# Unmanned aviation traffic forecast

**L. R. Newcome**
Principal Engineer,
Modern Technology Solutions
USA

## ABSTRACT

"*Prediction is very difficult, especially if it's about the future.*"
Niels Bohr

The pace at which new technologies are assimilated into society is driven by trends in the regulatory, budgetary, and societal environments in addition to the pace of technology development itself. This study merges trends in these areas to develop an integrated forecast of the levels to which unmanned aviation can be expected to emerge in the military, air cargo, business, general aviation, and airline aviation segments over the coming 40 years. One out of every 80 aircraft on an instrument flight rules (IFR) flight plan over the US are anticipated in this forecast to be unmanned by 2025 and two out of nine (18 of every 80) by 2050. Portions of this study were originally researched in 2005 in support of the Federal Aviation Administration's (FAA's) Joint Planning and Development Office (JPDO) for planning the Next Generation (NextGen) air traffic system and later presented at the 23rd Bristol UAV Systems Conference.

## 1.0 INTRODUCTION

The pace at which new technologies are assimilated into society is driven by trends in the regulatory, budgetary, and societal environments in addition to the pace of technology development itself. This study merges trends in these areas to develop an integrated forecast of the levels to which unmanned aviation can be expected to emerge in the military, air cargo, business, general aviation, and airline aviation segments over the coming 40 years. Portions of this study were originally researched in 2005 in support of the Federal Aviation Administration's (FAA's) Joint Planning and Development Office (JPDO) for planning the Next Generation (NextGen) air traffic management system.

Forecasts are often made to induce a desired effect, such as to spur growth in a particular market; Moore's Law is such an example. This forecast is not. Indeed, its original intent was somewhat the reverse—to catch up with a growing market by providing an objective estimate of unmanned air traffic growth to the US Government entity responsible for charting the expansion of the national airspace infrastructure needed to support its US$640,000,000,000 air traffic industry over the coming decades. To create that estimate, it looked at five trends and their 'forcing functions' (in parentheses):

- Air traffic density (regulatory), based on FAA documentation;
- Enabling technologies (technology), based on computer industry trends;
- Unmanned aircraft acquisition (budgetary), based on DoD documentation;
- Aircrew size (technology), based on aviation history; and
- Technology adoption (social), also based on history.

**Paper No. 3368**. Manuscript received 6 November 2008, revised version received 23 February 2009, accepted 11 March 2009.

https://doi.org/10.1017/S0001924000003122 Published online by Cambridge University Press

Once these five trends were characterised, they were used to create generalised forecasts of five aviation user segments by applying the prediction process formulated by H.G. Wells in 1902[1]. The tenets of this process are:

- Clockwork universe (assume prediction possible)
- Inductive thinking (gather data and relations)
- Law of large numbers (identify central tendencies)
- Science as a predictive discipline (use math, logic, facts)
- Future-oriented mindset (identify impact areas)
- Change drivers (identify possible drivers)
- Disciplined web of implications (pursue casual chains)

## 2.0 TREND 1: TRAFFIC DENSITY

The relative impact on today's National Airspace System (NAS) in the US by its five major user segments—airlines, air cargo, general aviation, business, and military—is shown in the accompanying 2000 pie chart (left pie) (Fig. 1) as percentages of IFR air traffic volume handled by traffic control centres. This accounts for virtually all airline, cargo, military, and business flying, but less than half, and perhaps as little as 10 percent, of general aviation, with its high proportion of visual flight rules (VFR) flying. As reference points, the combined airline and cargo segments (blue and yellow wedges) represent 5,300 aircraft flying 17·8m hours in 2000 and 12,500 aircraft flying 43·3m hours in 2025. Based on the rates at which each of these segments is changing, the Federal Aviation Administration (FAA) forecast a similar pie chart (middle pie) for 2025[3]. The author created the 2050 pie chart (right pie) by straight line extension of the trends provided by the FAA's 2000 and 2025 data.

The degree to which unmanned aviation will impact NAS operations over the next 25 to 50 years depends on the timing and level of its acceptance in each of these segments. 'Acceptance' will need to be composed of not only regulatory[4, 5], but also technical, economic, and societal factors. It is apparent from these diagrams that a large acceptance of unmanned aircraft in the near term by the military or business aviation segments would still not significantly affect NAS operations, whereas limited acceptance of them, even in the far term, in the airline or cargo segments would produce a significant impact. The perspective embodied in this last statement is critical to objectively assessing the potential of unmanned aviation to impact the future infrastructure of the NAS because today's unmanned aircraft community and the FAA are focused almost entirely on only one of these segments, the military. The following discussion attempts to broaden this perspective and quantify the extent to which unmanned aviation will likely impact the NAS in each of these five segments over the coming quarter to half century.

## 3.0 TREND 2: ENABLING TECHNOLOGIES

The emergence of unmanned aviation as a successful segment of the aviation market hinges on advances/decisions occurring in several enabling technologies, such as automating see and avoid, dedicating spectrum, securing communications, and certifying software. One key enabler, an automated see and avoid system capable of avoiding midairs with co-operative as well as non-co-operative traffic, is not presently commercially available. Prototypes of such a system are undergoing flight evaluation today (see the Department of Defense's See & Avoid Flight Demonstration (SAFD) and the See And Avoid Flight Test (SAAFT) experiments, both in 2006, and the ongoing Multiple Intruder Autonomous Avoidance (MIAA) project) and should lead to certified systems becoming available in a commercial package within the next five to eight years. The Traffic Collision Avoidance System (TCAS) provides a related capability today, but only for mutually cooperative traffic and is not certified to tie into any flight control systems; its installed price is in the $150,000 to $250,000 range. Only two airline midairs (Germany, 2002 and Brazil, 2006) have occurred since the introduction of TCAS following the 1986 midair over Los Angeles, and it is noteworthy that one of those accidents involved a pilot acting contrary to his TCAS advisory and the other a pilot not having his TCAS turned on - both human negations of equipment built to protect them.

