Operational Overview for Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project Flight Test Series 3

Steffi Valkov

AIAA Aviation – 5 June 2017

What is UAS-NAS?

- Increased urgency in the desire and ability to fly Unmanned Aerial Systems (UAS) in the National Airspace System (NAS)
  - National security
  - Defense
  - Scientific
  - Emergency management

- NASA project: "UAS Integration in the NAS"
  - Conducting research in the areas of:
    - Self Separation/Sense and Avoid Interoperability
    - Human Systems Integration (HSI)
    - Communication
  - Human-in-the-loop testing
  - Integrated flight-test activities

- Supporting the development of regulations governing the routine access of UAS to the NAS

Flight Test Series 3 (FT3)

- Flight Test Series 3 (FT3)
  - Integrated flight test part of the UAS-NAS campaign

- Goals of FT3 included development and evaluation of:
  1. Sense and Avoid (Detect and Avoid (DAA)) guidance algorithms in an end to end traffic encounter
     - Aircraft sensor to wind
     - TCAS II
     - Latency uncertainties to a Ground Control Station (GCS) display
  2. Prototype communication system
  3. Data collection to inform the preliminary draft of Minimum Operational Performance Standards (MOPS)
     - DAA
     - Command and Control (C2)
  4. Increased team's capabilities and reduced risks to follow-on flight tests such as Flight Test 4 (FT4) and beyond.

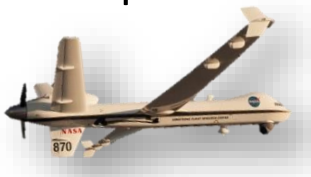
- Two parts:
  - Configuration 1
  - Configuration 2

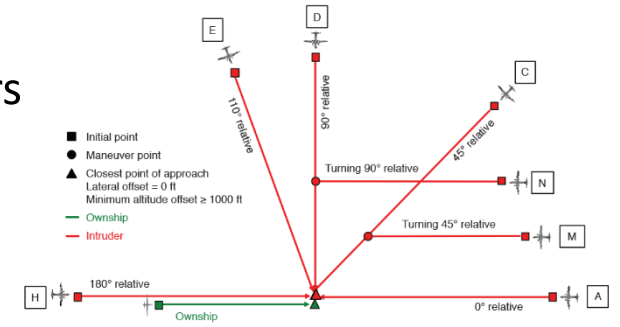
FT3 Stakeholders

Stakeholder	DAA Algorithm or SUT	Aircraft	Additional Information
NASA Ames Research Center (ARC)	• **JADEM DAA Algorithm** • CFG1: JADEM encounters • CFG2: HSI requirements • CFG2: "Virtual ATC"		
NASA Armstrong Flight Research Center (AFRC)	• Host of Live Virtual Constructive (LVC) – data distribution between ARC, GRC, and LaRC • CFG2: RGCS	• CFG1: NASA870 "Ikhana" • CFG1 and CFG2: Intruder(s)	• Responsible test organization
NASA Glenn Research Center (GRC)	• CFG2: CNPC	• CFG1: S-3B high-speed ownship (cancelled) • CFG2: NASA608 Surrogate	
NASA Langley Research Center (LaRC)	• **Stratway+ DAA Algorithm** • CFG1: Stratway+ encounters		
General Atomics Aeronautical Systems, Inc. (GA-ASI)	• **CPDS DAA Algorithm** • CFG1: Due Regard Radar (DRR) • CFG1: CPDS encounters • CFG1: Radar encounters • CFG1: TCAS encounters		
Honeywell International, Inc. (HON)	• Honeywell Fusion Tracker	• CFG1 and CFG2: N3GC C90 King Air intruder	

FT3 Configurations

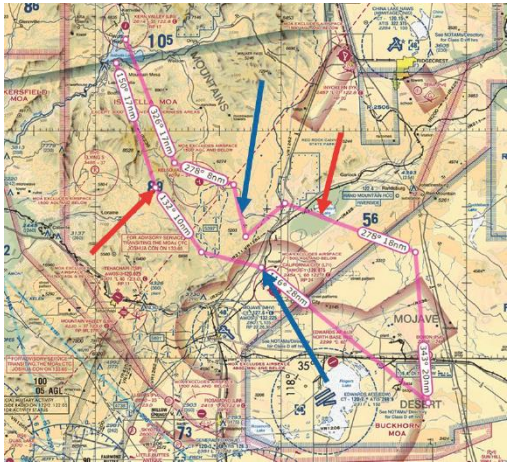
- Configuration 1: Pairwise Scripted Encounters
  - Evaluated advisories generated by SS and CA algorithms
  - Ownship Ikhana vs. one (or two) manned intruders





  - Configuration 1a: Low-speed ownship
    - Participants: ARC (SSI), LaRC, AFRC, GA-ASI, HON
  - Configuration 1b: High-speed ownship (not attempted)
    - Participants: ARC, AFRC, GRC

- Configuration 2: Full Mission
  - Ownship NASA608 vs. manned intruders and virtual traffic
  - Real flight data to improve simulation (IHITL)
  - Pre-planned flight plan
    - Represents fictitious fireline flown in Oakland Airspace
  - Pilot in Research Ground Control Station (RGCS)
    - Lateral control. Safety pilot perform airspeed and altitude changes
  - Participants: ARC (HSI), AFRC, GRC, HON



Terminology, Configuration, and Equipage

	Aircraft		EDM DRR	ADS-B	GPS	TCAS I	TCAS II	CNPC	Notes
Ownships		**NASA 870** CFG 1	✓	✓	✓		✓		+ HUD
Ownships		**NASA 608** CFG 2		✓	✓	✓		✓	
Intruders		**NASA 850** CFG 1			✓	✓			Z-12 GPS
Intruders		**N3GC** CFG 1, 2		✓	✓		✓		+ TCAS Recorder
Intruders		**NASA 865** CFG 1, 2		✓	✓	✓			
Intruders		**NASA 7** CFG 2		✓	✓	✓			

FT3 Flight Test Period

Config 1:
15 June 2015
through
24 July 2015

Configuration 1				
Flight	**Date**	**Hours***	**Encounters**	**Aircraft**
0	June 15, 2015	6.9	0	NASA 870
1	June 17, 2015	5.0	15	NASA 870, N3GC
2	June 18, 2015	4.9	23	NASA 870, N3GC
3	June 22, 2015	4.5	20	NASA 870, N3GC
4	June 24, 2015	4.7	20	NASA 870, N3GC
5	June 26, 2015	4.6	16	NASA 870, N3GC, NASA 865
6	July 7, 2015	4.8	22	NASA 870, N3GC
7	July 9, 2015	4.8	23	NASA 870, N3GC
8	July 10, 2015	4.6	20	NASA 870, N3GC, NASA 865
9	July 21, 2015	4.8	20	NASA 870, NASA 850, NASA 865
10	July 22, 2015	3.4	17	NASA 870, NASA 865
11	July 24, 2015	3.2	16	NASA 870, NASA 865
		56.2	**212**	

11 Data Collection Flights

Config 2:
13 July 2015
through
12 August 2015

Configuration 2				
Flight	**Date**	**Hours***	**Encounters**	**Aircraft**
1	July 13, 2015	3.1	0	NASA 608
2	July 16, 2015	1.3	0	NASA 608
3	July 28, 2015	3.1	2	NASA 608, NASA 865
4	July 29, 2015	2.0	0	NASA 608
5	July 29, 2015	1.9	0	NASA 608
6	July 30, 2015	1.1	0	NASA 608
7	August 3, 2015	3.3	4	NASA 608, NASA 7, N3GC
8	August 4, 2015	2.8	0	NASA 608
9	August 4, 2015	2.9	2	NASA 608, N3GC
10	August 5, 2015	3.0	5	NASA 608, N3GC
11	August 6, 2015	1.1	0	NASA 608, NASA 865, N3GC
12	August 7, 2015	2.8	1	NASA 608, NASA 865, N3GC
13	August 10, 2015	2.8	8	NASA 608, NASA 865, N3GC
14	August 11, 2015	2.7	8	NASA 608, NASA 865, N3GC
15	August 12, 2015	2.5	8	NASA 608, NASA 865, N3GC
		36.35	**38**	

