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Part 2 - Identification and Significance of the Innovation

The chief points of innovation for Cottrill Cyclodyne Corporation's 'Cyclodyne' powerplant design are: an efficient ramjet design encapsulated within a slightly larger static-running cyclical-flow design, and a front-end geometry which causes gradual transition from static-running operational mode to a reasonably efficient subsonic ramjet mode as forward velocity is increased over a practically attainable range. High affordability is a primary claim; a reasonable goal is total cost of ownership reduced to half that of equivalent turbocompressor designs, over the life of the engine. Other claims of interest are:

(1) complete absence of internal moving parts for powerplant operation;
(2) complete absence of pumped lubricants;
(3) extremely low cost to manufacture due to absence of any high speed balancing and high-precision machining requirements, overall mechanical simplicity, and no structural use of exotic materials;
(4) extremely low ongoing maintenance costs due to overall mechanical simplicity;
(5) very low engine weight and high thrust-to-weight ratio (at normal flight speeds);
(6) practically instantaneous power output response to throttle changes;
(7) efficient operation with a wide variety of cheap liquid fuels and, eventually, the possibility of the use of pure gaseous hydrogen as a non-polluting alternative fuel.

Because aircraft jet engines must be able to operate on the ground and at low speeds, ramjet designs have been ignored for normal category aircraft uses in favor of engines requiring mechanical compressor stages to supply air to the combustor section. While these designs offer reasonable efficiency, weight is fairly high for the value of thrust obtained, and a practical engine embodies a fairly high level of complexity, due to needs such as cooling and lubrication of bearings. Even with modern production methods, manufacturing costs remain high. Overall maintenance costs are high, and there are operational hazards relating to sudden imbalance caused by inhalation of foreign objects.

Advantages of ramjets include extremely light machine weight, very low maintenance requirements, ease of manufacture, very high thermal efficiency at flight speeds, relative immunity from catastrophic damage caused by inhaled small objects, and absolutely no mechanical torque; however, the ramjet cannot run on the ground and, in fact, must be accelerated to a relatively high forward speed in order to attain the intake air compression necessary to sustain combustion for efficient operation.

The success of turbine-driven compressor designs proves that a small fraction of the total combustion energy can be used to effectively drive the compression of air into the combustor; however, the use of a mechanical compressor is not the only efficient way such compression can be accomplished by parasitizing exhaust stream power. Two patents searches have shown a fair amount of prior art making a reasonable attempt to solve the static (zero speed) running problem in a design without moving parts by utilizing a portion of the exhaust flow stream directly as a means of air induction. Most practical designs are apparently fairly complex, however, particularly in terms of difficulty of manufacture. Complexity also impacts cost of maintenance (such as inspection and cleaning of fuel nozzles). Inventors' claims that the devices will accomplish static running appear theoretically sound, but there seems never to be any claim that performance characteristics will ever closely approximate those of a pure ramjet design. Most of these devices would appear to offer fairly high drag values at flight speed when compared to the very clean design of the classic ramjet.

As in the prior art mentioned, the 'Cyclodyne' design tries to achieve reasonably efficient static and low-speed operation by providing a means of supplying air to the combustor section of the engine without the use of internal moving parts by utilizing accelerated and recycled exhaust flow. Since this method of accomplishing static operation becomes valueless (and even possibly adverse to best engine efficiency) at high flight speeds, the front-end geometry is designed so that the naturally changing patterns of airflow within the device gradually reduce involvement of the recycling duct in supplying air as the engine is allowed to accelerate while allowing air impingement at the front of the device to take over, thus replicating the operation of a conventional ramjet design. Once a reasonably high forward speed is attained, the operation is supposed to be that of a subsonic ramjet with high relative thermodynamic efficiency and high thrust-to-weight ratio, although these characteristics cannot match those of an optimally designed ramjet. It is hoped that better than two thirds the thrust-to-weight and thrust-to-cross-sectional-area ratios of the classic ramjet pattern can be attained at moderately high flight speeds.

It is expected that thermal efficiency will be suboptimal in static and low-speed operational modes, when compared to mechanical compressor designs, due to the inherent 'low pressure' nature of the design. The basic idea is that savings in low initial cost and low ongoing maintenance costs will more than offset the relatively poor fuel economy in these modes of operation, which are, after all, tertiary to the basic intent of the device as an efficient powerplant for high subsonic flight speeds.

