UAV Flight Test AGARDOGraph Status Update

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ABSTRACT

Testing unmanned aircraft presents many challenges to the flight test community. Test methods and maneuvers that are easy for a manned platform are difficult or impossible to execute, while other test techniques that a pilot finds challenging are easy for the guidance system of an unmanned aircraft. And overlaying all test activities are the issues of safety, and the challenges of extremely long endurance sorties.

Flight test manuals for manned aircraft are inadequate to meet the needs of unmanned aviation. As a result, work began in 2018 on an AGARDOGraph to cover this subject. Authors from the U.S. Navy, U.S. Air Force, and the Netherlands contributed chapters. Information in this AGARDOGraph reflect experience from a wide range of UAV test programs, including the RQ-3, RQ-4A, MQ-4C, MQ-8, MQ-9, MQ-21, and MQ-25 systems. This AGARDOGraph is currently in the review and release process. This paper is intended to serve as a preview of the final document.

1.0 BACKGROUND

The last NATO AGARDOGraph on the testing of Unmanned Aerial Vehicles (UAVs) was written nearly twenty years ago, and did not reflect the lessons learned from the testing of 4th generation UAVs such as the RQ-4 Global Hawk. Since that time, unmanned aviation has come to play a substantial role in NATO air arms, and the advanced capabilities that were once the province of high-end UAVs such as the RQ-4 family have become commonplace.

The U.S. Naval Test Pilot School released FTM-110, a dedicated UAV flight test manual, in 2019. A new AGARDOGraph, based on FTM-110 but adding new material, was proposed in 2018. The approach used was to take the material from FTM-110, update it, then add new material in new chapters. This enabled individual authors to focus their efforts on a particular portion of the AGARDOGraph, but does produce some overlap in coverage. However, the editor considered having a range of perspectives on several issues to be more valuable than trying to concentrate multiple inputs into a single view.

It should be noted that the UAV Flight Test AGARDOGraph has UAV-specific test information only, and is intended to supplement existing flight test manuals containing flying qualities and performance test methods. This AGARDOGraph is currently in the review process for publication. Given the timing of this symposium, it was decided to provide a preview brief that would cover the contents and key points. Several other papers scheduled for this symposium will delve into the details of selected topics.

2.0 CHAPTER 1 - HISTORICAL PERSPECTIVES

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

2.1 Key Points:

- 5 generations of UAVs.
- Modern large UAVs are 4th generation.
- 5th generation capabilities are in technology development.
- Capable of useful military missions, including ISR and strike.
- Beware of overambitious marketing people signing the technology up to do what it can't.

3.0 CHAPTER 2 - SAFETY CONSIDERATIONS

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired); Ben Brierty, U.S. Naval Test Wing Atlantic

3.1 Key Points:

- Minimum of 2 links from the ground station to the air vehicle.
  - If you're down to one link, stop testing. Troubleshoot for a period, then return to base.
- Be a good neighbor when it comes to airspace.
  - Stay above FL500 if possible.
  - Stay out of national airspace if you can.
  - Taxi can be a problem.
- Don't rely on autonomous emergency procedures to solve problems.
  - Don't test in flight, use the Systems Integration Lab.
  - Do observe responses to failures in flight.
- Flight Termination Systems add one risk to mitigate another.
  - Remove when the risk mitigated is less than the risk added.
- Have a "What-If" policy for emergencies.

4.0 CHAPTER 3 - TEST TEAM DAILY OPERATIONS

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired); Ben Brierty, U.S. Naval Test Wing Atlantic

4.1 Key Points:

- Stay on good terms with civil airspace authorities.
- Testing large UAVs is a job for properly trained aircrew.
  - Test pilots by preference.
  - Test non-pilot officers and other aircrew.
- Testing will demand a large number of properly trained Test Event Directors.

- They are long-lead items.
- They are much in demand.
- Abuse them and lose them.
- They are part of Operations, but can be borrowed from other disciplines

- Test card decks require careful preparation, allow enough time/resources for it.
- Same for the flight briefing. Keep the spectators out.
- Pick your chase carefully.
- Large UAV testing has a lot of parts that require disciplined communications.
    - Crew Resource Management training should be required for all test personnel.
- Multi-shift operations will be routine for some designs.
    - Brief all shifts the day before, update for each shift just before taking stations.
- Manage test team tempo carefully.
- Debrief thoroughly.
    - Debriefs are for the test team only.
    - Expect to produce a same-day report.

5.0 CHAPTER 4 - TEST PROGRAM MANAGEMENT

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

5.1 Key Points:

- Early test planning is critical.
- Use test metrics that make sense, and won't swamp the test team to track.
- Manage overwork wisely.
- Expect operational deployment of test assets.
    - Plan and resource test program with this in mind.

