Selection of Optimal UAS Using Task Requirements and Platform Parameters to Optimize Operational Performance.

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Abstract

Literature on modeling and simulation (M&S) of unmanned aircraft systems (UAS) for the purpose of selecting the correct platform for specific applications has been limited. Most platforms are selected based on availability or popularity rather than systematically matching requirements and needs with system parameters and capabilities. Matching requirements with system capabilities makes sense from a business perspective because such organizations want tasking accomplished with efficiency, accuracy, minimal cost, and on schedule. For the past two years, the research team at Embry-Riddle Aeronautical University has been collecting data and specifications on available commercial-off-the-shelf (COTS) group 1 – 3 fixed wing and vertical take off and landing (VTOL) UAS (U.S. Army UAS Center of Excellence, 2010), available in domestic and international markets. A database of 500 UAS has been compiled for use in modeling and simulation of various platforms for select applications. The applications examined to date using M&S include 1) Airport Rescue and Fire Fighting (ARFF), 2) remote sensing perimeter flight, and 3) aerial communications relay. Results indicate that selection of optimal UAS offered significant savings in terms of time, cost, and efficiency of operations. Implications for future selection and use for the specific applications are discussed.

Keywords
UAS, Operational Performance, Task Analysis, ARFF, Infrastructure Inspection, Aerial Communications Relay

1. Introduction

Use of modeling and simulation (M&S) in business and research has been a widely accepted practice for decades. Accurate modeling of a system can provide the ability to simulate events or operations to obtain accurate, reliable results. The main reason for simulation’s popularity is its ability to deal with complicated models of correspondingly complicated systems [1]. M&S can provide an inexpensive and lower risk alternative to conducting experimentation with real prototype units or on multiple units, with significantly varying characteristics and performance parameters. Simulation can also provide improved control of extraneous variables and generate reportable metrics in a more useful manner than conventional experimentation alone. This is achievable, in large part, due to the flexibility afforded through use of many different kinds of simulations by allowing alteration of environmental configurations and unit/system parameters to accommodate a number of variations in potential experimental factors. These factors typically require consideration and attention, when evaluating the performance of varying platforms under less than ideal conditions in real-world settings.

This paper contains discussion of an ongoing research project featuring the use of M&S to examine relevant factors of UAS platform configurations across multiple applications. Operational performance parameters of 500 commercial-off-the-shelf (COTS) UAS platforms were identified, cataloged, and analyzed to create a series of representative performance models to be used in M&S experimentation. These models were used to generate data for subsequent statistical analysis of platform performance and determine end-suitability for use in potential applications. Observations and finding of this research offer insight toward the practical use of M&S to support UAS performance modeling and application analysis. The application modeling described features discussion of the functionality and
selection of UAS platform types that are best suited for specific applications, based on identifiable performance parameters.

2. Purpose

The following represent those applications that have been examined, to date, in this research project: 1) Airport Rescue and Fire Fighting (ARFF) response, 2) remote sensing perimeter flight, and 3) aerial communications relay. These three areas contain tasking that is representative of typical uses of many unmanned aircraft platforms and may be widely applicable to a broader area of tasking in the near future as Federal Aviation Administration (FAA) regulations become better defined. Thorough understanding of the potential uses and detailed review and comprehension of the capabilities and limitations of existing UAS platforms can assist in the selection of appropriate and optimal configurations, as well as subsequent operational planning tasks [2]. Evaluation of the anticipated tasking in relevant context is essential for accurate assessment of potential system performance. Previous preliminary assessment of UAS platforms in the area of UAS-ARFF response has produced promising results [2, 3]. This paper expands upon this earlier research and extends into two new application areas, perimeter flight and aerial communications relay.

3. Method and Experimentation

A series of calculations were created to determine accurate measures for the different operational applications. The calculations across all types of operational applications included computation of UAS flight parameters, visualization parameters, speed, maneuvers, and timing to arrive at the final results. The final results included a series of calculations (customized to each application) to determine total distance traveled, duration of operation, state of endurance (available or exceeded), state of range (available or exceeded), and time required to reach the site and return to point of origin for direct travel [2].

Each operation had some commonalities, yet each mission had a different purpose. Individual operational application included a launch, fly direct to target area, execute pre-determined orbit, return to point of origin, and landing/recovery phase. The platforms were differentiated by its specific performance parameters and payload capabilities. For example, the UAS ARFF operational application requires fast response to an unexpected emergency with high resolution video, possibly infra-red (IR) capability, and moderate endurance. The UAS perimeter flight analysis requires high endurance with high resolution video capability for inspection, security, and aerial filming. The UAS communications relay analysis requires long endurance with specialized communications relay equipment and capability.

