Context Note

The following document addresses the ongoing debate over the usage and implementation of unmanned aerial vehicles (UAVs) in US agriculture. Although scientists have long since held the position that they will present an enormous agricultural and economic benefit for the country, a wide rollout of drones has been continually delayed by the Federal Aviation Administration (FAA).

The audience of this paper is The Boeing Company, more widely known as Boeing. I will specifically be writing to the Product Strategy & Future Airplane Development division. This subdivision specifically handles the development of new commercial technologies meant to operate in federal airspace. I will be submitting this document directly to this team. No company has yet announced a project with an underlying concept similar to the one discussed in this proposal.

I will be referring to several technical terms in this document which may only be known to readers with a sufficient background in UAV technology. The term 'payload' refers to the carrying capacity of an aircraft, including but not limited to fuel, cargo, and scientific instruments. A 'quadcopter' refers to a helicopter propelled by four rotors. A 'fixed-wing' aircraft is similar to an airplane, which use the wing shape and forward airspeed to generate lift. The NDVI system is the 'normalized difference vegetation index,' and refers to a measurement tool used to analyze farmland. It supports applications as simple as describing the color of the observed plot of land, to high-quality image analyses which can locate and identify separate crop species.

A Proposal Regarding a Design Approach for the Sale of Unmanned Aerial Vehicles in U.S. Precision Agriculture

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Abstract

The two current approaches to introducing unmanned aerial vehicles (UAVs) to the field of precision agriculture are insufficient and unsustainable, and are the cause of a multi-billion dollar market remaining stagnant. The major obstacle in their path to implementation is the Federal Aviation Administration (FAA), which has passed strict regulations mandating UAV approval for sale in the US. Most companies are approaching this as a solvable engineering problem when it instead stands as an unsolvable legislation issue. Therefore, the best approach to enter the current agricultural UAV market is to develop single-purpose drones which can easily pass FAA regulations, but which are supplied with a uniform software package and user interface (UI) so that data can be passed between different modules. This method significantly reduces research, development, and manufacturing costs while remaining the most versatile and usable option available to the consumer.

Problem Overview

The US precision agricultural market has long awaited the wide-range implementation of UAVs in order to reduce the need for human labor and to increase crop yield. The value of this industry is currently estimated to be approximately $10 billion (Freeman & Freeland, 2015), while the worldwide UAV market will soon total $89 billion. However, the FAA has introduced legislation which requires newly-developed UAVs to first pass a series of rigorous tests, which limit variation in the product. These laws eliminate several features which customers favor, such as autonomous flight and large chemical payloads. Bound to these constraints, companies have been attempting to dominate the agricultural UAV market over the last decade, with little success.

There are currently two design models which are most popular for UAV manufacturing and together account for every product currently available. Every competitor with a large amount of capital is focusing on inventing a single machine which can fulfill all the needs on a farm while remaining within FAA guidelines. They are unknowingly attempting to solve an impossible problem. Their product will only receive FAA approval for sale after years of rigorous tests. This timeline is far too long to capitalize on the current market need. In opposition, smaller companies are releasing individual drones each specializing in a single process. They then continually optimize that design and release updated models, but provide no unified software package to interface with other drones. The lack of uniformity and a clean UI presents limitations on the capacity to which data can be extrapolated from the convergence of multiple sets. In turn, although the FAA is more likely to approve them for sale, the consumer is less likely to buy these products.

In this paper, an alternative design method will be presented. It is of great significance that the highest-quality drones are manufactured for the lowest cost, trimming away any excessive features to focus on the needs of the customer. Agricultural drones do not need many of the features that civilian drones must have to market and sell themselves. By focusing on manufacturing a line of UAVs each built for a single purpose but with an integrated software package and UI, Boeing can achieve superior results to the multipurpose machine at a lower manufacturing cost and with streamlined FAA approval.

Solution Benefits

The benefits of the proposed approach are numerous for manufacturer, customer and the FAA. By forgoing attempts to invent new technology for the multipurpose drone, research costs will be significantly reduced. This process would have the added benefit of being much more cost-efficient for the customer. To exemplify, the only all-in-one model to receive approval for sale in the US is the Yamaha RMax, which has a base price of $100,000 and a premium package costing $1,000,000 (Hanlon, 2004). It also took over twenty years and 2 million flight hours in a dozen countries for the FAA to approve its domestic sale because it failed to fall under all the necessary criterion. Waiting two decades between a product’s release and its approval for sale should not be a strategy under any serious consideration. Instead, three single-purpose drones accomplishing the same tasks as the RMax would altogether cost between $10,000 and $50,000 (Mondino & Gajetti, 2017) and could receive the approval for sale much more quickly. This allows Boeing to greatly profit from having a product which does not struggle to pass FAA regulation but will not need to compromise on its functionality to do so.

