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Modeling the Performance of Unmanned Aircraft for the En Route Automation Modernization System

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16. Abstract

The En Route Automation and Modernization (ERAM) system uses aircraft performance models to predict the speeds and vertical rates of air traffic and to alert air traffic managers to traffic conflicts in the US National Airspace System (NAS). With the anticipation of unmanned aircraft (UA) in the NAS in the near future, new UA performance models for ERAM are needed. This report lists 15 unmanned aircraft systems recommended for ERAM performance modeling to capture a suitable range of UA NAS traffic in the near future. It also serves as an inventory of FAA-held data that can be used to develop UA models for ERAM. There is a limited amount of FAA-held, protected track data that are viable for model development via ERAM's legacy statistical methods. More track data are available via FAA partnerships, but protection concerns inhibit sharing. FAA-held ground control stations can be used to collect high-fidelity data, but this would require a substantial effort to gather a statistically significant amount of track data. In the absence of track data for many needed models, alternate model development methods are desired. A method is proposed for modeling fixed-wing aircraft performance for ERAM from knowledge of only aircraft mass, geometry, and powerplant output.

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Executive Summary

The Separation Management and Modern Procedures Project is an initiative of the Federal Aviation Administration (FAA) under the Next Generation Air Transportation System (NextGen) Program to implement improvements to the National Airspace System (NAS) in the United States. The FAA's Air Traffic Organization En Route Program Office has employed the FAA's Concepts Analysis Branch (ANG-C41) to execute several studies investigating the impacts from various proposed prototypes and parameter changes in the Conflict Probe Tool (CPT) of the En-Route Automation Modernization (ERAM) system. The overall objective is to improve the performance of the CPT subsystem in ERAM in preparation for integration of conflict alert notification into the flight data block on the radar controller's main display.

With the anticipation of unmanned aircraft (UA) in the NAS in the near future, ERAM performance models for UA are needed. The legacy method for creating aircraft models for ERAM is a statistical analysis of NAS surveillance data; however, surveillance data for UA are limited. This study provides an inventory of data currently available to the FAA that can be used to create ERAM Aircraft Performance models for unmanned aircraft as well as alternate modeling methods that can be used in the absence of surveillance data. The inventory includes flight surveillance data, aircraft performance modeling tools, and ground control stations for unmanned aircraft. The most promising of these is the FAA ground control stations (GCS).

There are several useful GCS platforms at the NextGen Integration and Evaluation Capability (NIEC) laboratory at the FAA William J. Hughes Technical Center. These GCS are valuable because of the flexibility they provide for allowing data collection for unmanned aircraft NAS-wide and in a wide variety of scenarios of differing airspace, weather, and traffic. While it should be noted that these GCS are protected and any output from them is proprietary, they are relevant to this study for inventory and model development purposes. The most valuable of the GCS platforms are for the RQ-4B Global Hawk and the MQ-9B Reaper (commonly known as the Predator B). Complete ERAM Aircraft Performance Tables can be generated for these aircraft from the GCS alone.

There are three methods proposed for establishing ERAM Aircraft Performance tables for unmanned aircraft types. The first is to use the legacy methods that perform statistical analysis on surveillance data. The second is to survey operators and manufacturers of unmanned aircraft to populate the ERAM tables directly. The third is to establish performance modeling tools based on a parametric analysis.

The third method is referred to as the Parametric Method. In the absence of surveillance data for a given aircraft, a method for generating aircraft performance tables from vehicle configuration is desired. Utilizing techniques from the field of flight mechanics, the preliminary principles are presented for the development of this Parametric Method. The method draws upon the author's expertise in aeronautics and statistics to correlate to the aircraft mass, powerplant output, and wing geometry parameters. Complete development of this approach is left for future work.

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1 Introduction

The Separation Management and Modern Procedures Project is an initiative of the Federal Aviation Administration (FAA) under the Next Generation Air Transportation System (NextGen) Program to implement improvements to the National Airspace System (NAS) in the United States. The FAA's Air Traffic Organization En Route Program Office (ATO-E) has employed the FAA's Concepts Analysis Branch (ANG-C41) to execute several studies investigating the impacts from various proposed prototypes and parameter changes in the Conflict Probe Tool (CPT) of the En-Route Automation Modernization (ERAM) system. The overall objective is to improve the performance of the CPT subsystem in ERAM in preparation for integration of conflict alert notification into the flight data block on the radar controller's main display.

One of the tasks of the Separation Management and Modern Procedures Project is to establish models for the ERAM CPT for unmanned aircraft (UA). The purpose of this study is to develop methods for creating models of unmanned aircraft for use in the ERAM CPT and to inventory existing data that can be used in those methods. This study provides recommendations on the methods, data available, and gaps to be filled on how to model UA performance in ERAM. These aircraft perform differently than the typical civilian aircraft that ERAM models today. Accurate aircraft performance characteristics are a key ingredient for ERAM to provide trajectory and conflict prediction services.

The data analyzed in this paper were provided by the Lockheed Martin Corporation. These are the data that were used in the generation of the ERAM Aircraft Performance tables, as described in the Aircraft Data Analyzer (ACZR) User Manual (LMCO 2014). The data pertain to fixed-wing aircraft only.

2 Approach

The ERAM Aircraft Performance tables are used by ERAM to predict the paths of aircraft in the NAS. The tables are generated from statistical analysis of NAS radar surveillance data, which track the flights of aircraft flying in the NAS. In anticipation of increased unmanned aircraft traffic, this project, titled *Aircraft Performance Characteristics for UAS Flights*, was created to survey the inventory of available data and to establish methods for creating entries in the ERAM Aircraft Performance tables for unmanned aircraft types expected to be encountered in the future NAS. The inventory is presented in Section 3 and the model development methods are presented in Section 4.

There are three methods proposed for establishing ERAM Aircraft Performance tables for unmanned aircraft types. The first is to use the legacy methods, described in the ACZR User Manual, that perform statistical analysis on surveillance data. The second is to survey operators and manufacturers of unmanned aircraft to populate the ERAM tables directly. The third is to establish theoretical estimations based on a parametric analysis. The first two methods are described in Sections 4.1and 4.2. The third method, referred to in this tech note as the Parametric Method, is proposed in Section 4.3 and left for future development. The recommendations section (Section 5) relates the inventory of relevant data of Section 3 to the aircraft parameters needed to support each of the three methods of Section 4.

Aircraft are identified by their ICAO (International Civil Aviation Organization) designators in this report and in the ERAM Aircraft Performance Tables. The reader is referred to the FAA Order JO 7340.2E, Aeronautical Contractions (FAA, 2014) for a complete list of designators.

2.1 Description of the ERAM Aircraft Performance Tables

The data in the ERAM Aircraft Performance Tables are described completely in the ACZR User Guide (2014). Appendix A of that guide provides a table describing the data. It is presented in Table 1. The data are not actual track data, but compiled summaries of the track data in preset altitude and temperature bins. Each summary record contains the mean, standard deviation, and number of points of the specified bin. ERAM also maintains a distinction between "masters" and "clones." A master model is one that is developed from track data for the same aircraft. A clone model is one that is a copy of a model developed from another aircraft that is considered to be similar in performance.

Table 1: Fields of the ERAM Aircraft Performance Tables (ACZR User Guide, 2014)

Field Name	Description	Units
ac_type	ICAO designator	
vmnvr	-1 = Descent, 1 = Climb	
disa	Delta temperature from International Standard Atmosphere	Kelvin
alt	Altitude corresponding to start of altitude bin	ft
rocd_npt	Number of vertical rate data points included in altitude bin	
rocd_mean	Mean of vertical rate for all points included in the bin	fpm
rocd_std	Standard deviation of vertical rate for all points included in the bin	fpm
rocd_min	Minimum value of vertical rate in the altitude bin	fpm
rocd_max	Maximum value of vertical rate in the altitude bin	fpm
rocd_value	Vertical rate for the altitude bin (equal to rocd_mean for altitude > ACReferenceAlt, else computed based on fixed path angle = ACPathAngle)	fpm
rocd_flags		
tas_npt	Number of TAS data points included in altitude bin	
tas_mean	Mean TAS for all points included in the bin	kts
tas_std	Standard deviation of TAS for all points included in the bin	kts
tas_min	Minimum value of TAS in the altitude bin	kts
tas_max	Maximum value of TAS in the altitude bin	kts
tas_value	TAS for the altitude bin (equal to tas_mean for altitude > ACReferenceAlt, else computed based on gradual decrease from ACReferenceCAS to ACLandingTAS)	kts
tas_flags		

3 Inventory of UAS Data Sources

This section provides an inventory of the flight data, UAS ground control stations, and UA models available to the FAA. While the inventory is limited, it illustrates the relationships that the FAA has established with operators, analysts, manufacturers, and modelers. These relationships can be leveraged to gain needed data for the development of models for the ERAM Aircraft Performance Tables.

