Information fusion for real-time national air transportation system prognostics under uncertainty

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Co-I: Sankaran Mahadevan

Vanderbilt University

Co-I: PK Menon

Optimal Synthesis Inc.

Co-I: Barron Bichon

Southwest Research Institute

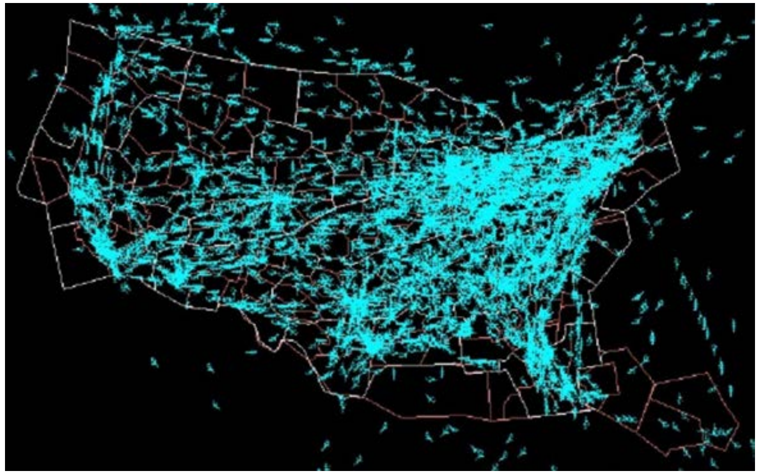
Co-I: Pingbo Tang

Carnegie Mellon University

Outline

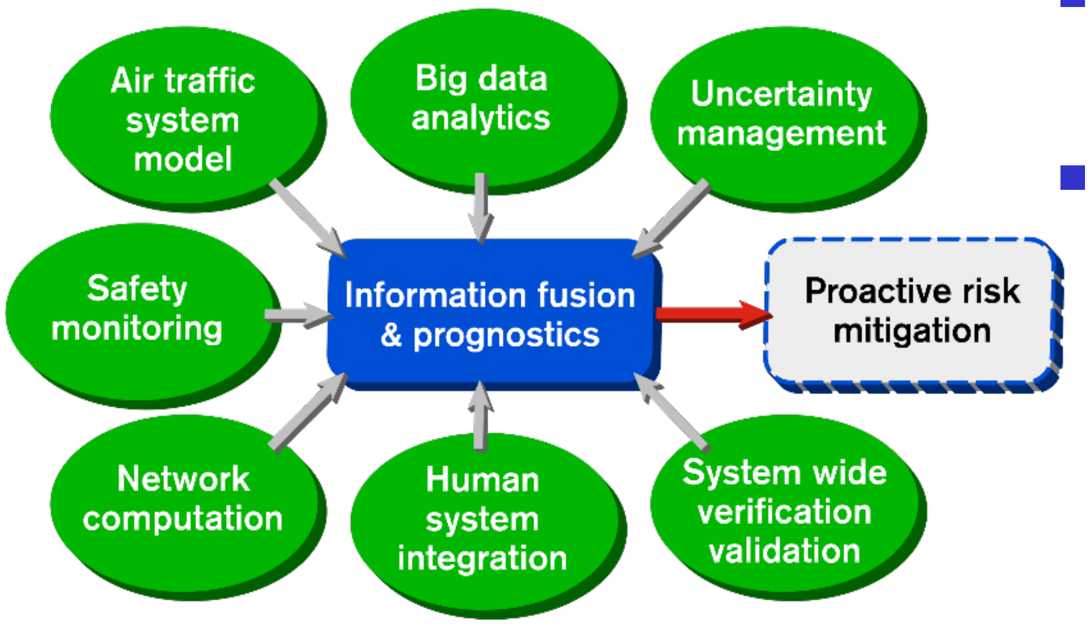
- Background and objectives
- Brief review of progress
  - Technical progress and achievements
  - Educational activities and achievements
- Other Highlights
  - Engagement of industrial partners - External advisory board
  - Participation of women in research, education, and review
  - Renovation of facilities for integrated education and research
  - Research dissemination and broad impact
  - Long term infusion beyond ULI
- Feedback to some requested questions

Background



- NASA Aeronautics Research Mission Directorate (ARMD) vision for aeronautical research that encompasses a broad range of technologies to meet future needs of the aviation community
- Recent technology advances in sensors, networking, data mining, prognostics, and other analytic techniques enable proactive risk management for National Airspace System (NextGen)
- Technology convergence of multidisciplinary research to develop transformative concepts and to enable a safe and efficient aviation system
- Systematic training of next generation engineers and workforce pipeline for future aerospace industries and research

