A Review on Recent Active Research Projects on Unmanned Aerial Vehicles

SkyGuardian

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Overview

- Introduction
- Classification of piloting an Unmanned Aerial Vehicle (UAV)
- 1. Detect-and-avoid
- 2. Automated recovery
- 3. Fault monitoring
- 4. Intelligent flight planning
- 5. Manned-unmanned aircraft teaming
- 6. Formation flight
- 7. Integration of UAVs into airspace
- 8. Cyber-security
- 9. X-Planes
- 10. UCAV

Introduction

- The applications of UAVs (both civil and military) are expanding exponentially.
- Number of UAVs in the air is increasing significantly.
- Technological advances in wireless communication, sensors, and micro electromechanical systems, make it possible to use inexpensive small autopilots.
- New challenges are rising.
- New research projects are conducted in many universities, industries, and government agencies.
- Unattributed figures are held in the public domain and are from either the U.S. Government Departments or Wikipedia.

Revolutions in Aeronautics

- 1. Wright Flyer (1903)
- 2. Jet engine (1940s)
- 3. UAVs (1990s)

2020 Budget Request

- 1. DOD: $718.2 billion
- Includes $104.3 billion for RDT&E
- 2. FAA: 17.1 billion
- Includes $202.6 million for the integration of unmanned aircraft systems into the National Airspace System
- 3. NASA: $21 billion
- 4. NOAA: $4.5 million
- 5. NSF (National Science Foundation): $7.1 billion
- Grant applicants will be accepted: 21 percent

New horizons

- There are always ways to innovate/improve.
- New aircraft (including UAVs) should be:
- 1. Safer
- 2. Faster
- 3. Quieter (including stealth)
- 4. Cleaner
- 5. Lower cost
- 6. New applications

UAV Sales Expected To Keep Growing

- Global personal drone sales grew from $1.7 billion to $2.36 billion in 2017.”
- Commercial (small non-model UAVs) registrations are totaled 110,604 in 2017, and are projected to grow to 451,800 in 2022.
- By January 2019, at least 62 countries are using or developing over 1,300 various UAVs.
- The number of small RC model (hobbyist) airplanes registered in the US will be 2.4 million units in 2022.

Example: Predator-series family

- General Atomics Aeronautical Systems, on **9 April 2018** announced that
- its Predator-series family of Remotely Piloted Aircraft, encompassing MQ-1 Predator, Predator B, Gray Eagle, MQ-9 Reaper, MQ-9B SkyGuardian, and Predator C Avenger, has achieved a historic industry milestone: five million flight hours.
- The milestone was achieved on April 4, with 360,311 total missions completed and more than 90 percent of all missions flown in combat.
- The Predator A was planned to retire from US Air Force service in 2018.

Classification of piloting a UAV

- 1. Remote control
- 2. Autopilot-assisted control (i.e., Automated)
- 3. Semi-full autonomy
- 4. Full autonomy
- 5. Higher-level autonomy - Intelligent

