THE DESIGN OF A PRIMARY FLIGHT TRAINER USING CONCURRENT ENGINEERING CONCEPTS

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Abstract

Concurrent Engineering (CE) concepts seek to coordinate the expertise of various disciplines from initial design configuration selection through product disposal so that cost efficient design solutions may be achieved. Integrating this methodology into an undergraduate design course sequence may provide a needed enhancement to engineering education. The Advanced Design Program (ADP) project at Embry-Riddle Aeronautical University (ERAU) is focused on developing recommendations for the general aviation Primary Flight Trainer (PFT) of the twenty first century using methods of CE. This project, over the next two years, will continue synthesizing the collective knowledge of teams composed of engineering students along with students from other degree programs, their faculty, and key industry representatives. During the past year (Phase I), conventional trainer configurations that comply with current regulations and existing technologies have been evaluated. Phase I efforts have resulted in two baseline concepts, a high-wing, conventional design named Triton and a low-wing, mid-engine configuration called Viper. In the second and third years (Phases II and III), applications of advanced propulsion, advanced materials, and unconventional airplane configurations along with military and commercial technologies which are anticipated to be within the economic range of general aviation by the year 2000, will be considered.

Introduction

Concurrent Engineering is presently receiving a great deal of attention in many segments of industry due to the significant reductions in development costs that can be realized with its implementation. It has long been recognized that ninety percent of all product development costs are locked in during the initial concept phase of preliminary design[1]. CE departures from the long standing approach to design as being a sequential activity. CE requires the combination of every function involved in the development of a product. This would include functions like engineering, procurement, marketing, sales and user support groups, all involved in design decision making early on in the design phase.

Why is CE important to engineering education programs? For one reason it is believed that the U.S. is losing its dominance in several industries as a result of engineering graduates who are poorly prepared in design and product development[2]. In fact, industry's view of engineering design education is that American engineering schools are producing great scientists but mediocre engineers. In other words, many universities do not view design as a credible research discipline. Thus, there has been an increasing number of engineering graduates specialized in theoretical and analytical methods, but with minimal design experience. Integrating CE into engineering education would help universities keep pace with the needs of industry and play more vital roles in a competitive U.S. design strategy.

Professional organizations such as the American Institute of Aeronautics and Astronautics (AIAA), and the Society of Automotive Engineers (SAE) strongly emphasize design activity at the university level; this may be the reason that the U.S. still lead in aerospace engineering by a thin margin. However, this dominance is continuing to erode from 73% of the market share in 1985 to 60% currently.[3] This trend may be linked to problems within the general aviation (GA) industry. GA makes up a large portion of the U.S. air transportation system.

Most of the primary flight trainers flying today are aging, almost to the critical point. Very few new designs (none from the U.S.) are being manufactured to fill the trainer roll. Most student pilots are being trained with pre-1980 aircraft. A poll of central Florida flight schools confirms the aging aircraft problem. All schools reported that at least 80 percent of their fleet are more than ten years old.[4]

Some of the more common aircraft used as trainers include: the Cessna models 152 and 172 (both introduced in the 1950's), the Grumman AG-5B Tiger (introduced in the 1970's), and the Piper Cadet (introduced in the late 1980's). Figure 1 indicates the dramatic decrease in the production of light aircraft occurring in the mid 1980's.

The problems within the GA industry associated with product liability laws and certification issues have led to the near extinction of new, single-engine aircraft in the U.S. Even the so-called newer designs, such as the Aerospatiale TB9 Tampico Club represent technology that is 20 years old. Furthermore, the skills developed in flying available trainers will be of little use to the pilot of a fly-by-wire airplane having velocity vectoring and a side-arm controller such as those seen in the corporate, airline, and military sectors.[4] Thus, the *utility* of general aviation aircraft becomes important in maintaining consistency with an expanding national airspace system.

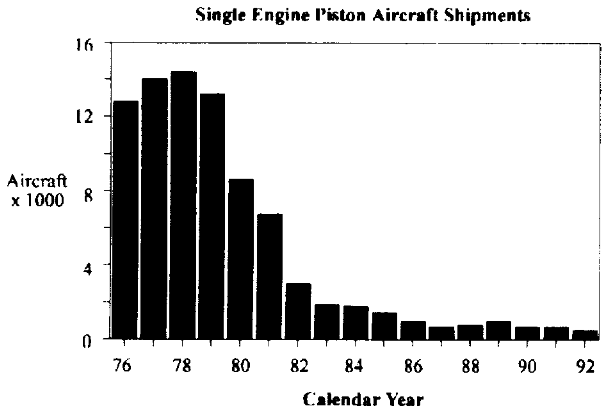

Fig. 1 U.S. Shipments of Single-Engine Primary Flight Aircraft.

Description of Project

The Advanced Design Program (ADP) at Embry-Riddle Aeronautical University (ERAU) is focused on developing recommendations for the primary flight trainer (PFT) of the twenty first century using methods of CE. Embry-Riddle has the unique opportunity to explore CE within the framework of aviation-related curricula. Students and faculty from a variety of programs such as aviation business, avionics, flight, aircraft maintenance along with engineering allow for collaborative efforts in the development of advanced primary flight trainers, representative of realistic, industry-type design projects. Thus, over the next two years, the ADP project will continue synthesizing the collective knowledge of teams comprised of engineering students, students from other degree programs, their faculty, and key industry representatives.