3.1 Data Related to the DoD UAS Joint Test

In 2014, the FAA conducted an unmanned aircraft performance validation study that was part of a Department of Defense (DoD) UAS procedure validation project. The study used UAS data from several different sources, although the data are proprietary. The information in this subsection is obtained from an FAA unpublished Memorandum to the UAS Airspace Integration Joint Test (UAS AI JT) dated 14 March 2014. The memorandum was obtained via subject matter expert communication (A. Schwartz, personal communication, 14 August 2014), and the information in this subsection is drawn from that communication.

The FAA reached an agreement with certain manufacturers to obtain performance data on the RQ-7B Shadow and MQ-9B Reaper (aka, Predator B) aircraft types for UAS validation as part of this DoD project. The data were used for simulation and are considered proprietary, but the availability of the data is useful for this study.

In addition to the flight data, the following documentation was obtained through the UAS-AI JT

- Shadow performance notes, which contained maximum climb rates and minimum descent rates. These rates were limited to one flight test at a low altitude.
- Pages from a document that contained information on the MQ-1C Gray Eagle aircraft.
- Turn rate and radius graphics file showing charts with turn rate and turn radius by altitude for an RQ-4 Global Hawk aircraft. It was determined that without the proper speeds for the aircraft the turn radius identified in the chart could not be reached in some altitudes.

The RQ-7B and MQ-9B flight data can be used for model development for the ERAM CPT, assuming relevant permissions are granted. The supplementary documentation is useful information for validating models developed by any means.

3.2 NASA BADA Information

EUROCONTROL's BADA is a widely used database of aircraft parameters for aircraft commonly encountered in commercial air traffic throughout the world (EUROCONTROL 2012). Its worldwide usage has made BADA-formatted aircraft models a familiar format for many air traffic simulators. Wieland, et al. (2012) performed a study in which models of several UAS were created in the format of BADA so that UAS traffic could be simulated in air traffic simulators. BADA does not currently have any directly-modeled UAS[1]. The NASA funded study was established to create simulation models for some of the most popular unmanned aircraft in the NAS. It should be noted, however, that the study's authors noted some deficiencies and limitations of the effort, which are summarized below:

- Limited manufacturer data
- BADA has limited aircraft type, class, and size information; no UA or rotorcraft aircraft types
- BADA has limited propulsion types; no electric engines
- BADA stall speed buffers are limiting
- BADA climb/descent schedules are often ill-suited for many UAs as they are usually restricted to take into account passenger comfort

3.3 UAS Data from Public Sources

Documents are available through public sources that contain information on UAS platforms. A few examples are provided. EUROCONTROL released a study on the integration of the Global Hawk into European airspace (EUROCONTROL 2010). This document contains limited information at a few flight levels but seems consistent with other Global Hawk flights. Billingsley (2006) conducted a study on the safety analysis of the Traffic Alert Collision Avoidance (TCAS) System that used Global Hawk data. The study contains data on Global Hawk climb and descent rates and speeds. These two documents illustrate that public sources of UAS data do exist.

3.4 Ground Stations at the FAA William J. Hughes Technical Center

A Ground Control Station (GCS) is a control center that provides for remote human control of an unmanned aircraft. The GCS may include manual control actuators, satellite communications, and multi-function workstations for viewing pertinent vehicle and flight data.

Table 2 is a list of unmanned aircraft for which BADA-like models were created in the Wieland, et al. study.

[1] BADA direct models are models that are developed from analysis of the relevant aircraft. BADA also establishes equivalents when direct modeling is not feasible. Equivalents are pointers to existing models of aircraft with similar performance characteristics.

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A Ground Control Station (GCS) is a control center that provides for remote human control of an unmanned aircraft. The GCS may include manual control actuators, satellite communications, and multi-function workstations for viewing pertinent vehicle and flight data.

Table 2: UAS for which BADA-like models were developed in Wieland, et al. (2012)

UAS	Manufacturer	Type
Aerosonde Mark 4.7	Aerosonde Pty (sub. of Textron Inc. via AAI Corporation)	Small (< 55 lb.), fixed-wing UAS with piston/propeller.
Cargo UAS	AAI	Hybrid rotary-wing/fixed-wing, 22.750 lb
MQ-8B Fire Scout	Northrup Grumman	Conventionally configured helicopter, turboshaft engine, 3150 lb.
RQ-4A Global Hawk	Northrup Grumman	HALE fixed-wing UAS with turbofan engine, MTOW 26,700 lb.
MQ-1C Gray Eagle	General Atomics	Advanced derivative of the RQ-1B Predator. Standard, fixed-wing with heavy fuel internal combustion engine and propeller, 3600 lb.
MQ-5B Hunter	Northrup Grumman	Standard, fixed-wing UAS with heavy fuel internal combustion engine and propeller, 1950 lb.
NEO S-300 Mk II VTOL	Swiss UAV	Conventionally configured helicopter, turboshaft engine, 150 kg.
Orbiter Mini UAV System	Aeronautics Defense Systems	Small, fixed-wing UAS, electric motor and propeller.
MQ-1B, Predator (aka Predator A)	General Atomics Aeronautical Systems, Inc.	Standard, fixed-wing UAS with internal combustion engine and propeller. 2250 lb.
MQ-9B, Reaper (aka Predator B)	General Atomics Aeronautical Systems, Inc.	Standard, fixed-wing UAS with turboprop engine. 10,500 lb.
Avenger (aka, Predator C)	General Atomics Aeronautical Systems, Inc.	Standard, fixed-wing UAS with turbofan engine. 18,200 lb.
Scan Eagle	Boeing Insitu	Small, fixed-wing UAS, electric motor and propeller.
RQ-7B Shadow B	AAI Corporation (subsidiary of Textron Inc.)	Fixed-wing UAS, internal combustion engine (rotary) with propeller, 375 lb.
X-47B UCAS	Northrup Grumman	Standard, fixed-wing (delta wing) UAS with turbofan engine. 44,000 lb.

The multi-function workstations can be used to communicate information that is mission- or user-specific. It may display a live video feed, meteorological data, map data, or communicate information via a multitude of sensors that may be onboard the aircraft.

The FAA William J. Hughes Technical Center in Atlantic City, NJ contains several fielded GCS with either a real unmanned aircraft or a flight simulator from the manufacturer. These GCS exist as part of the NextGen Integration and Evaluation Capability (NIEC). There are also several integrator GCS platforms that can be used to emulate several different vehicles. The fielded GCS platforms can be used to obtain real data, although the GCS platforms are protected or proprietary and require formal approval for use. Figure 1 is a depiction of the configuration of the NIEC laboratory.

Figure 1: Configuration of the NIEC Laboratory at the FAA William J. Hughes Technical Center illustrating the UAS Suites, which house the UAS ground control stations.

The NIEC collocates and integrates key NAS components into a single environment to address emergent research questions. The benefit to this is that weather, traffic, and airspace data can be added to any flight for the collection of track data. This means that UAS track data can be collected NAS-wide in this single laboratory. In addition, any GCS can be linked to legacy NAS equipment, flight management systems, or new, emerging, or conceptual facilities.

The impact, for the purposes of this technical note, is that the flight data from any of these field-version GCS may be used to collect accurate, NAS-wide flight track data. These data are of a fidelity that can be used to develop aircraft models for UAS in the ERAM Aircraft Performance Tables. The NIEC makes this capability available from one single laboratory.

Table 3 is a list of unmanned aircraft that exist as field GCS platforms at the FAA Technical Center's NIEC Laboratory and can be considered as a valid source of real UAS data.

Table 3: UAS GCS platforms that exist in the NIEC Laboratory of the FAA Technical Center

UAS	Vehicle Type	NIEC Capability
MQ-8B Fire Scout	Conventionally configured helicopter, turboshaft engine, 3150 lb.	Pending
RQ-4 Global Hawk	HALE fixed-wing UAS with turbofan engine, MTOW 32,250 lb.	GCS
RQ/MQ-9B, Reaper (aka Predator B)	Standard, fixed-wing UAS with turboprop engine. 10,500 lb.	GCS
ScanEagle	Small, fixed-wing UAS, electric motor and propeller.	GCS and vehicle
RQ-7B Shadow B	Fixed-wing UAS, internal combustion engine (rotary) with propeller, 375 lb.	GCS

4 Methods and Associated Requirements for Developing ERAM Aircraft Performance Tables

This section details the methods for developing aircraft models for inclusion in the ERAM Aircraft Performance Tables. The three methods are the empirical method, the survey method, and the parametric method.

