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Testing of Defensive Aids Sub-Systems for Small UAS to improve Combat Survivability

SCI-328 Symposium on ''Flight Testing of Unmanned Aerial Systems (UAS)

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Index of Contents

UAS SURVIVABLE VS EXPENDABLE (I)

- The days of **permissive airspace and electromagnetic environment are over**.
- How to carry out missions with **anti-access/area-denial (A2/AD)** against peer and near-peer adversaries.
- Enemy will use **C-UAS kinetic/non-kinetic** to shot down, attack electronically to prevent its freedom of maneuver.
- Current UAS have little or **no self-protection** systems to counter threats.
- The design features that manned aircraft rely on to survive were **never priority payloads in UAS**.

UAS SURVIVABLE VS EXPENDABLE (II)

- UAS are **key enablers** for:
  - Lifting the "**Fog of War**"
    - increase "Battlespace Awareness"
    - Information Superiority
  - **Combat Cloud** to shorten the **sensor-to-effector cycle**
    - Reaction times are reduced

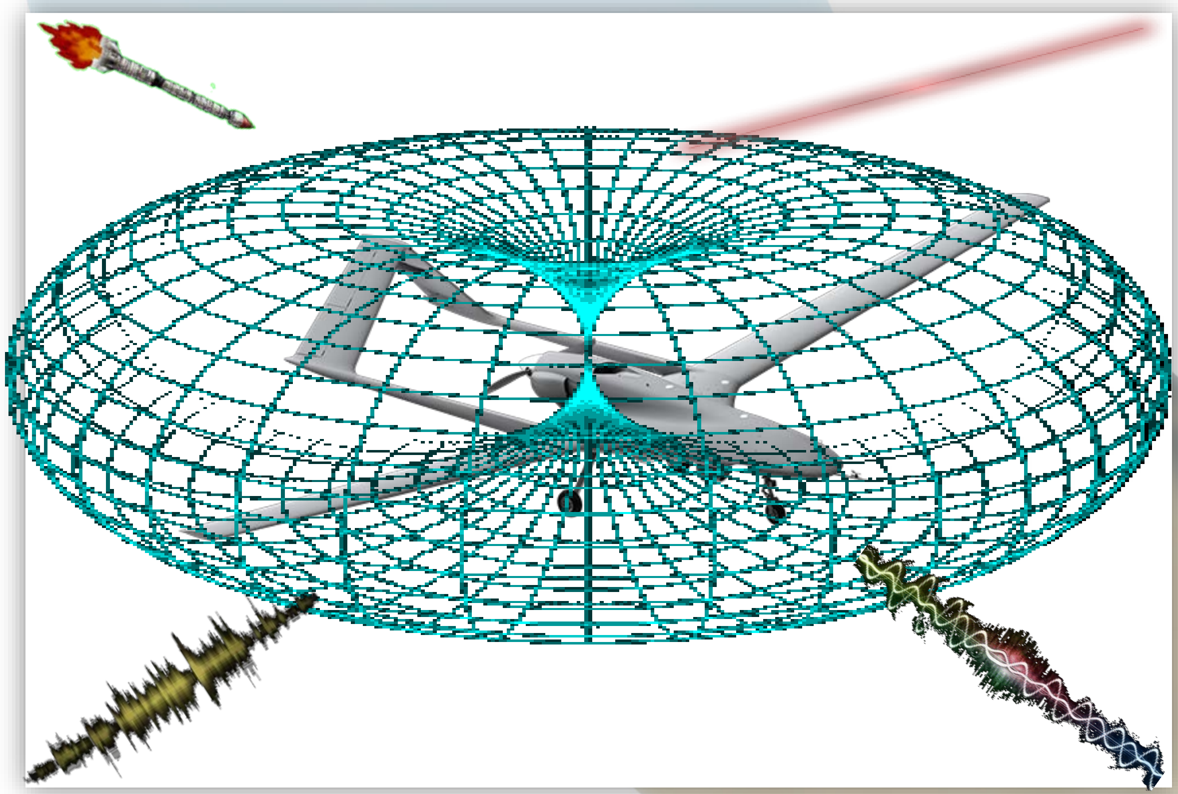
- NATO **F2T2E2A** cycle (Find, Fix, Track, Target, Engage, Exploit, Assess)
  - UAS used in the phases of Find (Detection), Fix (Obtaining), Track (Monitoring) and Battle Damage Assessment
  - UAS deployed for ISTAR and weapon attack missions (SEAD), key to succeed

- UAS have become **high-value assets**, and their loss could be detrimental to the **mission success**.
  - Hardly be considered expendable.

Index of Contents

SELF-PROTECTION SYSTEMS FOR UAS (I)

- **Miniatured EW** systems capable of installation in small UAS.
  - SWaP EW payloads available.
  - For instance, RWR with weight < 1 Kg; Chaff & Flares Dispensers 1/3 the weight and length of standard



- **Radar Warning Receiver (RWR)**
  - RWR enable UAS to detect radars and manoeuvre the UAS away from the threat.
  - RWR can also collect information on the adversary's electronic order of battle and can contribute to the overall intelligence picture.
  - RWR should be installed on all UAS expected to encounter enemy radar systems.

- **Laser Warning System (LWS)**
  - LWS enable UAS to detect laser range finders, laser designators and laser beam riding weapons

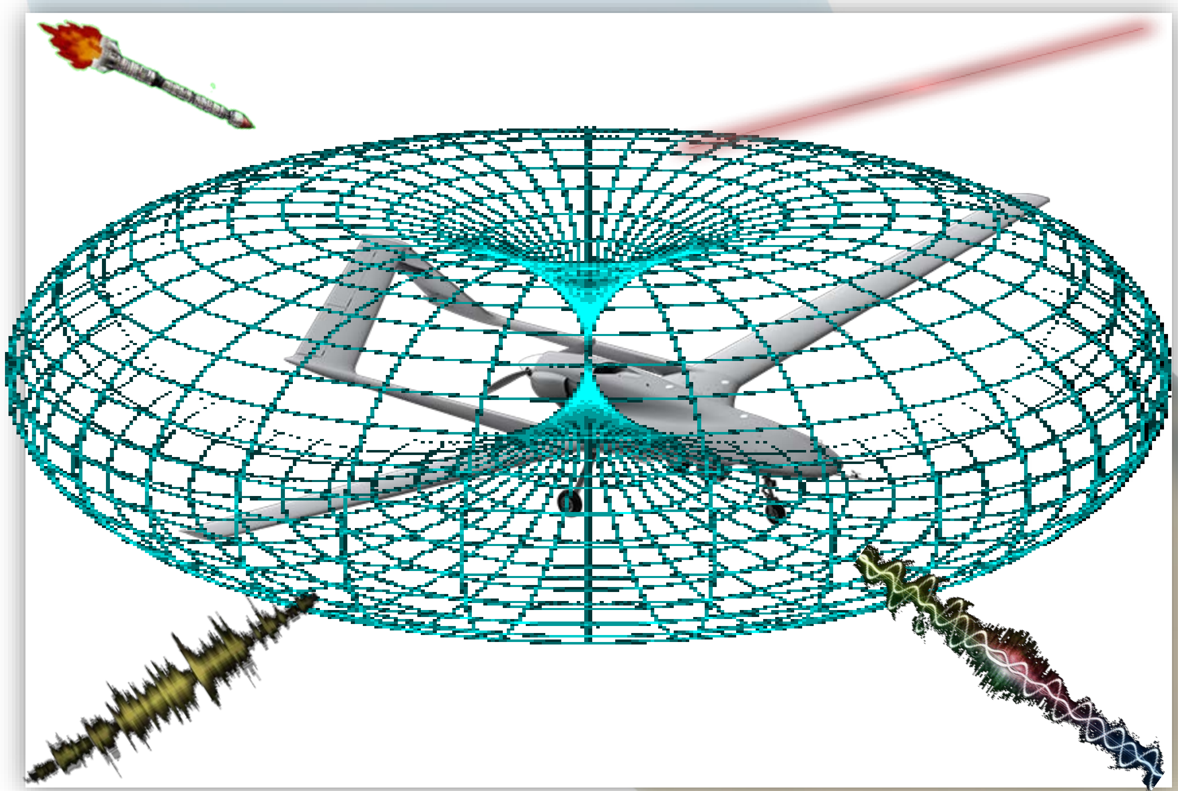
SELF-PROTECTION SYSTEMS FOR UAS (II)

❑ Missile Warning System (MWS)

- MWS enable UAS to detect incoming missiles and manoeuvre the UAS away from the threat.
- MWS should be installed on all UAS expected to encounter kinetic weapons.

❑ RF/IR Countermeasures

- Enables UAS to draw attacking IR-guided missiles and radars away from the UAS.



