AA241X: Design, Construction, and Testing of Autonomous Aircraft

SKYNET AA241X RED TEAM
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Authors:	*Degree & Department:*
Kartikey Asthana `kasthana@stanford.edu`	Ph.D. Candidate Aeronautics & Astronautics
Peter Blake `psblake@stanford.edu`	M.S. Candidate Graduate School of Business
Brandon Jennings `bjennin@stanford.edu`	M.S. Candidate Mechanical Engineering
Erik Moon `emoon1@stanford.edu`	M.S. Candidate Graduate School of Business
Sravya Nimmagadda `sravya@stanford.edu`	Ph.D. Candidate Aeronautics & Astronautics
Akshay Subramaniam `akshays@stanford.edu`	Ph.D. Candidate Aeronautics & Astronautics
Ian Villa `ianvilla@stanford.edu`	B.S. & M.S. Candidate Aeronautics & Astronautics
Jerry Watkins `watkins2@stanford.edu`	Ph.D. Candidate Aeronautics & Astronautics

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1 Introduction

Since the early 2000's, Stanford Aeronautics and Astronautics has taught the AA 241X: Design, Construction and Testing of Autonomous Aircraft course with various missions over the years. In Spring of 2014, teams were tasked with developing an autonomous aircraft to search and accurately locate four targets within the perimeter of Lake Lagunita. Among these teams was Skynet, a group of eight individuals from different backgrounds and expertise who, throughout the ten weeks, collaborated to organize, design, test, and fly various aircraft, guidance, control, and mission systems to optimally complete the search and rescue. The following report outlines the team's structure, mission strategy, aerodynamic design, control strategy, fabrication accounts, flight test data, and overall competition performance.

2 The Team

2.1 Team Structure

2.2 Team Communication & Logistics

In order to facilitate group discussions, a when2meet form was utilized online. Based on its results, the team met briefly after class on Mondays and Wednesdays for brief sub team status updates and coordination. Major team meetings were held on Fridays during the typical class time on the second floor of Durand and were spent discussing topics requiring everyone's attendance such as aircraft design and mission strategy.

The team also utilized online methods to meet communication needs. A Google Group was utilized for formalized notices and e-mail discussions. Short-form and quick information relays were handled by a GroupMe that could be accessed via phone or computer.

Data Storage and problem set completion was made possible via our Google Drive, Google Docs, and a Wordpress. All team data, code, and photos were uploaded into categorically defined folders in our Google Drive. Spreadsheets recording budget, weather data, contact information, useful links, and most importantly, problem set requirements were also held here. Having all of these documents in a single location and accessible by all of the team was the last step in facilitating good communication and ensured proper problem set completion. Once written, relevant text, data, graphs, and videos were uploaded to skynet241x.wordpress.com.

3 Mission

4 Airframe Design

4.1 Propulsion System Analysis

The propulsion system analysis was performed in three parts:

1. Propeller analysis
2. Motor analysis
3. Propeller and Motor matching

4.1.1 Propeller Analysis

For the propeller analysis, we used wind tunnel experimental data from the UIUC Propeller Data Site [1]. The exact same propeller data was unavailable in the database, so we used a very similar propeller (Graupner CAM Slim 9x5) albeit from a different manufacturer.

The data was given in terms of the rotations per second instead of the angular velocity and hence, the following scaling had to be performed

$$
\begin{aligned}
\lambda &= \frac{J}{\pi} \\
C_T &= \left(\frac{2}{3}\right)^3 C'_T \\
C_P &= \frac{1}{\pi}\left(\frac{2}{3}\right)^3 C'_P \\
\eta &= \eta'
\end{aligned}
$$

where λ is the advance ratio based on the angular velocity, J is the advance ratio based on the rotations per second, C_T is the thrust coefficient, C_P is the power coefficient and η is the propeller efficiency. The primed quantities are the ones reported in the database.

4.1.2 Motor Analysis

The motor analysis was performed by using the standard electric motor model. The motor speed constant, motor resistance and the no-load motor current were obtained from experimentally measured values on the manufacturer's website [2].

