Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Project

UTM Flight Testing at NASA LaRC

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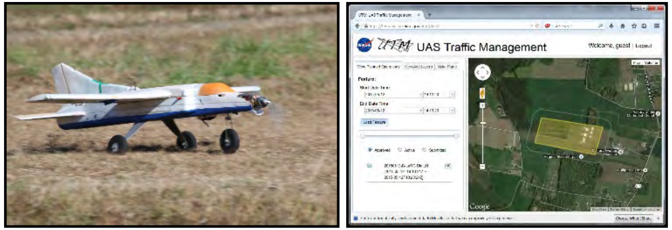
Outline

- General objectives of the presentation
  - Provide insights
  - Lessons Learned
  - Describe next steps and follow-on work
- Characterization of UTM LaRC Flight Tests
- Review selected flight tests
- Summary
- List of
  - Team Members
  - Reports
  - Invention disclosures, licenses and patents

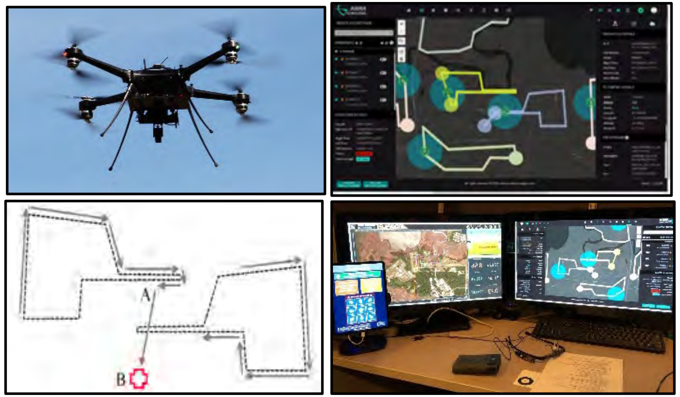
Overview and Characterization of UTM Flight Testing at LaRC

- First live vehicle connected to the NASA UTM system 2015
- Subsequent sUAS flight tests were performed to support an array of technical areas that included:
  - Autonomous Detect/Sense and Avoid (ASAA, eg ICAROUS)
  - Autonomous Contingency Management (ACM, eg Safe2Ditch)
  - Vehicle to Vehicle (V2V) communication
  - UTM traffic management system development and integration
  - Assured range containment
  - Autonomous powerline inspection
  - Human Factors for UTM Operators
  - Communication and Control (C2) links
  - Degraded GPS
  - Real-time ground risk assessment
  - Autonomous merging and spacing
  - Failure Modes Effects and Criticality Analysis (FMECA)
- Integrated UTM TCL-4 Pathfinder test performed in 2019
  - Provided integrated system evaluation
  - ACM, ASAA, V2V, UTM traffic management system
  - Human Factors assessment

First UTM Flight Operation (2015)



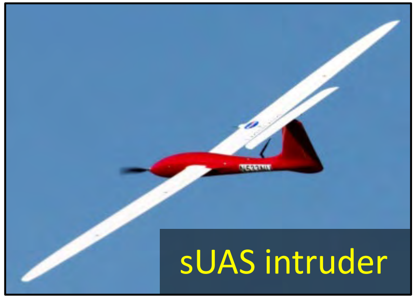
UTM Pathfinder (2019)

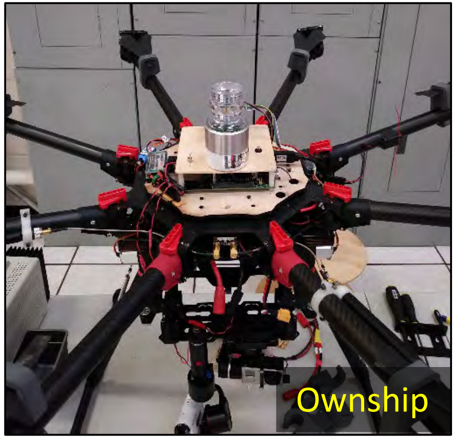


ICAROUS: Integrated Configurable Architecture for Reliable Operation of Unmanned Systems

