Engineering, Operations & Technology
Boeing Research & Technology

An Implementation Analysis of Communications, Navigation and Surveillance (CNS) Technologies for Unmanned Air Systems (UAS)

DASC2018 Conference
London, England
September 25, 2018

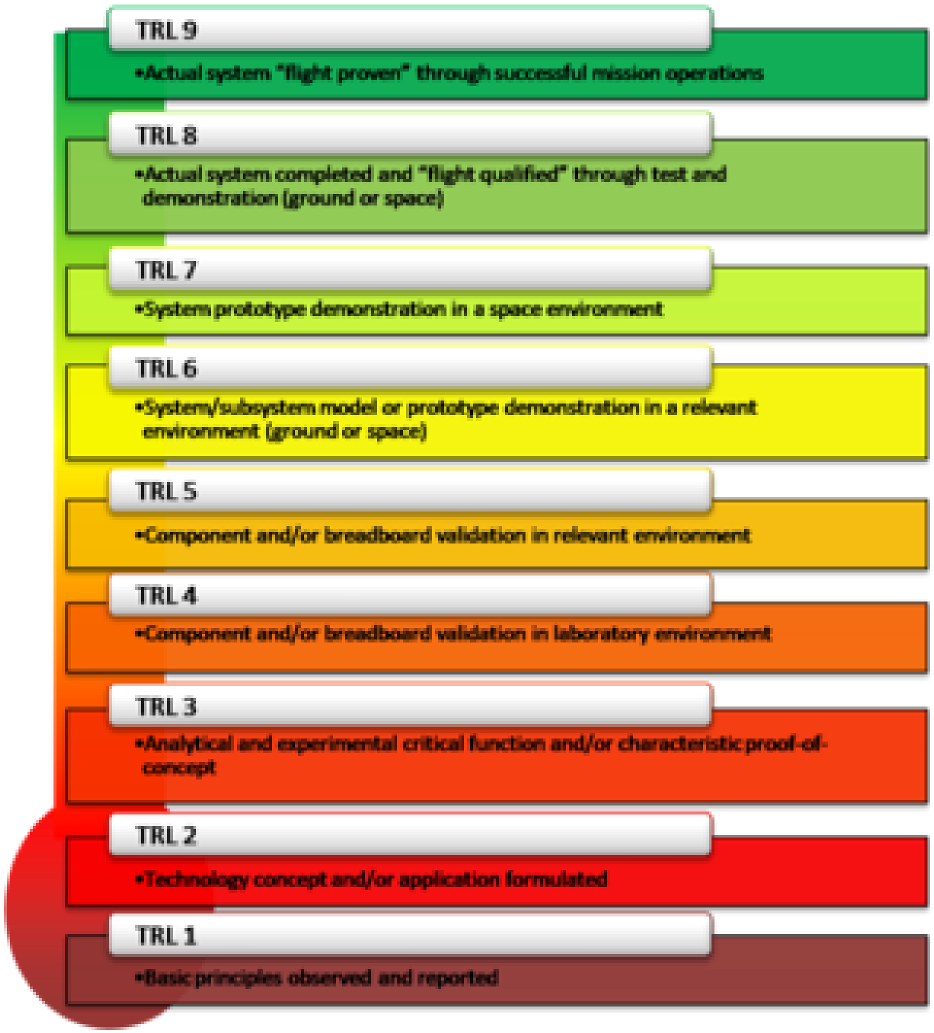
Denise Ponchak (NASA Glenn Research Center)
Fred Templin (The Boeing Company)
Raj Jain (APlus Systems)
Greg Sheffield (The Boeing Company)
Pedro Taboso (The Boeing Company)

Background: NASA Contract NNA16BD84C

- **NASA Safe Autonomous Systems Operation (SASO) – Communications, Networks and Surveillance (CNS)**
- **Boeing-led Reliable and Secure CNS and Networks (RSCAN) project**
- **"Revolutionary and Advanced universal, reliable, always available, cyber secure and affordable Communication, Navigation, Surveillance (CNS) Options for all altitudes of UAS operations"**
- **18 month performance period**
  - **Contract signed August 17, 2016**
  - **Kickoff meeting (work begins) September 17, 2016**
  - **First midterm review February 17, 2017**
  - **Second midterm review August 17, 2017**
  - **Final Review February 26, 2018**
  - **Final report March 17, 2018**

Implementation Technology Readiness Levels

- **NASA defines 9 Technology Readiness Levels (TRLs)**
- **Software and hardware advances from TRL1 - TRL9 through research, advanced development, engineering, testing and qualification**
- **This project has identified UAS CNS technologies at advanced TRL Levels that are ready for integrated flight testing**



https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

UAS CNS Communication Network Implementation Analysis

Communications Software for Network Layer and Above

- **Software Integration for Communications Networks combines inter-related and layered subsystems**
- **Internetwork: Internet Protocol, version 6 (IPv6)**
- **Routing: Border Gateway Protocol (BGP)**
- **Security: OpenVPN**
- **Mobility: Asymmetric Extended Route Optimization (AERO)**
- **Applications: CPDLC, STANAG 4586, ADS-IP, Navigation data, voice/video over IP, etc.**