2.1 Theory of Operation and Technical Description

Fig. 1 through **Fig. 4** immediately below show the basic layout and features of the device, almost exactly as embodied in the Proof of Concept Model to be completed as part of the Phase I project. **Section 2.1.1** discloses in summary form the theoretical basis for the design. **Sections 2.1.2** through **2.1.5** detail the theory of operation in three different modes of operation (based on rough categories of forward velocity) with references to the numeric pointers in the drawings, exactly as written for future patent application. This version of the device is referred to as 'Embodiment 1' in the descriptions.

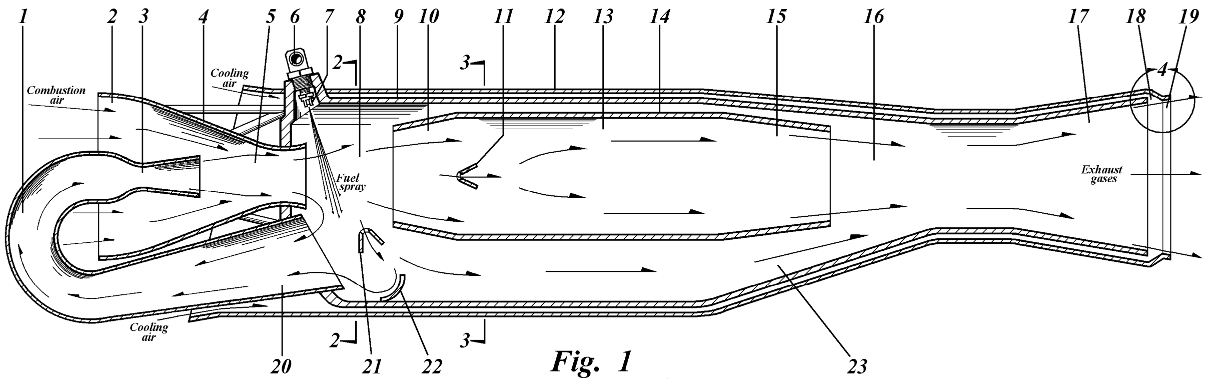


Fig. 1

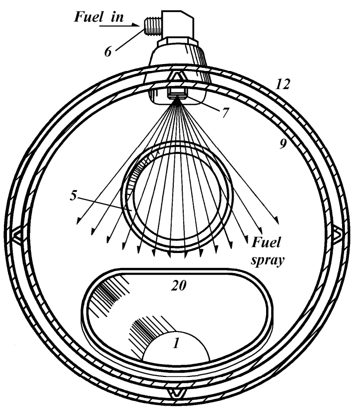


Fig. 2

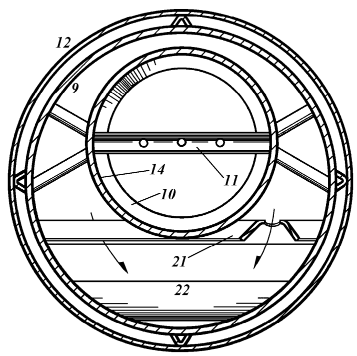


Fig. 3

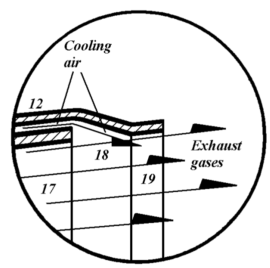


Fig. 4

2.1.1 Theoretical Basis of the Design

In fluids, all sensible 'pressure' is actually a value of total molecular momentum imparted to a unit surface area per unit time. In the case of jet thrust (essentially, acceleration through a nozzle), the total thrust can be interpreted as 'pressure' (in essentially a single direction) over the exit area of the nozzle. This sensible 'pressure' will, of course, be mostly due to fluid mass and spouting velocity in a practical gas jet application, with the actual static pressure of the fluid greatly reduced from that measured in the chamber supplying the gas. We could say that, at the nozzle exit, the momentum of the exiting gas overcomes the opposing momentum represented by the static pressure of the fluid outside the nozzle exit (generally, air) -- i.e., the higher momentum (per unit area per unit time) 'wins', even though the *static* pressure of the exiting fluid is much lower than that of either the gas supply or the air beyond the nozzle exit.