UTM ICAROUS Sense and Avoid Testing ISAAC

- Objectives
  1. Evaluate use of micro ADS-B receiver to provide ADS-B-in
  2. Evaluate the utility of using ADS-B-in to provide effective sUAS autonomous traffic deconfliction
     - sUAS to sUAS
     - sUAS to general aviation (GA) aircraft
  3. Assess performance of ICAROUS system to deconflict traffic
  4. Assess effectiveness of reduced-power ADS-B for sUAS applications
  5. Assess the well “clear definition” for sUAS
  6. Acquire high-res, position-correlated video of sUAS and manned aircraft
     - Used to develop optical-based traffic detection algorithms
- Results
  1. Micro ADS-B unit provides effective input
     - Ghost targets observed due to Mode-C transponder rebroadcast
  2. ICAROUS able to maintain well clear (2,000ft)
  3. Low-power ADS-B feasible (~400mW vs 40W)
  4. Low-cost/high-res cameras can support well-clear optical DAA (Sony Action cams)

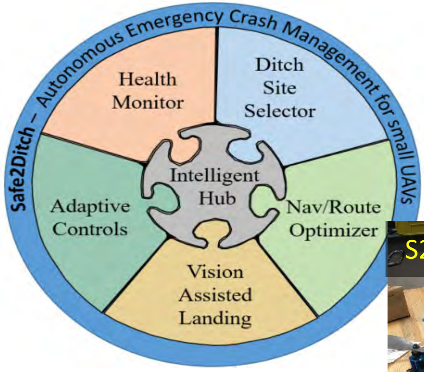


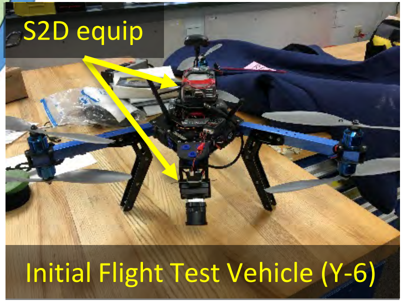


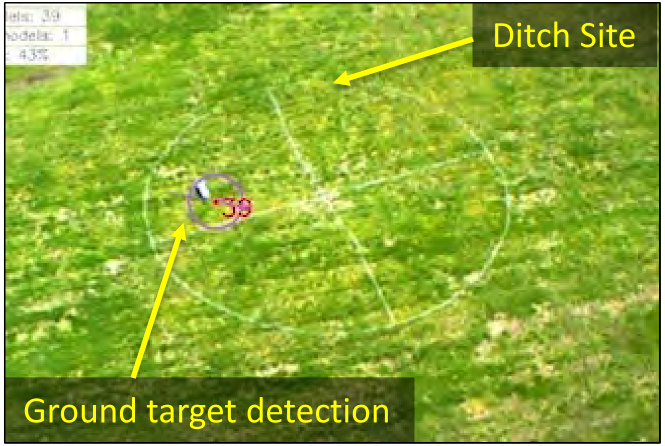
ICAROUS: Integrated Configurable Architecture for Reliable Operation of Unmanned Systems

UTM Safe2Ditch Testing

- Objectives
  - Perform efficacy testing of ACM concept
  - Assess autonomous machine vision verification of ditch site
  - Demonstrate autonomous re-routing based on ditch site state
  - Evaluate integration of S2D/ACM with overall system
- Results
  - ACM functions on sUAS can greatly mitigate ground risk
  - COTS cameras combined with state-of-the-art micro computers and algorithms enables autonomous ditch site verification
  - Geolocation of ground targets is adequate
    - Improved geolocation could support smaller ditch site usage
  - Integration of S2D with ICAROUS tested
    - Ditch site top of descent provided by S2D
    - ICAROUS provided route
    - Included geofencing around other vehicle’s airspace

