
# *Integration of Automated Systems (IAS) Flight Test Overview*

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# IAS-1 Spiral-2 Objectives

**Top-Level NC IAS-1 Goal (Subproject Plan)**
Evaluate NASA research concepts and technologies for complex operations through integrated automation and candidate operational concepts and scenarios

**IAS-1 Objective (Subproject Plan)**
Collect the required data to meet stakeholder objectives (see preliminary flight test matrices to the right)

**IAS-1 Spiral-2 (IAS1S2) Primary Objective (ORD)**
Mature AAM technologies in a relevant environment

**Sub-Objective 1 (ORD)**
Test maturing AAM technologies

**Sub-Objective 2 (ORD)**
Evaluate developing AAM technologies

**Sub-Objective 3 (ORD)**
Identify integrated pilot display requirements

***Requirements map back to Objectives***

HPA Flight Scenario Needs

| Phase of Flight | Intruder Equipage | Encounter Type | Estimated Duration (Hours) | Number of Runs* | Total Scenario Flight Hours |
|---|---|---|---|---|---|
| Terminal Area* (vertical takeoff/landing & transition to forward flight) | Non-Cooperative (i.e., non-transponding) | Corrective | 0.5 | 8 | 4 |
| | | RA | 0.5 | 8 | 4 |
| | Cooperative (e.g., ADS-B Out) | Corrective | 0.5 | 8 | 4 |
| | | RA | 0.5 | 8 | 4 |
| En-Route (forward flight) | Non-Cooperative (i.e., non-transponding) | Corrective | 0.5 | 8 | 4 |
| | | RA | 0.5 | 8 | 4 |
| | Cooperative (e.g., ADS-B Out) | Corrective | 0.5 | 8 | 4 |
| | | RA | 0.5 | 8 | 4 |
| Duplicates/Backups | | | 0.5 | 8 | 4 |
| Total Flight Hours | | | 4.5 | 72 | 36 |

FPM Flight Scenario Needs

Increasing Scenario Complexity

| FPM Scenario Name | Estimated Duration (Hours) | Number of runs (replicates and levels) | Total Scenario Flight Hours | Notes |
|---|---|---|---|---|
| Nominal/Characterization | 0.66 | 15 | 9.9 | Baseline case for trajectory prediction uncertainty bounds (TPUBs) calibration |
| Traffic Only | 0.66 | 6 | 3.96 | Verifying separation performance, vary conflict geometry and (TPUBs) |
| Required Time of Arrival (RTA) Only | 0.66 | 6 | 3.96 | Observe performance of just achieving a RTA with and without delay, different levels of RTA and (TPUBs) |
| Traffic+RTA | 0.66 | 6 | 3.96 | Traffic conflict with RTA constraint |
| Traffic+Corridor+RTA | 0.66 | 6 | 3.96 | Traffic conflict through a corridor with an RTA. Different traffic conflict types with different RTA delay levels and (TPUBs) values |
| Traffic+Coordination Delay+RTA | 0.66 | 8 | 5.28 | Vary (TPUBs), coordination delay, traffic conflict |
| Stressing | 0.66 | 6 | 3.96 | Vary (TPUBs), coordination delay, traffic conflict, corridor |
| Wildcard or repeats | 0.66 | 8 | 5.28 | Placeholder for repeats of bad runs or tech issues or test something we don't know right now |
| Total Flight Hours | | 61 | 40.26 | Required hours if calibration data collection needed (i.e., no data from Sikorsky) |
| Total Flight Hours without calibration flights | | | 30.36 | Fewer total hours needed if Nominal/Characterization flights can be eliminated with previously attained data |

