UAS in the NAS Flight Test Series 3 Overview

7 July 2015

- Goals/Objectives

- Participants

- Test Configurations

  – Config 1: Scripted Encounters

  – Config 2: Full Mission

- Future Testing/Schedule

UAS-NAS FT-3 Overview

Flight Test 3 Overview

Top Level Research Goals

Top Level Research Goals:

- Validate results previously collected during project simulations with live data
  - Sensor performance, uncertainty
  - State data uncertainty
  - Wind compensation

- Evaluate TCAS II/SS interoperability

- Test fully integrated system in a relevant live test environment
  - HSI Proof of Concept GCS and pilot guidance displays
  - CNPC performance

- Inform final DAA and C2 MOPS

- Reduce risk for Flight Test Series 4
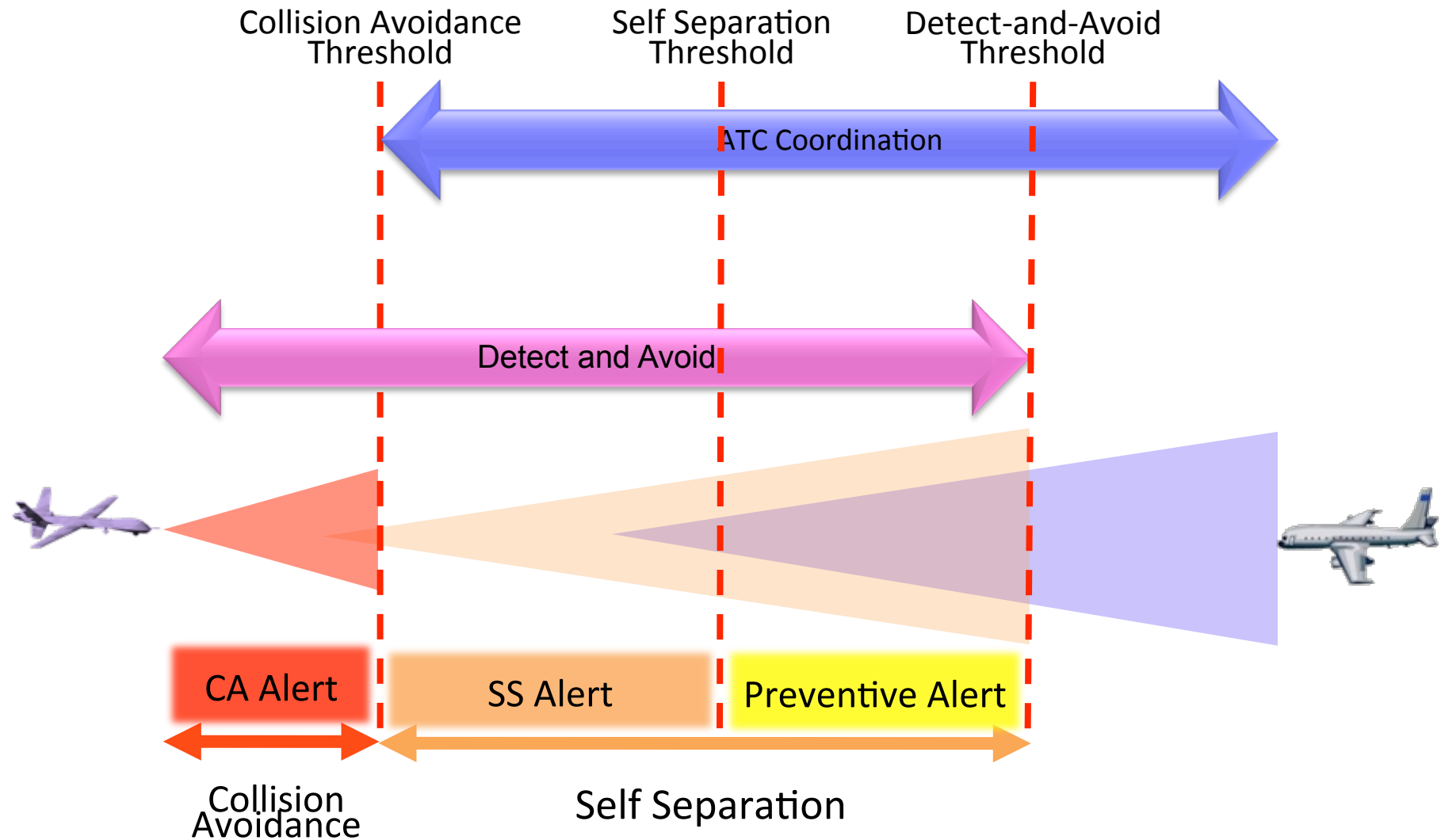 - More complex multi-intruder scenarios
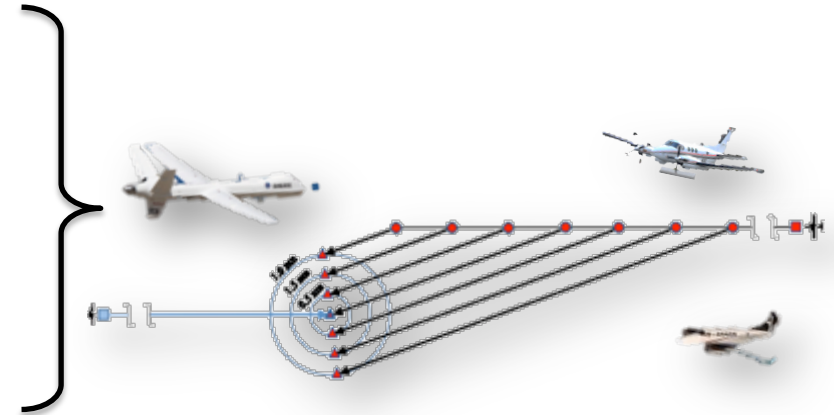
Full Mission Scenario Evaluations
- Live Ownship (Surrogate UA)
- Live and Virtual Intruders
- Representative Operational Mission
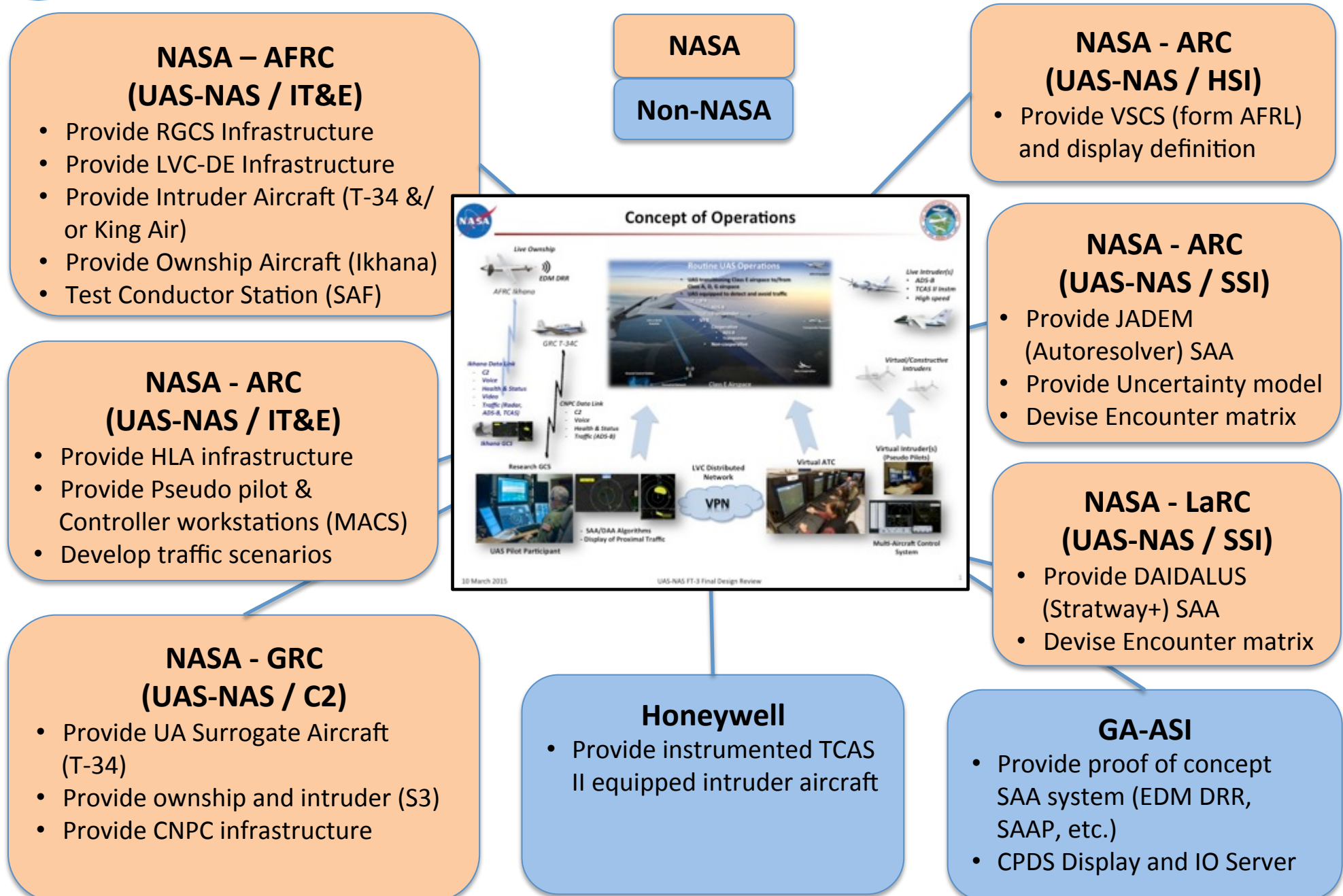- UAS Pilot Participants using RGCS

Detect-and-Avoid Overview

Collision Avoidance Threshold

Self Separation Threshold

Detect-and-Avoid Threshold

ATC Coordination

Detect and Avoid

CA Alert

SS Alert

Preventive Alert

Collision Avoidance

Self Separation

Integration Roles & Responsibilities Summary

NASA

Non-NASA

NASA – AFRC (UAS-NAS / IT&E)
- Provide RGCS Infrastructure
- Provide LVC-DE Infrastructure
- Provide Intruder Aircraft (T-34 &/ or King Air)
- Provide Ownship Aircraft (Ikhana)
- Test Conductor Station (SAF)

NASA - ARC (UAS-NAS / IT&E)
- Provide HLA infrastructure
- Provide Pseudo pilot & Controller workstations (MACS)
- Develop traffic scenarios

NASA - GRC (UAS-NAS / C2)
- Provide UA Surrogate Aircraft (T-34)
- Provide ownship and intruder (S3)
- Provide CNPC infrastructure

NASA - ARC (UAS-NAS / HSI)
- Provide VSCS (form AFRL) and display definition

NASA - ARC (UAS-NAS / SSI)
- Provide JADEM (Autoresolver) SAA
- Provide Uncertainty model
- Devise Encounter matrix

NASA - LaRC (UAS-NAS / SSI)
- Provide DAIDALUS (Stratway+) SAA
- Devise Encounter matrix

Honeywell
- Provide instrumented TCAS II equipped intruder aircraft

GA-ASI
- Provide proof of concept SAA system (EDM DRR, SAAP, etc.)
- CPDS Display and IO Server

Concept of Operations

Research Objectives

- **Research Objectives**
  - **Validate CPA prediction accuracy in realistic flight conditions**
  - **Evaluate TCAS/Self-separation interoperability**
    - **ownship CA/SS interaction**
    - **compatibility with Intruder's TCAS**
  - **Validate Self-separation trajectory model for ownship maneuvers**
  - **Qualitatively evaluate pilot impression of Self-separation advisories**
  - **Validate data fusion/best source selection model**
  - **Validate sensor and tracking models used for preliminary MOPS**
  - **Evaluate TCAS II installed performance on a UAS**
  - **Inform final MOPS**

- ## Test Requirements

  - ### Live Ownship (OS)

    - Low Speed OS – DRR, ADS-B, and TCAS Sensors, Sensor Fusion
      - » Higher Priority Test Points
      - » Ikhana
        - EDM DRR (±110° az and ±15° elev) non-coop sensor
        - ADS-B coop sensor
        - TCAS II v7.1 coop sensor
        - HON STM (sensor fusion/tracker)

