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

Small UAS Communications and Navigation

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UTM Technical Interchange Meeting
February 23rd, 2021

Outline

- UTM Research Transition Team (RTT) Communications and Navigation (C&N) Subgroup
- Communications and Navigation (C&N) Activities during Technical Capability Level (TCL) 2, 3, 4
- Publication of Research Findings
- Areas of Future Work
- Summary

UTM RTT Communications & Navigation Subgroup

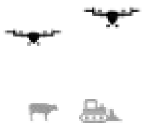
- The objective for this subgroup was to explore communications and navigation solutions to ensure that Unmanned Aircraft (UA) are under the operational control of the remote pilot (to the degree appropriate to the scenario) and remain within a defined area (around a planned trajectory or as a defined area)

- C&N subgroup kicked-off after TCL 1 concluded
  - 26 meetings including three joint meetings with the Sense and Avoid (SAA) subgroup
  - At peak more than 100 UTM community members interacted in the subgroup
  - Community responses to the Request for Information (RFI) became the basis of communications and navigation guideline and contingency management requirements

- Three C&N technical documentation packages produced, associated with TCL 2, TCL 3, and TCL 4

C&N Subgroup Activities during TCL 2

Aug 2015



TCL 1

Remote Population

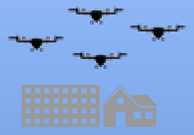
Low Traffic Density

Rural Applications

Multiple VLOS Operations

Notification-based Operations

Oct 2016



TCL 2

Sparse Population

Low-Mod Traffic Density

Rural / Industrial Applications

Multiple BVLOS Operations

Tracking and Operational Procedures

May 2018

TCL 3

Moderate Population

Moderate Traffic Density

Suburban Applications

Mixed Operations

Vehicle to Vehicle Communication

Public Safety Operations

Aug 2019

TCL 4

Dense Population

High Traffic Density

Urban Applications

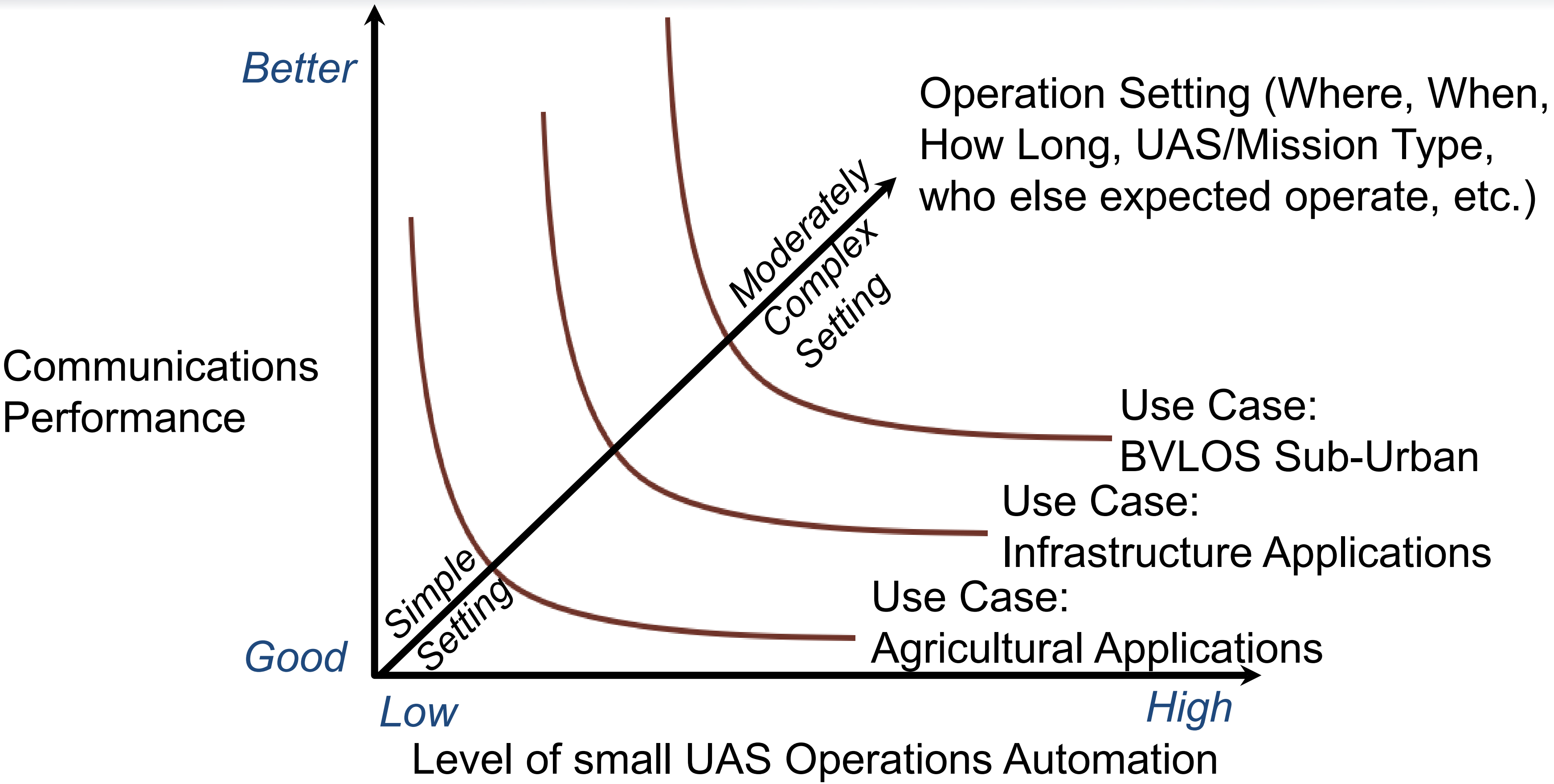
Dense BVLOS Operations

Large Scale Contingency Management

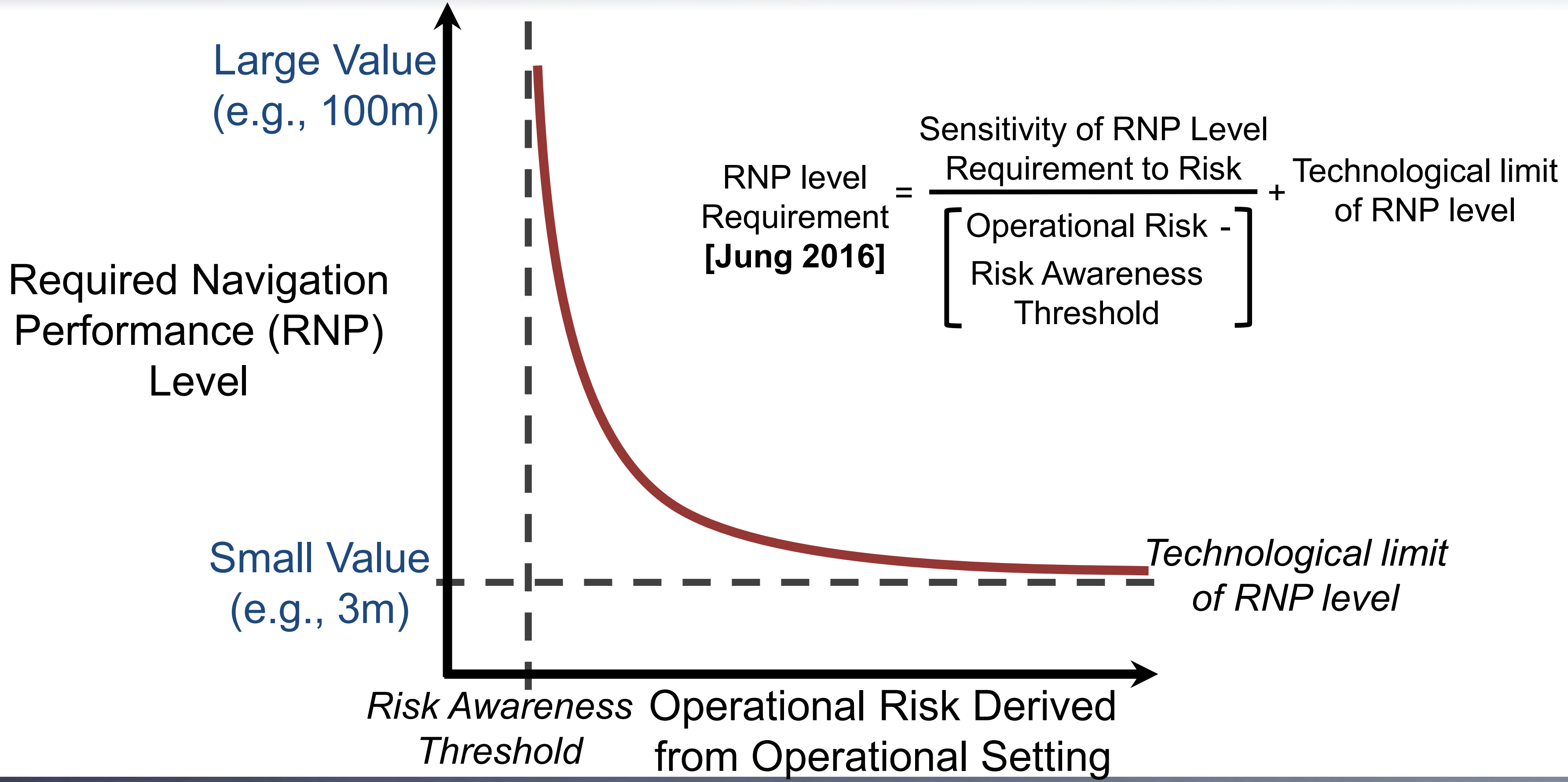
Initial C&N Request for Information and Discussion