This principle explains how the exhaust gas delivered forward through the recycling cone and duct in the proposed design can feed back into the combustion chamber, against the static pressure of continuous combustion. The maximum static pressure of combustion in the chamber will be less than 20 PSI above the surrounding air. By accelerating a portion of the combustion gases through the cone, a velocity increase of at least 4.5 to 1 will be achieved. This will happen within hundredths of a second of the first detonation of fuel sprayed into the chamber. Even though there will be significant 'backflow' of exhaust gas forward through the intake throat during this interval, this flow will be limited to about the mean molecular velocity represented by the chamber pressure (on the order of 200 ft/sec). As soon as the accelerated gas begins to exit rearward through the nozzle of the recycling duct (at nearly 1000 ft/sec) the backflow 'pressure' in the throat will be immediately overcome, and net flow will be rearward *into* the combustion chamber throughout the throat cross-section. The higher total momentum 'wins'.

At this point, looking at the throat from 'upstream' (i.e. from the front of the air intake) we see a large volume of heated gas (mostly air, since we assume lean combustion) going *away* from us at approximately 1000 ft/sec. -- in effect, an area of very low static pressure. I have not found a mathematical expression to derive pressure from such a 'receding' flow, but presumably it would approximate the *negative* value of the same total momentum per unit area per second, and could thus be interpreted as a negative pressure (relative to the static pressure of the air in the intake) within the throat area. Obviously, there is a practical limit -- the actual pressure sensed cannot be less than zero (absolute), so the best we can hope for is a pressure difference of 14.7 PSI at sea level (with no forward motion of the device). This pressure difference is admittedly not much of a 'compressor' to drive fresh air into the chamber, but it will be enough if the intake is sufficiently large and if the drag of the intake interior is held low by reasonable design (supposedly, something like that shown in the drawings). So, we should have an adequate exhaust-driven 'compressor' to sustain combustion, admittedly at fairly low pressure when compared to typical gas turbine or turbojet design.

In static mode operation, combustion takes place in the large gap immediately behind the intake throat, where the fuel spray mixes with the incoming air. Combustion gases expand mostly rearward through both inner and outer combustion chambers, with just a small portion of the expanding gases moving forward into the large end of the recycling cone. Gases flowing rearward will reach approximately five times the velocity measured at the rear of the primary combustion zone, due mainly to the rear exit nozzle and the smaller nozzle at the rear of the inner chamber itself (since there is significant combustion within the inner chamber and a resultant gas flow rearward). The total of this accelerated flow produces the total momentum per second that would be measurable as the net thrust of the device, in static operation. It seems obvious that in static running, the inner combustion chamber acts mostly as a flow duct, without much net effect on total flow velocity (and, hence, total thrust).

An important characteristic of static operation is that, for local conditions, airflow through the intake throat and into the chamber is well below critical (Mach) velocity; in fact, so far below that there is very rapid diffusion and retardation within the combustion gap (and some associated turbulence as well). This helps to keep combustion localized at the front of the outer combustion chamber and helps combustion product gases to spread out fairly uniformly for apportionment into the outer chamber, the inner chamber, and the recycling cone. Once the device is moving forward and impingement air ('ram air') grows to significance, all this changes, however.

As air impingement increases, the net velocity in the intake throat rises and the momentum value increases, while the static pressure is further reduced. This combination of factors makes it harder for the inflowing air to disperse quickly in the combustion gap; the effect is to reduce combustion-expanded air diverted into the recycling cone and even reduce the ability of combustion gases to expand around the outside of the inner chamber. The combustion zone itself shifts rearward, due to the higher velocity of the air feeding the process (since we won't get combustion until we reach some point where the air slows to something less than 200 ft/sec). At some reasonable forward speed, the air velocity is so great that the recycling cone is completely cut off, and there is practically no combustion outside the inner chamber -- at this point, the inner chamber is acting as a nearly ideal ramjet, carrying the whole operation of the device, with its exhaust simply traversing the rear gap without significant impediment and with the developed thrust transferred to the outer chamber through the interconnecting streamlined mountings. Even when forward speed is sufficient to create a sonic shock zone in the throat, the expansion behind is fully directed into the diffuser part of the inner chamber. As in any ramjet design, the inner chamber uses 'flameholder' structures to ensure a reasonable location for the combustion zone, both to maintain thermal efficiency and to prevent 'flameout'. Restricting the incoming air, whether by reducing forward speed or by providing a device to throttle down the air volume, will smoothly regress the transition process, ultimately getting back to the static operating mode with full recycling as the primary air input mechanism. The important feature to note is that all this is accomplished without any artificial mechanical reconfiguration of the interior of the device; the overall geometry (especially at the front end) accomplishes everything required for the mode transitions described.

