Effects of Unmanned Aircraft Voice Communication Delay on En Route Air Traffic Management Operations

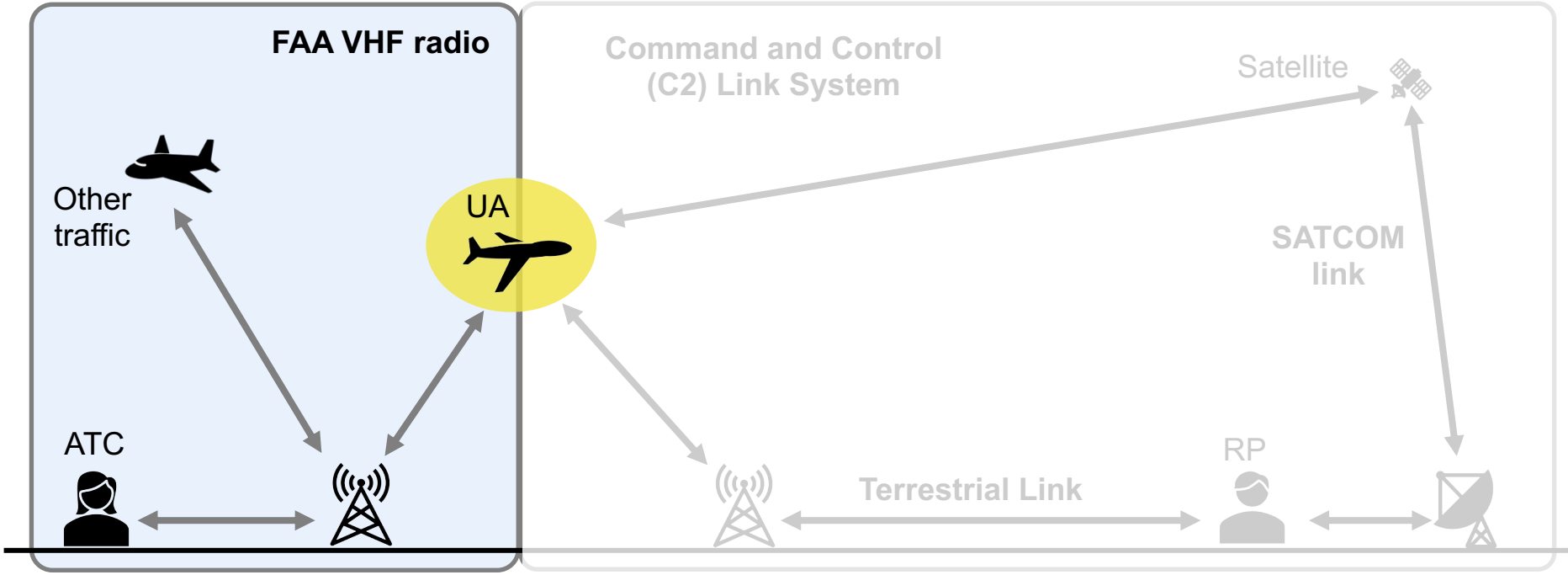
Miwa Hayashi, Jillian Keeler
NASA Ames Research Center

