THE PERSONAL LIFTING VEHICLE: A JOINT PROJECT OF MECHANICAL ENGINEERING AND AVIATION TECHNOLOGY AT PURDUE UNIVERSITY

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Abstract *¾ Faculty members of Mechanical Engineering (ME) and the Aviation Technology (AT) were looking for ways to join forces and to use each program's strengths to develop a project in which students of both programs could interact, learn from each other, and work on a realistic project. It was decided to develop and build a Personal Lifting Vehicle (PLV). The PLV is a small aircraft, which uses the lifting fan concept for lift and speed. The project will be completed in several phases. Phase 1 perform a feasibility engineering study. Phase 2 the construction of a ¼ scale model. Phase 3 ground and flight test of the ¼ scale model. Phase 4 the development of a modified full-scale model used for the integration of the lift and propulsion systems and phase 5 will be the development of the PLV prototype. So far, Phase 1 and 2 have been completed. Phase 3 is under development, and phase 4 and 5 are scheduled for the summer and fall semesters of 2002.*

INRODUCTION

The ability to fly like a bird has always been mankind's dream, although we can fly faster and farther than any bird we still can't copy all their flight characteristics. The Personal Lifting Vehicle (PLV) is an attempt to develop a vehicle that is relatively inexpensive to operate, will fit in a standard garage and is useful for daily transportation much like a motorcycle. It will fly at relatively low altitudes up to a 1000 ft. The operational limits of the LTV are illustrated in table I.

TABLE I
Operational limits of PLV

Maximum ceiling	1000 feet
Maximum speed	80 knots
Cruise speed	50-60 knots
Rate of climb	250 ft/min
Flight time	2 hours
Take of and landing	VTOL

The fundamental idea behind the project was to design and build a realistic vehicle, which would give the students a realistic introduction to a future work environment. The authors believed that engineering students need to develop more hands-on manufacturing skills and technology students need to be introduced in engineering and design practices. The intend of this combined project is to have engineering and technology students work together and experience each other's knowledge and skills. Many ground breaking engineers were people who conceived ideas and were able to build their inventions. People like the Wright brothers and other aviation pioneers who liked to experiment and tinker with ideas and hardware till they came up with something radically new that would change the world. Even the high tech computer industry started out this way. A few highly talented and motivated people started building computers in their garages and developed software and hardware that have changed our lives. The last decades, the focus of engineering training has shifted to more design work, and less hands-on skill development. There is hardly any time in the curriculum to practice hands-on activities, and hands-on work is considered by some as vocational and not worthy of an engineer.

Due to the complexity of the project it was divided into 5 phases: Phase 1 perform a feasibility engineering study, Phase 2 the construction of a ¼ scale model based on the engineering drawings and concepts of phase 1, Phase 3 ground and flight test of the ¼ scale model, Phase 4 development of a modified full-scale model used for the integration of the lift and propulsion systems, and Phase 5 development of the PLV prototype. The process will be adjusted if necessary. The design and fabrication processes were modeled after standard aerospace industrial practices.

PHASE I

The project started with researching available data. The Internet was a good source of general information, in addition the ME students had to learn basic aviation design and manufacturing techniques. Several faculty members of the Aerospace Engineering Department and Aviation Technology Department were consulted. The students found some interesting data from a company called Millennium Jet that has worked on the same concept, the students contacted the company, and they learned that the company is still working on the project, and were entering the ground-testing phase, but they didn't have a flying proto type yet. We have all seen the jet pack used in James Bond movies designed by Wendell Moore an engineer at Bell aerospace. The jet pack works fine, but the major disadvantage of the jet pack is that the flight time is limited to about 30 seconds. To be able to be used as a daily transportation vehicle we needed at least a 2-hour range.

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The students of the Mechanical Engineering (ME) Department were tasked with the initial design of a proto type. The students were divided into five teams and each team was responsible for different tasks as illustrated in table II. As with any flying vehicle weight is the predominate factor. The total vehicle weight was limited to 500 pounds including engine and pilot. The weight ceiling is limited due to fan blade loading and available engine horsepower. The introduction of a turbine shaft powerplant could improve this due to its high power to weight ratio.

TABLE II
Task Assignments

Ducted fans	**Airframe**	**Drive train**	**Engine**	**Stability/ control**
Prop	Ergonomics	Engine drive shaft	Cooling	Direction control
Spinner	Safety	Gearbox	Fuel capacity	Avionics
Housing	Cockpit	Couplings	Oil	Gps
Local drive train	Engine mount	CV joints	Vibration	Radio
Noise	Controls mount	Natural frequency	Throttle movement	Strobe lights
Actuators	Fan mount	Bearings	Alternator	Altimeter
Pushrod clearance	5 point harness	Drive shafts	Starter	Throttle control
Rotation angle	Landing gear		Endurance	
	Fuel tank			
Vibration analysis	Fire wall		Heat analysis	
Finite element analysis	Center of gravity		Sound analysis	
Weight	Weight	Weight	Weight	Weight

SUCCESSES

1. The design of the airframe was straightforward. The Aviation Department requested an aluminum structure due to the availability of materials and equipment. The Students initially designed a tubular frame much like an ultra light vehicle. After consulting the AT Department it was decided to design a semi-monoque construction consisting of sheet, frames, stringers and bulkheads. After studying the design, the AT department was confident that they could build the fuselage/frame.