The values of the model constants are reported below:

$$
\begin{aligned}
K_v &= 980\left(\frac{2\pi}{60}\right) \; rad/s/volt \\
R_m &= 0.220\,\Omega \\
i_0 &= 0.4\,A
\end{aligned}
$$

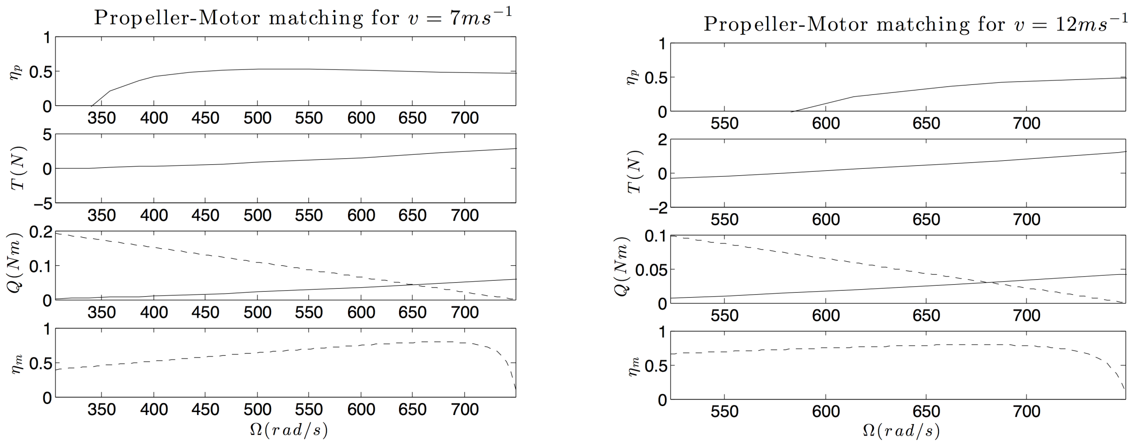
4.1.3 Propeller and Motor Matching

For a given free-stream velocity, the required torque for the propeller was calculated as a function of the angular velocity of the propeller. For the motor, the torque generated was calculated as a function of the angular velocity. By matching these two torques, we solved for the angular velocity and obtained the total propulsive efficiency. This process is illustrated in Figure 1.

For the 7 ms^{-1} case, we see that the propeller efficiency, η_p peaks at very low angular velocities and hence the total propulsive efficiency is poor. For the 12 ms^{-1} case, the propeller efficiency, η_p peaks at high angular velocities which again leads to a low total propulsive efficiency. Optimizing the total propulsive efficiency over different airspeeds, we get the best motor-propeller matching illustrated in Figure 2

The total propulsive efficiency and the thrust are plotted against airspeed in Figure 3.

[1] http://aerospace.illinois.edu/m-selig/props/propDB.html
[2] http://www.maxxprod.com/pdf/HC2808-xxxx.pdf



(a) $v = 7\ m/s$

(b) $v = 12\ m/s$

Figure 1: Propeller-Motor matching shown graphically. Solid lines: propeller curves. Dashed lines: Motor curves

4.2 Design Approach

For our mission plan, it is critical that we climb to an altitude of $400ft$ as fast as we can to efficiently scout the search area and sight all four targets as soon as we can. Hence, the rate of climb for our airplane is of crucial importance. In addition to this, the endurance of our aircraft is also very important since the allowed battery consumption is very limiting. We designed our aircraft mainly based on these two considerations.