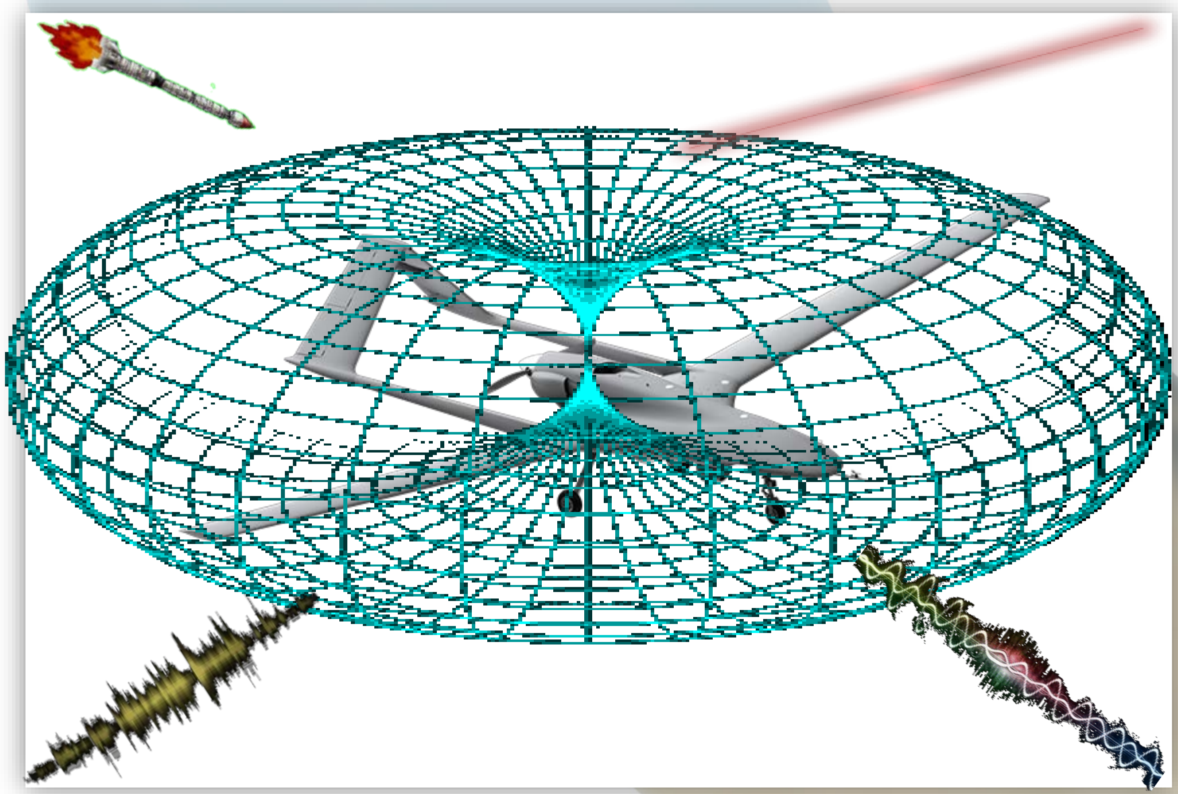
SELF-PROTECTION SYSTEMS FOR UAS (III)

- Three combat survivability enhancement have been proposed.
  - **Alternative #1**: installation of an **RWR** and **DRFM based ECM**.
  - **Alternative #2**: installation of an **RWR** and a **chaff and flares dispenser**.
  - **Alternative #3**: installation of a **MWS** and a **chaff and flares dispenser**.

- **UAS Loss Rate**:
  - Alternative #1: 0.02 kills per 1000 OH.
  - Alternative #2: 0.03 kills per 1000 OH.
  - Alternative #3: 0.01 kills per 1000 OH.

- **UAS endurance**:
  - Maximum endurance in Alternative #1.
  - Less endurance in alternatives #2 and #3.

- Alternative #3 has more benefits to UAS combat survivability, followed by #2 and then #1



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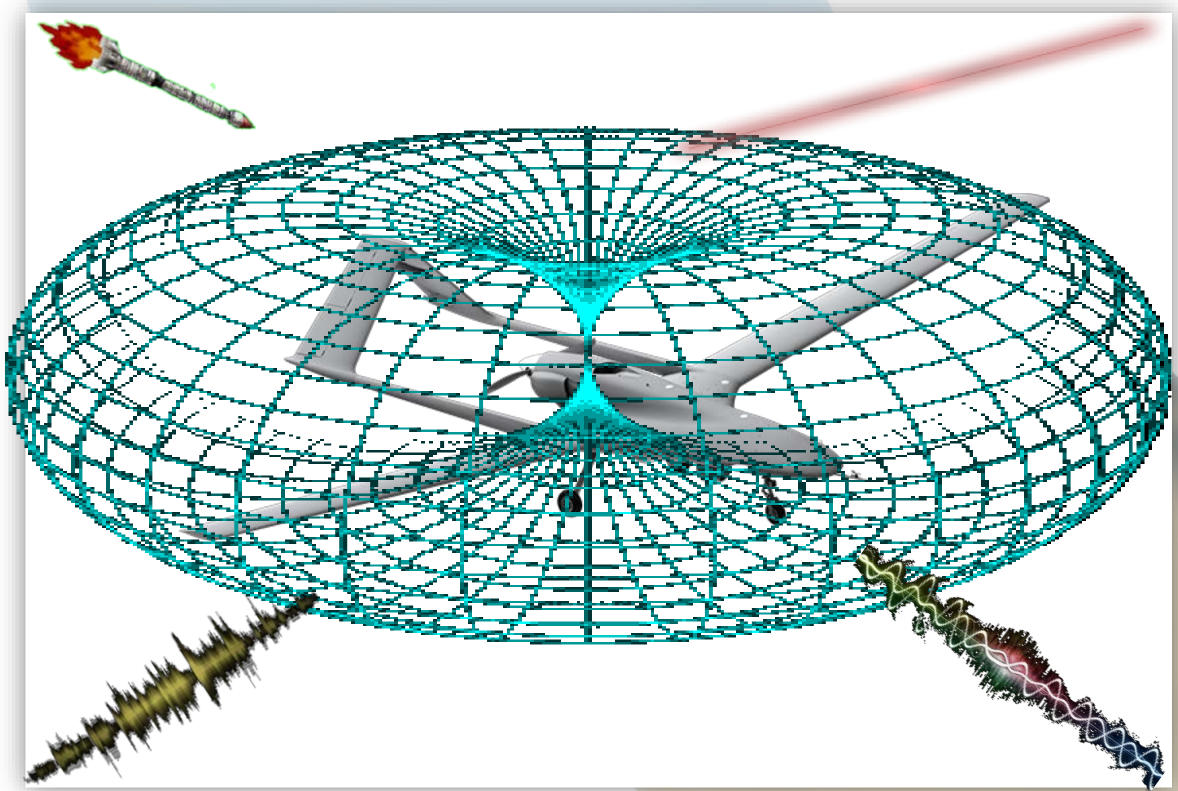
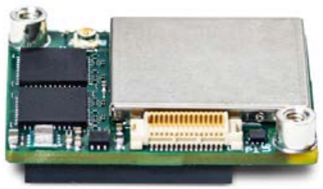
SELF-PROTECTION SYSTEMS FOR UAS (IV)

- **IFF Transponder Mode 5**
  - Determine if an inbound UAS is friend or foe.
  - Avoid the risk of accidental fratricide of UAS.
  - More security than legacy Mode 4

- **Military GNSS receiver**
  - Protection against GNSS jamming and spoofing.
  - Provide reliable PNT in GNSS denied/degraded environment.

- **Military V/UHF transceiver with SATURN waveform**
  - Provides Low Probability of Interception (LPI), Low Probability of Detection (LPD) and Anti-jamming against Electronic Attack in communications band.
  - Transmission Security in UHF NATO Band.





Index of Contents

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GROUND TESTING (I): EW suite

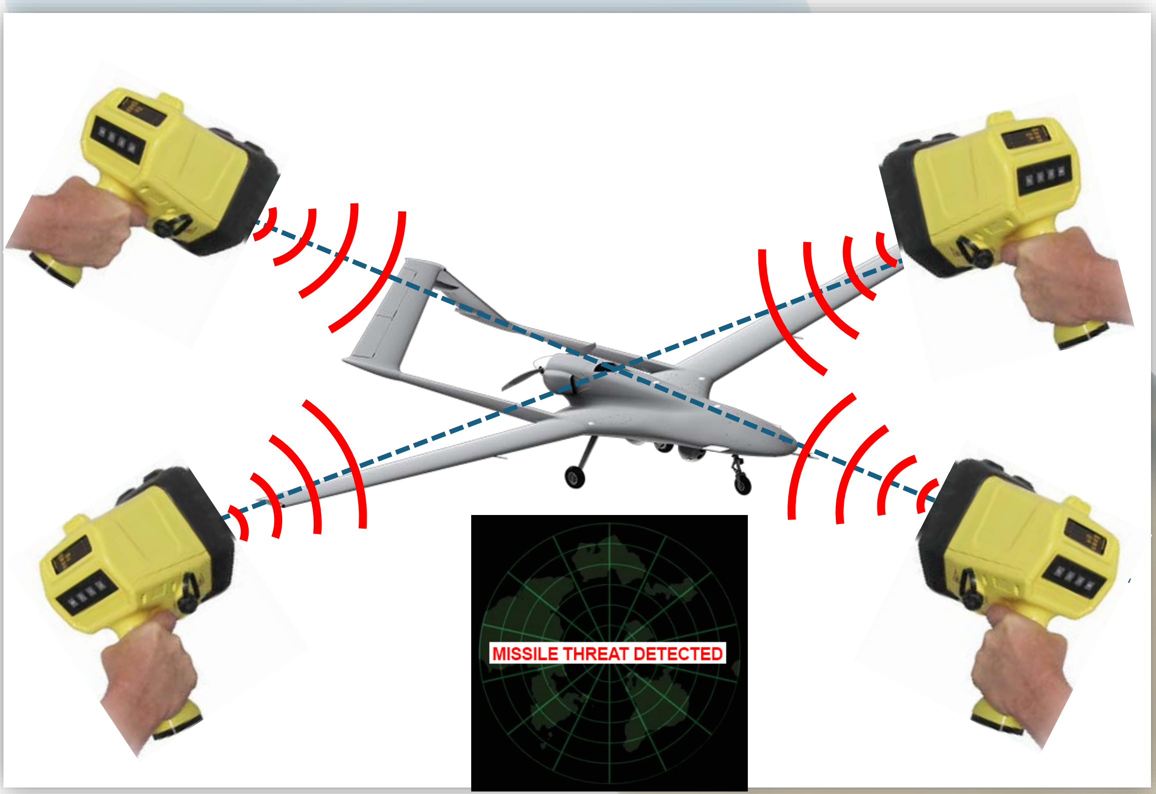
- There are failures that cannot be detected by the built-in test (BIT)
- **BIT cannot cover** the entire path from threat to alert to countermeasure.
- Go/No-go tests improve the level of confidence in the system's protection capabilities.
- **Pre-mission test in Flight Line** provides mission confidence
  - o Guarantees the operational readiness of self-protection system within minutes
- **3-in-1 EW tester for go/no-go tests right before the start of a mission**.
  - o Simulates a broad range of electronic attack characteristics such as radar, lasers, guided missiles
  - o Besides performing go/no-go test it can recognize sensor sensitivity degradations

GROUND TESTING (II): EW suite

- Test Procedure:
  - EW threat simulator points and emits towards the sensors of the MWS/LWS/RWR for a **threat detection to occur in each quadrant**.