When the Los Angeles Air Route Traffic Control Center (ARTCC) lost its voice switching and control system for 3 hours on 14 September 2004, ten of the 800 airborne flights in its sector violated FAA separation standards in the first 15 minutes, underscoring the single point failure implications of ground communications in today's NAS. Two points emerge from this incident, 1) human and TCAS see and avoid capabilities, even together, are still insufficient without ground cueing to ensure safety and 2) this would have been a non-incident in the Free Flight environment being developed by the FAA. TCAS is an interim measure, and the human eye is inadequate in certain collision scenarios, especially as air congestion increases. An automated, non-cooperative see and avoid capability is critical to manned aviation safety; it is not solely a requirement for unmanned aviation.

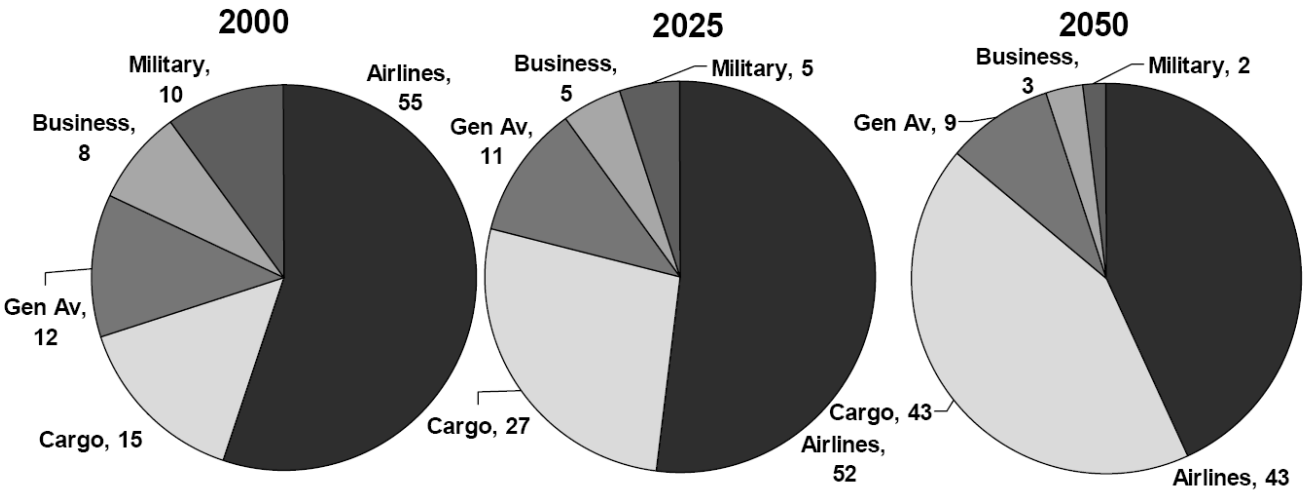



Figure 1. Actual (2000) and forecast IFR traffic by percentage in the United States for 2025 (by FAA[3]) and 2050 (by author).

https://doi.org/10.1017/S0001924000003122 Published online by Cambridge University Press

Of all phases of flight, landing is the most demanding of piloting skills and, by extension, the most challenging to automate in unmanned aircraft. Category 3 ILS-coupled auto-land, a ground-centric capability at selected major airport runways, has been available to most airliners for nearly two decades. More recently, Boeing's and Rockwell Collin's Global Landing System (GLS) has demonstrated an auto-land capability, using GPS combined with ground-based Local Area Augmentation System (LAAS) functionality, for any runway at any airport worldwide. Tests showed the ability to consistently auto-land within 3 feet of runway centreline, even in equatorial regions where GPS signals are least consistent. Both the FAA and Europe's Joint Aviation Authority (JAA) have certified this system. Commercial availability of the Rockwell Collins GLU-925 GPS/LAAS receiver is planned shortly. As it must also be with future see and avoid systems, manned aviation safety was the dominant driver for GLS achieving FAA certification.

The third capability needed, ground operations, has had the least effort undertaken on behalf of unmanned aircraft. However, its implementation can draw on current airport equipment, such as the Airport Surface Detection Equipment (ASDE), as well as the previous two technologies discussed, see and avoid for ground obstacle avoidance and landing for precision taxiing. This capability should be certified and commercially available in the 2015-2020 timeframe, assuming manned airliner ground operations are the dominant push, which is likely given the increasing rate of runway incursions.

Avoidance capabilities will eventually need to be extended to address environmental as well as the aforementioned collision hazards. Pilots today are expected to remain clear of thunderstorms and icing conditions, and to compensate for clear air turbulence, wake turbulence, micro-bursts, atmospheric bores, and such. Unmanned aircraft will have to become similarly (or better) adept at handling these natural and man-made environmental hazards.