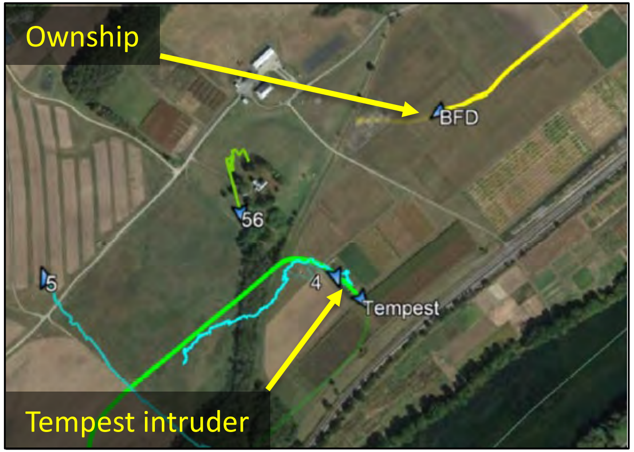






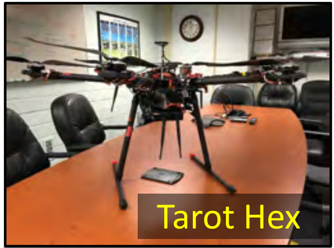
UTM RAAVIN

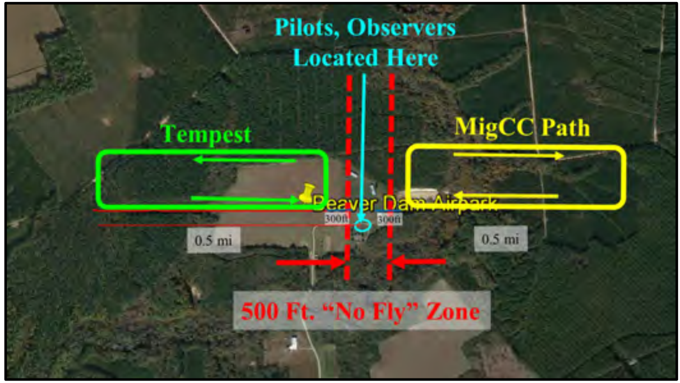
- Objectives
  1. Characterize performance of a prototype commercially available sUAS airborne radar to detect and track sUAS as well as General Aviation (GA) non-cooperative aircraft
  2. Integrate radar output into ICAROUS and evaluate non-cooperative autonomous sense and avoid scenarios
- Results
  - Collaborative flight testing performed with Mid-Atlantic Aviation Partnership (MAAP)
    - MAAP BFD multi-rotor ownship
    - Liberty University C-172
    - NASA ICAROUS software and Tempest sUAS
    - Used Kentland Farms MAAP test site
  - Prototype radar able to detect and track targets most of the time
  - Substantial background clutter issues were observed
  - Prototype radar: Echodyne Echoflight radar



UTM V2V

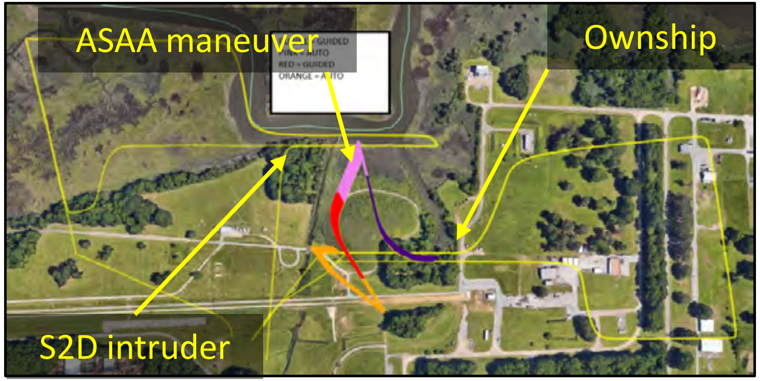
- Objective: Flight test effort aimed at developing and assessing technologies essential for UTM operations
  - Dedicated Short Range Communication (DSRC) V2V comm links
  - Evaluation of 4G cellular to provide command and control for sUAS
  - Collection of high-res position-correlated video for optical sense and avoid development (secondary)
  - Fixed wing evaluation of Safeguard (secondary)
- Results
  - DSRC effective range is limited to less than a 1km as tested
    - High frequency (5.9 GHz) and low-power (26 dB)
  - 4G cell comm is effective with some short-duration drop-outs
    - Tested in rural area
    - No link ~3% of the time
  - Sony action cams sensors/lenses can enable effective optical detect and avoid
    - Overall system weight still a challenge for full 360 deg coverage
  - Safeguard functioned adequately at fixed-wing speeds (20 m/s)