    Config #1a

    - High Speed OS – ADS-B coop sensor
      - » Lower Priority Test Points
      - » 250 KGS capable
      - » CNPC equipped
      - » S-3B-equipped with ADS-B only
        - Onboard pilot will maneuver based on onboard display cues of commands uplinked from RGCS pilot via CNPC link

    Config #1b

  - ### Live Intruder(s)

    - ADS-B equipped
    - TCAS II Instrumentation for interoperability test
    - High speed (250 KGS capable)
    - Multiple – 2

Live Ownship

ADS-B Out

Live Intruder(s)
- **ADS-B**
- **TCAS II**
- **High speed**

Ikhana Data Link
- **C2**
- **Voice**
- **Health & Status**
- **Video**
- **Traffic (Radar, ADS-B,TCAS)**
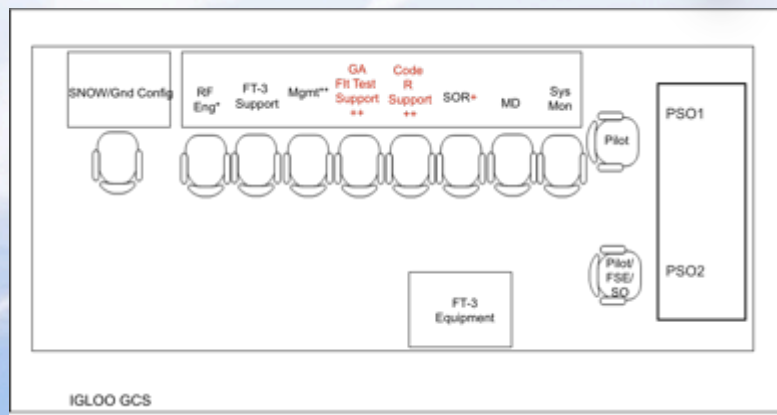
Displays of Proximal Traffic SAA/DAA Algorithms
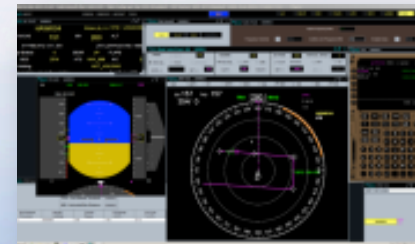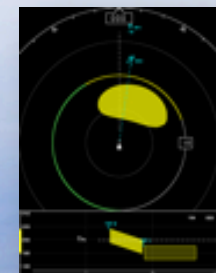

Stratway+/DAIDALUS

CPDS

Ikhana GCS

Autoresolver

Flight Test 3 Scripted Encounters

Test Requirements

- **Test Requirements**
  - **Live Ownship (OS)**
    - Low Speed OS – DRR, ADS-B, and TCAS Sensors, Sensor Fusion
      - » **Higher Priority Test Points**
      - » **Ikhana**
        - EDM DRR (±110º az and ±15º elev) non-coop sensor
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        - HON STM (sensor fusion/tracker)

        Config #1a

    - High Speed OS – ADS-B coop sensor
      - » **Lower Priority Test Points**
      - » **250 KGS capable**
      - » **CNPC equipped**
      - » **S-3B-equipped with ADS-B only**
        - Onboard pilot will maneuver based on onboard display cues of commands uplinked from RGCS pilot via CNPC link

        Config #1b

  - **Live Intruder(s)**
    - ADS-B equipped
    - TCAS II Instrumentation for interoperability test
    - High speed (250 KGS capable)
    - Multiple – 2

Live Ownship

GRC S-3B

ADS-B Out

Live Intruders
- **ADS-B**
- **TCAS II**
- **High speed**

CNPC
Data Link
- *C2*
- *Voice*
- *H&S*
- *Traffic*

Displays of Proximal Traffic
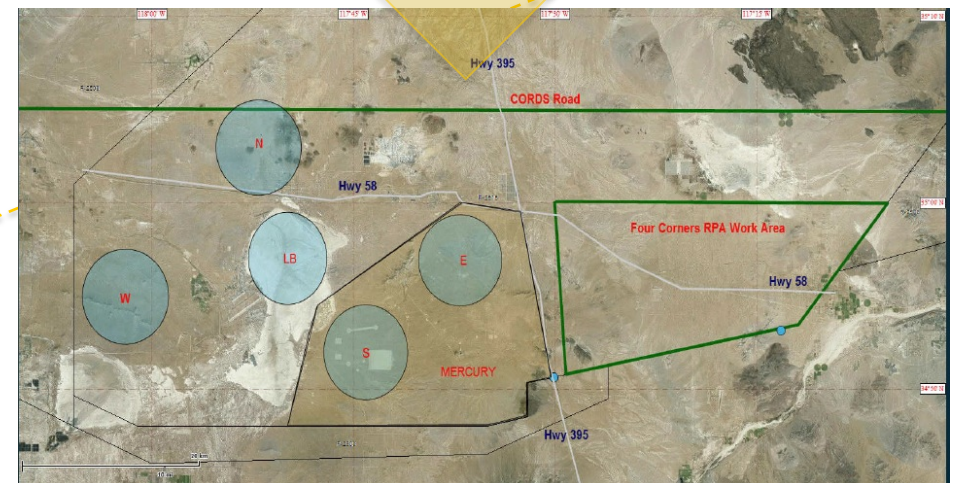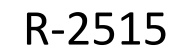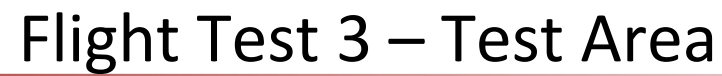**SAA/DAA Algorithms**

Research GCS

Autoresolver

FT-3 Aircraft Equipment Requirements

Aircraft	Responsibility	EDM DRR	ADS-B	GPS	TCAS-II	Config 1A	Config 1B	Config 2
	Ownship NASA AFRC's Ikhana UAS	✓	✓	✓	✓	✓		
	Ownship or Intruder UAS Surrogate NASA GRC, T-34 Mentor		✓	✓				✓
	NASA GRC S-3B Viking High Speed Ownship or Intruder		✓	✓		✓	✓	
	Honeywell Beechcraft King Air C90 manned aircraft used as an intruder		✓	✓	✓	✓	✓	✓
	Second / Backup Intruder NASA AFRC T-34		✓	✓		✓	✓	✓
	Second / Backup Intruder NASA AFRC King Air		✓	✓		✓	✓	✓

Flight Test 3 – Test Area


R-2508 Complex

R-2515

Mercury Spin & Four Corners

Configuration 1 Encounter Airspace
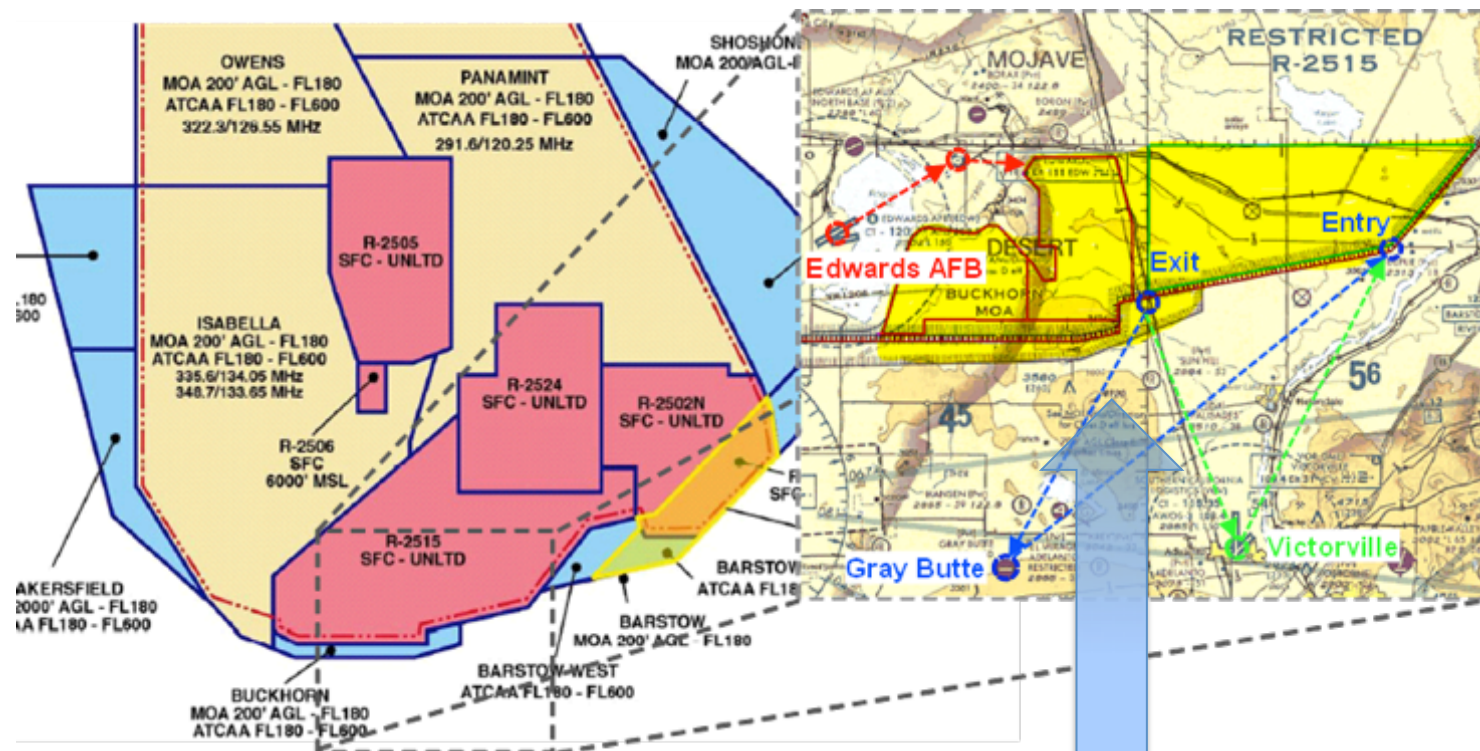
- Pairwise, low speed–low speed encounters that requires Ikhana ownship versus a low speed intruder aircraft (C90 or T-34C) [Configuration 1A];
- Pairwise, low speed–high speed encounters that requires Ikhana ownship versus S-3B [Configuration 1A];
- Pairwise, low speed–low/high speed encounters that requires Ikhana ownship versus multi-intruder aircraft (one low speed intruder (T-34C or C90) and one high speed intruder (S-3B) [Configuration 1A];
- Pairwise, high speed–low speed encounters that requires S-3B ownship versus a low speed intruder (T-34C or C90) [Configuration 1B].
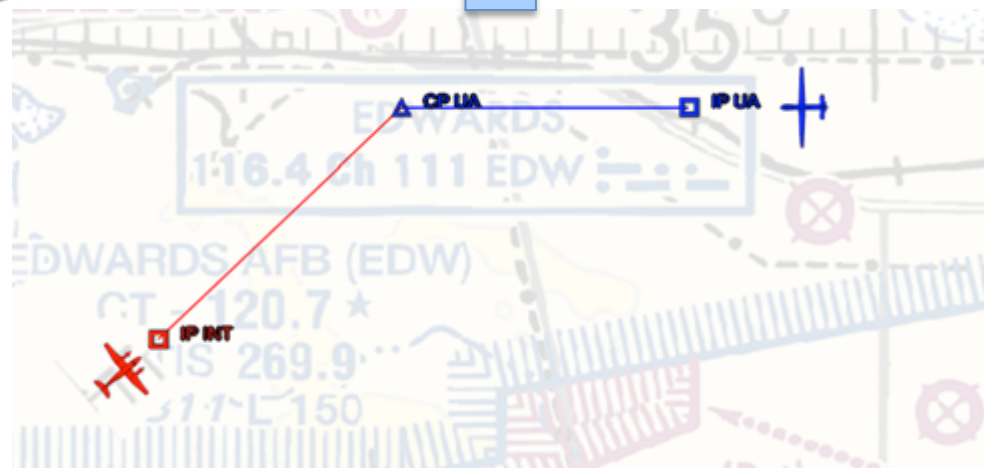
FT3 Sortie flow