    1. Missile/Laser/Radar threats detection in the front **left quadrant (AOA = [270º, 360º])**
    2. Missile/Laser/Radar threats detection in the front **right quadrant (AOA = [0º, 90º])**
    3. Missile/Laser/Radar threats detection in **right rear quadrant (AOA = [90º, 180º])**
    4. Missile/Laser/Radar threats detection in left **rear quadrant (AOA = [180º, 270º])**

  - During the test, the ground station operator will **visualize the simulated threat on the Electronic Warfare display and will hear the corresponding alert notice** through the audio system.



GROUND TESTING (III): EW suite

- Test Procedure:
  - **Chaff-and-flares simulator**. The simulator does not use any pyrotechnics.

    1. Install chaff and flares simulator instead of actual countermeasures dispenser.

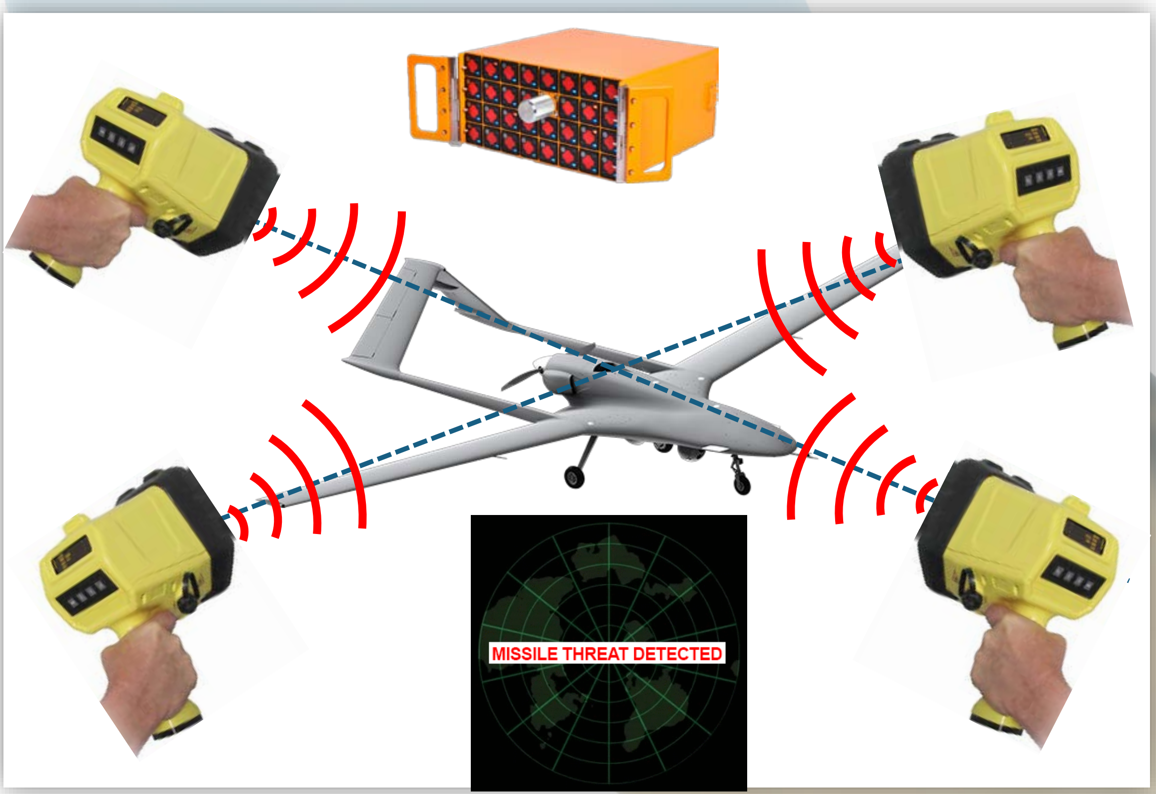
    2. Check that the **inventory of CHAFF / FLARES** shown on the Ground Station matches the one loaded into the dispensers.

    3. Operate the chaff and flare dispenser in **Manual Mode**. Select a **countermeasures program**.

    4. **Stimulate MWS/LWS/RWR** in the different quadrants with the EW tester.

    5. Check the **proper countermeasures are dispensed depending on the type of threat** (Flares for Missiles vs Chaff for Radar), and are **dispensed on the side** corresponding to the **detection of the threat**.

    7. **Check the remaining chaff and flares** in Ground Station



GROUND TESTING (IV): IFF M5

- Test Procedure:
  - **IFF Test Set is used as an Interrogator Simulator .**

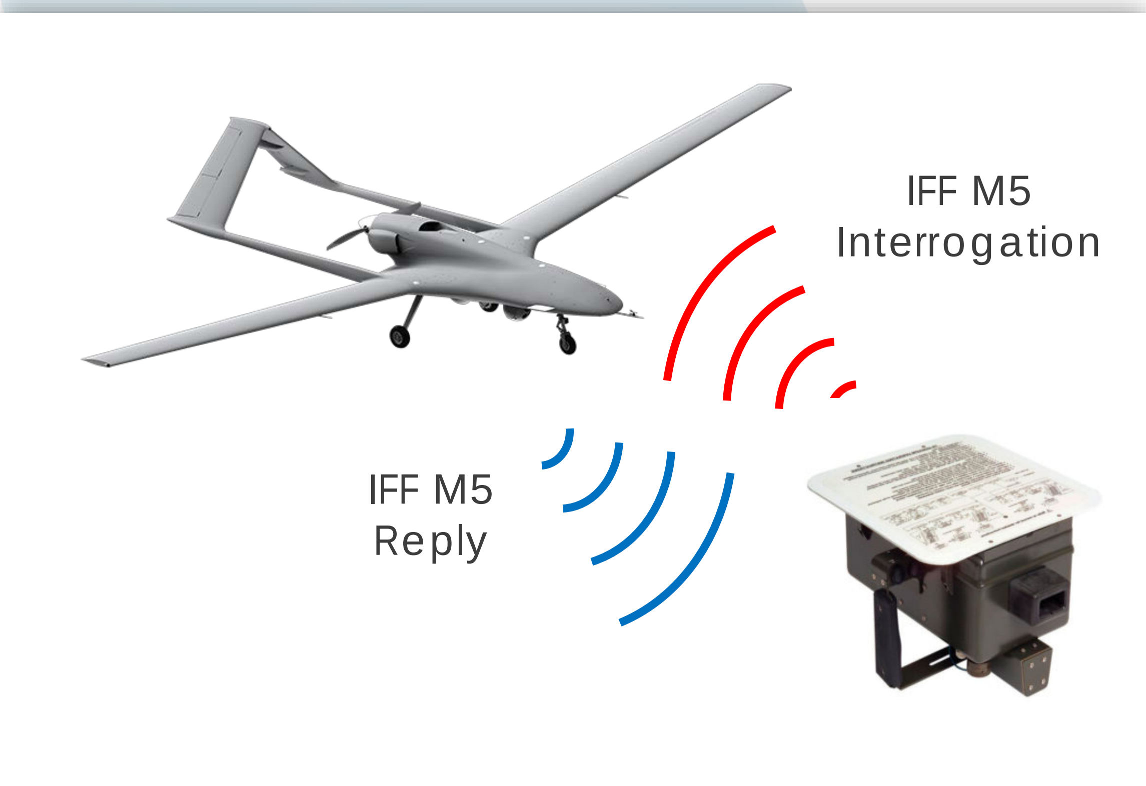
1. Install **Mode 5 crypto computer** in IFF Transponder and IFF Test Set. **Load of M5 Crypto Keys**.

2. Check **Mode 5 Crypto Keys status** in Ground Station.

3. IFF Test Set sends **M5 Interrogations** to UAS' IFF Transponder.

4. Check if UAS' IFF Transponder **replies properly in Mode 5**.

5. Push the **Secure Data Erase** to erase crypto codes in UAS' IFF Transponder. Check if in Ground Station is displayed a message indicating that IFF's crypto keys are missing.