Cynthia Wolter
San Jose State University Research Foundation

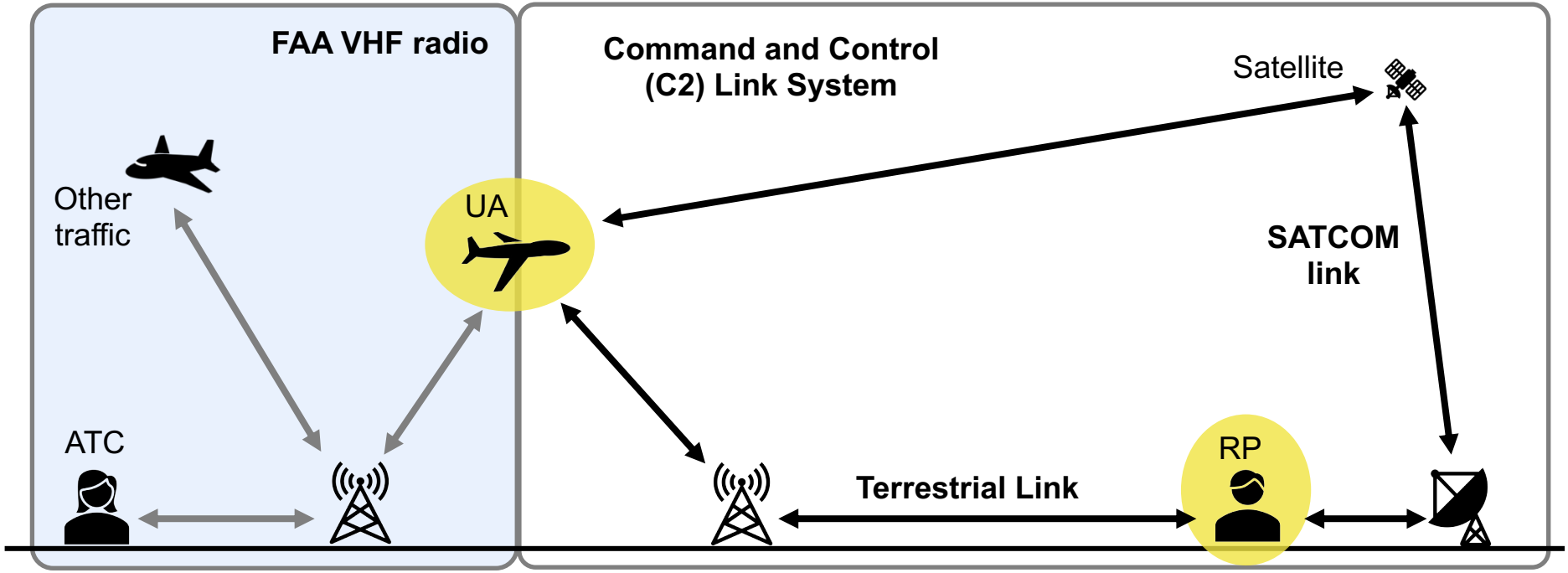
Wayne W. Bridges
Flight Research Associates