4.1 Empirical Method

Completion of the ERAM Aircraft Performance Tables for a given aircraft type via the Empirical Method is simply a repeat of the method already used by the ERAM Development Team to create the tables – statistical analysis of NAS flight surveillance data. This analysis requires a significant sample of surveillance data.

4.1.1 Background

The information in this subsection is obtained from subject matter expert communication (S. Torres, personal communication, 19 November 2014).

The process to generate aircraft characteristics tables in ERAM is based on analysis of recorded surveillance data. This process is based on the URET approach as documented in URET SIG2280 (Nagl, 2006). The process was streamlined with new tools and data collection capabilities. The process uses Lockheed-Martin's *Sarbot*[2] tool to collect RUC1[3] and track data from sites. The *AirCraft data analyZeR* (ACZR) program (Lockheed 2014) loads the *Sarbot* data, subtracts winds, and computes true air speed and vertical rate inside altitude transitions. A second pass of ACZR processing computes -- on a per aircraft type basis -- the true air speed and vertical rate averages in bins of altitude and (for climbs) in bins of temperature deviation from standard day. Note that only climb phase and descent phase of flight are analyzed (no cruise phase) for aircraft characteristics. Cruise modeling is based on assigned speed; there is no need for aircraft characteristics during cruise. Details of the data processing are available.

Since the aircraft characteristics tables are used by ERAM to model the trajectory vertical profiles from ground to top of climb (TOC) and from top of descent (TOD) to ground, it is important that the empirical data captures the entire vertical profile.

[2] *Sarbot* is ERAM's data recording and retrieval system. It is a tool developed by Lockheed Martin as part of the ERAM deployment that records and allows robust searches of CMS data and other ERAM output data.
[3] The RUC was a NOAA/NCEP operational weather prediction system. Further information can be found at ruc.noaa.gov

The derived true air speed and vertical rate averages that are used to populate the aircraft characteristic tables should include a representative sample of NAS operations. The larger the number of Air Route Traffic Control Centers (ARTCCs) included in the sample the better. There are anecdotal reports of large ARTCC-to-ARTCC variations in aircraft 'behavior' (i.e. an average descent into KATL looks different than an average descent into KSEA). A systematic look into the subject has been performed. An initial analysis indicates that for the most part the ARTCC-to-ARTCC variations are not statistically significant. In general the true air speed and vertical rate variances are high and the ARTCC-to-ARTCC differences (for the reduced sample of aircraft types analyzed) were no larger than 2-sigma (Torres, Little, & McKay, 2013). However, sample data from a variety of ARTCCs is desirable to ensure representative performance inclusive of all possible variations.

In order to obtain robust estimators of true air speed and vertical rate for trajectory modeling purposes it is necessary to impose a minimum sample size. URET SIG 2280 recommended a minimum of 1,000 to 1,500 flights per aircraft type. This number of flights (on a per aircraft type basis) is not easy to achieve for the aircraft types that are not common in the NAS. If one considers the altitude bin width of the tables (3,000 feet), a nominal vertical rate of 2,000 feet per minute and the 12-second track period, then one obtains a contribution of eight points per bin per operation. With 100 flights (again, on a per aircraft type basis) the expected number of points per bin would be 800, which is not an unreasonable sample size for statistical work. This number however, does not take into account segregation by temperature (which has to be done for climb profiles). With four temperature bins the effective number of points per bin would be 200, which is not ideal but better than no information.

When data are limited, temperature bins can be widened to accumulate more points per bin. Also, not all of the recorded data is usable; the data reduction algorithms apply a number of data quality checks which result in a portion of the data being discarded. For data recording purposes this means that the duration of recordings should be planned to allow for discarded data.

Recorded data should span the atmospheric temperature ranges that are found in the operational environment. Recorded track data should capture seasonal variations in temperature. Also, there should be a requirement related to the weather quality associated with the recording. During some days the weather conditions are not typical (severe storms, etc.). The recorded data should capture 'average' atmospheric conditions.

4.1.2 Recommendations

A summary of recommended data requirements for the empirical method is provided in Table 4.

Table 4: Recommended requirements on the NAS track data used in the Empirical Method for generating ERAM Aircraft Performance Tables.

- Tracks extend from ground to ceiling for the relevant aircraft type
- Recorded tracks span the atmospheric temperature ranges that are found in the operational environment.
- Recorded tracks capture seasonal variations in temperature.
- 1000 – 1500 total flights recommended for each aircraft type, NAS-wide. 100 flights is an absolute minimum.

The fields of Table 1 should be completed for a set of conditions that is representative of the flight envelope of the aircraft type. While there is no requirement for the number of altitudes and temperature deltas (because ERAM will simply interpolate to fill missing data), it is recommended that the record set outlined in Table 5 is created. (For an aircraft type with a ceiling of 30,000 feet, there would be 11 record sets of 8 records each for a total of 88 records.)

Table 5: Recommended record set for creation of ERAM Aircraft Performance Tables.

- A record set for each pressure altitude from 0 feet (sea level) to the ceiling of the aircraft type, stepped by 3000 feet pressure altitude.
- For each pressure altitude record set,
  - one descent record (vmnvr = -1) at ISA temperature and
  - seven climb records (vmnvr = 1) corresponding to disa = {-15K, -10K, -5K, 0K, 5K, 10K, 15K}

4.2 Survey Method

Completion of the ERAM Aircraft Performance Tables for a given aircraft type via the Survey Method requires a survey of an operator of that aircraft type. Table 6 represents the fields of an individual record and should be completed for a number of altitudes and temperature deltas that suitably represents the flight envelope of the aircraft type. While there is no requirement for the number of altitudes and temperature deltas (because ERAM will simply interpolate to fill missing data), it is recommended that the record set outlined in Table 5 is created.

Table 6: Required Fields for the Survey Method. This table is a subset of Table 1.

Field Name	Description	Units
ac_type	ICAO designator	
vmnvr	-1 = Descent, 1 = Climb	
disa	Delta temperature from International Standard Atmosphere	Kelvin
alt	Pressure altitude	ft
rocd	vertical rate	fpm
tas	True airspeed	kts

Table 7: Aircraft parameters needed for Parametric Method

Var.	Name	Description
W	Weight	A reference weight for the aircraft that is representative of a typical flight
S	Wing Area	The reference wing area, typically the planform area.
b	wing span	The span of the wing, from tip to tip
AR	aspect ratio	The aspect ratio, $AR = b^2/S$.
C_{D0}	profile drag coefficient	The profile drag coefficient is the drag coefficient due to friction and pressure drag not due to lifting forces. If this parameter is unavailable, it can be estimated from aircraft geometry (e.g., Torenbeek, 1982), but many more aircraft parameters will be needed.
K	induced drag coefficient	Produces the drag due to lift. It is the coefficient that multiplies the square of the lift coefficient in the function $C_D = C_{D0} + KC_L^2$. If this parameter is unavailable, it can be estimated from aircraft geometry (e.g., Torenbeek, 1982), but many more aircraft parameters will be needed.
Thr	Powerplant Thrust Model	The Parametric Method requires a model of the thrust produced by the aircraft's powerplant. The modeled thrust must be a function only of simple state variables like speed and altitude. The powerplant is the system that produces the aircraft's thrusting force to accelerate the aircraft and overcome resisting forces. Examples include a 1) turbofan engine and 2) an electric motor, propeller combination.

4.3 Parametric Method - Fixed-Wing Aircraft

The Parametric Method is intended for creating ERAM Aircraft Performance Table models for fixed-wing aircraft when the absence of reliable track or performance data for the aircraft being modeled make the empirical and survey methods impractical. The method uses aircraft parameters for geometry, mass, and powerplant to predict performance.

The Parametric Method finds a correlation between aircraft parameters and speed and vertical rate performance for the existing ERAM aircraft models and creates a function from which speed and altitude rate are empirically determined from wing geometry, mass, powerplant, and altitude. This function is used to create the ERAM Aircraft Performance Tables for aircraft (including UAS) that lack reliable track or performance data. Development of the method details is left for a future study. However, some preliminary principles of the method are discussed here.

4.3.1 Methodology

The speeds selected by an aircraft in any flight regime can vary greatly. In the ERAM Aircraft Performance Tables, the average standard deviation in the speed data is 21 knots, and the maximum standard deviation is near 50 knots. This means that a third of the ERAM data are more than 21 knots away, on average, from the speed that ERAM is using in its trajectory predictor. However, there are patterns that can be detected in the means of the speeds for a given flight regime.