It is essential to understand the specific characteristics of the FAA legislation which the proposed solution must meet. The major tests which yield FAA approval for sale include adherence to payload capacity, flight altitude limits, and autonomous navigation capabilities. They can be remotely operated only if they remain within the line-of-sight of the operator. Additionally, state legislatures implement rules on UAV-usage, many of which introduce severe constraints on autonomy. This renders autonomous navigation capabilities as an unnecessary luxury on agricultural drones; remote operation remains as the only viable option. In addition, a UAV operating in the US is limited to a 55 lb. payload (Freeman & Freeland, 2014). A drone built with functionality to address crop spraying, camera monitoring, radio communication, and in-flight data processing will quickly exceed the weight limitation. The maximum weight of the RMax exceeds 200 lbs., which is one of the major reasons its release in the US was delayed for two decades. On average, the price of a UAV increases by $2,360 for every additional kilogram of weight (Marinello *et al*, 2017). By designing a line of drones which each address a single purpose (one drone for crop spraying, one for radio communication, etc.), the cost for the manufacturer and the customer remain low while each individual drone will easily fall within federal restrictions (Zhang & Kovacs, 2012).

Cost Analysis

As previously mentioned, the Yamaha RMax has a premium model costing $1,000,000. However, Yamaha has overlooked some key details in the US market which prevent the RMax from becoming a dominant product (Amenyo et al., 2014). It was developed for use in Japan, where UAV laws are much more loose. Its two autonomous airframes are unnecessary when the FAA has already stated autonomous drones will not be approved for mass sale. Accessories included in the package such as ground stations, antennas, and computer monitors serve no purpose when the drone is required to be remotely piloted within a set distance. These features enabled the RMax to become extremely popular in Japan, but did not lead to success in the US. This is the key economic market which should be Boeing's goal. The American industry is under lock by the FAA, and until the time when their legislation is relaxed, it is best to remain well under their thresholds in order to sell products.

It was mentioned earlier that three drones costing $50,000 could achieve the same versatility as the Yamaha RMax. To elaborate, three drones which have already been approved by the FAA and have units operating in the US include the senseFly eBee SQ, the DJI Agras MG-1, and the PrecisionHawk Lancaster (Martinez, 2019). The eBee SQ uses infrared cameras and thermal imaging to survey crops from above, with analytic and mapping software built in to identify problem sectors and devise solutions. It retails for $5,000. The Agras MG-1 can spray 6,000 square meters of crops in just 10 minutes, and its payload can include chemical fertilizers, herbicides, and pesticides. It retails for $15,000. The Lancaster has the capacity to analyze humidity, pressure, temperature, and ambient lighting and then process that data provide drainage estimates and disease detection. It can also process diagnostics on atmospheric and weather conditions in real-time and accordingly adjust its flight metrics. It retails for $25,000. Thus, the cumulative cost of these three drones is $45,000. The services provided by them actually exceed the capabilities of the RMax, which cannot react to changing weather conditions, provide disease detection, or record data on certain field aspects. Table 1, located below, compares the characteristics of the four drones.

Table 1: UAV Characteristics

	Current Approach	Proposed Approach		
	Yamaha RMax	senseFly eBee SQ	DJI Agras MG-1	PrecisionHawk Lancaster
Cost	$120,000	$5,000	$15,000	$25,000
Maximum Weight with Payload	207 lbs.	2.4 lbs.	49.6 lbs.	7.5 lbs.
Flight Time per Charge	60 mins.	55 mins.	10 mins.	45 mins.
Pilot Number	2	1	1	1
Acre Coverage per Hour	5 acres/hr.	500 acres/hr.	60 acres/hr.	300 acres/hr.
Field Usability and Capabilities	1. Plant Count 2. Vegetation Indexing 3. 3D NDVI Mapping 4. Crop Spraying 5. 68 lb. Payload 6. 16L Liquid Tank Capacity 7. Plant Height 8. Topography Mapping 9. Flight Planning *10. 2 Autonomous Airframes* *11. Aerial Photography* *12. Stationary Hover Capability*	1. Plant Count 2. Vegetation Indexing 3. 3D NDVI Mapping **4. Soil Temperature** **5. Soil Moisture**	1. Crop Spraying 2. 22 lb. Payload 3. 10L Liquid Tank Capacity **4. Microwave Radar**	1. Plant Height 2. Plant Count 3. Vegetation Indexing 4. Topography Mapping 5. Flight Planning **6. Temperature Profiling** **7. Disease Detection** **8. Draining Estimation** **9. Weather Reaction**

Italic font indicates capabilities the RMax possesses which the other three do not, while bold font indicates capabilities those three possess which the RMax does not. The RMax only possesses three unique characteristics while the other three drones altogether boast seven additional operations. It is therefore notable that these three drones retail for half the cost as Yamaha's flagship aerial vehicle. Of particular interest to the consumer would be the fact that when the RMax is manually set to fly remotely, it requires 2 pilots while most commercial UAVs only require 1 (Hanlon, 2004). In addition, its payload exceeding 200 lbs. indicates just how impossible it would be for any company to design an all-in-one drone which passes FAA regulation. A difference of 152 lbs. would need to be resolved, an unachievable goal for a UAV truly capable of conducting all the most demanding operations on a farm.