AIAA Aviation Forum, June 27 – July 1, 2022

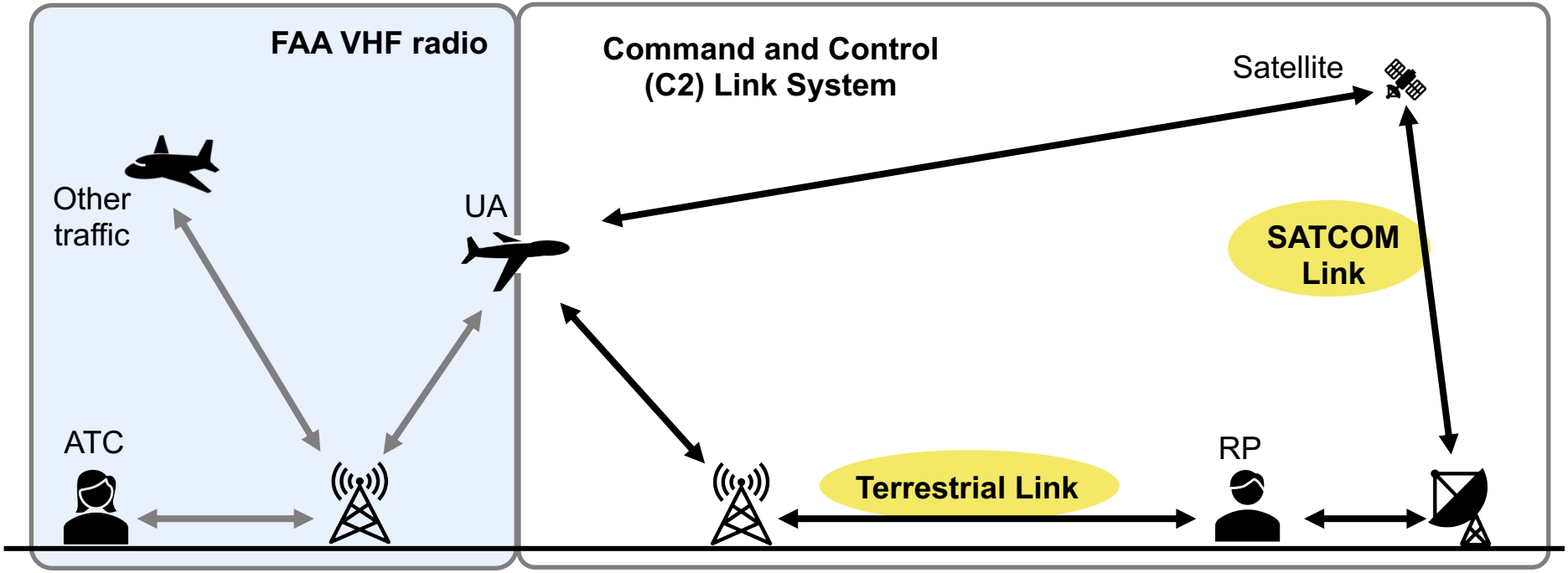
Background



The current assumption is that unmanned aircraft (UA) talks with the air traffic controller (ATC) through the FAA's VHF radio, using the UA as a relay.



Then, the UA and the remote pilot are connected via the Command and Control (C2) Link System.



The C2 Link System includes terrestrial or SATCOM link.

- **The C2 Link System's technologically achievable one-way transmission delays estimated by industry are approximately**
  - ~ 400 ms for terrestrial link, and
  - ~ 900 ms for SATCOM link.

- **In practice, the UA could experience even longer delay especially when it is on SATCOM.**

The difference between the voice delay and human's natural verbal response delay is, with voice delay, some parties hear sounds (or lack of sounds) asynchronously with the others.

This will increase chance of step-ons, i.e., accidental simultaneous transmissions by two or more speakers.

Also, presence of voice delay is often difficult to detect.

Speakers tend to blame the other person for being inattentive or interruptive.

- The current FAA requirement for the max voice delay in the National Airspace System (NAS) is 390 ms.

- The estimated UA voice delays of 400 and 900 ms exceed the FAA requirement.

Yet, so far, there has been no empirical evidence supporting that a UA voice delay longer than the FAA requirement negatively impacts air traffic management operations.

- In past human-in-the-loop simulation studies of UA flights, ATCs had rated even 1,800-ms UA voice delay acceptable.
- In these studies, however, the traffic-volume levels may have been not busy enough to show the negative effects of the UA voice delay.

In the present study, we hypothesized that the effects of UA voice delay on air traffic management operations are greater at higher traffic-volume levels, where the radio frequencies tend to be more congested.

- The hypothesis can be verified by the statistically significant **interaction effect** of Voice Delay × Traffic Volume Level.
- Remember: the current FAA requirement on the max voice delay is the same for any traffic-volume level.

Method

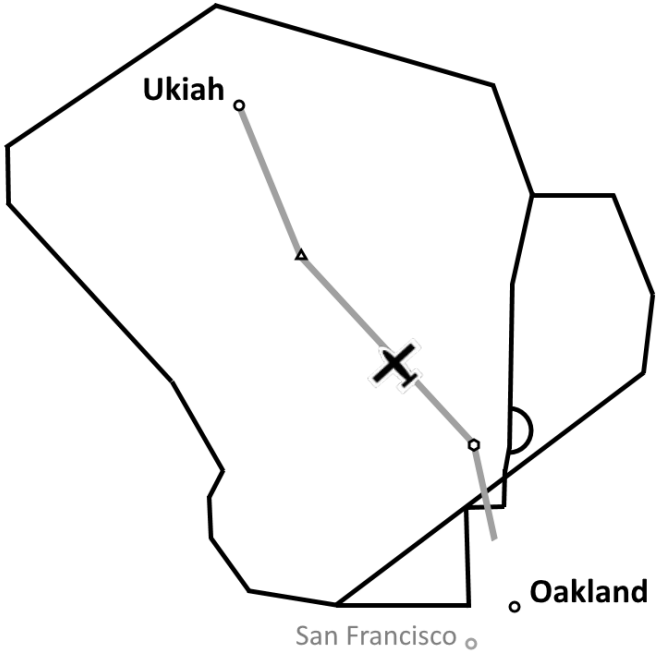
- **We conducted a human-in-the-loop simulation study.**
- **The Experiment design was 3 × 2.**
  - 3 voice delays of 400, 900, and 2,000 ms were tested.

    Each voice delay roughly corresponded to terrestrial, SATCOM, and long-SATCOM delays.
  - 2 traffic volumes of *High* and *Low* were tested.

