ILLINOIS INSTITUTE OF TECHNOLOGY

IPRO 317
Personal VTOL Aircraft

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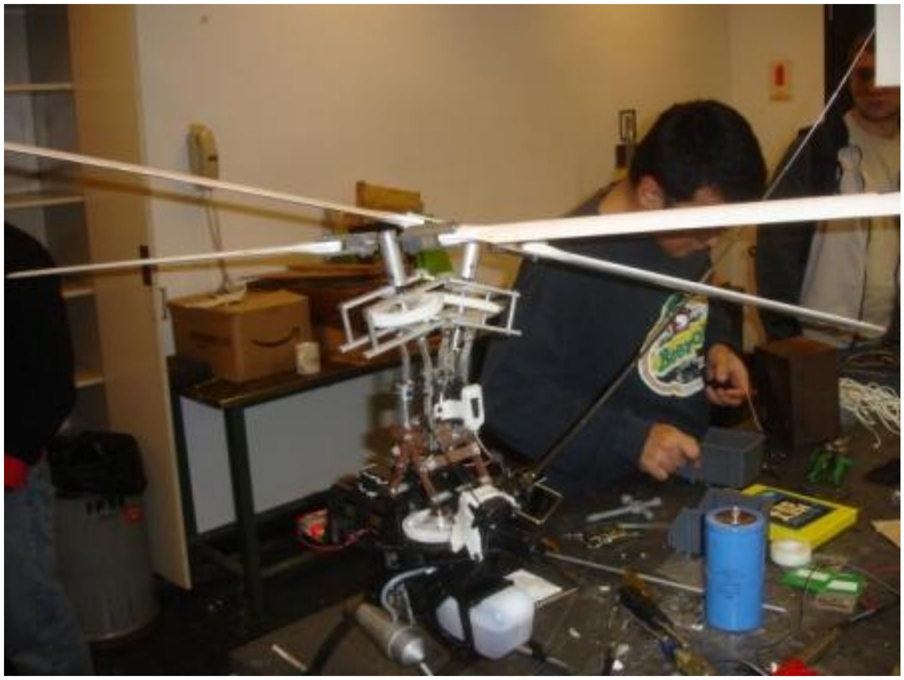
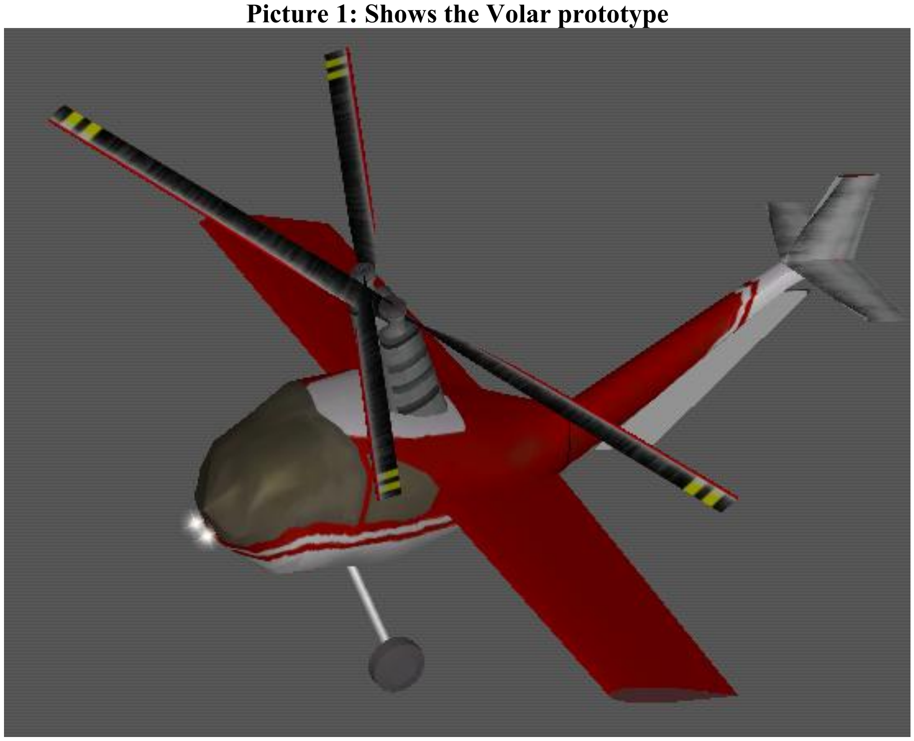
Introduction

