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DEVELOPMENT OF THNIKKAMAN MICRO AIR VEHICLE AT ROCHESTER INSTITUTE OF TECHNOLOGY

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ABSTRACT

This paper details the design and development process of the current RIT Micro Air Vehicle over the course of the 2003-2004 academic year. The objective of the RIT MAV Team is to construct an aircraft with minimal dimension that can successfully complete a surveillance mission of a distant target and have removable, "cartridge-style", payload capability. This paper illustrates the overall goals of the effort, design methods, analysis, testing regimes and fabrication techniques used to arrive at the final foam-based 12 inch wingspan design.

INTRODUCTION

Over the past decade, the study of Micro Air Vehicles has generated increasing interest in the aerospace community due to their potential military, intelligence and civilian applications. As the miniaturization of electronic sensor and surveillance equipment continues the list of possible mission profiles for very small, limited-duration aircraft grows.

RIT is a new entrant in the growing community of universities and companies involved in MAV research. Last year, a small group of underclassmen designed and constructed a vehicle for the 2003 International MAV Competition with little knowledge of the current state of MAV technology at other universities. Despite less than successful flight results, the team gained a tremendous amount of knowledge and has applied that insight to the current vehicle, *Thnikkaman*.

The primary goals of this project are three-fold. First, to be competitive in MAV design, RIT must investigate and determine the state-of-the-art in MAV technology. Second, a primary vehicle-oriented goal is to successfully capture surveillance imagery of a distant target using real-time on board video. Finally, the vehicle must also be capable of carrying a variety of payloads.

DESIGN PROCEDURE

As with most modern engineering design processes much of the design, analysis and testing of the various subcomponents of the project took place concurrently. It was decided at the very beginning of the project to organize the team into four subgroups that would each handle a specific aspect of the MAV design. Each team member was assigned according to their specific background and skills and would become the team "expert" on their particular portion of the project. The four subgroups are: airframe, propulsion, electronics and launcher. Integration of the work of the four groups is critical to the success of the design and all team members worked to make systems integration as seamless as possible.

A specific design procedure was followed in the development of the various systems and components to ensure a methodical, organized approach was taken. This would make certain that the team's multidisciplinary nature and widely varying individual backgrounds would be of most benefit to the design and ensure the success of the vehicle.

The design methodology employed was as follows:

1. Needs Assessment
2. Concept Development
3. Feasibility Assessment
4. Preliminary Design and Analysis
5. Detailed Design
6. Systems Integration
7. Flight Testing and Analysis
8. Final Design

AIRFRAME DEVELOPMENT

The airframe group was responsible for determining the fundamental configuration of the vehicle, including airfoil and planform selection, overall size of the vehicle, materials selection, and fabrication technique determination.

The first task facing the airframe group was the determination of the aircraft configuration. Little study was necessary to realize that a flying-wing aircraft configuration is optimal to meet our design requirements and keep the MAV as small as possible. While some degree of stability and margin for error is sacrificed by using a flying wing versus a standard tail configuration, it has been shown that, with careful placement of the aircraft's center of gravity, stability can be maintained.

After determining the aircraft would be a flying wing, the next step was to concurrently determine the planform shape and airfoil. The prototype planform design is based on the inverse Zimmerman and was arrived at primarily through a review of existing successful MAV designs and published research [1-3]. The shape chosen (Figure 1) allows for easy construction and has seen practical application in several MAVs with similar mission profiles and capabilities.

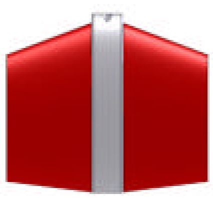

Figure 1 - Planform view of prototype RIT Thnikkaman MAV

The selection of an airfoil is extremely important because it helps ensure the aircraft will meet performance specifications and have adequate stability. Unfortunately, a review of published literature shows that it is not well understood whether cambered, thick airfoils have much benefit over very thin airfoils at low Reynolds numbers. The airframe group decided to pursue a thick airfoil design primarily due to manufacturing considerations and the stability benefits of a reflexed airfoil. From the list of dozens of airfoils that met the design requirements, the three shown in Figure 2 were chosen for further investigation.