Internetwork: Internet Protocol, version 6 (IPv6)

- **Original work began in 1994 as IPng (IP “next generation”)**
- **Chosen as the way forward instead of OSI networking**
- **Advanced through several levels of standardization**
- **Now a full standard of the Internet Engineering Task Force (IETF) as Request for Comments (RFC8200)**

- Now fully supported and deployed in all modern computing platforms, mobile devices, network equipment and low-end IoT elements
- Although ISP and enterprise uptake has been slow, major providers are beginning to turn on the service
- **Tech assessment: TRL9**

Routing: Border Gateway Protocol (BGP)

- Core routing protocol for the global Internet since early 1990s
- Responsible for correct forwarding of all Internet traffic worldwide
- Core Internet BGP routing tables still largely IPv4 based, but IPv6 is seeing linear growth
- IETF Standard RFC4271
- **Tech Assessment: TRL9**

Security: OpenVPN

- Overlay network security solution based on Internet standard securing services (SSL/TLS)
- Securely connects branch offices to home offices across the untrusted Internet
- Securely connects mobile device users to their home enterprise
- **Natural network security solution for UAS**
- Works on all major platform varieties (iOS, Android, Windows, linux, etc.)
- **Tech assessment: TRL 9**

Mobility: Asymmetric Extended Route Optimization (AERO)

- **Boeing-developed mobility and multilink networking solution**
- Under active consideration in ICAO; IETF
- Useful for Mobile Networks such as UAS
- Natural multi-link solution for UAS with multiple datalinks
- Works in conjunction with Mobile Ad-Hoc Networking (MANET) such as for C2VX/DSRC Vehicular Area Networks
- **Tech assessment: TRL6**

Applications

- **Command and Control (C2):**
  - Controller-Pilot Data Link Communications (CPDLC) for ATM in controlled airspace
  - STANAG 4586 for sUAS Pilot to Aircraft in UTM uncontrolled airspace
- **Situation Awareness (SA):**
  - Voice/video/data over IP: Rides over IPv6 virtual links provided by AERO/OpenVPN tunneling
  - Large file transfer/short text messaging: carried over any available data links
  - ADS-IP: Carried as ordinary IP packets for effective and secured surveillance
  - Navigation aids and data: carried as IP packets over the mobile, multilink, secured IPv6 virtual links
- **Tech assessment: various (TRL5 – TRL9)**

UAS CNS Communication Data Links Implementation Analysis

Satellite Links

- **Applicability: Large UAVs in Controlled Airspaces**
- **Advantages: Almost global availability**
- **Disadvantages:**
  - Low data rate, Large receiver sizes, Small number of vehicles supported.
- **Product Status:**
  - InmarSAT Swift Broadband 5 (800 Mbps/Satellite) and Iridium Next (72 Mbps/Satellite) using L-Band and Ka Band
- **Yet to be Done:**
  - High (Gigabit) data rates like SpaceX (50 Gbps/Satellite), small GPS size receivers for small UAVs in UTM
- **Technology Readiness Level: 8 (Subsystem development-Launch and operation)**

AeroMACS

- **Applicability: Airport Surface, take-off and landing, Large UAV. ATM to UAV Communication**
- **Advantages: Good for ATM/UTM Integration**
- **Disadvantages:**
  - Licensed band ⇒ Tower-to-Vehicle or Via Service Providers for pilot-UAV communications
  - 3 km range
- **Product Status:**
  - Standard exists. Limited trials.
- **Yet to be Done:**
  - Deployments, License-Exempt Band for Pilot-to-UAV large scale deployment or service providers
- **Technology Readiness Level: 5 (Technology Demonstration)**

L-DACS

- **Applicability: In-Flight Phase**
- **Advantages:**
  - L-Band ⇒ Longer Reach
  - ATM+UTM Integration
- **Disadvantages:**
  - Licensed band ⇒ Service provider
  - Limited Band ⇒ Scalability
- **Product Status:**
  - Analyzed, Simulated, Limited trials
- **Yet to be Done:**
- **Technology Readiness Level: 5 (Technology Demonstration)**

RTCA SC-228

- **ITU has identified multiple spectrum bands for Control and Non-Payload Communications (CNPC) for UAS**
- **RTCA SC-228 WG-2 is chartered to develop minimum performance standards (MOPS) and Minimum Aviation System Performance Standard (MASPS) for command and control (C2).**
- **Phase 1 of SC-228 WG-2 focused on terrestrial CNPC Link architectures for RLOS operations ⇒ DO-362 in Sep 2016.**
- **Phase 2 is extending it to Beyond RLOS (BRLOS) particularly using SATCOM including Ku, Ka, L, and C band allocations.**
- **SC-228, WG-2 Sep 2017 white paper describes their plan: C2 MASPS by Dec 2018, …, CNPC Link System MOPS by June 2010**

Ref: RTCA SC-228 WG-2, "Command and Control (C2) Data Link White Paper Phase 2," WP-4, Sep 21, 2017, 40 pp.

