APPLICATION OF THE VALVELESS PULSEJET ENGINE TO POWERED SAILPLANES

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INTRODUCTION

Several fundamental problems have been inherent in the sport of soaring since the early days of gliding. These include such things as: launch equipment requiring skilled crews which confine the pilot to areas where launch services are available; dependence upon prevailing atmospheric conditions to get to soaring locations; and the difficulty of extracting both sailplane and pilot from some emergency landing sites. The ardent sailplane enthusiast will probably not be overly worried by these difficulties and may even consider some of them to add to the adventure of soaring. Unfortunately, these conditions have limited soaring flight to a small segment of the flying population. There exists a definite need for a satisfactory solution to these problems if sport soaring is to expand beyond its present limited activity in this country.

Although motorgliders or auxiliary powered sailplanes have been with us for a number of years, it has been only recently that a special chapter of the FAI Sporting Code has been taken under consideration to deal with them. The ideal auxiliary powered sailplane (Fifty Powered Sailplanes by Soaring International) would be equipped with a propulsive unit that would be very lightweight, be extremely reliable, not affect the aircraft's power-off performance, and have a low first-cost and maintenance bill. Several very interesting jet-powered sailplanes have approached these basic criteria. An extremely attractive approach to these problems can be obtained with the pulsejet engine. As noted in Soaring, July/August 1951, SNECMA first put four Escopette pulsejet engines under the wings of a German Baby II training sailplane. Further attempts to use the pulsejet for soaring did not occur until recently (Soaring, May 1970) when a small, valveless pulsejet was made commercially available as a retrofit installation.

The basic advantages of the pulsejet for auxiliary power are that it is self-aspirating (runs statically with no mechanical compressors); has no moving parts (low maintenance); is relatively inexpensive to operate; requires no close tolerance manufacturing (low cost); and can be so configured as to be readily adapted to almost any aircraft configuration.

VALVELESS PULSEJET PROPULSION UNIT

There are various types of valveless pulsejets. The configuration that is dealt with in this paper is pictured in Fig. 1. This particular engine was designed for use on helicopter rotor blade tips; however, the same engine can be used for auxiliary sailplane power with only minor modifications. As indicated by the figure, the engine is very lightweight, weighing approximately 15 lb. The valveless pulsejet engine operates on an intermittent acoustic/thermodynamic cycle. Normal operating frequency for this engine is approximately 100 cps and is primarily dependent on engine length. The most important difference between the valveless pulsejet and the normal valved pulsejet engine is the replacement of the mechanical flapper valves with a non-moving aerodynamic inlet valve. With this modification, the valveless pulsejet becomes a lightweight, simply operated propulsion unit with no moving parts. In addition, the valveless pulsejet engine may be bent

FIGURE 1

into a variety of shapes with little effect on performance if the internal surfaces are kept fairly smooth and bends in the engine are not too sharp. Engine size can be varied so that optimum engines can be obtained for various aircraft without major development work.

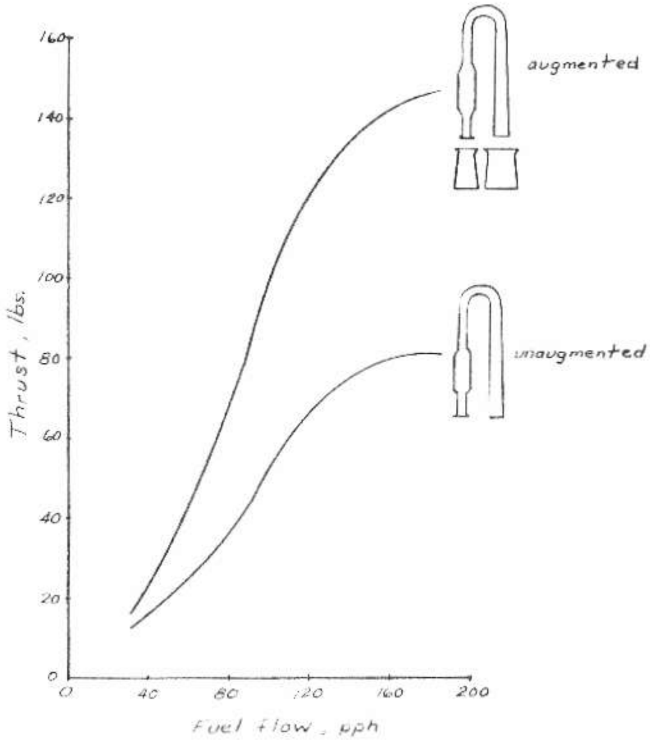
When the basic valveless pulsejet is combined with two augmenter tubes at the ends of the engine, a significant decrease in specific fuel consumption (SFC) is realized. Figure 2 shows the performance of a pulsejet engine with and without augmenters. These data are representative of the engine shown in Fig. 1. From an operations aspect, the valveless pulsejet refuses to ingest foreign particles, a vitally important consideration when operating over unprepared surfaces.