6.0 CHAPTER 5 - SYSTEMS INTEGRATION LABORATORY AND GROUND TESTING

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired); Thomas Maday , U.S. Naval Test Wing Atlantic; Ben Brierty, U.S. Naval Test Wing Atlantic

6.1 Key Points:

- UAVs require more ground testing than manned aircraft of similar complexity.
- The Systems Integration Laboratory (SIL) is a major ground test asset.
    - "Iron bird" for testing.
    - Used for development, troubleshooting, previews of high-risk tests.
    - Best practice is to have three of them.
- Stationary ground testing will be extensive.
    - Be sure to include testing the ground station.
    - Be sure to include testing the maintenance equipment.

7.0 CHAPTER 6 - EMPLOYMENT OF TESTBED AND SURROGATE AIRCRAFT

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

7.1 Key Points:

- Sometimes, it is advisable to use testbed and surrogate aircraft.
- Four general types.
  - "Flying SIL" for testing engines, radars, other sensors.
  - Experimental airframe to demonstrate new ideas.
  - Existing airframe controlled by test system.
  - Surrogates to refine tactics and procedures.
- Surrogate and testbed aircraft can save time and resources.
- Surrogate and testbed aircraft present unique issues.
  - Structural.
  - Flying qualities.
  - Human factors.
  - Procedures.
  - Operations.
  - UAVs impose other special considerations.
- Understand the definitions of success.

8.0 CHAPTER 7 - SURROGATE TEST AIRCRAFT AND THEIR EMPLOYMENT

Author: 1st LT Avery Leonard, USAF, Edwards AFB

9.0 CHAPTER 8 - TAXI TESTING

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired); Ben Brierty, U.S. Naval Test Wing Atlantic

9.1 Key Points:

- Higher level of risk than stationary testing.
- Buildup
  - Speed from ~5 kts to ~3/4 of takeoff speed.
  - Complexity from straight line to multiple turns.
- Duration will depend on maturity
  - Can take several months for completely new design.
- Arresting gear rollover tests can be a problem.
  - May wish to defer if possible.

- Takeoff abort is last test prior to flight.
  - Dress rehearsal
  - Need a flight clearance.
  - Very fast-paced.

10.0 CHAPTER 9 - FIRST FLIGHT

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

10.1 Key Points:

- One takeoff, one landing, no smoking holes.
- Limited scope.
  - 0.5-1.5 flight hours.
  - 10-30,000 ft.
  - Gear DOWN unless required to retract, or high confidence.
  - Conservative command envelope.
- Rehearse thoroughly.
- Work with Public Affairs beforehand, they can be a valuable ally on the flight day.
- Be mindful of first flight traditions.
- Take lots of photos.
  - Ground.
  - Flight.
  - Postflight.
- No first flight plan survives first flight, be ready to improvise.
- Control the debrief.

11.0 CHAPTER 10 - STABILITY, CONTROL, AND HANDLING QUALITIES TESTING

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired); Ben Brierty, U.S. Naval Test Wing Atlantic; Jill Stoner, U.S. Naval Test Wing Atlantic

11.1 Key Points:

- UAVs have a Command Envelope of commands that can be given to aircraft.
  - Treat expanding this as carefully as buildup in altitude, G, airspeed, etc.
  - Test in SIL, then verify in flight.
  - Have a way to get out if one doesn't work right.
- Altitude/airspeed/G/configuration expansion is similar to manned aircraft.
  - Change only one parameter at a time.
  - Some UAVs have very narrow envelopes, not much expansion in that area.
- No "stick free" stability & control characteristics.
  - Use closed-loop inputs to get data.

  - Need engineering test commands (ETCs) to do some tests.
  - ETCs need to be identified and in software requirements ~ 2 years before flight.
- No handling qualities, computers work the controls.
  - Mission relation always works for testing.

12.0 CHAPTER 11 - PERFORMANCE TESTING

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

12.1 Key Points:

- Generally like manned aircraft.
- High-precision navigation systems on UAVs make some tests easier.
  - Pitot-static testing can use data to extract position error.
  - Takeoff and landing performance data can be obtained and corrected for test day.
- Limited flight envelope may significantly impact test approach.
  - Work with what is available.
  - Brute force methods will work when nothing else will.
- Mission relation is essential.

13.0 CHAPTER 12 - EMPLOYMENT OF SURROGATE AIRCRAFT IN AERIAL REFUELING AND CARRIER SUITABILITY TESTING

Author: Brian Karlow, U.S. Naval Test Wing Atlantic

13.1 Key Points:

- Surrogates often used for development of UAV guidance logic and capabilities
  - Contain risk.
  - Real-time data without telemetry.
  - Safety of test.
- Extensive use for USN carrier-based UAV testing
  - X-47.
  - MQ-25.
- Non-aircraft surrogates can also be useful.
- No handling qualities, computers work the controls.
  - Mission relation always works for testing.