The development of the ADP/PFT is divided into three phases. All phases are supported by the research activities of a graduate teaching assistant visiting NASA/Langley Research Center during a summer internship. The first phase investigates conventional trainer configurations that comply with current regulations and existing technologies; the *now* airplane. In the second phase, applications of advanced propulsion, advanced materials, and unconventional airplane configurations will be considered. Third year activities will focus on the adaptation of military and commercial technologies which are anticipated to be within the economic range of general aviation by the year 2000.

NASA Langley Research Center

The ADP at Embry-Riddle commenced with the gathering of pertinent information applicable to PFT designs driven by methods of CE. Areas of investigation included:

- Low Reynolds Number/Laminar Flow Technology
- Stall Pattern Tailoring
- In-Flight Operational Loads
- Forecasting of GA Activity
- Changes in Airworthiness Regulations
- Product Liability and Certification Issues
- Advanced Prototyping and Manufacturing Technology
- Proven Concurrent Engineering Programs

Preliminary recommendations as a result of this research activity included:

- Utilization of existing NASA NLF airfoils which have been enthusiastically accepted by the GA industry.
- Consideration of leading edge droops as an effective means for preserving aileron authority at high angles of attack and eliminating wing twist.
- Investigation of in-flight data acquisition systems for improving future designs, pilot performance evaluations, and safety.

Phase I

Over one-hundred students, faculty, and representatives from the aerospace community have been involved in design and research activities during this phase. The initial two semesters of the project (92-93 academic year) were structured to generate modern, FAR Part 23 certifiable aircraft designs to be used as standards of comparison against the future designs of Phases II and III. This structuring was based on the fact that no existing PFT aircraft fully comply with the present FAR Part 23. By imposing design constraints such as use of certified, in-production engines, selection of proven aerodynamic configurations, and employment of proven fabrication methods, several *now* airplane designs were developed.

Embry-Riddle employs an aircraft preliminary design course and an aircraft detail design course. The preliminary design activities included concept and mission selection, configuration sizing, powerplant substantiation, weight and balance, stability and control, cost estimates, and considerations of manufacturing, repairability, and disposal of the aircraft. This past year, 22 teams were involved in preliminary design and were introduced to concurrent engineering through teleconferences and visits from engineers at NASA/Langley Research Center. In addition, instructors from non-engineering programs such as Embry-Riddle's Aircraft Maintenance Technology and Aeronautical Science departments supplied information regarding maintainability, repairability, human factors and pilot preferences essential in the design of a primary flight trainer.

For this project, a set of design parameters and mission profiles had to be tailored to fit the requirements of both the design course and a PFT as decided upon by the design course instructors. The design parameters require that aircraft:

- comply with FAR Part 23 including occupant safety and crashworthiness.
- use an FAA certified powerplant currently in production.
- comply with FAA VFR standards upgradable to IFR.
- accomadate two to four occupants.
- demonstrate good spin recovery characteristics.
- assure a structural life of at least 10,000 flight hours.
- reach cruise speed of at least 120 knots.
- be able to take-off or land in no more than 3,000 feet.
- cost no more than $50,000, excluding avionics, for production of 1,000 aircraft over five years.

Each aircraft had to satisfy one of two mission profiles. The first mission represents a general transportation scenario while the second that of a flight trainer.

Mission 1: Take-off
Climb to 5,000 ft
Cruise for 500 nautical miles
Loiter for 45 minutes with reserve
Land

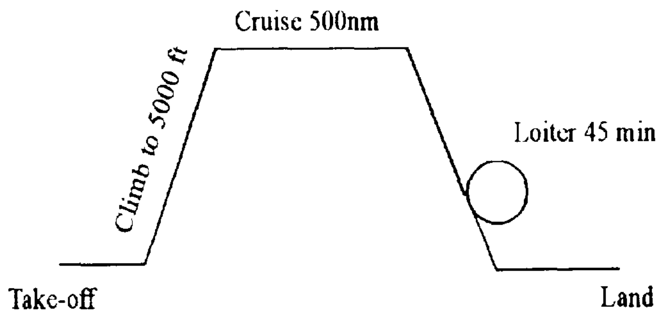

Fig. 2 Mission Profile 1.

Mission 2: Ten cycles of take-off and land (Touch and Go)
Take-off
Climb to 3,000 ft
Maneuver at 2 g's for 15 minutes
Cruise 100 nautical miles with reserve
Land

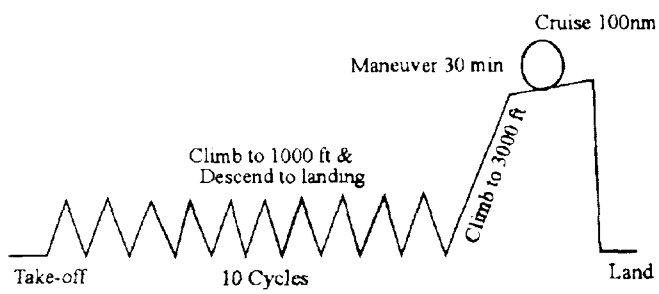

Fig. 3 Mission Profile 2.

The aircraft detail design course activities include structural design, load calculations and load path evaluation, system design and installation, material selection, manufacturing processes, and hardware familiarization. This past spring there were 14 teams assigned to conduct structural designs of the wing, empennage, and tail surfaces as well as the operation and installation of the control system. All components were designed for fatigue life and operational environments outlined in a statement of work for each project.

From the eight preliminary aircraft designs developed in the first semester of the program (Fall of 1992), two were selected for detail design. This selection was based upon the design's level of creativity, feasibility, and potential role as a primary flight trainer plus the completeness of the supporting documentation. The combined efforts of the preliminary and detail design courses have resulted in two baseline concepts, a high-wing, conventional design named Triton and a low-wing, mid-engine configuration called Viper.

