Abstract—Drone, remotely piloted vehicle (RPV), remotely piloted aircraft (RPA), remotely operated aircraft (ROA), Unmanned Aerial Vehicles (UAV), or Unmanned Aircraft Systems (UAS) refer to aircraft without a human pilot on board. UAVs are classified based upon the weight, operating altitude and airspeed. The FAA currently requires a Certification of Authorization (COA) and special airworthiness certificate –experimental category for all UAVs to fly in National Airspace. Restrictions limit commercial use of UAS, though they are in use by the military, law enforcement and for university research. Businesses, farmers and others have been clamoring for new UAS regulations from the FAA, which officials say could come as early as the end of 2015.

Safety is paramount for the integration of unmanned and manned aircraft into the United States or national airspace (NAS). This article introduces the issues comparing “seek and avoid” for manned aircraft and “sense and avoid” for unmanned aircraft systems. The largest UAS have all of the safety equipment and capabilities of commercial passenger carrying aircraft, only with ground based pilots and observers. The pilot training requirements for UAS matches or exceeds the requirements for similar categories of manned aircraft. Collision avoidance systems such as TCASII have been used on commercial and military aircraft for years with improved safety outcomes. UAS will require advanced sensors to assure safe operation in NAS.

I. INTRODUCTION

For the United States, the Federal Aviation Administration (FAA) regulates pilots and crews for manned aircraft systems and specifies airworthiness requirements for all categories of air systems from gliders to high performance jet aircraft. The combination of pilot and crew training, aircraft maintenance and ATC procedures has resulted in low accident rates per millions hours of operation as shown in Figure 1.

Despite the terrifying prospect of a mid-air collision, aviation travel is incredibly safe. A person who flew continuously on a jet transport aircraft in today’s environment could expect to survive more than 11,000 years of travel before becoming the victim of a mid-air collision. According to a MIT Lincoln Laboratories report, the number of hours flown annually by jet transport aircraft has more than quadrupled since 1970, but the rate of mid-air collisions over that period of time has dropped by an order of magnitude. The result is that today we can expect one mid-air collision every 100 million flight hours. Ref [4]

Unmanned Aircraft Systems (UAS) are rapidly developing new commercial applications, however, currently all flights require an FAA Certificate of Authorization (COA) to operate in National Airspace. The National Defense Authorization Act (NDAA, Dec. 2011), and its associated Appropriations Act (H.R. 2055, Public Law No. 112-74, Dec. 2011) and the recent FAA Reauthorization and Reform Act (H.R. 658, Feb. 2012) – mandate the Federal Aviation Administration (FAA) to “develop a comprehensive plan to safely integrate commercial unmanned aircraft systems into the national airspace ... the plan shall provide for the safe integration of civil unmanned aircraft systems into the national airspace system as soon as practicable, but not later than Sept. 30, 2015.”

Collision Avoidance Systems (CAS) for aircraft flying in the United States National Air Space has been researched, developed, analyzed and improved since the 1960s and 1970s. Massachusetts Institute of Technology, MITRE, United States Air Force, Boeing and the Federal Aviation Administration have worked on systems, algorithms and procedures to reduce mid-air collisions.

The Federal Aviation Administration (FAA) has authorized transformation of the United States Air Traffic Control System from a radar based technology to a system utilizing Global Positioning System (GPS) Technology over the time period...
2013-2020 which will require all aircraft, commercial and general aviation, operating in controlled airspace to be in compliance on January 1, 2020. Aircraft transponders will be upgraded from Mode-C, radar based, to Mode-S, GPS based which will provide precise position, altitude, velocity, and flight direction. Aircraft equipped with ADS-B receivers and multi-function displays (referred to as “glass cockpit” equipment) will connect to ground stations to provide current weather and aircraft traffic graphically displayed for increased safety. The FAA Next Generation Air Transportation System is a transformative change in the management and operation of how we fly. NextGen enhances safety, reduces delays, saves fuel and reduces aviation’s adverse environmental impact.

The benefits of the NextGen Flight Control System include the dollar value of savings in fuel, time, net reduction in CO2 emissions, and the consumer surplus associated with the additional flights accommodated because of the rule. The estimated quantified benefits of the rule range from $6.8 billion ($2.1 billion at 7% present value) to $8.5 billion ($2.7 billion at 7% present value).