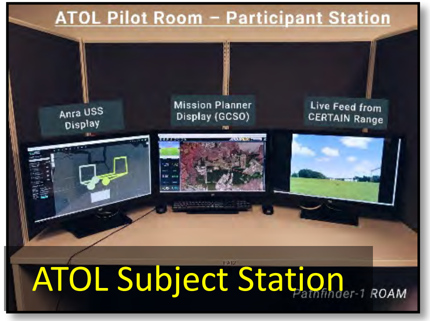


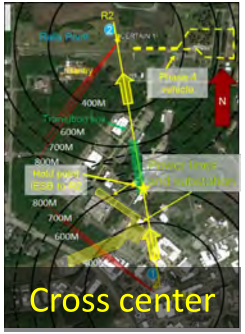


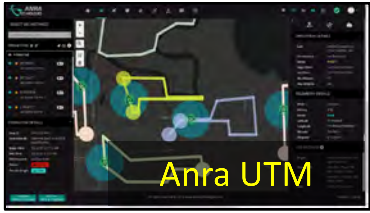
UTM TCL-4 Pathfinder

- Objectives
  1. ICAROUS/S2D contingency management and effects on UTM system
     - *Evaluate Ground Control Station (GCS) operator situational awareness, workload, reactions to contingency operations using representative UTM interface*
     - *Assess the effect of Autonomous Sense and Avoid (ASAA)*
     - *Evaluate effect of airspace-constrained contingency management (ICAROUS routing/re-routing)*
     - *With high-density operations (simulated aircraft)*
  2. Evaluate Flight Alarm (FLARM) for sUAS ASAA
  3. Long range cross-center operations
  4. Botlink 4G characteristic data
- Results
  - FLARM is effective for sUAS ASAA
  - ICAROUS can effectively perform sUAS traffic separation
  - Human separation of sUAS traffic is a monotonous task
  - HF results indicate vehicle intent is highly-desirable





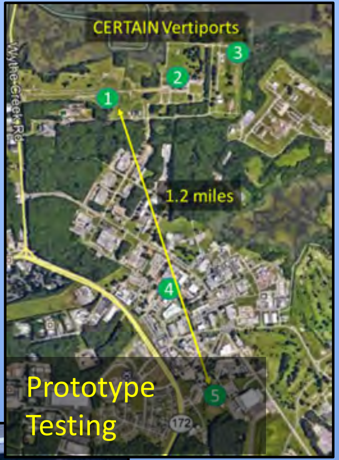




Summary

- Insights
  - Many challenges exist towards ubiquitous sUAS operations
  - Both for on-ground an airborne aspects
  - The UTM project achieved progress in both
  - Fully-operational sUAS transportation system is required before UAM
- Lessons Learned
  - Separate technology development and testing is effective
  - Integration and testing of technologies is difficult
  - Integrated testing has extremely high value
- Next Steps
  - STEReO: Application of UTM technologies for disaster response
  - AAM HDV
    - Prototype UAM system development and test
    - Leverage technologies from UTM/SWS/ATM-X/TTT
    - Enable effective management of off-nominal scenarios
    - Coordination of dynamic re-routes throughout the UAM system
    - Operational credit for NASA/other technologies
    - sUAS Part-135 BVLOS advancement

High Density Vertiplex



List of LaRC personnel

#	First	Last
1	Swee	Balachandran
2	Randy	Beard
3	Viren	Bijaj
4	Dave	Bradley
5	Eric	Chancey
6	Matt	Coldsnow
7	Toby	Comeaux
8	Maria	Consiglio
9	Chester	Dolph
10	Thane	Downing
11	Brendan	Duffy
12	Mark	Frye
13	Tyler	Garrett
14	Lou	Glaab
15	Trish	Glaab
16	Alex	Glandon
17	Rich	Grube
18	Dave	Hare
19	Dan	Healey

#	First	Last
20	Jeff	Hill
21	Troy	Landers
22	Ticatch	Larry
23	Justin	Lisee
24	Parker	Lusk
25	Mahyar	Malekpour
26	Chris	Manderino
27	Robert	McSwain
28	Sami	Mian
29	Andrew	Moore
30	Chris	Morris
31	Cesar	Munoz
32	Anthony	Narkawicz
33	Andrew	Peters
34	Mike	Politowics
35	Nick	Rymer
36	Matt	Schubert
37	Scott	Simms
38	Kyle	Smalling
39	George	Szatkowski