3.1 sUAS Operational Analysis and Platform Selection

To provide an effective analysis for a range of platforms, a series of statistical analysis profiles of sUAS were generated, based upon the various performance features and capabilities, termed attribute performance models (APMs) [2]. The APMs developed for this research included the following platforms characteristics: speeds (cruise and maximum), altitudes (operational and maximum), endurance, range at cruise speed, weights (empty and maximum), payload capacity, propulsion type (internal combustion or electric), wind limit, and platform cost [2, 3]. Some of these parameters were used to support platform categorization (e.g., speeds, altitudes, weights, and propulsion type) and some were used for flight performance calculation (see. Table 1). The APMs include categories of sUAS (less than 55 pounds) and Micro UAS (less than 4.4 pounds) [4, 5] as well as a series of subcategories based on observable features and characteristics.

<table>
<thead>
<tr>
<th>UAS APM Type</th>
<th>Cruise Speed (kts)</th>
<th>Maximum Speed (kts)</th>
<th>Endurance (minutes)</th>
<th>Range (SM)</th>
<th>Wind Limit (kts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sUAS FW</td>
<td>34.29</td>
<td>61.83</td>
<td>201.81</td>
<td>158.57</td>
<td>26.31</td>
</tr>
<tr>
<td>sUAS VTOL</td>
<td>21.39</td>
<td>35.01</td>
<td>54.77</td>
<td>42.97</td>
<td>23.25</td>
</tr>
<tr>
<td>sUAS Elec</td>
<td>25.25</td>
<td>43.98</td>
<td>63.13</td>
<td>39.98</td>
<td>24.43</td>
</tr>
<tr>
<td>sUAS IC</td>
<td>42.22</td>
<td>73.71</td>
<td>444.48</td>
<td>403.63</td>
<td>24.89</td>
</tr>
<tr>
<td>Micro FW</td>
<td>23.45</td>
<td>45.39</td>
<td>52.14</td>
<td>22.71</td>
<td>19.45</td>
</tr>
<tr>
<td>Micro VTOL</td>
<td>17.06</td>
<td>27.43</td>
<td>21.87</td>
<td>9.02</td>
<td>17.06</td>
</tr>
</tbody>
</table>
Within the sUAS category, four types of subcategories were included, fixed-wing (FW), vertical takeoff and landing (VTOL), electric (Elec), and internal combustion (IC). Fixed-wing (sUAS FW) represent those platforms that feature horizontal takeoff and landing and rely on lift generation from a wing or multiple wings. The platforms in this category are typically hand launched or need a small area in which to accelerate to flight speed prior to takeoff. VTOL (sUAS VTOL) represent those platforms that are launched vertically and then transition to translational or forward flight, returning to vertical flight for recovery. Many sUAS VTOL feature conventional rotary-wing (single rotor with variable pitch, collective, and tail rotor) or multiple rotor (e.g., tandem, dual counter-rotating, intermeshing, or fixed-pitch multirotor) configuration where lift is generated through variable rotation of rotor blades. A limited number of sUAS VTOL feature design traits of fixed-wing, but have incorporated unique means of achieving VTOL to transition between vertical and horizontal flight [6]. Further subcategorization was used in this study to differentiate between electric and IC propulsion source. Electric (sUAS Elec) represents those platforms featuring electrically driven motors, thus requiring batteries for functionality. IC (sUAS IC) represents those relying on use of conventional reciprocating, combustion engines and therefore necessitate the carriage and distribution of liquid fuels [2, 3]. The Micro UAS categories included fixed-wing (Micro FW) and VTOL (Micro VTOL) platforms. However, all of the Micro UAS examined in the course of this research only featured use of electric propulsion, therefore no differentiation was made in this category for propulsion source. Lastly, an experimental category was included in the study to manipulate specific metrics (i.e., cruise speed and endurance) to observe results based on experimentation. This model was used to identify minimum performance requirements or to determine the effectiveness of individual platforms, if performance metrics were known [2]. Once the APMs were generated, the various categories and subcategories were collated for use within the M&S analysis.