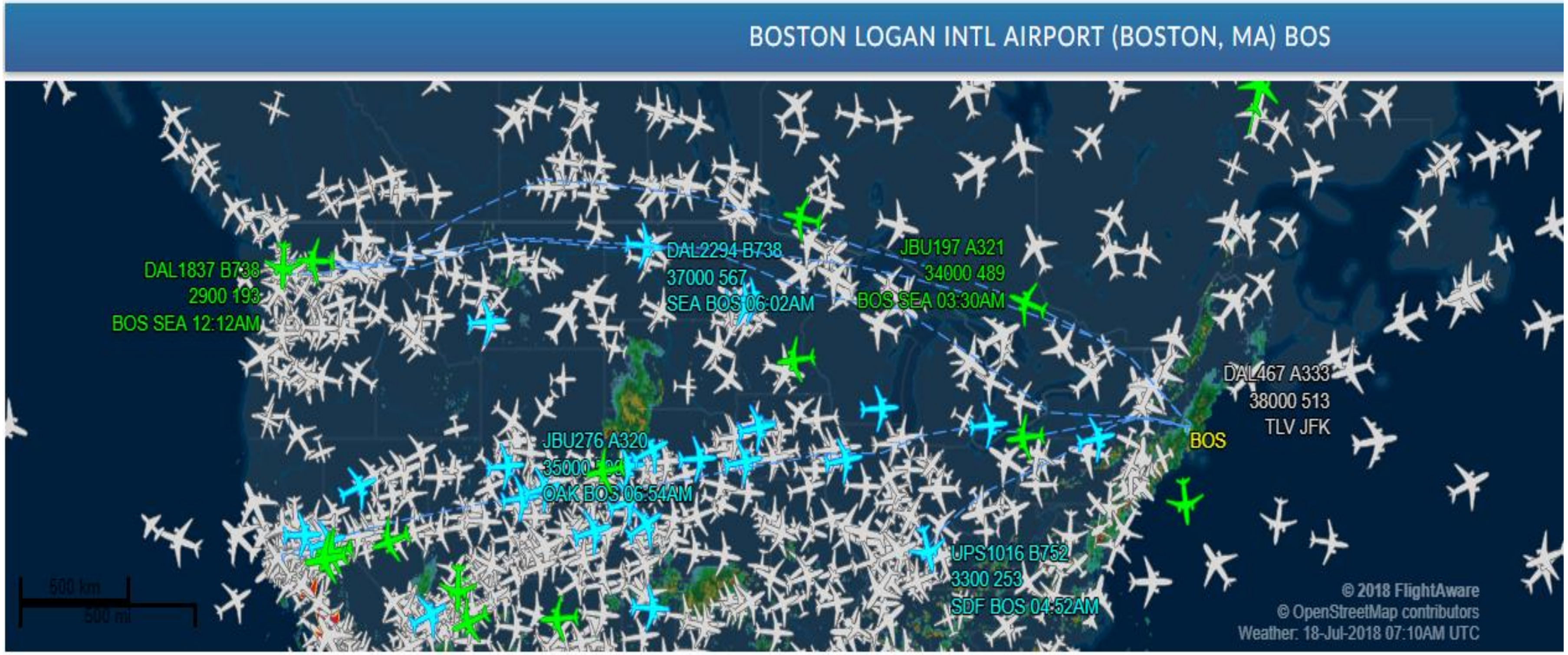
1. Detect (i.e., Sense)-and-Avoid

Detect-and-Avoid - 1

- Collision avoidance is a primary concern to the FAA regarding aircraft safety.
- Currently, the traffic alert and collision avoidance system (TCAS) is the primary cooperative collision avoidance system and is in use by a variety of airspace users.
- The current adapting technologies are not at such reliable level.
- High computational requirement is an obstacle.
- A major design issue of UAVs is that any black box is additional weight, and weight restrictions for some smaller UAVs may restrict UAV functionality or the inclusion of cooperative systems.

Detect (i.e., Sense)-and-Avoid - 2

- Active solutions include the use of machine vision, and GPS/radar to detect collision threats, and precision control to avoid collision.



https://flightaware.com/

Hybrid approach in navigation

- Vision sensors are suboptimal at determining orientation, but quite good at measuring location.
- On the other hand, accelerometers and conventional IMUs yield an increased error due to integration.
- Hybrid approach is a solution to reduce the challenges of navigation in measuring orientation and translation (i.e., state estimation) in space.
- Pairing IMU and vision sensors or GPS will provide a more precise measurement for a full six degree of freedom motion in space.

Example 1: A NASA project

- Ownship (Ikhana/Predator B UAV), remotely piloted/monitored
- Intruder (King Air (human piloted), and F/A-18)
- 3 flights per day, 4 hours of data collection, 10 minutes per encounter
- Briefing at 4:30 AM
- Ends: at 4 PM
- 500 ft: Vertical separation
- 0.5 mile: Horizontal separation
- 300 unique encounters
- 20 encounters per day
- If the intruder is higher: UAV descends
- If the intruder is lower: UAV climbs
- 30 people involved.

Example 2. Air Force Project

- Ownship: RQ-4 Global Hawk
- Intruder: F-16
- Airspeed: 150 knot
- Altitude: 6,000 ft
- F-16 was almost stalling for intruding
- Flight rehearsal: 8-16 hours (full team: pilots + engineers)
- This project also tested: 1. flight quality, 2. performance, 3. sensors.
- Some flight data are junk (e.g., at 30,000 ft, data link were not working).
- Have mis-hap plans, if mishap happens, lock-down everything, and investigate.