Keep in mind that the following subsections **2.1.2** through **2.1.5**, including their titles, are copied directly from the proposed patent application, so they appear in a more formal 'legalese' style than the surrounding subsections. The value of total gas momentum per unit area per unit time is referred to as 'velocity pressure', simply to distinguish it from the more common use of the word 'pressure' as meaning normal static pressure. Air impingement is referred to as 'impaction'. The physical arrangement of a fluid intake driven by a high velocity fluid flow through its narrow throat is called an 'ejector'. The design as a whole is referred to as 'Embodiment 1'. These discussions are included because of the close resemblance of the drawings to the actual form of the Proof-of-Concept model, and because of the value in having the customary reference numbers to the individual parts as shown in **Figures 1** through **4**.

2.1.2 Brief Description of the Drawings for Embodiment 1

The preceding drawings and the following detailed description disclose a specific embodiment of the invention; however, it is to be understood that the inventive concept is not limited thereto since it may be embodied in other forms. Reference is to the preceding figures as follows:

Fig. 1 is a side view of Embodiment 1 of the invention shown in full longitudinal cross-section;
Fig. 2 is an enlarged transverse cross-sectional view taken along line **2--2** in **Fig. 1**;
Fig. 3 is an enlarged transverse cross-sectional view taken along line **3--3** in **Fig. 1**;
Fig. 4 is an enlarged portion of Embodiment 1 taken along line **4** in **Fig. 1**.

2.1.3 Detailed Description of Embodiment 1 in Static Operating Mode:

Referring to **Figs. 1-4**, it will be seen that the first embodiment of the invention is incorporated in a reaction engine which may be described in its static operating mode (zero forward velocity) as follows:

Ignition of the fuel-air mixture in diffusion gap ***8*** in the forward part of outer combustion chamber ***9*** causes most of the combustion gases to flow rearward into outer exhaust cone ***23***, but also causes a fraction of the combustion gases to flow forward through recycling cone ***20*** into recycling duct ***1***. Combustion gases circulate around inner combustion chamber ***14*** as well as through it because the gas velocity from ejector throat ***5*** is insufficient for the gases to smoothly cross diffusion gap ***8*** into diffuser cone ***10*** at the forward end of the inner chamber before significant expansion, and due to turbulence after exiting the throat. The majority of the combustion product in outer chamber ***9*** flows rearward due to outer exhaust cone ***23*** having a much larger entrance area, and hence lower resistance, than recycling cone ***20***. Combustion also spreads rearward through inner combustion chamber ***14*** by entering diffuser cone ***10***, flowing rearward through inner plenum ***13*** and being directed through inner exhaust cone ***15*** across exhaust gap ***16*** into exhaust nozzle ***17***. Gases in recycling duct ***1*** are redirected rearward through ejector nozzle ***3*** into ejector throat ***5***, where their high velocity creates very low static pressure, causing fresh air to be drafted in via air intake ***2*** at the forward end of concentrator ***4*** (alignment of which is stabilized with the external bracing shown), creating an oxygen-rich exhaust/air mixture in ejector throat ***5***. The high velocity pressure of these gases guarantees positive flow into diffusion gap ***8*** against the static pressure of the combustion gases. Liquid fuel at high pressure is delivered through fuel inlet ***6*** and sprayed via fuel spray assembly ***7*** in the form of a flat, fan-shaped spray pattern transversely crossing the mixed exhaust/air stream exiting from the ejector throat and is readily burned in the air-rich mixture flowing out of the throat. Combustion is initiated by an ignitor (not shown) such as an electric spark plug mounted in the chamber wall but is carried on soon after starting by the elevated temperature of the internal parts. Flame holder/turbulator ***21***, a perforated transverse strut of folded metal, spans transversely across outer chamber ***9*** just below and forward of inner chamber ***14*** and acts as a flame holder and turbulator, as well as acting as a deflector to help route combustion gases toward turning vane ***22***, which helps establish flow into recycling cone ***20***. A similar flame holder/turbulator ***11*** is mounted transversely across the forward end of inner plenum ***13*** to help stabilize combustion there. After starting, the device is fully capable of static running due to the constant high gas velocity through the ejector section, the constant drafting and mixing by the ejector of fresh air into the diffusion gap, the constant injection of fuel into the diffusion gap and the constant supply of exhaust gases through the recycling cone into the recycling duct and hence through the ejector nozzle. In this operating mode, a significant level of combustion takes place within the recycling cone and recycling duct due to the availability of air and fuel routed downward and forward. To control the working temperature of outer chamber ***9***, outer exhaust cone ***23*** and exhaust nozzle ***17***, these parts are surrounded entirely by thin outer cooling shell ***12***, with supporting longitudinal stringers, providing a uniform narrow air space around the hot surfaces. Forced draft airflow through this air space from front to rear is maintained even while the device is run without forward motion because of constant low pressure in rear ejector gap ***18*** due to high-velocity exhaust gas flow out of exhaust nozzle ***17*** across gap ***18*** and through annular ring ***19***, thereby embodying another use of the ejector principle.