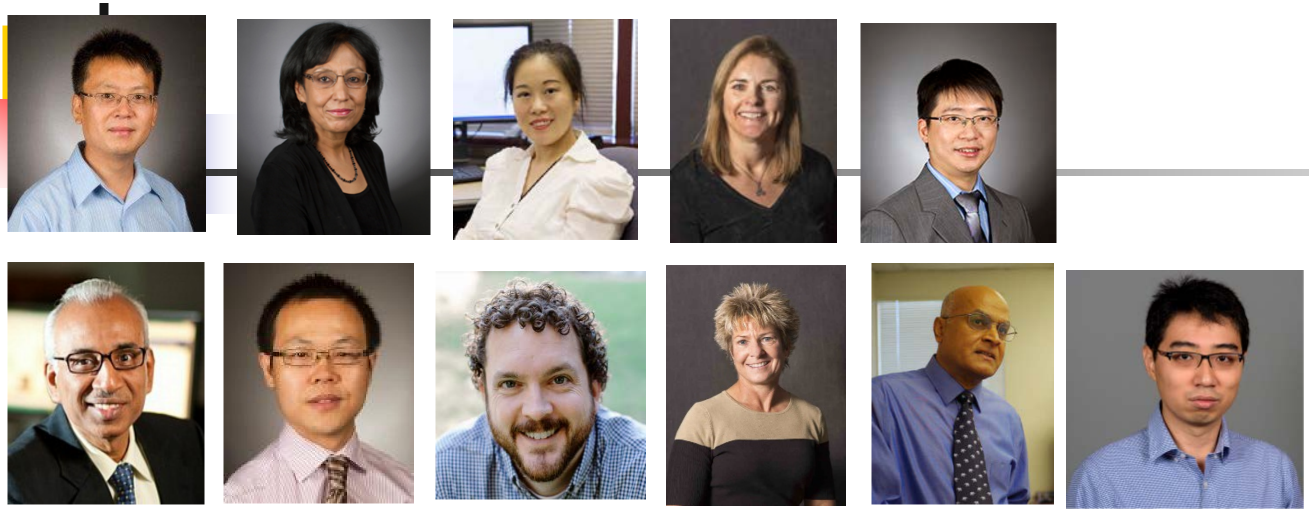
Proposed methodology and tasks

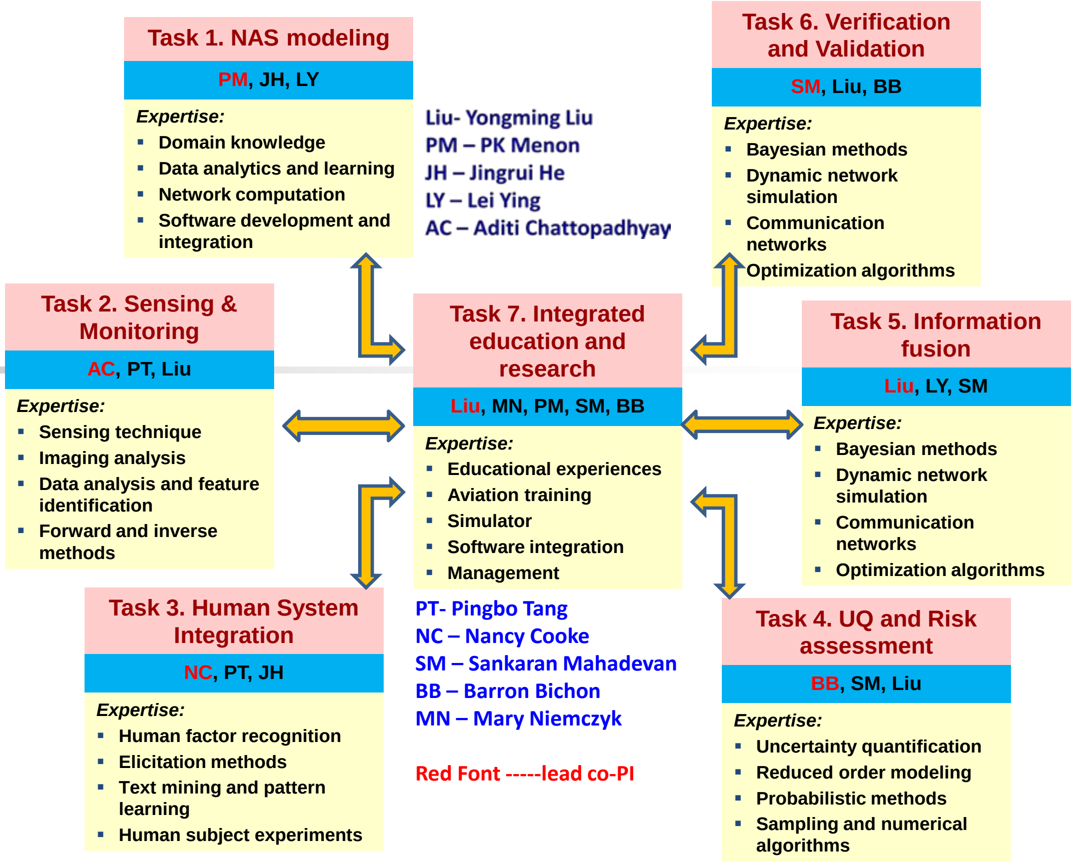


Schematic illustration of the proposed major research themes

- Highly multidisciplinary research themes are integrated together
- Seven major tasks:
  - Task 1. System-wide air traffic modeling and failure simulation
  - Task 2. Multi-modality safety monitoring, detection and data analysis
  - Task 3. Human system integration
  - Task 4. Uncertainty management and risk assessment
  - Task 5. Information fusion and prognostics
  - Task 6. Verification, validation, and safety assurance
  - Task 7. Integrated education, research, and demonstration