3 Data Collection Flights

*Flight hours based on Ownship

CONFIGURATION 1

Aircraft, Airspace, and Admin

Ownship

NASA 870
"Ikhana"
MQ-9 Predator

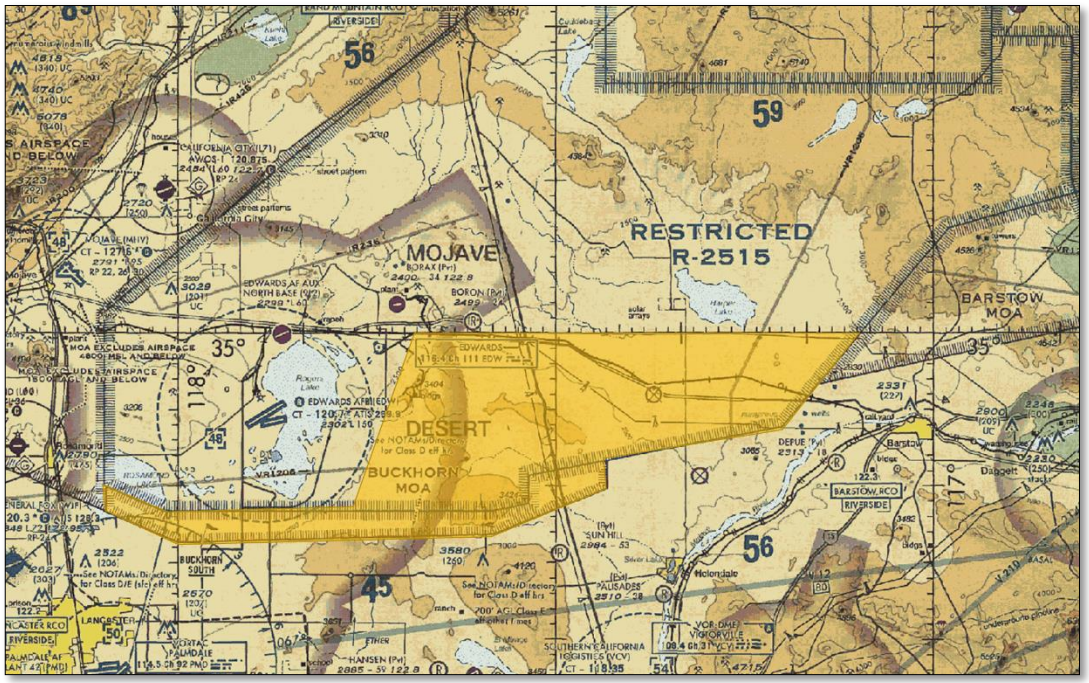
Intruders

N3GC
King Air

NASA 865
T-34

High-Speed Intruder

NASA 850
F-18



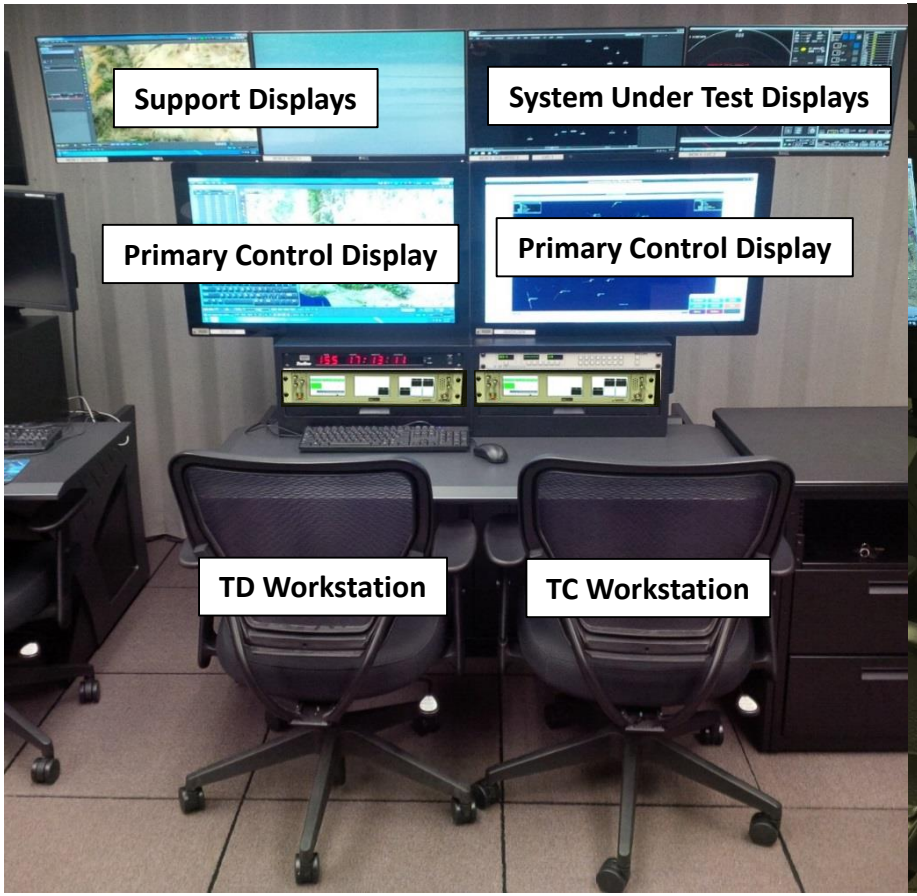
Work Area:

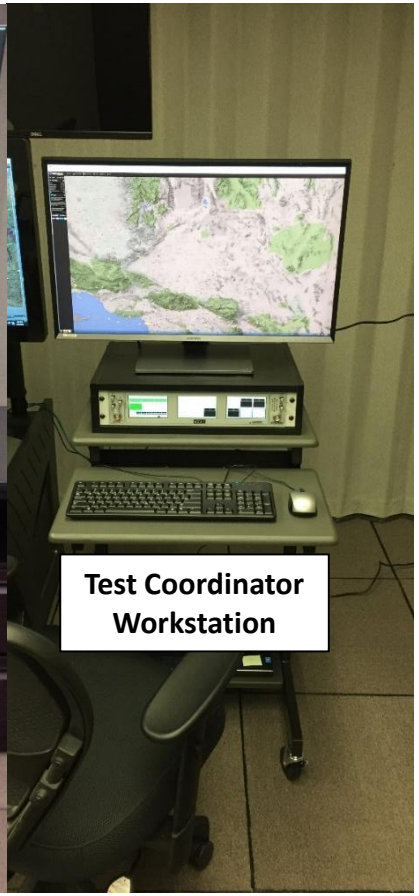
- Edwards AFB R-2515 and Buckhorn MOA
- Primarily used Mercury Spin and Four Corners

Flights:

- Day Prior Brief
- Morning Brief
- Takeoff 0600L - Land 1100L
- Debrief

Stand Alone Facility (SAF) Mission Control Room



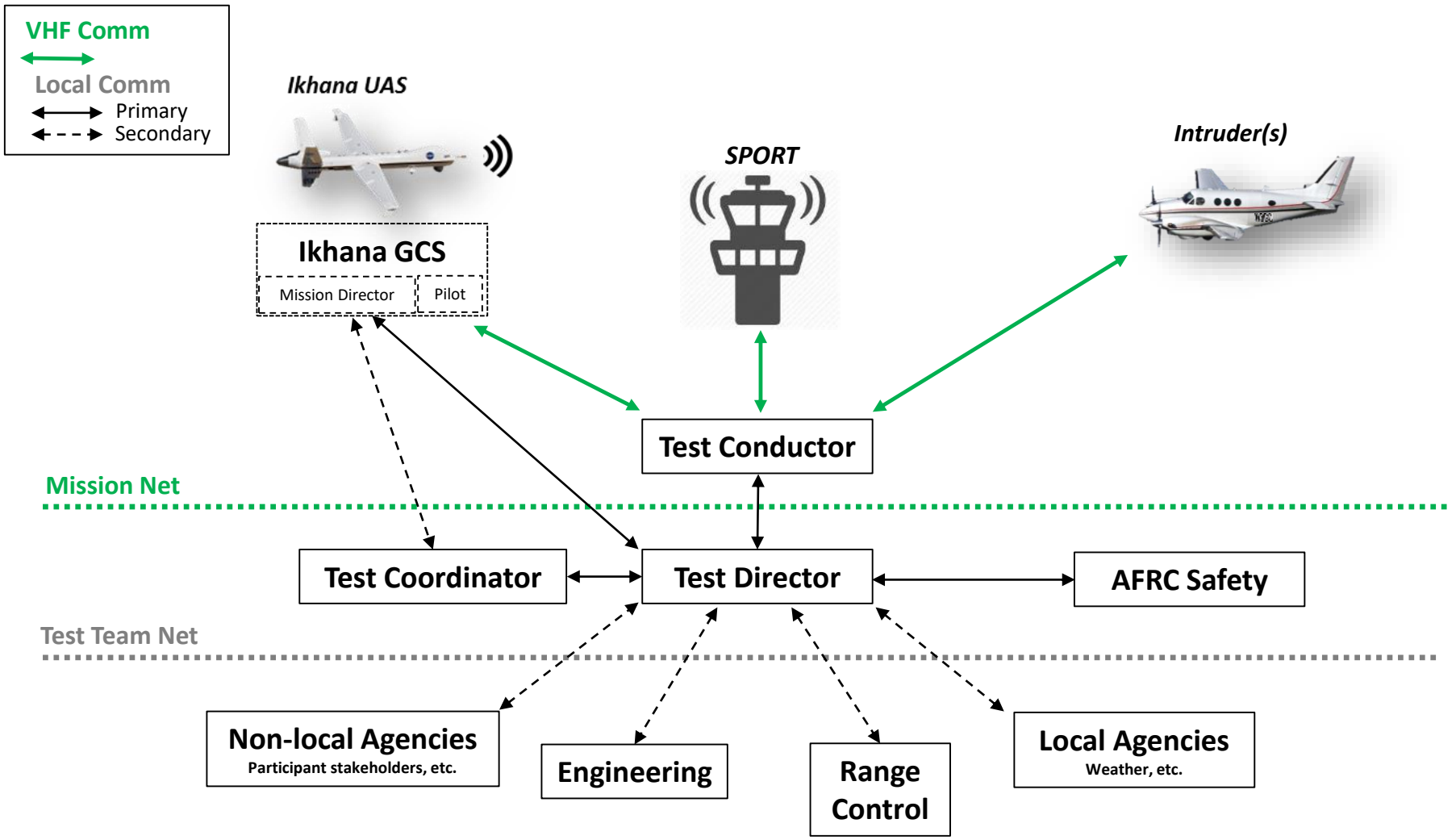


Test Conductor: Managed mission execution over voice communication on mission net (VHF radio) with Ikhana pilot, intruder pilots, and local ATC