- At the beginning of the C&N subgroup activities, RFI was sent out to gain insights into small UAS communications and navigation
- Responses from 20 organizations were received; discussion of the response led to the following insights
  - C&N system performance must reflect the **operational setting**
    - Operation over where and when
    - UAS configuration, mission type, and duration
    - Who else is expected in the area
  - Communications between UA and its operator can be disrupted especially when the protected aviation spectrum is not used
  - Given the prevalent use of Global Navigation Satellite System (GNSS) receiver, such as the Global Positioning System (GPS), in the UA navigation system, navigation performance can be degraded due to radio frequency (RF) interference, blocked radio line-of-sight to GNSS satellites, and reflected satellite signal (i.e., multipath)

Notional Relation among small UAS Communications Performance, Level of small UAS Operations Automation, and Operational Setting



Hypothetical Relation between small UAS Navigation Performance and Operational Setting



TCL 2 C&N Evaluations

UTM TCL 2 National Campaign (NC 2) highlighted the relation between operational setting and C&N performance **[Aweiss 2018] [Jung 2018a]**

- C&N data collection flew over sparsely populated area with the unobstructed view of the sky
- UA remained close to the Ground Control System (GCS), maximum distances ranging from 2300 feet to 4200 feet
- 4 out of 47 flights (8.5%) experienced Loss of Command and Control (C2), defined as Received Signal Strength Indicator (RSSI) at UA remaining at or below -90 dBM for more than 10 seconds
- The 900MHz and 2.4GHz radios provided sufficient performance to cover relatively short distance between the GCS and UA
- Unobstructed radio line of sight between UA and the GCS likely contributed to this small number of incidence of loss of C2 link

TCL 2 C&N Evaluations (cont.)

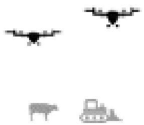
- 2 out of 118 flights (1.7%) encountered loss of navigation, defined as navigation system tracking six or fewer GPS satellites for more than ten seconds

- The NC 2 aircraft used GPS for navigation and the unobstructed view of the sky likely contributed to this small incidence of loss of navigation

- NASA TCL 2 test results and analysis **[Johnson 2017]** showed that that communications and navigation performance is not only important for individual UA operation but for overall UTM ecosystem
    - Weather, operational intent, geo-fence information exchange
    - Beyond Visual Line-of-Sight (BVLOS) operations with altitude stratification

C&N Subgroup Activities during TCL 3

Aug 2015



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Multiple VLOS Operations

Notification-based Operations

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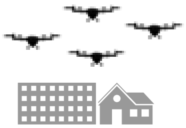