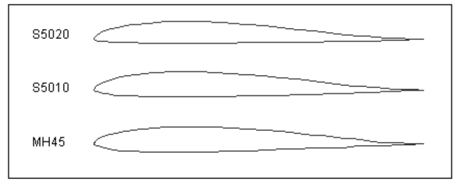

Figure 2 - Airfoils investigated further

Using well-regarded published infinite wing data [4], data gathered in the RIT Wind Tunnel and data derived from XFoil analysis software [5], the lift, drag and pitching moment for each airfoil was compared. After considerable study, the airframe group decided to utilize the S5010 airfoil in the vehicle design. The S5010 uses a small amount of reflex to give a relatively flat moment coefficient through a range of angles of attack. This, along with the near-zero value of the pitching moment gives the aircraft stability and the ability to be trimmed with very little elevator input.

Another initial concern facing the airframe group was the size of the vehicle. Through sponsor requirements it was determined the aircraft must be capable of lifting a significant payload while maintaining acceptable performance characteristics. Initial vehicle component investigation yielded a final maximum design gross weight of approximately 100 grams. Using this value and approximated propulsion data provided by the propulsion group, aerodynamic performance calculations [6,7] yielded a wingspan and root chord of approximately 10" and 8" respectively.

With airfoil data and wing sizing values in hand, aerodynamic performance and stability calculations were performed. Among other results, this yielded predicted flight performance and thrust required to meet our performance goals. The flight velocity envelope based on vehicle drag and a constant 30 grams of thrust available is shown below in Figure 3.

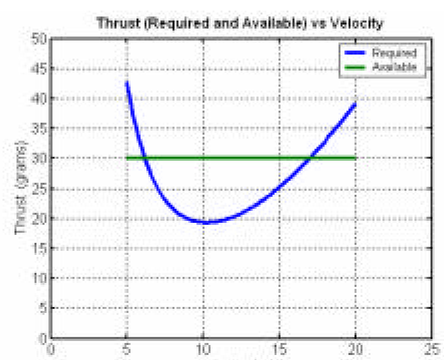

Figure 3 - Flight velocity envelope with 30 g thrust

Simplified stability calculations were performed to determine an approximate location of the aircraft center of gravity [8]. Little confidence was held in the result however due to questionable airfoil moment data. CG location for longitudinal stability would largely be determined through flight testing. A five degree dihedral angle was designed into the MAV to ensure lateral stability. This would also allow the vehicle to be more effectively rolled by just rudder input, thereby eliminating the need for ailerons.

Finally, with the fundamental characteristics of the wing decided, the airframe group considered how to build the airframe itself. Several ideas were investigated, including a standard balsa buildup, carbon-rib structure and a straight composite structure. In the end, a foam structure was selected. The major factors influencing this design decision were the ease of fabrication, team experience with the technique, simplicity of component placement within a precision milled foam structure and relative durability of the foam. Several drawbacks to this choice exist, including the slightly higher weight versus a ribbed, hollow structure, but it was decided the benefits are more numerous. The foam airframe design (Figure 4) is also very inexpensive, allowing more funds to be diverted to costly electronics.

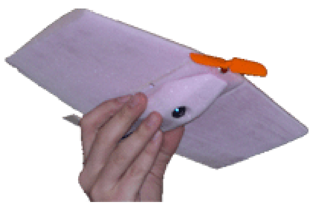

Figure 4 - RIT Thnikkaman MAV (foam construction)

The body is constructed of lightweight polystyrene foam, similar to standard housing insulation. Using well-established wire-cutting techniques two people can create a set of two wings and a central body in only fifteen minutes. By attaching thin aluminum airfoils of different sizes to either side of a foam block and running a hot-wire over the profiles, the complex curves of the swept, tapered, dihedral wing are accurately produced. Control surfaces made of thin balsa wood are attached via miniature R/C ball-joint hinges.

PROPULSION DEVELOPMENT

The primary tasks of the propulsion group were the determination of a power source and propeller selection through extensive thrust testing.