The FAA must not only address current congestion, but also be poised to handle future demand that will surely return as the nation’s economy improves. The FAA has been developing the Next Generation Air Transportation System (NextGen) for the purpose of changing the way the National Airspace System (NAS) operates. NextGen will allow the NAS to expand to meet future demand and support the economic viability of the system. In addition, NextGen will improve safety and support environmental initiatives such as reducing congestion, noise, emissions and fuel consumption through increased energy efficiency.

The benefits of ADS-B In are already being realized at over 100 airports where Traffic Information Service-Broadcast and Flight Information Service-Broadcast are supported by NextGen ground and satellite equipment. One concern for General Aviation is the equipage cost which has been estimated to be over $20,000 and may not justify the benefits received for non-commercial aircraft owners. FAA plans to reduce the number of Secondary Surveillance Radars in the time period of 2020-2035 for additional operating and equipment cost savings. However, the business case for ADS-B Out for aircraft-to-aircraft data links has not been established and would benefit commercial airlines since delays, congestion, energy efficiency have less effect on General Aviation. Data link issues such as 1090 MHz ES not supporting Flight Information Services-Broadcast will reduce the benefits and this data link is the common standard used by aircraft in international air travel. Finally, military aircraft must comply with NextGen flight control and there are Mode-S transponder tests that are not supported by the avionics used in military aircraft.

II. GENERAL COMMENTS

Federal Aviation Regulations (FAR) and Aeronautical Information Manual (AIM) are updated annually under the authority of Title 14 of the Code of Federal Regulations (14CFR), Transportation Security Regulations to become the basis for all aspects of National Air Space control in the USA. All aircraft operating in NAS must be registered and have an airworthiness certificate as well as being flown by pilots who meet the FAA requirements. Unmanned Aerial Vehicles present new challenges for operating in NAS.

A. Abbreviations and Acronyms

ATC-Air Traffic Control
1090 Extended Squinter -data link operating at 1090 MHz
ADS-B-Automatic Dependent Surveillance-Broadcast
AGL - Above Ground Level
CAS-Collision Avoidance Systems
FAA- Federal Aviation Administration
FIS-B- Flight Information Service-Broadcast
GPS- Global Positioning System
ILS- Instrument Landing System
KIAS - Knots (nautical miles per hour) Indicated Air Speed (1nm =1.15 sm)
MSL - Mean Sea Level
NAS-National Air Space, specifically in the United States
NextGen- FAA program to upgrade the Flight Control within the United States over the time period 2013-2020
RA- Resolution Advisory
TA- Traffic Advisory
TCAS- Traffic Alert and Collision Avoidance System
TIS-B-Traffic Information Service-Broadcast provides real time weather briefing for pilots
TSO- is a Technical Standard Order that specifies the minimum performance standard issued by the FAA for certain items used on civil aircraft
UAT-Universal Access Transceiver data link Equipment operating on the Frequency of 978 MHz.

Accident Rates and Onboard Fatalities by Year

Figure 1 Aircraft Accident Rates and Fatalities by Year[1]

III. MANNED AIRCRAFT SYSTEMS OPERATION

Flights in controlled airspace may be in Visual or Instrument Metrological Conditions (VMS or IMC). During VMC operation and as conditions permit, pilots and crew are required to visually “seek and avoid” other aircraft by performing sector scans to detect oncoming aircraft. Aircraft
operation in IMC requires an Instrument Flight Rating (IFR) and an approved flight plan showing the route and check-in waypoints for the flight plan that will be activated before departure. All aircraft operations in Class A airspace, which is above 18,000 feet, require an IFR rating and a flight plan.

IFR flights are typically routed from VHF Omnidirectional Range (VOR) stations near airports to enroute Victor airways, that may not be the shortest distance between the departure and the destination. Departure and arrival procedures with holding patterns are designed to provide buffers to achieve traffic spacing of 3 miles for aircraft operating within 40 miles of the radar antenna site, 5 miles between aircraft operating over 40 miles from the radar antenna site and 1,000 feet vertical separation, as required for safety per Aeronautical Information Manual paragraph 4-4-11. Precision instrument approaches are provided by the FAA as Terminal procedures for each airport that have the required equipment to support GPS, ILS or Precision Approach Radar (PAR) approaches that provide horizontal and vertical guidance.