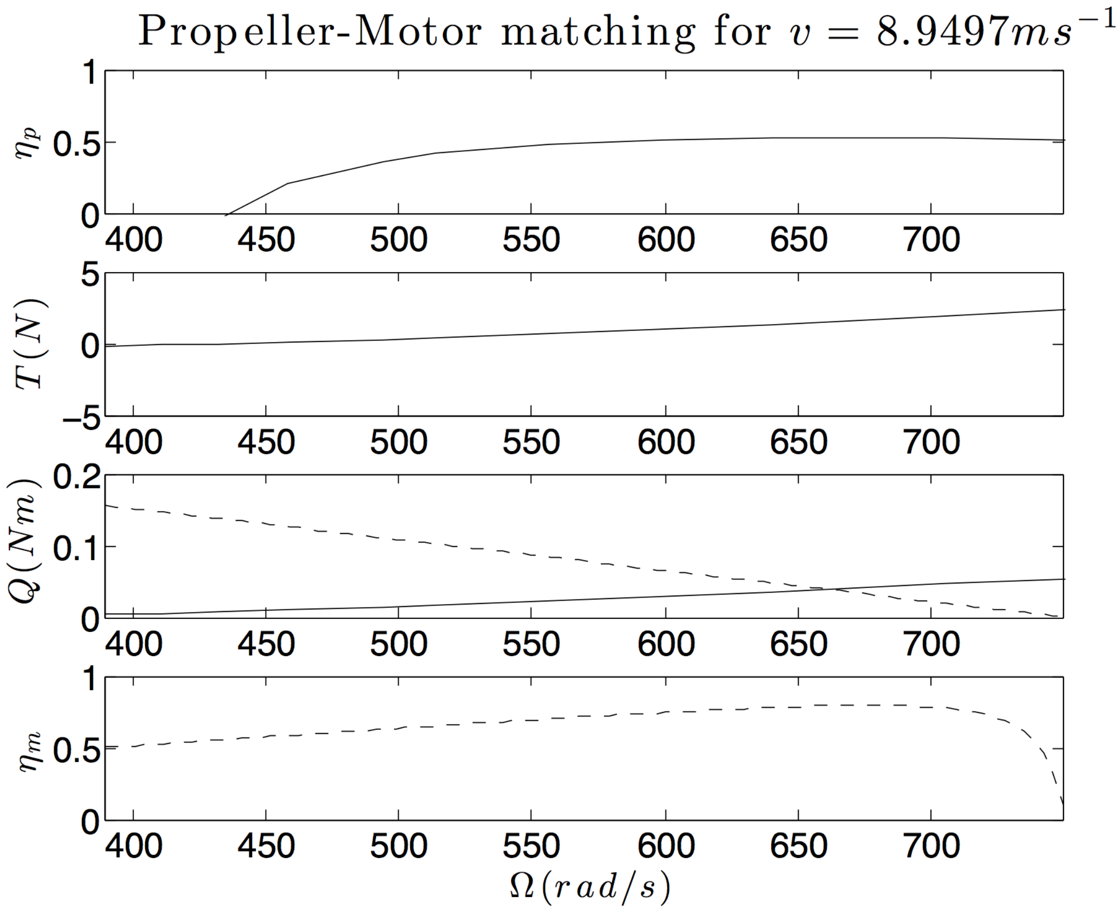


Figure 2: Optimal Propeller-Motor matching shown graphically. Solid lines: propeller curves. Dashed lines: Motor curves

4.3 Performance Characteristics

4.4 Flight Performance

5 Controls

5.1 Control Strategy

5.2 Flight Performance

6 Fabrication

6.1 Prototype Construction Approach

6.1.1 Mk-I "The Red Baron"

6.1.2 Mk-II "Big Boy"

6.1.3 Mk-III.1

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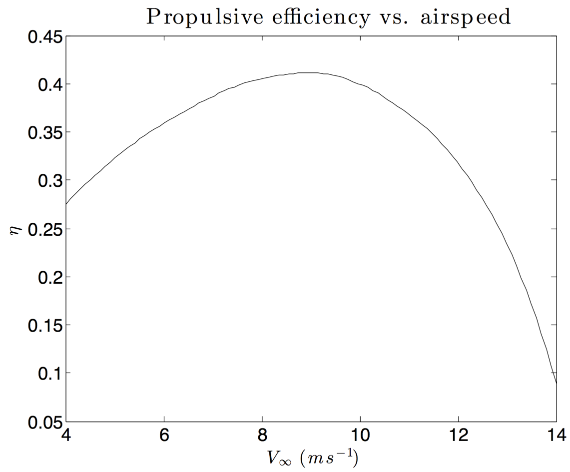
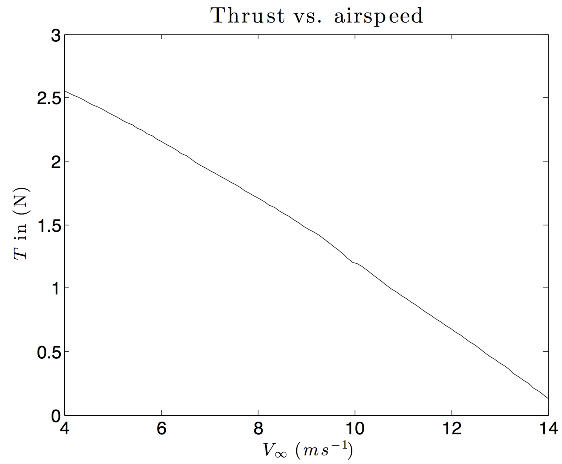
7 Flight Testing



(a) Plot of the total propulsive efficiency against airspeed



(b) Plot of the total thrust against airspeed

Figure 3: Thrust and efficiency plots

8.2 Analysis of Flight Data

9 Conclusions & Lessons Learned

10 Future AA241X Recommendations