Wi-Fi/Long-Range WiFi/Bluetooth/Zigbee

- **Applicability: Small UAVs within a few km range (Wi-Fi, ZigBee), 20-30 km (Long-Range Wi-Fi), 30m for swarms (Bluetooth),**
- **Advantages:**
  - Universal availability
  - License exempt band and Low cost
- **Disadvantages:**
  - Limited Reach
  - Mostly proprietary versions used $\Rightarrow$ No interoperability among UAVs
- **Product Status: Currently used in a majority of sUAVs except for long-range Wi-Fi (need to prove feasibility)**
- **Yet to be Done: Interoperability**
- **Technology Readiness Level: 9 (Wi-Fi/Bluetooth/ZigBee), 3 (Long-Range Wi-Fi)**

Cellular and C-V2X

- **Applicability**:
  - In competition with Satellites in many areas.
  - Both Small and Large UAVs
  - Although C-V2x is being designed for Automobiles, applicable to UAVs.
- **Advantages**: **Service providers. Existing infrastructure.**
- **Disadvantages**:
  - Available only along highways
  - Available only in populated areas
  - Tower antenna pointing downwards
- **Product Status**: **Demonstrations and trials**
- **Yet to be Done**: **Wide-scale use**
- **Technology Readiness Level**: **9 (LTE: Deployed), 5 (C-V2X: Tech Dev.)**

UAS CNS Navigation Implementation Analysis

UAS On-board Navigation Architectural Framework (Supports All Airspace Classes)

A flexible resilient position, navigation, and timing system.

- **Support launch to recovery in all airspace classes**
- **Global Navigation Accuracy: GPS equivalent**
- **All-Weather; 24/7 Availability**
- **Operating Altitude: Sea Level to 65K feet**
- **Augment human in/on the loop with better than GPS-like position & velocity accuracy**
- **Improved C-SWaP+P (cost, size, weight, & power + performance) through the use of integrated modular avionics and software virtual machine computing**

RF-Based NavAid

GPS/GNSS

TRL: 9

Opportunity: Commercially available.

Technical Approach: Integrate within UAS.

Risk: C-SWAP

Benefits:

- Supports navigation accuracy required for controlled airspace operations
- All-Weather; 24/7 Availability

GBAS

TRL: 9

Opportunity: Leverage regional GBAS to support UAS navigation in Class B, C, & D airspaces.

Technical Approach: Integrate UAS with GBAS equipage.

Risk: C-SWAP

Benefits:

- Support launch & recovery
- Better than Global Navigation Accuracy
- All-Weather; 24/7 Availability

WAAS

TRL: 9

Opportunity: Leverage WAAS to support UAS navigation in all airspace classes.

Technical Approach: Integrate UAS with WAAS equipage.

Risk: C-SWAP

Benefits:

- Support all flight phases
- Global Navigation Accuracy
- All-Weather; 24/7 Availability

GBN

TRL: 9

Opportunity: Leverage regional Navaids to support UAS navigation in Class B, C, & D airspaces.

Technical Approach: Integrate UAS with Navaids equipage.

Risk: C-SWAP

Benefits:

- Support launch & recovery
- Better than Global Navigation Accuracy
- All-Weather; 24/7 Availability

Signals of Opportunity (SOP)

Cellular

TRL: 4 - 6

Opportunity: Leverage cell phone towers as additional signals of opportunity

Technical Approach: Integrate UAS with Cellular SOP.

Risk: C-SWAP & accuracy

Benefits:

- **Supports all flight phases**
- **All-Weather; 24/7 Availability**

Cell Phone Towers

Another method of navigation is the use of cell phone towers and transmissions to create beacons serving as pseudo-lites for UAS's.

Disadvantages

- sparse in areas
- technical unknowns…obtaining range measurements
- access to components of the cell phone signal that service providers are not willing to release
- precise position coordinates of cell tower are not always publicly available

LEO Space Vehicle Constellations (SV)

TRL: 4 - 6

Opportunity: Leverage Low Earth Orbital SVs as additional signals of opportunity

Technical Approach: Integrate UAS with LEO SOP.