Project team

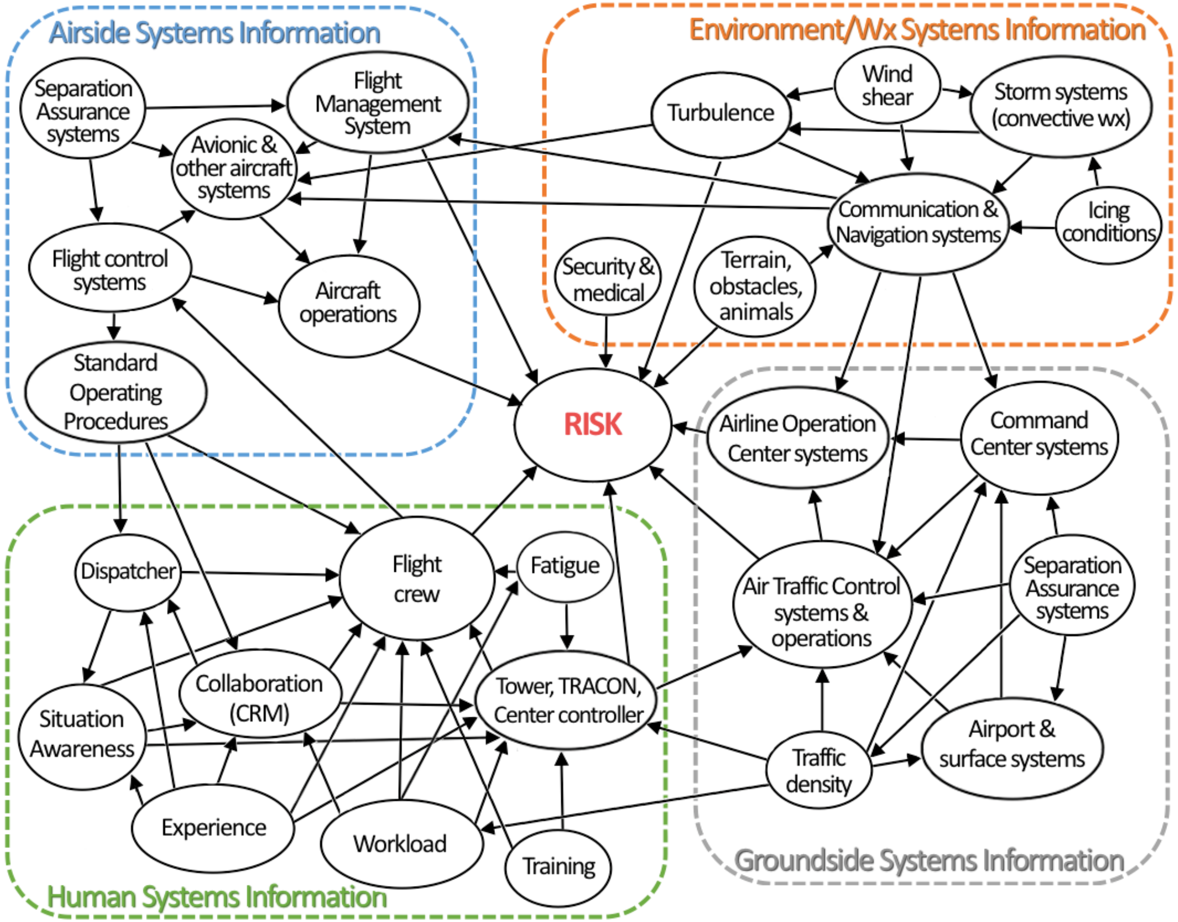




Team integration flow chart

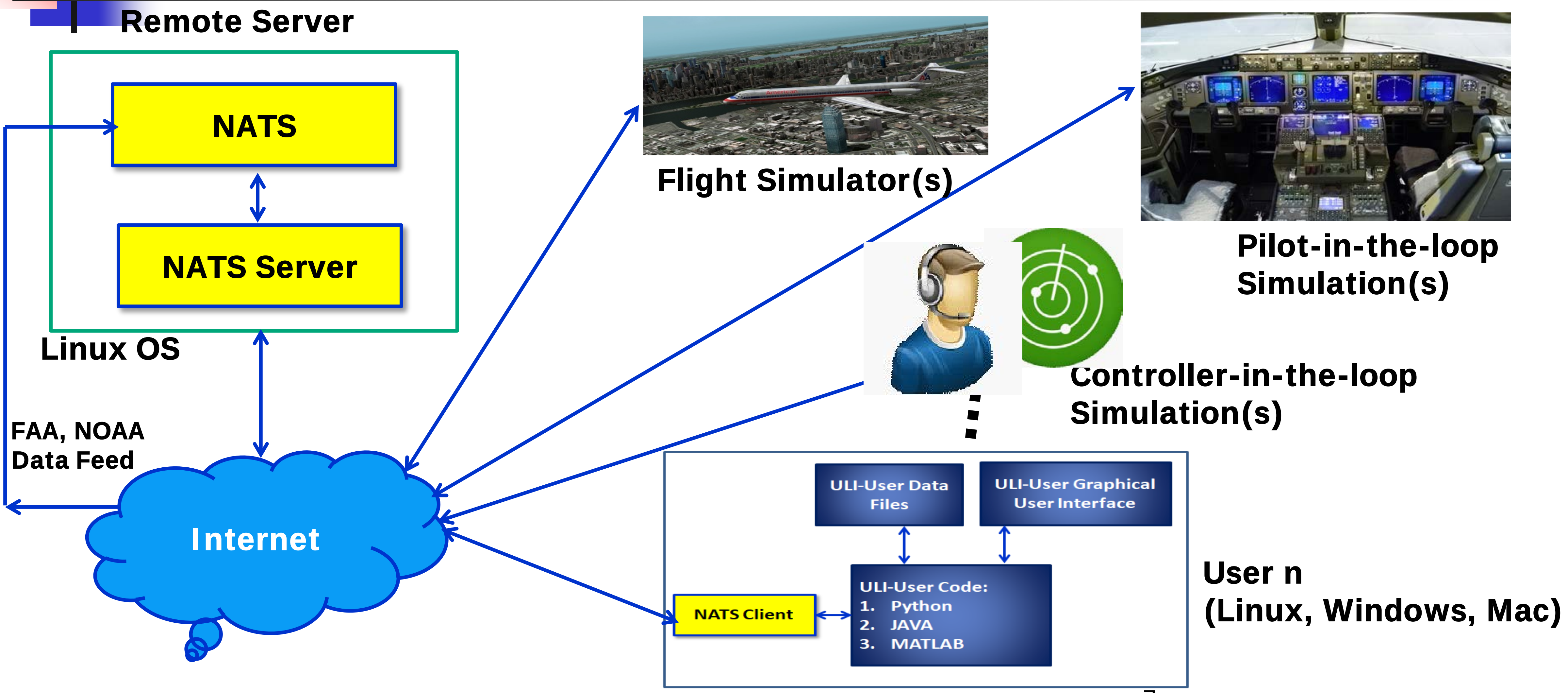
- Diverse, multidisciplinary team that includes faculty in ASU’s Ira A. Fulton Schools of Engineering and collaborators from Vanderbilt University, Carnegie Mellon University, Southwest Research Institute, and Optimal Synthesis Inc.
- Big data analysts, applied statisticians, image processors, psychologists, computer scientists, and aerospace engineers
- Expertise from information theory, applied statistics, data mining and analytics, risk management, airspace software systems, monitoring and imaging, and network science
- Smooth transition from academia basic research to applications of aerospace industry

Cyber-physical-human Information fusion: interplay of data, physics, and people



- Integrate knowledge among multiple domains within the airspace system
- Explore complex system-of-systems with human-autonomy interaction
- Improve safety of air travel through multisystem simulations, multimodality monitoring, and multidisciplinary information fusion
- Develop extreme-scale data analytics and simulation methods to enhance real-time system-of-systems risk management

Air traffic simulation – real-time cloud-based computing



Sense & Measure Human Factors Associated with ATC Performance

Air Traffic Controllers

+

ATC Performance

Scorecard

Safe & Effective NAS

Situation awareness

Cognitive Workload

Fatigue

Density

Weather

Separation

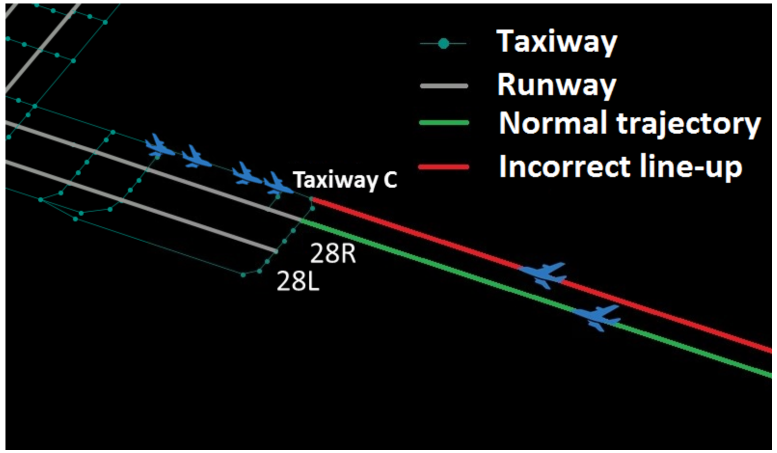
Real Time Communication Data as a Surrogate

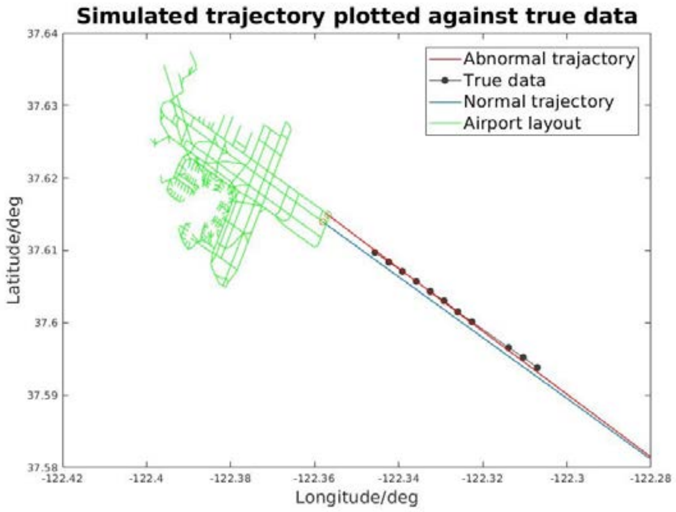
Develop Model of Controller-Pilot Performance