The intermittent cycle of the pulsejet engine may briefly be described with the help of Fig. 3. Starting is accomplished by simultaneously turning on the ignition, fuel, and starting air. The resulting explosion causes a pressure build-up within the engine. The air and combustion products expand out both ends of the engine, introducing the exhaust phase. Once stable operation has been obtained, ignition and start air are turned off. The momentum of these exhaust gases flowing from the combustion chamber results in an over-expansion and reversal of the flow in the exhaust pipe and inlet. During the inflow phase, when combustion chamber pressures fall below the fuel manifold pressure, fuel is forced into the fresh incoming charge. The air columns which enter the combustion chamber from both ends of the engine collide with vigorous mixing. Hot combustion particles from the previous cycle which did not escape from the exhaust pipe provide multiple points of ignition for the next combustion phase. The performance of the engine does not primarily depend on the types of fuel used in the engine. Successful operation has been obtained with a variety of fuels ranging from kerosene to propane. Common automotive gasoline is normally used. Of additional importance is the engine's very rapid thrust response. It is estimated that the pulsejet engine's throttle response is complete within three or four cycles or approximately 0.04 sec for this particular engine (Fig. 1).

Figure 2

VALVELESS PULSEJET

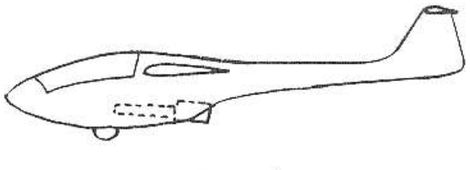
PERFORMANCE



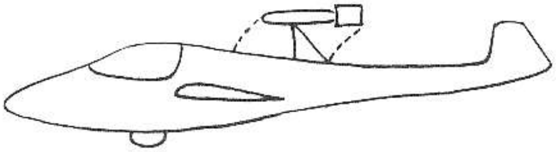
The thrust of the pulsejet engine can be substantially increased through the use of augmenters. These augmenters are specially shaped, short tubes which are placed at the ends of the pulsejet engine. They add very little to the overall engine weight and involve no moving parts. The performance advantages of these augmenters is obvious from Fig. 2.

ENGINE INSTALLATION CONSIDERATIONS

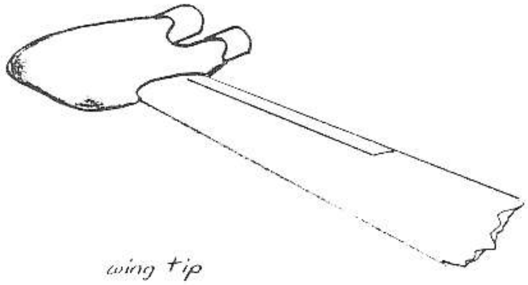
There are several important areas to be considered when auxiliary sailplane propulsion units are being proposed, especially jet propulsion units. First and foremost, the installation must produce as little added drag as possible. This is accomplished most easily when the propulsion unit is designed as an integral part of the airframe. Several options for this type of installation are shown schematically in Fig. 4. An alternate solution is to provide a retrofit propulsion package that could be used on a variety of sailplanes at the expense of performance. Other installation problems associated with pulsejet operational units are: (a) sufficient care must be taken to dissipate the radiant heat from the engine shell; (b) depending on the fuel