14.0 CHAPTER 13 - CARRIER SUITABILITY

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

14.1 Key Points:

- Significant challenges for carrier operations.
  - Many mode changes.
  - Precision of control.
  - Integrating a datalink/command-and-control architecture in a heavy EMI environment
  - Coordinating the installation of hardware on the ship to support UAV operations
- Deck handling comes first.
  - Ashore first.
  - Then afloat.
  - EMI/EMC testing before going to sea!
- Catapult launches.
  - Ashore, then afloat.
  - Watch the guidance mode transitions.
- Arrested landings.
  - Buildup – Low approach/waveoff, then touch-and-go, finally full arrested landings.
  - Ashore then afloat.
  - Last ~30 seconds critical.
  - Watch the guidance mode transitions.
- Off-Nominal Arrestments.
  - Define requirements for flight control laws early
- Superior proven guidance and control performance of the UAV may eliminate/reduce the requirement for traditional (manned) off-nominal arrestments
  - Need way to “fool” guidance system into doing them.
  - If using Engineering Test Commands, minimum 18 months lead time, preferably 24.

15.0 CHAPTER 14 - AIRWORTHINESS CERTIFICATION

Author: Jan Willekens, Flight Test and Certification/NLR, Amsterdam, The Netherlands

15.1 Key Points:

- Certification standards and requirements.
- Functional requirements.
- Performance-based requirements.
- Preparing the certification basis.
- Preparing the means of compliance
- Preparing the certification plan
- Conducting the compliance demonstration
  - Flight test plan
  - Flight test report
- Preparing the certification report
- Military type certificate
- Examples

16.0 CHAPTER 15 - LIGHTER-THAN-AIR SYSTEMS

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

16.1 Key Points:

- LTA and UAV technologies both suited to long-endurance missions.
- Basic materials on LTA technologies and approaches are in TM-94-1-FW.
- Expect to do a lot of tow testing as part of “taxi” testing.
- Don’t get too aggressive on first flight.
- Airships have some unusual flying qualities.
  - Watch for possible overstress by flight control systems.
- Performance generally like fixed-wing, but with static heaviness substituting for gross weight.
  - Pressure control can limit climb and descent performance.
- Expect to see more LTA systems among the next generation of unmanned aircraft.

17.0 CHAPTER 16 - HUMAN FACTORS

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

17.1 Key Points:

- Human factors design is a major challenge.
  - Lots of information.
  - No “seat of the pants”, limited external view.
  - Expect a lot of deficiencies.
- Moving map is primary situational awareness display.
- Primary Flight Display is a supplement/control input.
  - Make sure status is displayed clearly and in reference to limits.
  - Check operative sense of controls.
- Caution and Warning systems can be as much problem as solution.
- If an input device has multiple functions, be wary of mode changes.
- Watch the control transfer process.
- Test the ground support equipment.
- Early involvement by the test team prevents deficiencies.

18.0 CHAPTER 17 - COMMUNICATIONS LINKS

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

18.1 Key Points:

- 3 major families.
  - Line-of-sight.

    - Over-the-horizon direct from ground station.
    - Networked over-the-horizon.
- Different links have VERY different characteristics.
    - Capacity.
    - Reliability.
    - Lag.
- Test each link alone, then together.
    - Effects of multiple links on each other.
    - Time/difficulty of switchover from one link to another.
- Test buildup.
    - Ground stationary.
    - Ground taxi.
    - In flight.
- Voice relay.
    - Qualitative to start.
    - Modified Rhyme Testing if needed to quantify problems.

19.0 CHAPTER 18 - EXTERNAL CONNECTIVITY

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

19.1 Key Points:

- Ground stations have many connections to outside world.
    - Information and tasking in.
    - Intelligence products out.
- Major test area for UAVs with ISR missions.
    - Testing may require going beyond program-of-record.
- Test buildup.
    - Each path independently at light load.
    - Each path independently at full load.
    - Repeat with multiple paths at once.
    - Test incoming as well as outgoing.
- Security is major area of test.
    - Methods outside scope of this FTM.
    - Can avert major issues if precautions taken early in design phase.
    - Systems physically side-by-side may be on completely separate nets.

20.0 CHAPTER 19 - MISSION PLANNING SYSTEMS

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

20.1 Key Points:

- Mission plans very complex.
  - Major area of test.
- Test by planning missions.
  - Ease/time required.
  - Accuracy and correctness of mission plan.
  - Mission-relate results.
    - Fleet operators may not be as proficient.
    - Fleet operators may draw on pre-generated libraries for some portions.
- Dynamic mission replanning is theoretically possible.
  - Cautious buildup recommended.