	JADEM			CPDS		Stratway+			High Speed		
	1	2	3	4	5	6	7	8	9	10	11
	17-Jun	18-Jun	22-Jun	24-Jun	26-Jun	7-Jul	9-Jul	10-Jul	20-Jul	22-Jul	24-Jul
	W	Th	M	W	F	Tu	Th	F	M	W	F
1	18 - L12A	10 - L13A	15 - L15A	137 - L53C	124 - L55G (90)	1 - L42A	3 - L55A	62 - L12N	79 - H12A	80 - H12A	83 - H12A
2	19 - L52A	32 - L13C	37 - L15C	137 - L53C	108 - L12A (2)	2 - L42B	4 - L55B	63 - L12N	81 - H12A	82 - H12A	85 - H12A
3	20 - L32A	52 - L13D	57 - L15D	146 - L54D	107 - L12A (1)	21 - L42C	22 - L55C	8 - M59Q	87 - H12C	88 - H12C	91 - H12C
4	29 - L12C	16 - L16A	11 - L13A	146 - L54D	112 - L11A (2)	42 - L42D	43 - L55D	9 - M59U	89 - H12C	90 - H12C	93 - H12C
5	30 - L52C	38 - L16C	33 - L13C	140 - L55A	111 - L11A (1)	64 - L42F	65 - L55F	27 - M59R	95 - H12D	96 - H12D	99 - H12D
6	31 - L32C	58 - L16D	53 - L13D	140 - L55A	164 - L42M	25 - L53C	7 - L57A	28 - M59V	97 - H12D	98 - H12D	101 - H12D
7	49 - L12D	14 - L15A	17 - L16A	151 - L56F	165 - L52M (1)	46 - L53D	24 - L57C	48 - M59S	72 - H42A	80 - H12A	84 - H12A
8	50 - L52D	36 - L15C	39 - L16C	151 - L56F	166 - L52M (2)	68 - L53F	45 - L57D	70 - M59T	73 - H42C	82 - H12A	86 - H12A
9	51 - L32D	56 - L15D	59 - L16D	159 - L57D	167 - L52M (3)	26 - L54C	67 - L57F	71 - M59W	74 - H42D	88 - H12C	92 - H12C
10	60 - L12E	15 - L15A	18 - L12A	159 - L57D	168 - L52M (4)	47 - L54D	21 - L42C	8 - M59Q	75 - H42F	90 - H12C	94 - H12C
11	40 - L12M	37 - L15C	19 - L52A	128 - L32A	169 - M79X (1)	69 - L54F	42 - L42D	9 - M59U	76 - M59R	96 - H12D	100 - H12D
12	62 - L12N	57 - L15D	20 - L32A	128 - L32A	170 - M79X (2)	5 - L56A	64 - L42F	27 - M59R	77 - M59S	98 - H12D	102 - H12D
13	12 - L14A	11 - L13A	29 - L12C	129 - L32C	171 - M79X (3)	6 - L56B	25 - L53C	28 - M59V	78 - M59T	79 - H12A	103 - H12H
14	34 - L14C	33 - L13C	30 - L52C	129 - L32C	160 - M67Q	23 - L56C	46 - L53D	48 - M59S	76 - M59R	81 - H12A	105 - H12H
15	54 - L14D	53 - L13D	31 - L32C	130 - L32D	162 - M27Q	44 - L56D	26 - L54C	70 - M59T	77 - M59S	87 - H12C	
16	61 - L12E	17 - L16A	49 - L12D	130 - L32D	172 - M27Q	66 - L56F	47 - L54D	71 - M59W	78 - M59T	89 - H12C	
17	41 - L12M	39 - L16C	50 - L52D	131 - L32F	161 - M68Q	20 - L32A	22 - L55C	31 - L32C	72 - H42A	95 - H12D	
18	63 - L12N	59 - L16D	51 - L32D	131 - L32F	163 - M28Q	31 - L32C	43 - L55D	51 - L32D	73 - H42C	97 - H12D	
19	13 - L14A	9 - M59U	12 - L14A	152 - L32B	173 - M28Q	51 - L32D	65 - L55F	62 - L12N	74 - H42D	136 - L53A	Margin
20	35 - L14C	48 - M59S	34 - L14C	152 - L32B	132 - L31A	68 - L53F	24 - L57C	63 - L12N	75 - H42F	136 - L53A	
21	55 - L14D	71 - M59W	54 - L14D	153 - L32G	132 - L31A	69 - L54F	45 - L57D	133 - L31C	110 - L12A (4)	138 - L53D	
22	61 - L12E	60 - L12E	10 - L13A	153 - L32G	155 - L31B	23 - L56C	67 - L57F	133 - L31C	109 - L12A (3)	138 - L53D	
23	41 - L12M	40 - L12M	32 - L13C	154 - L32H	155 - L31B	44 - L56D	158 - L57A	134 - L31D	114 - L11A (4)	139 - L53F	
24	63 - L12N	62 - L12N	52 - L13D	154 - L32H	156 - L31G	66 - L56F	158 - L57A	134 - L31D	113 - L11A (3)	139 - L53F	
25	13 - L14A	14 - L15A	16 - L16A	115 - L32G (110)	156 - L31G	122 - L31G (90)	119 - L54G (110)	135 - L31F	127 - L92P	141 - L55C	
26	35 - L14C	36 - L15C	38 - L16C	117 - L53G (110)	157 - L31H	125 - L55G (90)	118 - L55G (110)	135 - L31F	123 - L53G (90)	141 - L55C	
27	55 - L14D	56 - L15D	58 - L16D	121 - L32G (90)	157 - L31H	116 - L51G (110)	120 - L56G (110)		126 - L56G (90)		

Sortie length concerns

Total Sorties – 11
Total Encounters – 282
- 105 JADEM
- 80 Stratway+
- 83 CPDS
- 14 - Config 1b JADEM

| Priority 1 |
| Priority 2 |
| Priority 3 |
| Priority 4 |

JADEM Only:
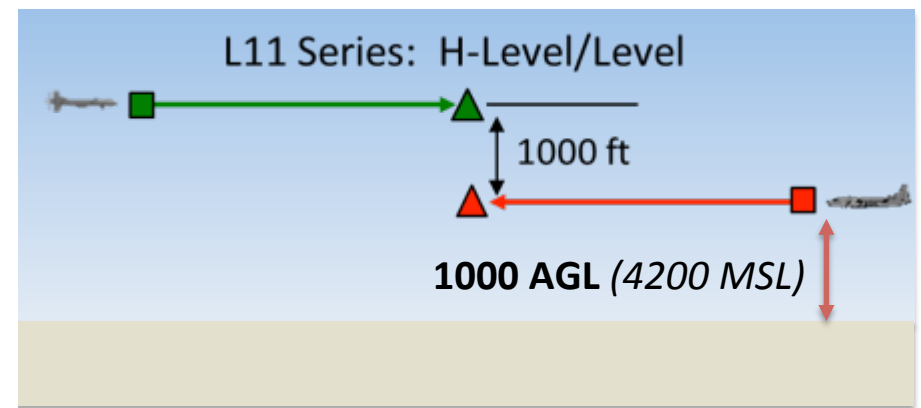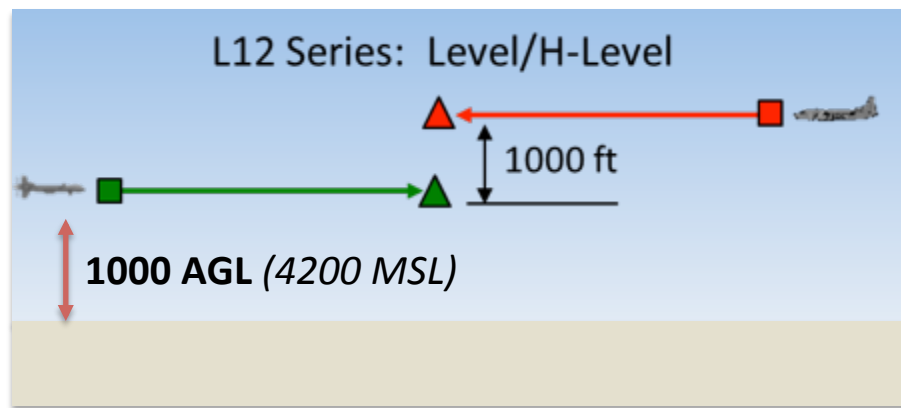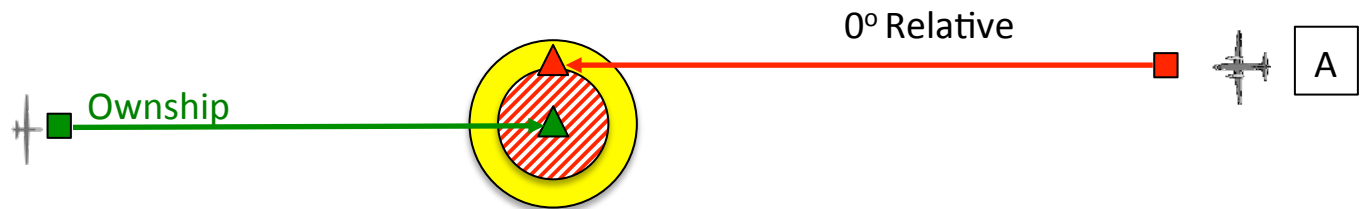
Autoresolver 1
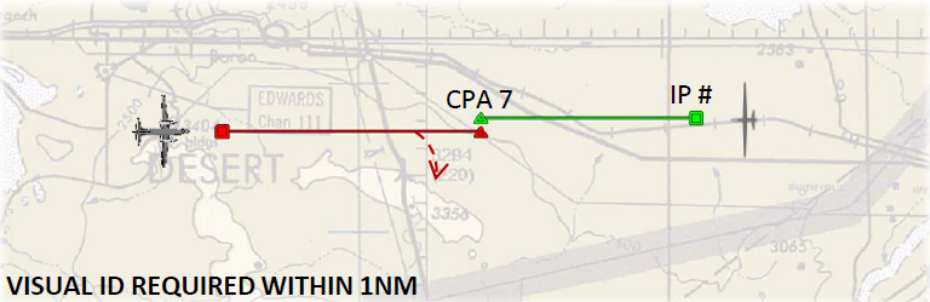Autoresolver 2
XML File Change

Display Change:

CPDS
Stratway+

7 July 2015

...overview

14

GA-ASI Radar Encounters (Ground Clutter)

Flight 5 26-Jun	Flight 9 20-Jul
108 - L12A (2)	110 - L12A (4)
107 - L12A (1)	109 - L12A (3)
112 - L11A (2)	114 - L11A (4)
111 - L11A (1)	113 - L11A (3)

0° Relative

A

Ownship

L12 Series: Level/H-Level

1000 ft

1000 AGL (4200 MSL)

L11 Series: H-Level/Level

1000 ft

1000 AGL (4200 MSL)

■ Initial Point (IP)
● Maneuver Point (MP)
▲ Closest Point of Approach (CPA)
⊘ Lateral Offset = 0.5 nmi
○ SS Alerting Boundary=0.75 nmi
Minimum Altitude Offset ≥ 1000 ft

Card# L56A — Ownship

Card# — **L56A** — Ownship

VISUAL ID REQUIRED WITHIN 1NM

1. TC announces COMEX time.
2. Announce "<Callsign>, IP Inbound, altitude & special procedure review" crossing IP.
3. Aircraft on condition at least 2 minutes prior to CPA.
4. TC calls "terminate" when run complete.
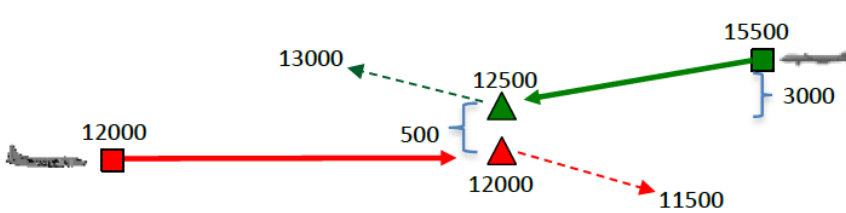5. TC announces next Card Number.