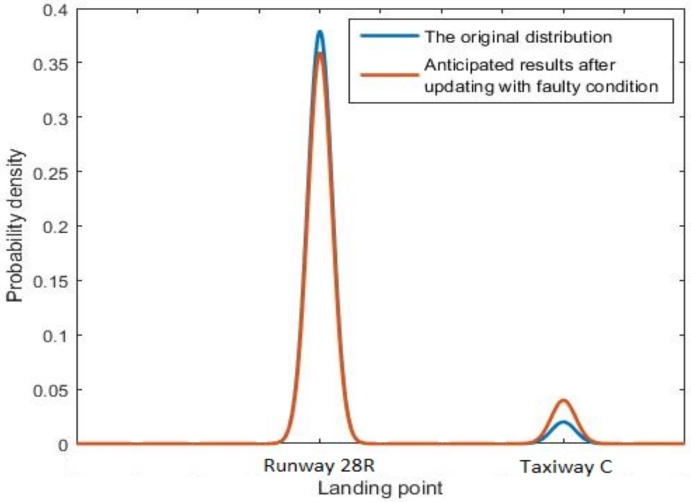
How do human factors (fatigue, cognitive load) of ATCs interact with factors in the NAS to affect ATC performance and a safe NAS?

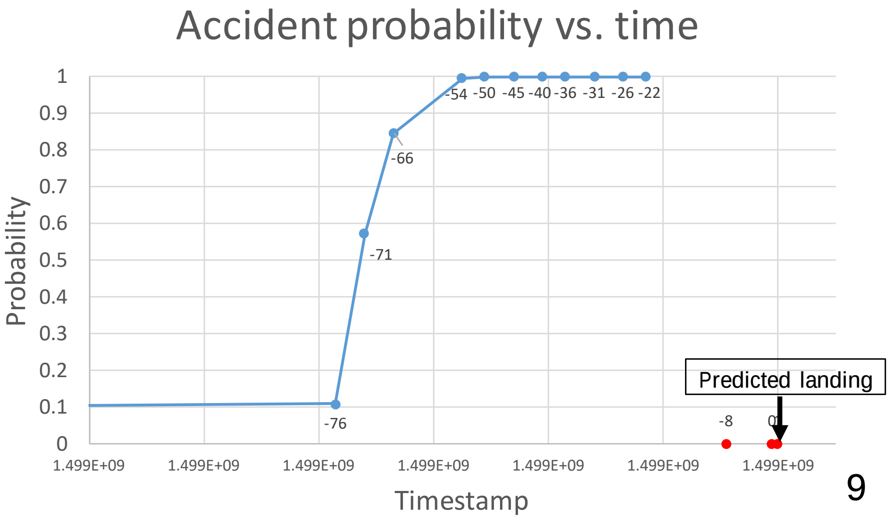
Information fusion – prognostics and safety metrics

- Simulating accidents for landing on taxiway using NATS
- Update the trajectory using ADS-B information and BEN
  - Predict the landing point at the airport and confidence level
  - 60 seconds lead time for prognostics and risk mitigation



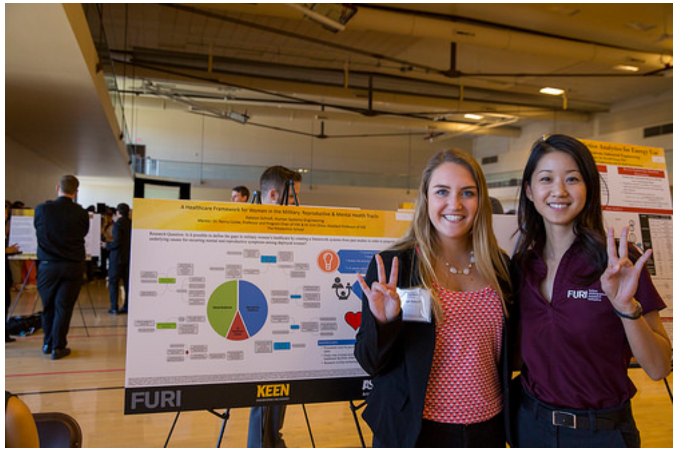






Integrated education, training, and research

National Summer Transportation Institute



Fulton Undergraduate Research Initiative

Air Traffic Management Degree Program

- Multi-level education integration: K-12 Education Outreach Program, Fulton Undergraduate Research Initiative, and graduate student training
- Interaction with actual pilot training and air traffic management program
- Demonstration and data collection with ASU simulator facilities
- Preparation of future engineers in aviation and aerospace industries

Metrics for educational and technical achievement

- Significant educational and technical achievements during the past two years

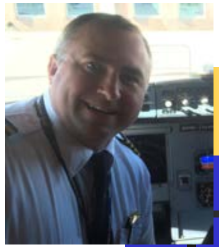
Number of students supported (graduate and undergraduate students): **30**
Number of postdocs supported (including past and current): **9**
Number of journal articles published/accepted: **4** published / **8** under review
Number of conference papers/abstracts: **37**
Number of awards (best paper, poster, student award, etc.): **5**

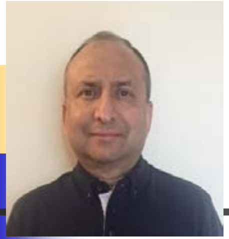
- Best Theory Paper award PHM 2018
- SwRI Best Student Paper Award in Non-Deterministic Approaches AIAA Scitech 2019
- Airport Cooperative Research Program (ACRP) Graduate Research Award 2018
- Best poster: PHM society 2018 Best poster award
- Student award: several PHM society 2018/2019 Doctoral Symposium Award

Number of invited talks/presentations: **20**
Other notable achievements: **Research dissemination and community impact**

5 students graduated, 1 student working in ATM software development; 1 student working for FedEx; 4 special sessions organized in two conferences (PHM 2018 and AIAA Aviation 2019); Released six versions of NATS to the community and two versions of PARA ATM to general public; public domain media release to enhance the broader impact

External Advisory Board


Jeffrey Panhans, Allegiant Air


Chid Apte, IBM


Eric Haugse, Boeing


Chuck Farrar , LANL


Eric Ji, Intel


Stephanie Cope, Intel


Lou Gullo, Raytheon

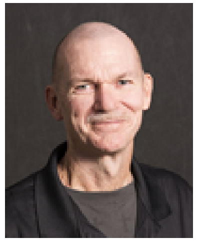

Heinz Erzberger , UC Santa Cruz


Habib Fathi, Pointivo


Roger Mandeville , ATAC


Banavar Sridhar, USRA


Xinzhou Wu , Qualcomm


Verne Latham


Ping Xue, Boeing retired


Pete Kostiuk, Robust Analytics


Liping Wang, GE


Genghis Khan, GE


Angela Campbell, FAA


John Shade, ATAC


Dan Larsen, MITRE


ANDREW LACHER, Boeing


Christina Young FAA


Jonathan Rein FAA


Somil Shah FAA

- **External Advisory Board (EAB) – members from various disciplines and industries**

EAB roles: 1) provide feedback and comments on the proposed research and research progress; 2) participate (in person or via telecom) in annual project meeting; 3) participate in regular progress teleconferences; 4) provide feedback and suggestions on future research directions to address important gaps in the community.