GROUND TESTING (V): MILITARY GNSS RECEIVER

- Test Procedure:

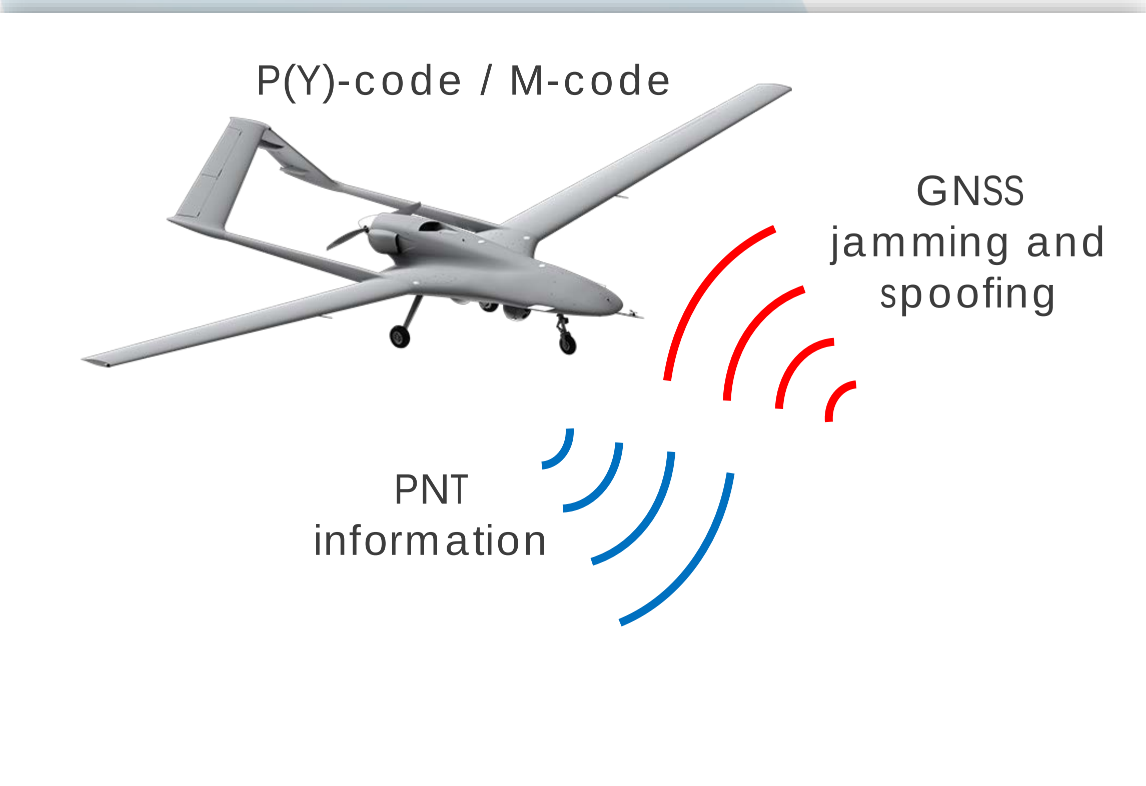
1. **Load of Crypto Keys** in GNSS receiver in order to enable military codes (P(Y), M).

2. Check **GNSS Crypto Keys status** in Ground Station.

3. Use special equipment for **GNSS jamming and spoofing** scenarios to simulate Navigation Warfare (NAVWAR).

4. Check if GNSS receiver operating with military codes provides **correctly PNT information**.

5. Push the **Secure Data Erase** to erase crypto codes in UAS' GNSS receiver. Check if in Ground Station is displayed a message indicating that GNSS's crypto keys are missing.



GROUND TESTING (VI): MILITARY V/UHF - SATURN

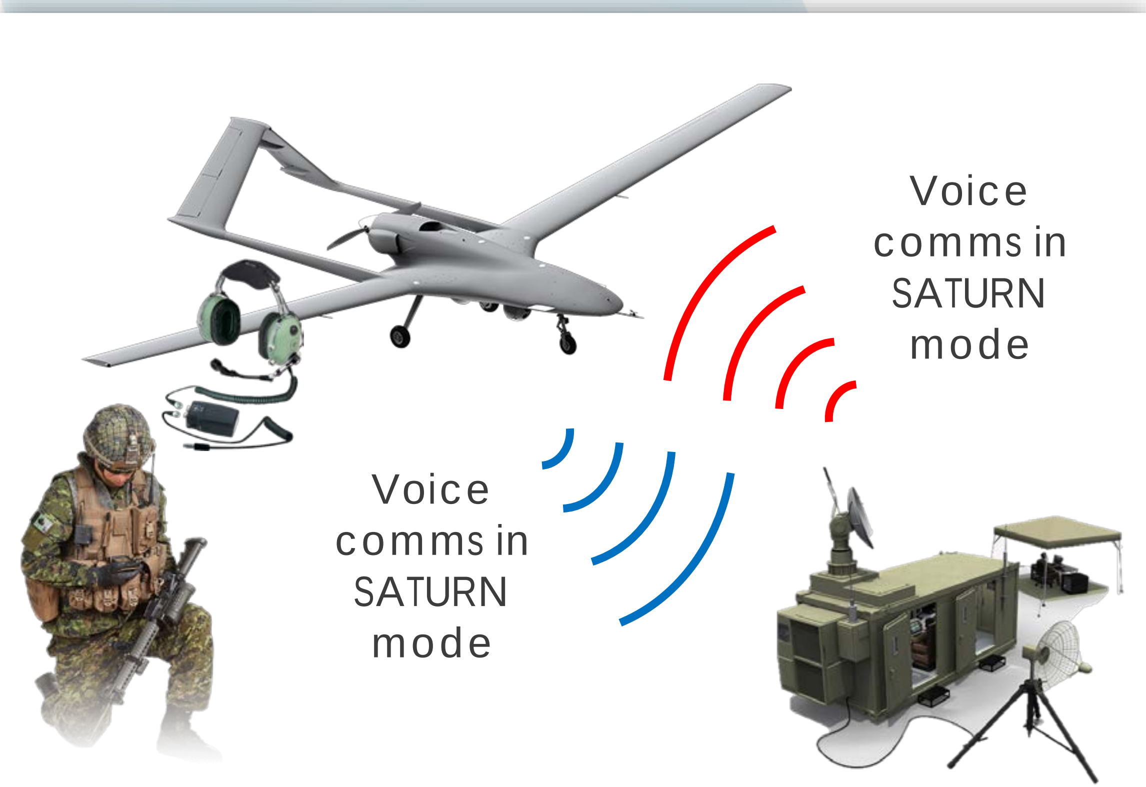
- Test Procedure:

1. **Load of Crypto Keys** in UAS V/UHF transceiver and Ground Station's V/UHF transceiver in order to enable SATURN waveform

2. Check **V/UHF Crypto Keys status and SATURN mode availability** in Ground Station.

3. Use Ground Station's V/UHF transceiver to **communicate with UAS' V/UHF transceiver on SATURN mode**.
   - A **Headset Interface Adaptor** is used to connect a groundcrew headset to the audio interface of UAS' V/UHF transceiver.
   - Check reception on the V/UHF transceivers is **loud and clear in SATURN mode**.

4. Push the **Secure Data Erase** to erase crypto codes in UAS' V/UHF transceiver. Check if in Ground Station is displayed a message indicating that V/UHF's crypto keys are missing.



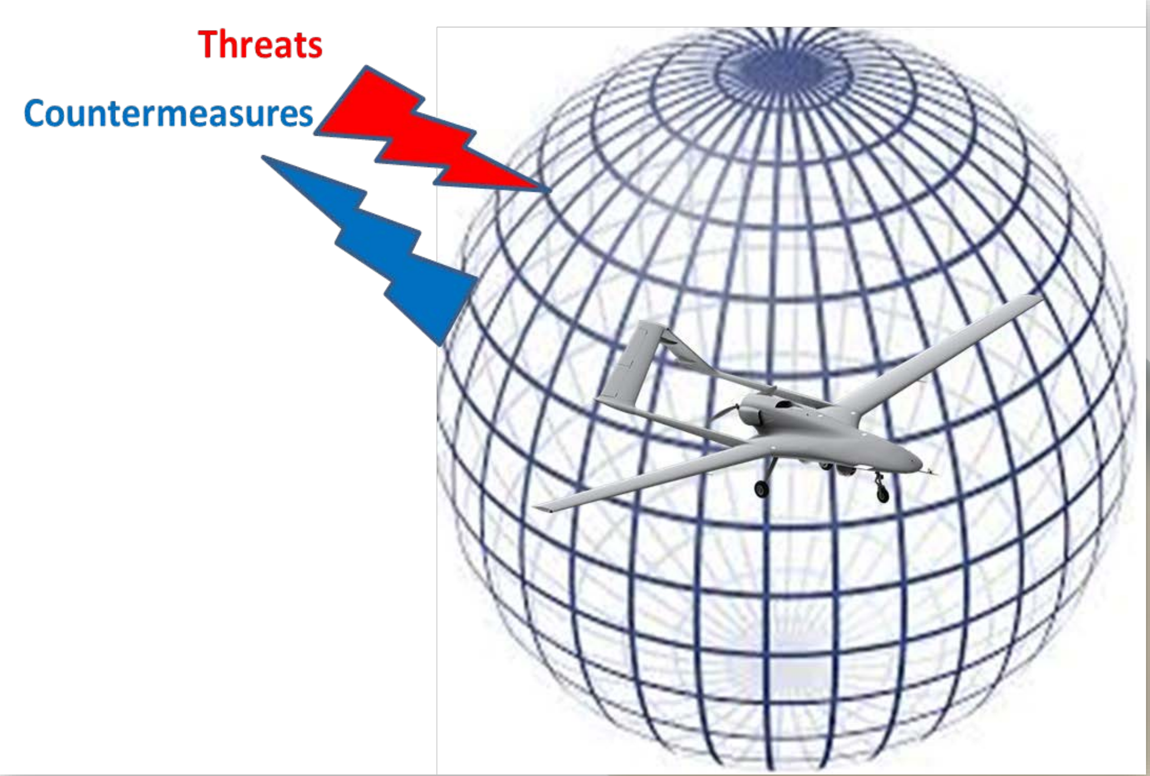
Index of Contents

FLIGHT TESTING (I): EW suite

❑ The objectives of the Flight Tests are:

1. Demonstrate successful launch and recovery of UAS carrying the Electronic Warfare payloads (self-protection suite).
   - **Airworthiness**
   - **Safety**

2. Determine the **effectiveness of EW payload** installed on UAS. Check:
   - False alarm rate.
   - Possibility of a threat not being detected.
   - Detection range
   - Time required to detect and identify threats
   - Angle of arrival for the threats. Blind zones?
   - Coverage of RF frequency and Wavelength bands
   - Identification according to Threats Library
   - Proper countermeasures deployment
   - Reaction time
   - Number of simultaneous threats the system can deal with
   - Information reported in the Ground Station



Configuration of UAS for the flight tests must be **fully representative** of the final installation of the system

FLIGHT TESTING (II): EW suite

- Before starting the Flight Tests, the Ground Tests and the **EMI/EMC Tests** have been carried out successfully.