IPRO 317 is the exciting step into Vertical Take-Off and Landing (VTOL) aircraft. Its goal is to design, showcase, and eventually deliver a personal VTOL aircraft. This IPRO has existed for several years now and is reaching the stage where hard work is being realized in physically operating prototypes. The tasks to undertake were divided into three categories for which our team was partitioned. These categories were construction, simulation, and website/funding. The construction group handled assignments relating to the physical construction and alteration of a prototype scale model of our VTOL aircraft design (herein called the Volar). The simulation group worked with X-Plane, software for the design and simulation of aircraft. The website/funding group dealt with matters of public relations, applications for grants, and the website.

The Volar itself is a distinctive VTOL design. It is almost half airplane and half helicopter. The Volar employs a dual counter-rotating and intersecting vertically mounted rotor design. The counter-rotating design eliminates the need to use a tail rotor for directional stability because the angular momentum of each rotor cancels out. However, the rotors are at a slight angle to each other to accommodate the intersection of every revolution. Also, the whole rotor assembly tips longitudinally and laterally. This is the control aspect, and allows for easy transition between vertical takeoff and forward flight. In addition the Volar has wings that begin to develop lift as the Volar transitions from vertical flight to forward flight. Thus, in forward flight this reduces the lifting demand on the rotors, and improves efficiency. Following are a couple pictures of the Volar (the prototype does not have wings yet in this picture):



Picture 1: Shows the Volar prototype



Picture 2: Shows the simulated Volar from X-Plane

Needless to say, the enthusiasm for this project is powerful because VTOL aircraft are very exciting.

Background

Previous iterations of IPRO 317 have been working with the construction of the physical prototype scale model Volar. In earlier sessions, IPRO 317 purchased and modified a model gas powered RC helicopter. Its distinctive counter-rotating design was implemented, however with no longitudinal or lateral control. This prototype was simply to prove that the design could lift itself, and tests were extremely limited so as not to destroy the prototype (beyond repair).

Other assignments completed by previous IPRO 317 groups include the design in X-Plane ver.6 of a full scale Volar. This research was to predict flight characteristics, power requirements, and size of our personal VTOL aircraft. In X-Plane, the simulated Volar (that exhibited all of the characteristic design attributes) was shown to be very stable and easy to fly. It was also observed in X-Plane simulations that the basic theory behind the Volar applies. This theory being that after the transition from vertical to forward flight is made, the wing lift developed accounts for the majority of the lifting force required to keep the Volar airborne.

Purpose

The goals of the construction group encompassed those pertaining to the assembly and operation of the scale model Volar. This work was important for many reasons. If research and development on the VTOL aircraft design are to succeed, it needs to shown to possible donors and organizations that the design is structurally sound, reasonably more feasible than current designs, and worth their time. The completion of the scale model Volar will make a representative icon for IPRO 317, an icon of success and progress.

Emulation of various scale Volar models was handled by the simulation group. Simulation is very important to any design of any product because it can save time and resources because they can predict the performance of the Volar and allow estimations for requirements of the VTOL design. The simulation group then chose to simulate the Volar design on three size scales. These scales were full scale, 1:5.3, and 1:6.6 (these ratios are determined by size comparison to the full scale Volar). The full-scale model was chosen because it will be important to know how the final product will perform. The 1:5.3 scale-model (herein referred to as "prototype") was chosen because that is the size of the prototype that the construction team is working on, and predicting its performance is equally important. The 1:6.6 scale model (herein referred to as the "micro") was chosen for simulation because it is on a small enough scale that complete battery powered operation is feasible and desirable to implement. As discovered, there are many issues with the first prototype model aside from the implementation of our characteristic Volar design elements. The ease of the micro scale estimations will allow real life higher series prototype construction.