The aircraft branch of Boeing already has facilities specializing in unmanned vehicle research and testing, so costs could be even lower compared to these three aforementioned models, which had to have been built in lower bulk and with higher facility costs. If Boeing were to utilize its decades of experience in UAV manufacturing, it could very easily replicate these basic designs and then cut down on manufacturing costs. This is indicative of the strengths of this proposal. The drone technology has already been developed and is on the market, but no company has yet realized the benefits of releasing a unified line of drones boasting the same software and UI. Such a product line would be preferable to the agricultural market because the UAVs can interact with each other and could provide data which can be displayed in a single analytic set.

In addition, the aforementioned drones are only three of a plethora of UAV options available for purchase. Research has been done on a wide variety of UAV sensor suites, so there is no limit on the number of different UAVs that can be made. The only necessity would be to maintain software unity across devices. Boeing also has decades of proprietary research on unmanned aircraft, so entirely custom drones could be released. In either of these scenarios, research and development costs would be drastically reduced. While other companies are currently pouring thousands of dollars into an attempt to discover a nonexistent UAV, Boeing merely has to adapt the massive library of available research in order to tap into the market needs.

Design Process & Implementation

The specifics of the approach will now be discussed in regards to the complete design cycle, from inception to product sale. The first step would be to collect the relevant research both from within Boeing and also from the wider community of academia. There is a large quantity of research, so the major task would be to collect the information relevant for UAV manufacturing in regards to the on-board sensor suite. The goal should be to categorize data on different sensors, their applications, and their implementation. After that is completed, the next step would be to design drones to work with each different sensor. A UAV meant for crop dusting would be be much more ably served by a quadcopter design than a fixed-wing frame, as the former has more control and versatility in their movement and can more ably balance a payload. In contrast, a UAV meant for crop monitoring with cameras and GPS units should operate with a fixed-wing model in order to increase its on-board data-processing functionality. In this way, the drones should be customized to their functionality, as unification of the disparate products will be achieved in the software implementation as opposed to the hardware.

Each UAV should also aspire to overall goals; for example, they should all be built to fly for at least 45 minutes. The DJI Agras described earlier is the fastest crop-spraying drone in the world, capable of velocity over 5 times that of the RMax. However, it is undermined by a short flight time of only 10 mins. This is where the benefits of the proposed method can optimize the design process. Each drone only needs to be capable of a single purpose and omit all other functionality, which will be performed by other UAVs. By removing unnecessary weight from the UAV to allow for longer flight time and greater acre coverage, each drone becomes the best product of its specific kind. The Agras can have its microwave radar functionality removed from it to increase flight time, because another drone built only for 2D and 3D mapping will be the unit capable of those aspects. Of course, FAA regulations are the highest constraints on the device. If the difference between a UAV flying for 40 minutes and 1 hour is the difference between a 50 lb. and 60 lb. payload, then the FAA payload restriction remains the most significant priority.

After developing the characteristics of each drone in this manner, the next goal should be to create the software package and UI. Standard programs for commercial drones should be implemented at the very beginning. For example, a program which prevents the drone from flying past 400 ft. in altitude would be beneficial to integrate into the overall package. A transparent software package in regards to UAV safety would make the FAA's approval process operate more smoothly. There are a number of simple programs which can be designed and would comprise only a fraction of the UAV on-board processing power. For example, a program could be implemented which would force the drone to automatically stop and hover in place if it senses a foreign object accelerating towards it. Although this may seem like an unnecessary program because the drone is being remotely piloted, it is a gesture to the FAA that the drone itself does not possess the capability to break legislation. This class of products receive FAA approval extremely quickly; the senseFly eBee SQ is one example. Developing the product for easier testing by the FAA will allow for Boeing to quickly deploy its products.

After developing the drones in this fashion, the last goal is to create interconnectivity between the multiple UAV units. For example, if a drone with weather-monitoring is designed, it should have some way to communicate this information to the other drones so they can modify their flight paths and data accumulation process concurrently. In addition, the operator should be able to extrapolate and intersect multiple sets of data in order to make more well-informed decisions regarding land cultivation. Creating an easy-to-use interface would be extremely convenient for the operator and might serve as Boeing's major marketing point, as no other product currently on the market can compare to it. Even an all-in-one drone may not necessarily boast this functionality, as there is no guarantee that all the on-board sensors have the same underlying language behind them. The software developers at Boeing should therefore make every attempt to unify the software both for ease of manufacturing and for customer sales.

Conclusion

The design approach proposed in this paper indicates economic, legal, social, and manufacturing improvements over the current approaches employed within the industry. Other major corporations are pursuing productS which will not reach the market for many years because they fail to realize the constraintS they are working with and the necessities of their audience. If the process described in this paper were implemented, Boeing will soon be able to sell UAVs to US consumers and tap into the multi-billion dollar potential of the market.

Citations

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