The Triton Primary Flight Trainer

Configuration. The Triton Primary Flight Trainer (PFT) is a side-by-side, two-place, fixed-gear aircraft that conforms to all of the project design parameters. The aircraft has a cantilever high wing which provides excellent downward visibility, easy ingress and egress, and houses a gravity-fed fuel system. The Triton can be certified in either the normal or utility category. A single Lycoming O-235 engine enables the aircraft to attain a cruise speed of 120 knots. A summary of specifications and dimensions of the Triton are on the following page.

Design Features. The Triton has several modern design features that make it different from most of today's general aviation planes. First and foremost, the cabin was designed with ample internal volume for occupant safety and with structural reinforcement to insure increased protection. The cantilever wing eliminates the need for external strut bracing and thus reduces parasite drag and increases downward visibility. A large forward-opening "hood" to accommodate maintenance of the engine, and permits easy inspection and preflight procedures. There are inspection panels located throughout the aircraft for maintenance and inspection of control systems, flap mechanisms, wiring, and structures. Since high wing aircraft generally have poor upward visibility, a tinted window is provided between the wing spars in the cabin roof. The cargo area (42.5 ft^3) in the Triton can also accommodate a third seat which would meet the requirements of the flight instruction program currently employed at Embry-Riddle. This program, called Gemini flight instruction, has two students and one instructor in the same aircraft during training. One student receives flight instruction while the other observes the process.

Versatility. Mission versatility was one of the design goals for the Triton design team. While sized for the Lycoming O-235, the engine compartment can accommodate a larger engine. Utility category certification, baggage compartment accessibility, and baggage capacity enable the aircraft to be used for cargo or general aviation transportation. A three-passenger version configured for the Gemini flight training program is achieved without airframe changes or the need for supplemental certification. Since the high wing with the overhead window allow for excellent visibility, the Triton could also be used as an observation and reconnaissance aircraft. The high wing design and tricycle gear arrangements also permit conversion from a land-based aircraft to an amphibian.

Occupant Safety. There are several safety features employed in the Triton to maximize occupant safety and crash protection. The firewall is angled at the bottom so that the aircraft can slide along the ground without digging into the earth during a forward, falling impact. Angling the firewall also reduces the chance of fuselage buckling in the event of a crash[5]. Separate fuel tanks are set in the wing to avoid leaking and accidental puncture. The Triton is also equipped with energy-absorbing, "S-frame", JAARS[6] passenger seats.

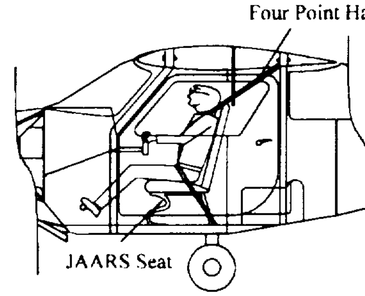

Fig. 4 Triton Cockpit layout.

The seat tracks are rigidly fastened to the floor structure so that they can absorb crash loads without dislodging from the airframe. Finally, four-point occupant restraint harnesses are attached at the floor and the wing carrythrough structure.

Configuration Sizing and Aerodynamics. Before any configuration sizing was done, the preliminary weight and fuel fractions were calculated for each of the two missions to determine which of these yielded the highest gross take-off weight. A weight of 1,785 lb came from the first mission (see **Mission Profiles**) and was used throughout the conceptual design phase until weight and balance was completed. The weight was further reduced after completing the structural design of certain parts of the aircraft (see **Structure**).

Following the take-off gross weight (TOGW) determination, the cruise power required was calculated to demonstrate that the Lycoming O-235 (rated at 118 hp) would be sufficient for the mission profile. The preliminary sizes of the fuselage, wing, tail surfaces, and control surfaces were then determined from the gross weight, and the wing planform was designed for desired flight characteristics as agreed upon by the design team. These characteristics include mild stall progression, aileron authority at stall, induced drag reduction, tip vortex distribution, flap effectiveness, wing twist, and incidence angle. A summary of aerodynamic coefficients for the Triton, based on the preliminary weight and sizing results are zero lift drag coefficient of 0.026, cruise lift coefficient of 0.303, maximum lift coefficient of 1.35 clean and 1.7 flapped, and a stall angle of attack of 10.7° clean and flapped.

After the wing configuration was finalized, the engine compartment and firewall section were proportioned to accommodate the engine and accessories. This task included the design and arrangement of a Dynafocal engine mount, exhaust manifold layout, carburetor intake duct, cabin heating system, and cooling air pathway. Further calculations sized the propeller to deliver the desired