Test Director: Primary liaison with test conductor and managed voice communication on test team net with Ikhana mission director, safety, engineering, local agencies, and non-local agencies (as required)

Test Coordinator: Acted as a scribe and managed secondary SAF tasks

Communication



Mission Information

- Planned: 3 flights per week
  - About 4 hrs of data collection
  - 10 min per encounter
- Briefs
  - Roll call
  - Mission summary
  - Mission timeline
  - Weather/NOTAM
  - UAS status
  - Mission information
  - GCS status
  - Airspace/airfield
  - Support assets
  - Contingencies
  - Miscellaneous
  - Flight card review

Time of day	Ikhana	NASA850 F-18	NASA865 T-34
1200	T-1		
N/A	Prep		
0415	Mass brief		
0430	Individual unit briefs		
0500	Walk		
0600	Take off		
0620		Take off	
0630		On station altimeter calibration	
0635	Commence exercise (4+00 hours on station)		
0735			Take off
0800	Complete 1v1. Start 1v2.		
0840		Return to base-fuel	
TBD			Altimeter calibration
TBD		Take/off on station	
1030	Knock-it-off return to base		
1100	Land		
1200	Debrief		
1415	End of test day		

Safety and Mission Rules

Safety working groups analyzed and discussed flight test hazards to create mission rules.

Admin

- System Under Test (SUT) not used for safe separation of aircraft
- Weather
  - 3 or greater miles of visibility
  - Clear of clouds 1000' above and below planned maneuvers, including aborts

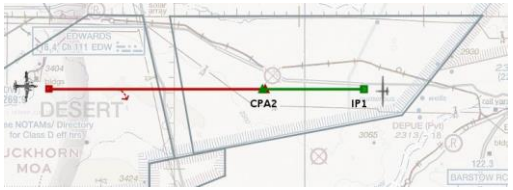
Procedural

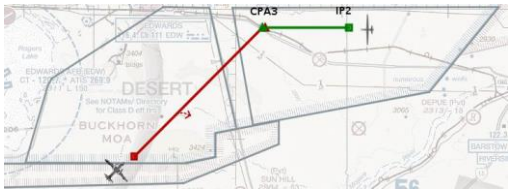
- Time hack for all participants
- Altimeter calibration (for flight days with encounters < 500 ft vertical)
- Update, and Ikhana Lost Link verified
- Check aircraft navigation quality
- Between encounters, mode set to advisory or OFF
- Between encounters, stay at deconfliction altitude

Execution

- Visual required within 1 NM for encounters < 500 ft vertical separation
- TCAS (other than test card) followed only if from non-participating aircraft and have SA on participants
- Operations outside approved FT3 envelope prohibited during encounters
- Aborts for reasons that cause unsafe conditions
- Encounter aborted if TCAS opposite of expected
- When within 1 NM, minimum vertical separation 200'
- Timing constraint resets

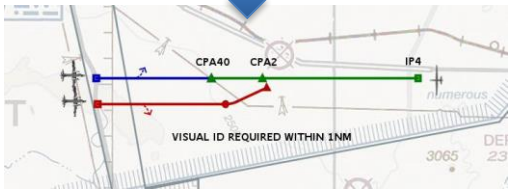
Build-Down Philosophy





Simple

Complex



To the extent possible, encounter order was designed with a "build-down" philosophy.

Per Test Day:

- Encounters flown ≥500 ft vertical separation are considered to have 'standard separation' (NAS) and do not require a visual to execute
- Perform encounters with standard separation and transition to visual required encounters (500 ft, to 300 ft, to 200 ft)
- Perform "simple" geometries first
- Group together similar encounters
- Altitude blocks grouped together
- Single intruder encounters followed by multiship
- Encounters with same intruders grouped
- Advisory prior to auto maneuvers
- Once encounter type is cleared, continue through deck next day

Nomenclature

Configuration 1 nomenclature

[Series] [Min altitude offset] [Vertical profile] [Encounter angle]

- Series
  - L = Low speed
  - H = High speed
  - M = Multiship
- Minimum altitude offset
  - 1 = 1000 ft
  - 2 = 200 ft / 700 ft
  - 3 = 300 ft
  - 4 = 400 ft
  - 5 = 500 ft
  - 6 = 300 ft / 700 ft
  - 7 = 400 ft / 500 ft
  - 8 = 2500 ft
  - 9 = 4000 ft
- Vertical profile (ownship/intruder)
  - 1 = H-level/level
  - 2 = Level/H-level
  - 3 = Level/climb
  - 4 = Level/descent
  - 5 = Climb/level
  - 6 = Descent/level
  - 7 = Climb/descent
  - 8 = Descent/climb
  - 9 = Level/H-level/L-level
- Encounter angle
  - A = 0 degrees
  - B = 20 degrees
  - C = 45 degrees
  - D = 90 degrees
  - E = 110 degrees
  - F = 135 degrees
  - G = 160 degrees
  - H = 180 degrees
  - J = -45 degrees
  - K = -90 degrees
  - L = -135 degrees
  - M = Turning 45 degrees
  - N = Turning 90 degrees
  - P = Zig-zag
  - Q = 0 / 0
  - R = 0 / 45
  - S = 0 / 90
  - T = 0 / 135
  - U = 20 / -20
  - V = 45 / 90
  - W = 90 / 135
  - X = Turning 45 degrees / 180 degrees

Test card nomenclature: Quick, easy way to gain SA and identify properties of the specific encounter

Example:
L42A

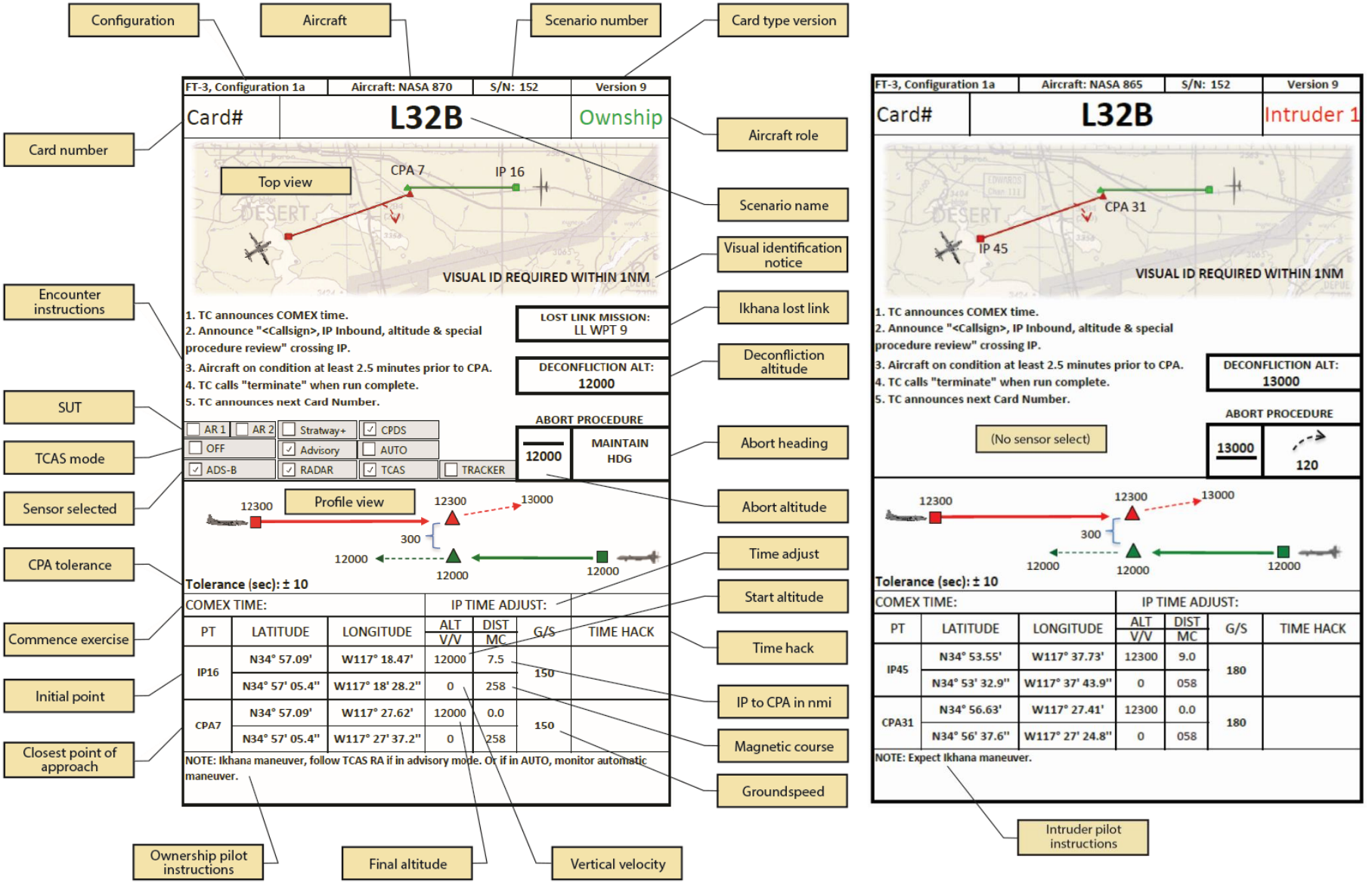
- Low-speed ownship
- 400 ft vertical separation
- Ownship below intruder
- 0 degree angle offset between ownship and intruder