It is well documented in flight mechanics literature (e.g., Andersen, 2000) that wing geometry has relationships to an aircraft's drag properties for subsonic flight. As such, an aircraft's wing geometry is closely coupled to its most efficient speeds for climbing and cruising. It is expected that the flights used to establish the ERAM Aircraft Performance tables are, on average, a reflection of aircraft flying at similarly efficient speeds.

There are other factors that affect a selected speed. Powerplant efficiency tends to vary with speed and altitude and aircraft operation would benefit from flying at speeds that are most efficient for engine performance. But powerplant models are typically unavailable or inaccurate; and it might be expected that aircraft designers would optimize wing and engine design so that optimal speeds coincide. Aircraft weight can vary with mission, and while mass has effects on efficient speeds, mass is mission-specific and typically protected information. Atmospheric conditions also have an influence on efficient speeds. Lastly, an aircraft operator may have other factors unrelated to aerodynamic efficiency that influence the selection of flight speed, such as flight time, crew time, and operating costs. None of these factors can be included in the proposed analysis, yet all of them lead to the great variation seen in selected aircraft speeds.

Figure 2 is a plot of the variation of climb speeds selected by each aircraft type with altitude, from the ERAM Aircraft Performance Tables. The plots are separated by engine type, where J is a jet-engined aircraft, P is a piston-engined aircraft, and T is a turboprop-engined aircraft. The marker size indicates the number of points used to generate the ERAM summary record. The lines are generated smoothers to the data, delineating aircraft type. The plot shows a clear distinction in the trends by engine type; however, these differing trends are more a reflection of aerodynamic design of the respective vehicles. The aircraft designer chose an engine that would facilitate flight in the designed envelope. As a point of clarification, a high-altitude, long-endurance (HALE) UAS is designed for lower speeds and would exhibit a climb profile similar to a turboprop, but it would need a jet engine to reach design altitudes, illustrating the need to base prediction methods more on geometry than engine type.

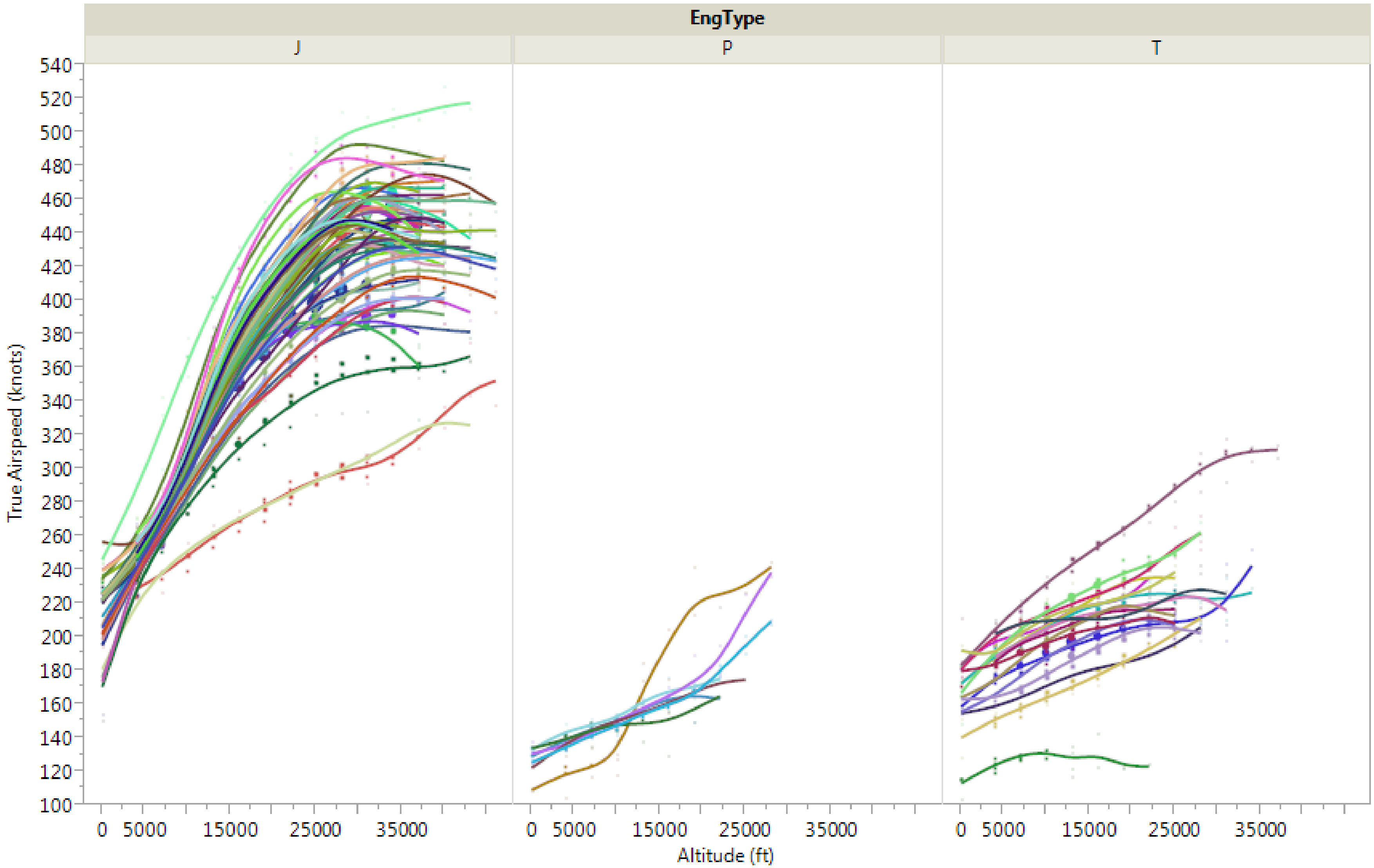

Figure 2: Mean of the true airspeed in climb versus altitude by engine type. Data are from the ERAM Aircraft Performance tables.

To measure the accuracy of the modeled speed, a Speed Metric, ζ, is defined. The Speed Metric is defined as the ratio between the actual mean climb speed, V_a, at an altitude (from the data) and the modeled speed, V_e, at that altitude to the standard deviation of the data for the relevant record. By using the standard deviation in the speed metric, the analysis provides a measure of how well the modeled speed represents the collection of actual aircraft-selected speeds in the climb or descent. Ideally, ζ would be close to zero, which would mean that the modeled speed represents the actual speeds as well as the mean does. A value of $|\zeta|$ greater than two would mean that the modeled speed lies further than two standard deviations from the mean, commonly known as 2-sigma.

$$\zeta\left(h, V_e(h)\right) = \frac{V_a(h) - V_e(h)}{\sigma_a(h)} \tag{1}$$

The approach to the modeling of the altitude rate for a given aircraft type is based on parameters of the aircraft type and the flight conditions. Equation (3.2-6) of the BADA User Manual (EUROCONTROL, 2012) is the total energy equation for calculating the altitude rate. It is reproduced here as equation (2).

$$\dot{h} = \left[\frac{(\mathrm{Thr} - \mathrm{D})\mathrm{V}}{\mathrm{mg}}\right] \mathrm{f}\{\mathrm{M}\} \tag{2}$$

The two prominent unknowns in equation (2) are the thrust, *Thr*, and the mass, *m*. Aircraft maximum mass is provided in most parametric models of aircraft, but the actual mass for a given flight has quite a large range and its mission-specific value is typically unknown. The drag, *D*, is based on the aircraft parametric model (e.g., BADA), speed, and atmospheric density. The true airspeed and density come from the flight conditions and the International Standard Atmosphere (ISA). The Energy Share Factor, *f{M}*, is also unknown, although it is a function of the speed and The BADA User Manual (EUROCONTROL 2012) provides methods for estimating it.

However, the total energy equation also provides an indication of the parameters that affect altitude rate: thrust-to-weight ratio, drag, and speed. The approach for the parametric method is to correlate the altitude rate from the data to functions in these parameters.

To measure the accuracy of the modeled altitude rate, an Altitude Rate Metric, $\zeta_{\dot{h}}$, is defined. It compares the difference in the actual altitude rate at an altitude ($\dot{h}_a$, from the data) and the modeled altitude rate, $\dot{h}_e$, at that altitude to the standard deviation of the data for the record. Once again, by using the standard deviation in the metric, the analysis provides a measure of how well the estimate represents the collection of actual aircraft altitude rates. Ideally, ζ_h would be close to zero, which would mean that the estimate represents the actual altitude rates as well as the mean does. If $|\zeta_h|$ is greater than two, the altitude rate estimate lies further than two standard deviations from the mean, commonly known as 2-sigma.

$$\zeta_{\dot{h}}\left(h, \dot{h}(h)\right) = \frac{\dot{h}_a(h) - \dot{h}_e(h)}{\sigma_{\dot{h}}(h)} \tag{3}$$

5 Recommendations

There are a great number of unmanned aircraft on the market today. Most, however, are small UAS that are not likely to enter airspace that is of interest to ERAM. The Appendix presents an abridged list of unmanned aircraft manufactured in the US, the UK, and Israel. A review of the aircraft in the listing confirms that most are small UAS.