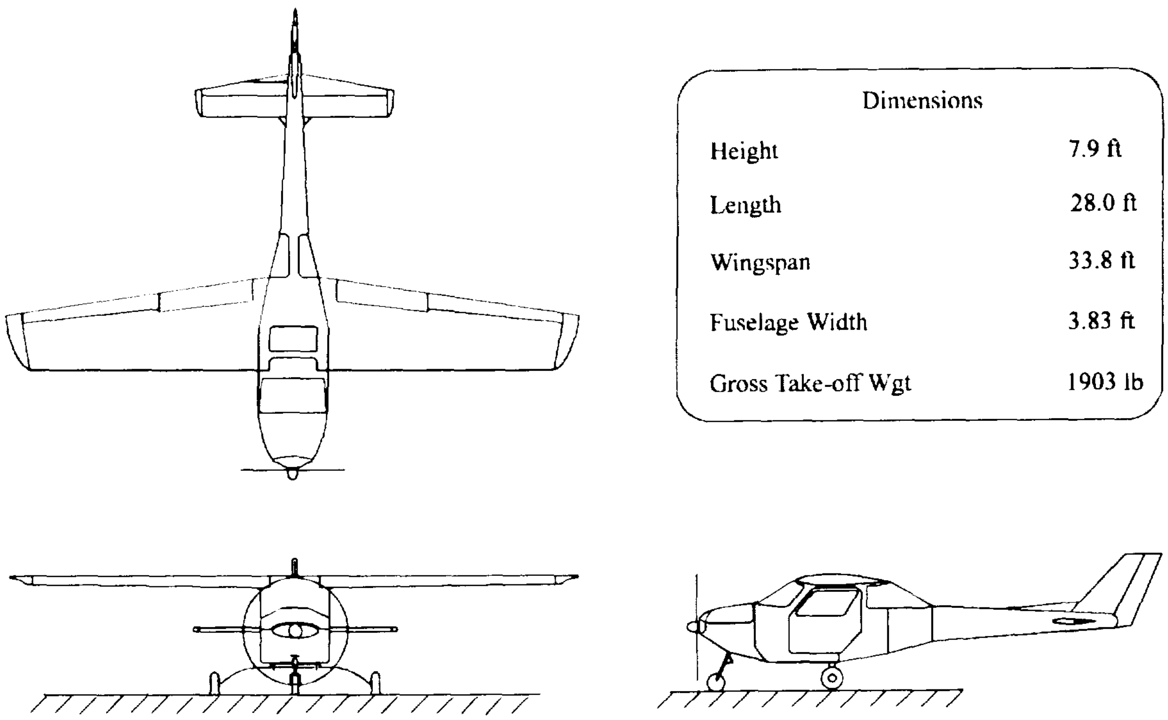

Fig. 5 Triton General arrangement

Triton Size/Configuration

Length (ft)	28.0
Height (ft)	7.9
Wing	
Span (ft)	33.8
Area (sq ft)	150.6
Aspect Ratio	7.4
Taper Ratio	0.56
Airfoil	NACA 64_1-A212
Horizontal Tail	
Span (ft)	12.25
Area (sq ft)	25.0
Aspect Ratio	6.0
Taper Ratio	0.56
Airfoil	NACA 0009

Vertical Tail	
Span (ft)	4.0
Wing Area (sq ft)	12.8
Aspect Ratio	1.25
Taper Ratio	0.30
Airfoil	NACA 0009
Performance	
Engine Type	(Lyc) O-235
Horse Power	118
Prop Diameter (in.)	74
Rate of Climb SLS (fpm)	724
Max. Velocity SLS (kts)	128
Cruise Velocity (kts)	120
Stall Velocity (kts)	53

performance and meet the far-field noise level as described in FAR Part 36.

The landing gear of the Triton was then positioned to satisfy the tipback angle, static tail down angle, maximum stall angle, and overturn angle requirements. To accomplish this, a rough estimate of the center of gravity location had to be assumed from aircraft geometry. Landing and braking loads, strut deflection, and tire size for each wheel was then determined. The Triton can use differential braking, a steerable nosewheel or both to maneuver on the ground. A redesign of the initial engine mount was required to accommodate the final nosewheel mount.

Airframe and Structure. Triton's airframe is designed to be constructed using traditional metal fabrication employing flat wrap construction. The primary structure of the aircraft consists of fuselage frames, wing and tail surface ribs, doublers, longerons, and stringers all surrounded by an aluminum skin. The cross-section of the aircraft begins square at the firewall and remains such until just behind the door, where it transitions into a circular section at the tail cone. The cabin floor is raised four inches above the lower skin by several C-section stiffeners to which the landing gear strut, seat tracks, and occupant harnesses are attached. Also in this space are the fuel selector valve, control system pulleys, and trim wheel assembly, all located between the two seats and serviced by a removable floor panel. The instrument panel, firewall, and doors are rigidly mounted to the longerons and stringers which shape the 46-inch wide (internal) cabin.

The Triton wing (Figure 6) has two spars, several stringers, ribs, and skin that are constructed from aluminum using extrusion and flat wrap construction methods. The complete structure is joined with NAS or MS standard, aviation fasteners. The spars are assembled from two altered T-sections riveted to a sheet aluminum web forming an I-beam. Each spar is one continual piece to ease construction and save weight by eliminating multiple spar assembly points. The wing skin varies in thickness depending on the shear and torque loads encountered in each panel. Provisions were made for easy access to the fuel tank and inspection of the flap and aileron controls. The entire wing is attached to fuselage cabin bulkheads with eight bolts.

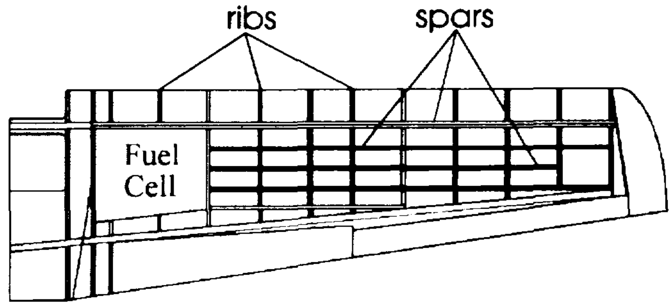

Fig. 6 Triton wing structure.

The tail surfaces are composed of ribs, stringers, and two spars wrapped with aluminum sheeting to form a NACA 0009 airfoil section. The flight loads to which the surfaces were designed were calculated using the methods found in FAR Part 23. The summation of the worst case loads was then used to design the empennage structure. The horizontal stabilizer and vertical fin have similar construction, as do the elevator, trim tab, and rudder. Each surface is bolted to the empennage using mating interface connectors. All components in each surface are designed to meet a 10,000 flight hour fatigue requirement.