Example 3: Another NASA project

- Goal: an UAV is flown to a new area to detect objects (from various altitudes)
- Object image: more than 1,000 classes (examples: tree, pole, cat, …)
- GPS versus PTAM (Parallel Tracking And Mapping)
- Object detection: 1. indoor, 2. outdoor (5% unsuccessful)
- Image sensors: 1. Odroid (LaRC), 2. TX2, Nvidia Jetson (NASA Ames)

NASA Langley Research Center in Hampton, Virginia

Ames Research Center - NASA's center in Silicon Valley

NASA UAV Flies Solo For the First Time

- In June 2018, NASA flew a Ikhana UAV equipped with detect-and-avoid technologies through the national airspace system for the first time without a safety chase plane following it.
- This flight over California moves the US closer to allowing unmanned aircraft operation within the US national airspace.
- It flew west from Edwards Air Force Base in the Mojave Desert "into Class A airspace where airliners fly, north to Fresno and south through Class E general aviation airspace, including an approach to Victorville airport."
- As part of the test, the aircraft also transitioned between air traffic controllers.

2. **Automated Recovery**

Automated Recovery - 1

- A regular recovery could be either regular automated landing or to recover by some means such as net, skyhook, and arresting line.
- The UAV must have a number of fail-safes in place in case of any elemental failure.
- The automated recovery is a challenge .

Automated Recovery - 2

- Since physical pilot control is not present, there is a high potential for unsuccessful recovery.
- Another source of failure is communication failure or data link loss.
- In the event that command and control links have been completely severed between an UAV and the ground station, the UAV should be switched to pre-programmed mode to attempt for some fixed period of time to re-establish communications, or to independently complete the mission.

3. Fault Monitoring

Fault Monitoring -1

- Unscheduled UAV maintenance creates a lot of issues and cost for large UAV operator units, because spare parts are not always available at any place and sometimes have to be shipped across the world.
- If a flight mission has to be canceled or even delayed, the UAV causes significant costs.
- Reducing the number of unscheduled maintenance is a great cost factor for UAV operators.
- For this objective, and to ensure the integrity of the UAV systems, fault monitoring must be continually conducted on flight.
- Fault monitoring ensures that undetected system faults will not lead to a catastrophic failure of the UAV's systems, which may eventually lead to human casualties on the ground.

Fault Monitoring - 2

- Failure prediction is the combination of condition (i.e., health) monitoring and condition prediction to forecast when a failure will happen.
- In the event of system faults, the UAV must have the capability to reconfigure itself and re-plan its flight path in a fail-safe manner.
- The predictive UAV health monitoring is able to predict failures so that maintenance can be planned ahead.

Objectives of Fault Monitoring

- 1. Reduction of unscheduled maintenance
- 2. Advanced failure prediction
- 3. Condition monitoring
- 4. Ability to better plan maintenance
- and finally
- 5. Prevent failures

Wiring example

- In 1984, A Boeing 767-200ER had 140 kilometers of wiring.
- In 2012, a modern twin-aisle aircraft like the Boeing 787 has about 500 kilometers.
- Predator B is equipped with a fault-tolerant flight control system, and triple redundant avionics system architecture.

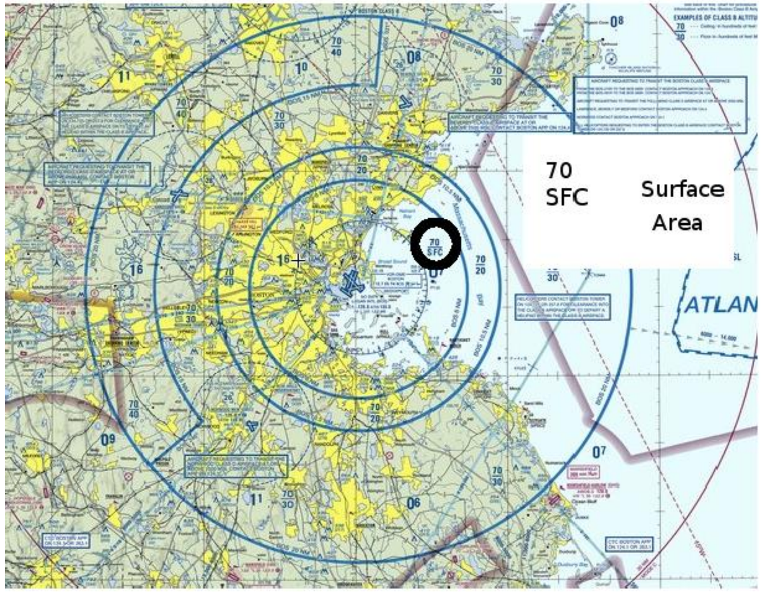
4. Intelligent Flight Planning

Intelligent Flight Planning - 1

- An intelligent UAV system must have the ability to plan and re-plan its own flight path, to cope with undesired situations.
- This results in the requirement for advanced sensors, and a high level computing environment where flight planning algorithms can be executed.
- The intelligent flight planning requires a significant improvement in software and hardware performance.