Developing recommendations for UAS types to be modeled in ERAM in the near term future requires a forecast of the types that will be flying. MITRE performed a study to forecast the unmanned aircraft that will be flying in the NAS in the 2020 time frame (MITRE 2013). While the study did not attempt to identify specific airframes expected, it did forecast the numbers and types of airframes. Table 8 is a list of the types of airframes forecast in the MITRE study, along with type descriptions.

Regarding Table 8, while the need to distinguish small UAS in VLOS and BVLOS missions for policy purposes is recognized, there is no reason to expect that their performance will be significantly different. The MITRE forecast even mentions that aircraft currently exist that perform both missions.

RTCA also performed a forecasting study of unmanned aircraft expected to be flying in the NAS in the near future (RTCA 2010). That study didn't attempt to identify specific airframes either. The study did identify airframes types and developed more detailed type classifications. The RTCA study is more relevant to this report because the type classifications are based on performance categories. Table 9 is a list of the type classifications and performance categories identified in the RTCA forecast.

From currently available track data for unmanned aircraft and from a review of the trends in unmanned aircraft testing at FAA-approved UAS test locations, it is expected that Global Hawk, Predator, and ScanEagle models will be common in the NAS in the near future, and so models of these vehicles should exist in the ERAM Aircraft Performance Tables.

Also, in the interest of capturing the performance of the range of type classifications, it is recommended that a general model for each fixed-wing category/subcategory combination in Table 9 exist in the ERAM Aircraft Performance Tables. However, the following notes are made.

- The "conversion" subcategory can be removed from consideration because there is no reason to expect that an unmanned version of a manned aircraft will perform differently than the manned version. It is expected that an existing ERAM model of a manned aircraft can be cloned to represent the conversion aircraft.
- Airships and VTOL aircraft models are currently beyond the scope of this document, so no recommendations are made.
- Table 5 lists the recommended record set for creation of the ERAM Aircraft Performance Tables.
- When developing models via the Parametric Method for electrically-powered, propeller-driven, fixed-wing aircraft, the method for piston aircraft should be used.
- Regarding the engine used to drive a propeller on a fixed-wing aircraft, differences in performance variation with altitude warrant different models for each engine type: electric, normally-aspirated reciprocating, supercharged/turbocharged reciprocating, and turbine.
- When developing models via the Empirical Method, Table 4 should be used to establish requirements on the needed data.

- When developing models via the Survey Method, Table 6 should be used as guidance for the needed fields.

Table 8: UA type classifications identified in MITRE (2013).

Category	Description
sUAS VLOS	small UA (under 55 pounds) that are operated with the visual line of sight (VLOS) of the pilot or observer.
sUAS BVLOS	small UA that are operated beyond the visual line of sight (BVLOS) of the pilot/observer
Recip	fixed-wing UA with an internal combustion engine, operated above sUAS limits
Turboprop	fixed-wing UA with a turboprop engine, operated above sUAS limits
Turbojet	fixed-wing UA with a turbofan or turbojet engine, operated above sUAS limits
HALE	high-altitude, long-endurance (HALE) aircraft, operated above FL450

Table 9: UA type classification (ie, performance categories and sub-categories) identified in the SC-203 Report (RTCA 2010).

Categories
Turbojet fixed-wing
Turboprop fixed-wing
Reciprocating/electric fixed-wing
Vertical take-off and landing (VTOL)
Airship

Sub-Categories		
Sub-Category	**Description**	**Example**
Standard	UA resembling manned aircraft in terms of size, capabilities, and performance	Predator A Predator B
Non-Standard, Small	UA with a physical size and weight that is considerably smaller than the smallest manned aircraft	Scaneagle Raven
Non-Standard, HALE	UA capable of operating at altitudes and endurances well-beyond those of manned aircraft	Global Observer
Conversion	UA that are converted from manned aircraft	Cessna Caravan Gulfstream V

The following list is a list of 15 aircraft models recommended for development in the ERAM Aircraft Performance Tables, although since four of the direct model vehicles will suffice as recommended generic models, the list is effectively reduced to 11.

1. RQ-4B, Global Hawk, Northrup-Grumman
   The FAA has Global Hawk track data as well as a GCS in the NIEC laboratory that can be used for the development of a model in the ERAM Aircraft Performance Tables.

2. RQ/MQ-1B, Predator (aka Predator A), General Atomics Aeronautical Systems, Inc.
   The FAA has relationships that can be leveraged to attain Predator track or parametric data.

3. RQ/MQ-9B, Reaper (aka Predator B), General Atomics Aeronautical Systems, Inc.
   The FAA has a Reaper GCS in the NIEC laboratory that can be used for the development of a model in the ERAM Aircraft Performance Tables.

4. ScanEagle, Boeing Insitu

The FAA has ScanEagle track data as well as an actual ScanEagle vehicle and a GCS in the NIEC laboratory that can be used for the development of a model in the ERAM Aircraft Performance Tables.

5. Normally-aspirated reciprocating, fixed-wing, standard
   The MQ-1B Predator model can be used to fulfill this need with appropriate adjustments for reduced engine performance for a normally-aspirated reciprocating engine.

6. Supercharged/turbocharged reciprocating, fixed-wing, standard
   The MQ-1B Predator model is recommended to fulfill this need.

7. Reciprocating, fixed-wing, small
   Currently no data are available to support development of this generic model. It is recommended that an appropriate model be selected for model development via the parametric method.

8. Electrical, fixed-wing, standard
   The MQ-1B Predator model can be used to fulfill this need with appropriate adjustments for powerplant performance for an electric motor, propeller combination.

9. Electrical, fixed-wing, small
   The Scaneagle model is recommended to fulfill this need.

10. Turboprop, fixed-wing, standard
    The MQ-9B Reaper model is recommended to fulfill this need.

11. Turboprop, fixed-wing, small
    Currently no data are available to support development of this generic model. It is recommended that an appropriate model be selected for model development via the parametric method.

12. Turboprop, fixed-wing, HALE
    Currently no data are available to support development of this generic model. It is recommended that an appropriate model be selected for model development via the parametric method.

13. Turbojet/turbofan, fixed-wing, standard
    Currently no data are available to support development of this generic model. It is recommended that an appropriate model be selected for model development via the parametric method.

14. Turbojet/turbofan, fixed-wing, small
    Currently no data are available to support development of this generic model. It is recommended that an appropriate model be selected for model development via the parametric method.

15. Turbojet/turbofan, fixed-wing, HALE
    The Global Hawk model is recommended to fulfill this need.

List of Acronyms and Variables

ACZR	AirCraft Data Analyzer
ANG-C41	FAA Advanced Operational Concepts Division, Concept Development & Validation Branch
ARTCC	Air Route Traffic Control Center
BADA	Base of Aircraft Data
BVLOS	Beyond Visual Line of Sight
CPT	Conflict Probe Tool
disa	Delta temperature from International Standard Atmosphere
ERAM	En-Route Automation Modernization
FAA	Federal Aviation Administration
fpm	feet per minute
ft	foot/feet
HALE	High-altitude, Long-endurance
ICAO	International Civil Aviation Organization
ISA	International Standard Atmosphere
J	Jet-engined Aircraft
K	Kelvin
KATL	Atlanta, Hartsfield Airport
kg	kilograms
KSEA	Seattle Airport
kts	knots
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NIEC	NextGen Integration and Evaluation Capability
P	Piston-engined Aircraft
sec	seconds
sUAS	Small UA
T	Turboprop-engined Aircraft
TAS	True Air Speed
TOC	Top of Climb
TOD	Top of Descent
UA	Unmanned Aircraft
UAS	Unmanned Aerial System

URET	User Request Evaluation Tool
VLOS	Visual Line of Sight
vmnvr	Vertical maneuver
VR	Vertical Rate
VTOL	Vertical Take-off and Landing

Variables

W	Weight
S	Wing Area
b	wing span
AR	aspect ratio
C_{D0}	profile drag coefficient
K	induced drag coefficient
e	Oswald efficiency factor
Thr	Powerplant Thrust
h	altitude
$\dot{h}$	altitude rate
$\zeta_{\dot{h}}$	Altitude rate metric
ζ	Speed metric
f_{D_i}	Induced Drag Factor
f_{D_i/D_0}	Drag Ratio Factor
m	Mass
$\dot{m}$	Mass rate, which for aircraft is fuel burn
V	True airspeed
V_e	Modeled true airspeed
V_a	Actual true airspeed (from data)
σ_a	Standard deviation
$f\{M\}$	Energy share factor
D	Drag
$\sigma_{\dot{h}}$	Standard deviation in altitude rate
ρ	Air density
M_{max}	Maximum takeoff mass
γ	Flight path angle
C_L	Lift coefficient

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Appendix

The data in the table of this appendix is a selection of unmanned aircraft manufactured in the US, the UK, and Israel. The data are extracted from the 2013 UAV Roundup (AIAA 2013). The information in the "Category" and "Subcategory" columns is added by the author in an attempt to classify these unmanned aircraft per Table 9.