2.1.4 Detailed Description of Embodiment 1 in Transition from Static Operating Mode to Recycling-Assisted Ramjet Operating Mode:

Referring to **Figs. 1-4**, it will be seen that the first embodiment of the invention may be described in its transitional operating mode (accelerating through moderate forward velocity) as follows:

As the device is allowed to accelerate forward, there is an increased ram (air impaction) effect which eventually and automatically leads to fully continuous ramjet operation of the device without any change in mechanical configuration. The transition, as it takes place in accelerating moderate airspeed flight, is as follows: As velocity pressure increases at intake ***2***, there is an increase in velocity pressure in ejector throat ***5*** from the exit face of the throat into diffusion gap ***8***. As the velocity of air in throat ***5*** increases, the exhaust/air mixture increases in available oxygen content in diffusion gap ***8***, providing leaner and more efficient combustion. At the same time, the velocity of the gases leaving throat ***5*** increases, so more of the mixed gas flow crosses diffusion gap ***8*** into diffuser cone ***10*** and into inner chamber***14***, and less of the mixture is able to diffuse and flow around the inner chamber to combust in outer chamber ***9***. Also, there is therefore less combustion gas available for recycling cone ***20*** and thence into recycling duct ***1***, so recycling becomes less influential as the flow of impaction air increases. Fuel pressure and flow through fuel inlet ***6*** and fuel spray assembly ***7*** are increased to maintain proper mixture and increasing combustion pressure, by taking up the increase in available oxygen. Most of the fuel is carried rearward into the chambers, due to the high velocity and flow of the air stream exiting the ejector throat, reducing the level of combustion activity in the recycling cone and duct. Diffuser cone ***10*** is tapered toward the ejector throat to assist diffusion into inner chamber ***14***, and inner exhaust cone ***15*** is tapered toward exhaust nozzle ***17*** to increase exhaust velocity across exhaust gap ***16*** and, hence, out through the nozzle. The basic action is that of a suboptimal ramjet design assisted by recycled gases which add some momentum to ram air entering the combustion chamber.