21.0 CHAPTER 20 - AERIAL REFUELING

Author: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired)

21.1 Key Points:

- Aerial refueling potentially very useful.
- Significant technical challenges.
  - Changes in guidance modes.
  - Navigation relative to tanker.
  - Navigation relative to drogue.
  - X-47B solved, refueled successfully.
- Test approach.
  - Far away, then closer.
  - Watch the guidance mode transitions.
  - Watch stability of position behind tanker.
  - Test breakaway procedure before connection.
  - Connection.
  - Fuel transfer.
  - Disconnect and resume mission.
- Rotary-wing should be similar approach.

22.0 CHAPTER 21 - SMALL UAV TESTING

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired); MAJ David Zyga, USMC

22.1 Key Points:

- Small UAV programs present special challenges to the tester.
- Don't underestimate the safety risks.
  - Adhere to Chapter 2 safety precautions where possible.
  - Consider a Flight Termination System as a safety precaution.

    - Consider limiting fuel or using a tether.
    - Small UAVs may be cheap enough to be attrition assets.
    - Community safety may be driver, not the airframe.
- Management is also an issue.
    - Unrealistic expectations from non-aviation sponsors.
        - Scope.
        - Schedule.
    - Operators without aviation backgrounds.
        - Use trained testers for initial testing.
        - Double-check with representative operators.
- Significant flying qualities challenges.
    - Test methods relying on stabilized flight difficult to impossible.
    - Fly-by-output systems displacing fly-by-joystick.
    - Flying the mission and mission-relating results always works.
- Significant performance test challenges.
    - Turbulence will make testing harder.
- May need to use brute force methods more frequently.
    - Be familiar with reciprocating engines.
- Exotic propulsion also possible.
- Launch and recovery methods will differ from those of large UAVs.
- Human factors may be even more of a problem.

23.0 CHAPTER 22 - HIGHLY AUTONOMOUS SYSTEMS

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired);MAJ David Zyga, USMC; Jeffery Jessen, USAF AFMC

23.1 Key Points:

- Highly autonomous systems will be a major part of future systems.
    - Methods still being developed
- Several different definitions of autonomy.
    - Don't get bogged down in nomenclature.
- Test philosophy.
    - Disassemble task into sub-tasks.
    - Evaluate execution of sub-tasks.
- Separate airframe from autonomy testing.
    - Wring airframe out first.
    - Wring autonomy out separately.
    - Put together only when you have each working.
- Safety first.
    - Have a 'snatchback" capability.

24.0 CHAPTER 23 - TRAINING SYSTEMS

Authors: Dr. Aaron Judy, R. Cao, and B. Ferguson; U.S. Naval Training Systems Division

24.1 Key Points:

- UAS presents a different set of training challenges due to the lack of traditional cockpit cues.
- The goal of simulation is to support “transfer,” which is the transfer of knowledge and skills to the student.
- UAS training systems have unique characteristics compared to manned aircraft systems.
  - Understanding key areas of command and control and emergency procedures.
  - Levels of UAS training fidelity.
  - Early UAS training to support first flight and flight test.
  - Maintenance training considerations and support equipment.
- UAS trainers are complex integrated systems.
  - Integration with real aircraft hardware and the Ground Control Station (GCS).
  - Other considerations and unique aspects of UAS training design, integration, and test.
  - Evaluation of UAS trainers.

25.0 CHAPTER 24 - WEAPONS SEPARATION

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired); LCDR Alex Dulude, UX-24

25.1 Key Points:

- It's much like manned aircraft.
  - Analysis
  - Fit checks
  - Captive carriage
  - Weapon interface with airframe
  - Weapon interface with ground control station
- Don’t underestimate the safety risks.
  - What happens when things go right?
  - What happens when things go wrong?

26.0 CHAPTER 25 - FUTURE DEVELOPMENTS AND GENERAL CONCLUSION

Authors: Michael McDaniel, U.S. Naval Test Wing Atlantic (Retired); LCDR Alex Dulude, UX-24

26.1 Key Points:

- Unmanned aviation will be part of the future
- Expect to see UAV capabilities creeping into manned aircraft

- 'Loyal Wingman' and swarming will present challenges to testers
- This is the frontier of flight test

27.0 CONCLUSION

The AGARDOGraph version currently under review runs 226 pages. Because of the multiple authors and organizations involved, and the retirement of the editor from the U.S. Government, the review process is necessarily time-consuming. However, the final document should be well worth the effort. As with all documents dealing with a rapidly advancing field, there are gaps - in this case, a supplement dealing with test methods for swarming and "loyal wingman" systems