Intelligent Flight Planning - 2

- The flight planning process requires knowledge of the UAV’s surroundings; including:
- 1. airspace
- 2. terrain
- 3. other traffic
- 4. weather
- 5. restricted areas
- 6. obstacles
- 7. closest airfield



Intelligent Flight Planning - 3

- The UAV must plan the optimal route for its mission, considering the local environment, to minimize the flight time and fuel usage.
- The intelligent planning will detect any incoming aircraft for collision avoidance.

A DJI Phantom quadcopter

5. Manned-Unmanned Teaming

F-16

Global Hawk

Manned-Unmanned Teaming - 1

- Today's aircraft inventory includes a diverse mix of manned and unmanned systems.
- The statistics is growing exponentially.
- Unmanned aircraft systems (UASs) are subject to regulation by the FAA to ensure safety of flight, and safety of people and property on the ground.
- Incidents involving unauthorized and unsafe use of small, remote-controlled aircraft have risen dramatically.

Number of UAVs

- A: Hobby UAVs
- 2016: 1.9 million
- 2020: 4.3 millions

- B: Commercial UAVs
- 2016: 600,000
- 2020: 6.2 millions

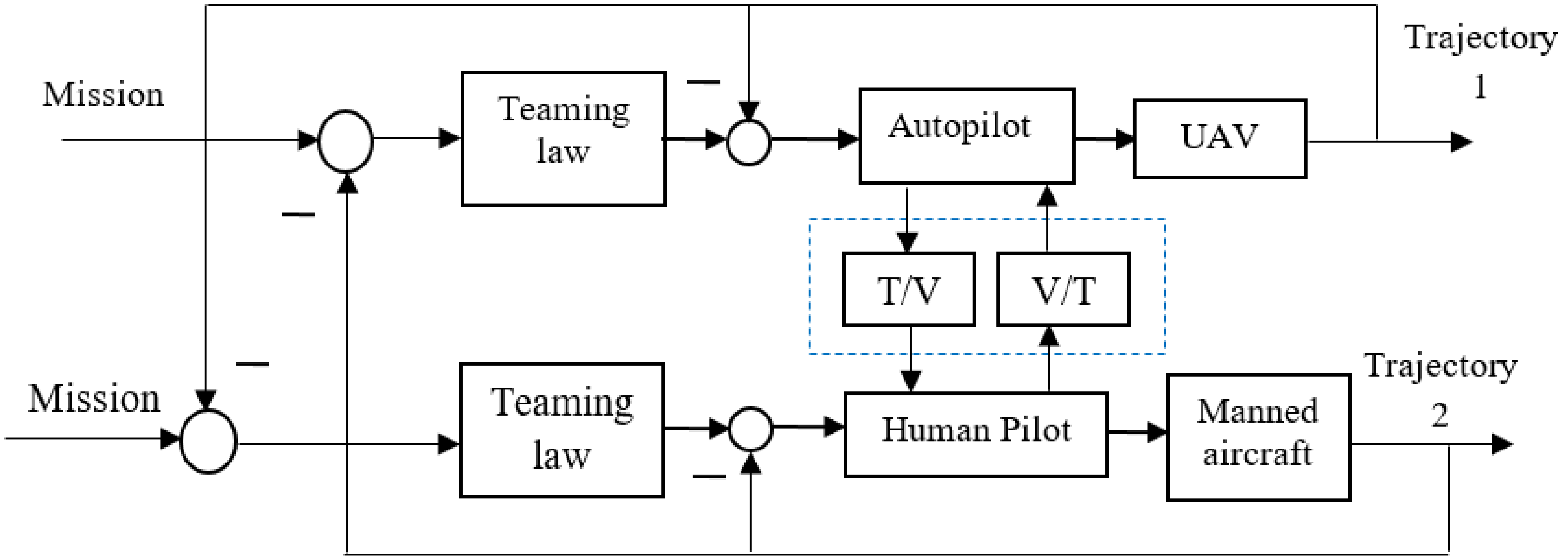
Manned-Unmanned Teaming - 2

- One of the main goals for the manned-unmanned teaming is to provide flexible flight operations.
- Teaming a UAV system with manned systems will offer advantages to both.
- 1. Follower UAV, and leader manned aircraft
- 2. Follower manned aircraft, and leader UAV