Flight Test Matrix

- Comprehensive matrix built to track over 300 unique encounter scenarios
- Tracked information such as scenario name, aircraft involved, groundspeeds, altitudes, and waypoints
- Part of mission planning and ensuring encounters fit in allotted airspace
- Used look-up tables to automatically generate and populate the flight test cards

	Scenario Number	Scenario Name	Leg Time (minutes)	Min Vertical Separation (ft)	Angle Into	Lateral Offset (ft)	GSOWN	GSINT1	GSINT2	Ownship Initial Altitude	Ownship Vertical Velocity	Ownship Final Altitude	Intruder 1 Initial Altitude	Intruder 1 Vertical Velocity	Intruder 1 Final Altitude	Intruder 2 Initial Altitude	Intruder 2 Vertical Velocity	Intruder 2 Final Altitude	CPA Tolerance (sec)	On Condition (min)	Ikhana Lost Link
Head-On Level/Ascending/Descending	1	L42A	3	400	0	3000	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 9
	2	L42B	3	400	20	3000	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 9
	3	L55A	3	500	0	3000	130	180	NA	11000	1000	14000	14500	0	14500	NA	NA	NA	±10	2.5	LL WPT 9
	4	L55B	3	500	20	3000	130	180	NA	11000	1000	14000	14500	0	14500	NA	NA	NA	±10	2.5	LL WPT 9
	5	L56A	3	500	0	3000	130	180	NA	16000	-1000	13000	12500	0	12500	NA	NA	NA	±10	2.5	LL WPT 9
	6	L56B	3	500	20	3000	130	180	NA	16000	-1000	13000	12500	0	12500	NA	NA	NA	±10	2.5	LL WPT 9
	7	L57A	3	500	0	3000	130	180	NA	11000	1000	14000	17500	-1000	14500	NA	NA	NA	±10	2.5	LL WPT 9
	8	M59Q	3	500	0	3000	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 2
	9	M59U	3	500	20/-20	3000	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 5
	10	L13A	3	1000	0	0	150	140	NA	16500	0	16500	12500	1000	15500	NA	NA	NA	±10	2.5	LL WPT 9
	11	L13A	3	1000	0	0	150	140	NA	16500	0	16500	12500	1000	15500	NA	NA	NA	±10	2.5	LL WPT 9
	12	L14A	3	1000	0	0	150	140	NA	12000	0	12000	16000	-1000	13000	NA	NA	NA	±10	2.5	LL WPT 9
	13	L14A	3	1000	0	0	150	140	NA	12000	0	12000	16000	-1000	13000	NA	NA	NA	±10	2.5	LL WPT 9
	14	L15A	3	1000	0	0	120	150	NA	12000	1000	15000	16000	0	16000	NA	NA	NA	±10	2.5	LL WPT 9
	15	L15A	3	1000	0	0	120	150	NA	12000	1000	15000	16000	0	16000	NA	NA	NA	±10	2.5	LL WPT 9
	16	L16A	3	1000	0	0	120	150	NA	16000	-1000	13000	12000	0	12000	NA	NA	NA	±10	2.5	LL WPT 9
	17	L16A	3	1000	0	0	120	150	NA	16000	-1000	13000	12000	0	12000	NA	NA	NA	±10	2.5	LL WPT 9
	18	L12A	3	1000	0	3000	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 9
	19	L52A	3	500	0	3000	150	180	NA	12000	0	12000	12500	0	12500	NA	NA	NA	±10	2.5	LL WPT 9
	20	L32A	3	300	0	3000	150	180	NA	12000	0	12000	12300	0	12300	NA	NA	NA	±10	2.5	LL WPT 9
45° Crossing Level/Ascending/Descending Left-to-Right	21	L42C	3	400	45	3000	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 9
	22	L55C	3	500	45	3000	130	180	NA	11000	1000	14000	14500	0	14500	NA	NA	NA	±10	2.5	LL WPT 9
	23	L56C	3	500	45	3000	130	180	NA	16000	-1000	13000	12500	0	12500	NA	NA	NA	±10	2.5	LL WPT 9
	24	L57C	3	500	45	3000	130	180	NA	11000	1000	14000	17500	-1000	14500	NA	NA	NA	±10	2.5	LL WPT 9
	25	L53C	3	500	45	3000	150	180	NA	14500	0	14500	11000	1000	14000	NA	NA	NA	±10	2.5	LL WPT 9
	26	L54C	3	500	45	3000	150	180	NA	12000	0	12000	15500	-1000	12500	NA	NA	NA	±10	2.5	LL WPT 9
	27	M59R	3	500	0/45	3000	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 8
	28	M59V	3	500	45/90	3000	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 10
	29	L12C	3	1000	45	3000	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±8	2.5	LL WPT 9
	30	L52C	3	500	45	3000	150	180	NA	12000	0	12000	12500	0	12500	NA	NA	NA	±8	2.5	LL WPT 9
	31	L32C	3	300	45	3000	150	180	NA	12000	0	12000	12300	0	12300	NA	NA	NA	±8	2.5	LL WPT 9
	32	L13C	3	1000	45	0	150	140	NA	16500	0	16500	12500	1000	15500	NA	NA	NA	±10	2.5	LL WPT 9
	33	L13C	3	1000	45	0	150	140	NA	16500	0	16500	12500	1000	15500	NA	NA	NA	±10	2.5	LL WPT 9
	34	L14C	3	1000	45	0	150	140	NA	12000	0	12000	16000	-1000	13000	NA	NA	NA	±10	2.5	LL WPT 9
	35	L14C	3	1000	45	0	150	140	NA	12000	0	12000	16000	-1000	13000	NA	NA	NA	±10	2.5	LL WPT 9
	36	L15C	3	1000	45	0	120	150	NA	12000	1000	15000	16000	0	16000	NA	NA	NA	±10	2.5	LL WPT 9
	37	L15C	3	1000	45	0	120	150	NA	12000	1000	15000	16000	0	16000	NA	NA	NA	±10	2.5	LL WPT 9
	38	L16C	3	1000	45	0	120	150	NA	16000	-1000	13000	12000	0	12000	NA	NA	NA	±10	2.5	LL WPT 9
	39	L16C	3	1000	45	0	120	150	NA	16000	-1000	13000	12000	0	12000	NA	NA	NA	±10	2.5	LL WPT 9
	40	L12M	3.25	1000	45	0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 9
	41	L12M	3.25	1000	45	0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 9
90° /110° Crossing Level/Ascending/Descending Left-to-Right	42	L42D	3	400	90	3000	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 10
	43	L55D	3	500	90	3000	130	180	NA	11000	1000	14000	14500	0	14500	NA	NA	NA	±10	2.5	LL WPT 10
	44	L56D	3	500	90	3000	130	180	NA	16000	-1000	13000	12500	0	12500	NA	NA	NA	±10	2.5	LL WPT 10
	45	L57D	3	500	90	3000	130	180	NA	11000	1000	14000	17500	-1000	14500	NA	NA	NA	±10	2.5	LL WPT 10
	46	L53D	3	500	90	3000	150	180	NA	14500	0	14500	11000	1000	14000	NA	NA	NA	±10	2.5	LL WPT 10
	47	L54D	3	500	90	3000	150	180	NA	12000	0	12000	15500	-1000	12500	NA	NA	NA	±10	2.5	LL WPT 10
	48	M59S	3	500	0/90	3000	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 9
	49	L12D	3	1000	90	3000	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±5	2.5	LL WPT 10
	50	L52D	3	500	90	3000	150	180	NA	12000	0	12000	12500	0	12500	NA	NA	NA	±5	2.5	LL WPT 10
	51	L32D	3	300	90	3000	150	180	NA	12000	0	12000	12300	0	12300	NA	NA	NA	±5	2.5	LL WPT 10
	52	L13D	3	1000	90	0	150	140	NA	16500	0	16500	12500	1000	15500	NA	NA	NA	±10	2.5	LL WPT 10
	53	L13D	3	1000	90	0	150	140	NA	16500	0	16500	12500	1000	15500	NA	NA	NA	±10	2.5	LL WPT 10
	54	L14D	3	1000	90	0	150	140	NA	12000	0	12000	16000	-1000	13000	NA	NA	NA	±10	2.5	LL WPT 10
	55	L14D	3	1000	90	0	150	140	NA	12000	0	12000	16000	-1000	13000	NA	NA	NA	±10	2.5	LL WPT 10
	56	L15D	3	1000	90	0	120	150	NA	12000	1000	15000	16000	0	16000	NA	NA	NA	±10	2.5	LL WPT 10
	57	L15D	3	1000	90	0	120	150	NA	12000	1000	15000	16000	0	16000	NA	NA	NA	±10	2.5	LL WPT 10
	58	L16D	3	1000	90	0	120	150	NA	16000	-1000	13000	12000	0	12000	NA	NA	NA	±10	2.5	LL WPT 10
	59	L16D	3	1000	90	0	120	150	NA	16000	-1000	13000	12000	0	12000	NA	NA	NA	±10	2.5	LL WPT 10
	60	L12E	3	1000	110	0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 10
	61	L12E	3	1000	110	0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 10
	62	L12N	3.5	1000	90	0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 9
	63	L12N	3.5	1000	90	0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 9
135° Overtaking Level/Ascending /Descending Left	64	L42F	3	400	135	3000	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 1
	65	L55F	3	500	135	3000	130	180	NA	11000	1000	14000	14500	0	14500	NA	NA	NA	±10	2.5	LL WPT 1
	66	L56F	3	500	135	3000	130	180	NA	16000	-1000	13000	12500	0	12500	NA	NA	NA	±10	2.5	LL WPT 1
	67	L57F	3	500	135	3000	130	180	NA	11000	1000	14000	17500	-1000	14500	NA	NA	NA	±10	2.5	LL WPT 1
	68	L53F	3	500	135	3000	150	180	NA	14500	0	14500	11000	1000	14000	NA	NA	NA	±10	2.5	LL WPT 1
	69	L54F	3	500	135	3000	150	180	NA	12000	0	12000	15500	-1000	12500	NA	NA	NA	±10	2.5	LL WPT 1
	70	M59T	3	500	0/135	3000	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 6
	71	M59W	3	500	90/135	3000	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 10
High Speed Level Encounters 0/45/90/135/180	72	H42A	3	400	0	3000	150	300	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 2
	73	H42C	3	400	45	3000	150	300	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 10
	74	H42D	3	400	90	3000	150	300	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 10
	75	H42F	3	400	135	3000	150	300	NA	12000	0	12000	12400	0	12400	NA	NA	NA	±10	2.5	LL WPT 1
	76	M59R	3	500	0/45	3000	150	300	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 6
	77	M59S	3	500	0/90	3000	150	300	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 6
	78	M59T	3	500	0/135	3000	150	300	150	13000	0	13000	13500	0	13500	12500	0	12500	±10	2.5	LL WPT 6
	79	H12A	3	1000	0	0	130	210	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 6
	80	H12A	3	1000	0	0	130	210	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 6
	81	H12A	3	1000	0	0	130	250	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 6
	82	H12A	3	1000	0	0	130	250	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 6
	83	H12A	3	1000	0	0	210	130	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 9
	84	H12A	3	1000	0	0	210	130	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 9
	85	H12A	3	1000	0	0	250	130	NA	12000	0	12000	13000	0	13000	NA	NA	NA	±10	2.5	LL WPT 9