- Two types of flights will be carried out:
  - **Flight Type #1**: to **check Threats Warning** Systems.
  - **Flight Type #2**: to **check Countermeasures** Systems.

- An **accompanying helicopter** equipped with RF, UV, Laser threat simulators flying around the UAS.

- **Challenges** for the flight tests of these EW systems is the **interaction between UAS and manned aircraft**.

- **UAS** must include the ability to "**sense and avoid**" (**ADS-B/Transponder Mode S + TCAS**) other aircraft in order to prevent collisions between UAS and helicopter

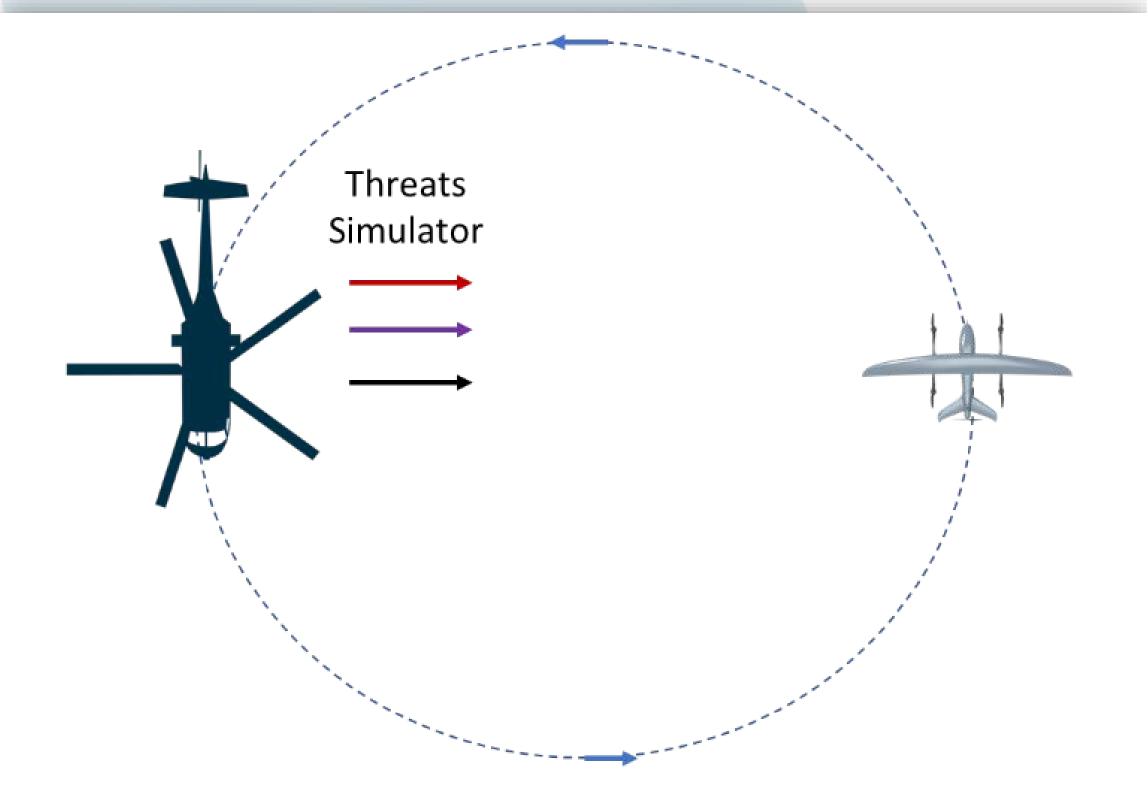
FLIGHT TESTING (III): EW suite

- Threats generator positioned in an escort helicopter placed at the same flight level or above the UAS under test, and either to one side or the other of it.

- **Flight Test Card – Flight Type 1**:

  - Step #1: **Power-up in flight** of UAS's self-defense systems.

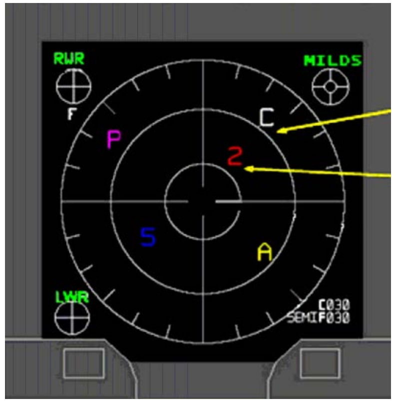
  - Step #2: **Missiles threats test** by illuminating the UAS from the accompanying helicopter sweeping 360º in azimuth

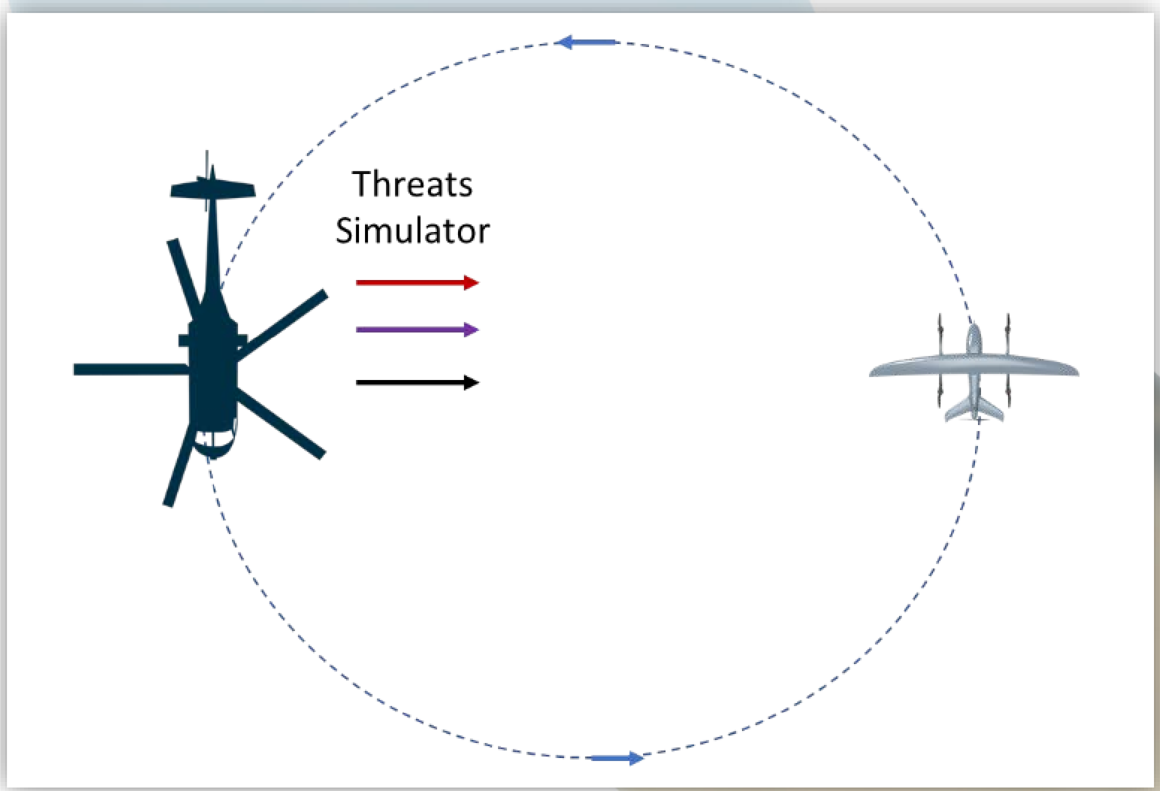


FLIGHT TESTING (IV): EW suite

- Step #3: **Laser threats test** by illuminating the UAS from the accompanying helicopter sweeping 360º in azimuth.

- Step #4: **Radar threats test** by illuminating the UAS from the accompanying helicopter sweeping 360º in azimuth





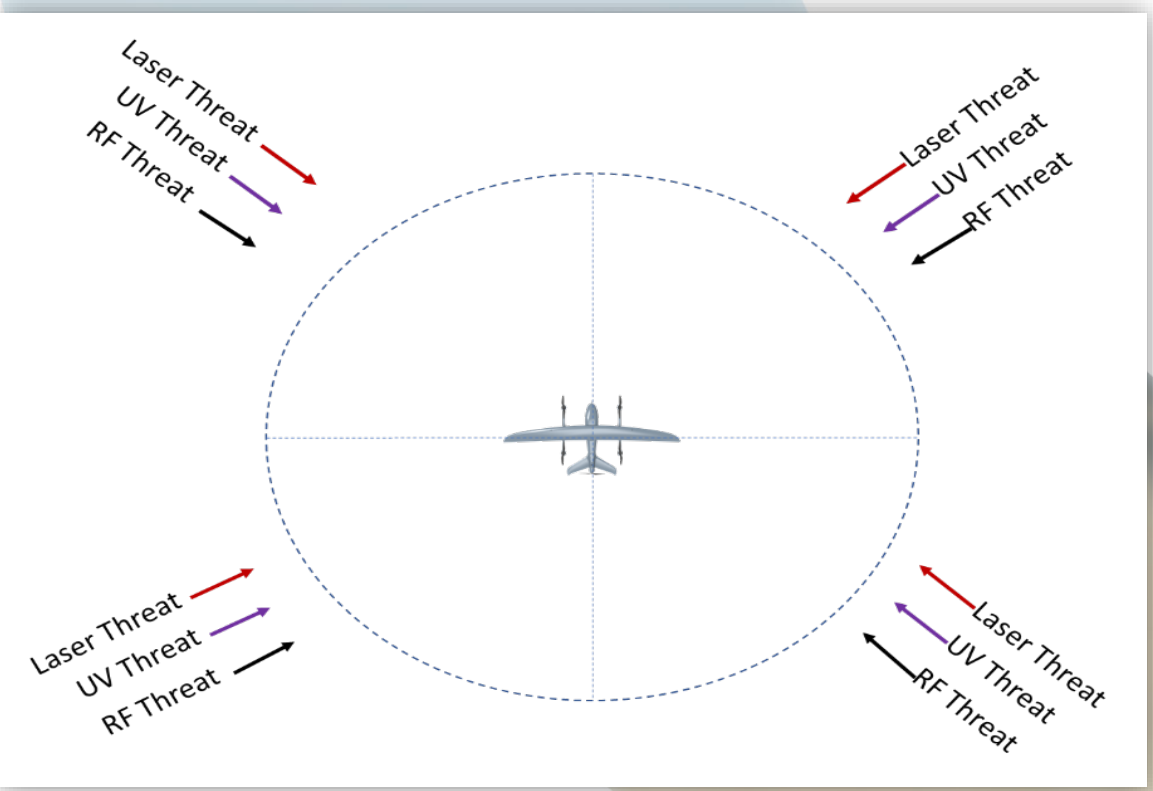
FLIGHT TESTING (V): EW suite

- **Flight Test Card – Flight Type 2**:

  - After carrying out the previous flight test, the UAS will be brought to the ground in order to load the dummy countermeasures.