If the ultimate end-state of unmanned aviation is to be truly autonomous operation, where 'autonomous' implies a human-equivalent processor replacing the onboard pilot, then the speed, memory, and algorithms composing that processor will need to approach, if not match, those same aspects of the human mind. Algorithms in this context equate to the pilot's thinking patterns, experience, and judgment. The speed and memory aspects are more easily addressed (Fig. 2). Indeed, IBM and the Ecole Polytechnique Federale de Lausanne (EPFL) are jointly developing a mechanical similitude of the human brain to the molecular level. 'Blue Brain' is to become operational on a mainframe computer in 2015.[2, 8] Historically, PCs lag mainframes in speed and memory by 10-15 years, so we should expect human equivalency on our desktops by 2025-2030 (Fig. 3)[7]. This date coincides well with the commercial debut of unmanned aviation (air cargo) forecast later in this paper. Such progress, however, hinges on the maturing of suitable algorithms that can capitalise on these achievements in speed and memory to provide the computer-equivalent of judgment.

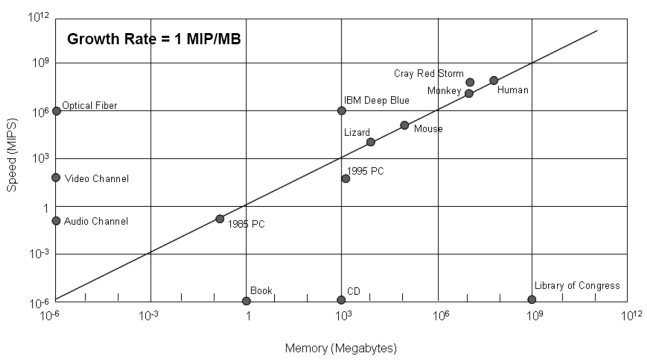



Figure 2. Speed *vs* memory trend in computers.[7]

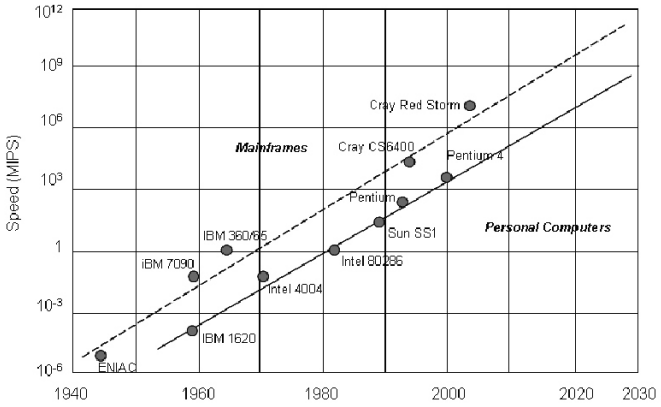



Figure 3. Mainframe and PC speed trends.[7]

## 4.0 TREND 3: UAS ACQUISITION

Today, the US military operates over 350 unmanned aircraft potentially capable of IFR operations and some 10,000 smaller, model airplane-size (VFR-only) ones.[9]. The former represent 2·5 percent of all military aircraft (some 14,500). By 2010, DoD plans to nearly double this number and should increase it by 450 percent over the coming decade, as the Army's Future Combat System and the Navy's Littoral Combat Ship come on line, both planned to be heavy employers of unmanned aircraft. These and various other unmanned programs' acquisition plans provide a clear upward trend for the numbers of unmanned aircraft expected to be in the military segment by certain dates, as shown in Table 2. This trend indicates an annual growth rate of 11·5 percent in airframes.

Two reasonable assumptions for purposes of making forecasts later are 'buried' in this percentage. The first is that the percentage of growth in military airframes is directly proportional to the percentage of growth in military IFR flights. This assumption is ratified in the airline, air cargo, and general aviation segments by aircraft fleet size and flight hour growth rates generally being within a few tenths of a percent of each other[3]. A second assumption is that the total number of aircraft operated by the military remains constant over the period of the forecast, when in fact its long term trend shows a decrease as older model manned aircraft inventories are replaced by smaller inventories of newer models, as has happened for recent aircraft, e.g., 21 B-2s for 160 B-52s and 183 F-22s for 700 F-15s. This decline would inflate the percentage of unmanned military aircraft.

## 5.0 TREND 4: CREW SIZE

Pilot unions accepting the removal of their members from airliner cockpits will arguably be the strongest challenge faced by unmanned aviation being accepted in the passenger-carrying role. History is against them, however. Figure 4 illustrates the steady decline in cockpit crew size since the introduction of passenger service.

**Table 2**
**Numbers of unmanned aircraft to be in the military segment by 2017**

| Service | 2004 | 2007 | 2010 | 2015 | 2017 |
|---|---|---|---|---|---|
| Air Force | 80 | 107 | 165 | 250 | 321 |
| Army | 130 | 232 | 430 | 850 | 1,004 |
| Navy/Marine Corps | 35 | 18 | 75 | 175 | 258 |
| Coast Guard | 0 | 0 | 5 | 20 | 25 |
| Totals | 245 | 357 | 675 | 1,290 | 1,608 |

https://doi.org/10.1017/S0001924000003122 Published online by Cambridge University Press

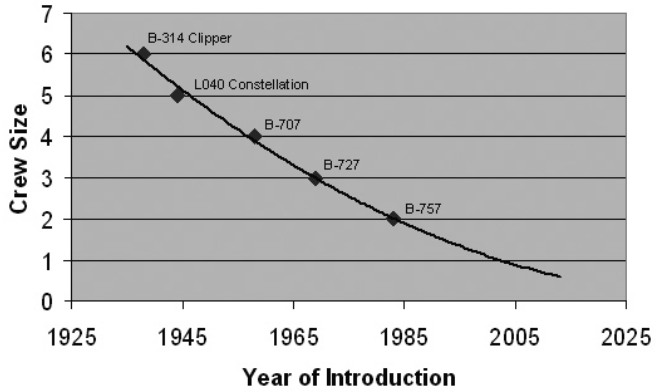



Figure 4. Trend in crew size on commercial airliners.