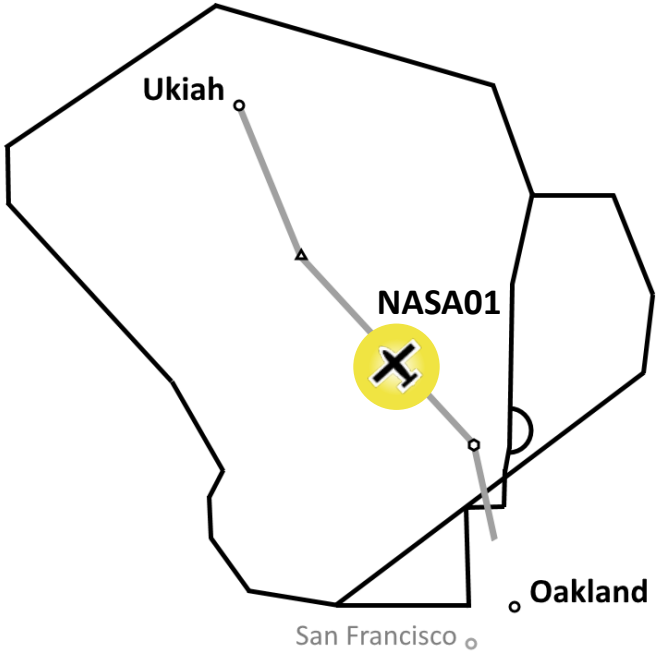
    High traffic volume scenario was representative of 110% of the sector's peak capacity, whereas *Low* was of 66%.

	Traffic Volume	
Voice Delay	**High**	**Low**
400 ms		
900 ms		
2,000 ms		

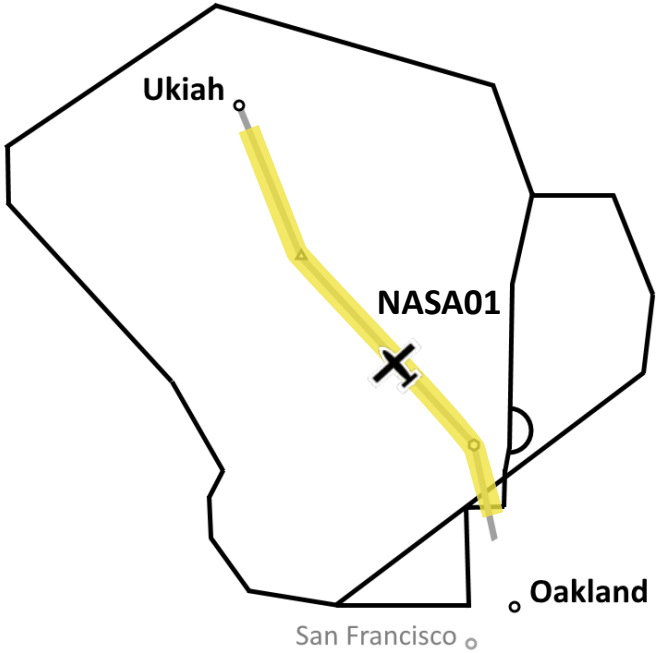
- **Workload ratings and questionnaire responses were collected from the ATC and remote pilot participants as subjective measures.**
- **Radio voice and flight data were recorded as objective measures.**



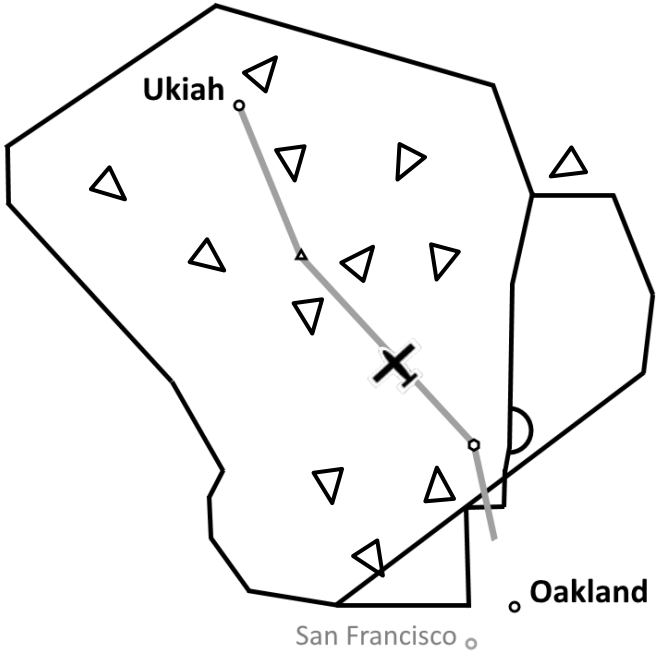
Oakland en route Center's (ZOA) combined sector 40/41 was simulated.