LOST LINK MISSION:
LL-CP7 (WP7)

DECONFLICTION ALT:
13000

☐ AR 1	☐ AR 2	☐ Stratway+	☐ CPDS
☐ OFF		☐ Advisory	☐ AUTO
☐ ADS-B		☐ RADAR	☐ TCAS	☐ TRACKER

ABORT PROCEDURE

13000 — MAINTAIN HDG

COMEX TIME: — **IP TIME ADJUST:**

PT	LATITUDE	LONGITUDE	ALT / V/V	DIST / MC	G/S	TIME HACK
IP	N34° 57.09'	W117° 18.47'	15500	7.5	150	
	N34° 57' 05.4''	W117° 18' 28.2''	-1000	258		
CPA7	N34° 57.09'	W117° 27.62'	12500	0.0	150	
	N34° 57' 05.4''	W117° 27' 37.2''	0	258		

Card# L56A — Intruder 1

Card# — **L56A** — Intruder 1

VISUAL ID REQUIRED WITHIN 1NM

1. TC announces COMEX time.
2. Announce "<Callsign>, IP Inbound, altitude & special procedure review" crossing IP.
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4. TC calls "terminate" when run complete.
5. TC announces next Card Number.

DECONFLICTION ALT:
12000

ABORT PROCEDURE

11500 — 120

COMEX TIME: — **IP TIME ADJUST:**

PT	LATITUDE	LONGITUDE	ALT / V/V	DIST / MC	G/S	TIME HACK
IP	N34° 56.60'	W117° 38.60'	12000	9.0	180	
	N34° 56' 35.8''	W117° 38' 36.0''	0	78		
CPA	N34° 56.60'	W117° 27.62'	12000	0.0	180	
	N34° 56' 35.8''	W117° 27' 37.2''	0	78		

Ikhana FT-3 Config 1a Typical Mission Flow

- T-1 (Noon-ish): Day before detailed brief
  - To protect crew rest for back-to-back flights
- T-0 (0415): All crew pre-flight delta brief
- (0430): Individual aircraft crew brief, as required
- Each aircraft take-off to arrive within R2515 at required time
  - 0600 for Ikhana
- Ikhana and single manned aircraft perform altitude calibration
  - If multiple intruders, manned and manned aircraft perform altitude calibration
- Prior to each scenario
  - Verify scenario number
  - Verify LL Mission and Initial Way Point and Altitude Loaded (Ikhana)
  - Verify FT-3 software mode (Ikhana)
  - Verify expected FT-3/Ikhana behavior
  - Review scenario abort procedures
  - Verify Nav error
  - Verify appropriate display is being displayed to pilots (Ikhana)

- Provides 'full picture' to Test Conductor & Test Director
- Enhancements include:
  - Large screen displays (32")
  - SS display repeater
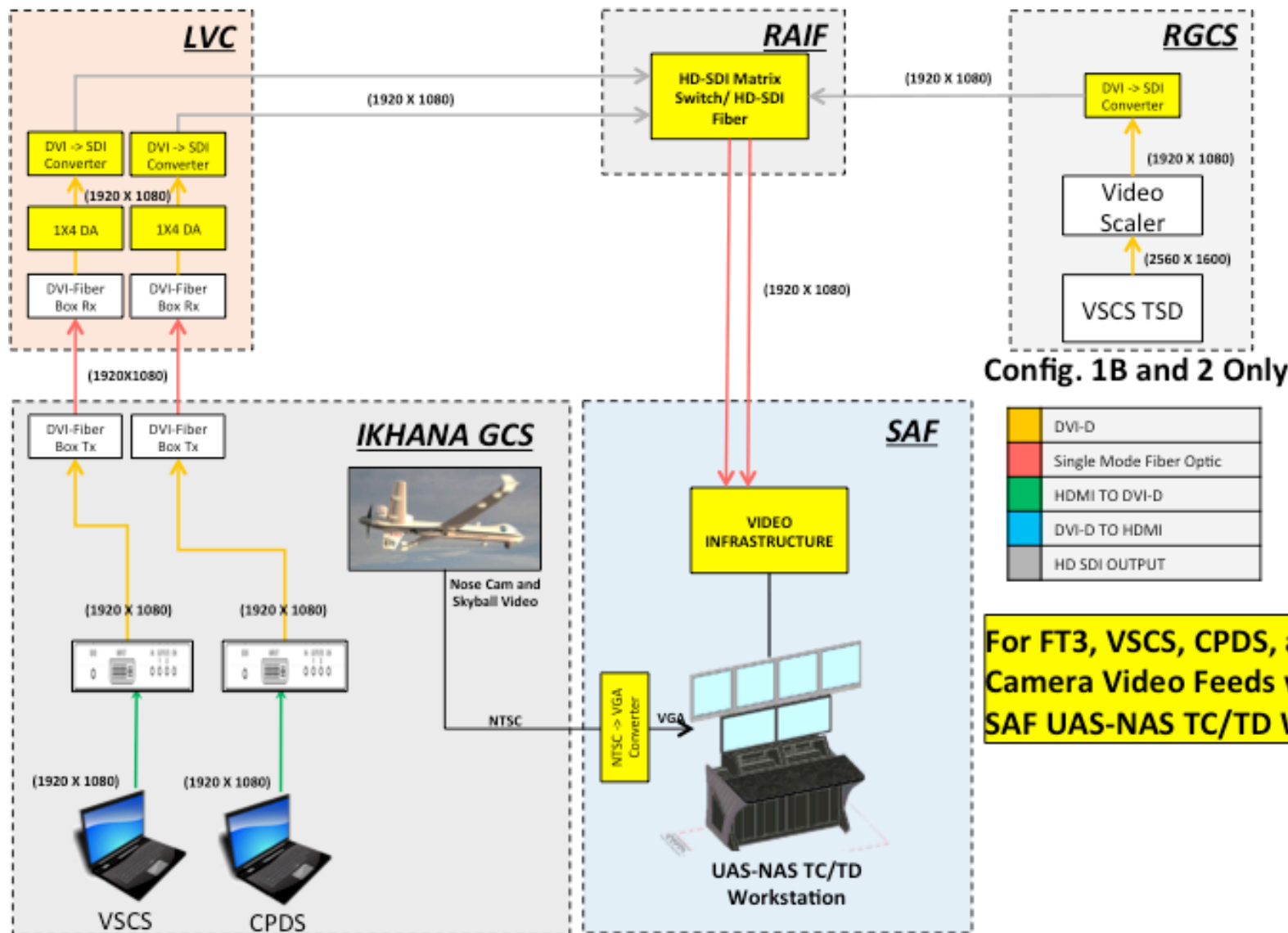 - Common architecture

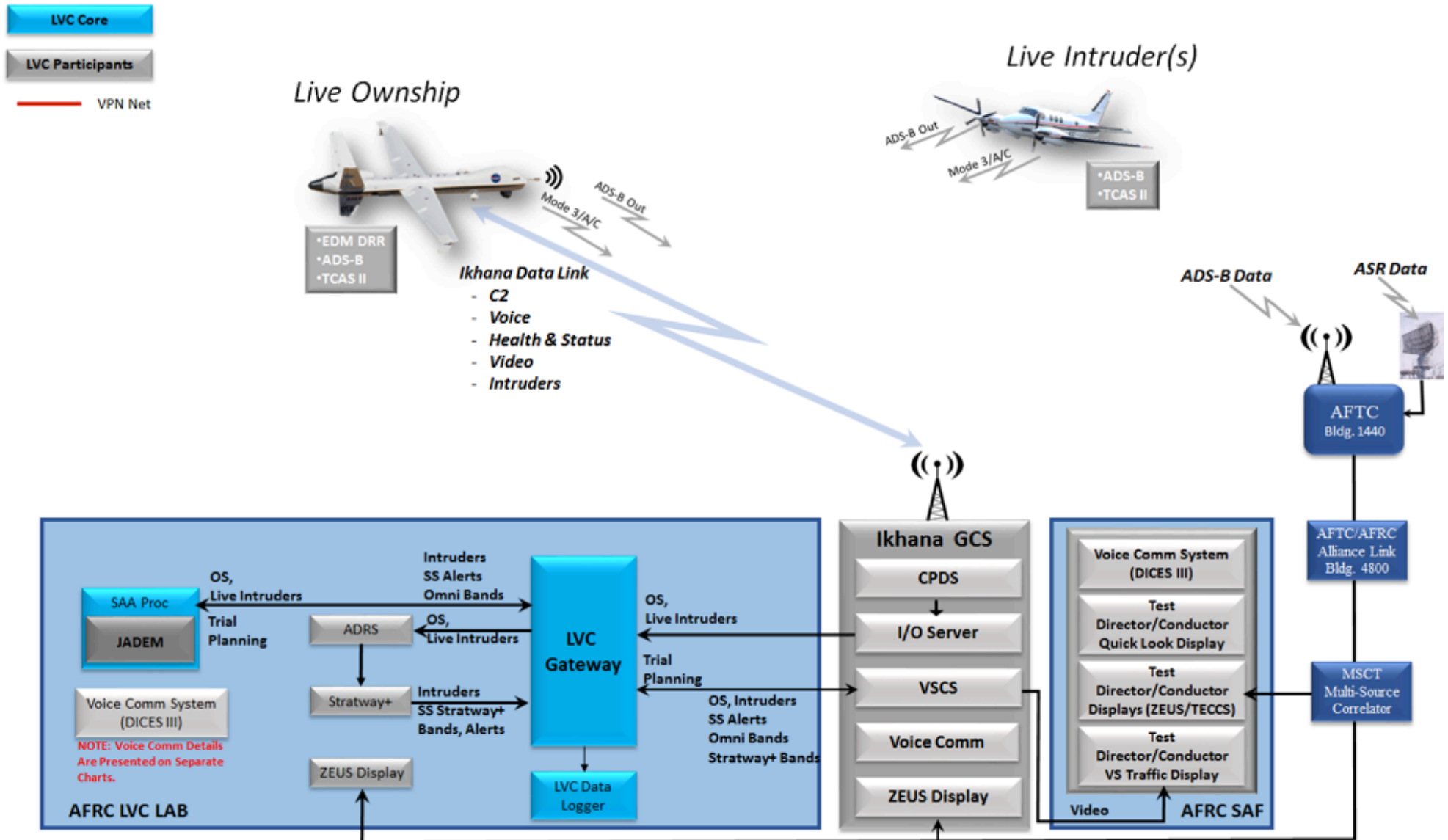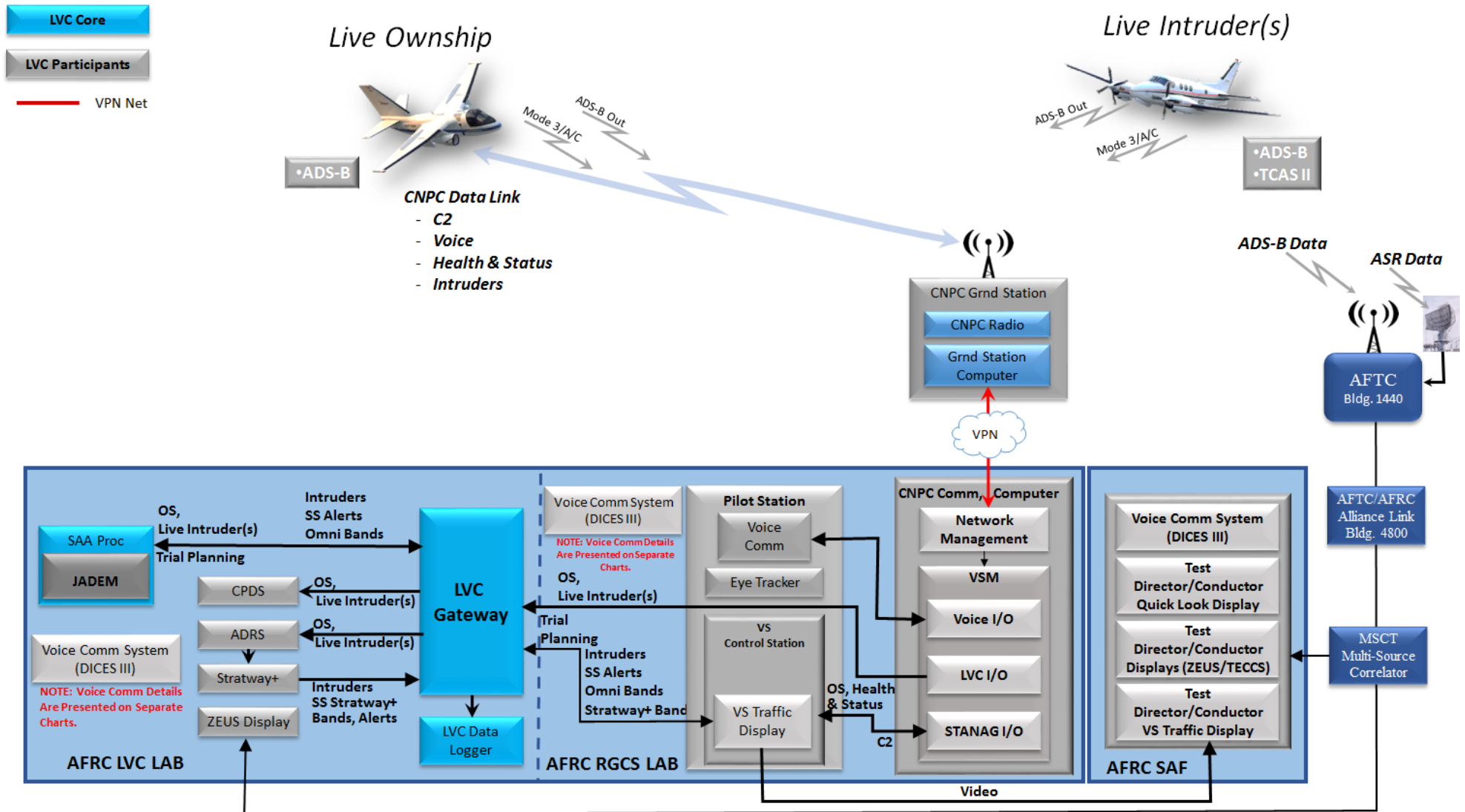Zeus Secondary   Ikhana Nose Video   Ikhana MTS Video   SS Display Repeater