2.1.5 Detailed Description of Embodiment 1 in Transition from Recycling-Assisted Ramjet Operating Mode to Full Ramjet Operating Mode:

Referring to **Figs. 1-4**, it will be seen that the first embodiment of the invention may be described in transition to its best efficiency operating mode (high forward velocity) as follows:

As the device continues to accelerate forward, air impaction eventually becomes the sole source of fresh air input to the device, and full ramjet operation is attained without any change in mechanical configuration, as follows: As a consequence of the velocity pressure increase at intake ***2***, there is an increase in velocity pressure in ejector throat ***5***. At high forward velocity, Mach (supersonic) gas velocity is attained at the narrowest point in ejector throat ***5***, accompanied by the formation of a transverse shock wave. Expansion of the air rearward of this shock wave into diffusion gap ***8*** is very rapid, but the velocity into the gap is so high that all the air leaving the throat enters diffuser cone ***10*** where it expands into inner chamber ***14***. Outer chamber ***9*** (including flame holder/turbulator ***21***, turning vane ***22*** and outer exhaust cone ***23***) as well as recycling cone **2*0***, recycling duct ***1*** and ejector nozzle ***3*** are completely starved of exhaust gases. Fuel pressure and flow are increased to maintain proper mixture by taking up the increase in available oxygen. All of the fuel spray is carried rearward into the inner chamber by the high velocity and flow of the air stream exiting the ejector throat. Diffusion gap ***8*** and exhaust gap ***16*** have no significant effect on flow at this velocity, so the inner combustion chamber acts as a classic subsonic ramjet with diffuser, combustion chamber with flame holders, and exit nozzle. The only adverse element is the presence of the recycling duct and ejector nozzle in the midst of concentrator ***4***, but the drag effects can be minimized by careful design of the shape and spacing of this part of the duct, of the exterior of the duct nozzle, and of the interior of the concentrator. The basic action is that of a near-optimal subsonic ramjet of conventional design.

2.2 The Production Prototype Model

While the Proof-of-Concept model should be adequate to prove the basic operability of the design, it has several important shortcomings. Most basically, it proves nothing about economical manufacture, which is essential to commercialization. Also, there are three significant technical deficiencies in the design of the proof-of-concept model: First, the 'inner combustion chamber' is merely built from easily available standard parts -- as such, it is not sized or shaped as an optimal ramjet; the intent is only for the overall design to be good enough to prove static operation and show that transition toward ramjet mode will occur as air impingement increases. Second, the outer cooling shell is not provided, due to the presence of large gasket flanges and their associated heavy-duty clamps which hold the subassemblies together, the intent of which is to provide easy disassembly & re-assembly for experimentation. This means that the model will quickly reach red hot shell temperatures if run for more than a few seconds, unless significant external forced cooling is provided. Third, there is no air throttle capability at the intake, since the need for this was not appreciated at the time of the proof-of-concept model design. Theoretically, this could be retrofitted, but this level of experimentation is deemed more appropriate as part of Production Prototype testing. The Production Prototype model is illustrated by the (unfinished) patent drawing shown as **Figures 5** through **7**, immediately below.