The empennage consists of several ring-shaped formers held in place by eight stringers and an aluminum skin. The stringers were sized to transmit any bending and axial loads developed by the tail surfaces into the fuselage and the skin thickness was sized for the torsional loads. The frames were then placed to reduce stringer and panel buckling under the applied loads. Similar fatigue assessment was done on the components at both the fuselage and tail surface interface locations. Access panels and a ground tie provision were also incorporated in the design.

In addition, subassembly determination and assembly decomposition, snow load reactions, moisture drainage provisions, and system corrosion resistance were considered in the Triton design. After the size and strength of each component were determined, any fasteners integrated with the parts were also sized and documented.

Weight and Balance. A preliminary center of gravity location was estimated during the conceptual design phase but was later refined after approximating weights for most of the aircraft's structure and major components. Any weights not obtained from calculation or other sources were estimated. A spreadsheet program was used to evaluate various pilot, baggage, and fuel weights to determine the c.g. range and approximate locations. The new c.g. position was used to recalculate the landing gear requirements and was also used in the stability and control calculations.

Stability and Control. The Triton's static stability and control parameters were estimated. Longitudinal, directional, and lateral stability were evaluated, as were roll rate and spin recovery. For longitudinal evaluation, the neutral point location, static margin, horizontal tail incidence, and elevator deflection were determined. Directional criteria included C_{N_β} and ample rudder deflection to maintain control in an 11.5° crosswind, while lateral parameters included C_{l_β}, roll rate using the preliminary aileron size, and spin recovery behavior. All values except C_{N_β} and C_{l_β} were acceptable for this type of aircraft. A dynamic stability calculations was also performed on the aircraft for long and short period longitudinal modes, rolling mode, spiral mode, and dutch roll tendencies. Although the Triton is statically stable and controllable, a divergent long period phugoid mode (Figure 7) was predicted. While this is acceptable under FAR Part 23, such dynamic flight characteristics may cause liability problems and could result in unnecessary lawsuits.

Phugoid Mode

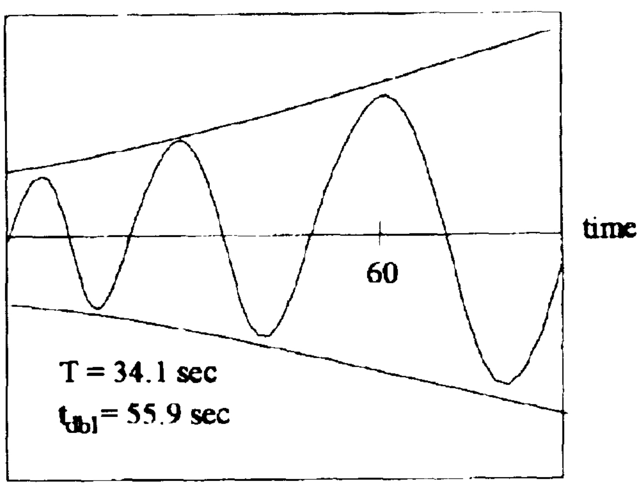

Fig. 7 Triton in phugoid mode.

The control system of the Triton is all cable-actuated from the yoke to the control surfaces. This was done primarily to keep the system weight within the prediction stated in the weight and balance calculations. The system was designed to deliver maximum control surface deflection without failure even if the pilot limit loads exceed those determined by FAR Part 23. Adequate maintenance provisions were incorporated into the design, as were considerations for thermal expansion, dust/dirt intrusion, corrosion, and component wear.

Cost. Both the production and operating costs of the Triton were evaluated using two computer programs. The production cost program determined whether 1,000 aircraft could be produced over five years with a ten percent profit margin while staying under the $50,000 per aircraft limit (less avionics and liability insurance). This schedule yields an overall production cost of $46,020 and therefore meets the design parameter. The operating cost program required yearly flight hours, loan values, and ownership type. With a schedule of 1,000 yearly flight hours, a 90 percent loan value, and company ownership, the operating cost is slightly over $36 per flight hour. This value compares with current aircraft rental rates and shows that the Triton would be competitive with all primary flight training aircraft.

The Viper Primary Flight Trainer

Configuration. The Viper is a two person, low wing, low tail configured primary flight trainer with fixed tricycle gear. The most unique feature of the Viper's design is its mid-mounted Lycoming O-235 engine. The Viper is designed to be certified under FAR Part 23 in the utility category.

Design Features. Viper's mid-mounted engine concept was chosen for several reasons. The mid-engine presented a potential for a smaller frontal area which should reduce drag. Since the placement of the engine produces a smaller moment arm in the center of gravity calculations, this allows the wing to be positioned rearward which improves downward visibility. The engine is serviced by removing a horseshoe-shaped hood over the engine, through an underside access panel, or through small preflight inspection panels around the engine. The Viper's tricycle landing gear allows for good visibility over the nose during ground operations. There are two doors on each side of the Viper. The top door is a gull-wing door that allows head clearance during entry while the lower door swings down and acts as a step to enter the aircraft. The lower door grants access to the cockpit control system, the underside of the instrument panel, and contains part of the engine cooling ducts.

Versatility. The Viper can be used in roles beyond those of a flight trainer. Its performance makes it attractive as a small business plane and its visibility makes it ideal for observation in law enforcement, wildlife preservation, or traffic-reporting.