2. The engine team successfully selected a commercially available 2 stroke, 4-cylinder engine that could produce over 130 horsepower. Turbo charge or supercharge could possibly increase horsepower by 25 to 30 %. This engine had enough horsepower to justify a weight of 500 pounds, but max horsepower is produced at 6000 RPM. A very reliable engine is required because engine failure will probably result in a crash. The AT department would prefer a lower RPM due to excessive engine wear, noise and vibration. Reduction of airframe weight below 500 pounds will be necessary to achieve this.

3. The Drive train team designed a system of 3 gearboxes, drive shafts and universal joints, which could be manufactured by the machine shop. After discussions with the AT department, it was recommended to change the materials due to corrosion characteristics of the materials, and to make changes in the design to improve maintainability and accessibility of core components.

4. The ducted fans team selected a NACA 0012 as their optimum fan blade design after many hours of research and consulting several Aerospace faculty. They calculated that if they used a 2 ft diameter fan that they could produce 336 pounds of trust. The students decided to use composite blade and shroud material due to lightweight and relatively easy manufacturing processes. The ducted fan team had to learn the most due to unfamiliar material like the calculation of trust and lift which is not part of a ME curriculum.

FAILURES

1. The stability and controls team reported that they thought that it was impossible to design a stable vehicle. Their calculations proved that a concept of two fans was inherent instable and could not sustain controlled flight. In their final analysis they stated that 3 or 4 fans were necessary. Many members of the other teams including faculty disagreed with their findings, and it was concluded to build an experimental design to prove that the concept could work or not. Due to time limitations this project was forwarded to the next semester. Next semester a team of AT and ME students will try to solve the stability and control problems.

2. We selected the senior design class to design the PLV; the major disadvantage of this choice was that they wouldn’t be around for the next phases. There was no opportunity for the ME students to participate in the actual construction of the vehicle and it was just another paper design. We will have to select students in their junior year for this project so that they can actually participate in the building and testing of the vehicle.

3. Students were making wonderful designs on the computer using CAD, ProEngineer software and finite element testing, but forgot to envision how this could be built. The students didn’t design for

the life cycle of the vehicle, and didn't take in account the maintainability and reliability issues involved.

At the end of the semester the Mechanical Engineering students presented their design. Several Mechanical engineering, aerospace and aviation faculty members attended the presentation and supported the teams' findings.

PHASE II

Five students of the AT department, who were enrolled in an aerospace materials course, were tasked with building a radio controlled experimental prototype to study the possibility of the concept and to provide feedback to the Engineering teams. The faculty member of the ME department who taught the senior design class acted as team leader of the group. There was plenty of room to improvise and this was often necessary, because the original design could simply not be build per specifications due to impractical design or limited shop equipment and tooling. The students were scheduled to work on the project for eight hours a week, although in reality they worked many more hours to get it finished. Although the vehicle was completed in time it looked rather crude and will need some refining.

As the students started to build parts, they quickly found out that building to scale is often more difficult and requires different techniques and tooling. It was also important to realize that there is a difference between a paper design and the final product. They had to develop solutions and consult with the ME faculty member to redesign parts. It was interesting to see the creative solutions the students came up with.

CONCLUSIONS

The actual structures and sheet metal skills of the AT students were not developed enough, and this resulted in many rework and quality issues. For the next phases we need to recruit students who have finished all three aerospace structures courses and are in their junior year. The students were able to manufacture a ¼ scale proto-type, based on the original design, the students had many opportunities to modify the design and be actively involved in the redesigning process. The combination of an engineering faculty member leading a team of Aviation Technology students worked out fine, and there was a good interaction.

Some students received training in the Mechanical Engineering machine shop on how to operate and program CNC equipment not available in the materials laboratory.

The students were satisfied with their experiences and all of them were very enthusiastic and wanted to participate in phase 3.

VII. Phase 3

Having completed the first two stages, we were left with some problem areas. First, the ME students had to solve the stability problem of the original PLV design, and they had to learn a new software program to design the vehicle (SolidWorks). Phase 3 was the first phase in which ME and AT students jointly designed, developed and manufactured a project. The ME students were tasked with the redesign of the vehicle using the feedback from phase 2. A total of twenty-five engineering students were involved in the development of the PLV. They were divided in 5 engineering teams similar to phase I. The group of students elected a program and assistant program manager and the ME faculty member had the final design responsibility for the project. The Aviation Department tasked four selected students with the building of the vehicle and two AT faculty members were advising and leading the AT student's efforts. Due to the small group of students, the AT faculty members actively participated in the construction. The AT department's efforts were divided in two separate divisions: Airframe construction and final assembly in the materials laboratory, and the manufacture of fan blades and shrouds in the composites laboratory.