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C&N Off-Nominal Situations Management Requirements RFI

- C&N off-nominal situations management concepts and 18 high-level requirements developed, and RFI for feedback sent out; all requirements were deemed reasonable as written and is needed in UTM **[Jung 2020a] [Jung 2020b]**

- It was identified that in many cases mitigation of Communications or Navigation off-nominal situations results in the landing of UA
  - Prolonged loss of communications between UA and operator
  - Severely degraded navigation performance

- Therefore, maintaining safe landing capability, where “safe landing” is defined as “landing of UA without causing detrimental impact to people and property” is understood as having paramount importance

Recommendation on Handling C&N Off-Nominal Situations

- When off-nominal situations occur, whether the operation should enter the emergency phase or not should reflect the status of the safe landing capability
  - Uncertainty Phase: The situation is being mitigated with intact safe landing capability
  - Alert Phase: The situation is being mitigated with compromised safe landing capability
  - Distress Phase: The situation poses an imminent danger to people or property

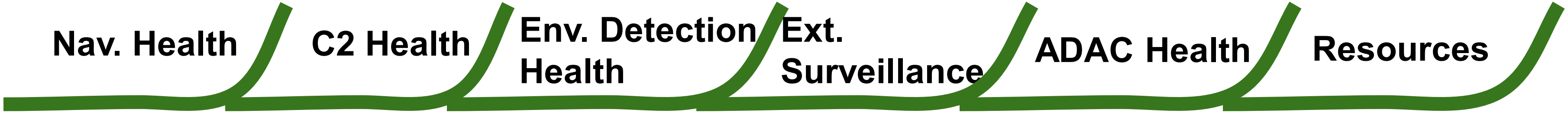
- Safe landing capability can take different shapes and forms: fly to safe-to-land locations (e.g., fenced-off sandbox), avoid people and property when landing, transfer small kinetic energy upon impact (e.g., 11 foot-pounds or less), etc.

- Therefore, the following six areas should be monitored concurrently, constituting safe to land capability monitoring

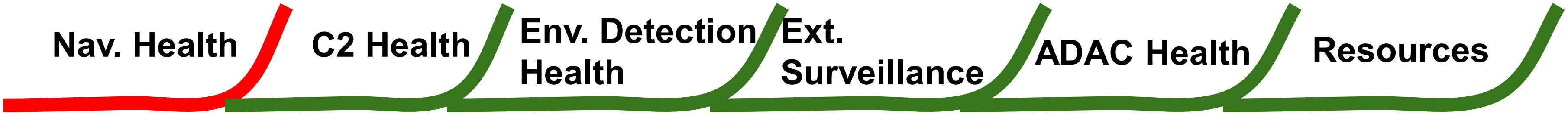
External Surveillance: Vehicle position information that does not originate from the vehicle's navigation system
ADAC: Attitude Determination and Control
Resources: e.g., range to reach safe-to-land location, thrust to perform vertical landing or reduce kinetic energy, etc.

Safe Landing Monitoring Examples

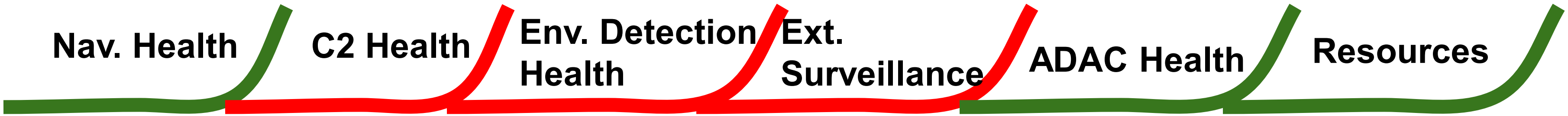
Nominal operation



Emergency Phase Uncertainty Example 1: Use Ext. Surveillance and C2 to mitigate

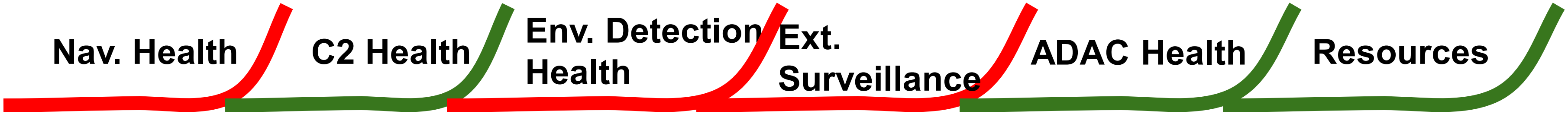


Emergency Phase Uncertainty Example 2: With functioning Nav., fly to safe-to-land location to mitigate



Safe Landing Monitoring Examples (cont.)