Occupant Safety. The Viper was designed to conform to current FAR Part 23 crashworthiness requirements. Its JAARS seats will withstand the 26g forward loads required by FAR 23.562. Occupants are restrained by four-point harness systems. The engine is mounted in a truss-type mounting box which isolates it from the passenger compartment in the event of a crash. The propeller shaft, contained in the armored console, has three support bearings along its length and uses frangible couplings at both ends for safety if a crash were to occur. The shaft also has a dry clutch at the engine attachment to provide safer, smoother flight. Since the engine is behind the cabin, the exhaust is prevented from entering the cockpit with the aid of a venting system located behind the cabin; gases exit into a low-pressure portion of the slipstream.

Configuration Sizing and Aerodynamics. In examining the mission profiles for the Viper, the 500 nautical mile cruise mission consumed the most fuel, approximately 200 lb. The initial sizing was done based on this fuel weight. The required horsepower for the mission was 83.9 which is within the limits of the 97 HP Lycoming O-235. The total weight estimate was 1642 lb.

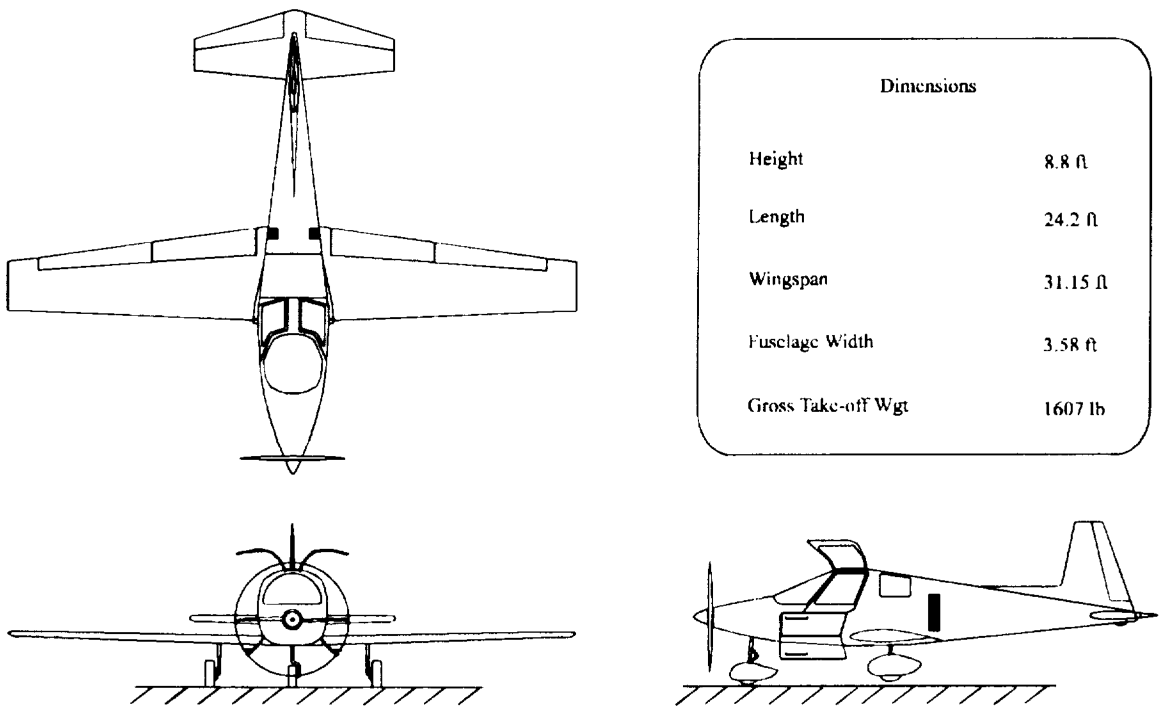

Fig. 8 Viper general arrangement.

Viper Size/Configuration

Length (ft)	24.2	Vertical Tail	
Height (ft)	8.8	Span (ft)	4.5
		Wing Area (sq ft)	12.9
Wing		Aspect Ratio	1.57
Span (ft)	31.15	Taper Ratio	0.40
Area (sq ft)	124.4	Airfoil	NACA 0012
Aspect Ratio	7.98	Performance	
Taper Ratio	0.45	Engine Type	(Lyc) O-235
Airfoil	NACA 64_2-415	Horse Power	118
Horizontal Tail		Prop Diameter (in.)	74
Span (ft)	10.95	Rate of Climb SLS (fpm)	1,140
Area (sq ft)	30.0	Max. Velocity SLS (kts)	140
Aspect Ratio	4.0	Cruise Velocity (kts)	136
Taper Ratio	0.45	Stall Velocity (kts)	46.5
Airfoil	NACA 0012		

Using these values and the Raymer text, the wing, stabilizers, and fuselage was then sized[5]. The wing airfoil chosen was the NACA 64_2-415 with a platform area of 124.4 sq ft and a 31.15 foot span. The aerodynamic coefficient for Viper are as follows, zero lift drag coefficient of 0.027, cruise lift coefficient of 0.400, maximum lift coefficient of 1.3 clean and 1.8 flapped, and stall angle of attack of 12° clean and flapped.

The Dynafocal engine mount is placed in a mounting structure to transfer the engine loads into the aircraft structure. For adequate engine cooling, two 60 sq in ducts were designed into the aircraft, one on either side of the cabin. Carburetor intake will also be from these inlets. To insure an even distribution of cool air, the left inlet cools the front cylinders while the right inlet cools the rear cylinders. The fixed-pitch propeller far-field noise calculations were less than the FAR Part 36 maximum of 70 dB. The landing gear was designed using criteria for static loads, braking requirements, gear stroke, dynamic loads, and tire selection.