This trend has occurred due to technical advances (inertial navigation systems eliminated navigators, etc.) and its acceptance eased by the thin (or negative) profit margins and frequent pilot layoffs inherent in the airline industry. The trend predicts zero cockpit crew sizes in the post-2020 timeframe. While that may be realistic for air cargo, various factors will likely push this date out by a decade or two for airliners, but 'roboliners' will likely debut sometime in the 2025-2050 period. Before the two-pilot crew gives way to the one-pilot one (or even skips this step), pilot unions will undoubtedly raise the spectre of the single pilot being incapacitated inflight by food poisoning or heart attack. Unfortunately, pilot suicides (SilkAir, 1997; EgyptAir, 1999) have proven to be a more frequent occurrence than medical incapacitation. Robots are not subject in either case.

The recent experience of the railroad industry in adopting remote control locomotives (RCLs) for use in railyards is instructive on this point. After a decade of fierce union opposition, some 10 percent of US locomotives are RCLs. In that time, the accident rate in railyards (which itself accounts for half of all US rail accidents) has been cut in half, meaning total rail accidents have been reduced by 25 percent. Railyard-incurred injuries have been reduced by 57 percent, and the average cost per railyard accident by 34 percent. Union opposition, originally predicated on accident and injury rates increasing, has now shifted to expressing concern about the ergonomics of the RC-equipment harness and electromagnetic radiation hazards from the RC transmitters (less than from cell phones). For those who associate technology leadership with America, European railyards operate three times as many RCLs, and Canada began using RCLs a decade before the US[6, 10].

Public acceptance of roboliner flight is inevitable and will not be the major barrier envisioned by many in the aviation community. When elevators were introduced in department stores, elevator operators were employed to reassure the shopping public of their safety until their reliability was established in the public's mind. Has the reliability of elevators changed significantly between then and now? No, but the public's acceptance of them has. Similarly, the flying public has already accepted the elimination of registered nurses as flight attendants and the inclusion of women as pilots. When both pilots of a recent US Airways flight reported for duty intoxicated, their flight's passengers still filed onboard without questioning the sobriety of their replacements. When boarding, most passengers never even look left into the cockpit to see if the pilots are there. Those same passengers will unhesitatingly board a driverless airport tram to take them to other terminals. The fact that roboliners will not be subject to hijacker or terrorist demands may even make them preferable in some travelers' eyes. The flying public trusts the FAA to ensure the airlines are safe, so the FAA, not the public, may prove to be the 'acceptance barrier.' Once unmanned cargo aircraft demonstrate a record of safe, reliable flight over, perhaps, a decade, roboliner acceptance should follow.

## 6.0 TREND 5: TECHNOLOGY ADOPTION

Manned and unmanned aviation tend to regard themselves as two separate (some would say incompatible), non-overlapping communities within aviation. The relationship between them should be viewed from the following perspective to gain a better perspective on how the unmanned side will impact the NAS in the future, because in the near future the distinction between the two will become blurred. Is an aircraft 'unmanned' if the only people onboard are passengers?

Aviation history has exhibited a long, continuing trend of pushing technology to automate the piloting function since its start in 1903. Only eight years after the Wright brothers flew (1911), Sperry demonstrated a prototypical autopilot, whose further development (by Sperry's company and others) produced the first commercial autopilots by 1930, 19 years later. These autopilots served as relief pilots, a desirable adjunct to the human pilot onboard but not a flight critical one, but with that step, pilots began the transition from continuously flying their aircraft to occasionally being flown by it.

Shortly after WW2, auto-trim capability was added, relieving pilots of another function. NASA began testing digital autopilots, in which a computer acted as a translator between the pilot and the aircraft's control surfaces in a F8U in the late 1950s and employed this new 'fly-by-wire' (FBW) technology in its Mercury capsules (1961-63) in case the astronaut became incapacitated. By the mid-1970s, the autopilots in the F-16 and Concorde had evolved into FBW flight control systems, necessitated by the numerous, continuous control inputs that were beyond the abilities of their human pilots. FBW systems moved into airline cockpits on a wholesale basis when the Airbus A320 entered service in 1988 without a moment's hesitation from the passenger public. Without FBW, these aircraft would be uncontrollable, so pilots now transitioned from flying their aircraft to being flown by it.

The next step in this evolution occurred in 1986, when Boeing's Condor made the first fully automated flight from takeoff to touchdown without a pilot onboard, a capability that became productionized in Global Hawk 17 years later. Manual piloting in any phase of flight had been demonstrated as unnecessary. Notably, in each example, the time from first demonstration to widespread use occurred over a span of 17-19 years (Fig. 5).

The final step in this evolution will occur when automated aircraft are trusted to carry man as a passenger. The final enabling technologies, autoland and see and avoid, are becoming commercially available in the next few years, again after some 20 years of development. Whether as a stunt or as a serious demonstration, that milestone will almost certainly occur within the next 10 years.