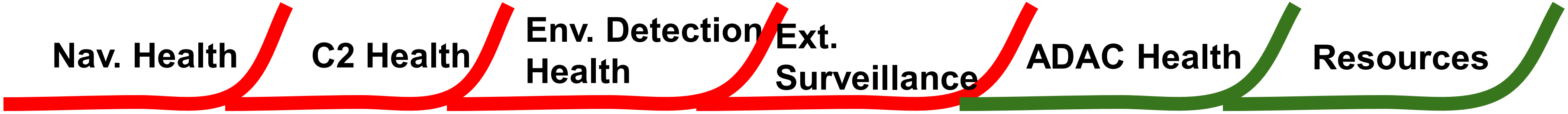
Emergency Phase Alert Example 1: Use manual control with line of sight to the vehicle to mitigate



Emergency Phase Alert Example 2: Locate the vehicle and clear people under to mitigate, while resources last

Safe Landing Monitoring Examples (cont.)

Emergency Phase Distress Example 1



Emergency Phase Distress Example 2

Emergency Phase Distress Example 3

TCL 3 C&N Evaluations

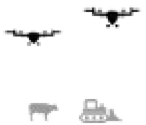
- Evaluated the Effectiveness of Redundant Communications Systems in Maintaining Operational Control of small UAS, Generating Recommendations for Urban Operations **[Jung 2019]**

- Analyzed at-altitude Long Term Evolution (LTE) Power Spectra for C2 Communications **[Kerczewski 2019]**

- Evaluated the impact of Ownship generated Electromagnetic Interference (EMI) on LTE bands **[Jung 2018b]**

C&N Subgroup Activities during TCL 4

Aug 2015



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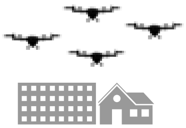

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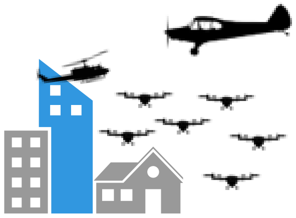

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Large Scale Contingency Management

Introducing the Notion of "Timeout"