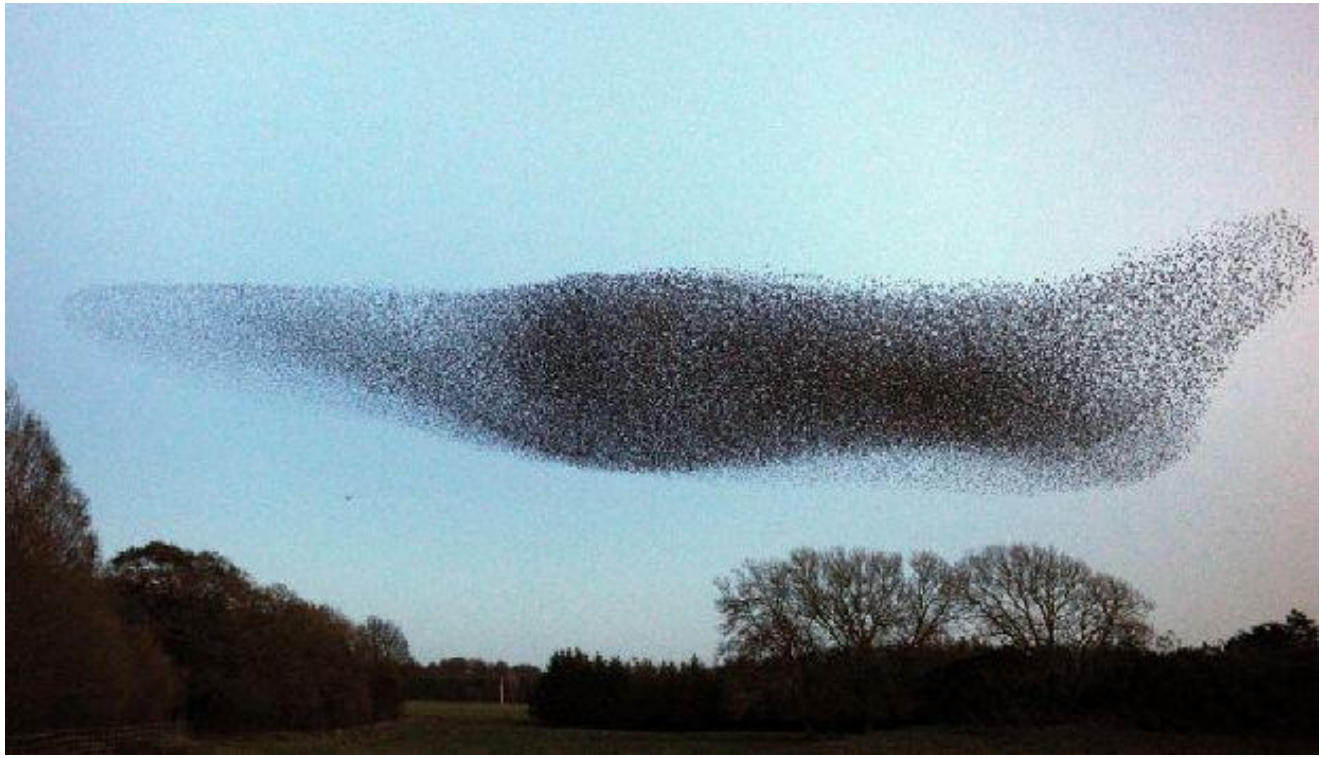
Manned-Unmanned Teaming - 3

- To achieve the full potential of unmanned systems at an affordable cost, efforts must be conducted to implement technologies and evolve tactics, techniques and procedures that improve the teaming of unmanned systems with the manned aircraft.
- The functions of a UAV in a team with manned aircraft depend in nature on the different UAV configurations and their characteristics.
- To this end, the critical challenges must be identified for further growth to fulfill expanding UAV roles in supporting the aviation safety goals.
- New technologies need to be developed.
- New regulations must be prepared.