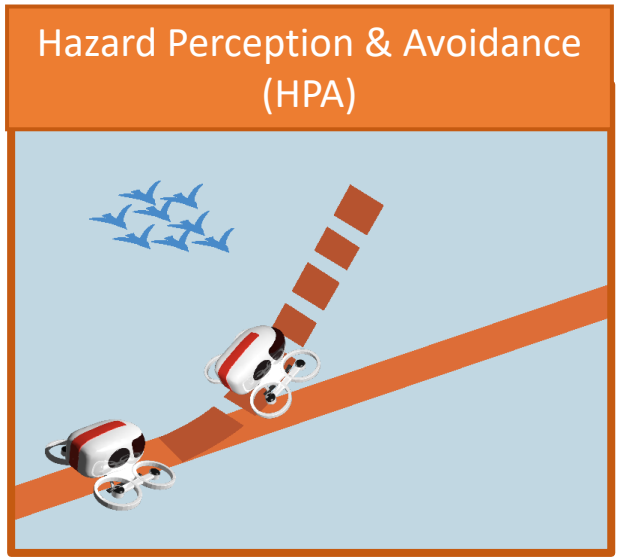
- Approximately 33 flight hours of test targeted for HPA and FPM technologies, as presented at MCR.
- Minimum Success criteria requires collecting data to validate that the algorithms function as designed in a relevant environment

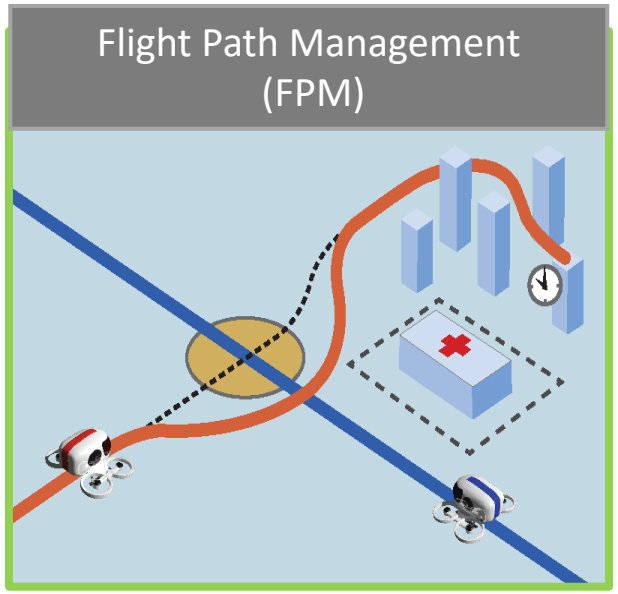
# Overview of Technologies being Flight Tested

*Two primary technologies being integrated for IAS-1 flight test:*

- Hazard Perception and Avoidance (HPA)
  - ➢ Tactical (near-term) response to conflicts with the flight path
  - ○ Detect and Avoid (DAA) advises the pilot for non-imminent events
  - ○ Collision Avoidance (CA) and Resolution Advisories (RA) automation takes corrective action for imminent events

- Flight Path Management (FPM)
  - ➢ Strategic (far-term) response to conflicts with the flight path
  - ○ Options created by the system to resolve the conflict by adjusting the ownship's route
  - ○ System tries to solve the conflict while maintaining the Required Time of Arrival (RTA)
  - ○ Options presented to the pilot for selection