Two realistic options exist for powering a fixed wing MAV: electric motor driven propeller and combustion engine driven propeller. Last year's RIT MAV Team decided to pursue the 0.01 in^3 Cox Tee-Dee combustion engine because of its superior thrust-to-weight ratio. However, due to its inability to start reliably and its difficult integration into the vehicle, it was not pursued further this year. This less than pleasant experience with the combustion engine prompted the current team to choose a DC motor as the power source.

Using information gained from the literature search a test matrix was created to most efficiently find the best DC motor and propeller combination. The test matrix included all of the available propellers of 80mm of diameter or less. Each of these propellers were tested with a larger motor to characterize the propellers' performance. The propeller's tips would also be modified to further investigate the most efficient propeller for the Thnikkaman. Propellers were not designed and fabricated by the team because of the time and facility constraints. The best propellers determined from the data collected using the larger motor would then be tested with the two motors that have been chosen for possible power plants on board the MAV.

The testing began using the larger motor: Maxon Motors RE-16. The motor was mounted to an SMD Miniature Platform Load Cell as seen in Figure 5, which allowed for the measurement of thrust. The RPM, voltage and current draw of the motor were also recorded. This data both characterized the propeller along with the power requirements needed from a motor to obtain the desired propeller performance. For instance, the current draw of the motor was very important because it is proportional to the torque required of the motor.

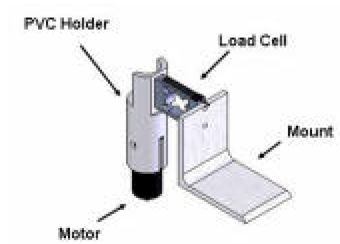

Figure 5 - Static thrust testing setup

The commercially available propellers, U-80 and EP-0320, were tested with the RE16 along with the modified versions of same propellers. Figure 6 shows the stock propellers and the modified tip shapes tested. Tip shape A has both the leading and trailing edge rounded off, tip shape B has only the leading edge rounded off and tip shape C has an elliptical tip where the edges come to a point.

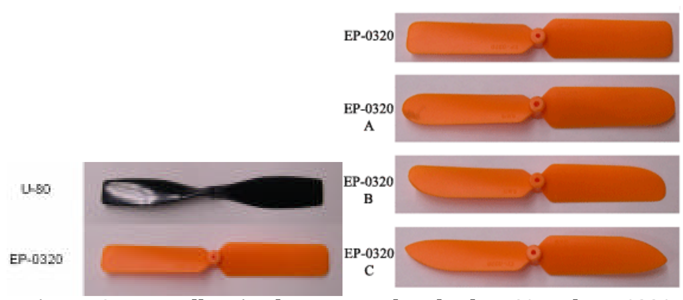

Figure 6 - Propeller tip shapes tested on both U-80 and EP-0320

The first stage of testing with the RE16 was successful in finding the most effective propellers along with determining the requirements of the final motor. The tip shape did not seem to have an advantageous affect for the U-80, however it seemed to affect the performance of the EP-0320 significantly.

The results for the EP-0320 are shown in Figure 7 as a thrust vs current draw relationship, which is similar to a thrust vs torque relationship and represents an efficiency of the propeller. From the chart it can be seen that both the stock EP-0320 and tip shape B performed the best and were chosen to go on to the next stage of testing.

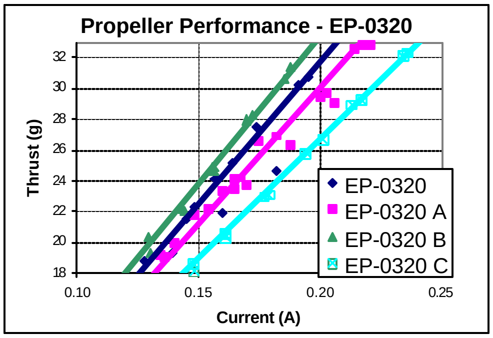

Figure 7 - EP-0320 tip shape testing with RE-16 motor

The same relationship was plotted for the U-80 propeller and the results for the U-80 show the stock U-80 as the best option for further testing. U-80 B was also tested further based on the results for the EP-0320, even though the results for the U-80 B did not show a significant improvement.