Ownship and Intruder Example Cards



Schedule

FT3 CONFIGURATION 1

	JADEM			CPDS		Stratway+			High Speed Intruder Stratway+	AutoResolver	CPDS	High Speed Ownship AutoResolver
	1	2	3	4	5	6	7	8	9	10	11	12
	17-Jun	18-Jun	22-Jun	24-Jun	26-Jun	7-Jul	9-Jul	10-Jul	21-Jul	22-Jul	24-Jul	27-Aug
	W	Th	M	W	F	Tu	Th	F	Tu	W	F	Th
1	18 - L12A	31 - L32C	61 - L12E	137 - L53C	108 - L12A (2)	25 - L53C	22 - L55C	8 - M59Q	72 - H42A	61 - L12E	110 - L12A	83 - H12A
2	19 - L52A	51 - L32D	41 - L12M	137 - L53C	107 - L12A (1)	46 - L53D	43 - L55D	8 - M59Q	72 - H42A	41 - L12M	109 - L12A	85 - H12A
3	20 - L32A	10 - L13A	63 - L12N	146 - L54D	112 - L11A (2)	68 - L53F	65 - L55F	28 - M59V	73 - H42C	63 - L12N	114 - L11A	91 - H12C
4	29 - L12C	32 - L13C	13 - L14A	146 - L54D	111 - L11A (1)	26 - L54C	24 - L57C	28 - M59V	73 - H42C	13 - L14A	113 - L11A	93 - H12C
5	30 - L52C	52 - L13D	35 - L14C	140 - L55A	164 - L42M	47 - L54D	45 - L57D	71 - M59W	74 - H42D	35 - L14C	159 - L57D	- H12D
6	31 - L32C	16 - L16A	55 - L14D	140 - L55A	165 - L52M (1)	69 - L54F	67 - L57F	71 - M59W	74 - H42D	55 - L14D	130 - L32D	H12D
7	49 - L12D	38 - L16C	15 - L15A	151 - L56F	166 - L52M (2)	5 - L56A	7 - L57A	9 - M59U	75 - H42F	15 - L15A	131 - L32F	84 - H12A
8	50 - L52D	58 - L16D	37 - L15C	151 - L56F	167 - L52M (3)	6 - L56B	3 - L55A	27 - M59R	75 - H42F	37 - L15C	152 - L32B	86 - H12A
9	51 - L32D	14 - L15A	57 - L15D	115 - L32G (110)	168 - L52M (4)	23 - L56C	4 - L55B	48 - M59S	76 - M59R	57 - L15D	153 - L32G	92 - H12C
10	60 - L12E	36 - L15C	11 - L13A	121 - L32G (90)	169 - M79X (1)	44 - L56D	21 - L42C	70 - M59T	76 - M59R	11 - L13A	154 - L32H	94 - H12C
11	40 - L12M	56 - L15D	33 - L13C	117 - L53G (110)	170 - M79X (2)	66 - L56F	42 - L42D	9 - M59U	77 - M59S	33 - L13C	155 - L31B	100 - H12D
12	62 - L12N	10 - L13A	53 - L13D	124 - L55G (90)	171 - M79X (3)	1 - L42A	64 - L42F	27 - M59R	77 - M59S	53 - L13D	156 - L31G	102 - H12D
13	12 - L14A	32 - L13C	17 - L16A	159 - L57D	160 - M67Q	2 - L42B	26 - L54C	48 - M59S	78 - M59T	17 - L16A	157 - L31H	103 - H12H
14	34 - L14C	52 - L13D	39 - L16C	159 - L57D	~~162 - M27Q~~	21 - L42C	47 - L54D	70 - M59T	78 - M59T	39 - L16C	168 - L52M	105 - H12H
15	54 - L14D	16 - L16A	59 - L16D	128 - L32A	~~162 - M27Q~~	42 - L42D	22 - L55C	63 - L12N	23 - L56C	59 - L16D	164 - L42M	
16	61 - L12E	38 - L16C	61 - L12E	128 - L32A	161 - M68Q	64 - L42F	43 - L55D	63 - L12N	44 - L56D	18 - L12A	127 - L92P	
17	41 - L12M	58 - L16D	41 - L12M	129 - L32C	~~163 - M28Q~~	20 - L32A	65 - L55F	31 - L32C	66 - L56F	29 - L12C	116 - L31G	
18	63 - L12N	12 - L14A	63 - L12N	129 - L32C	~~163 - M28Q~~	31 - L32C	24 - L57C	51 - L32D	31 - L32C	49 - L12D	119 - L54G	
19	13 - L14A	34 - L14C	13 - L14A	130 - L32D	132 - L31A	51 - L32D	45 - L57D	23 - L56C	51 - L32D	18 - L12A	158 - L57A	
20	35 - L14C	54 - L14D	35 - L14C	130 - L32D	132 - L31A	68 - L53F	67 - L57F	44 - L56D		29 - L12C	133 - L31C	
21	55 - L14D	60 - L12E	55 - L14D	131 - L32F	155 - L31B	69 - L54F	25 - L53C	66 - L56F		49 - L12D	134 - L31D	
22	61 - L12E	40 - L12M	15 - L15A	131 - L32F	155 - L31B	23 - L56C	46 - L53D	122 - L31G (90)			135 - L31F	
23	41 - L12M	62 - L12N	37 - L15C	152 - L32B	156 - L31G	44 - L56D	119 - L54G (110)	125 - L54G (90)			120 - L56G	
24	63 - L12N	14 - L15A	57 - L15D	152 - L32B	156 - L31G	66 - L56F	118 - L55G (110)	116 - L31G (110)			123 - L53G	
25	13 - L14A	36 - L15C	11 - L13A	153 - L32G	157 - L31H	3 - L55A	120 - L56G (110)				126 -L56G	
26	35 - L14C	56 - L15D	33 - L13C	153 - L32G	157 - L31H	4 - L55B	123 - L53G (90)				118 - L55G	
27	55 - L14D		53 - L13D	154 - L32H		22 - L55C	126 -L56G (90)					
28			17 - L16A	154 - L32H		43 - L55D						
29			39 - L16C			65 - L55F						
30			59 - L16D			125-L54G (90)						
31						116-L31G (110)						
32						122-L31G (90)						