### 3.2 UAS-ARFF Response Analysis

The continued goal of this project was to assess mission parameters (needs) and match with appropriate equipment, while taking into account prior recommendations and factors that could affect operational performance and safety. Implications for addressing challenges are discussed as they relate toward optimizing benefits, effectiveness, safety, and specified application support. Observations and findings of this investigation indicate the effectiveness of simulated UAS performance modeling, and application analysis, in addition to identification of specific UAS platform types to support the subject application (ARFF response operations). UAS platforms were considered suitable for this application if they were able to arrive on scene faster than conventional ARFF response and were capable of relaying video information back to first responders before they arrived on scene.

This aspect of the research also included development of six baseline APMs (group 1-3 fixed-wing and VTOL), which were used to create the six previously described category models, in addition to two custom UAS-ARFF APM categories; tube-launched and optimal (see Table 2; performance updated with values from latest database results).

<table>
<thead>
<tr>
<th>UAS APM Type</th>
<th>Cruise Speed (kts)</th>
<th>Maximum Speed (kts)</th>
<th>Endurance (minutes)</th>
<th>Range (SM)</th>
<th>Wind Limit (kts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 FW</td>
<td>29.39</td>
<td>53.19</td>
<td>82.87</td>
<td>47.78</td>
<td>27.11</td>
</tr>
<tr>
<td>Group 1 VTOL</td>
<td>19.52</td>
<td>31.57</td>
<td>30.53</td>
<td>19.55</td>
<td>21.07</td>
</tr>
<tr>
<td>Group 2 FW</td>
<td>41.96</td>
<td>75.33</td>
<td>395.77</td>
<td>326.53</td>
<td>22.66</td>
</tr>
<tr>
<td>Group 2 VTOL</td>
<td>25.65</td>
<td>42.84</td>
<td>111.77</td>
<td>92.47</td>
<td>27.12</td>
</tr>
<tr>
<td>Group 3 FW</td>
<td>53.04</td>
<td>91.91</td>
<td>523.38</td>
<td>557.51</td>
<td>23.61</td>
</tr>
<tr>
<td>Group 3 VTOL</td>
<td>42.41</td>
<td>68.63</td>
<td>238.60</td>
<td>217.38</td>
<td>27.27</td>
</tr>
<tr>
<td>Tube-launched</td>
<td>43.50</td>
<td>77.71</td>
<td>81.67</td>
<td>62.58</td>
<td>125</td>
</tr>
<tr>
<td>Optimal-ARFF</td>
<td>35.03</td>
<td>60.21</td>
<td>95.68</td>
<td>60.07</td>
<td>36.32</td>
</tr>
</tbody>
</table>

### 3.3 sUAS Perimeter Flight Analysis

A series of flight scenarios (trials; 30) were developed to calculate and identify performance results of simulated sUAS model APMs to highlight characteristics and requirements necessary to successfully complete typical remote sensing perimeter flight for the capture of spatial and temporal data [7, 8]. The simulated trials were designed to be representative of sUAS circuit flight around a feature or region, including terrain or structures, and were subcategorized into inspection, security, aerial filming, or research purposes (see Figure 1). These subcategories reflect
common uses of sUAS, including governmental operations to support the provision of emergency and conventional services [5], as well as civil operations, such as research and the capture of marketing video [9].

For simplicity, each flight path was designed to contain two primitive longitudinal legs (North and South) and two latitudinal (East and West) [7]. The northwest origin position and dimensions of the flight in statute miles (SM) were also identified and used to calculate the resultant flight area size (SM^2) and flight distance (SM; based on number of circuits). The flight distances ranged from .32 to 8SM, with a mean of 2.34SM across the trials. In addition, average annual wind values for given locations were captured and used among the scenario and model performance calculations [10]. These wind values ranged from 5.72 to 10.36kts, with a mean of 8.77kts.

The six previously described sUAS APMs were examined, in addition to a customizable experimental model, which could be modified as needed. The performance of each model was calculated using the flight distance, number of circuits, platform cruise speed (in knots [kts]), endurance (in minutes), average wind speed (kts), and a five-minute power reserve (in accordance with proposed rules for operation of sUAS) [4, 5]. The resultant values were used to further calculate the time to transit the circuit (in minutes), total time to transit perimeter flight (in minutes), total endurance remaining at completion of flight (in minutes), and state of platform, as it related to proposed flight (i.e., acceptable performance, insufficient reserve, or insufficient endurance). Wind directions and magnitude were calculated originating and perpetuating from several directions, over the entire duration of each flight. Head-wind, tail-wind, and crosswind effects for all three directions were determined, with the direction exhibiting the longest completion timing being selected to support evaluation for worst case scenario. If the speed of the platform was equal to or less than the wind speed, it was deemed unsuitable (wind too high) and the performance was reported as a 0 for the given trial. The results of model performances across the trials was used to determine a series of minimum values for use in identifying suitable sUAS platforms.