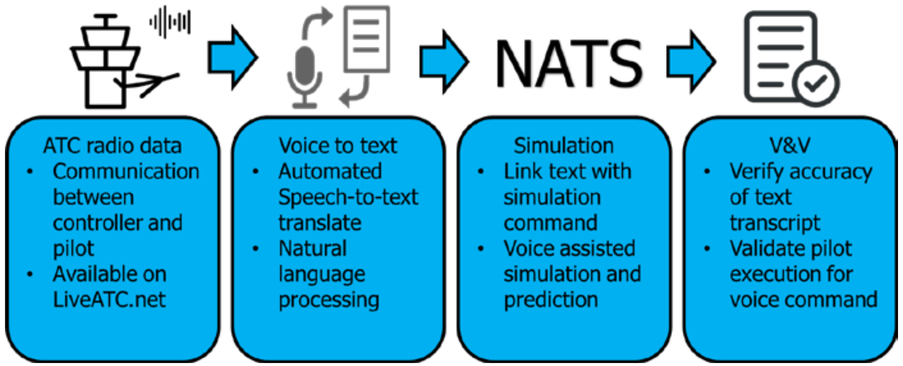
Review mechanism

- Self-organized review by our EAB members
- Online review questionnaire – lessons learned
- Onsite meeting discussion and presentation – led by Dr. Banavar Sridhar
- Official documentation and record will be submitted to NASA
- Team responses to all comments/suggestions during quarterly/annual meetings

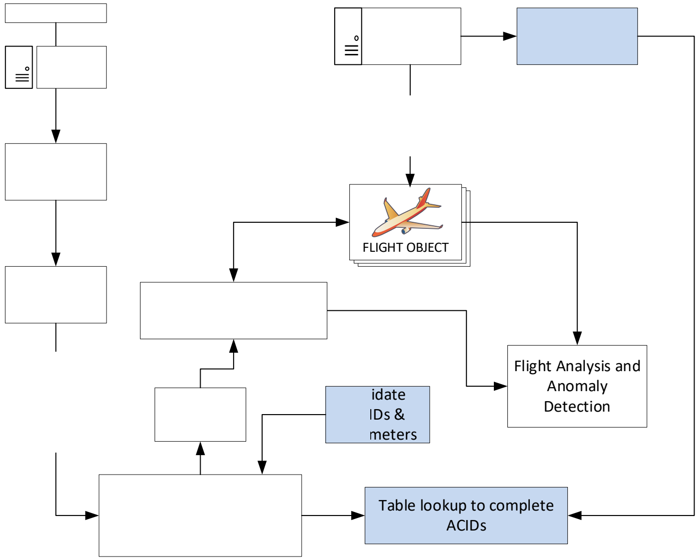
1. 10 choice/scale questions and 5 short answer questions using google forms to collect survey and to generate statistics
2. Two-month lead time with all past reports and presentations; one-week lead time for 2019 review materials
3. Based on existing templates for large scale project review and added comparison with similar programs nation wide
4. Focus on the overall ULI progress and management review
5. Fully anonymous to PIs and NASA management team

Engagement with industry case study 1 - Voice Communication-Augmented Simulation (VCAS)

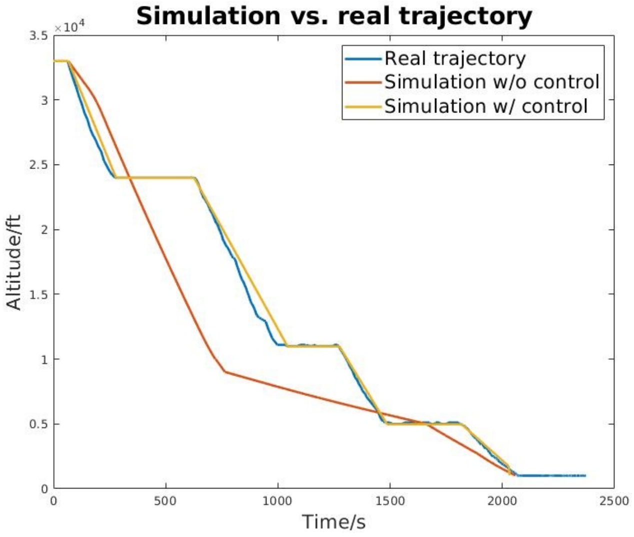
- Using radio communication to assist NATS simulation for more accurate trajectory prediction
- Collaborative work between Robust Analytics, Inc., IBM, OSI, and ASU



Proposed framework



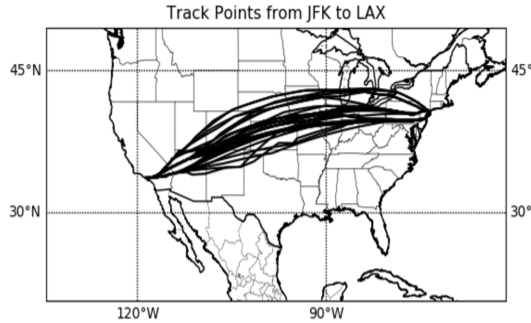
Automatic translation

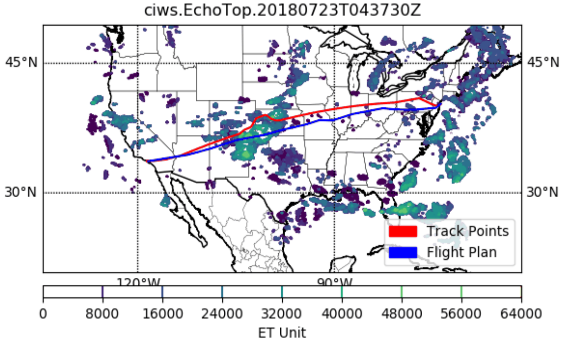


Preliminary results

Engagement with industry case study 2 – Big data analytics for trajectory prediction