CANCELLED

Priority	1	2	3	4

~20 encounters/day

Execution

Execution – Quad Video

CONFIGURATION 2

Aircraft, Airspace, and Admin

Ownship

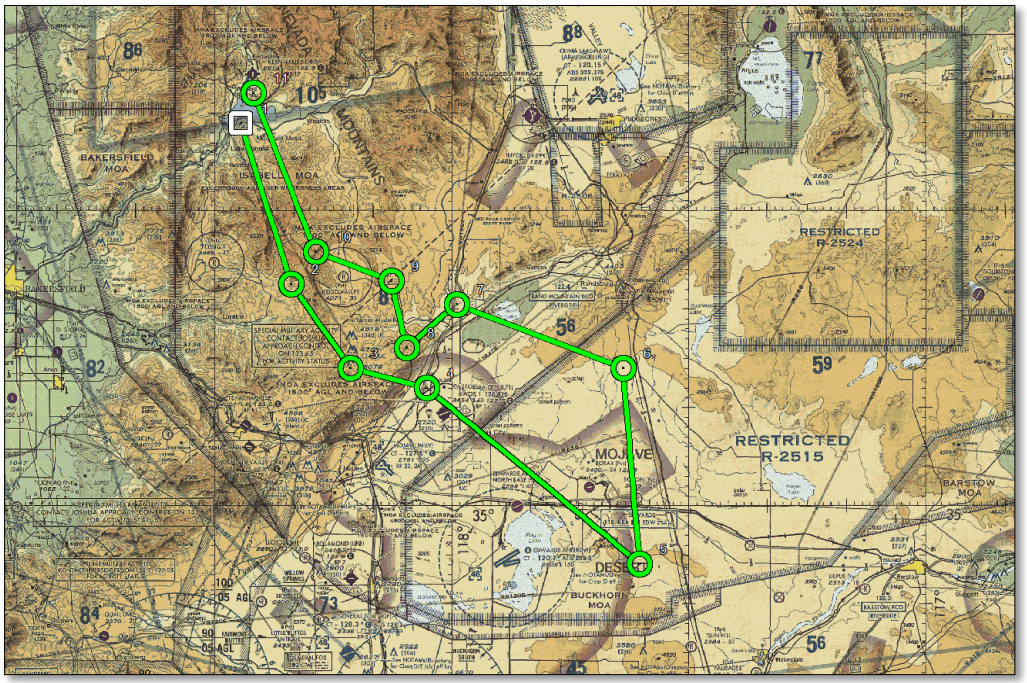
NASA 608
T-34

Intruders

N3GC
King Air

NASA 865
T-34

NASA 7
King Air



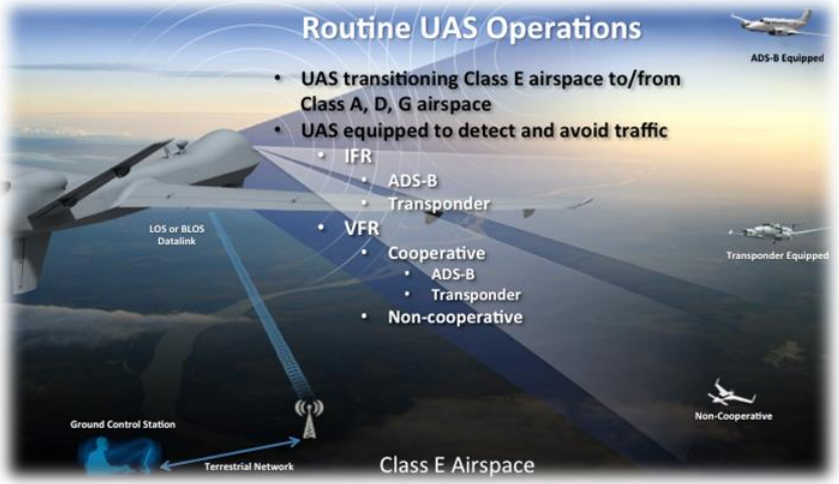
Work Area:

- R-2508
- R-2515, Isabella MOA

Flights:

Brief 1200L (Performed once)
Takeoff 1430L
Land 1730L
Debrief

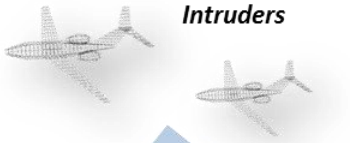
Configuration 2 Concept of Operations



Live Intruder(s)
- *ADS-B*

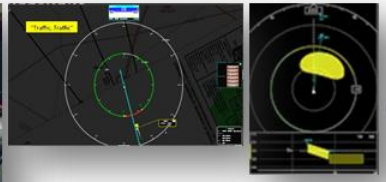
GRC T-34C

CNPC Data Link
- *C2*
- ~~*Voice*~~
- *Health & Status*
- *Traffic (ADS-B)*



Virtual/Constructive Intruders

Research GCS



UAS Pilot Participant

- SAA/DAA Algorithms
- Display of Proximal Traffic

LVC Distributed Network

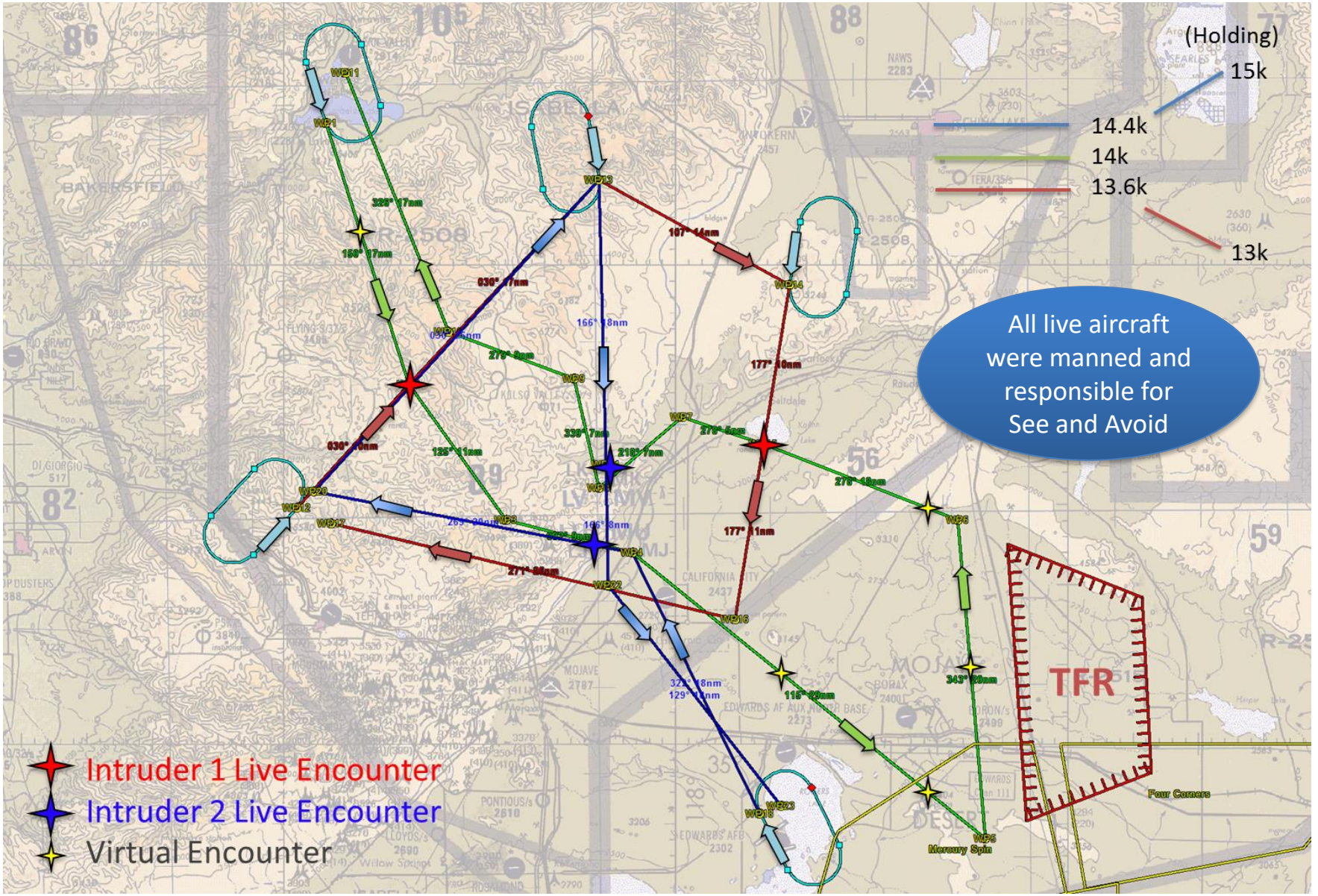
VPN

Virtual ATC

Virtual Intruder(s) (Pseudo Pilots)