From this point, motor selection and propeller selection occurred simultaneously because of their close dependence. The team chose to investigate the Maxon RE-10 and the WesTechnik DC5-2.4 motors using the four previously mentioned propellers. Based on the calculations by the airframe group, the propulsion system must be capable of producing between 25 and 30 grams of thrust to be viable. Results of the testing showed that the RE-10 was incapable of achieving the desired thrust output without risking damage to the motor, regardless of propeller choice. The DC5-2.4 motor achieved the desired thrust output, but with significantly greater current draw. A decision was made that the larger current draw was acceptable given the amount of thrust generated.

Propeller diameter was also modified in the tests to determine its influence on thrust generated. The EP80B (EP-0320 at 80mm with tip shape B) proved to have the best performance; however, it has been decided that the team will utilize the stock U-80 for actual flights. Even though its performance is slightly below that of the EP-0320 B, the EP-0320 style propeller must be attached to the DC5-2.4 motor with epoxy, where the U-80 does not require epoxy. Epoxy was sufficient for static thrust tests but has been found unsuitable for actual flight. Conversely, the U-80 attaches to the motor via a simple press-fit. The slight loss in performance realized by using the U-80 is more than offset by the realistic concern of not losing a propeller during flight.

ELECTRICAL SYSTEM DEVELOPMENT

The electrical group's main focus was investigating and selecting a set of electrical components that integrate into the given envelope and help to meet the performance goals. Each component was considered based on mass and spatial limitations, as well as current draw specifications. The list of components includes the speed controller, control receiver, control surface actuators, video camera, video transmitter and batteries. Several options were examined for each component. The list of final selections is seen in Table 1.

Component	Manufacturer / Part	Quantity	Total Weight (g)
Voltage regulator	Nat. Semi. LM2940IMP-5.0	1	2
Batteries	iRate Lithium Polymer 500 mAh	2	28
Receiver	Wes-Tech/ R4P-JST	1	3.8
Speed Controller	Wes-Tech/ YGE3	1	1
Servos	Wes-Tech/ LS-2.0	2	5
Video Camera	Panasonic CX161 CCD Camera	1	11.6
Video Transmitter	Black Widow AV 2.4GHz Tx	1	7
Video Receiver	Hyperlink Tech HG2424G	N/A	N/A
		Overall Weight	**58.4**

Table 1 - Electrical component list for surveillance mission

As mentioned, the primary considerations when examining the component options were the size and weight. Current draw and other electrical specifications were also important for certain components. For instance, the choice of speed controllers was influenced by the maximum continuous current allowed by each. The motor and servos are not expected to draw more than 2 Amps at any time; therefore the choice of the lightweight, 2 Amp current limited Wes-Technik YGE3 was a logical choice.

When considering control receivers, range became a paramount concern. During range testing, the Wes-Technik R4P-JST was found to have a maximum usable range of approximately 1000 meters despite a lesser manufacturer specification.

Wes-Technik LS-2.0g servos were selected to integrate with the control receiver to actuate the control surfaces. Magnetic actuators were examined but were not used in favor of the more reliable mechanical servos. In fact, the LS-2.0g servos from Wes-Technik itself were found to be highly unreliable. However, a newer version available from HomeFly.com has shown excellent reliability and operation.

The camera system selected operates on a 5-volt feed regulated by a simple National Semiconductor voltage regulator. The selected camera, the Panasonic CX161 (Figure 8), gives excellent image quality with 52 degrees field of view and 330 lines of resolution. While this CCD camera is heavier than CMOS alternatives, the superior image quality was considered important to recognizing targets and piloting the vehicle remotely. The BlackWidowAV 2.4GHz transmitter was chosen as the video transmitter to send real-time flight video back to the pilot. With the standard video receiver at the base station, range of the video link would be severely limited. However, by using a high-gain antenna at the base station the range of video transmission increases dramatically. A Hyperlink Technology HG2424G Parabolic Grid Antenna is used to receive the video signal. Testing has shown that this combination of video transmitter and receiver ensures a video link out to over 450 meters. It was determined that careful aiming of the narrow bandwidth grid antenna is necessary, but no significant signal degradation was seen over the range tested.