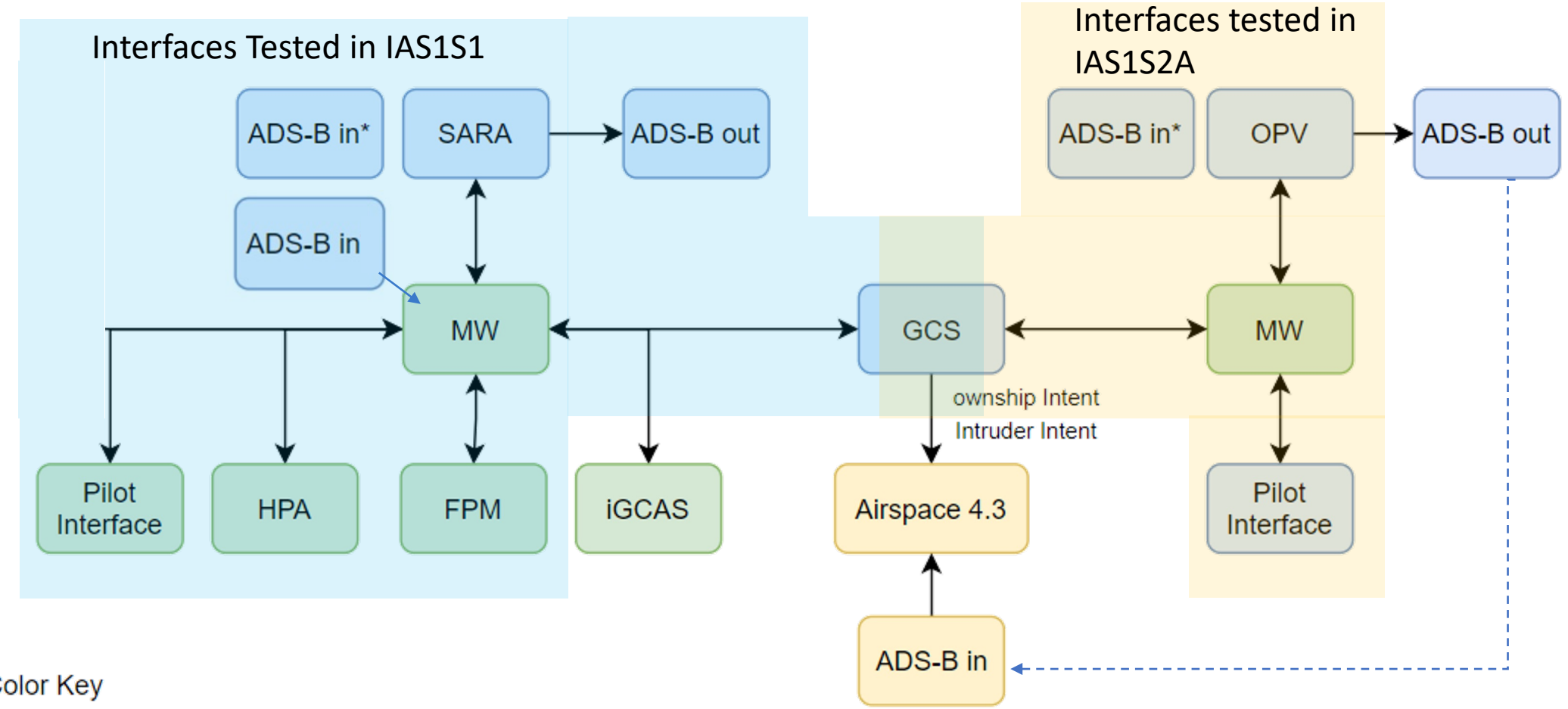
# Test Aircraft

- SARA (Sikorsky Autonomous Research Aircraft) – “Ownship”
  - Modified S-76B helicopter
  - Crew: Sikorsky safety pilot and NASA research pilot
  - IAS Middleware (MW) will be hosted on the aircraft
  - MW will communicate with ACAS Xr software and aircraft to enable HPA routes

- OPV (Optionally Piloted Vehicle) – “Intruder”
  - Modified S-70 Blackhawk
  - Crew:  2 Sikorsky pilots or 1 Sikorsky/1 NASA H-60 qualified pilot and NASA XP in the back
  - IAS MW will be hosted on aircraft to enable control of intruder routes

Both aircraft are fault-tolerant test beds with physical separation from Class A software

# IAS-1 High Level Architecture




Secondary Technologies to be tested as resources allow:

1) Airspace 4.3 Integration
2) iGCAS Integration

# Campaigns Build up to IAS-1 Capstone Exercise

Sikorsky Innovations

Simulated Intruder

100's of Aircraft are simulated to create dense traffic for FPM to plan around

Simulated Intruder

Simulated Intruder

Simulated Intruder

Real Intruder

Intruder Original Intent

Intruder New Intent

Simulated Terrain

**1 Take-Off and Transition to Ops**

SARA AMM is used for automated Terminal Operations using NASA eVTOL profiles

**2 FPM Planning**

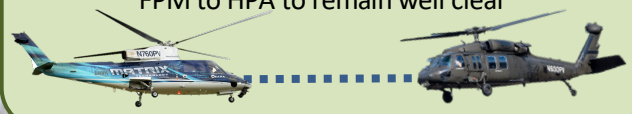
MW shifts pilot's view from AMM to FPM once in operation area

**3 FPM Planning**

FPM receives Intruder Intent change from GCS and responds to remain well clear at all times

**4 HPA**

If conflict is not resolved MW shifts pilot's view from FPM to HPA to remain well clear



**5 iGCAS**

iGCAS avoids simulated CFIT

**6 FPM Planning**

Focus returns to FPM after HPA and iGCAS activities complete

**7 Landing**

When the Terminal area is reached SARA's AMM is used for auto-land using NASA eVTOL profiles

Airspace 4.3 is gathering IAS flight test telemetry in real-time for monitoring

All algorithms are running simultaneously, but the MW will need to output only one based on the phase of flight

The goal is to loosely tie together automation technologies and demonstrate their role throughout the standard phases of flight

# IAS Plans

- The IAS flight test is being conducted as a series of Spirals
  - All flights occurring at Sikorsky in Stratford, CT
  - Multiple spirals have been completed and were used to test ownship and intruder performance & NASA middleware functionality
  - 2 spirals remain and will be used for FPM & HPA data collection:
    - **Spiral 2B** – May 22-26, initial test cards
    - **Spiral 2C** – Aug/Sept, full test card set & capstone demonstration

- HPA IAS Objectives
  - Test the performance & acceptability of FAA's tactical collision avoidance system for rotorcraft, Airborne Collision Avoidance System (ACAS) Xr in a live flight environment
    - Assess effectiveness of ACAS Xr alerting & guidance
    - Assess NASA's implementation of *automated* Resolution Advisory (RA) maneuvers
    - Test both ACAS "configurations"
    - Test under different flight regimes

# ACAS Xr Background

- ACAS Xr Configurations
  - **TA/RA**: similar to TCAS II; Collision Avoidance only
    - Traffic Advisories (TAs) are caution-level and issued prior to Resolution Advisories (RA)
    - RAs are warning-level alerts which command specific type of maneuver and must be flown
  - **DAA**: provides Detect and Avoid + Collision Avoidance
    - DAA alerting and guidance replaces TAs
    - RAs are issued if the DAA threat is not resolved

- Resolution Advisory (RA) types:
  - Horizontal RAs command a target track angle
  - Vertical RAs command a target vertical speed
  - Blended RAs command a target track & vertical speed simultaneously

# ACAS Mode Examples

## TA/RA Configuration

- *Traffic Advisory* (TA) issued first
  - Visual & aural alert (“Traffic, Traffic”)
  - Not used to maneuver - no maneuver guidance
  - Pilot can try to visually acquire traffic


- *Resolution Advisory* (RA) eventually issued
  - Visual & aural alert (e.g., “Climb, Climb”, “Turn Right, Turn Right”)
  - Vertical and/or horizontal guidance dictates how pilot maneuvers
  - Maneuver expected within 5 seconds