Airframe and Structure. The forward fuselage of the Viper is made up of longerons along the bottom with stringers and formers used to reinforce the cabin. The seats and harnesses fasten directly to the floor longerons. Sections around the doors and access panels were reinforced. The aluminum-tube propeller shaft is covered by a shroud where it runs through the cabin. Yoke control system routing is done under the shroud.

The structures of all lifting, stabilizer, and control surfaces consist of ribs, spars, stringers, and flat wrap skin. All non-moving and permanent parts are riveted together while removable sections are fastened by bolts. Each section was calculated for shear and buckling loads and fatigue life.

The wing spar is composed of two units joined by four rivets. The spars consist of L-section caps and a linearly tapered web. The wing has no angle of incidence and a 1.6° dihedral angle. The wing was designed to handle the worst case loading scenario of a vertical 3g landing with fully extended flaps and ailerons. The wing carrythrough structure is composed of a two C-sections riveted to the fuselage airframe. The wing/fuselage interface consists of mating the C-sections to the front and rear spars using twelve bolts each.

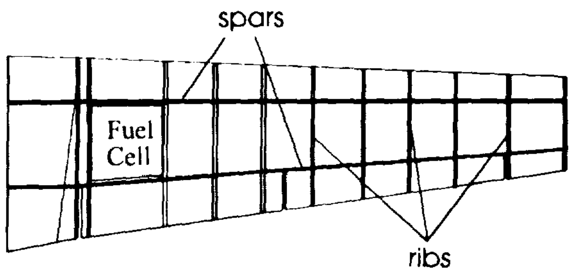

Fig 9. Viper wing structure.

The empennage is composed of the vertical and horizontal stabilizers and the tailcone. The stabilizers are similar in design to the wing with front and rear spars, ribs, stringers, hinges and torque tubes for the elevator and rudder assembly. The vertical stabilizer skin panels are beaded to reduce panel buckling. The tailcone assembly consists of 8 stringers and 3 ring frames. The last frame located at the point of the tailcone is made of cast aluminum and has a small hoop which will act as the tie down. The remaining frames are made from hydropressed aluminum blanks. Since the skin carries all of the torsional loads, while panel buckling criteria was used for sizing.

Access panels and lightening holes aid in the assembly or disassembly of the stabilizers, wing, and tailcone. These panels also provide for control system installation, maintenance, and inspection.

Weight and Balance. The weight and balance began with a detailed weight evaluation of the aircraft components. Actual component weights were used whenever possible. When these weights were not available, estimations were made using Raymer's statistical weight equations. The center of gravity was evaluated for a variety of loading conditions by varying the fuel load, number of passengers, and amount of baggage. The overall c.g. travel is 13.8% mean aerodynamic chord (MAC). The most forward position is 19.6% of MAC

Stability and Control. It is necessary that a plane possess the natural tendency to return to its original attitude, yaw, bank, and speed after a disturbance. To ensure this, several stability and control parameters were examined. For static stability, the neutral point and static margin were calculated. As a result the neutral point for Viper is 43.4% MAC and the static margin is 10%. Other calculations done to verify stability were incidence angles, directional stability, and lateral stability. Calculations were done for elevator deflection, directional and roll control, and spin recovery. In all cases, the Viper has adequate stability and control. A dynamic stability evaluation was conducted by a group of graduate students as a continuation of Phase I and concluded that the Viper also has good dynamic stability except in the phugoid mode. In this mode, the Viper has a divergent trend with a period doubling in 500 seconds. This is acceptable in normal conditions, but may pose a liability problem if a crash were to occur.

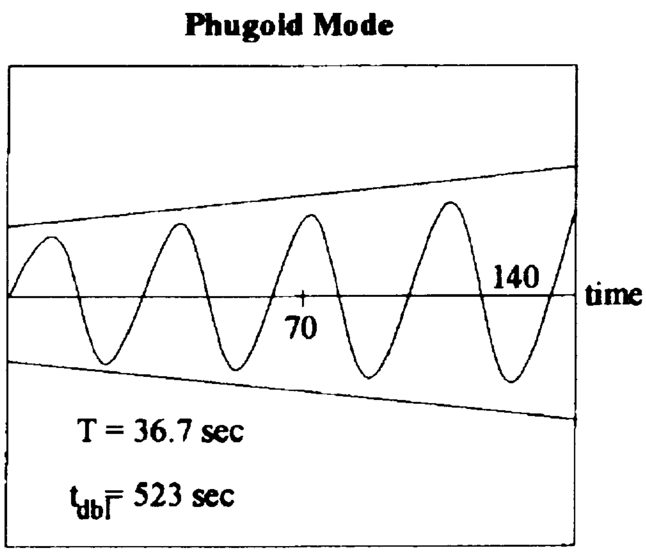

Fig. 10 Viper in phugoid mode.

The design of the control system provides a simple, reliable assembly that will withstand a training environment without excess cost or weight. An adjustable yoke in the cabin is connected to an all push-pull rod control system. Push-pull rods were selected for pilot feel and thermal expansion. The rudder control system provides both rudder and nosewheel deflection as well as differential braking. The elevator control system was designed using the loading conditions listed in FAR Part 23 and human factors specifications given in MIL-STD-1472.

Design substantiation was done for all control system components. Calculations consisted of Margin of Safety calculations, pilot limit loads, ultimate loading cases, and fatigue life. The current design provides a simple effective cockpit control system meeting FAR Part 23 specifications and will allow for comfortable flying.