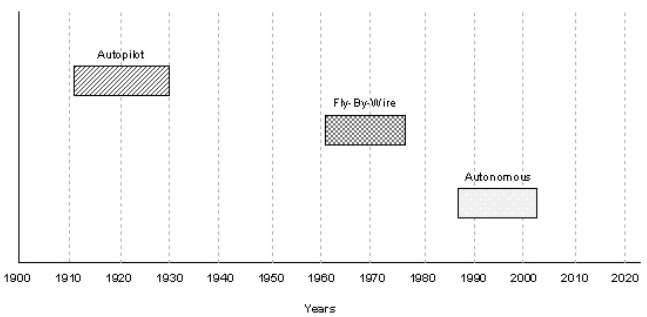



Figure 5. Evolution of pilot automation, from demonstration to production.

https://doi.org/10.1017/S0001924000003122 Published online by Cambridge University Press

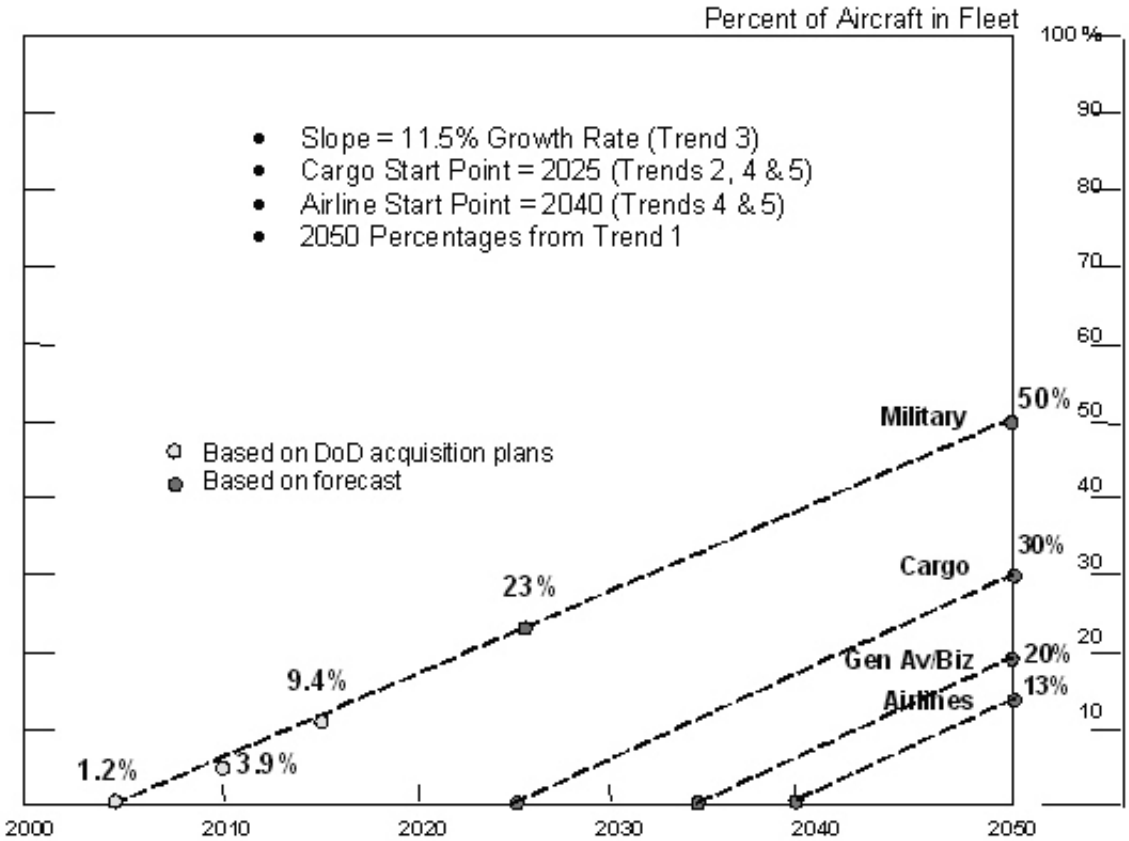



Figure 6. Percentage of unmanned aircraft in IFR flight by year.

## 7.0 CREATING THE FORECAST

These five trends form the basis for the forecast presented in Fig. 6. Trend 3 was used to establish an initial growth rate for unmanned IFR airframes, and by presumption, unmanned IFR traffic. Trend 1 was used to establish the relative proportions of IFR traffic among the five user segments as they evolve out to 2050. Trends 2, 4, and 5 were then used to predict the period during which the first follow-on (non-DoD) traffic segment will start using unmanned aircraft. Trends 4 and 5 were then employed to justify the periods when subsequent segments begin unmanned IFR operations. These latter segments were assumed to grow at the same rate, i.e., in parallel, as that demonstrated by the military segment in Trend 3.

H.G. Wells' prediction process, described earlier[1], was applied in the following manner:

- Clockwork universe (assume prediction possible)

  We assumed unmanned aviation will flourish, i.e., emerge as a widespread aviation capability.
- Inductive thinking (gather data and relations)

  We linked UAS budget plans, air traffic estimates, airliner crew sizes, and computer advances.
- Law of large numbers (identify central tendencies)

  We leveraged recent US-wide aviation traffic percentages and worldwide adoption of RCLs.
- Science as a predictive discipline (use math, logic, facts)

  We extrapolated from historical numbers (e.g., computer speed, technology adoption lag time).
- Future-oriented mindset (identify impact areas)

  We identified future scenarios that could promote unmanned aviation (e.g., commuter gridlock).
- Change drivers (identify possible drivers)

  We examined regulatory, economic, societal, and technological drivers in aviation and robotics.
- Disciplined web of implications (pursue casual chains)

  Smarter computers enable increased automation; automation use is increasing in transportation.