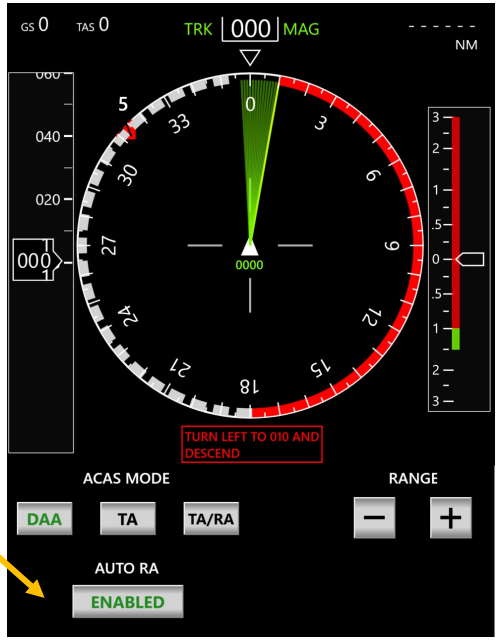

## DAA Configuration

- *DAA Corrective* alert issued first
  - Visual & aural alert (“Traffic, Avoid”)
  - Guidance “banding” used by pilot to determine if/how to maneuver
  - Airspeed, heading and vertical speed bands offered


- *Resolution Advisory* (RA) issued if not resolved
  - Presentation same as TA/RA Mode

# Scenarios

- 10 flight cards per ACAS Xr Configuration (TA/RA & DAA)
  - Ownship & intruder will be in forward flight (~90kts), 500-1500' AGL, & level for all encounters
    - Intruder equipped with ADS-B Out
  - 8 of 10 will have logic enabled that will *automatically execute* the RA without pilot intervention (via translation made by NASA middleware)
    - Remaining 2 will have manual RA responses
  - The 8 primary encounters are being designed to generate a variety of RA types – horizontal, vertical & blended RAs
    - 2 of these will involve Descend RAs at lower altitudes (e.g., 500ft AGL)
- Pilots will have ability to disable/disengage auto-RA response prior to and during RAs
  - Deflecting the stick and/or pressing a dedicated Auto-RA button on ACAS display will disable the auto-RA behavior
  - Pilots will be able to re-enable the auto-RA function by pressing the same button



# Flight Test Data

- Objective Data Sources
  - ACAS Xr logs
  - Middleware logs
  - Aircraft state data
  - Intruder state data
  - Voice logs
  - ACAS display screen recordings

- Subjective Data Sources
  - Will ask pilots acceptability & usability questions throughout the testing
    - Post-encounter questionnaires presented via tablet
    - Post-flight questionnaires presented on the ground
    - Post-spiral questionnaire & debrief on the ground

**Section III – Resolution Advisory (RA) Alerts and Guidance**

This section refers specifically to the *Resolution Advisories* issued by the ACAS Xr alerting and guidance system. This alert level is intended to prompt you/the vehicle to maneuver immediately to avoid a near midair collision (NMAC). *Traffic Advisories* (TAs) were only issued in conditions where we used the "**TA/RA Mode**" of ACAS Xr. Resolution Advisories (RAs) were issued in both the "TA/RA" and "DAA" Modes of ACAS Xr.
RA "guidance" is depicted as red and green arcs on the PFD (i.e., vertical RAs) and navigation display (i.e., horizontal RAs).

| Alert Type | Symbol & Aural Alert | Meaning |
|---|---|---|
| Resolution Advisory |  "Climb"/"Descend" x2 "Turn Right"/"Turn Left" x2 | Maneuver immediately to avoid collision |

*Please **circle the response** that best represents your answer:*

1. I found the TA/RA Mode – which included TAs & RAs but no DAA alerting and guidance – effective for maintaining sufficient separation from nearby traffic:

| Strongly Disagree | Somewhat Disagree | Neither Agree nor Disagree | Somewhat Agree | Strongly Agree |
|---|---|---|---|---|

2. In which, if any, of the following flight phases/flight regimes did you find the TA/RA Mode and associated alerting and guidance to be unnecessary or inappropriate:
   - Cruise/forward flight
   - Approach ____
   - Hover/low speed ____

3. I found the vertical RAs (i.e., target vertical speed) issued by ACAS Xr useful:

| Strongly Disagree | Somewhat Disagree | Neither Agree nor Disagree | Somewhat Agree | Strongly Agree |
|---|---|---|---|---|