Figure 8 - Panasonic CX161 camera and BlackWidowAV 2.4GHx Tx

Perhaps the most important component choice facing the electrical group was battery selection. Each component integrated within the MAV must be considered in battery selection. Lithium-polymer batteries were decided upon because of their extraordinary power-to-weight ratio. The list of candidate batteries is seen below in Table 2.

Manufacturer Model	Kokam SLPB104330	Kokam SLB452128	Kokam SLPB283452H	iRate LP500
Capacity	48 mAh	145 mAh	340 mAh	500 mAh
Weight (per cell)	1.7 g	3.5 g	10 g	13 g
Max Continuous Current	NA	725 mA	6.8 A	4.0 A
10 min Flight	288 mA	870 mA	2.04 A	3 A
15 min Flight	192 mA	580 mA	1.36 A	2 A
20 min Flight	144 mA	435 mA	1.02 A	1.5 A

Table 2 - Lithium polymer battery options

The batteries chosen for use in the MAV are the Kokam 340 mAh's. These batteries supply the necessary amount of current without adding a tremendous amount of weight. The 145 mAh could not be used because of the inability to supply the 1 Amp requirement of the motor; the 500 mAh cells weigh too much to justify the extra capacity.

A Global Positioning System (GPS) investigation was also completed by the team. A GPS unit would provide valuable information about vehicle location and altitude, which would be beneficial during surveillance and reconnaissance missions. In addition to this, RIT would be the first school to integrate GPS onto an MAV. A GPS receiver was chosen based on weight and size limitations. A video overlay board was also selected as a method to transmit the data back to the ground station (Figure 9). This GPS system would still require the use of the video camera and transmitter.

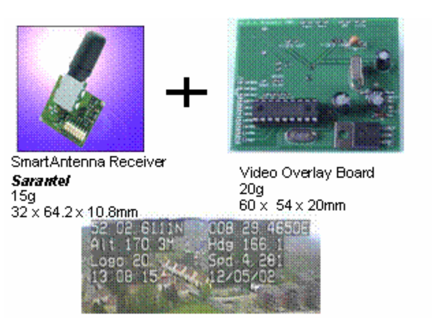

Figure 9 - GPS Unit

The investigation concluded that the GPS components are too heavy and large to integrate onto this year's MAV. However, this technology will be pursued further by next year's team, where RIT will design and fabricate smaller components to allow this capability to be incorporated into an MAV.

LAUNCHER DEVELOPMENT

A mechanical device was developed to assist with the task of launching the vehicle. The development of the launcher has yielded a working design that will launch an MAV at the correct trajectory to ensure a successful flight. A post test feasibility assessment was done that found the current design of the launcher to be unfeasible. The MAV is easily launched by hand and therefore does not need to be assisted in any way. If the pilot were alone, the launcher would be useful, but the current design would need to be sized down to a portable size.

SYSTEMS INTEGRATION & CONSTRUCTION

The final integration of the various systems into the MAV was successful because of constant communication between the various subgroups. To further support a smooth integration, the group members were only loosely assigned and participated in more than just one group.

It was found that the most difficult task in systems integration was placing the components within the MAV such that the center of gravity location for the aircraft was correct. The advantages provided by the foam airframe construction material helped solve some of these problems. Pockets are easily milled into the foam with great accuracy such that the components press-fit into the proper places. A small amount of epoxy holds the servos, motor and thin balsa wood stabilizer surfaces in their milled emplacements. A milled slot running the length of the body of the MAV allows the batteries to slide longitudinally so that the CG of the aircraft can be easily adjusted.

