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

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Background: NASA Contract NNA16BD84C

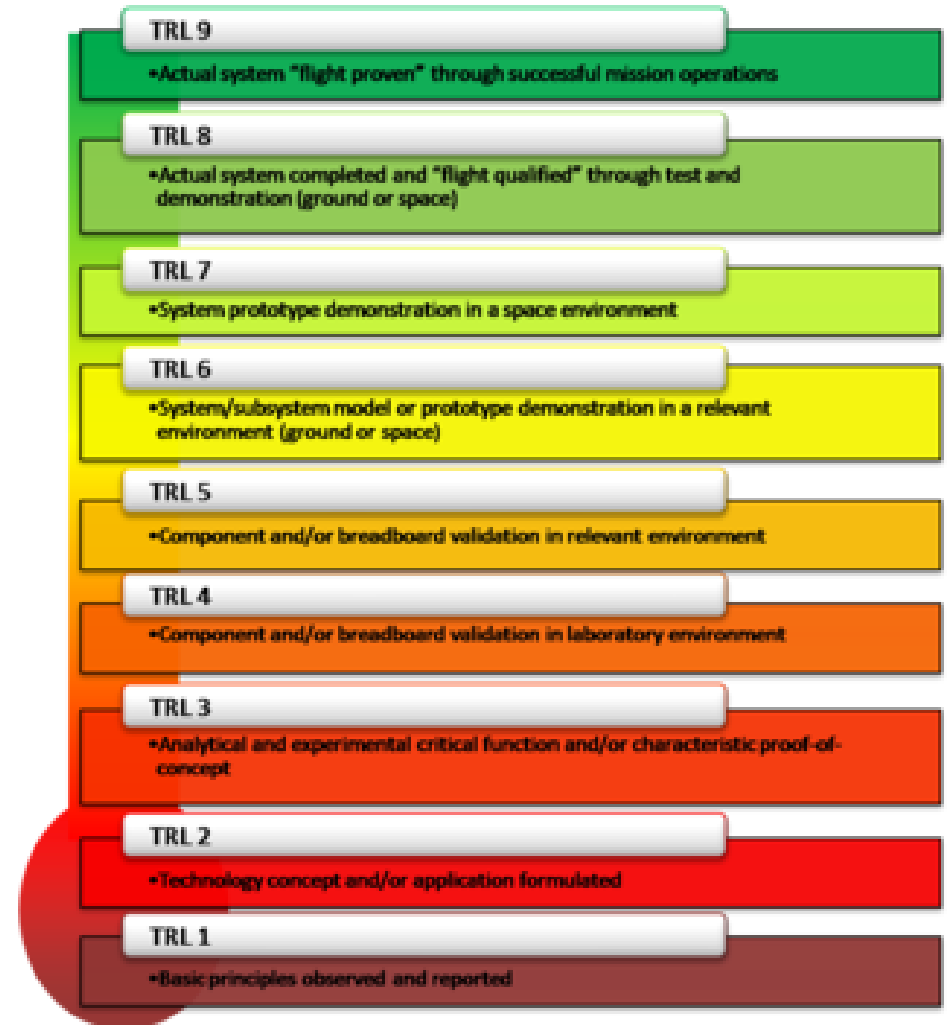
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- **NASA Safe Autonomous Systems Operation (SASO) – Communications, Networks and Surveillance (CNS)**
- **Boeing-led Reliable and Secure CNS and Networks (RSCAN) project**
- **“Revolutionary and Advanced universal, reliable, always available, cyber 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

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- 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





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UAS CNS Communication Network Implementation Analysis

Communications Software for Network Layer and Above

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- **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)

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- **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)

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- 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

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- 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)

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- **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

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- **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)**



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UAS CNS Communication Data Links Implementation Analysis

Satellite Links

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- **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

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- **Applicability:** Airport Surface, take-off and landing, Large UAV. ATM to UAV Communication
- **Advantages:** Good for ATM/UTM Integration
- **Disadvantages:**
 - Licensed band \Rightarrow 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

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

RTCA SC-228

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- **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**

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

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- **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

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- **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.)



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UAS CNS Navigation Implementation Analysis

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

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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

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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

TRL: 9

WAAS

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

TRL: 9

GBN

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)

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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

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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

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TRL: 9

Opportunity: Commercially available.

Technical Approach: Integrated within UAS navigation computer.

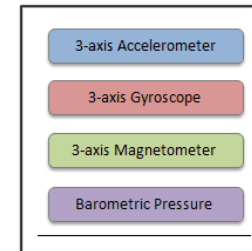
Risk: C-SWAP

Benefits: Supports period of loss navigation inputs

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

Grade	Accelerometer Bias Error [mg]	Horizontal Position Error [m]			
		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



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UAS CNS Surveillance Implementation Analysis

Approach to the surveillance proposal

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- **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

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Technology Innovation	Supporting technology
ADS-IP	<ul style="list-style-type: none">• GNSS.• V2X Communication: Cellular, Satellite, Wi-Fi, DSRC.• Communication/surveillance management computer.• Cloud computing.
uADS-IP	<ul style="list-style-type: none">• GNSS.• V2X Communication: DSRC.• Communication/surveillance management computer.• Cloud computing (PKI).
Drone Surveillance Radar (DSR)	<ul style="list-style-type: none">• Low power – High frequency radar
Image recognition for positioning and identification.	<ul style="list-style-type: none">• HD/IR cameras.• Lightweight multi-core image processor computer.
Electromagnetic signatures for positioning and identification.	<ul style="list-style-type: none">• Multiple point receivers for multilateration/signature analysis.
Light/acoustic signaling for safety enhancement.	<ul style="list-style-type: none">• High-Efficiency LEDs.• Acoustic transducers.• Encoding manager device (TX and RX).

Supporting Technology Readiness

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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

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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



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Futures

Futures

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- **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

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