Zeus Primary

Quicklook

DICES
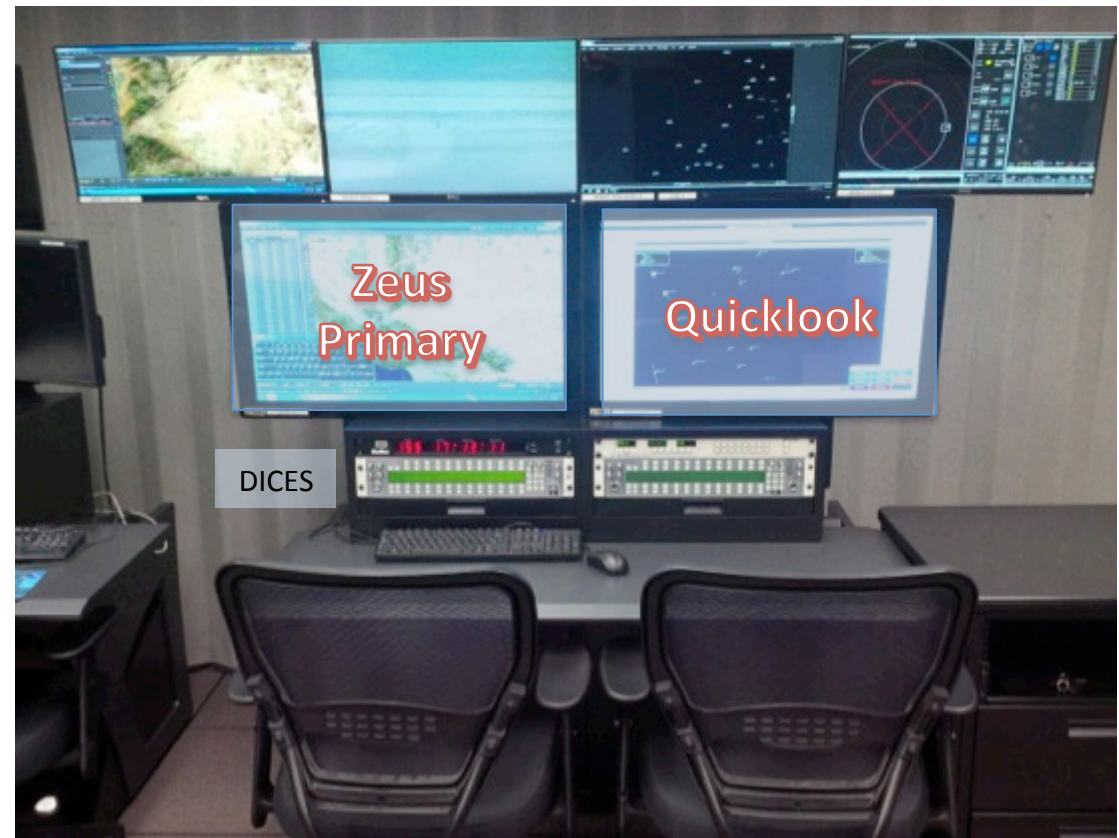
Video Distribution System

Test Configuration #2: Full Mission

Oakland Center
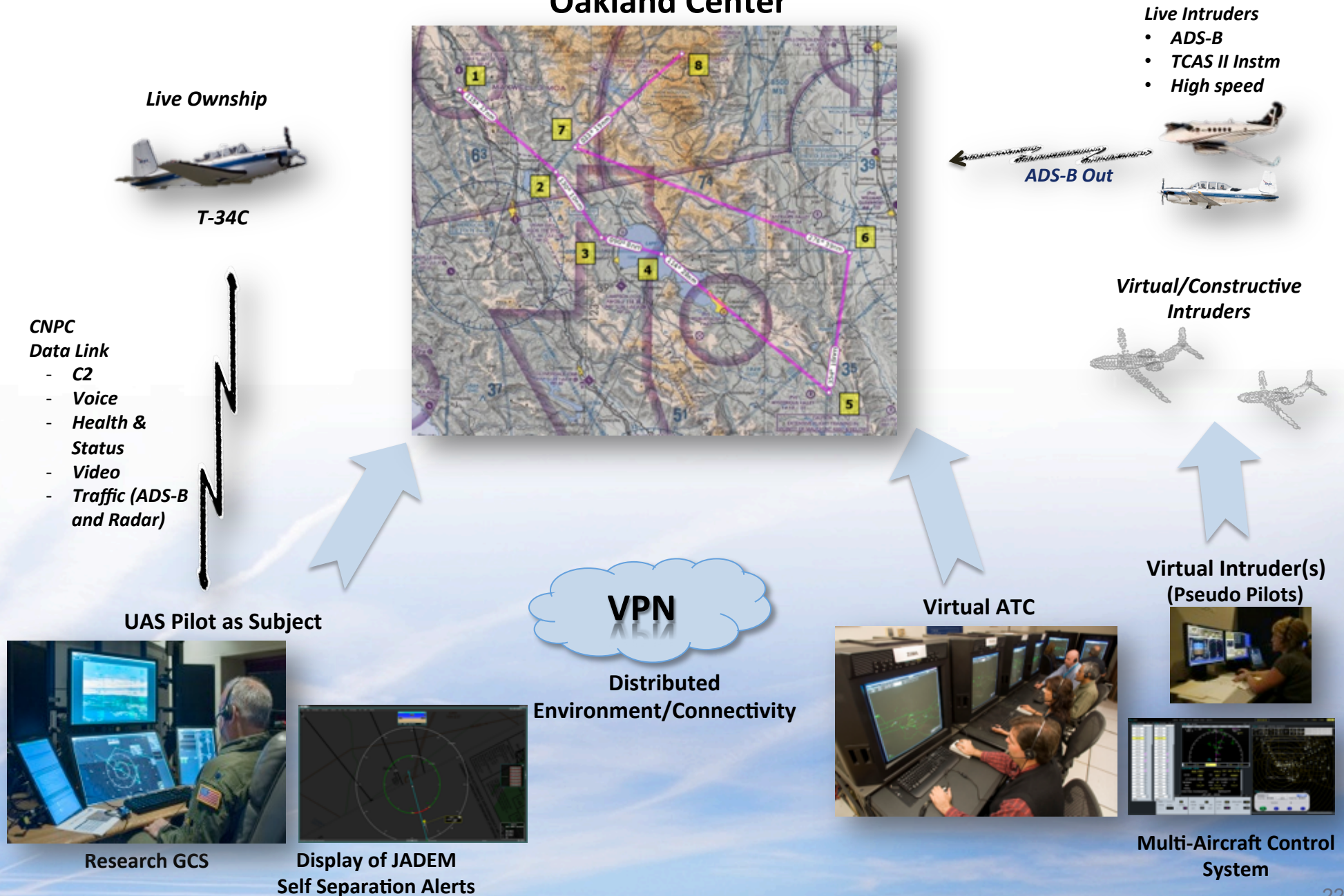
Live Ownship

T-34C

Live Intruders
- *ADS-B*
- *TCAS II Instm*
- *High speed*

ADS-B Out

CNPC Data Link
- *C2*
- *Voice*
- *Health & Status*
- *Video*
- *Traffic (ADS-B and Radar)*

Virtual/Constructive Intruders

UAS Pilot as Subject

VPN

Distributed Environment/Connectivity

Virtual ATC

Virtual Intruder(s) (Pseudo Pilots)

Research GCS

Display of JADEM Self Separation Alerts

Multi-Aircraft Control System

- **Research Objectives**
  - Evaluate the integrated Self Separation algorithms, GCS Traffic displays, and prototype CNPC systems in a realistic environment
  - Evaluate UAS pilots' ability to maintain well clear
  - Gather objective and subjective pilot data to evaluate/validate Well-clear definition
  - Analyze the performance of 4th generation CNPC systems

- **Test Requirements**
  - **Fire Line Route at 12k-15k MSL**
  - **Six encounters require maneuvering to prevent WCV; four with live intruders**
  - **Live Ownship**
    - T-34C UAS Surrogate controlled from the RGCS
      » CNPC equipped
      » ADS-B coop sensor
      » Lateral maneuvering (autopilot) via heading commands uplinked from the RGCS pilot
      » Vertical maneuvering via display cues of altitude commands uplinked from RGCS pilot
  - **Coop Live Intruder(s)**
    - ADS-B equipped
    - Multiple – 2
  - **Non-Coop Intruders will be simulated using DRR Rng, Az, and Elev models/ filters in JADEM**
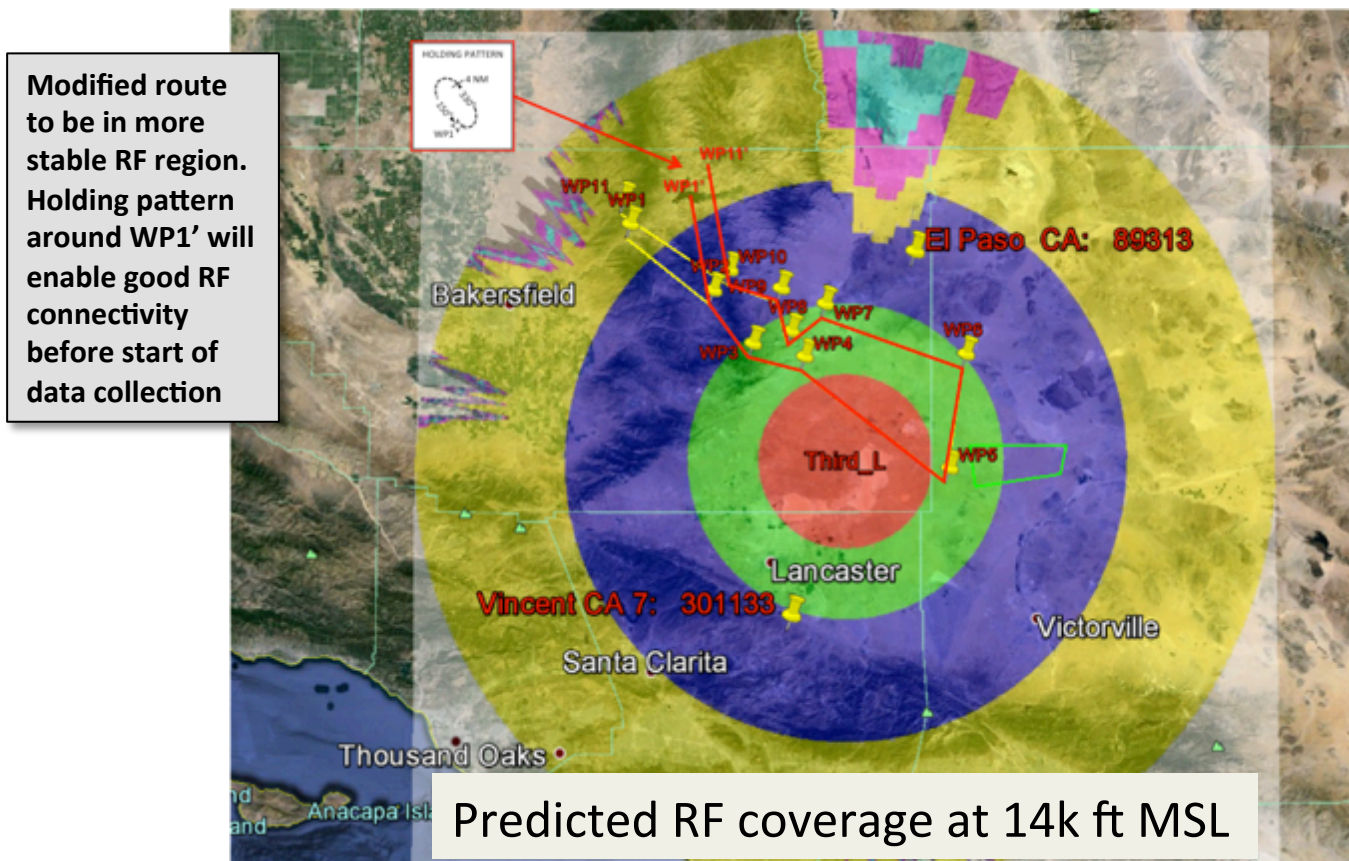
FT-3 Aircraft Equipment Requirements