Website and funding tasks were equally as important as the other categories. It is important to generate interest in our project. If we can promote our idea to possible investors and others in the aviation industry it would be possible that those interested industries would donate to our cause. These funds could then be readily put to use for further iterations of IPRO 317.

Methodology

In IPRO 317 the tasks were divided into three sub categories for the ease of distribution and assignment. The divisions created were a construction team, a simulation team, and a website/funding team. The members of the construction team included Doug Elkins, Sean McCann, and Ben Smith. The simulation group encompassed Jesse Collins, Brandon Honore, and Julia Northrop. The website/funding group included Akash Garg, Vikram Kumar, Kabir Mehta, and Neal Patel. All sub teams met at least weekly to confer about the progress of each other and offer troubleshooting assistance.

The methodology used by the construction team was quite simple. Once a problem with the aircraft was identified, engineering experience was used to solve the problem. This consisted of everything from cutting metal to form a stop for the motion of the gimbal to molding plastic to hold the servos to the frame. Occasionally, Dr. Ruiz was asked to give input when the construction team did not have enough experience to solve the problem.

The methodology for testing the aircraft centered around one main point. This main point was to do everything possible to keep the aircraft from being wrecked. Again, engineering experience was used to determine the best way to keep the aircraft safe during tests, as well as which tests would be safe to run. This strategy was successful in that the aircraft never crashed during the testing.

The simulation group's method to task completion was a little more open ended. The group knew what had to be done. However, this was only after frequent conference with our IPRO faculty advisor, Professor Ruiz. The research conducted involved many simulations in X-Plane ver.8. These simulations involved testing the ease of flight of our VTOL design and comparing it to conventional helicopters or other VTOL designs. Since the aim of this IPRO is to deliver a VTOL aircraft "for the masses", our design has to be readily accessible. It will need to be practically as easy to conduct as a car. Most of this research then, was devoted to answering the question, "How easy is the Volar to fly for someone unfamiliar with complex aviation?" The answer to the question was readily found and assisted by the fact that, although all simulation group members are Aerospace engineers, none are pilots or have ever independently flown a real aircraft. It was here that the Volar systems and characteristic features were implemented with the average human in mind.

The Website / Funding sub-group always worked as a team for all the tasks assigned to us. The team met together both in and out of class to complete the necessary tasks. The two biggest tasks of creating an effective website and applying for a grant from NCIIA were equally divided amongst the four members of the team. Each member of the team contributed to both tasks. The beauty of working as a team was that each member of the team learned something new from another team member. For example, those members who were not proficient in html or action script got a chance to learn how to create a website using the above languages. In short, the team worked together as a whole and used its combined knowledge to complete the overall objective of adverting and procuring funds for the Volar project.

Assignments -

With each sub-group working on different tasks, the list of assignments to complete becomes divided into categories:

Construction Group

The construction group's tasks were more open ended. No one member has specific tasks within the sub-group. Assignments were completed as new problems arose and were handled by the team member that had the resources to complete them. However, in the least each team member was required to attend the specified work periods so that decisions to be made could still be done in a democratic fashion. Following, are the assignments the construction group took on:

- Brought in moldable plastic to attach the servos to the frame.
- Brought in paints to paint the final version of the aircraft.
- Purchased the supplies needed for testing, including wooden rods and rope.
- Attached gimbal stops to keep rotor assembly from tipping to point of locking the U-joint.
- Balanced the rotors to keep vibrations down on prototype model.

Simulation Group

The simulation group all worked together during the specified IPRO meeting times and sometimes met outside those times too. Most of the assignments completed by the simulation group were always done as a whole. Each decision was decided upon in a group and tasks were undertaken as a group. With that, now follows a list of the simulation group assignments:

<u>Full scale Volar</u>:

- Updated older Volar file from an obsolete version of X-Plane
- Added rudder for yaw control and increased stability
- Optimization of characteristic Volar traits

<u>Prototype scale Volar</u>:

- Creation of the computer model based on the existing prototype Volar
- Improve upon the existing traits of the prototype (addition of rudder, etc.)