Cost. The cost of the Viper was determined by using the LITECOST computer program developed at Embry-Riddle by Professor Charles N. Eastlake. This program uses the following parameters in determining cost: airframe weight, avionics cost, engine horsepower, production rate, number of aircraft produced, time to completion, and profit percentage. The Viper will cost $41,978 for a production of 1000 aircraft at 17 per month with a 15% profit. This price does not include avionics or liability insurance.

Materials, Manufacturing Methods, and Hardware

The primary construction material for both Triton and Viper is 2024-T3 aluminum. This material is either cast, extruded, or used as sheet to construct various components of the aircraft. Some parts are made of other aluminum alloys such as 7075 and 6061 depending on the stresses and loads in the part. Steel alloys such as 4130 are used for some highly-stressed critical components.

All components and assemblies for each aircraft are to be made from traditional manufacturing methods such as brake and hydropress forming, flat wrapping, and basic machining operations. Operations like stretch forming, double-action press forming, and spin forming were avoided due to expense, tooling complexity, and manufacturing time.

Parts are assembled using various aviation rivets and AN or NAS type bolts, nuts, and washers. The quantity and size of the fasteners were determined depending on the part load, assembly method, and orientation. Safety wire restraint is used on some bolts to eliminate loosening due to vibration or part motion.

Avionics

The statement of work for this phase required that all aircraft designed have at least visual flight rules (VFR) equipment aboard. This includes a communication transceiver, an emergency locator transmitter (ELT), and a transponder. The option to upgrade the aircraft to instrument flight rules (IFR) capability was considered. This would require adding an automatic direction finder (ADF), encoding altimeter, and distance measuring equipment.

Phase II

The design courses in phase two of the project will incorporate the use of thermoset structural composites, new powerplants, and Natural Laminar Flow (NLF) airfoils. The use of resin transfer molding increases the production rate of composite parts and lowers the manufacturing cost. Composite parts reduce weight and allow compound curves making the process suitable for the production of aerodynamic shapes such as natural laminar flow airfoils.

Several new powerplants are emerging that have great potential for use in general aviation aircraft. The water and oil/air-cooled Rotax 914 is half the size, weight, and cost of the Lycoming O-235. The multi-fuel, 4-cylinder, Zoche Aero-Diesel has a 2000 hour time between overhaul (TBO) and runs with turbine smoothness. The six-cylinder Dyna-Cam, certified in 1960, has a unique 4-stroke design that provides 210 hp at 2000 rpm and 650 ft-lb of torque at 1200 rpm. The newly certified, fuel-injected, air-cooled, Teledyne/Continental IO-240 is based on an engine originally developed by Rolls-Royce. Other powerplants that could be considered for use in the aviation field are converted automobile engines, rotaries, and stratified charge diesels. Alternate fuels such as automotive gas, alcohol, and diesel are being considered for aviation use.

Although NLF airfoils have less drag and better overall performance than existing airfoils, their acceptance may suffer from a history of disappointing results from the general aviation use of the NACA 6-series airfoils, known as the first generation of laminar flow airfoils. With the newly developed NLF-0414, laminar flow can be maintained back to 70 percent of the chord, which allows for a significant decrease in drag.

Phase III

Phase three of the project will explore advanced flight controls, cockpit displays, flight load monitoring, and structural thermoplastic composites. Advanced flight controls and cockpit displays include heads-up display, side stick control, CRT flat panel displays, and GPS navigation. To defuse the speculation in liability claims, a microprocessor-based flight load monitoring/recording system could be used to monitor the flight loads applied during the aircraft's life and indicate possible structural failure. The use of thermoplastic composites such as polyether-ether-ketone (PEEK) will allow for faster fabrication compared to thermoset composites. The advantages of thermoplastic composites over thermoset composites are low moisture absorption, high fracture toughness, and delamination resistance under low-energy impact conditions[8]. Also, thermoplastic material can be recycled, while thermosets cannot.

Recommendations and Conclusions

In 1992 the United States general aviation industry produced approximately 900 aircraft, including turboprops and jets. Of those 510 were single engine piston[7]. A decade ago the numbers were three times higher. The aircraft produced today still use technology from the 1970's. None of these currently comply with the current Federal Aviation Administration airworthiness regulations. Not one single engine piston aircraft produced in either the United States or broad employ state-of-the-art technology currently available in commercial and military aircraft. Applications of such technology could improve product reliability, operational safety and skill level attainment for the student pilots involved. The vehicles students currently use for primary flight training are technologically decades apart from the aircraft they will use as commercial pilots. As our national airspace system continues to expand, maintaining a parallel growth in the general aviation aircraft sector becomes increasingly more important.

The primary flight trainer aircraft market has the potential to be a multi-billion dollar per year industry in the United States. This can only be achieved if new material and manufacturing technology are explored along with significant changes in our liability laws and certification procedures. Improved methods for teaching design in engineering education can also contribute in a positive way. Concurrent Engineering at the undergraduate design level has proven to be successful as a means to bolstering student enthusiasm and interest during Phase I of this project. Student interaction on teams with input from other interested groups like engineers from industry and other previous preliminary design teams and flight instructors from ERAU's Aeronautical Science department has yielded better designs than previously accomplished in the capstone activities. The use of leading edge technology to form of stereolithography to produce models of student projects has led to a better understanding of design and manufacturing. Phase I exceeded the parameters set forth in this document. The program not only designed a better performing aircraft than required but it went in-depth in dynamic stability, cost manufacturing, engine selection for Phase II and safety constraints.

The Triton and Viper designs are important in that they represent a modern way of accomplishing an airplane design.

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