Communication between manned and unmanned aircraft



6. Formation flight



Formation flight - 1

- Multi-agent UAVs
- Nature: Flight of starlings
- A. Coordination constraints
- B. Temporal constraints
- UAVs:
- 1. Reference agent,
- 2. leader(s),
- 3. followers

Formation flight - 2

- **Intel's 500 Drone Light Show (2016): https://www.youtube.com/watch?v=aOd4-T_p5fA**
- In 2018, Intel succeeded to perform a record-breaking performance with 1200 Shooting Star quadrotors collaborated by orchestra in Olympic Opening Ceremony in South Korea.
- This swarming flight require carefully coordinated sequences. One wrong move, one drone out of line, and it can send a lot of UAVs crashing down.
- https://www.youtube.com/watch?v=fCd6P7Ya160
- **Intel World Record. Over Two-Thousand Drones Light Up the Sky!** **https://www.youtube.com/watch?v=u6uIRr4CWQY**

7. Integration of UAVs into Airspace

Integration of UAVs into Airspace - 1

- Integration of UAVs into Airspace is another major research project.
- FAA is working with several teams to develop a framework for integration.
- European Commission released Blueprint For UAV Standards.
- Pilot reports of interactions with suspected unmanned aircraft have increased from 238 sightings in all of 2014 to 780 through August of 2015.

NASA To Test UAV Management System For Cities

- In April 2019, NASA has "launched the final stage of a four-year effort to develop a national traffic management system" for UAVs.
- The agency is testing beyond visual line of sight (BVLOS) flights of UAVs in cities "for the first time".
- Multiple UAVs "took to the air at the same time above downtown Reno in a series of simulations testing emerging technology that someday will be used to manage hundreds of thousands of small unmanned commercial aircraft."
- The FAA has "authorized individual test flights in cities before, but never for multiple drones or outside the sight of the operator."

European Commission Blueprint for UAVs

- The European Commission has released a "blueprint" for UAV standards which will "unify laws across the EU" by creating a "common low-level airspace called the U-space that covers altitudes of up to 150 meters."
- U-space UAV air traffic control "will be automated using tools like e-identification and geo-fencing," to be developed through the European Commission, which plans to have the system "up and running" by 2019.

8. Cyber-Security

Cyber-security - 1

- Protection of computer systems from the 1. theft, 2. damage to their
- A. hardware
- B. software
- C. information.
- Plus the protection of computer systems from disruption or misdirection of the services they provide.

Cyber-security - 2

- Nuclear powerplant are disconnected from internet.
- A redirected UAV can be a serious threat to the security.
- Billions of dollars are spent on cyber-security projects.
- Solution: Encryption

9. X-planes

Experimental Aircraft

- In USA: X-1 (1944) to X-57 (2016)
- Building x-plane is expensive.
- Some questions cannot be answered by CFD.
- X-plane lead research centers: AFRC (Air Force), LaRC (Langley), GRC (Glenn),…
- Resist "nice-to-have" requirements, to reduce cost.
- Weight drives cost.

Experimental Aircraft

- From X-35 to F-35 (very similar) – some changes came from flight test, not theory.
- X-31 lessons learned is on "YouTube".
- Some lessons cannot be learned from books.
- Enabler technologies are developed.
- https://www.youtube.com/watch?v=x1E3xpePbmA

X-planes

- No:
- 1. anti-ice
- 2. lightning protection
- 3. bird strike
- 4. ejection seat
- Use design margin to eliminate: 1. wind tunnel test, 2. structural test.
- Example: SF = 3 for composite structure.

X-Planes example

- NASA HARV (High Alpha Research Vehicle) F-18
- 3 phases in 10 years
- 1987-1990 (101 flight test)
- 1990-1994 (176 flight)
- 1995-1996 (106 flights)

X-planes

- F-16XL: extensive difference between theory and practice:
- Example 1: theory: 2.5 g, practice: 1.8 g
- Example 2: theory: 199 knot, practice: 288 knot
- F-117
- X-48
- Plus: certified highly modified for test: 1. Gulfstream III, 2. Learjet, 3. F-15B

Latest X-planes

Pegasus X-47B	Northrop Grumman	DARPA, USN		2003	Unmanned combat air vehicle (UCAV)[4]:57
X-48	Boeing	NASA		2007	Blended Wing Body (BWB)[4]:58
X-49 Speedhawk	Piasecki	US Army		2007	Compound helicopter Vectored Thrust Ducted Propeller (VTDP) testbed.[11]
X-50 Dragonfly	Boeing	DARPA		2003	Canard Rotor/Wing[4]:60
X-51 Waverider	Boeing	USAF		2010[12]	Hypersonic scramjet[13]
X-52	—	—	—	—	—
X-53	Boeing	NASA, USAF		2002	Active Aeroelastic Wing[14]
X-54	Gulfstream	NASA		N/A	Supersonic transport[15] in development.
X-55	Lockheed Martin	USAF		2009	Advanced Composite Cargo Aircraft (ACCA)[16]
X-56	Lockheed Martin	USAF/NASA		2012	Active flutter suppression and gust load alleviation
X-57 Maxwell	ESAero/Tecnam	NASA		2016	Low emission plane powered entirely by electric motors[18]