<u>Micro scale Volar</u>:

- Research of fully electric RC helicopter specifications
- Creation of an even smaller scale prototype Volar in X-Plane based on available RC helicopter parts

Website/Funding

The primary assignment for the Website / Funding team was to promote the Volar to potential customers and investors. The main objective of the website is to delineate the current status and future plans of the Volar project. The website is used as a marketing tool so that we can procure the necessary funds for a full-scale prototype to be built in the near future. The job of the website / funding team is to advertise the Volar as effectively as possible so that potential customers / investors are intrigued by the affordable VTOL aircraft. The assignments undertook include:

- Writing the code for the website
- Coming up with an appropriate way to display the status of the project
- Coming up with catchy slogans / writing the text for the website
- Updating the blog used to show the progress of the project
- Writing certain sections of the narrative for the NCIIA grant
- Researching the necessary parts and prices needed for a full-scale prototype (an itemized parts list needed to be included in the NCIIA grant)

Obstacles -

Likewise, with three different sub-groups within our IPRO 317 group, the obstacles encountered by each sub-group were quite different. Thus, it is more desirable to partition the obstacles for each subgroup:

Construction Group

During initial testing, the aircraft was not controllable. The servos controlling the rotors could not be moved, and the aircraft could not be turned off. The problem was thought to be fixed by our second test, but the aircraft was still uncontrollable. This problem still has not been solved. A few theories for why the Volar is uncontrollable are that there could be excessive vibrations, interfering with the servos or that the forces on the servos are too great and they do not have enough torque to overcome them.

Another setback that occurred was the loss of the main gear during testing. Most of the teeth were ripped off of the main gear during the second test. Considerable time was taken trying to repair that. Also, because this model has been used for so long, the helicopter that it is based off of is discontinued. This caused great difficulty in obtaining spare parts. The main gear needed to be shipped from Thailand. As can be imagined, this took a considerable amount of time.

Simulation Group

The simulation group had its fare share of problems and setbacks as well. One of the biggest problems to get around was the fact that X-Plane software is not documented very well. Though one team member purchased the full version of X-Plane ver.8, there was still a steep learning curve for the program. Near the beginning of the IPRO the assignments took a little longer to complete because of this.

Another problem seemed to arise from the fact that X-Plane seems to be tailored to the operation of larger aircraft. The obstacles we encountered started becoming more frequent when we began work on the smaller scale prototypes. The smaller scale models are usually meant for more stable atmospheric conditions, however indoor flight can't be simulated. The weather options thus had to be improvised. Also problematic with the 1:6.6 scale prototype model in X-Plane was its flight characteristics. It is theorized that the blade element theory that X-Plane utilizes possibly breaks down over such small user defined geometries. This may be due to rounding errors when certain values (areas, pressures, or forces) become too small.

Website/Funding

The Website / Funding team experienced several obstacles that were fortunately overcome due to diligence and persistence. One of the major obstacles encountered when constructing the website involved debugging action script code which is the language the team first used for the website. After much effort, the team realized that the UNIX server did not support action script modules and thus the team was forced to revert to an html based website with action script elements. Another obstacle encountered for the website was that the Office of Technology Services (OTS) stated that they could not allot a user-defined domain name for an IPRO, which made the URL of the website not as professional as had been hoped.

In terms of funding, the team first encountered a problem with the requirements needed for the application for the grant provided by the National Collegiate Inventors and Innovators Alliance (NCIIA). The application requires a detailed itemized parts list with a projected budget of each part for the full-scale prototype. At first, the team had no idea as to what exact parts were needed for a full-scale prototype. However, after considerable research, the team was able to gather the necessary information in order to complete the itemized parts list.

Results -

In order to obtain forward, lateral, and rotational control of our aircraft without the assistance of variable pitch rotor blades or a tail, a gimbaled rotor mount with two degrees of freedom and a rudder had to be designed and constructed. This was our characteristic control scheme for the Volar. However, this system had to be robust enough that it would resist the level of vibration present in the system while providing enough power to move the structure during flight.