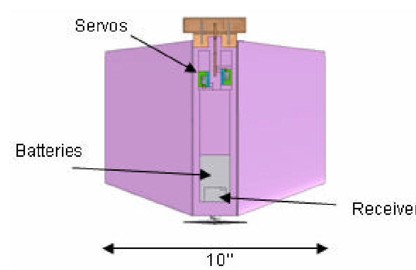

Figure 10 - Component placement in body

A separate foam pod carries the mission-payload. This "cartridge-style" design allows for a wide variety of payloads to be carried with a single platform vehicle. Pods of varying sizes could carry any number of different sensor packages (including the RIT wildfire sensor being developed by our sponsor) provided that the portion of the pod interfacing with the MAV platform remains the same and the size and weight are within the design limitations. The pod attaches to the central body of the MAV, covering the internal components, via a series of pins that are slid through carbon reinforced pin-holes on both pod and body. For the required surveillance mission the cartridge payload carried in the pod is the camera/transmitter system.

FLIGHT TESTING / PERFORMANCE

The flight testing of the Thnikkaman began indoors with a series of glide tests. While short glide tests for proper CG location showed success, power-on flights failed. This was solved by reevaluating component placement and CG location using solid-modeling software. From this point, flight testing would resume inside the gymnasium with an MAV that had no video components on board. The ideal flight conditions presented in the gym and the lighter vehicle would help the team isolate any problems immediately. Successful flights were achieved as a result of a few minor changes: replacement of the carbon pins with tape for the POD/body interface, replacement of taped hinges with plastic ball hinges and the reduction of the upper vertical surface to achieve desirable CG location. As the vehicle began to evolve into a more efficient and reliable design, the weather improved and the flight testing moved outside.

The flight testing outside brought a new element into the equation: wind. The vehicle behaved satisfactorily as it was still controllable and somewhat reliable. However, when the video package was finally integrated, the vehicle failed to climb. At this point, the team attended the International MAV Competition at the University of Arizona, competing with a one minute and thirty second endurance flight and a twenty second surveillance flight. The flights achieved in competition were deemed successful in that much was learned about the Thnikkaman and RIT was able to score in their first MAV competition. Using the knowledge acquired from competition, the team switched to a thinner airfoil, eliminated unneeded foam and investigated the motor's tendency to overheat.

Flight testing continued at RIT with the new changes: the airfoil was modified by decreasing the thickness from 9.8% to 4.5%, decreasing the camber to 1.5%, and adding additional reflex to assist with longitudinal stability. Also, the fuselage and POD were sanded down to further eliminate drag. To correct the overheating problem, a heat-sink was fabricated out of aluminum and integrated onto the vehicle. Flight testing with the heat sink was also unsuccessful as the vehicle would still not climb.

Figure 11 - Flight testing outside

A very significant design change was made at this point. To reduce the drag significantly, the aspect ratio was increased from 1.39 to 2.32. This was achieved by increasing the wingspan to 12 inches, changing the wings to a 6" root and a 4" tip chord and a 6 inch fuselage. The airfoil was also modified again by increasing the camber from 4.5% to 6.5% along with the additional reflex added to the trailing edge. These changes incorporated along with the heat-sink, allowed for a 9 minute flight. During this flight, the aircraft had a short period longitudinal instability which was eventually corrected with the addition of winglets and rounding of the leading edge.

CONCLUSION

This year's MAV research effort at RIT has focused on developing an MAV platform capable of completing a variety of missions and bringing RIT up to speed with what is occurring at other universities. The resulting aircraft, Thnikkaman, has a wingspan of 12 inches and a maximum gross weight of approximately 100 grams.

Using published research data and wind tunnel testing, a flying wing, thick airfoil, foam based design was produced. A large propeller/motor static thrust study was performed and characterized commercially available propellers based on tip shape. Electronics components were selected for use on the aircraft based on size, weight and electronic specifications. Flight testing proved to be invaluable to the successful development of the Thnikkaman. The team has learned a great deal about the performance characteristics of the MAV within this flight regime. Flight testing also has shown the important relationship between CG location and MAV performance.

The final vehicle configuration has successfully met the project goals by completing a 9 minute flight with live video surveillance. This effort has started RIT on the path to the forefront of Micro Air Vehicle technology.

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