Aircraft	Responsibility	EDM DRR	ADS-B	GPS	TCAS-II	Config 1A	Config 1B	Config 2
	Ownship NASA AFRC's Ikhana UAS	✔	✔	✔	✔	✔		
	Ownship or Intruder UAS Surrogate NASA GRC, T-34 Mentor		✔	✔				✔
	NASA GRC S-3B Viking High Speed Ownship or Intruder		✔	✔		✔	✔	
	Honeywell Beechcraft King Air C90 manned aircraft used as an intruder		✔	✔	✔	✔	✔	✔
	Second / Backup Intruder NASA AFRC T-34		✔	✔		✔	✔	✔
	Second / Backup Intruder NASA AFRC King Air		✔	✔		✔	✔	✔

CNPC Ground Stations

- CNPC ground station scheduled for installation the week of 7/6/15.
- Flight testing of RF coverage from the ground station is currently scheduled for 7/14/15

Modified route to be in more stable RF region. Holding pattern around WP1' will enable good RF connectivity before start of data collection

Predicted RF coverage at 14k ft MSL

- To stand up a tower at ATF2.

Full Mission Flight Airspace

- Full Mission flown entirely within R-2508 Complex
- Airspace includes: R-2515 + Porterville, Bakersfield & Isabella MOAs
- Altitudes 12-15K ft MSL
- 40 min mission (T-34C ownship aircraft)
- 2-live intruders (King Air & T-34) performing 2 runs each
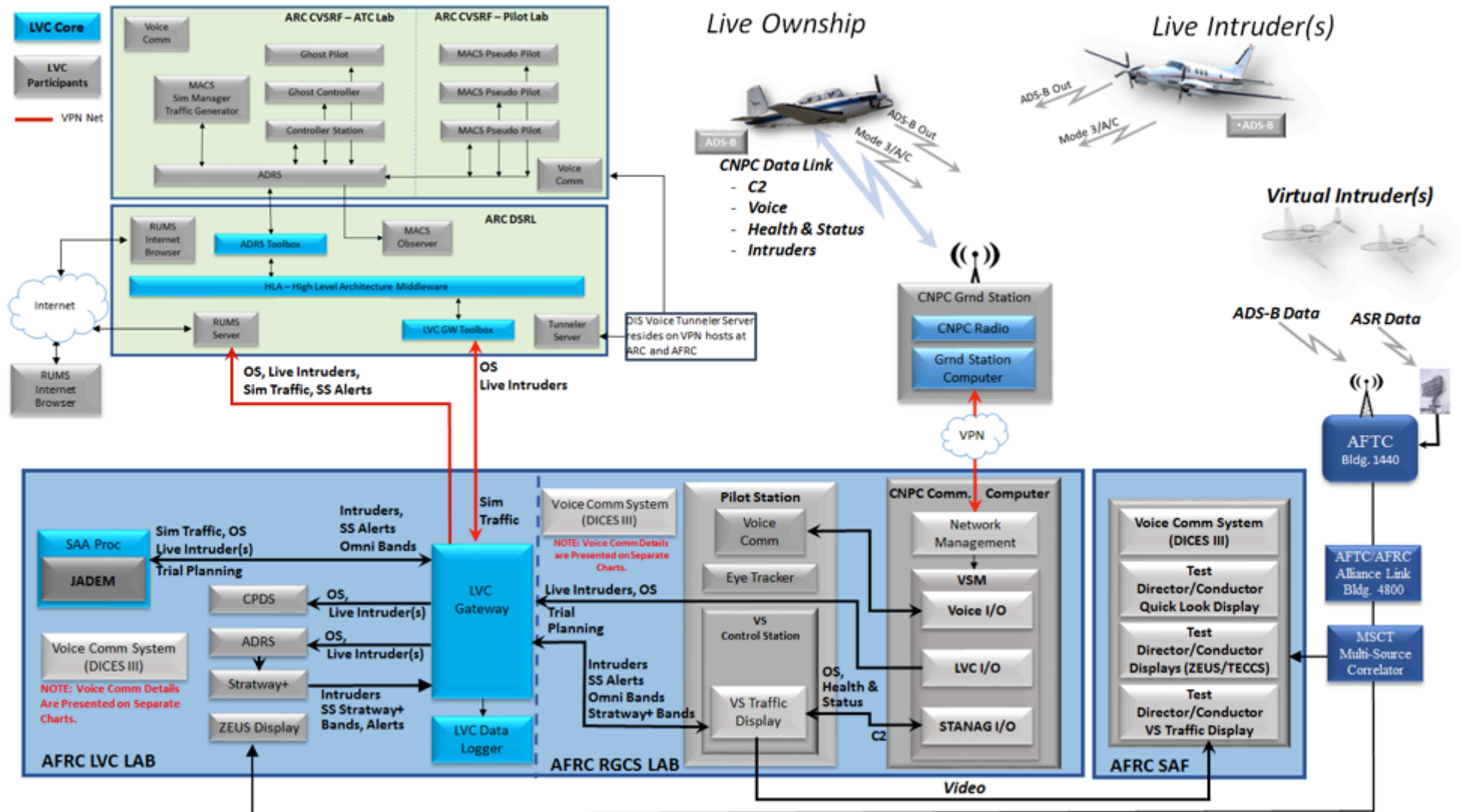- 5-virtual intruders performing 1 run each

RGCS Stations

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Project Simulation/Flight Activities

FY12   FY13   FY14   FY15   FY16

CNPC Radio Sim

Channel Sounding for Comm

DAA/C2 White Papers

UAS CAS 1

Part Task 5

Preliminary MOPS

Final MOPS

CNPC Gen 4 Radio

UAS ADS-B Flight

LVC Characterization

CPNC Gen 2 Radio

Part Task

Alerting Times HITL

Part Task 6

Target Sources

Full Mission Sim

IHITL

Flight Test 3   Flight Test 4

Distributed Demo

Backup

➢ 3 Self-Separation Algorithms under test

- AutoResolver
    - Directive SS Algorithm developed by NASA ARC SSI Team
    - Results displayed on Vigilant Spirit Control Station (VSCS) display
- Stratway +
    - Passive SS Algorithm developed by NASA LaRC SSI Team
    - Results displayed on VSCS display
- Conflict Prediction and Display System (CPDS)
    - Passive SS Algorithm provided by GA-ASI
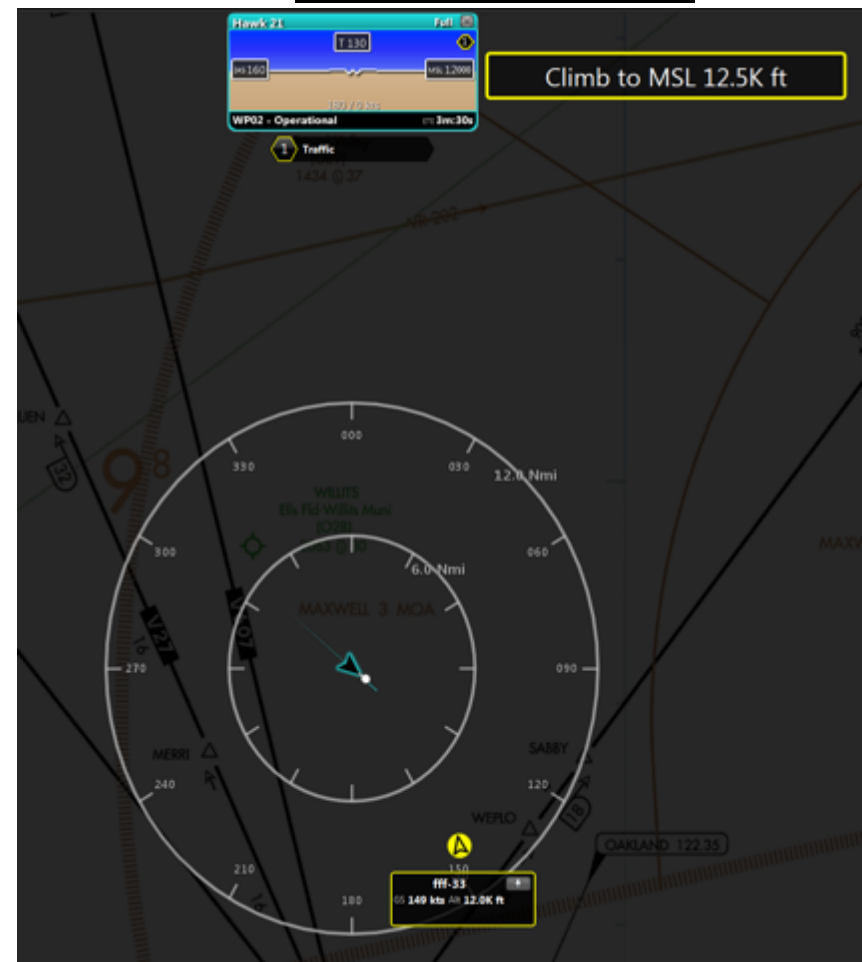   - Algorithm and Display integrated as one unit

Autoresolver

➤ Autoresolver's recommended maneuver will appear at top center of display for **Corrective** and **Warning** alerts only

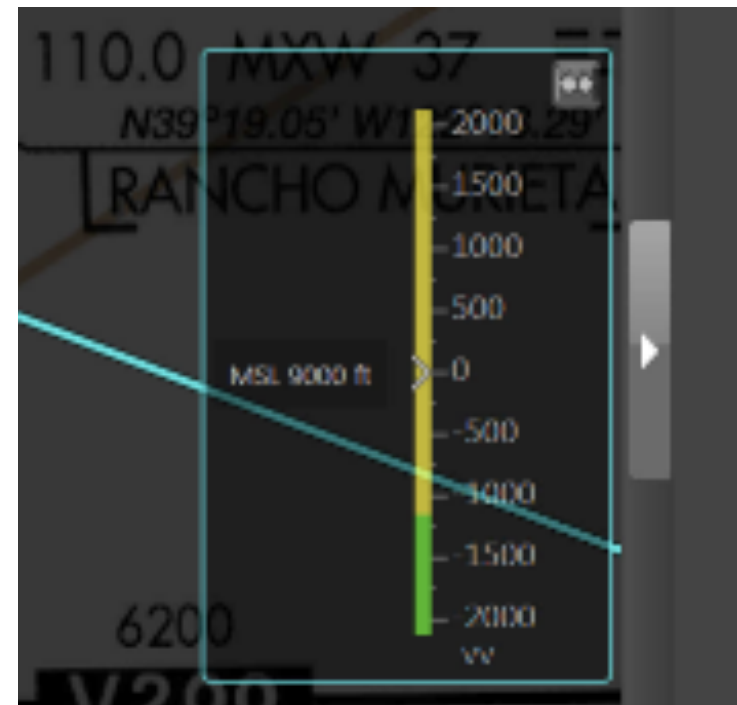**Turn Maneuver**

Altitude Maneuver

Stratway Self-Separation Bands

➤ Self-separation bands indicate <u>headings</u> and/or <u>vertical speeds</u> that will result in a loss of well clear.