Multi-Aircraft Control System

Fireline Route



Mission Information

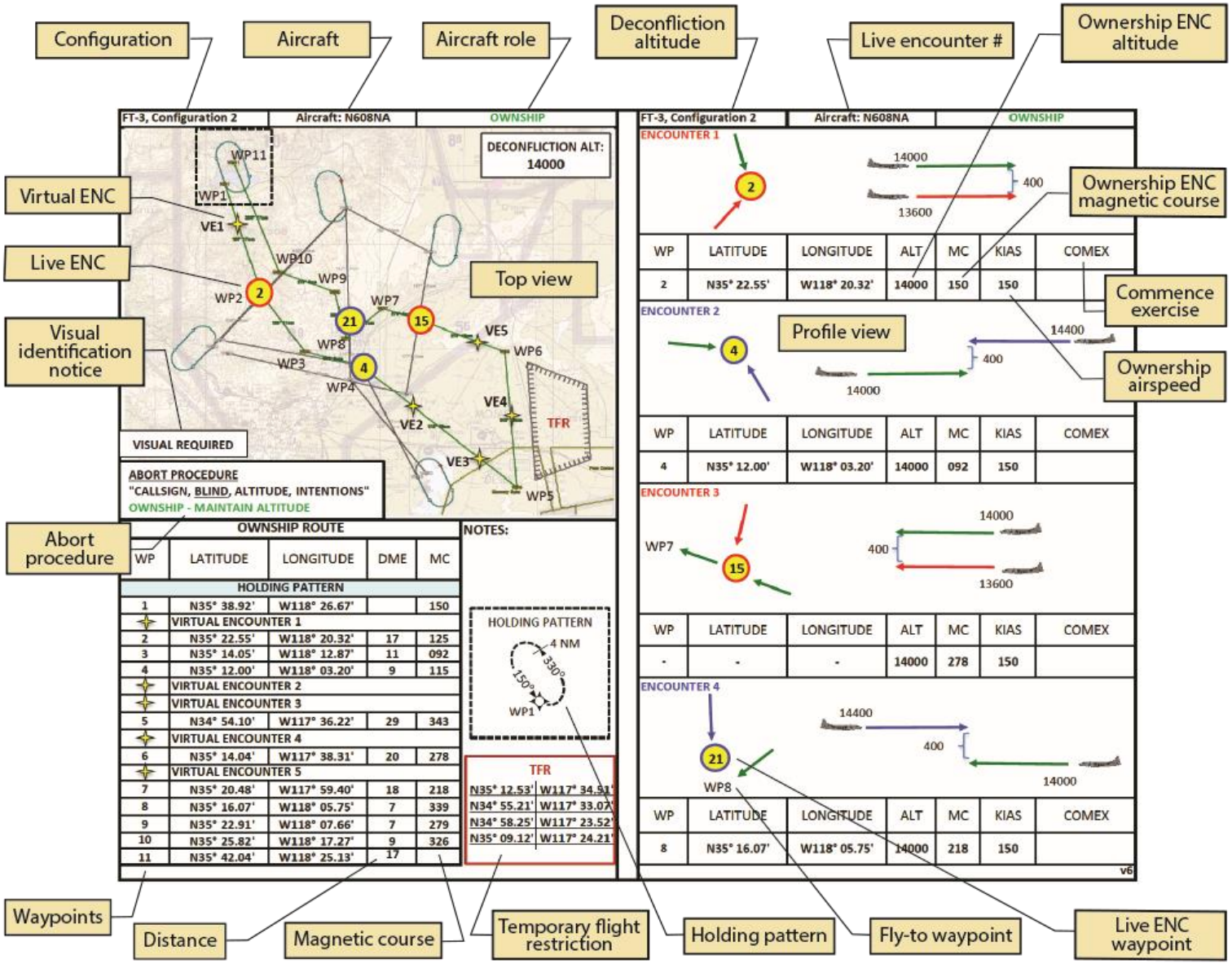
- Only one pre-brief required (static nature of fireline)

	Ops# 2793-1	Ops# 2793-2	Ops# 2793-3		
Time of day	NASA608 T-34	NASA 7 King Air	N3GC King Air	Ames Research Center DSRL	HSI activity
TBD	Start of test day			In the loop	
1200	Mass briefing				Attend
					Human systems integration training (2.0 hours)
Takeoff LSP	1430 KBFL	1430 KEDW	1430 KEDW		
	DSRL/LVC/RGCS up and running				System under test ready
1445	Establish data flow (system check)				
1515	Commense exercise run 1 (40 min + 20 min setup)				Begin test
	Commense exercise run 2				
	Commense exercise run 3				
	Finish exercise - return to base (data archiving)				End test
Recover	1730 KBFL	1770 KEDW	1745 KVNY		
1845	Flight debrief				Attend
1945	End of test day				

Schedule

Flight	Date	Day of Week	System Under Test	Encounter Types	Planned LIVE Encounters	Flown LIVE Encounters	LIVE Points Achieved	Virtual Points Flown
GRC 1	13-Jul-15	M	CNPC	(None)	0	0	0	0
CST 1	16-Jul-15	Th	CNPC	Targets of Opportunity	0	0	0	0
CST 2	28-Jul-15	Tu	CNPC	Live	4	2	0	0
GRC 2	29-Jul-15	W	INS	(None)	0	0	0	0
CST 3	29-Jul-15	W	CNPC	(None)	0	0	0	0
GRC 3	30-Jul-15	Th	CNPC	(None)	0	0	0	0
Rehearsal 1	3-Aug-15	M	CNPC	Live	8	4	0	0
GRC 4	4-Aug-15	Tu	CNPC	(None)	0	0	0	0
CST 4	4-Aug-15	Tu	CNPC	Live, Virtual	4	2	0	2
CST 5	5-Aug-15	W	CNPC	Live, Virtual	6	5	0	9
Rehearsal 2	6-Aug-15	Th	CNPC	(None)	8	0	0	0
Rehearsal 3	7-Aug-15	F	CNPC	Live	8	1	0	0
Data 1	10-Aug-15	M	HSI/RGCS	Live, Virtual	8	8	7	11
Data 2	11-Aug-15	Tu	HSI/RGCS	Live, Virtual	8	8	6	9
Data 3	12-Aug-15	W	HSI/RGCS	Live, Virtual	8	8	5	10
Data 4	13-Aug-15	Th	HSI/RGCS	CANCELLED				
Data 5	17-Aug-15	M	HSI/RGCS	CANCELLED				
Data 6	18-Aug-15	Tu	HSI/RGCS	CANCELLED				
Data 7	19-Aug-15	W	HSI/RGCS	CANCELLED				
Data 8	20-Aug-15	Th	HSI/RGCS	CANCELLED				
Data 9	21-Aug-15	F	HSI/RGCS	CANCELLED				
Data 10	24-Aug-15	M	HSI/RGCS	CANCELLED				
				Totals	**62**	**38**	**18**	**41**

Example Flight Card



WP	LATITUDE	LONGITUDE	DME	MC
HOLDING PATTERN				
1	N35° 38.92'	W118° 26.67'		150
VIRTUAL ENCOUNTER 1				
2	N35° 22.55'	W118° 20.32'	17	125
3	N35° 14.05'	W118° 12.87'	11	092
4	N35° 12.00'	W118° 03.20'	9	115
VIRTUAL ENCOUNTER 2				
VIRTUAL ENCOUNTER 3				
5	N34° 54.10'	W117° 36.22'	29	343
VIRTUAL ENCOUNTER 4				
6	N35° 14.04'	W117° 38.31'	20	278
VIRTUAL ENCOUNTER 5				
7	N35° 20.48'	W117° 59.40'	18	218
8	N35° 16.07'	W118° 05.75'	7	339
9	N35° 22.91'	W118° 07.66'	7	279
10	N35° 25.82'	W118° 17.27'	9	326
11	N35° 42.04'	W118° 25.13'	17	

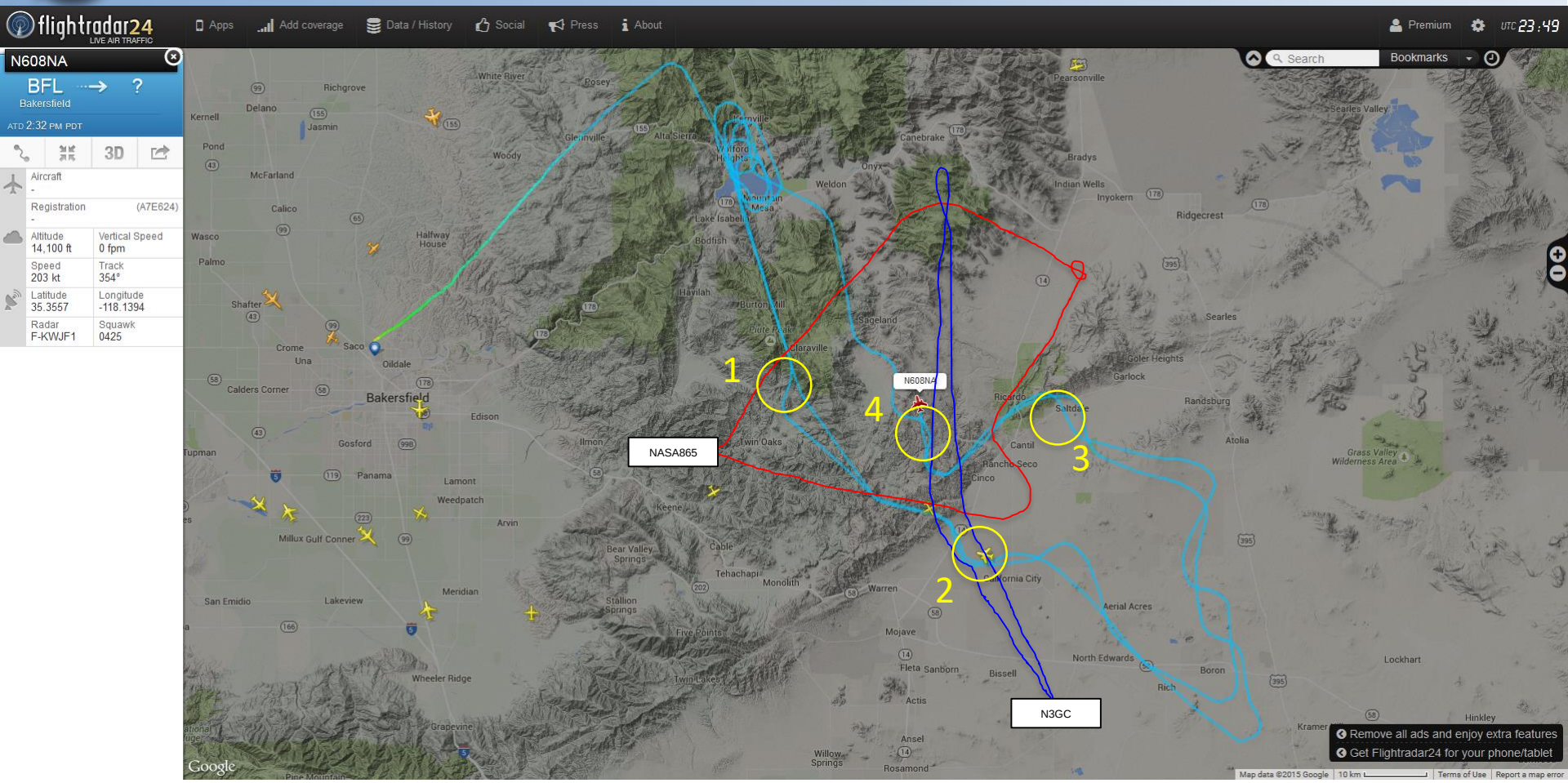
WP	LATITUDE	LONGITUDE	ALT	MC	KIAS	COMEX
2	N35° 22.55'	W118° 20.32'	14000	150	150	