One of the reasons for the PLV project was that in recent exit interviews students had indicated that they would like to develop more practical skills in addition to all the required theory. They felt that the lack of manufacturing skills makes them feel uncomfortable around machines, tooling, and equipment.

THE FIRST EIGHT WEEKS

At the time of submission of this paper we have completed the first eight weeks of phase 3, and below we will give a short overview of the work accomplished so far.

At the beginning of the semester the students were given eight weeks to redesign the PLV. The final design review date was set for 6 March 2002. We have noticed in the first phase that it takes students about 3 to 5 weeks to make the step from being a student to become an engineer. At first they treat the project as another class assignment, and basically expect to find all the perfect answers or if they can't figure it out the professor will explain it. An important lesson for them is that they have to learn to accept that there is not always a solution or that the best solution is not always the most beautiful or technologically advanced option.

The students had to learn the SolidWorks 3D software package, before they could design the PLV. Although the students didn't have prior experience with it, they mastered it quickly. One limitation to this particular software is that it enables you to design parts that can't be manufactured unless you have a billion dollar state of the art machine shop equipped with laser cutting and CNC equipment. The following was a typical example of this. The students prepared a part drawing of a rib design and they used angles of 53.13 degrees, they realized when they started to lay out the design on the material and had to make the part that this was absolutely impractical and unnecessary. There was no particular reason for 53.13 degrees they admitted, it just came out that way when they dimensioned the part and they didn't think that it would matter. They learned an important lesson that sometimes you will have to adjust your tolerance and design complexity to the tooling that is available. A proper understanding of standard production and manufacturing equipment will greatly improve the ability to design a practical component.

The students had eight weeks to further develop the initial design of phase 1 and 2. We encouraged them to make the drawings available to the AT students so that they could manufacture sample parts which could be tested and analyzed and if necessary redesigned. The AT students would analyze the drawing and would ask the following questions:

- Can it be built using the tools and equipment available?
- Can we make it lighter or simpler?
- Can we repair it if it fails?
- Do we have access to engine and drive train components?
- Can the vehicle be serviced and maintained?

One of the first examples of the close cooperation between the two student groups was to develop landing gear pads for the tripod landing gear. The engineering group developed round pads with 60-degree flanges. The AT students had to explain to them that it was possible, but that it would take several heat treatments and the development of special tooling. The anticipated construction time to make the part would be 2 days. The AT students suggested to make a design with straight edges, which could be made in less than an hour. The engineers recalculated the strength requirements and redesigned the landing gear pads on the spot.

It was apparent that the two student groups were quite different. One AT student made the remark " She talks a total different language, I don't know what she is talking about". The two students worked in one group and manufactured a landing gear pad together. The first action of the engineering student was to open her bag and pull out a calculator, while the AT student was looking for material and layout tools. The AT students seemed to be more comfortable with experimenting than the engineering students. The first completed part of the vehicle was the tripod landing gear. The airframe team worked closely with the AT students to develop a tripod landing gear. The initial design was the construction of a U-beam design, due to the unfamiliarity with aluminum sheet material, the ME students didn't anticipate that an open construction like a U-beam of only 0.020" 2024T3 aluminum alloy is strong in compression and tension but lacks torsion strength. The AT students build the original design together with the ME students and they quickly found out that they needed to reinforce the structure. The close cooperation of the students resulted in a quick solution and a very stiff box design. The landing gear was designed to hold 300 pounds; it failed at 332 pounds during compression testing.

A group of ME students supervised by an AT faculty member are manufacturing the fan blades and shrouds in the composites laboratory. So far they have made sample pieces, which have been successfully tested. The engine team has selected an engine, and needs to find ways to purchase this engine within the budget of the project, and integrate the engine with the airframe. The drive train team has selected a drive system consisting of pulleys, gearboxes. The stability control group is working on the flight by wire control system.

It is anticipated that the project will be completed before the end of the semester. We are scheduled to begin ground testing and flight-testing in Phase 4, which will begin in the summer of 2002, and the fall semester of 2002. Phase 5 is scheduled for 2003.

CONCLUSION

We started the project to motivate our students and to give them a meaningful experience. The idea was to create a practical engineering effort, and using the strength of both the engineering and technology students was our goal. As we expected we found that the engineering students have very good computer software skills and were able to design beautiful designs on the computer using advanced programs like CAD, SolidWorks, and ProEngineer, but lack fundamental hands-on skills, which resulted at times in impractical designs. The idea of designing for maintainability and the complete life cycle of the vehicle need to be addressed in the future phases. The technology students needed more software related engineering skills and were not always able to clearly communicate with the engineering students due to a limited knowledge of engineering software.

We have completed the first two phases and experienced successes and setbacks. Phase 3 is taking place at the moment and the initial outcome looks promising.