List of additional 2020 reports

- Andrew Peters, Swee Balachandran, Brendan Duffy, Kyle Smalling, María Consiglio, and César Muñoz, *Flight Test Results of a Distributed Merging Algorithm for Autonomous UAS Operations*, Proceedings of the 39th Digital Avionics Systems Conference (DASC 2020), Virtual Conference, US, 2020.
- Brendan Duffy, Swee Balachandran, Andrew Peters, Kyle Smalling, María Consiglio, Louis Glaab, Andrew Moore, and César Muñoz, *Onboard Autonomous Sense and Avoid of Non-Conforming Unmanned Aerial Systems*, Proceedings of the 39th Digital Avionics Systems Conference (DASC 2020), Virtual Conference, US, 2020.
- Sami Mian, Tyler Garrett, Alexander Glandon, Christopher Manderino, Swee Balachandran, César Muñoz, and Chester Dolph, *Autonomous Spacecraft Inspection with Free-Flying Drones*, Proceedings of the 39th Digital Avionics Systems Conference (DASC 2020), Virtual Conference, US, 2020
- Swee Balachandran, Christopher Manderino, César Muñoz, and María Consiglio, *A Decentralized Framework to Support UAS Merging and Spacing Operations in Urban Canyons*, Proceedings of 2020 International Conference on Unmanned Aircraft Systems (ICUAS 2020), 2020.
- Brendan Duffy, Swee Balachandran, María Consiglio, Louis Glaab, César Muñoz, Kyle Smalling, Nicholas Rymer, David Bradley, David Hare, Richard Grube, Matthew Coldsnow, Scott Sims, Jeffrey Hill, and Mahyar Malekpour, *Sense and Avoid Characterization of the ICAROUS Architecture* , Technical Memorandum, NASA/TM-2020-220591, May 2020.
- Politowicz, M.; Chancey, E.; Glaab, L.:. *Effects of Autonomous sUAS Separation Methods on Subjective Workload, Situation Awareness, and Trust.* SciTech 2020.

List of additional 2017, 2018 and 2019 reports

- 2019
- Swee Balachandran, Viren Bajaj, Marco Feliú, César Muñoz, and María Consiglio, A Learning-Based Guidance Selection Mechanism for a Formally Verified Sense and Avoid Algorithm, Proceedings of the 38th Digital Avionics Systems Conference (DASC 2019), San Diego, California, US, 2019.
- George N. Szatkowski, Andrew Kriz, Larry A. Ticatch, Robert Briggs, John Coggin, and Christopher M. Morris, Airborne Radar for sUAS Sense and Avoid , Proceedings of the 38th Digital Avionics Systems Conference (DASC 2019), San Diego, California, US, 2019.
- Brendan Duffy and Louis Glaab, Variable-power ADS-B for UAS , Proceedings of the 38th Digital Avionics Systems Conference (DASC 2019), San Diego, California, US, 2019.

- 2018
- Swee Balachandran, Anthony Narkawicz, César Muñoz, and María Consiglio, A geofence violation prevention mechanism for small UAS, Proceedings of the 31st Congress of the International Council of the Aeronautical Sciences (ICAS 2018), Bello Horizonte, Brazil, 2018.
- Swee Balachandran, César Muñoz, María Consiglio, Marco Feliú and Anand Patel, Independent Configurable Architecture for Reliable Operation of Unmanned Systems with Distributed On-Board Services, Proceedings of the 37th Digital Avionics Systems Conference (DASC 2018), London, England, UK, 2018.
- Andrew J. Moore, Matthew Schubert, Nicholas Rymer, Swee Balachandran, María Consiglio, César A. Muñoz, Joshua Smith, Dexter Lewis, Paul Schneider, Inspection of electrical transmission structures with UAV path conformance and lidar-based geofences, Proceedings of the 2018 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), 2018.
- Moore, Andrew J., NASA Langley Research Center ; Matthew Schubert, Analytical Mechanics Associates, lnc.; Nicholas Rymer: Autonomous Inspection of Electrical Transmission Structures with Airborne UV Sensors and Automated Air Traffic Management 2018 AIAA Information Systems-AIAA Infotech@ Aerospace (p. 1628).
- Andrew J. Moore, Matthew Schubert, Nicholas Rymer, Swee Balachandran, María Consiglio, César A. Muñoz, Joshua Smith, Dexter Lewis, Paul Schneider, UAV Inspection of Electrical Transmission Infrastructure with Path Conformance Autonomy and Lidar-based Geofences, NASA/TM-2017-219673, October 2017.

- 2017
- Marco A. Feliú, Camilo Rocha, and Swee Balachandran. Verification-driven Development of ICAROUS Based on Automatic Reachability Analysis , International SPIN Symposium on Model Checking of Software (SPIN 2017), Santa Barbara, CA, USA, July 2017

Invention Disclosures, Licenses, and Patents

- Invention Disclosures and Open Source Releases
  - ICAROUS (https://github.com/nasa/icarous): LAR-18850-1, LAR-18936-1, LAR-18975-1, LAR-19281-1
  - WebGS (https://github.com/nasa/webgs): LAR-19641-1
  - CRATOUS (https://github.com/nasa/cratous) : LAR-19533-1
- Patents
  - Safe2Ditch: US Patent #10,403,153

Backup Stuff

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