In addition to the capabilities that must be designed for, there were a number of structural limitations on the model that had to be designed around. The helicopter chassis that was used as the basis for the Volar prototype had a number of hard points in which one could securely attach the servo motors needed for the control surfaces of a conventional model. However, the compound movement requirements of our rotor structure would necessitate servo-motor mounts elsewhere. The drive shaft for the rotor was also connected by a u-joint that could not exceed certain angles, so limiters also had to be included to prevent a catastrophic part failure.

Before suitable motor locations were identified, we first had to determine how strong the motors needed to be to move the rotor while in steady, level flight (hovering in this case). We measured the weight of our helicopter and approximated the total thrust generated by the rotor to calculate the restoring moments about the rotor structure's rotation axis. We then ordered higher torque motors and set up our connection points on the structure in order to get the needed moment arms for operation. Motors were secured with custom made casings constructed from a thermal-set plastic that could be bolted directly to the frame using the existing holes. The movement afforded by this allows for fore/aft and lateral motion through thrust redirection with hovering stability in the neutral position. For rotational control, a rudder that would redirect the wash from the rotor was installed and secured using the same method as the other motors. With this setup, the Volar's characteristic control scheme is in place.

There is evidence now that our VTOL design will fly. It has been proven in the X-Plane environment to be very easy to fly in fact. This is partly because of two aspects of its control. The first of which is that it is very stable in flight. It is always in a converging equilibrium during flight. Any disturbances that it encounters are dimmed down back to steady level flight after a few oscillations. The second aspect of its control that contributes to its ease of flight is how the Volar transitions from vertical flight to forward flight. Though the way it does this is with thrust vectoring, it is not a complex setup like those found in other VTOL designs. That control is the same yoke control found in traditional aircraft. Thus, this makes the thrust vectoring as seamless and intuitive as possible. Because of this, transitions between forward and vertical flight are seamless and effortless. These aspects of what makes the Volar easy to fly are what suggest that average people could own and operate our Volar design. This gives us hope that the Volar could one day become as prevalent as the automobile.

Simulation also was able to predict and test suggestions for new design elements to be applied to the actual Volar prototype. One example of this was the yaw control applied to the Volar prototype. The simulation group was able to predict the usefulness and control developed by a rudder-like flap that sits in the downwash of the thrust and can deflect to provide a yaw moment. After this prediction was made, application to the existing prototype was made.

The website / funding team has successfully uploaded a website that effectively portrays the status of the Volar Project. The website is aesthetically pleasing as well as informative so that potential customers / investors are kept eager to see the progress of the final Volar Project. The website can be viewed at the following address: http://www.iit.edu/~ipro317s05/.

In terms of funding, the application for the NCIIA grant has been completed. It includes a six-page narrative that delineates the overall objective of IPRO 317: VTOL for the Masses. The narrative also includes the overall aim of the Interprofessional Projects Program (IPRO) at IIT. Finally, the application includes specifics regarding this semester's work as well as the resumes of all participants involved in this project. The application will be sent out for evaluation and a response from NCIIA is due by the end of March, 2007.

In terms of advertising, a story regarding the Volar Project is going to be published on Slashdot, which is a website for technical news. Slashdot is aimed towards people interested in new and improved technology. By publishing a story about the Volar Project on this site, many technical people will become aware of the significance and advantages of the Volar VTOL aircraft.

Recommendations

For further iterations of IPRO 317 there are a few suggestions that we veterans have. The first of which is to attain more funding. Without funding, the work and progress of our Volar design will come to a halt. Another suggestion is for further iterations to begin a very detailed parts, cost, and assembly planning and cost estimations for a full-scale prototype model. This information was already needed for the NCIIA grant that our IPRO applied for. However, many investors and contributors would be more readily to donate to our cause if they knew exactly what IPRO 317 was going to do with their money. Finally, we recommend that the next iteration conduct controlled flight tests of the scale model Volar. It is important to show that our VTOL design is feasible and that not only a computer program can predict that it will fly. We will need concrete evidence that our design is a sound and able one.

References -

The website / funding team has used the following resources in order to expedite our assignment:

Funding Purposes:
National Collegiate Inventors and Innovators Alliance (NCIIA): www.nciia.org

Advertising:
The Volar's official website: http://www.iit.edu/~ipro317s05/.

www.slashdot.org (story about the Volar Project to be published in near future)