Country	Prime	Designation	Status	Launch/Propulsion	Category	Subcategory
Israel	Aeronautics Defense	Aerolight	Completed	C-L - P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Aeronautics Defense	Aerostar	In production	Fuel injection - P-P	Electric/Internal Combustion	S - Standard
Israel	Aeronautics Defense	Dominator	In production	Dual turbodiesel	Turboprop fixed-wing	S - Standard
Israel	Aeronautics Defense	Picador	In production	G-Rotary	Vertical take-off & Landing (VTOL)	NS - Non-standard small
Israel	Aeronautics Defense	Orbiter I	In production	C-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Aeronautics Defense	Orbiter II	In production	C-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Aeronautics Defense	Orbiter III	In production	C-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Aeronautics Defense	Aerosky	Completed	G-L, C-L - P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Bluebird Aero Systems	Blueye	Completed	G-L - Prop	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Bluebird Aero Systems	Boomerang	Completed	C-L - Electric P-P	Reciprocating/electric fixed-wing	NH - Non-standard HALE
Israel	Bluebird Aero Systems	MicroB	In production	Hand-held launcher - P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Bluebird Aero Systems	SpyLite	In production	C-L - Electric	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Bluebird Aero Systems	ThunderB	In production	C-L	Reciprocating/electric fixed-wing	NH - Non-standard HALE
Israel	Bluebird Aero Systems	WanderB	In production	G-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Innocon	MiniFalcon I	Under way	P-P - C-L	Turboprop fixed-wing	NH - Non-standard HALE
Israel	Innocon	Minifalcon II	Under way	C-L, G-L	Reciprocating/electric fixed-wing	NH - Non-standard HALE
Israel	Innocon	MicroFalcon I	Under way	Joined-wing - B-L	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Innocon	Spider	Under way	Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Innocon	Falcon Eye	Under way	P-P - AvGas	Reciprocating/electric fixed-wing	NH - Non-standard HALE
Israel	Israel Aircraft Industries (IAI)	Birdeye 400	In production	Electric - BL or HL	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Birdeye 650 .	Completed	Electric - BL, C-L	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	ETOP	In development	Tethered - Electric rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small

Country	Prime	Designation	Status	Launch/Propulsion	Category	Subcategory
Israel	Israel Aircraft Industries (IAI)	Ghost	In development	G-L - Electric	Vertical take-off & Landing (VTOL)	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Harop			Turboprop fixed-wing	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Heron 1/Mahatz 1	In production	G-L - HF PP	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Heron TP	In production	G-L - Turbo P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Hunter	Completed	HF - RATO	Turbojet fixed-wing	S - Standard
Israel	Israel Aircraft Industries (IAI)	Panther VTOL	In production	G-L - Electric	Vertical take-off & Landing (VTOL)	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Mini-Panther VTOL		G-L, S-L - Electric	Vertical take-off & Landing (VTOL)	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Mosquito		H-L, B-L -Elec. prop	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Naval Rotary UAV (NRUAV)	Under way	S-L - GAS rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
Israel	Israel Aircraft Industries (IAI)	Searcher III	Under way	GAS P-P	Vertical take-off & Landing (VTOL)	S - Standard
Israel	Israel Military Industries	ATALD	Completed	A-L	Turboprop fixed-wing	NS - Non-standard small
Israel	Steadicopter	Black Eagle-50	Completed	G-L - Rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
Israel	TopiVision	Casper 250	Under way	H-L, B-L -Elec. prop	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	TopiVision	TAS	Under way	Tethered LTA	Airship	NS - Non-standard small
Israel	Urban Aeronautics	AirMule II	Under way	Turboshaft	Vertical take-off & Landing (VTOL)	NS - Non-standard small
Israel	UVision Global Aero Systems [nee EMIT]	Blue Horizon 2	Completed	C-L, G-L - Elec. P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	UVision Global Aero Systems [nee EMIT]	Butterfly	Under way	GAS	Vertical take-off & Landing (VTOL)	NS - Non-standard small
Israel	UVision Global Aero Systems [nee EMIT]	Griffon	Under way	Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	UVision Global Aero Systems [nee EMIT]	Marabou	In development	H-L - Elec. P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	UVision Global Aero Systems [nee EMIT]	Sparrow N	Under way	Piston P-P - C-L	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	UVision Global Aero Systems [nee EMIT]	WASP		Canister - Elec. P-P	Reciprocating/electric fixed-wing	NS - Non-standard small

Country	Prime	Designation	Status	Launch/Propulsion	Category	Subcategory
Israel	UVision Global Aero Systems [nee EMIT]	Dragonfly DF 16B	Under way	Piston - R-L	Reciprocating/electric fixed-wing	NS - Non-standard small
Israel	UVision Global Aero Systems [nee EMIT]	Dragonfly 2000	Under way	Piston - R-L, G-L	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	BAE Systems with Dassault Aviation	Herti XPA-1B	Unknown	G-L - P-P	Turboprop fixed-wing	NH - Non-standard HALE
U.K.	BAE Systems with Dassault Aviation	Mantis	In development	G-L - P-P	Turboprop fixed-wing	NH - Non-standard HALE
U.K.	BAE Systems with Dassault Aviation	Telemos	In development		Turbojet fixed-wing	NH - Non-standard HALE
U.K.	BAE Systems with Dassault Aviation	Taranis	Testing	G-L - Turbofan	Turbojet fixed-wing	NH - Non-standard HALE
U.K.	Barnard Microsystems Ltd.	InView	Under way	G-L - AvGas twin prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	Barnard Microsystems Ltd.	VuFab	Under way	G-L - GAS Prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	Cranfield Aerospace with Tasuma	Observer	Under way	C-L - Gas P-P	Turbojet fixed-wing	S - Standard
U.K.	Cranfield Aerospace with Tasuma	MinO	Testing	C-L -	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	CyberFlight	CyberEye II	In production	G-L - Electric or gas P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	CyberFlight	CyberEye II	Deployed	G-L - GAS P-P	Vertical take-off & Landing (VTOL)	NH - Non-standard HALE
U.K.	CyberFlight	CyberQuad	In production	G-L - Elec. multirotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.K.	CyberFlight	DM-65	In production	G-L - Elec. multirotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.K.	CyberFlight	Dominator	In production	G-L - Elec. multirotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.K.	CyberFlight	E-SwiftEye	In production	H-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	CyberFlight	Maveric	In production	H-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	CyberFlight	Midge	In production	H-L - Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	CyberFlight	Zygo	In production	H-L - Elec. or gas prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	Meggitt Defence Systems	Banshee	Deployed	C-L -	Reciprocating/electric fixed-wing	S - Standard
U.K.	Meggitt Defence Systems	Snipe	Deployed	H-L, C-L (land/sea) - Gas P-P	Electric/Internal Combustion	NS - Non-standard small
U.K.	Meggitt Defence Systems	Voodoo	Deployed	C-L - Gas prop	Electric/Internal Combustion	NS - Non-standard small
U.K.	Singular Aircraft	SA03	In development	G-L - Gas prop	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.K.	Skyships	C1000	Under way	G-L - Gas or Elec.	Airship	NS - Non-standard small