➤ Both bands are updated constantly to reflect the most up-to-date information.
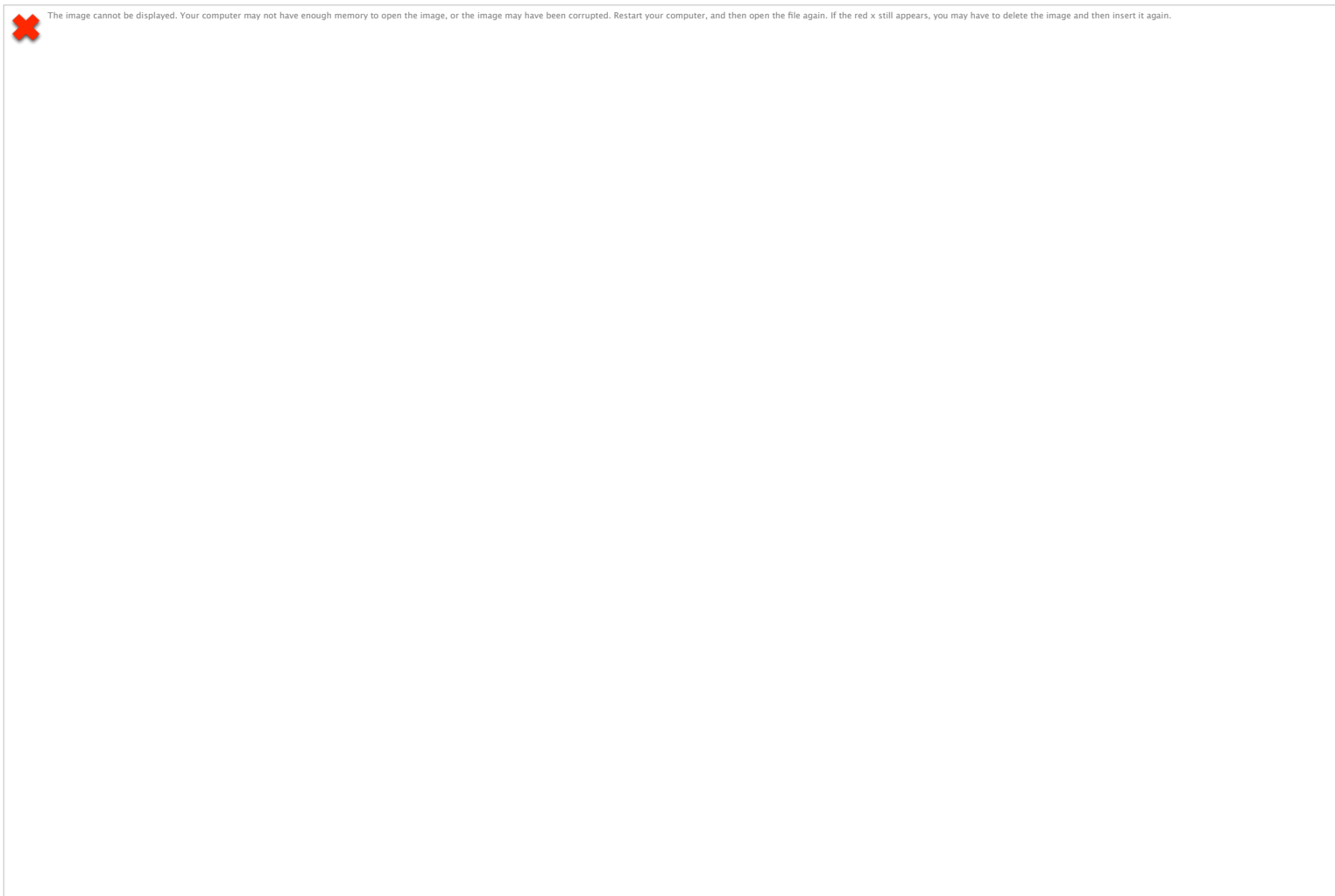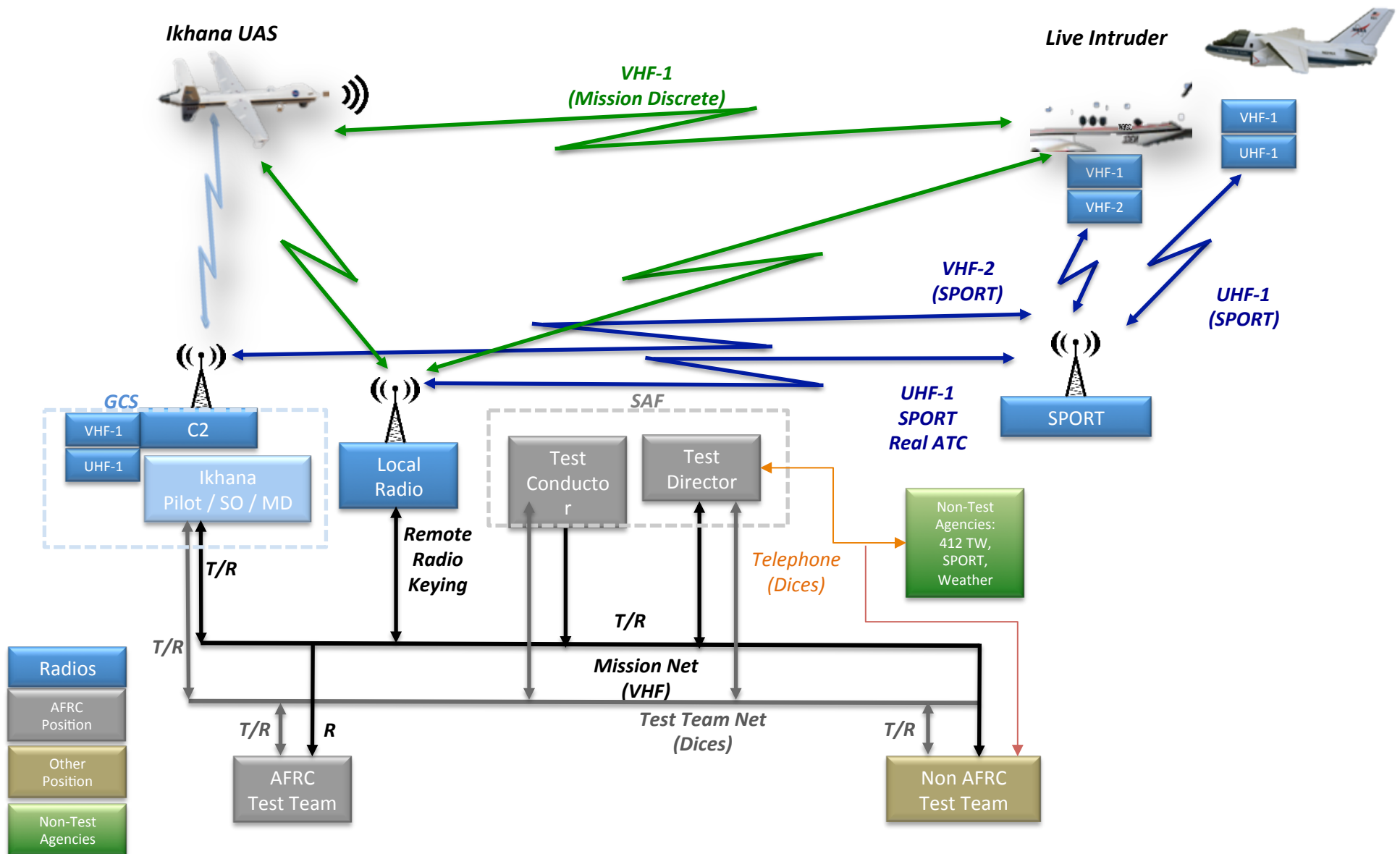
Heading Bands

Vertical Speed Band

➢ CDTI provides the operator with a 2-D plan view of ownship and surrounding airspace traffic when present. It also provides SA of potential conflicts.

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IT&E Flight Test 3 – Configuration 1A
Voice Communications Architecture

Flight Test 3 – Configuration 1B
Voice Communications Architecture

Live Intruder

VHF-1
(Mission Discrete)

GRC S-3B

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

VHF-1

VHF-1
UHF-1

VHF-1
VHF-2

VHF-2
(SPORT)

UHF-1
(SPORT)

UHF-1
SPORT
Real ATC

SPORT

RGCS

VHF-1 | C2
UHF-1 | RGCS Pilot

Local
Radio

SAF

Test
Conductor | Test
Director

Non-Test
Agencies:
412 TW,
SPORT,
Weather

**Remote
Radio
Keying**

*Telephone
(Dices)*

T/R

T/R

T/R

Radios

AFRC
Position

Other
Position

Non-Test
Agencies

**Mission Net
(VHF)**

*Test Team Net
(Dices)*

T/R | R

AFRC
Test Team

T/R
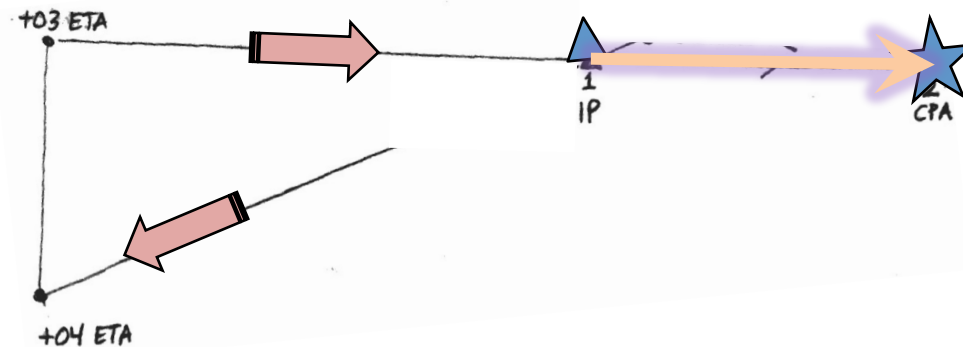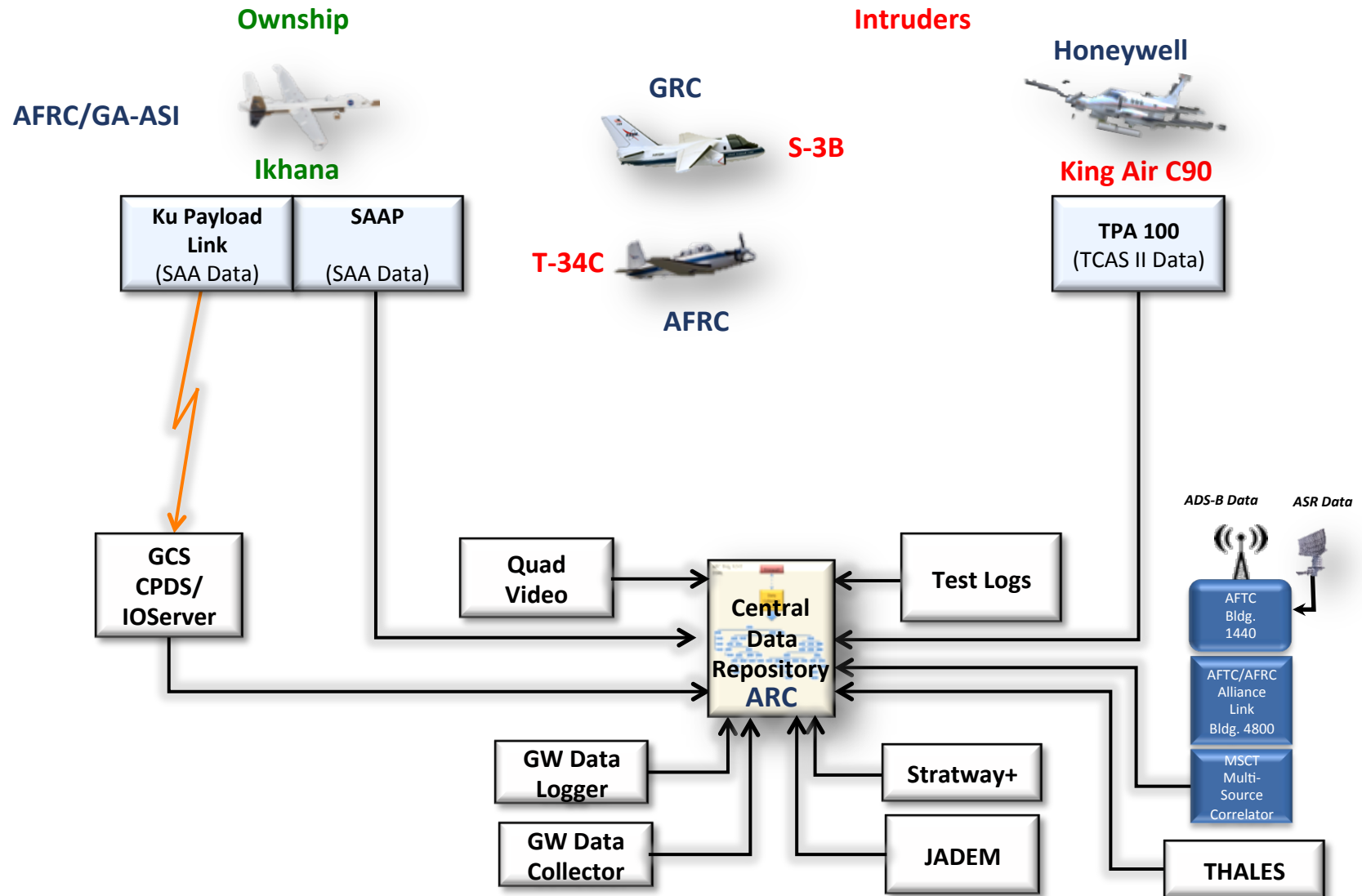
Non AFRC
Test Team