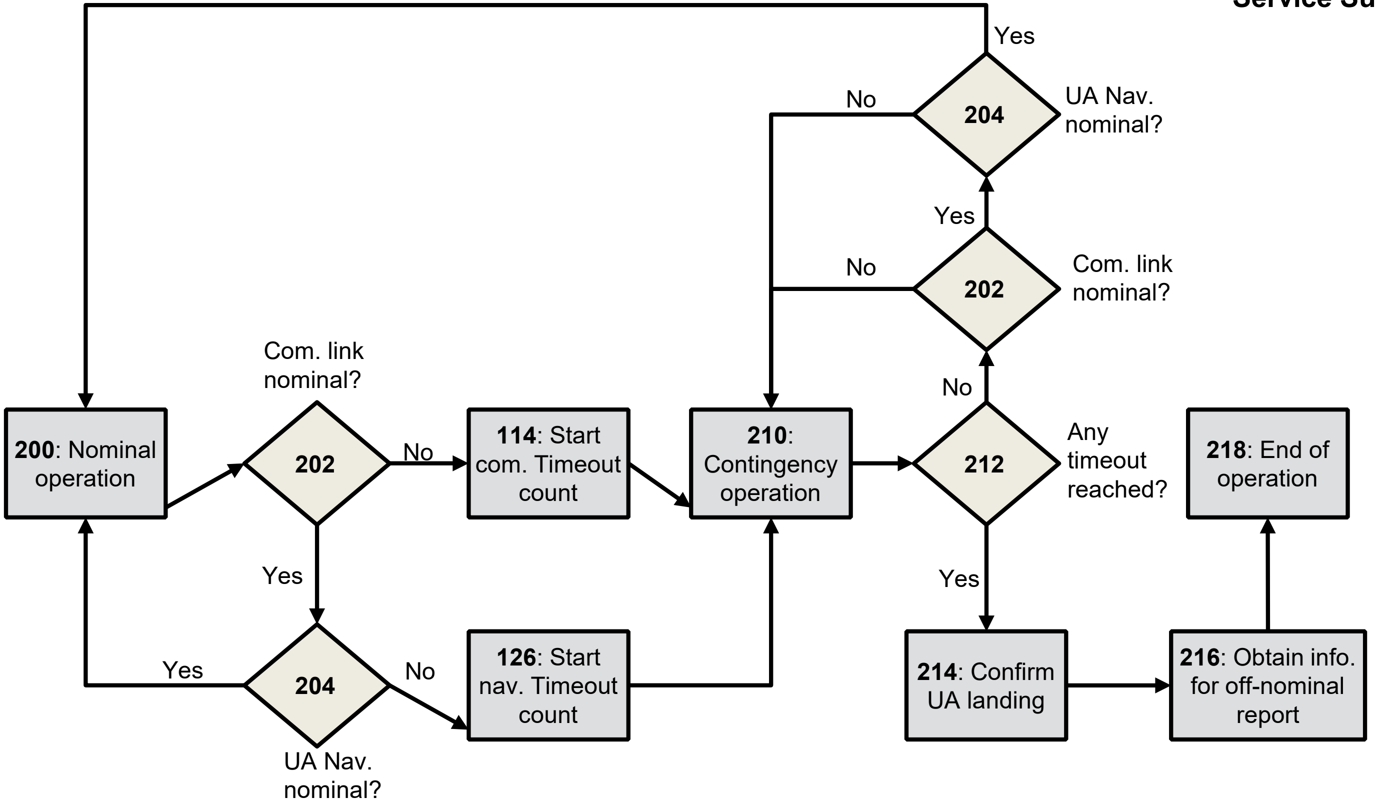
- "Timeout" – fixed amount of time for the operator to resolve off-nominal situations

- Once timed-out, UA must display predictable behavior, such as initiating safe landing procedure

- Three timeouts introduced
  - UA to Operator C2 Link Loss (telemetry loss)
  - Operator to UA C2 Link Loss (command/control loss)
  - Navigation Degradation

Integration of UAS and USS for Off-Nominal Situations Processing

Unmanned Aircraft System Service Supplier (USS)



TCL 4 C&N Evaluations

- Practiced C&N off-nominal situations management requirements during the TCL 4 demonstration **[Jung 2020b]**

- Calculated Measure of Performance for small UAS C&N **[Jung 2020d]**
  - Rate of loss of C2
  - Rate of C2 loss during a conflict
  - Rate of navigation degradation during a conflict
  - Rate of safe landing

- Collected and analyzed off-nominal situations report **[Jung 2020c]**
  - USS in a key position to collect both digital and contextual data from off-nominal situations
  - Continued collection and analysis of off-nominal data key to gaining insight and reducing the occurrence