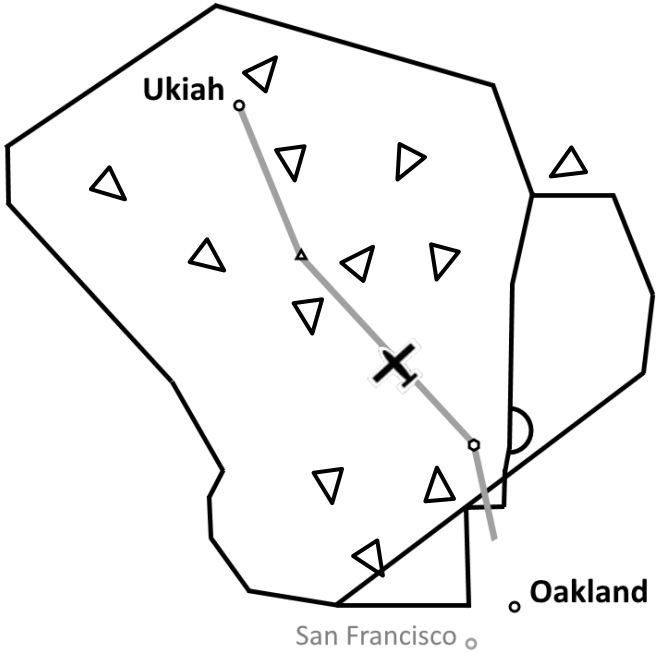
The UA ownship, NASA01, was modeled as fixed-wing, twin turboprop aircraft.



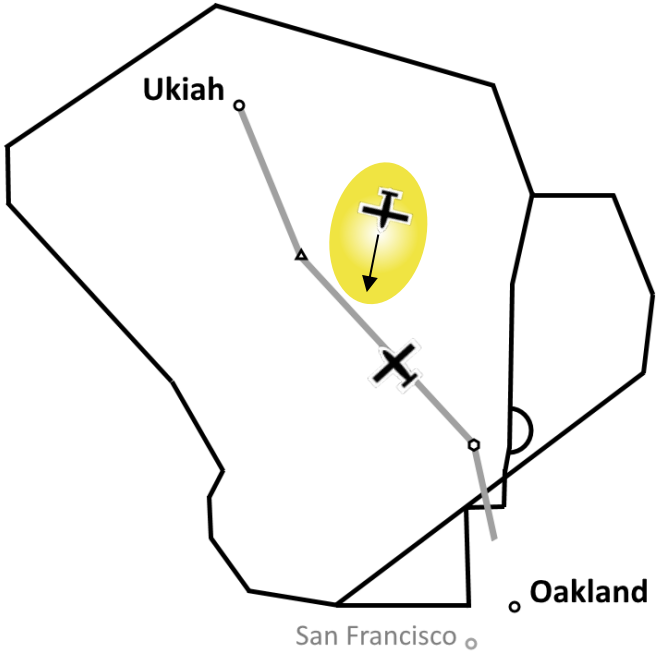
NASA01 departed from Oakland airport, and headed to the Ukiah airport, 96 nm Northwest.