Country	Prime	Designation	Status	Launch/Propulsion	Category	Subcategory
U.K.	Tasuma	Hawkeye III	In production	H-L or C-L / Elec.	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	Tasuma	FR Raven II	Testing	C-L	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	Tasuma	Vindicator	Low-rate prod	AR731 rotary		S - Standard
U.K.	Tasuma with Cranfield	Observer	Under way	C-L - Gas P-P	Turbojet fixed-wing	S - Standard
U.K.	Tasuma with Cranfield	MinO	Testing	C-L -	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	Thales	Watchkeeper WK450	Deployed	P-P	Turboprop fixed-wing	S - Standard
U.K.	UAVSI	Vigilant	Completed	Electric	Turboprop fixed-wing	S - Standard
U.K.	UTS	GSAT-200	Under way	C-L - Gas prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	UTS	MSAT-500/NG	Under way	C-L - Gas P-P		NS - Non-standard small
U.K.	UTS	Mercury	Under way	Piston - C-L	Turboprop fixed-wing	NH - Non-standard HALE
U.K.	UTS	Vigilant	Under way	C-L -Electric prop	Turboprop fixed-wing	S - Standard
U.K.	Warrior (Aero-Marine Ltd.)	GULL 24 UXV	Under way	G-L, Water- L - Gas prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	Warrior (Aero-Marine Ltd.)	GULL 44 UXV	Under way	G-L, Water- L - Gas prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.K.	Warrior (Aero-Marine Ltd.)	GULL 68 UXV	Under way	G-L, Water- L - Gas prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	AAI	RQ-7B Shadow 200 TUAS	Completed	Hydraulic launch; rotary MOGAS engine	Reciprocating/electric fixed-wing	S - Standard
U.S.	AAI	Shadow 400	Completed	P-P	Reciprocating/electric fixed-wing	S - Standard
U.S.	AAI	Shadow 600	Completed	Rotary P-P	Reciprocating/electric fixed-wing	S - Standard
U.S.	AAI	Orbiter		C-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	AAI	XMQ-19A Aerosonde 4.4	Under way	C-L - FI Gas P-P	Reciprocating/electric fixed-wing	S - Standard
U.S.	AAI	XMQ-19A Aerosonde 4.7	In development			
U.S.	Advanced Defense Technologies Reconnaissance	Amphibious UAV	In production	G-L, W-L - Gas prop	Electric/Internal Combustion	S - Standard
U.S.	Advanced Defense Technologies Reconnaissance	Electric UAV	In production	G-L - Electric P-P	Reciprocating/electric fixed-wing	S - Standard

Country	Prime	Designation	Status	Launch/Propulsion	Category	Subcategory
U.S.	Advanced Defense Technologies Reconnaissance	Electric Tactical UAV	In production	G-L - Electric prop	Reciprocating/electric fixed-wing	S - Standard
U.S.	Advanced Defense Technologies Reconnaissance	Gasoline UAV	In production	G-L - Gas or electric P-P	Reciprocating/electric fixed-wing	S - Standard
U.S.	Advanced Defense Technologies Reconnaissance	Advanced Intelligent	Testing	C-L		NS - Non-standard small
U.S.	Advanced Defense Technologies Reconnaissance	Seeker Wing				
U.S.	AeroVironment with DARPA	RQ-11B Raven	Completed	H-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	AeroVironment with DARPA	RQ-14 Dragon Eye	Deployed	B-L - Electric dual prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	AeroVironment with DARPA	RQ-20A Puma AE	Under way	H-L -Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	AeroVironment with DARPA	Shrike	In development	Electric multirotor	Reciprocating/electric fixed-wing	S - Standard
U.S.	AeroVironment with DARPA	Switchblade	In development	Tube-launched - Elec.	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	AeroVironment with DARPA	Wasp AE	Under way	H-L -Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	AeroVironment with DARPA	Global Observer	RDT&E	G-L - Hybrid liquid hydrogen/elec. prop	Reciprocating/electric fixed-wing	S - Standard
U.S.	AeroVironment with DARPA	Nano Hummingbird	Demonstrator	H-L - Elec.	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	American Dynamics Flight Systems	AD-150	Under way	G-L, S-L - AvGas twin turboprop	Turboprop fixed-wing	S - Standard
U.S.	Applewhite Aero	Bala B	In development	H-L - Electric	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Applewhite Aero	Jago B	In development	H-L - Electric	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Applewhite Aero	Invenio	In development	H-L - Electric	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Applied Research Associates	Nighthawk	Completed	H-L -Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Arcturus UAV Atair	T-15	Under way	C-L - Elec. or HF prop	Reciprocating/electric fixed-wing	S - Standard

Country	Prime	Designation	Status	Launch/Propulsion	Category	Subcategory
U.S.	Arcturus UAV Atair	T-16XL	Under way	C-L - Elec. or HF prop	Reciprocating/electric fixed-wing	S - Standard
U.S.	Arcturus UAV Atair	T-20	Under way	C-L - MoGas prop	Electric/Internal Combustion	S - Standard
U.S.	Arcturus UAV Atair	LEAPP Type I	Complete	G-L - Supercharged diesel	Electric/Internal Combustion	S - Standard
U.S.	Arcturus UAV Atair	Insect (LEAPP Type II)	Under way	G-L - GAS	Electric/Internal Combustion	S - Standard
U.S.	Arcturus UAV Atair	Micro LEAPP (Type III)	Complete	G-L - GAS	Electric/Internal Combustion	S - Standard
U.S.	Aurora Flight Sciences	Centaur	Under way	G-L - HF twin turboprop	Turboprop fixed-wing	S - Standard
U.S.	Aurora Flight Sciences	Excalibur	In development	G-L - Turbine-elec. hybrid	Reciprocating/electric fixed-wing	S - Standard
U.S.	Aurora Flight Sciences	Orion	In development	G-L - AvGas twin prop ducted rotor		S - Standard
U.S.	Aurora Flight Sciences	Skate SUAS	Under way	H-L, V-L - Electric	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Aurora Flight Sciences	SunLight Eagle	Experimental	G-L - Solar electric prop	Reciprocating/electric fixed-wing	S - Standard
U.S.	AutoCopter	E15	In production	VTOL - Electric rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	AutoCopter	G15	In production	VTOL - Electric rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	AutoCopter	HD65	In development	VTOL - Gas rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	BAE Systems	Coyote	Under way	A-L from sonobuoy tube - Electric P-P		
U.S.	BAE Systems	Manta B4	Under way	G-L - Gas reverse rotation tractor P-P		
U.S.	BAE Systems	Silver Fox D	Under way	C-L - Gas/elec. prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	BAI Systems [part of L-3 Communications]	XPV-1 Tern	Completed	GAS	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	BAI Systems [part of L-3 Communications]	Dragon	In production	GAS - R-L, RATO	Electric/Internal Combustion	
U.S.	Bihrle Applied Research	Mantra	In development	G-L, T-L		NS - Non-standard small
U.S.	Boeing Defense, Space & Security Phantom Works	A160T Hummingbird	Uncertain	G-L - Turboshaft rotor	Vertical take-off & Landing (VTOL)	S - Standard
U.S.	Boeing Defense, Space & Security Phantom Works	Phantom Eye	In development	C-L - Liquid hydrogen prop		NH - Non-standard HALE
U.S.	Boeing Defense, Space & Security Phantom Works	Phantom Ray	In development			NS - Non-standard small
U.S.	with NASA	Dominator	In development	C-L (air/land/sea/sub)	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	with NASA	ScanEagle	Deployed	C-L - Gas or HF P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	with NASA	NightEagle	In production	C-L - Gas or HF P-P	Electric/Internal Combustion	NS - Non-standard small

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U.S.	with NASA	Transonic Demonstrator	Still in concept		Turbojet fixed-wing	S - Standard
U.S.	DARPA	TERN	Solicitation March 2013	S-L	Vertical take-off & Landing (VTOL)	S - Standard
U.S.	Dragonfly Pictures	DP-5X	In production	HF - G-L	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Dragonfly Pictures	DP-6	In production	G-L - Electric	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Dragonfly Pictures	DP-12	LRIP	G-L - MOGAS -	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Dragonfly Pictures	DP-12T	In development	HF - G-L, S-L	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	DRS Unmanned Technologies	Sentry HP	Completed	G-L - Gas prop	Electric/Internal Combustion	NS - Non-standard small
U.S.	DRS Unmanned Technologies	RQ-15 Neptune	Completed	C-L (land/sea) - AvGas P-P	Electric/Internal Combustion	NS - Non-standard small
U.S.	Elbit Systems of America	Hermes 450	Deployed	G-L - Gas P-P		NH - Non-standard HALE
U.S.	Elbit Systems of America	Skylark I-LE	Deployed	H-L -Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Elbit Systems of America	Skylark Block 2	In development	H-L - HF prop	Electric/Internal Combustion	NS - Non-standard small
U.S.	General Atomics Aeronautical Systems	I-GNAT ER/Sky Warrior	Deployed	Turbo P-P	Turboprop fixed-wing	NH - Non-standard HALE
U.S.	General Atomics Aeronautical Systems	Predator (RQ-1A/MQ-1)	Deployed	Turbo P-P	Turboprop fixed-wing	NH - Non-standard HALE
U.S.	General Atomics Aeronautical Systems	Predator B (MQ-9 Reaper)	In production	Turboprop	Turboprop fixed-wing	NH - Non-standard HALE
U.S.	General Atomics Aeronautical Systems	MQ-1C Gray Eagle	LRIP	Thielert 135 HF	Turboprop fixed-wing	S - Standard
U.S.	General Atomics Aeronautical Systems	Guardian	Deployed	Turboprop	Turboprop fixed-wing	NH - Non-standard HALE
U.S.	General Atomics Aeronautical Systems	Predator XP		Rotax 914 turbo	Turboprop fixed-wing	NH - Non-standard HALE
U.S.	General Atomics Aeronautical Systems	Predator C Avenger	Testing	PW545B	Turboprop fixed-wing	NH - Non-standard HALE
U.S.	Griffon Aerospace	MQM-171A Broadsword	Under way	C-L target/G-L XL version	Reciprocating/electric fixed-wing	S - Standard
U.S.	Griffon Aerospace	MQM-170A Outlaw	In production	C-L, G-L - Electric P-P	Reciprocating/electric fixed-wing	S - Standard

