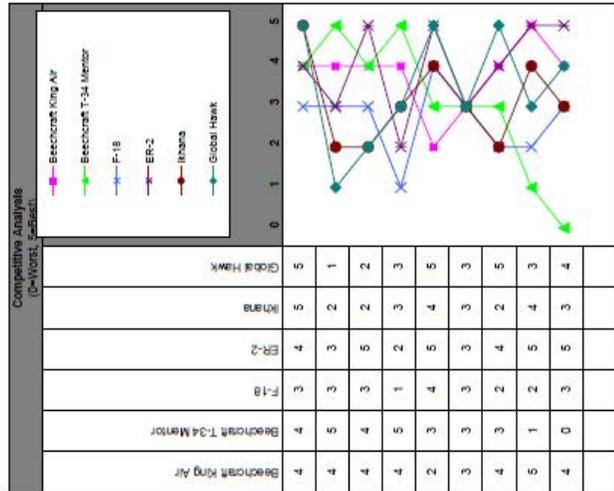
### UAS in the NAS Project Milestones<sup>22</sup>



**DFRC Research Aircraft Fleet HOQ**



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
1	9	13.2	9.0	Direction of Improvement: (Minimize (▼), Maximize (▲), or Target (X))	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
2	9	11.8	8.0	Quality Characteristics (a.k.a. "Functional Requirements" or "How's")  Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
3	9	11.8	8.0		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
4	9	13.2	9.0		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
5	9	10.3	7.0		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
6	9	14.7	10.0		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
7	9	7.4	5.0		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
8	3	5.9	4.0		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
9	9	11.8	8.0		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
10																					
					Target or Limit Value	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
				Max Relationship Value in Column	663.2	499.5	576.5	564.7	11.8	100.0	17.6	194.1	529.4	357.4	369.1						
				Weight / Importance	17.1	12.8	14.8	14.5	0.3	2.5	0.5	5.0	13.6	9.2	9.5						
				Relative Weight																	



Competitive Analyses (C=Best, S=Second, W=Third, L=Fourth, F=Last)	Beechcraft King Air	Beechcraft T-34 Mentor	F-18	ER-2	Ikhana	Global Hawk
Study and simulate conflict avoidance algorithms and sensors	4	4	3	4	5	5
Suitability for use as a UAS or a surrogate UAS (aircraft under test)	4	4	3	3	2	1
Suitability for use as a cooperative or intruder aircraft	4	4	3	3	2	2
Ease of outfitting aircraft with SAA algorithms and sensors	4	4	3	5	2	2
Operating Cost	4	4	3	1	2	3
Operating altitude between FL400 - FL600	2	3	4	5	4	5
Availability of test aircraft	3	3	3	3	3	3
Availability of test aircraft	4	3	2	4	2	5
Cruise speed between 200 - 400 KTAS	5	1	2	5	4	3
Useful payload, lbs.	4	0	3	5	3	4
Available onboard power						

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*Semper ad meliora.*

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