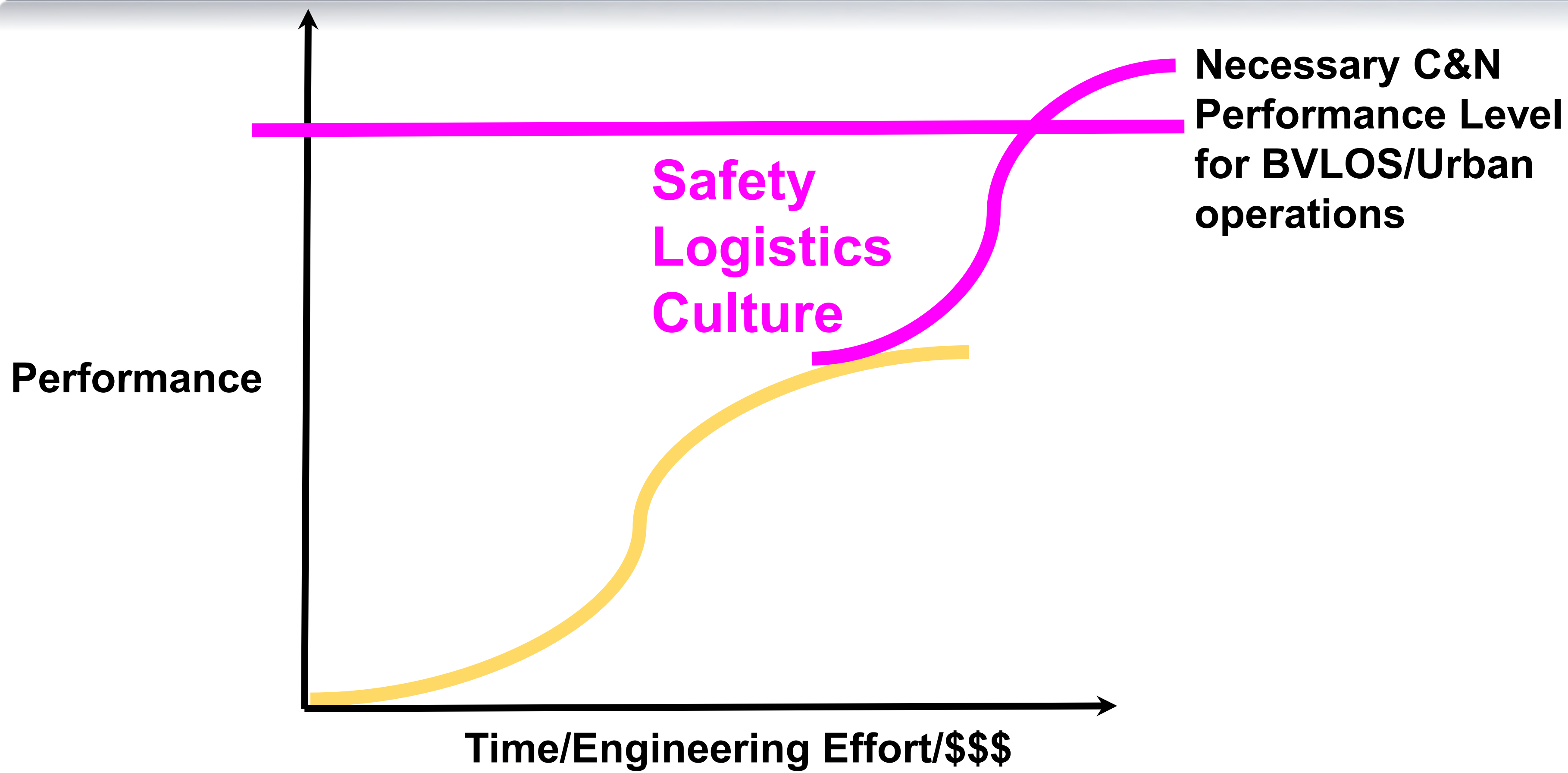
Publication of Research Findings

- [Aweiss 2018] “Unmanned Aircraft Systems (UAS) Traffic Management (UTM) National Campaign II”, Aweiss, Arwa S., NASA, Brandon D. Owens, Stinger Ghaffarian Technologies, Inc., Joseph L. Rios, Jeffrey Homola, NASA, Christoph P. Mohlenbrink, San Jose State University. AIAA SciTech Forum. January 8-12, 2018, Kissimmee, FL.
- [Johnson 2017] “Flight Test Evaluation of an Unmanned Aircraft System Traffic Management (UTM) Concept for Multiple Beyond-Visual-Line-of-Sight Operations”, Johnson, Marcus, Jaewoo Jung, Joseph Rios, Joey Mercer, Jeffrey Homola, Thomas Prevot, Daniel Mulfinger, Parimal Kopardekar, NASA Ames Research Center. 12th USA/Europe Air Traffic Management Research and Development Seminar (ATM2017), June 26-30, 2017, Seattle, WA.
- [Jung 2016] “Applying Required Navigation Performance Concept for Traffic Management of Small Unmanned Aircraft Systems”, Jung, Jaewoo, Sarah D'Souza, Marcus Johnson, NASA Ames Research Center; Abraham Ishihara, Hemil Modi, SGT, Inc., Ben Nikaido, Hashmatullah Hasseeb, Science and Technology Corp./NASA Ames Research Center. ICAS 2016, September 25-30, 2016, Daejeon, Korea.
- [Jung 2018a] “Initial Approach to Collect Small Unmanned Aircraft System Off-nominal Operational Situations Data”, Jung, Jaewoo, NASA Ames Research Center; Charles R. Drew, Wyle Labs, Moffett Field CA; Sreeja Nag, Bay Area Environmental Research Institute, Moffett Field, CA; Edgar O. Torres, Science Application International Corp., Moffett Field, CA; Abraham K. Ishihara, Minh Do, Stinger Ghaffarian Technologies, Inc., Moffett Field, CA; Hemil C. Modi, Science and Technology Corp., Moffett Field, CA. AIAA Aviation 2018, June 25-29, 2018, Atlanta, GA.
- [Jung 2018b] “Small Unmanned Aircraft Electromagnetic Interference (EMI) Initial Assessment” Jung, Jaewoo, Corey Ippolito, Christopher Rogers, NASA Ames Research Center; Robert Kerczewski, Anal Downey, NASA Glenn Research Center; Konstantin Matheou, Zin Technologies, Inc. ICNS 2018, April 10-12, 2018, Herndon, VA.

Publication of Research Findings (cont.)

- [Jung 2019] “Effectiveness of Redundant Communications Systems in Maintaining Operational Control of Small Unmanned Aircraft”, Jung, Jaewoo, NASA Ames Research Center, Sreeja Nag, Bay Area Environmental Research Institute at NASA Ames Research Center; Hemil C. Modi, Science and Technology Corp. at NASA Ames Research Center.