4. I found the horizontal RAs (i.e., target track) issued by ACAS Xr useful:

| Strongly Disagree | Somewhat Disagree | Neither Agree nor Disagree | Somewhat Agree | Strongly Agree |
|---|---|---|---|---|

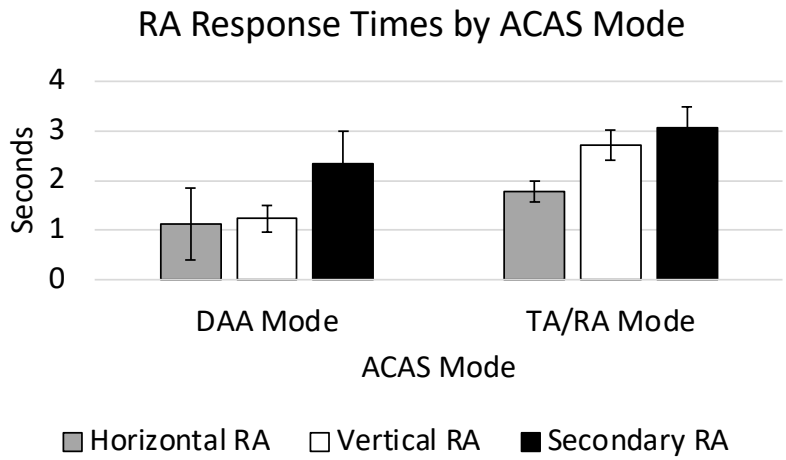
5. I found blended RAs (i.e., target vertical speed & target track) issued by ACAS Xr useful:

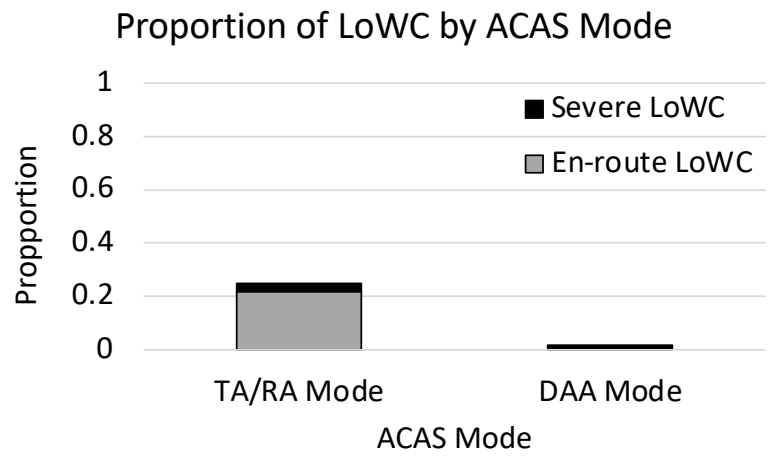
| Strongly Disagree | Somewhat Disagree | Neither Agree nor Disagree | Somewhat Agree | Strongly Agree |
|---|---|---|---|---|

Example ACAS Xr questionnaire

# Analysis and Reporting

- Typical HPA metrics:
  - Pilot response time to DAA and (manual) RA alerts
  - Instances of losses of DAA well clear and/or NMACs
  - Instances of pilots intentionally non-complying with ACAS RAs
  - Pilot ratings on timeliness & effectiveness of alerting
  - Pilot ratings on usability of ACAS display and aural alerts
  - Pilot ratings on utility of the automated-RA function
  - Comparison of TA/RA vs DAA Modes