Country	Prime	Designation	Status	Launch/Propulsion	Category	Subcategory
U.S.	Griffon Aerospace	MQM-170C Outlaw G2	In production	C-L - P-P	Reciprocating/electric fixed-wing	S - Standard
U.S.	Guided Systems Technologies	SiCX-10E	Deployed		Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Guided Systems Technologies	SiCX-25	Development completed	G-L - GAS	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Guided Systems Technologies	SiCX-75	Development under way	G-L - GAS	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Guided Systems Technologies	SiCX-290	Development under way	G-L - GAS	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Honeywell	T-Hawk	Under way	G-L - Gas ducted fan	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Innovative Automation Technologies (IAT)	Axo	Completed	H-L (land/sea) - Electric	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Innovative Automation Technologies (IAT)	Pelican		G-L - Dual electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Innovative Automation Technologies (IAT)	Point and Toss UAS		H-L	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Innovative Automation Technologies (IAT)	Saitis		VTOL - Quad electric	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Innovative Automation Technologies (IAT)	SkyStinger		H-L - Elec. EDF/Prop/P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Innovative Automation Technologies (IAT)	Lethal Miniature Aerial Munition System	In development			NS - Non-standard small
U.S.	Kaman Aviation	K-MAX UAT	Deployed	Single-engine twin rotor	Vertical take-off & Landing (VTOL)	S - Standard
U.S.	L-3 Unmanned Systems	Cutlass	Under way	Can (land/air) - Elec. P-P	Reciprocating/electric fixed-wing	S - Standard
U.S.	L-3 Unmanned Systems	TigerShark	Under way	G-L - Gas/oil P-P	Reciprocating/electric fixed-wing	S - Standard
U.S.	L-3 Unmanned Systems	Viking 100	Completed	ATOL - Gas P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	L-3 Unmanned Systems	Viking 300	Under way	ATOL - Gas P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	L-3 Unmanned Systems	Viking 400	Under way	ATOL - Gas P-P	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Lockheed Martin	Desert Hawk III	Deployed	H-L -Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Lockheed Martin	Fury 1500	In development	C-L - HF P-P	Electric/Internal Combustion	NS - Non-standard small
U.S.	Lockheed Martin	Indago	In development	Single-engine twin rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small

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U.S.	Lockheed Martin	Falcon HTV-2	In development	Hypersonic RATO		NH - Non-standard HALE
U.S.	Lockheed Martin	Stalker	Under way	H-L, B-L - Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Lockheed Martin	Stalker XE	Under way	B-L - SOFC prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Lockheed Martin	UCLASS	In development	S-L	Turbojet fixed-wing	NH - Non-standard HALE
U.S.	Lockheed Martin	VARIOUS	Concept			
U.S.	Lockheed Martin	X-56A	Testing			NH - Non-standard HALE
U.S.	Marcus UAV	Zephyr 2	Under way	H-L - Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Mission Technologies	BUSTER	In production	AvGas Prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Mission Technologies	E-BUSTER	In production	Electric P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	MLB	Bat 4	In production	G-L - Gas/oil P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	MLB	Super Bat	In production	C-L - Gas/oil or AvGas P-P	Electric/Internal Combustion	NS - Non-standard small
U.S.	MLB	V Bat	In production	G-L - gas/oil ducted rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	MMIST	CQ-10A	Deployed	VTOL - Single-eng. twin rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	MMIST	CQ-10B	Under way	VTOL - Gas rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Moller	Aerobot	In development	VTOL - Gas or electric ducted rotor	Vertical take-off & Landing (VTOL)	S - Standard
U.S.	Moller	Pathfinder				S - Standard
U.S.	Naval Research Lab	Ion Tiger	Testing	LH2 fuel cell	Electric/Internal Combustion	NS - Non-standard small
U.S.	Naval Research Lab	Stop-Rotor Rotary Wing Aircraft	In development	G-L - Elec. [hybrid possible]	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Northrop Grumman Aerospace Systems	EuroHawk (RQ-4E)	On hold	G-L - HF turbofan	Turbojet fixed-wing	NH - Non-standard HALE
U.S.	Northrop Grumman Aerospace Systems	RQ-4 Blocks 20/30/40 - Global Hawk	In production	G-L - Turbofan	Turbojet fixed-wing	NH - Non-standard HALE
U.S.	Northrop Grumman Aerospace Systems	X-47B UCAS-D	RDT&E	C-L S-L - Turbofan	Turbojet fixed-wing	NH - Non-standard HALE
U.S.	Northrop Grumman Aerospace Systems	Bat 12	Deployed	R-L, S-L - GAS or HF EFI P-P	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Northrop Grumman Aerospace Systems	MQ-4C Triton	Testing		Turbojet fixed-wing	NH - Non-standard HALE

Country	Prime	Designation	Status	Launch/Propulsion	Category	Subcategory
U.S.	Northrop Grumman Aerospace Systems	MQ-5B Hunter	Completed	Heavy fuel	Reciprocating/electric fixed-wing	S - Standard
U.S.	Northrop Grumman Aerospace Systems	MQ-8B FireScout	In production	VTOL - HF rotor	Vertical take-off & Landing (VTOL)	S - Standard
U.S.	Northrop Grumman Aerospace Systems	MQ-8C Fire Scout	LRIP	VTOL - Turbine FADEC rotor	Vertical take-off & Landing (VTOL)	S - Standard
U.S.	Proxy Aviation Systems	SkyRaider	Under way	G-L - Turbo P-P	Turbojet fixed-wing	NH - Non-standard HALE
U.S.	RotoMotion	SR5	In production	Electric	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	RotoMotion	SR7	In production	Electric	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	RotoMotion	SR20	In production	Electric	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	RotoMotion	SR30	In production	GAS	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	RotoMotion	SR100	In production	Electric or GAS	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	RotoMotion	SR125	In production	GAS	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	RotoMotion	SR200	In production	GAS	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	RotoMotion	SR200-A	In production	HF	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	Textron Defense Systems	Battlehawk	In development	G-L	Electric/Internal Combustion	NS - Non-standard small
U.S.	Textron Defense Systems	Shadow M2	Development under way	AvGas, HF - R-L, T-L	Electric/Internal Combustion	NS - Non-standard small
U.S.	Textron Defense Systems	Shadow 200	In production - deployed	AvGas - R-L, T-L		NS - Non-standard small
U.S.	Theiss Aviation	Ferret	Under way	H-L, B-L -Electric prop	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	Theiss Aviation	Super Ferret	Under way	H-L - Electric P-P	Reciprocating/electric fixed-wing	NH - Non-standard HALE
U.S.	Theiss Aviation	Tarzan TD-1c	Under way	G-L - Gas Prop	Electric/Internal Combustion	NS - Non-standard small
U.S.	UAV Factory	Penguin B	In production	G-L, R-L, T-L - Gas FI	Electric/Internal Combustion	NS - Non-standard small
U.S.	UAV Research Lab	Merlin 200	In production	G-L, C-L - GAS P-P	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	UAV Research Lab	Rotor Buzz	In production	G-L - GAS rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small
U.S.	UAV Research Lab	Silhouette	LRIP	G-L - GAS or electric	Reciprocating/electric fixed-wing	NS - Non-standard small
U.S.	WSGI	Argus One	Under way	LTA	Airship	S - Standard
U.S.	Xtreme Drones	Velocicopter	In production	Rotor	Vertical take-off & Landing (VTOL)	NS - Non-standard small