  - Step #5: **Test of dispensing countermeasures** against threats.

    - UAS will be illuminated by Threats generator from the accompanying helicopter, sweeping 360º in azimuth, verifying that the countermeasures have been dispensed on the side corresponding to threat.

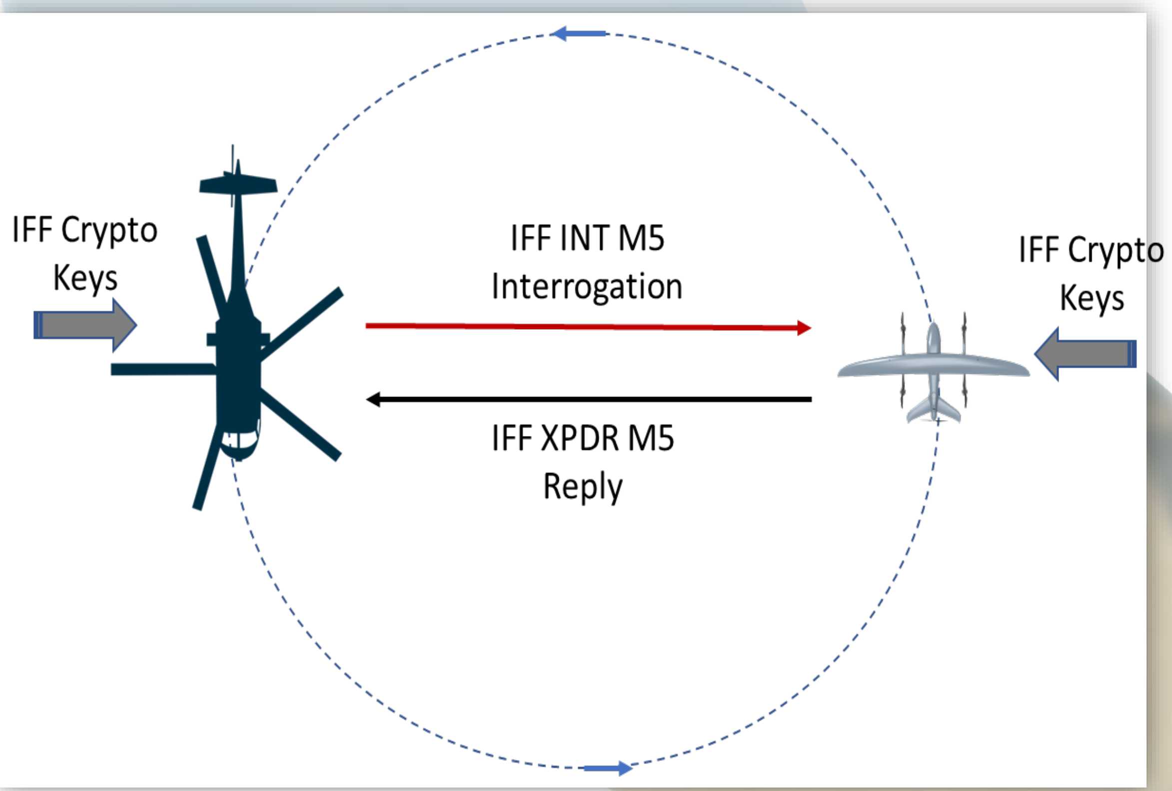


FLIGHT TESTING (VI): IFF Mode 5

- The objectives of the Flight Tests are:

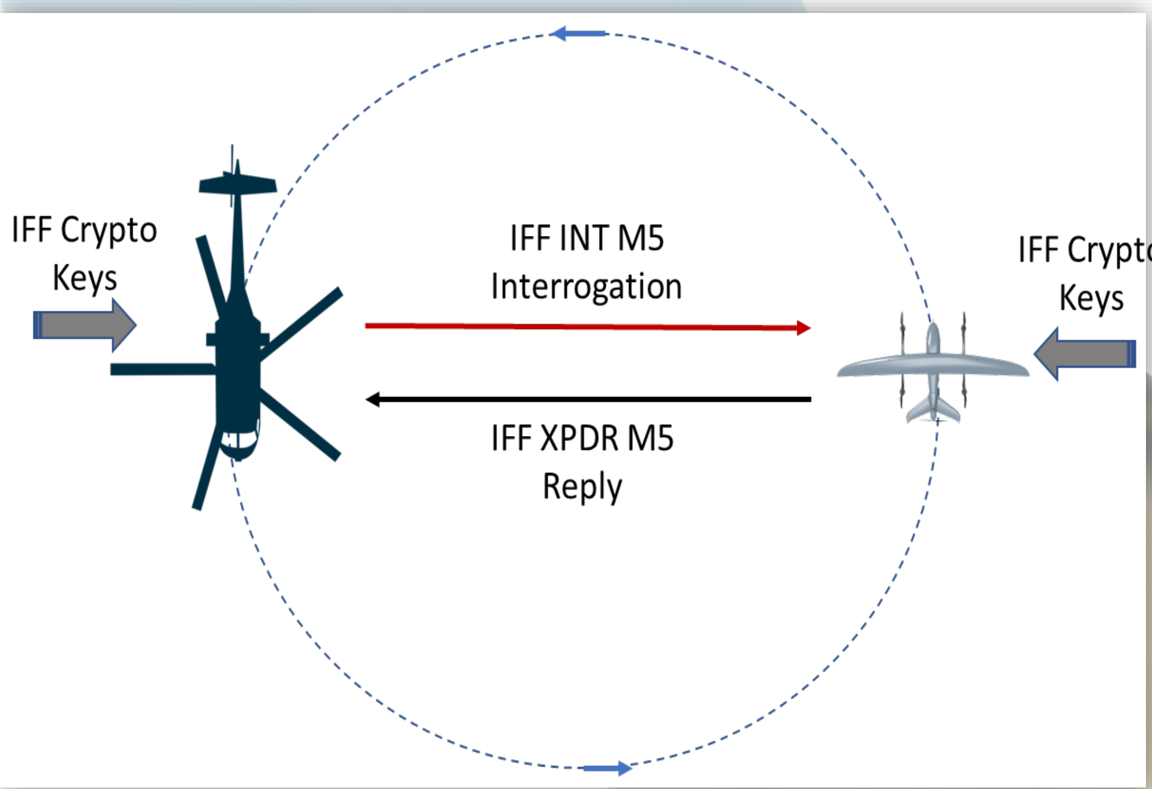
1. Demonstrate successful launch and recovery of UAS carrying the IFF Transponder Mode 5.
   - Airworthiness
   - Safety

2. Determine the proper work of IFF Transponder Mode 5 installed on UAS. Check:
   - **Crypto Keys** are proper **loaded** and **zeroized**.
   - IFF Transponder **replies properly in Mode 5** to interrogations.
   - Ground Station properly **reports about the crypto keys status, Mode 5 availability and Mode 5 responses**



FLIGHT TESTING (VII): IFF Mode 5

- **Flight Test Card** :
  - Step #0: **Install Mode 5 Crypto Computer** in UAS' IFF Transponder and Helicopter's IFF Interrogator.
  - Step #1: **Loading of M5 Crypto Keys in IFF** Transponder and IFF Interrogator.
  - Step #2: **Power-up** in flight of UAS's IFF Transponder M5.
  - Step #3: Check that **M5 Crypto Keys are present and M5 available** in both IFF Transponder and Interrogator.
  - Step #4: Helicopter's **IFF INT sends M5 interrogation** to UAS' IFF XPDR.
    - Check that **IFF XPDR replies properly to M5**.
  - Step #5: Push **Secure Data Erase** to erase crypto codes in UAS' IFF Transponder.
    - After that, check if a message is displayed indicating that **IFF's crypto keys are missing**.