10. UCAV

Manned Aircraft

A-10 Thunderbolt II

F-22 Raptor

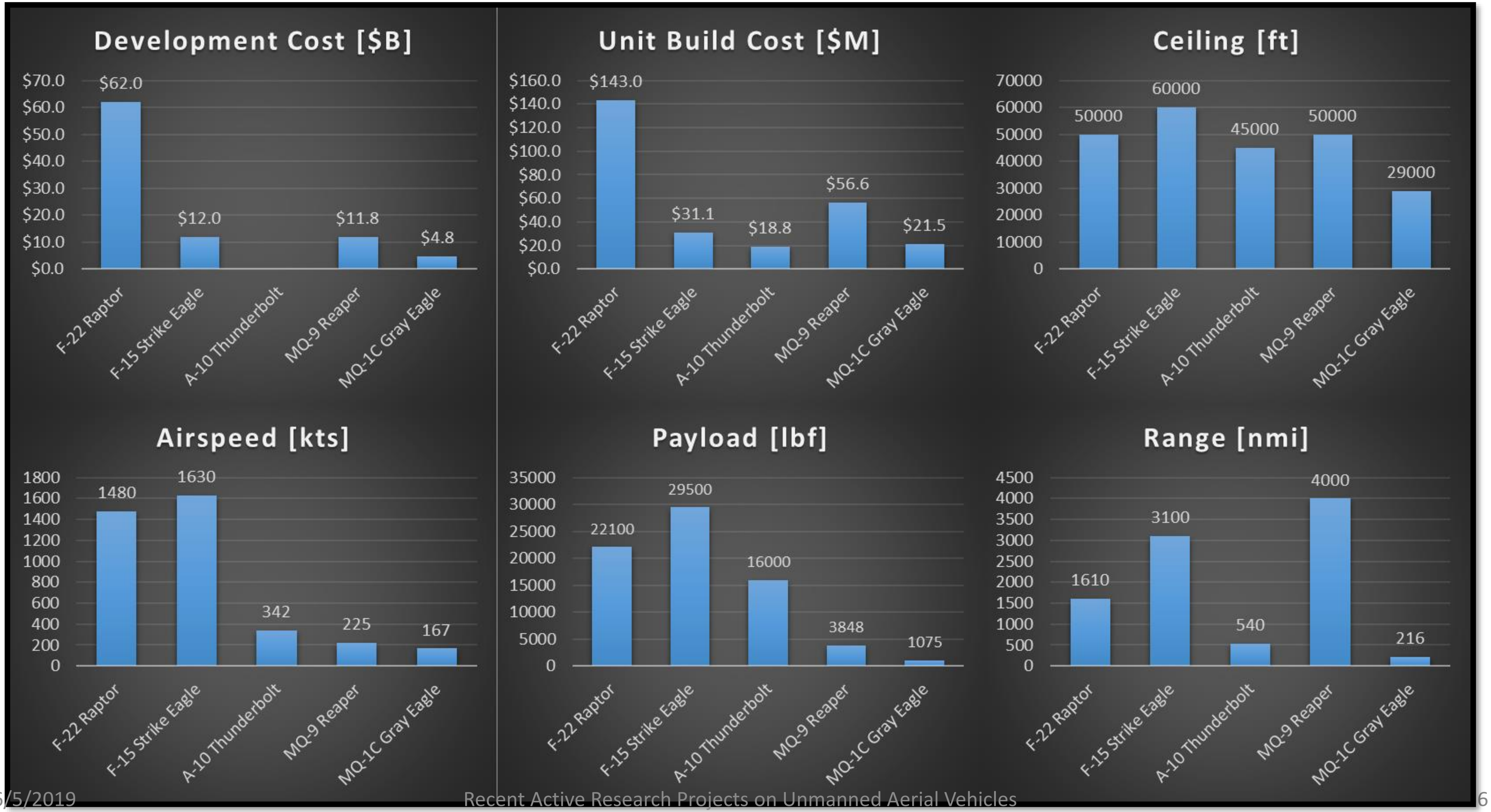
F-15 Eagle

UAVs

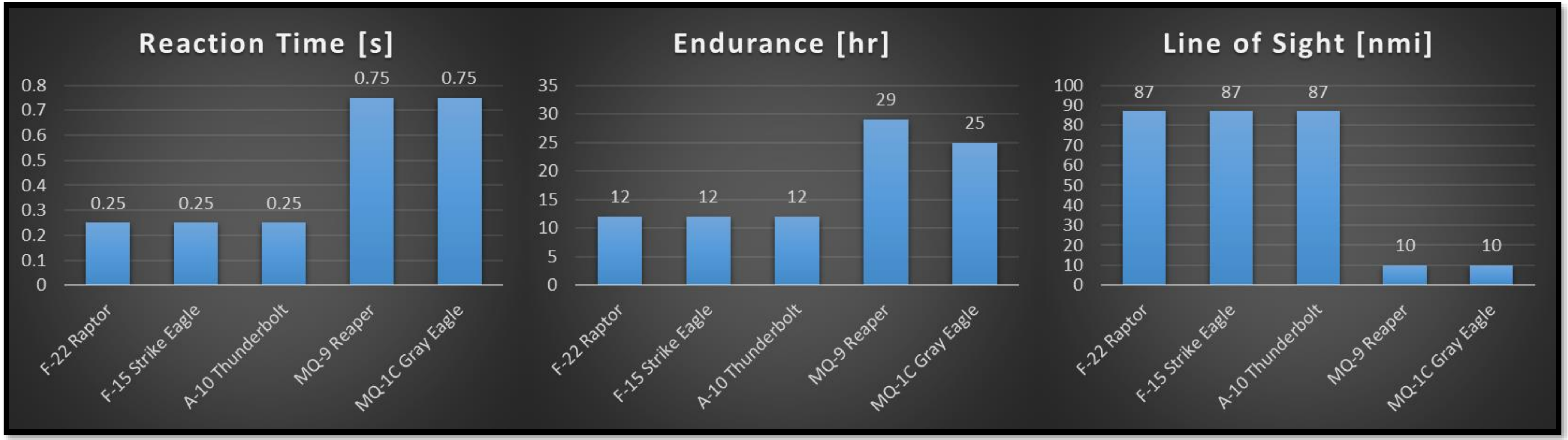
MQ-9 Reaper

MQ-1C Gray Eagle

Cost & Performance Comparisons



Performance Comparisons

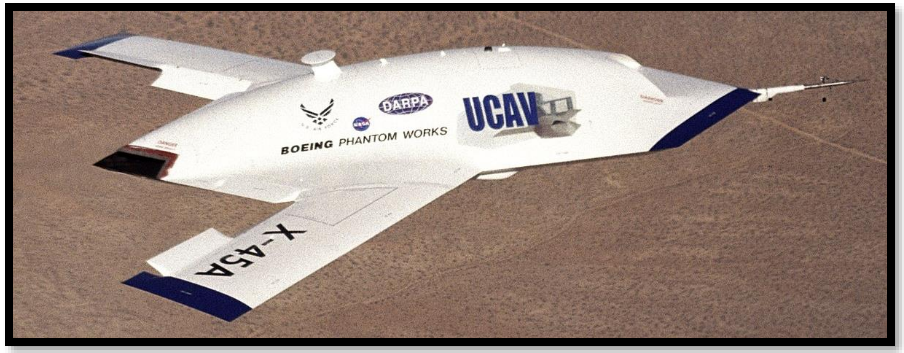


Air to Air Altercations

- 2002 Iraqi MiG-25 intercepted a Predator UAV
  - Both fired missiles at each other
  - MiG-25 evaded but Predator was shot down
- 2012 USAF testing retrofitted F-16's with UAV equipment
  - Flies along a manned aircraft
- 2018 USAF UAV shot down a target UAV
  - First air-to-air kill for a UAV

1. Boeing X-45

- Max alt: 35,000 ft
- Cruise speed: Mach 0.75
- Began project in 1999
- First flight May 2002
- Easily transportable
  - 6 per C-17
- Primarily ground attack munitions
- Program postponed



2. Northrop Grumman X-47

- Started 2001
- Force multiplier
- Joint strike fighter
- Naval implementation
- 600 nmi radius
- First autonomous aerial refueling 2015

China Unveils “Dark Sword” UCAV

- In early 2019, China has unveiled a prototype for its “Anjian (Dark Sword) jet-powered unmanned combat aerial vehicle (UCAV).
- The design features canards, a delta wing, twin slanted vertical stabilizers, and a single engine, and a diverterless supersonic inlet design.
- This UCAV will have a takeoff weight of around 15 tons, a payload of one ton and an operational radius of approximately 1,000 km, and the ability to perform turns in excess of nine G’s.

Summary

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Q and A