- [Jung 2020a] “Processing Loss of Safe Landing Capability in Unmanned Aircraft Systems Traffic Management Environment”, Jung, Jaewoo, NASA Ames Research Center; Sreeja Nag, Bay Area Environmental Research Institute, Moffett Field, CA, response to DRONE ENABLE 2021 Unmanned Aircraft System Traffic Management (UTM) Request for Information (RFI)
- [Jung 2020b] “Automated Management of Small Unmanned Aircraft System Communications and Navigation Contingency”, Jung, Jaewoo, NASA Ames Research Center. Sreeja Nag, Bay Area Environmental Research Institute. AIAA SciTech Forum, January 2020, Orlando, FL.
- [Jung 2020c] “Small Unmanned Aircraft System Off-Nominal Operations Reporting System”, Jung, Jaewoo, Joseph L. Rios, NASA Ames Research Center, Charles R. Drew, Wyle Labs, Hemil C. Modi, Science and Technology Corp., Kimberly K. Jobe, San Jose State University. NASA/TM-2019-220302, February 2020.
- [Jung 2020d] “Small Unmanned Aircraft System Communications and Navigation Performance: Results and Analysis from NASA's Unmanned Aircraft Systems Traffic Management Technical Capability Level 4 Demonstration”, Jung, Jaewoo, NASA Ames Research Center, Nicholas Craven, Millennium Engineering and Integration Company. NASA/TM-2020-5007032, August 2020.
- [Kerczewski 2019] “Analysis of At-Altitude LTE Power Spectra for C2 Communications for UAS Traffic Management”, Kerczewski, Robert J., Alan N. Downey, Konstantin J. Matheou, Jaewoo Jung, Corey A. Ippolito, and Hemil Modi, NASA Technical Report, Document ID 20190025410

Areas for Future Research



Summary

- Collaborations with the UTM community was a key to gain insights and develop requirements

- Field testing results showed the following
  - Use of unprotected spectrum could meet the small UAS communications need when UA and GCS are within the radio line of sight, the flight takes place in a remote location away from population and sources of RF interference
  - GPS could meet the small UAS navigation need when UA flies in the area with an unobstructed view of the sky
  - Altitude reporting need to be compatible among operations
  - Off-nominal situations should be mitigated with USS in the loop

- More Research & Development (R&D) to be done for BVLOS/urban operations!