internal



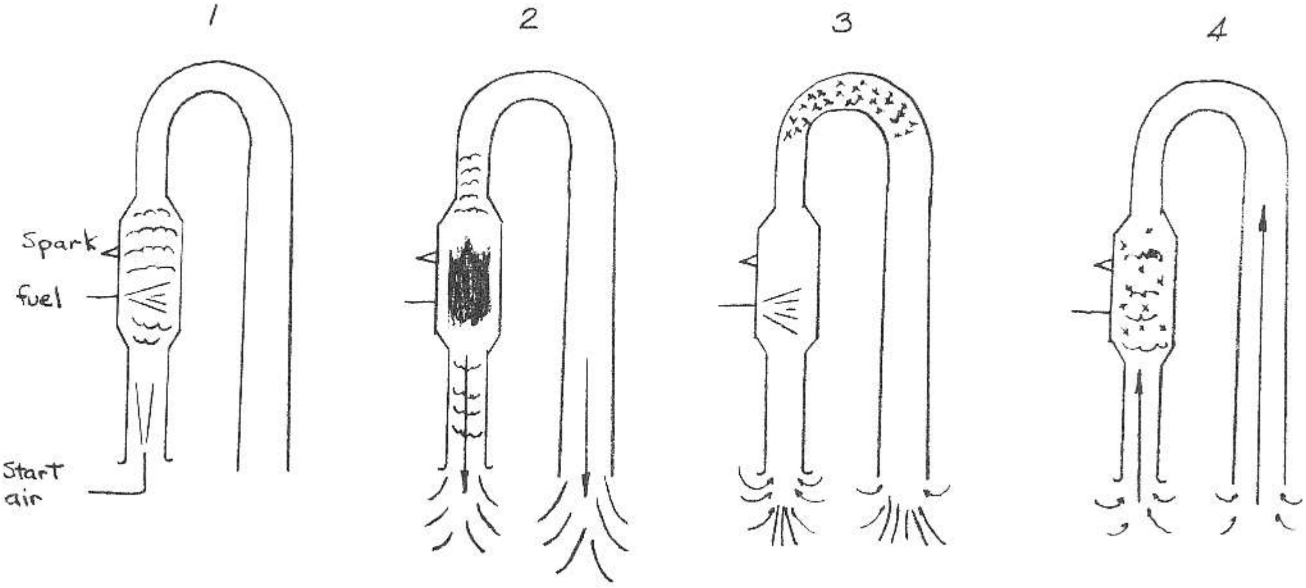
retractable



wing tip

Figure 4

POSSIBLE ENGINE INSTALLATIONS



Ignition and combustion

Exhaust

Inflow

Pre-combustion pressure rise and vigorous mixing

FIGURE 3. VALVELESS PULSEJET WORKING CYCLE

requirements, placement of the tanks should be made such that no C.G. shifts result from fuel consumption; and (c) provision must be made to adequately isolate the effect of wake vibration on the structure and allow for engine shell thermal expansion in the mounting attachment.

EFFECT OF PULSEJET AUXILIARY POWER ON SAILPLANE PERFORMANCE

There are three flight regions where the auxiliary propulsion unit influences the overall sailplane performance. These areas are: (a) take off; (b) climb to soaring altitude; and (c) emergency cruise. To illustrate the effectiveness of the auxiliary valveless pulsejet propulsion unit, a typical soaring flight profile will be assumed and a hypothetical sailplane will be examined.

The typical flight profile is shown in Fig. 5. Conditions where auxiliary power is used are shown as heavy lines. The condition which determines the engine size and thrust is the emergency field take-off. An estimate of the thrust necessary to lift off in 700 ft from a rough field is given by the following relationship which is quickly solved by iteration:

$$\frac{700}{KE}\,T_e - \frac{\ln F_s/F_g}{F_s/F_g - 1} = \frac{700}{KE}\,(0.1W + D)(1)$$