For aircraft operating in VMC conditions in Class B airspace, the maximum airspeed is 200 knots. Knowing that Distance = rate * time, for two aircraft on a direct collision course at the same altitude with minimum spacing of 3 miles, the short time to crash is only 23.5 seconds! This emphasizes the importance of “seek and avoid” during flights operating in high density traffic areas such as terminals in Class B airspace.

The aircraft position accuracy is validated from a surveyed ground location and the position transmitted from the ADS-B system with equipment as shown in Figure 2. The aircraft position transmitted shall be within the allotted NACP accuracy limit. For example, if the aircraft reports a NACP = 8, the ADS-B position should be within 92.6 meters, 0.05 nm. If the aircraft reports a NACP = 10, the ADS-B position should be within 10 meters. See Reference [2] appendix I for a complete list of NACP values. If the transmitted position accuracy is smaller or equal to the resolution of the test equipment, it is acceptable to use plus or minus one Least Significant Bit as the pass/fail criteria. Vertical aircraft is validated by a similar test.

The barometric altitude transmitted from the ADS-B system shall be accurate to within 125 feet. If the aircraft has a transponder installed and must also be shown that the ADS-B barometric altitude matches the transponder barometric altitude.

Traffic Alert and Collision Avoidance System (TCAS) functions, as shown in Figures 2 and 3, is an advisory system consisting of software and hardware to provide a warning system that is independent of the ATC radar or GPS tracking system. TCAS issues traffic alerts and Resolution Advisories when an imminent collision is projected. TCAS II was designed to operate in traffic densities of up to 0.3 aircraft per square nautical mile (nmi), i.e., 24 aircraft within a 5 nmi radius, which was the highest traffic density envisioned over the next 20 years [5].

TCAS detects incoming aircraft called intruders that penetrate a pre-defined airspace around the ownship aircraft. Initially, a traffic alert is issued and when a mid-air collision is projected, a Resolution Advisory is given. For example, during VFR flight, the correct evasive action to be taken when another aircraft flying at the same altitude, is on a head-on collision course, then both pilots are to immediately turn right 90 degrees. When both aircraft flying at the same altitude, on a collision course have TCAS systems, a coordinated response will be given for one aircraft to climb and the other aircraft to descend to maintain a safe separation.

IV. UNMANNED AIRCRAFT SYSTEMS OPERATION

Unmanned aircraft systems (UAS) are a disruptive, rapidly developing technology with “the Worldwide UAV Market to Top $80 Billion by 2025” according to Ramon Lopez/Editor, AT’s Daily Brief. Many applications will benefit our society but invasion of personal privacy remains a concern. On April 8, 2014, the Aircraft Owners and Pilot Association (AOPA) was among 33 organizations calling on the FAA to step up its plans for integration of UAS into the national airspace system—action that in the first decade would create 100,000 jobs and $82 billion in economic activity, they said.

Randy Willis, air traffic manager of the FAA UAS Integration Office, told attendees at the UAS Action Summit in June 2014 in Grand Forks that there are currently 675 authorizations for UAS to fly in the National Airspace System, with 226 more applications pending.

The U.S. Congress has made a mandate to the Federal Aviation Administration (FAA) to “develop a comprehensive plan to safely integrate commercial unmanned aircraft systems into the national airspace by September 30, 2015”. This presents a significant challenge to the aviation community, since safety is paramount for all FAA equipment and procedures and this is a short time-frame to develop an integration plan that has assessed and mitigated the major risks of integrating unmanned aircraft operating in National Airspace. A major issue for Unmanned aircraft operation is the protection of a person’s privacy since the unmanned aircraft may be equipped with visual and infrared cameras that may be used for unauthorized surveillance. Well known, is the fact that Paparazzi have infringed on people’s privacy which in some cases, have resulted in injury and death, e.g. Princess Diana.

Unmanned aircraft may operate in autonomous mode or be remotely piloted using a data link to provide control and take appropriate action when a traffic alert or Resolution Advisory occurs. The response procedures for evasive actions would be similar for piloted and remotely piloted aircraft.