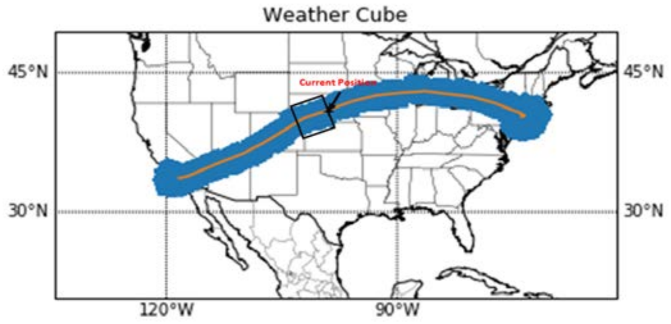
Collaborative work between ATAC and ASU

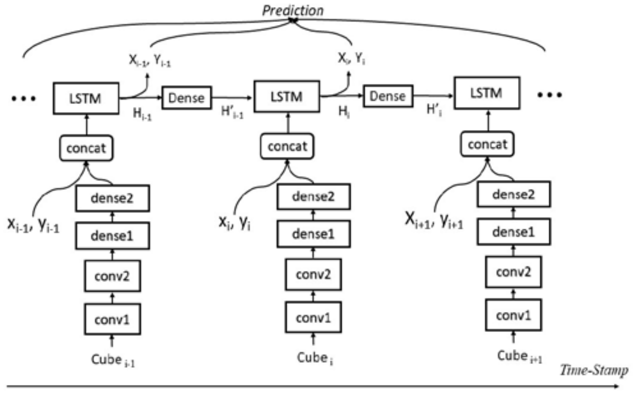




❖ Sherlock Data Warehouse (SDW)

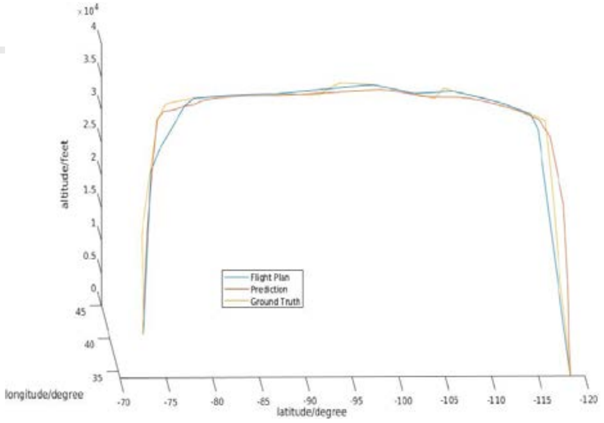
- We use Integrate Flight Format (IFF) data and Convective Integrated Weather Service (CIWS) for EchoTop (ET) weather data

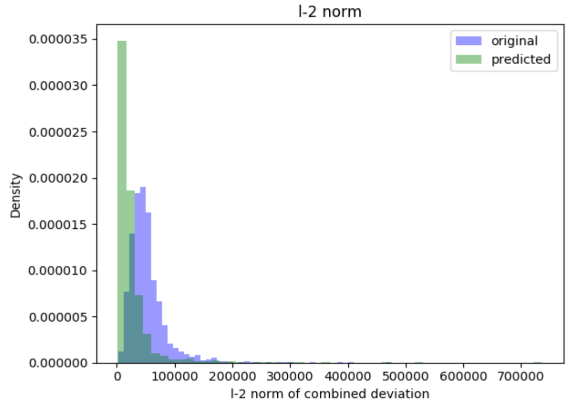




❖ Data processing and training

- Data partition and RNN+CNN training for trajectory prediction





❖ 4D trajectory prediction

- Variance reduction with included weather information
- Still large discrepancies and need additional modeling capability

Participation of women in research, education, and review

Investigators

Aditi Chattopadhyay

Jingrui He

Nancy Cooke

Nancy Cooke

EAB members

Angela Campbell, FAA

Christina Young FAA

Stephanie Cope, Intel

Liping Wang, GE

Students/Engineers

Sarah Ligda

Jueming Hu

Erin DeCarlo

Yingxiao Kong

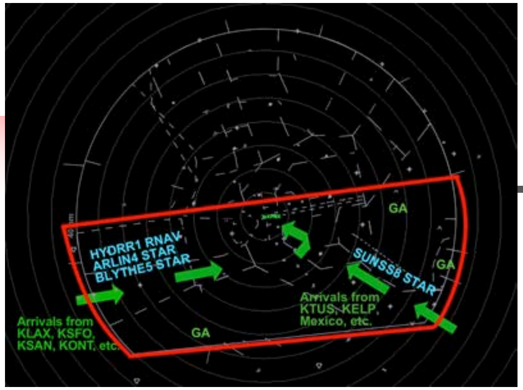
Kasey Stevenson

Yanyu Wang

Ying Shi

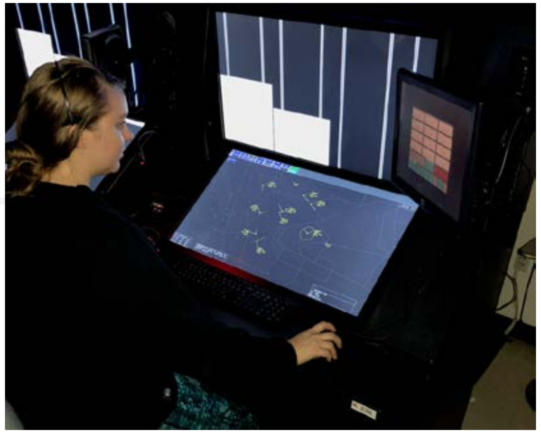
Encourage the hiring for women and minority students; working with university level recruiting office