WP	LATITUDE	LONGITUDE	ALT	MC	KIAS	COMEX
4	N35° 12.00'	W118° 03.20'	14000	092	150	

WP	LATITUDE	LONGITUDE	ALT	MC	KIAS	COMEX
-	-	-	14000	278	150	

WP	LATITUDE	LONGITUDE	ALT	MC	KIAS	COMEX
8	N35° 16.07'	W118° 05.75'	14000	218	150	

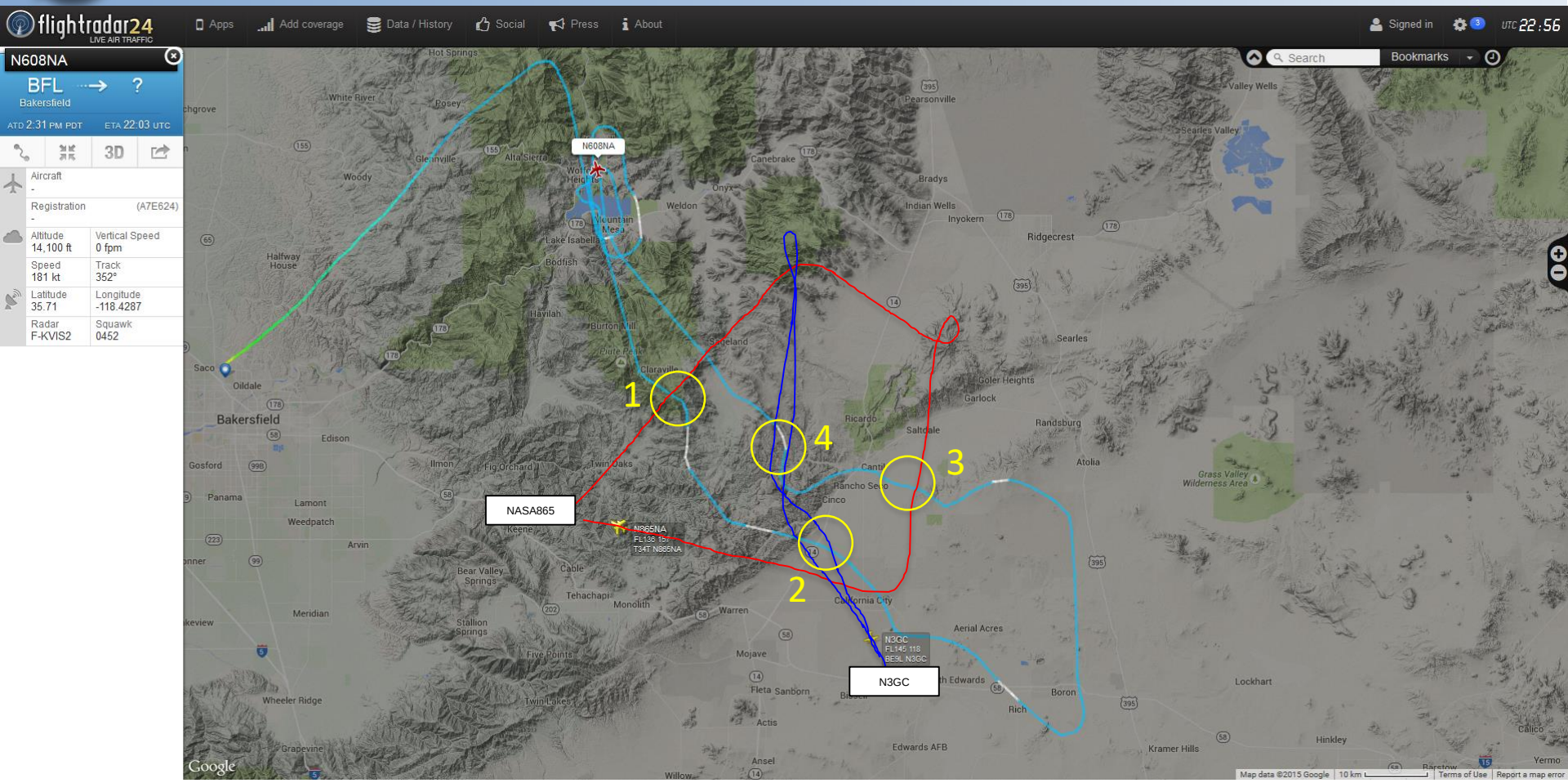
Data Collection 1, Run 2: August 10, 2015



1: Maneuver
2: Maneuver
3: Maneuver
4: Maneuver

- Incorrect alerting on encounter 4

Data Collection 2, Run 1: August 11, 2015



1: Maneuver
2: NO maneuver – timing
3: Maneuver
4: Maneuver

- NEW heading for Intruder 2 into encounter 4

LESSONS LEARNED

Operational Observations

1. Configuration 1 and 2 flight tests were distinct and separate
2. Configuration 2 flights were cancelled after 3 of 10 data collection flights and Configuration 1b was not attempted
3. Multiple operating/staging locations decreased efficiency in test execution
4. Low priority within R-2515 resulted in missed flight-test opportunities
5. An intruder was within 1 nmi and less than 500 ft vertical separation without being visual on Ikhana
6. Haze, clouds, and wind aloft affecting encounters
7. Understanding success criteria and training operators was critical to mission success

CONCLUDING NOTES

Conclusion

- FT3 Configuration 1 successful
  - All researchers reached main objectives for their SUT
  - For many researchers, first time receiving real flight data
  - Flew milestone encounters:
    - Live UAS multi-ship encounter
    - TCAS Auto
    - TCAS sequential advisory
- FT3 Configuration 2 cancelled after 3 data collection flights
  - Gathered many lessons learned to improve FT4 and beyond

- Flight Test Series 4 (FT4) was successfully flown in 2016
  - Similar to FT3 Configuration 1
  - Even more intruders, sensors, and configurations
  - Operational successful built heavily on lessons learned from FT3
- ACAS Xu FT2 will begin next week!
  - NASA Armstrong acting as responsible test organization once again

FT3 Team Photo

BACKUP

Altimeter Calibration Card

ver 3

FT3 ALTIMETER CALIBRATION

REJOIN AND ALTITUDE CALIBRATION:

1. All aircraft set with 29.92" altimeter setting.
2. IKHANA loads appropriate Lost Link Mission. (IKHANA Only)
3. OWNSHIP holds at CP6, LEFT HAND TURNS.
4. CHASE arrives for rejoin at an initial altitude of 11,000' then climbs to mainain 500 feet sparation until visual, then completes rejoin at 12,000'
5. OWNSHIP calls altitude in feet MSL.
6. CHASE adjusts altimeter setting to match OWNSHIP altitude.
7. CHASE calls altitude in feet MSL. Maintain new altitude setting for duration.
8. For multiship missions intruders (CHASE) cycle sequentially according to prebrief.
9. CHASE maintain new altitude setting for test runs.

"ALT cal complete, N3GC cleared off <dir> <alt>"
Perform visual calibration if required.

PT	LATITUDE	LONGITUDE	OWNSHIP ALTITUDE	CHASE ALTITUDE	A/S
IP 20	34° 57.89'	117° 33.62'	**12000**	**11000**	**140 KIAS**
	34° 57' 53.4"	117° 33' 37.3"			
CPA6	N34° 57.89'	W117° 24.47'	**12000**		
	N34° 57' 53.4"	W117° 24' 28.2"			