Figure 6 can be used to forecast the percentage of IFR traffic that will be unmanned for each of the five aviation segments between the present and 2050 The conservative assumption in Fig. 6 is that once a technology takes root in one segment (e.g., military) and is then adopted into another segment (e.g., air cargo), it will grow at the same rate, but history shows that adoption rate accelerates in follow-on markets. This tendency could raise the forecast percentages for the four follow-on (non-military) segments.

### 7.1 Forecast: airline traffic

The major challenges to airlines accepting unmanned aircraft (as in passenger flight without a pilot onboard) are technology availability, pilot unions acceptance, and customer acceptance. The major technical hurdles are automating see and avoid, approach and landing, and ground operations and have been previously described. The airline segment is driving the few remaining enabling technologies needed by unmanned aviation to enter into any

https://doi.org/10.1017/S0001924000003122 Published online by Cambridge University Press

segment; the last of these technical barriers (ground operations) should be overcome by 2015-2020. Union and public acceptance should follow in 2025-2050 once the FAA allows it. The airline segment presents the superset of barriers to unmanned acceptance, but each barrier will have been overcome one at a time in other segments by the time roboliners appear. Once the technical hurdles are overcome (2015-20), airline industry economics will dictate when and how quickly this transition occurs.

***2025/2050 Forecast:*** Based on Figs 1 and 6, of the airline segment's 52 percent of total IFR air traffic handled in the NAS in 2025, 0 percent will be unmanned, or 0 percent of the total. By 2050, its IFR share will decline to 43 percent, roboliners will have been introduced, and their portion will constitute 13 percent of airline IFR operations, or 5·6 percent of total IFR traffic.

### 7.2 Forecast: air cargo traffic

Well recognised within unmanned circles as its 'great commercial hope,' air cargo freighters seem to possess all the attributes — long, dull, over water missions, hubs at secondary (Class C) airports — and none of the drawbacks — no passengers — desired to initiate unmanned operations. They present only two of the three major challenges inherent in the airline segment, technology availability and union acceptance, and the latter as a much lower hurdle. The technology challenges are the same as those postulated for the airlines, and indeed the cargo segment is an equal driver for the auto-land capability. The cargo segment will likely begin transitioning to single pilot operations in the 2010 decade and unmanned operations in the 2020 decade, initially on long haul, transoceanic routes, followed by the longer overland routes, then the remainder. American (NAS) unmanned cargo operations will probably follow their introduction on Asian routes by 5-10 years. Asia is a more likely proving ground because approaches to its major airports are over water (Singapore, Hong Kong, Narita, Inchon) and the air cargo market is experiencing its greatest growth in that regional market.

***2025/2050 Forecast:*** Based on Figures 1 and 6, of the air cargo segment's 27 percent of total IFR air traffic handled in the NAS in 2025, 0 percent will likely be unmanned, or 0 percent of the total volume by 2025, although unmanned air cargo operations should begin around this timeframe. By 2050, its IFR traffic share will grow to 43 percent, of which its unmanned portion should constitute 30 percent, or 12·9 percent of the total.

### 7.3 Forecast: general aviation traffic

Many general aviation pilots fly for the personal satisfaction of flying, i.e., there is no motivation in this segment currently to transition to unmanned operations. Indeed, the present position of the Aircraft Owners and Pilots Association (AOPA) (as an organisation, not necessarily its individual members) is that unmanned aviation will pose a threat to the safety of its pilots. It fears the current generation of UASs (non see-and-avoid equipped), if allowed routine access to the NAS, raising the potential for mid-airs with its members as much as fearing the superior see-and-avoid capabilities of future UASs raising the regulatory requirement for (and the incumbent expense for) such equipage. Ironically, the highest midair rate of any segment occurs among general aviation pilots (one every 2 million hours), making them the primary beneficiary of the see-and-avoid technology being developed for unmanned aircraft. The intersection of general aviation and unmanned interests therefore occurs in the potential for reducing mid-airs, making the major challenge in this segment the previously addressed one of see-and-avoid technology. Making the cost of such a system low enough is key to acceptance by the general aviation population.

There is, however, a potential future development in general aviation that would drive a significant portion of it to embrace unmanned operations. NASA's Personal Aircraft System (PAS) program envisions a robust market for airborne commuters, i.e., non-pilots and families being flown short to medium distances in 'smart planes' (note the psychological branding) within a generation. PAS is exploring the hardware and software requirements for such aircraft now and finding few technical hurdles enroute. Transitioning harried commuters from their one-dimensional worlds to one of three dimensions may seem quite a leap, but the subject of 'mini-jets' presently seems to have equal or greater credibility than do unmanned aircraft in FAA's envisioned future. PAS, or mini-jets, are actually unmanned (or more properly, 'fully automated'), in that there is to be no pilot onboard, with the rare exception of those passengers who happen to also be pilots. If PAS/mini-jets do come to fruition, they will help pave the path to public acceptance of roboliners. If a future commuter trusts his life daily to an automated aircraft, why not occasionally to an automated airliner? Before dismissing the possibility of a PAS/mini-jet society occurring in the next 25 years as illogical or extravagant, consider how the logical requirements for a commuter vehicle (single passenger, high gas mileage, low weight for low taxes, small size for ease of parking) have somehow resulted in the large proportion of Suburban Utility Vehicles (SUVs) during rush hour now compared to 25 years ago.