Example Ikhana Circuit / Setup Tasks (Each Run)

- Ensure can meet next IP timing (adjust pattern / speed as required)
- Downwind tasks:
  - Update Next Lost Link Start Point (far end of run line, beyond CPA),
  - Update ILLH to match run, Set Control Point on IP
  - MD give abbreviated card review
- Inbound leg to IP:
  - Final adjustments (timing / track); get ON PARAMETERS at IP
  - Keep on Track & Maintain Ground Speed to the CPA
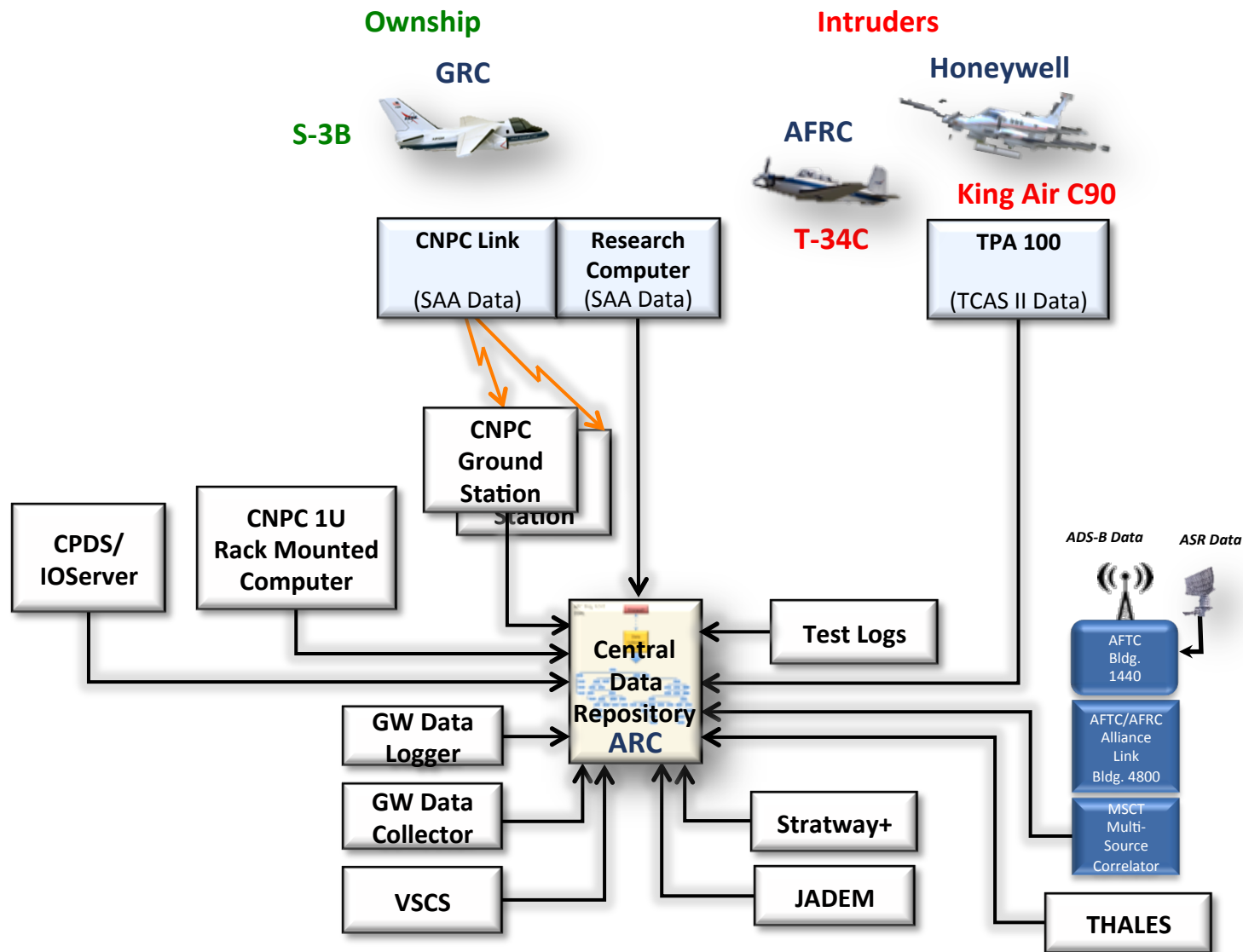 - At IP... Call: **IP inbound, altitude, *Special procedure is reviewed** (*abort)*
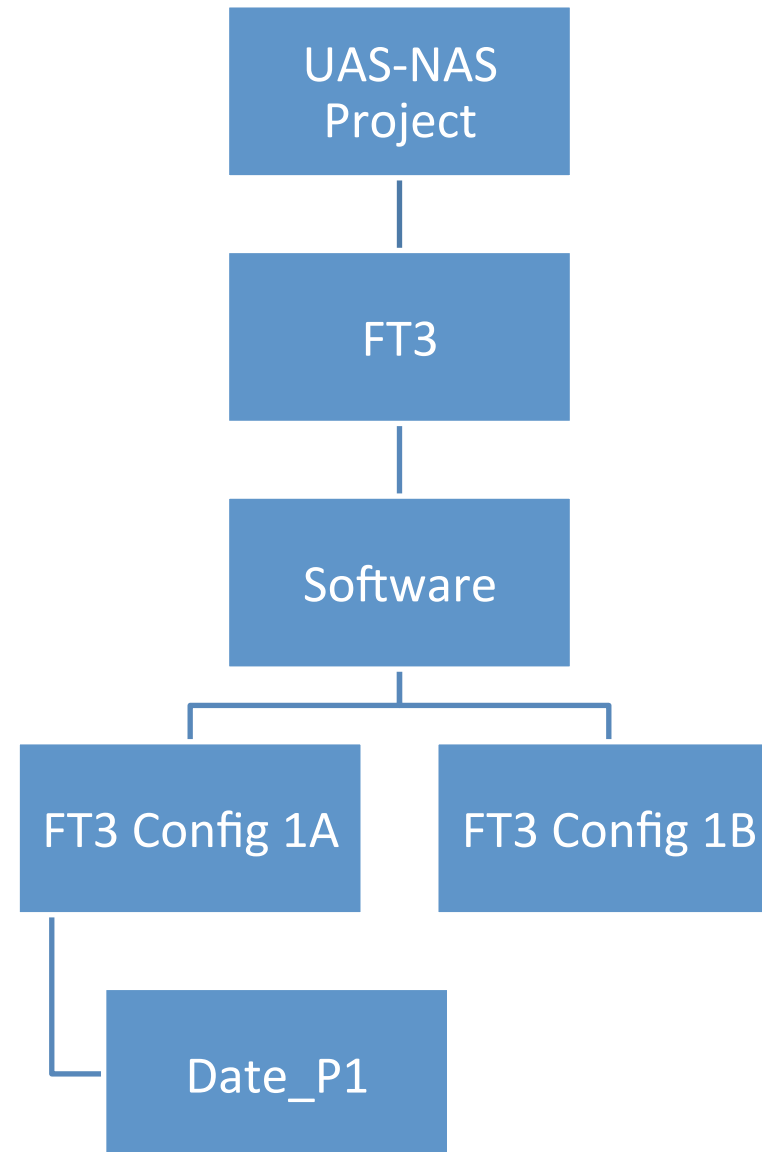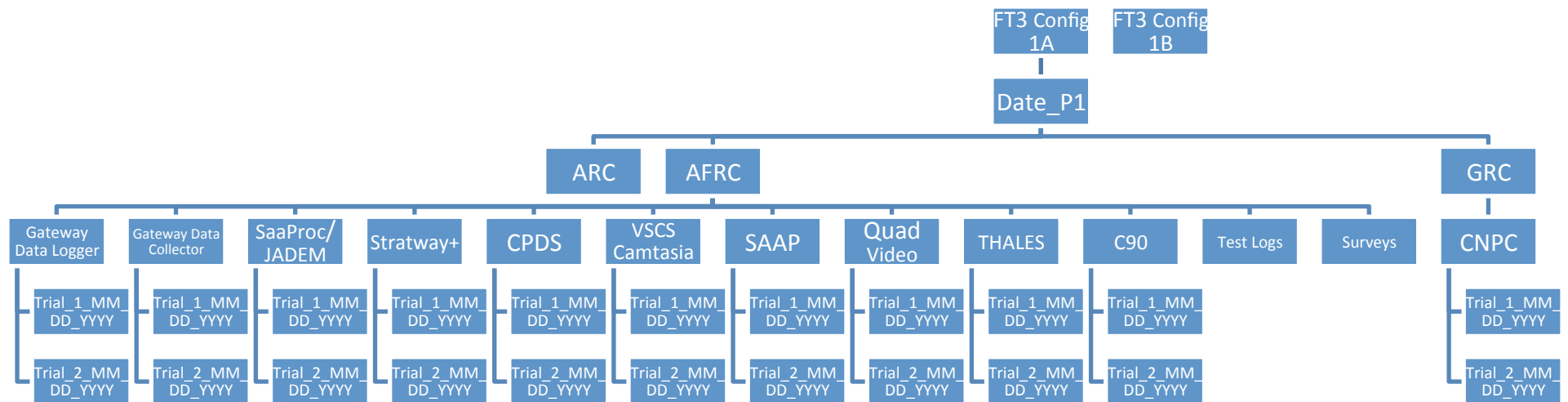
Data Collection – Configuration 1A

Ownship

Intruders

AFRC/GA-ASI

Honeywell

GRC

Ikhana

S-3B

King Air C90

Ku Payload Link (SAA Data)	SAAP (SAA Data)

T-34C

AFRC

TPA 100 (TCAS II Data)

ADS-B Data   ASR Data

GCS CPDS/ IOServer

Quad Video

Central Data Repository ARC

Test Logs

AFTC Bldg. 1440
AFTC/AFRC Alliance Link Bldg. 4800
MSCT Multi-Source Correlator

GW Data Logger

GW Data Collector

Stratway+

JADEM

THALES

Data Collection – Configuration 1B

FT3 Directory Structure

FT3 Directory Structure

FT3 Directory Structure

UAS-NAS FT-3 Overview