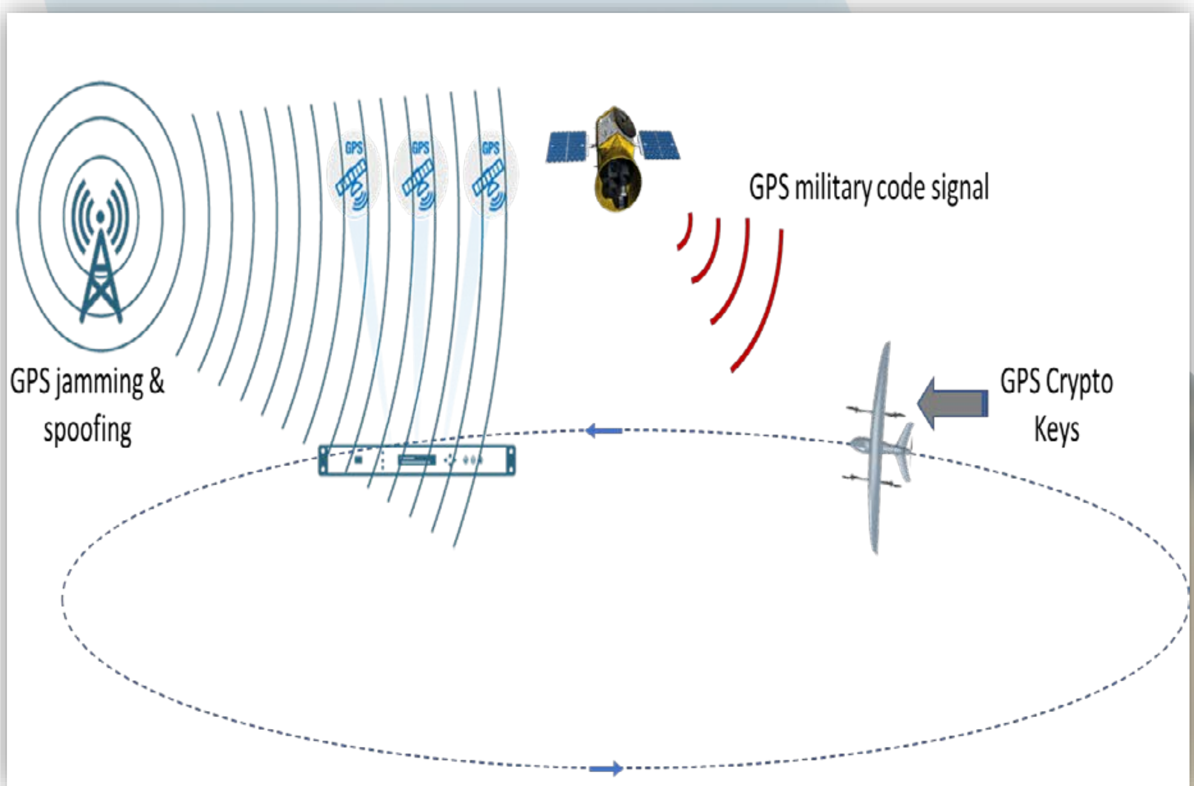


FLIGHT TESTING (VIII): Military GNSS Receiver

❑ The objectives of the Flight Tests are:

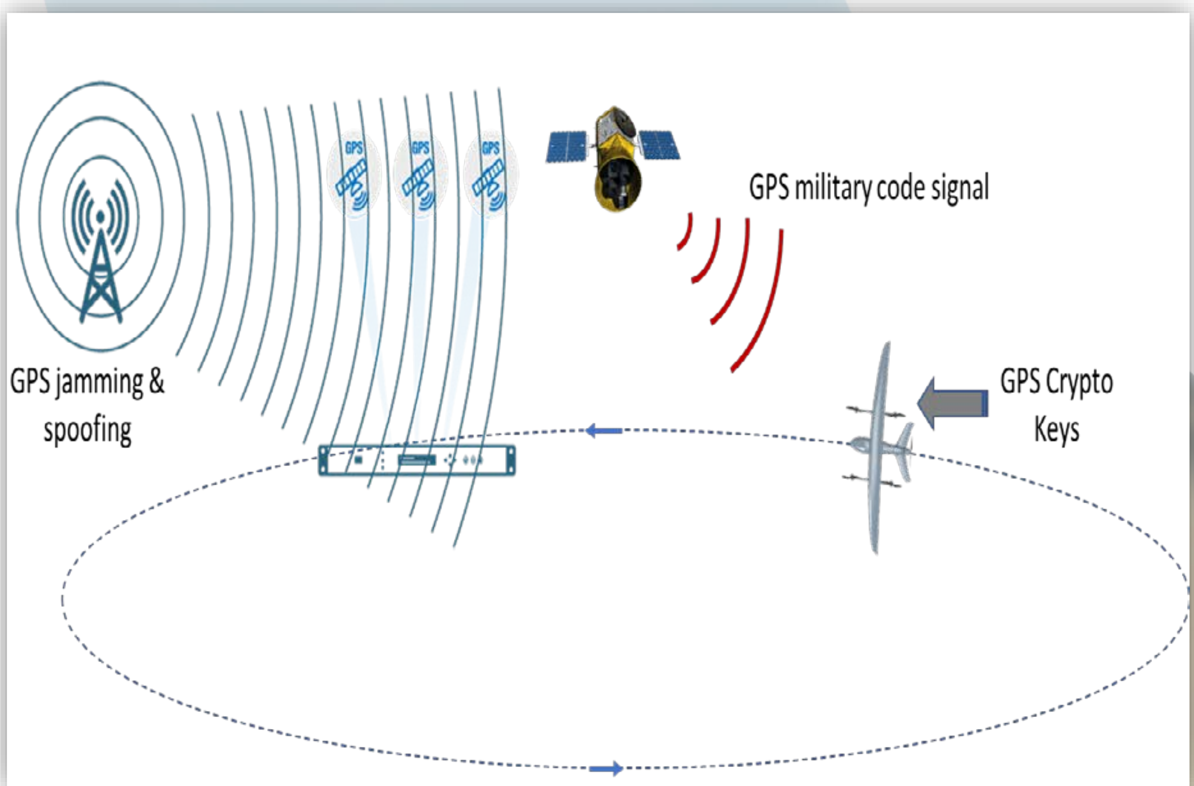
1. Demonstrate successful launch and recovery of UAS carrying military GNSS receiver.
   - Airworthiness
   - Safety

2. Determine the proper work of military GNSS receiver installed on UAS. Check:
   - **Crypto Keys** are proper **loaded** and **zeroized**.
   - GNSS receiver operates properly (PNT) in military modes.
   - Ground Station properly **reports about the crypto keys status, and GNSS' military codes availability.**



FLIGHT TESTING (IX): Military GNSS Receiver

- **Flight Test Card** :
  - Step #1: **Loading of Crypto Keys in GNSS receiver**.
  - Step #2: **Power-up** in flight of UAS's GNSS receiver.
  - Step #3: Check that **GNSS Crypto Keys are present and military codes are available**.
  - Step #4: Check that GNSS receiver provides **properly PNT without GNSS degradation or denial**.
  - Step #5: Check that GNSS receiver **works properly with military codes** to **provide properly PNT** with **GNSS degraded**.
  - Step #6: Check that GNSS receiver **works properly with military codes** to **provide properly PNT** with **GNSS denied**.
  - Step #7: Push **Secure Data Erase** to erase crypto codes in UAS' GNSS receiver.
    - After that, check if a message is displayed indicating that **GNSS's crypto keys are missing**.

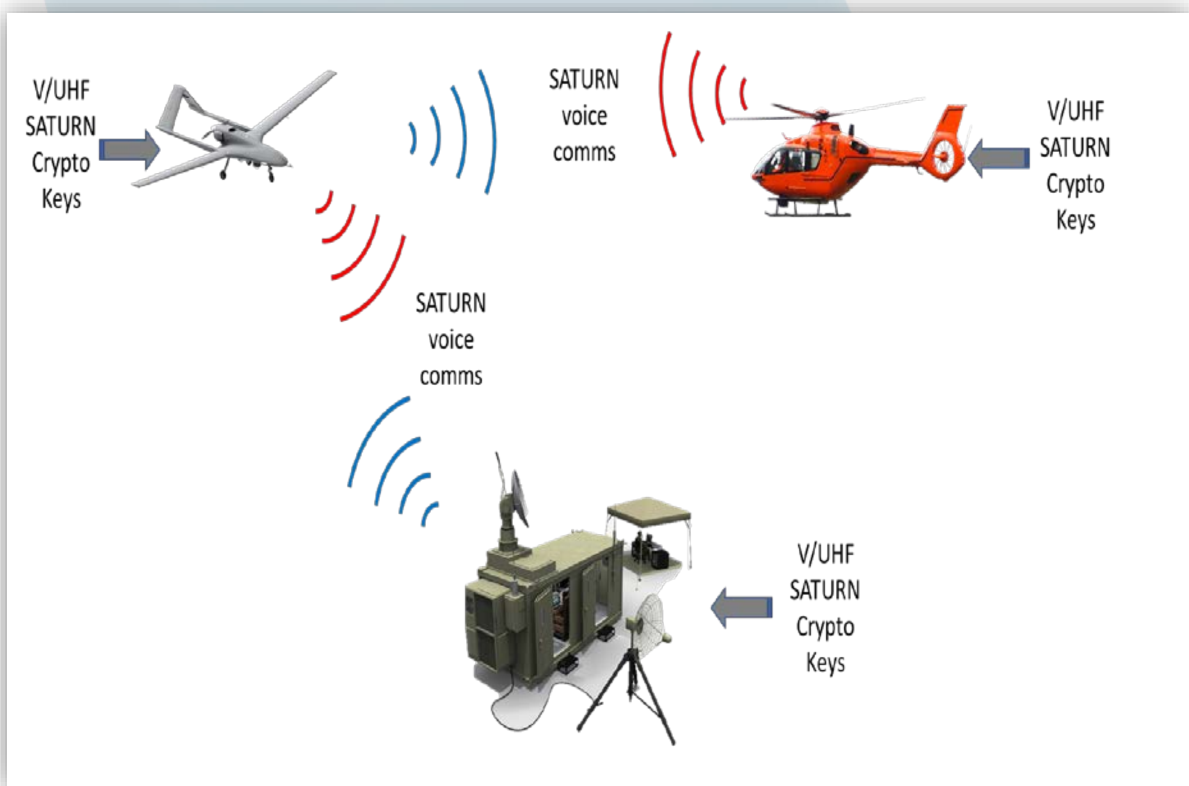


FLIGHT TESTING (X): V/UHF Transceiver - SATURN

❑ The objectives of the Flight Tests are:

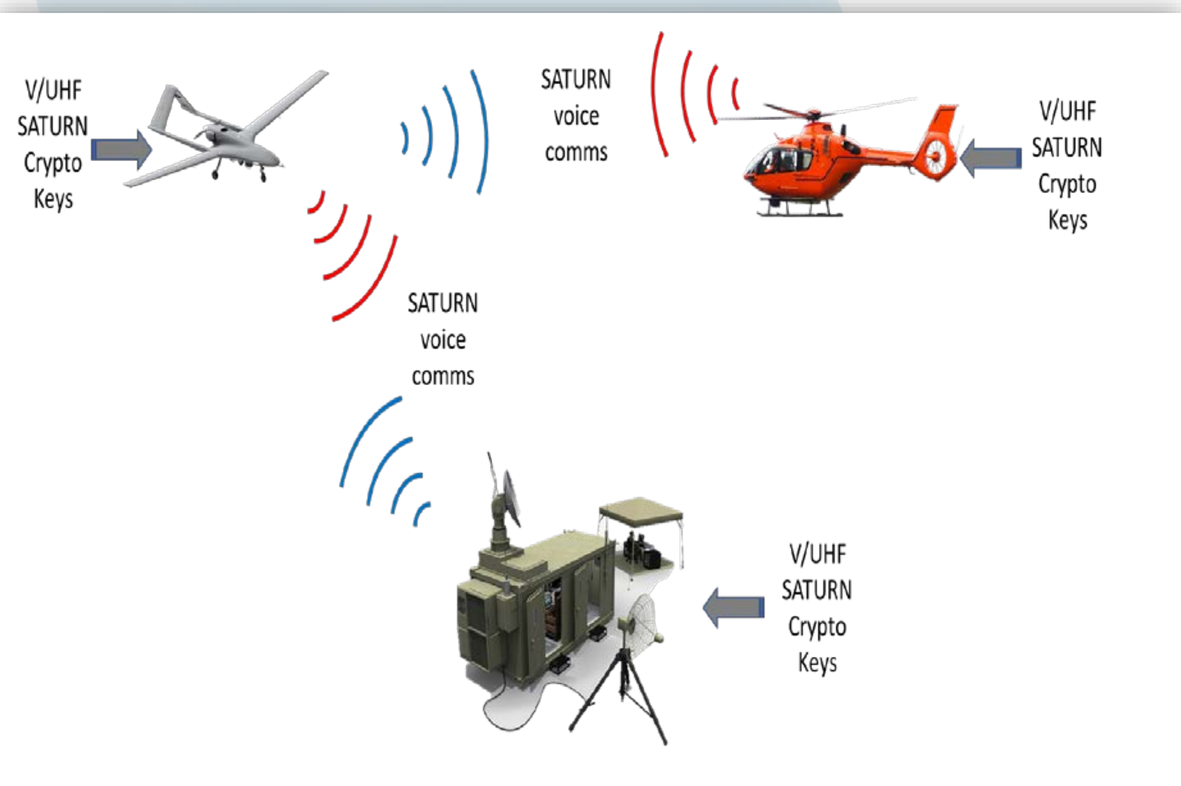
1. Demonstrate successful launch and recovery of UAS carrying military V/UHF Transceiver.
   - Airworthiness
   - Safety

2. Determine the proper work of military V/UHF Transceiver installed on UAS. Check:
   - **Crypto Keys** are proper **loaded** and **zeroized**.
   - V/UHF transceiver operates properly with SATURN waveform.
   - Ground Station properly **reports about the crypto keys status, and SATURN mode availability.**



FLIGHT TESTING (XI): V/UHF Transceiver - SATURN

- **Flight Test Card** :
  - Step #1: **Loading of Crypto Keys in V/UH Transceivers** of UAS, helicopter and Ground Station.
  - Step #2: **Power-up** in flight of UAS's V/UHF Transceiver.
  - Step #3: Check that **Crypto Keys are present and SATURN mode available** in all V/UHF transceivers.
  - Step #4: **Helicopter's V/UHF transmits voice** to the UAS' V/UHF, operating **UAS as a communications relay** to Ground Station's V/UHF.
    - Check reception on the V/UHF transceivers is **loud and clear**
  - Step #6: **Ground Station's V/UHF transmits voice** to the UAS' V/UHF, operating **UAS as a communications relay** to helicopter's V/UHF.
    - Check reception on the V/UHF transceivers is **loud and clear**
  - Step #5: Push **Secure Data Erase** to erase crypto codes in UAS' V/UHF Transceiver.
    - After that, check if a message is displayed indicating that **V/UHF's crypto keys are missing**.



FLIGHT TESTING (XII)

UAS must survive in order to accomplish successfully its mission

- **Combat Survivability Assessment (Ps)**:
  - $P_s = P_{ssp} / P_{deccm}$
  - Where:
    - P_{ssp}: **Probability** of **success** of UAS **self-protection** system
      - Probability of Threats Detection x [(Probability of activation of Countermeasures / Threats Detection) x Percentage of effectiveness of Countermeasures against Threats]
    - P_{deccm}: **Probability** of **defeat** of enemy's **counter-countermeasures**
      - 1 – (Probability of enemy's Counter Countermeasures deployment x Percentage of effectiveness of enemy's Counter Countermeasures / Counter Countermeasures deployment)

- **Measure of Mission Success (MOMS):**
  - $MOMS = P_s \times MAM$
  - Where:
    - MAM: measure of **mission accomplished**

Index of Contents

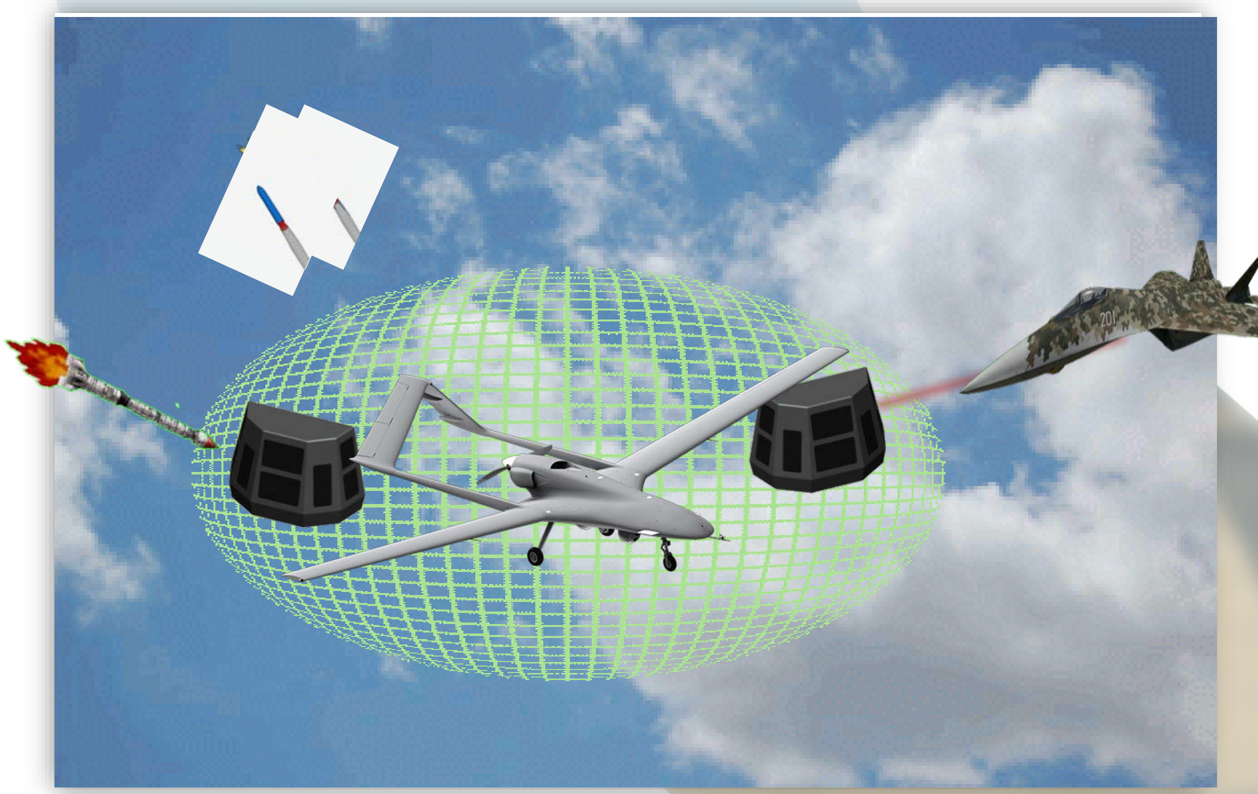
CONCLUSIONS

- **Electronic Warfare** (EW) has a vital role to play in the **protection of UAS as valuable assets**.

- **EW payloads** are getting **smaller** so that they can be inserted in **small UAS**.

- The **Flight Tests of UAS** equipped with EW pose certain challenges.
  - Interaction of **UAS with manned aircraft** in the same airspace
    - Equip the **UAS with Sense & Avoid** systems.

- Highlighted parameters of UAS self-defense system measured during the Flight Tests:
  - False alarm rate
  - Misdetection rate
  - Detection range
  - Spatial coverage (azimuth and elevation)
  - Frequency/Wavelength coverage
  - Reaction time



The UAS with both the **highest survivability and mission success rate** are those that have **Threats Warning Systems and Countermeasures** against the threats.

TESTING OF DEFENSIVE AIDS SUB-SYSTEMS FOR SMALL UAS TO IMPROVE COMBAT SURVIVABILITY

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