***2025/2050 Forecast:*** Based on Figures 1 and 6, of the general aviation segment's 11 percent of total IFR air traffic handled in the NAS in 2025, 0 percent will be unmanned, or 0 percent of the total volume. Assuming the introduction of a PAS-like market by 2030 and that it grows over 20 years at the same 8·28 percent exhibited for IFR traffic by general aviation in the mid 1990s, 20 percent of general aviation, or 1·8 percent of the total, could be unmanned general aviation by 2050.

### 7.4 Forecast: business traffic

Corporate jets represent aviation's express lane, flying the few at unscheduled times to unscheduled places. Their passengers are typically driven to and from the airport and expect to continue to be driven between airports, so the business aviation segment will be the last bastion of pilot chauffeurs. This segment's major hurdle to unmanned operations will be solely customer acceptance. Corporate pilots will be retained as status symbols as much as for any feelings of insecurity with automation. Seemingly, the record of high profile accidents in this segment (Golfer Payne Stewart, 1999; Governor Mel Carnahan, 2000; Senator Paul Wellstone, 2002) would encourage an eager and early transition to automated flight.

***2025/2050 Forecast:*** Based on Figures 1 and 6, of the business aviation segment's 5 percent of total IFR air traffic handled in the NAS in 2025, 0 percent will be unmanned, or 0 percent of the total volume. By 2050, unmanned business aviation is expected to mirror the overall general aviation trend and be 20 percent unmanned, or 0·6 percent of the IFR total.

### 7.5 Forecast: military traffic

The military segment's adoption of unmanned aircraft faces one major hurdle, technology availability, specifically for the three capabilities (see and avoid, landing, and ground operations) described earlier. Some would add customer (or union-equivalent) acceptance, pointing to what is termed the 'white scarf mafia' or mentality, a reference to the objections of some military pilots who supposedly see flying with or against an unmanned aircraft as somehow unheroic and demeaning to their profession. Its more accurate connotation is that it represents the conservative voice of progress within the military aviation community, those saying be wary of jumping too quickly to new technologies and concepts until they have proven themselves in combat. The pace of unmanned aircraft adoption by the military services reflects this cautious progress. Table 3 illustrates how the numbers of types and roles of unmanned aircraft have gradually increased with their use in each conflict of the past 20 years. In that time, unmanned aircraft have

https://doi.org/10.1017/S0001924000003122 Published online by Cambridge University Press

**Table 3**
**History of unmanned aircraft roles in conflict over the past 15 years**

| Conflict | Dates | UAV types deployed | Missions performed |
|---|---|---|---|
| Persian Gulf | 1991 | Pioneer, Exdrone, Pointer, Mart (Fr) | Gunfire spotting, reconnaissance |
| Bosnia | 1993-96 | Gnat 750, Predator, Pioneer, Fox AT (UN), Crecerelle (Fr) | surveillance, reconnaissance |
| Kosovo | 1998-99 | Pioneer, Hunter, Predator, Phoenix (UK), CL-289 (Ger), Crecerelle (Fr) | surveillance, reconnaissance, target designation |
| Afghanistan | 2001-present | Predator, Global Hawk, Dragon Eye, Pointer, Raven, Luna (Ger), Sperwer (Can), Tern | surveillance, psyops, reconnaissance, strike, target designation |
| Iraq | 2003-present | Predator, Global Hawk, Hunter, Shadow, Pioneer, DarkStar B, Dragon Eye, FPASS, Silver Fox, Pointer, Raven, Tern, AQM-34, Phoenix (UK), Scan Eagle | surveillance, reconnaissance, strike, target designation, diversionary decoy, base security |

progressed from a few small types flying only imagery reconnaissance missions to over 20 types of large to miniature unmanned aircraft flying strike, diversion, and base security missions in addition to reconnaissance.

***2025/2050 Forecast:*** The FAA forecasts the military's percentage of IFR traffic to decline from 10 percent in 2000 to 5 percent by 2025; it should decline further to 2 percent by 2050. Based on Figs 1 and 6, of the military segment's 10 percent of total IFR air traffic handled in 2000, 1·5 percent (<0·2 percent of total IFR traffic) was unmanned. However, 26 percent will be unmanned, or some 1·2 percent of the total volume, by 2025, assuming the inventory continues to triple each decade (1,400 UASs in 2015 times 3 in 2025 = 4,200 of the military's 14,500 air and rotorcraft) and the total aircraft inventory remains constant. These percentages will likely continue to increase, to 50 percent, or 1·0 percent of total IFR traffic, by 2050.

## 8.0 FORECAST SUMMARY

In summary (Table 4 and Figures 6 and 7), less than 0·2 percent of the IFR traffic handled by the FAA today is unmanned. By 2025, 1·2 percent (1 out of 80 flights) is expected to be unmanned and, assuming PAS-like inroads into general aviation , 22 percent (2 out of 9 flights) by 2050. Figure 7 can be compared with Fig. 1 to visualise this growth (shaded portions).