Risk: C-SWAP

Benefits:

- **Supports all flight phases**
- **Better than Global Navigation Accuracy**
- **All-Weather; 24/7 Availability**

- **Geolocation accuracy and rate of convergence**
  - Dependent on geometries between SVs and receiver position on the ground
- **Improved accuracy and convergence rates**
  - Fusion of timing and Doppler between multiple SVs
- **Challenges**
  - Compatible timing and doppler message formats
  - Share orbit trajectory and other characteristics

Air Data Systems

TRL: 9

Opportunity: Commercially available.

Technical Approach: Interface with UAS navigation computer.

Risk: C-SWAP

Benefits: Supports period of loss navigation inputs and used to confirm other navigation sources

- **This systems, rather than individual instruments, can determine the calibrated airspeed, Mach number, altitude, and altitude trend data from an aircraft's pitot-static system.**

Pitot-static tube

Altimeter

Air Data Computers

IMU & Clock – Maintaining P, V, A, T Accuracy

TRL: 9

Opportunity: Commercially available.

Technical Approach: Integrated within UAS navigation computer.

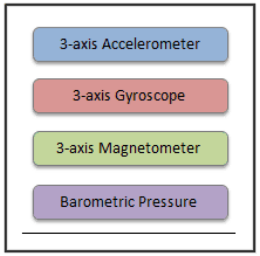
Risk: C-SWAP

Benefits: Supports period of loss navigation inputs

- IMU(1) (Instrument Measurement Unit) Accuracy:

	Accelerometer Bias Error		Horizontal Position Error [m]			
Grade	[mg]		1s	10s	60s	1hr
Navigation	0.025		0.13 mm	12 mm	0.44 m	1.6 km
Tactical	0.3		1.5 mm	150 mm	5.3 m	19 km
Industrial	3		15 mm	1.5 m	53 m	190 km
Automotive	125		620 mm	60 m	2.2 km	7900 km

10-axis IMU



- Onboard Clock
  - Ordinary quartz clocks drift by about 1 sec in 11-12 days. (10^{-6} secs/sec).
  - High precision quartz clocks drift rate is about 10^{-7} or 10^{-8} secs/sec

UAS CNS Surveillance Implementation Analysis

Approach to the surveillance proposal

- **Conservative points:**
  - Use of communication technology currently ready.
  - Use of positioning technology currently ready.
  - Technology enhancements (for both communications and positioning) have been taken into account.
  - Integration with current surveillance technology (controlled airspace).

- **Innovative points:**
  - Following/fostering upcoming UAS regulations.
  - Automated surveillance capabilities (MBE-based).
  - Secure deployment for all types of UAS.
  - High-availability while affordable.

- Most of these innovative points are based in IT/Cloud architecture.

Surveillance Technology Proposals

Technology Innovation	Supporting technology
ADS-IP	• GNSS. • V2X Communication: Cellular, Satellite, Wi-Fi, DSRC. • Communication/surveillance management computer. • Cloud computing.
uADS-IP	• GNSS. • V2X Communication: DSRC. • Communication/surveillance management computer. • Cloud computing (PKI).
Drone Surveillance Radar (DSR)	• Low power – High frequency radar
Image recognition for positioning and identification.	• HD/IR cameras. • Lightweight multi-core image processor computer.
Electromagnetic signatures for positioning and identification.	• Multiple point receivers for multilateration/signature analysis.
Light/acoustic signaling for safety enhancement.	• High-Efficiency LEDs. • Acoustic transducers. • Encoding manager device (TX and RX).

Supporting Technology Readiness

Supporting Technology	TRL
GNSS	9
V2X Communication: Cellular, Satellite, Wi-Fi, DSRC.	Analysis presented in the datalink section
Communication/surveillance management computer.	9
Cloud computing	9
Low power – High frequency radar	6
HD/IR cameras	8
Lightweight multi-core image processor computer	6
Multiple point receivers for multilateration/signature analysis	6
High-Efficiency LEDs, Acoustic transducers, Encoding device	8

Technology innovation definition level

Technology Innovation	TDL
ADS-IP	8
uADS-IP	4
DSR	9
Image recognition for positioning and identification.	7
Electromagnetic signatures for positioning and identification.	7
Light/acoustic signaling for safety enhancement.	5

Futures

Futures

- **NASA Final Report Submitted 3/17/2018**
- **Seeking additional publication opportunities (e.g., DASC 2018, IEEE Aerospace 2019, etc.)**
- **Lead industry forums (RTCA SC223/SC228)**
- **Lead the transition:**
  - remotely-piloted UAS with mobile remote pilots
  - increasingly-autonomous operations
  - eventual fully-autonomous operations
- **Investigate opportunities for continuation**
  - UAS in the NAS Systems Integration and Operationalization (SIO)
  - UTM Pilot Program (First Workshop March 2018)
  - Other NASA/FAA opportunities

Backups