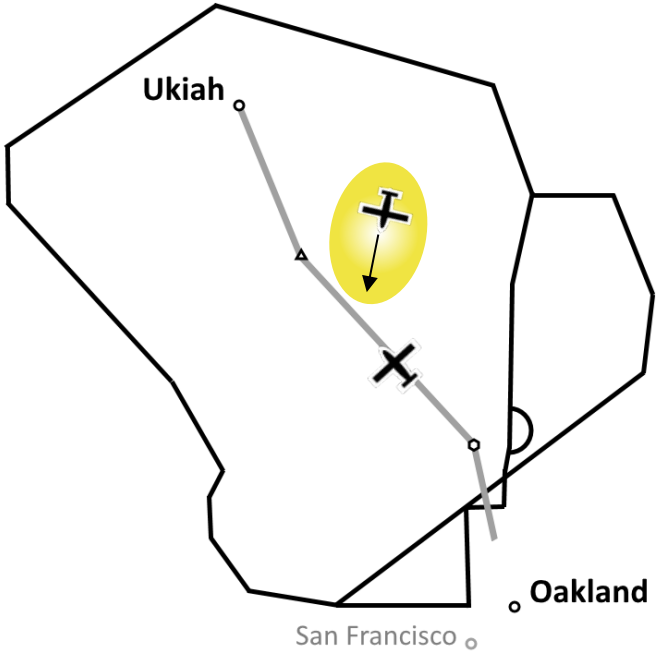
In any given minute, the ATC was typically managing 16-22 aircraft in the *High* traffic volume scenario, or 8-12 aircraft in the *Low* traffic volume scenario.



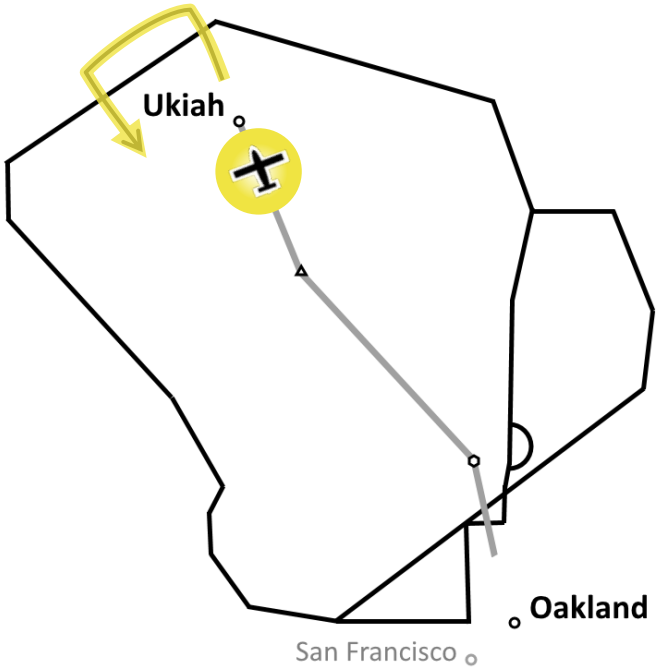
3 pseudo pilots flew the background traffic. They were non-test participants in the study.



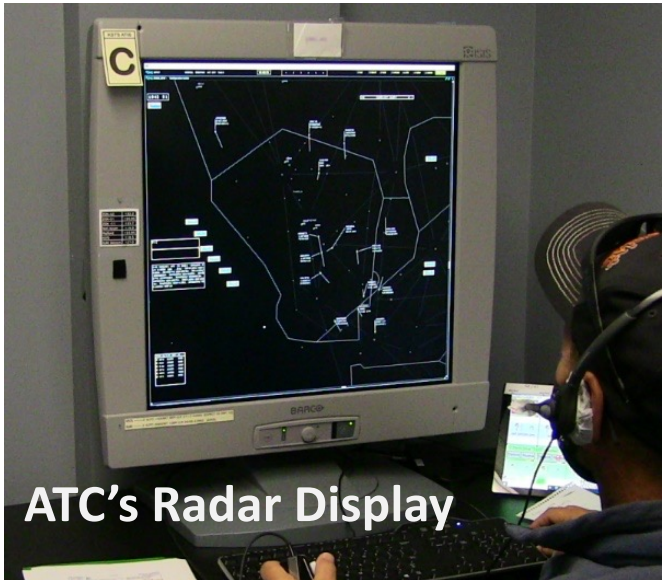
One scripted traffic conflict with a *non-cooperative* aircraft (without transponder signal) was inserted to force a Detect-and-Avoid (DAA) alerting event.