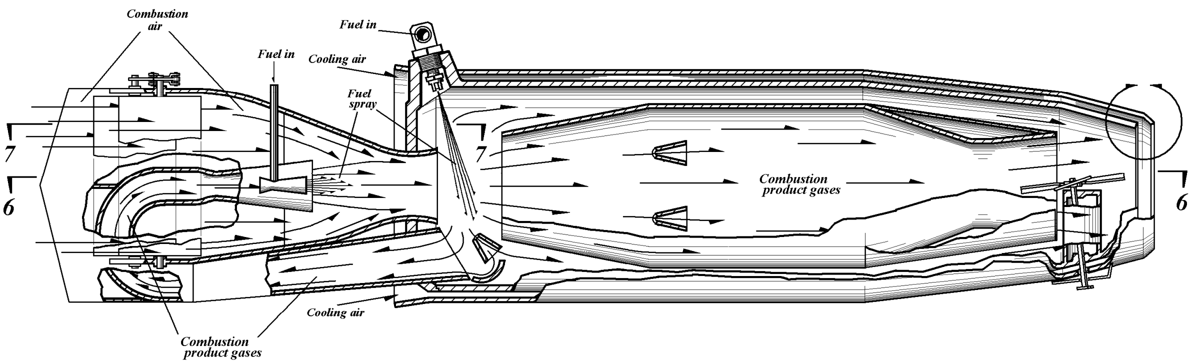
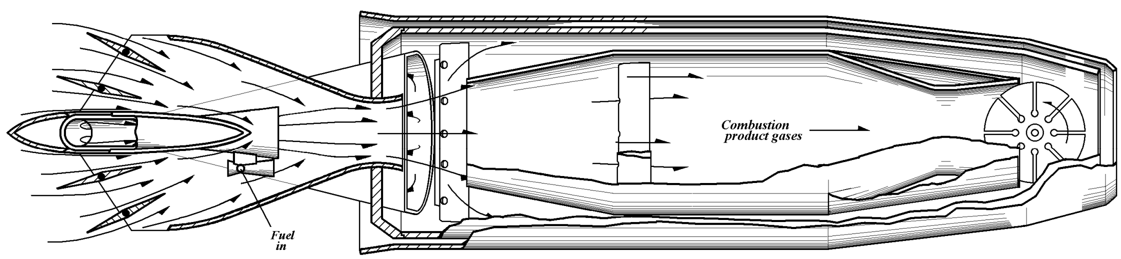
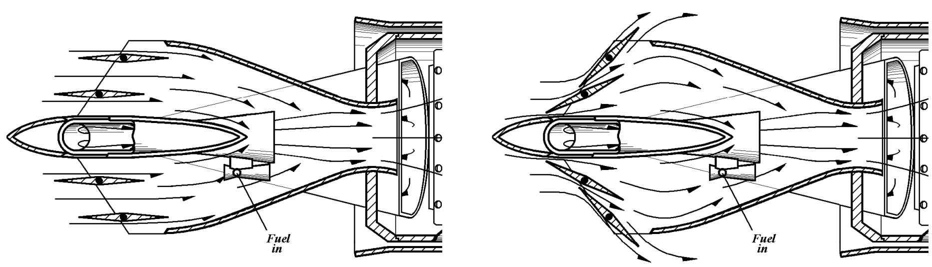


Fig. 5



Open Throttle Position

Fig. 6



Mid-Throttle Position ***Closed Throttle Position***

Fig. 7

The Production Prototype model is an attempt to overcome all the deficiencies in the earlier model while relying on ordinary sheet metal fabrication techniques almost exclusively. The only tubing remaining is in the fabrication of the recycling duct itself -- all other structural parts are fabricated from sheet stainless, using modern standard shop methods and tools. There are three basic subassemblies, each produced as a complete weldment: the front end (comprising the air intake with mountings for the air throttle vane bearings, the streamlined vertical center fin enclosing the recycling cone and duct, and the combustion chamber front plate with mountings for the fuel injector and spark plugs), the outer combustion chamber assembly (comprising the outer chamber and exhaust nozzle, the complete outer cooling shell, the engine mounts, and internal thrust shoes to receive the inner chamber mounts) and the inner combustion chamber (comprising the diffuser cone, chamber body, flame holder/turbulators, inner exhaust nozzle, and streamlined struts and thrust mounts). Minor assemblies, all attached at the front end, include the air throttle vanes and bearing plates, the throttle control linkages, and the fuel spray assembly. The drawing shows a simple helical vane turbine (for accessory shaft drive) centered just aft of the inner chamber nozzle exit, but this will be omitted from the Production Prototype model proposed and left for future experimental development. The outer engine mounts are not shown in the drawings, but would be located radially around the front end of the outer chamber, minimally perforating the cooling shell near its leading edge. Also not shown are the spark plugs (4) which would thread into mounts welded into the front plate in pairs just to the right and left of the air inlet throat where it perforates the plate, and the streamlined interconnecting struts which hold the inner chamber in place within the outer chamber wall.

Except for the effects of throttling, the principles of operation are exactly as described earlier. The main difficulty in relation to throttle control is the coordination of changes in fuel delivery with changes in air intake volume. The principal reason air throttling is needed is the difficulty of maintaining combustion while 'throttling down' -- if fuel control only were used, any attempt to quickly reduce power at flight speed would result in immediate flame-out due to excessive leanness of the air/fuel mixture, due to high intake air flow. It was decided that the simplest and most automatic way to achieve proper mixture control during throttling actions is to go to a combination of air throttling, fuel injection (arranged as in the earlier model), and carburetion, using direct injection to the chamber only for starting and maintaining a slightly richer mixture for throttled operation (e.g. glide slope, taxiing). This is achieved by locating a simple fuel suction venturi immediately to one side of the recycling duct nozzle, where its fuel draw will be directly determined by the velocity of air flowing toward the intake throat. This location also provides thermal coupling to the recycling duct, preventng icing in the venturi under humid conditions. In theory, a fairly high level of fuel injection would be used for starting and warmup; then, injection would be cut back to a lower level where it would remain during normal operations. At its minimum, fuel injection would always be set up at a rate that would ensure stable combustion under any fully throttled flight or ground condition. And of course, injection could be increased to richen the mixture for high power demand operations where fuel economy becomes a secondary consideration (e.g. takeoff and climbout, aerial combat).