where T_e = engine thrust, lb

KE = kinetic energy of sailplane at lift-off speed, ft-lb

$F_s = T_e - 0.1W$, lb

$F_g = T_e - (0.1W + D)$, lb

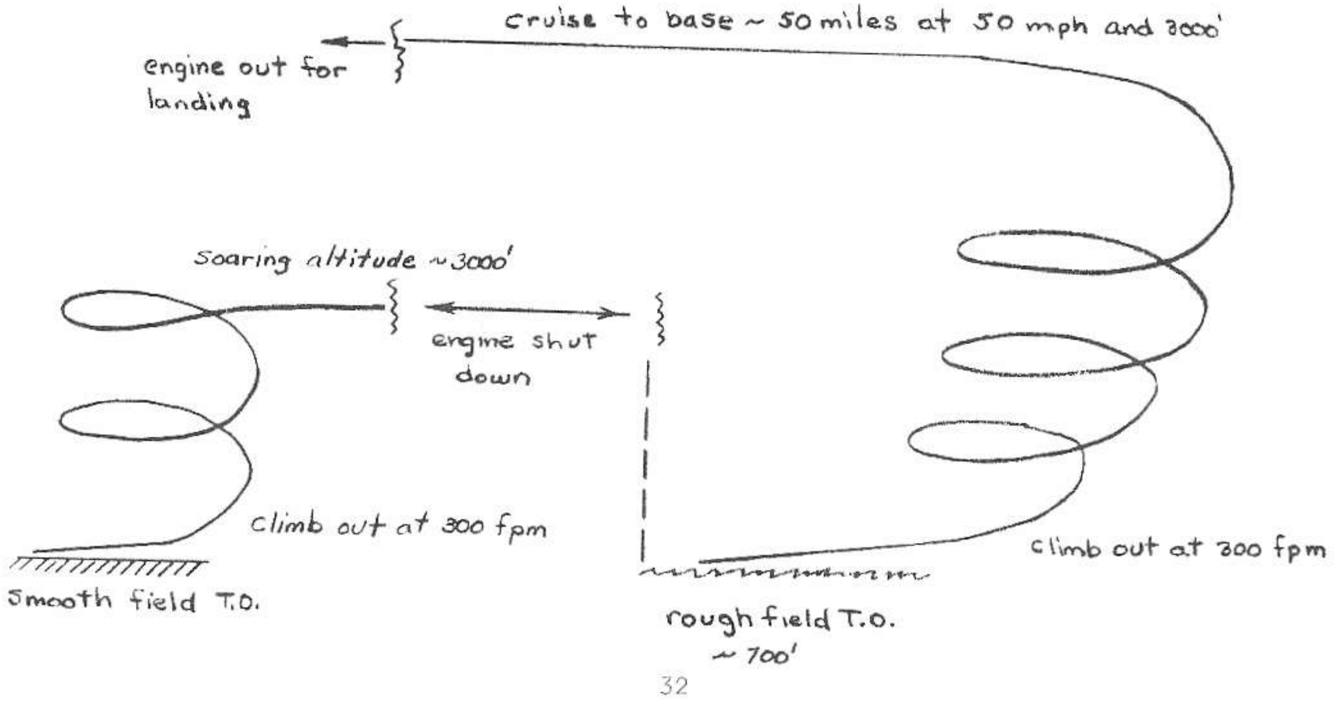
W = aircraft weight, lb

D = aircraft drag at lift-off, lb

Knowing the engine thrust, engine size may be determined from the following constants for the configuration shown in Fig. 1:

Figure 5

TYPICAL FLIGHT PROFILE



$$T_e/A_c \sim 3 \text{ psi}$$

$$L/D_c \sim 14$$

where D_c = engine combustion chamber diameter, in.

A_c = engine combustion chamber area, in.

L = total engine length, in.

Other parameters of interest for determining the effect of the auxiliary valveless pulsejet engine on sailplane performance are the rate-of-climb and the smooth field take-off distance.

Rate-of-climb may be calculated knowing the sailplane's gross weight and L/D:

$$R/C = \frac{T_e V}{W} - \frac{V}{L/D}\text{, ft/sec} \qquad (2)$$

The take-off distance can be calculated from the following equation:

$$S = \frac{1}{2}\frac{W}{g}V^2 \frac{\ln F_s/F_g}{F_g(F_s/F_g - 1)}\text{, ft} \qquad (3)$$

An example of the preceding procedures would best illustrate the valveless pulsejet's capabilities. In addition to the conditions outlined in the flight profile, a typical sailplane configuration will be assumed with a built-in engine and augmenter.