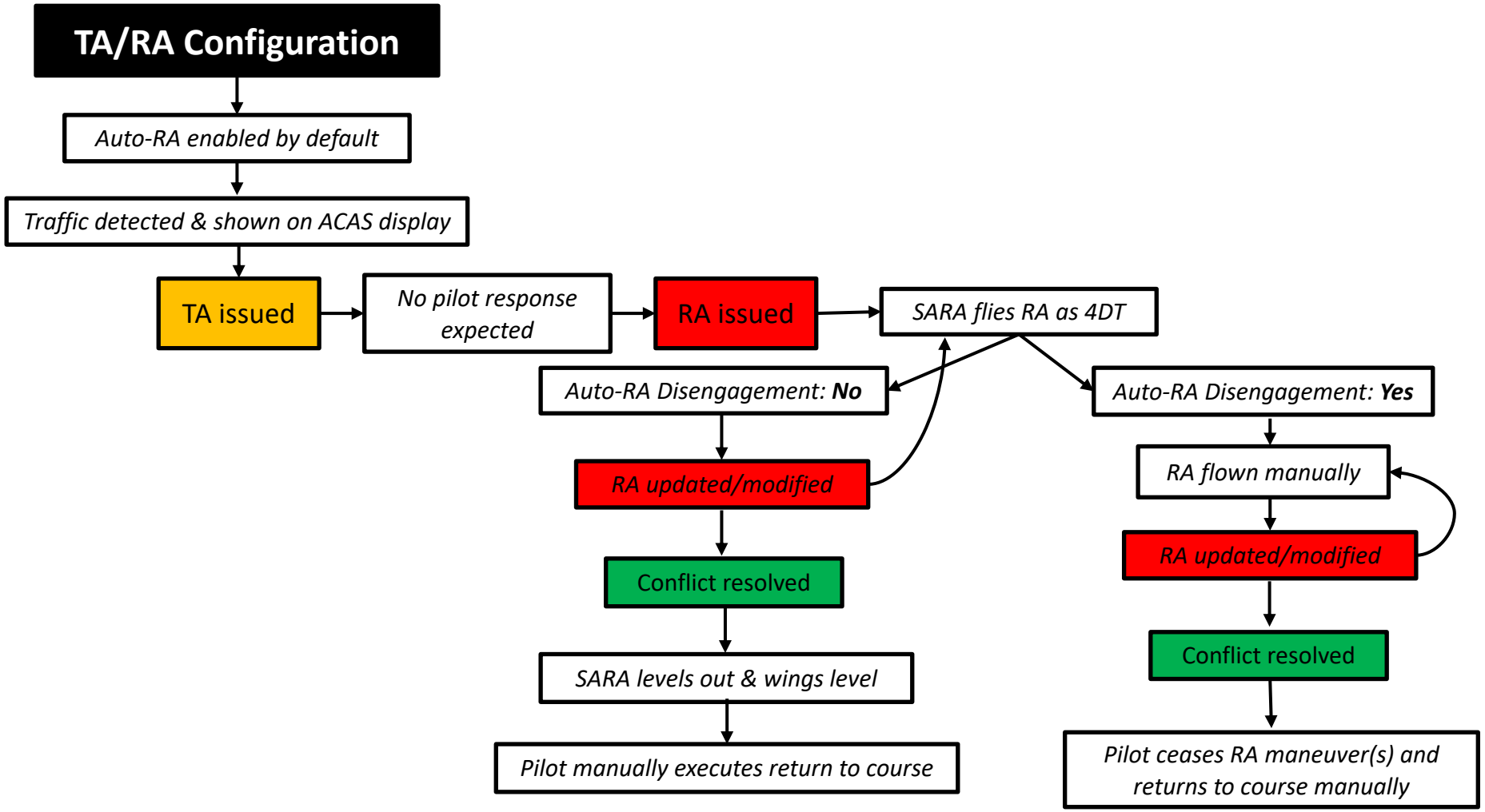
# Spiral 2C

- Spiral 2B will focus on simpler encounters (forward flight, level encounters)

- Spiral 2C will introduce greater complexity:
  - Hover & low-speed scenarios (e.g., 0kt & 10kt ownship scenarios)
  - Ownship & intruder maneuvering prior to alert
  - Terminal area & corridor intruder designation encounters
  - Inject virtual intruders for multi-threat encounters

# BACKUP

# Activity Diagram



# Activity Diagram