**Table 4**
**Forecast of unmanned aircraft usage by 2025 and 2050**

| Segment | Number of US aircraft | % of all IFR traffic | Current % unmanned | 2025 % U/M forecast | 2050 % U/M forecast |
|---|---|---|---|---|---|
| Airlines | 5,400 | 55 | 0 | 0 | 5·6 |
| Cargo | 1,035 | 15 | 0 | 0 | 12·9 |
| General Av | 149,800 | 12 | 0 | 0 | 1·8 |
| Business | 37,500 | 8 | 0 | 0 | 0·6 |
| Military | 14,500 | 10 | <0·2 | 1·2 | 1·0 |
| Totals | 208,235 | 100 | <0·2 | 1·2 | 21·9 |

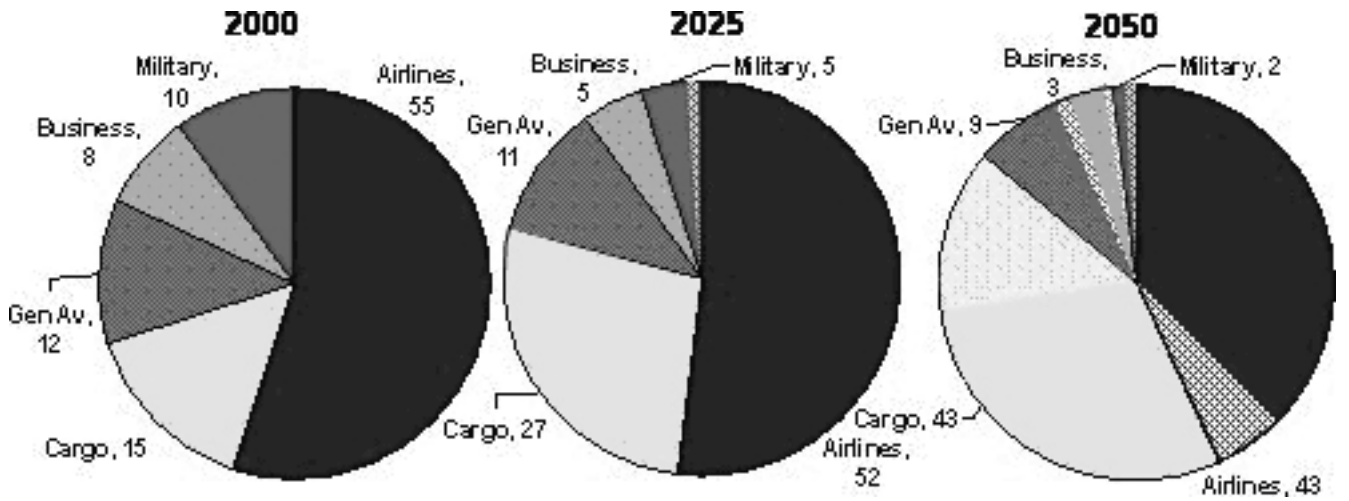



Figure 7. Portions of US IFR air traffic becoming unmanned (shaded areas).[3]

https://doi.org/10.1017/S0001924000003122 Published online by Cambridge University Press

- Computing technologies approaching pilot-equivalency will be emerging over the next 20 years that will enable greater autonomy in unmanned aviation; the aviation market will not be driving these technologies.
- Pilot-related capabilities typically take 15-20 years from initial demonstration to broad acceptance; several key capabilities for unmanned aviation are in their initial demonstration phase now (2005-2010).
- In large measure, military unmanned aviation should be poised to transition to routine NAS operations in the 2015-2020 timeframe.
- Cargo airlines are the 'great commercial hope' for civil acceptance of unmanned aviation; expect to see them begin unmanned operations in the 2025-2030 timeframe.
- About 1 out of 80 IFR flights in the NAS will be unmanned by 2025 (1·2 percent) and 2 out of 9 (18 of every 80) by 2050 (22 percent).

## 9.0 CONCLUSION

The trends examined in this paper agree that the remaining technology enablers for unmanned aviation will likely emerge in the 2015-2025 decade and that its expansion beyond military roles will begin in the 2025-2035 period, led initially by the air cargo market. By 2025, 1 of 80 IFR flights in the United States is expected to be unmanned, rising to 2 of 9 (18 of 80) by 2050.

## REFERENCES


1. CRABTREE, P. Discovering the Future, *The Futurist,* May-June, 2008.
2. Ecole Polytechnique Federale de Lausanne, http://bluebrain.epfl.ch/. 2009.
3. FAA-APO-00-5, FAA long-range aerospace forecasts fiscal years 2015, 2020, and 2025, Federal Aviation Administration, Office of Aviation Policy and Plans, June 2000.
4. Interim operational approval guidance 08-01, Unmanned aircraft Systems Operations in the U.S. National Airspace System, Federal Aviation Administration, AIR-160, 13 March 2008.
5. Unmanned Aircraft Operations in the National Airspace System (NAS), Federal Aviation Administration, AJR-36, Air Traffic Organisation Policy N JO 7110.495, 15 January 2009 (cancellation notice 7110.497 dated 14 January 2009).
6. LUCZAK, M. The power of remote control: US railroad experience strongly suggests that remote control locomotive technology is safe and efficient, *Railway Age,* February, 2005. http://findarticles.com/p/articles/mi_m1215/is_2_206/ai_n13455603.
7. MORAVEC, H. *Robot*, Oxford University Press, New York, 1999.
8. PAIN, E. Leading the Blue Brain project, *Science,* 6 October 2006, http://sciencecareers.sciencemag.org/career_development/previous_issues/articles/2006_10_06/leading_the_blue_brain_project/(parent)/68
9. US Department of Defense, OSD unmanned systems roadmap, 2007-2032, 2008. Reference Appendix A.3 'UAS Airspace Integration,' which is based on the *OSD airspace integration plan for unmanned aerial vehicles*, released in November 2004. http://www.acq.osd.mil/uas/docs/2007_Unmanned_Systems_Roadmap.pdf
10. US Department of Transportation, Federal Railroad Administration, Final report: safety of remote control locomotive (RCL) operations, March, 2006. http://www.fra.dot.gov/downloads/safety/05_007775finalreport_RCL.pdf


https://doi.org/10.1017/S0001924000003122 Published online by Cambridge University Press