W = 800 lb

V = 40 mph (lift-off airspeed)

L/D = 30 at V = 50 mph

f_e = 5 ft^2 (equivalent flat plate drag area)

Engine Size

Equation 1 is solved by iteration for the above configuration:

$$\frac{700}{43,000}T_e - \frac{\ln \dfrac{T_e - 80}{T_e - (80+20.5)}}{\dfrac{T_e - 80}{T_e - 100.5} - 1}$$

$$= \frac{700}{43,000}(80 + 20.5)$$

$$0.0163\, T_e - \frac{(T_e - 100.5)}{20.5}\ln\frac{T_e - 80}{T_e - 100.5}$$

$$= 1.64$$

$$T_{e_{aug}} \simeq 153 \text{ lb}$$

Augmenters presently in use will approximately double the basic valveless pulsejet engine thrust, therefore:

$$T_e = 77 \text{ lb}$$

and

$$A_c = \frac{77}{3} = 25.6 \text{ in.}^2$$

$$D_c = 5.7 \text{ in.}$$

$$L = 14(5.7) = 80 \text{ in.}$$

Standard take-off time calculations indicate approximately 17 sec are required to lift off.

Smooth Field Take-Off Distance

Equation 3 is used. A power setting of 100 percent and $\mu = 0.02$ are also assumed.

$$S = \frac{1}{2}(25)(58.6)^2 \frac{\ln \dfrac{153 - 16}{153 - 36.5}}{116.5\left(\dfrac{153 - 16}{153 - 36.5} - 1\right)}$$

$$= 328 \text{ ft.}$$

Approximate time spent during this flight condition, according to standard take-off time calculation procedures is 7 sec.

Rate-of-Climb

To achieve a climb rate of 300 ft per minute, Eq. 2 is rearranged as follows:

$$T_e = \frac{R/C + V/L/D}{V/W} = \frac{\dfrac{300}{60} + \dfrac{58.6}{30}}{\dfrac{58.6}{800}}$$

$$= 93 \text{ lb (61 percent of full power)}$$

Time to climb to 3000 ft is 10 minutes.

Cruise

During the cruise portion of the flight profile, enough thrust must be supplied to overcome aircraft drag at 50 mph.

$$D = 1/2\rho V^2 f_e = 1/2(0.00218)(74)^2(5)$$

$$= 29.5 \text{ lb (19.3 percent of full power)}$$

Time required at this thrust level is one hour.

A summary of the estimated engine run-time, power required, and fuel consumed at an SFC 1.0 may now be made.

CONCLUSIONS

The valveless pulsejet engine suggested in this paper for auxiliary sailplane propulsion has many favorable qualities. It has no moving parts which simplifies maintenance and inspection, it can be formed into a variety of shapes and cowled to a low drag configuration, it can easily be restarted, and it requires a minimum of components for operation. This design has the capability of demonstrating a practical solution to the problems now associated with soaring flight.

CONDITION	RUN-TIME, HRS.	PERCENT POWER	FUEL USED, LB
Smooth Field T.O.	0.002	100.0	0.3
Climb	0.17	60.8	15.7
Rough Field T.O.	0.0047	100.0	0.7
Climb	0.17	60.8	15.7
Cruise	1.0	19.3	29.5
		Total Fuel Weight 61.9 lb	

EDITOR'S CORNER

A NASA-sponsored study (POTENTIAL STRUCTURAL MATERIALS AND DESIGN CONCEPTS FOR LIGHT AIRCRAFT, March 1969) available as NASA Report CR-1285, was carried out by San Diego Aircraft Engineering, Inc., and addressed the area of structural materials and design concepts. The primary objectives of that study were concisely stated in the introduction to CR-1285 and are quoted directly:

1. "To make a comparative evaluation of a wide variety of materials and structural concepts, presently and potentially available for application to light aircraft, by investigating the affect of design, manufacturing, operational, and material requirements on the cost of this class of aircraft."
2. "To apply the more promising materials and structural concepts to the conceptual design of light aircraft."
3. "To identify key problem areas where additional research may increase the potential of promising materials or concepts."

The scope of the report can be seen from the principal section headings listed below:

COST CONSIDERATIONS
  Dollar Value and Price Trends
  Cost as a Function of Speed and Empty Weight
  Cost by Component
  Cost Breakdown
POTENTIAL STRUCTURAL MATERIALS
  Material Costs
  Promising Candidate Materials
  Metallic Materials
  Non-Metallic Materials
EVALUATION OF PROMISING CANDIDATE MATERIALS
  Tension Members
  Simple Columns
  Compression Structure
  Shear Panels

(Editor's Corner continued on p. 35)