UAVs operating in autonomous mode require precise knowledge of the Concept of Operations, operating environment and uncertainty of responses to unknown conditions such as false alarms and system failures. [6]. Table 1 shows the Unmanned Aircraft System categories by weight, typical maximum altitude and speed as defined by the U.S. Department of Defense (DoD).
TABLE I. UAS CATEGORIES PER DoD

<table>
<thead>
<tr>
<th>UAS Category</th>
<th>Max. Gross Takeoff Weight (lbs.)</th>
<th>Normal Operating Environment (Feet)</th>
<th>Speed KIAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>0-20</td>
<td>&lt;1,200 AGL</td>
<td>100</td>
</tr>
<tr>
<td>Group 2</td>
<td>21-55</td>
<td>&lt;3,500 AGL</td>
<td>&lt;250</td>
</tr>
<tr>
<td>Group 3</td>
<td>&lt;1320</td>
<td>&lt;18,000 MSL</td>
<td>any</td>
</tr>
<tr>
<td>Group 4</td>
<td>&gt;1320</td>
<td>&lt;18,000 MSL</td>
<td>any</td>
</tr>
<tr>
<td>Group 5</td>
<td>&gt;1320</td>
<td>&gt;18,000 MSL</td>
<td>any</td>
</tr>
</tbody>
</table>

Unmanned aircraft must use “Sense and Avoid” which is a total dependence upon sensors, algorithms and hardware functions to provide alerts and warnings. Collision avoidance is considered a key enabler for UAV integration, however, without an on-board pilot, the implementation will be a different version from TCAS, since pilots can monitor collision advisories and ATC radio communications to determine safe and appropriate actions to be taken. The Pilot-in-Command (PIC) is ultimately responsible for the safety of the aircraft, crew and passengers. The UAS PIC/operator certification is equivalent to the FAA private Pilot airplane with an instrument rating and valid Class II medical certificate. The FAA endorsed or military Observer training for the ground crew, must maintain line of sight of the UAS, other aircraft, obstructions and weather since flight rules currently are the same for UAS and manned aircraft operating in NAS.

Reference [7] lists performance comparisons for Multicopter or Quadcopter, Fixed Wing and Parachute Aerial Vehicle UAS. The Group 4 and 5 category UAS have all of the safety capabilities of commercial passenger aircraft but group 1-3 UAS have strict power and weight limitations which reduce the onboard safety equipment. Conversely, due to kinetics, the lighter UAS in group 1 may cause the least damage to other aircraft and property.

The Federal Aviation Administration announced December 30, 2013 that six states will host test sites for drones, a major step toward allowing the commercial use of drones in U.S. skies. The six UAV test site locations are the University of Alaska; the State of Nevada; Griffiss, International Airport in Rome, N.Y.; the North Dakota Department of Commerce; Texas A&M University’s Corpus Christi campus; and Virginia Tech University in Blacksburg. “These test sites will give us valuable information about how best to ensure the safe introduction of this advanced technology into our nation’s skies,” said U.S. Transportation Secretary Anthony Foxx in a statement.

- Agricultural monitoring and border surveillance, local crime scene investigations, search and rescue missions.
- Disaster response (e.g., wildfires and floods), military missions training with small UAS having the greatest growth potential.
- Concerns - how UAS will impact existing aviation, especially in terms of safety, privacy, frequency crowding, and airspace congestion.
V. CONCLUSIONS AND THE FUTURE

Integration of manned and unmanned aircraft systems poses a serious safety risk to air traffic and to persons and property on the ground that may be hit after a mid-air collision. The best solution may be to allocate new airspace to unmanned aircraft that is separate from airspace that is used by commercial and general aviation.

Air travel is expected to outgrow the current radar based air traffic control system’s capability at the nation’s busiest Class B airports and the surrounding airspace including Class A enroute airways. The FAA has begun rule making for integration of UAS into NAS but many safety and logistic issues remain to be solved.

Carefully constructed regulations are required for the integration of unmanned aircraft systems into the US airspace. The safety trade-off decisions are dedicated airspace for UAS, corridors for UAS or full integration of UAS into all NAS which presents the most significant challenge to pilots and avionics equipment companies.

ACKNOWLEDGMENT AND DEDICATION

This paper is dedicated to the over 70,000 commercial Airline Transport Pilots and FAA personnel who keep American skies safe and provide air transportation for leisure travelers, industry, academics and government employees.

REFERENCES