The filtering and identification of recommended platforms was dependent on the development of a speed-endurance lookup table, derived from experimental modification of the customizable model and observation of values across the trials, to determine minimum performance required to successfully achieve 100 percent trial completion. The resulting table exhibited the relationship between cruise speed and endurance, where endurance decreased at a non-constant rate, as the speed increased. This table contained a series of speed-endurance pairings, ranging from 15kts to 87kts with corresponding endurance values from 62 to 8 minutes. Each of the speed-endurance pairs were used to calculate a minimum range necessary to achieve flight completion across all the trials. To improve the likelihood of flight completion, given dynamic real world conditions, the highest calculated range value was used (18.69SM), along with the maximum wind speed reported in the source data (15kts), to filter possible sUAS platform options from the UAS database. Upon completion of the analysis, 49 of the 379 sUAS platforms were identified as exhibiting suitable performance to support the modeled perimeter flights; 36 fixed-wing (sUAS FW), 13 VTOL (sUAS VTOL), 42 electric (sUAS Elec), seven internal combustion (sUAS IC), and five micro fixed-wing (Micro FW), while none of the Micro VTOL platforms provide sufficient performance to meet the identified operational requirements.
3.4 sUAS Communications Relay Analysis

The utility of unmanned aircraft as aerial communication network platforms has been demonstrated through extensive military research and application [11, 12, 13]. This concept has begun to grow in the domestic market, with companies such as Facebook and Google exploring use of the platforms to provide long endurance coverage to remote areas [14], and governmental agencies looking to further support emergency response efforts [15, 16, 17]. In support of better understanding the potential suitability of sUAS and identification of specific platforms capable of completing these types of operations, an analysis and series of simulated trials were developed.

The 30 flight scenario trials originally developed for the perimeter flight analysis were modified by changing the shape of the flight path from a polygon to a circle (see Figure 2) and including a randomly generated number of circuits (1 to 10). Modifying the shape of the flight path geometry required calculation of the circumference of the circular path, where the circumference is equal to two times Pi times the radius \( C = 2\pi r \). This circumference represented the flight distance (in SM) of a single circuit. The trials were designed to be representative of sUAS circuit flight over the same regions used in the perimeter flight analysis, which required recalculation of the flight path routes using the average lengths of the legs from the previous routes. These modifications resulted in an increase to the cumulative flight distance per flight ranging from .5 to 12.56SM, with a mean of 3.67SM.

![Figure 2: Examples of sUAS communication relay flights](image)

The six previously discussed sUAS APMs were examined, in addition to the customizable experimental model, which was modified to calculate applicable values for the speed-endurance lookup table. As with the perimeter flight, the results of the experimental model’s performance was used to calculate minimum performance required to achieve 100 percent trial completion. The lookup table cruise speed values ranged from 15 to 87 knots, with corresponding endurance from 583 to 105 minutes, based on increased cumulative flight distance associated with function of the platform as a communication relay. The minimum range necessary was calculated as 173.94SM. Upon completion of the analysis, five of the 379 sUAS platforms were identified as exhibiting suitable performance to support communications relay application; three fixed-wing (sUAS FW), two VTOL (sUAS VTOL), and five internal combustion (sUAS IC), while none were electric (sUAS Elec) or micro platforms (Micro FW or Micro VTOL).

4. Conclusions

The operational applications described in this research are representative of UAS applications that will be common in the near future. As the FAA makes progress in defining operational rules and guidelines for UAS use in the National Airspace System (NAS), UAS for commercial, civilian, and emergency use will increase dramatically. Government agencies, commercial entities, and individuals will need to be informed of the capabilities and limitations of the multitude of platforms available for use in order to select appropriate systems that are efficient and cost effective based on needs and requirements of the intended use. This data could be used by future users to select the most appropriate system for commercial use or it could be used by system designers to modify future platforms to become more suitable for use in specific applications. In this research, a number of potential platforms were identified as suitable for three specific operational applications through the use of modeling and simulation. By identifying needs specific to operational applications and matching those needs to specific system capabilities, improvement to system design and
efficiency of operation can be easily achieved as the functionality and utility of these new technologies become more available and ready for use. With so many platforms available for selection, advocates of M&S utilization for these purposes will clearly benefit when making decision to purchase units suitable for their specific operational applications.

References