Renovation of ATC facilities

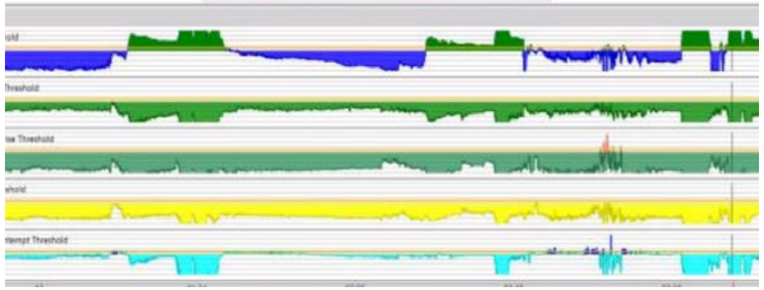


Integrated Software Control

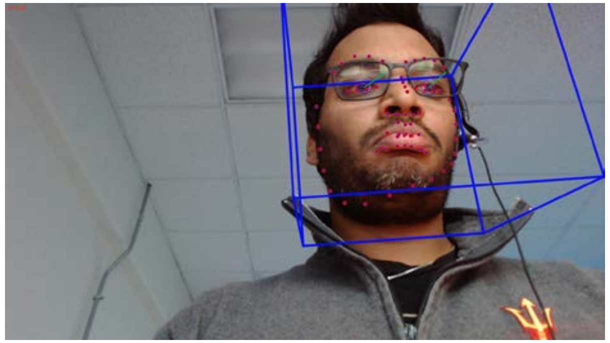
ATC simulator at ASU

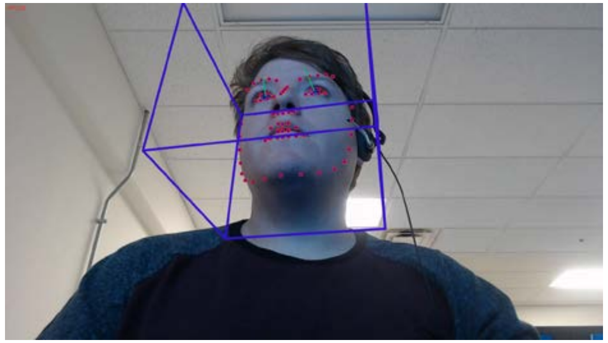


Communication recording and analysis



Biometric measurements



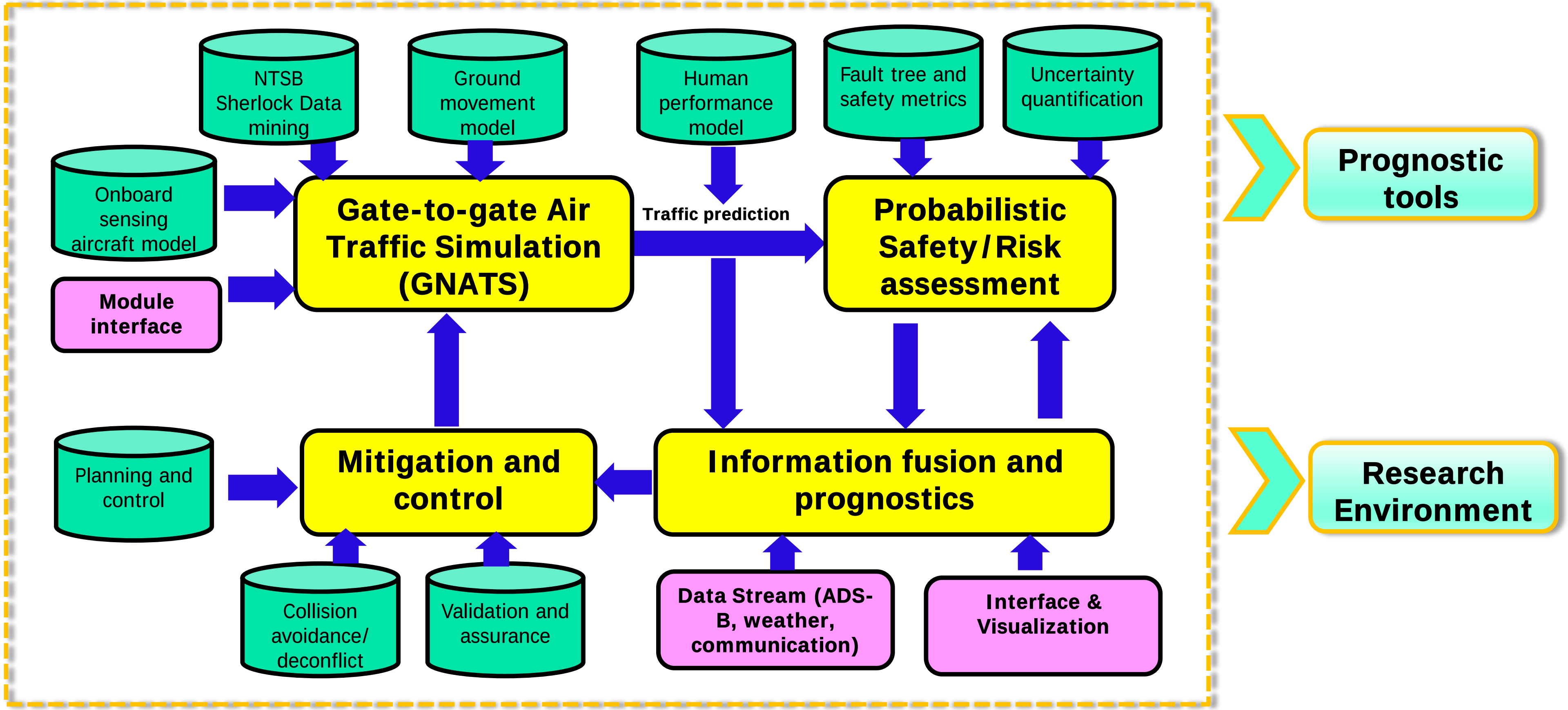


Facial expression capturing systems

- Renovation of an education-based ATC facility to an integrated research-training facilitity
- One of a kind human-in-the-loop testing facility in all US universities

Research dissemination and broad impact

- **PARA-ATM – Prognostic Analysis and Reliability Assessment of Air Traffic Management**
- **An in-time prognostic system and research environment for ATM**
- **Fully open platform and is available from github**
- **Sustained development for the community beyond 5 years**