Non-cooperative **aircraft is not visible on the ATC's radar scope. So, the remote pilot needed to initiate the ATC communication to request the maneuvers.**

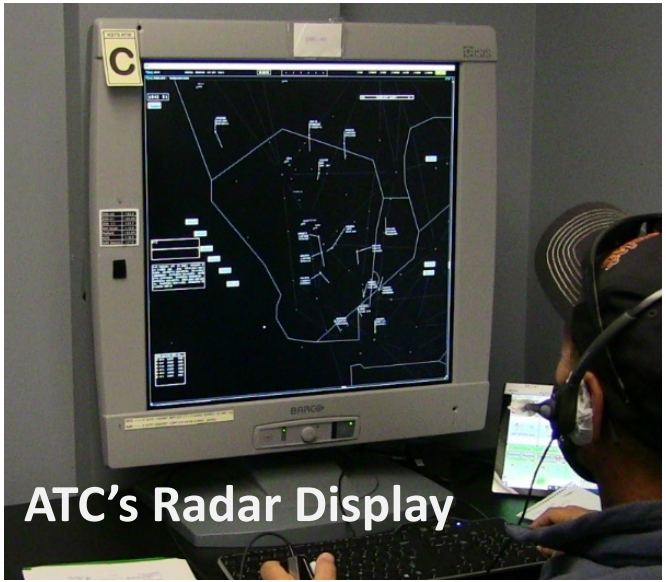


At Ukiah, NASA01 performed an instrument approach that ended with a missed approach. Each run lasted for 45 minutes.



Photos provided by the author

A pair of 1 ATC and 1 remote pilot participated in 6 runs consisting of all the 3 × 2 combinations.



Photos provided by the author

8 pairs were enrolled in the study. The order of conditions were counterbalanced within and between the participants.

- **The UA voice delay was one-way delay and added to *both* transmission and reception of the remote pilot's communication.**
- **The participants were informed that *NASA01* was remotely piloted UA with a voice delay; however, the length of the delay was not disclosed to them.**

Results

Voice Delay	Traffic Volume: High	Traffic Volume: Low
400 ms		
900 ms		
2,000 ms	x	x

The study found the following Voice Delay effects statistically significant:

When 2,000-ms voice delay was inserted for the UA, regardless of the traffic volume levels,

- Radio step-ons involving the remote pilot increased, and
- DAA Corrective Alert was more often elevated to a Warning Alert for the scripted non-cooperative traffic encounter.
  - When the UA voice delay was 2,000 ms, the traffic avoidance maneuvers were sometimes delayed because
    - The remote pilot could not find a gap to talk with the ATC in time, or
    - The remote pilot's attempts to speak with the ATC were blocked by step-ons.

Voice Delay	Traffic Volume: High	Traffic Volume: Low
400 ms		
900 ms		
2,000 ms	x	

The study also found the following Voice Delay × Traffic Volume interaction effects statistically significant:

Only when 2,000-ms voice delay was inserted AND the traffic volume level was High,

- ATCs' self-reported workload ratings increased,
- ATCs' acceptance ratings for accommodating additional UA in the sector decreased,
- The ATCs more often rated the UA voice delay was disruptive for the air traffic management operations, and
- Remote pilots' acceptance ratings for the DAA alerting and guidance for remaining DAA Well Clear decreased.

Key Take-Aways

- **If UAs with 2,000-ms voice delay are to be introduced into the NAS, some remedies should be considered, such as**
  - Increased separation buffers for UAs
  - Restricted background traffic volume levels in areas where UAs operate
  - Limiting the total number of UAs allowed to fly in each sector, and/or
  - Data Link or dedicated communication channels for the UAs.
- **For 400- and 900-ms voice delays, no major adverse effect was found in the conditions simulated in the study.**
  - However, these delays still exceed the FAA's current requirement for the max delay; thus, additional safety verifications are required.

- **The study's findings provide explanations for the gap between the current FAA requirements for the voice delay and the past studies' non-findings of negative effects of the UA voice delay.**

- **The findings may suggest that the UAs with additional voice delay may be carefully introduced into low traffic-density airspace in the NAS.**

Suggested future study topics are to evaluate

- Combined effects of
  - UA Voice delays
  - UA command execution delays, and
  - Other C2 Link System delays;

and

- Effects of having more than a single UA in a sector.

For more details, please see the paper,

Effects of Unmanned Aircraft Voice Communication Delay on En Route Air Traffic Management Operations.

Thank you for your attention.

Miwa.Hayashi@nasa.gov

Image credit: the icons on Slide 3 (all but the aircraft) were provided via Microsoft Office 365 Subscription.