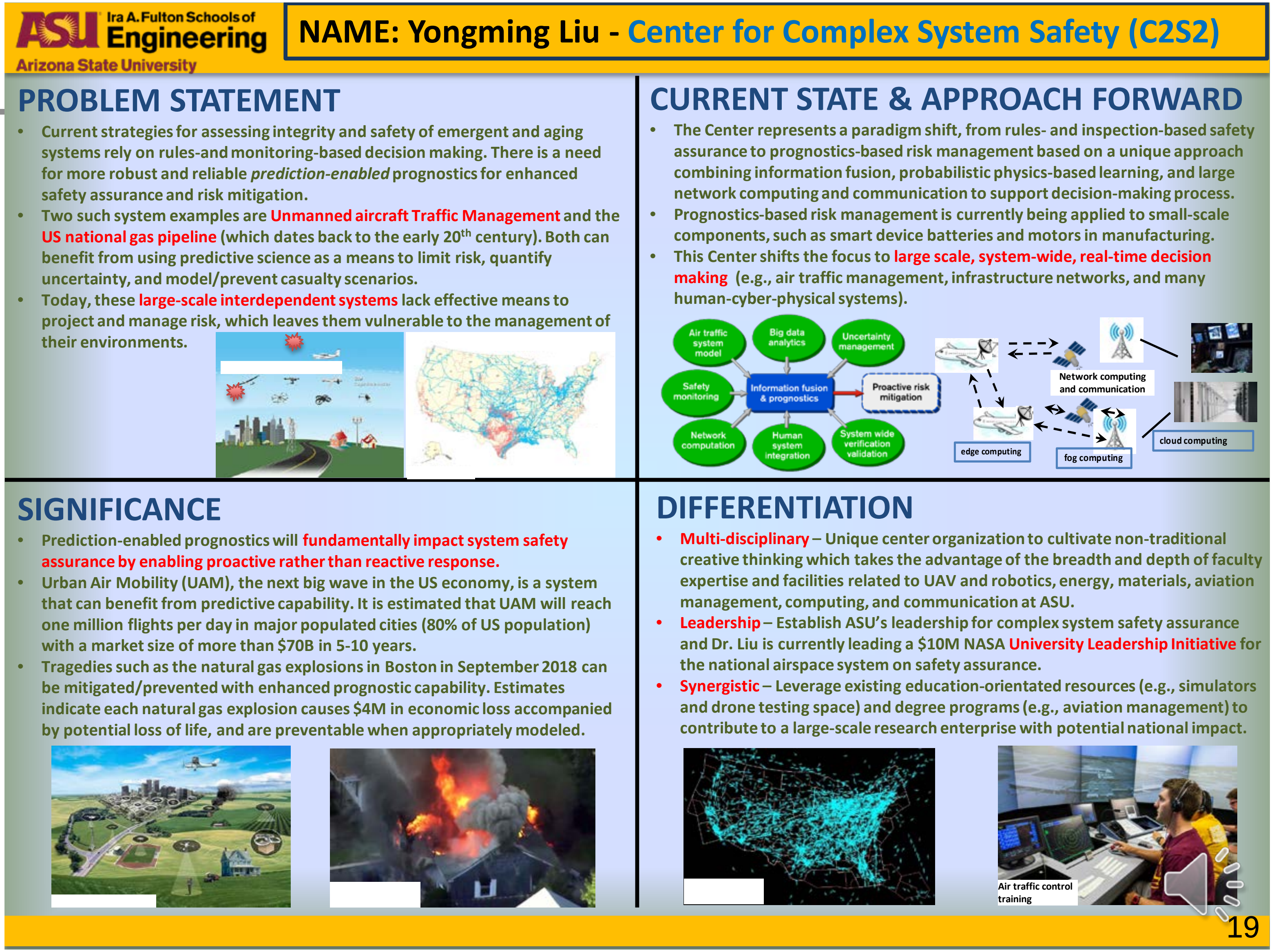
Plan beyond ULI

- Regent Innovation Fund (RIF) by the State of Arizona
- State-wide Center for Complex System Safety (C2S2) – Arizona State University (Director: Yongming Liu), University of Arizona (co-Director: Samy Missoum), Northern Arizona University (co-Director: David Auty)
- 18 faculties from 6 different departments/schools
- Focusing areas

  - Next generation air transportation (NAS and UAS)

  - Aging infrastructure system

  - Forestry


ASU Ira A. Fulton Schools of Engineering Arizona State University

NAME: Yongming Liu - Center for Complex System Safety (C2S2)

PROBLEM STATEMENT

- Current strategies for assessing integrity and safety of emergent and aging systems rely on rules-and monitoring-based decision making. There is a need for more robust and reliable *prediction-enabled* prognostics for enhanced safety assurance and risk mitigation.
- Two such system examples are Unmanned aircraft Traffic Management and the US national gas pipeline (which dates back to the early 20th century). Both can benefit from using predictive science as a means to limit risk, quantify uncertainty, and model/prevent casualty scenarios.
- Today, these large-scale interdependent systems lack effective means to project and manage risk, which leaves them vulnerable to the management of their environments.

CURRENT STATE & APPROACH FORWARD

- The Center represents a paradigm shift, from rules- and inspection-based safety assurance to prognostics-based risk management based on a unique approach combining information fusion, probabilistic physics-based learning, and large network computing and communication to support decision-making process.
- Prognostics-based risk management is currently being applied to small-scale components, such as smart device batteries and motors in manufacturing.
- This Center shifts the focus to large scale, system-wide, real-time decision making (e.g., air traffic management, infrastructure networks, and many human-cyber-physical systems).

SIGNIFICANCE

- Prediction-enabled prognostics will fundamentally impact system safety assurance by enabling proactive rather than reactive response.
- Urban Air Mobility (UAM), the next big wave in the US economy, is a system that can benefit from predictive capability. It is estimated that UAM will reach one million flights per day in major populated cities (80% of US population) with a market size of more than $70B in 5-10 years.
- Tragedies such as the natural gas explosions in Boston in September 2018 can be mitigated/prevented with enhanced prognostic capability. Estimates indicate each natural gas explosion causes $4M in economic loss accompanied by potential loss of life, and are preventable when appropriately modeled.

DIFFERENTIATION

- Multi-disciplinary – Unique center organization to cultivate non-traditional creative thinking which takes the advantage of the breadth and depth of faculty expertise and facilities related to UAV and robotics, energy, materials, aviation management, computing, and communication at ASU.
- Leadership – Establish ASU's leadership for complex system safety assurance and Dr. Liu is currently leading a $10M NASA University Leadership Initiative for the national airspace system on safety assurance.
- Synergistic – Leverage existing education-orientated resources (e.g., simulators and drone testing space) and degree programs (e.g., aviation management) to contribute to a large-scale research enterprise with potential national impact.

Responses to some questions - 1

- -Can you compare your proposed and actual deliverables as well as the timelines? Any challenges associated with producing these deliverables at the proposed timeline?

Most deliverables/milestones are corresponding to the schedule. COVID-19 did cause some issues to human testing and we are working on it.

- -How free do you feel to define the project?

The team appreciates the structure of ULI to have very flexible research plans to archive the goal and can adapt to newly identified research topics within the general framework.

- -How much do you feel industry is really interested in what you are doing, or is industry interested in the students who are being educated?

Some topics really draw attention from industry, for example, machine learning for text mining. Some are more fundamental science and may be less relevant to the short-term goal of industry needs. Students really benefits from the training and industries really like their capability and potential.

- -What are the impacts of Covid-19 on the funded project?

Mainly on human testing and we cannot perform the testing until now. Travels are not possible which changes the originally planned collaboration mechanisms.

Responses to some questions - 2

- -How did you select the peer reviewers, how often do you meet with them?

Based on the individual disciplines and recommended by the investigators or EAB members. Meet with all on annual meeting and quarterly meeting. Private meeting with specific topics, 1-2 times per month

- -How often do you provide reports and/or updates to the peer reviewers as well as NASA and what typical feedback do you receive from both the peer reviewers and NASA? Has the feedback been helpful?

Formal feedback on annual and quarterly report meeting. Informal feedback from individual meeting. They are very helpful and many new research topics are proposed by EAB based on their new findings.

- -What tools do you use to engage team members in your collaboration?

Zoom, web portal, github, and other document/data sharing services

- -Are you developing new technologies or enhancing/supporting existing ones?

Both.

- -How do you choose students and postdocs for your project?

From the application pools or recommendation from peers

- -What attracted you to this opportunity?

Have the opportunity to try sth which is not possible with this ULI funding level and mechanism

- -How did you find out about the opportunity?

Email subscription from NSPIRES/grants.gov

Responses to some questions - 3

- -What has been most valuable about ULI so far?

Working with huge diversity people; enjoying the student success

- -What has been the most significant outcome(s)?

Students, technology improvements, PARA-ATM

- -Describe the student participation in ULI.

Students are actively involving the research, forum discussion, collaborative activities

- -Describe your ULI dissemination activates.

Standard journal article and conference proceedings, organized special sessions, public media, github

- -If you could change just one or two things about ULI, what would it be?

The timing should be better aligned with university cycle, e.g., student hiring; thinking about phase 2 to continued developed from successful phase 1 projects

Thanks!
Questions?

Acknowledgments

The research reported in this presentation was supported by funds from NASA University Leadership Initiative program (Contract No. NNX17AJ86A, Project Officer: Dr. Anupa Bajwa, Program coordinator: Koushik Datta, Principal Investigator: Dr. Yongming Liu). The support is gratefully acknowledged.