2.3 Patentability

As mentioned above, two patent searches show that there is considerable prior art teaching the feasibility of drafting air into a combustion chamber by means of recycled combustion gases alone. Similarly, the principles of basic ramjet design are already well established. There is no particular physical component of the proposed design (with the possible exception of the folded sheet metal flame holder/turbulator, which has not been separately searched) that would be patentable as a claim in itself. The only basic claim to patentability is thought to be the unique internal physical geometry and its ability to redirect incoming air more fully into an internal combustion chamber (ramjet section) as forward velocity increases, ultimately leading to true ramjet operation. This is not taught by any of the prior art found, and I believe it to be a sufficiently important innovation to assure issuance of utility patent rights.

Part 3 - Phase I Technical Objectives

The Phase I objectives are:

(1) Completion and basic static testing of the proof-of-concept model, including experimentally determined design adjustments. A demonstration of reasonably efficient static running and preliminary evaluation of basic operational characteristics is the output of this objective.

(2) Basic positive forward velocity testing of the proof-of-concept model, including experimentally determined design adjustments, using an external high-velocity fan. A demonstration of the capability of the design to transition automatically to at least the threshold of true ramjet operation is the output of this objective.

(3) Completion of the production prototype model. A demonstration that the production prototype design is manufacturable using readily available commercial sheet metal fabrication methods and an absolute minimum of machining is the output of this objective.

(4) Basic static testing of the production prototype model, including experimentally determined design adjustments. A demonstration of reasonably efficient static running and preliminary evaluation of basic operational characteristics, including dynamic characteristics of the air throttle design, is the output of this objective.

(5) Basic positive forward velocity testing of the production prototype model, including experimentally determined design adjustments, using an external high-velocity fan. A demonstration of the capability of the design to transition automatically to at least the threshold of true ramjet operation while supplying thrust on the order of magnitude of the theoretical design value is the main output of this objective. Once the model is experimentally optimized, thrust/weight and thrust/cross-section ratios can be derived.

(6) Throttled positive forward velocity testing of the production prototype model, including experimentally determined design adjustments of the air throttle design, using the high-velocity fan. A demonstration of the value of the air throttle as a thrust and mixture control, including an evaluation of the air throttle as the principal in-flight power control, is the output of this objective.

(7) Static and positive forward velocity testing of the production prototype model using gaseous hydrogen, including experimentally determined design adjustments of fuel nozzle design and delivered gas pressures. A demonstration of full-range operability using gaseous hydrogen alone is the output of this objective.

Part 4 - Phase I Work Plan

In order to achieve the eight objectives described in Part 3 of this Proposal, we have divided the project into 13 major tasks. The following table provides our projected allocation by work provider by task. All numbers to the right of the task description are estimated hours to complete.

The PI has all the skills and tooling necessary for execution of the Phase I contract, except in the case of the fabrication of the Production Prototype model. It is desired to have the prototype subassemblies (all 316 stainless material) produced using methods as close to modern standard production practice as possible. The chosen subcontractor, Quality Manufacturing, Inc. of Urbandale, Iowa, is eminently qualified to execute this part of the project, and will provide all materials procurement and fabrication effort to produce the finished subassembly weldments; subcontractor and PI division of responsibilities will be as detailed in **Section 4.2** below. All other work, including other materials procurement, site preparation, construction of apparatus, testing, engine modifications, and documentation, will be performed by the PI or under his direct personal supervision under the company's Phase I contract obligation.

TASK	DESCRIPTION	PI	QMC
1	Complete Proof of Concept working model	60	0
2	Fabricate Production Prototype working model	100	81
3	Construct test pit & test site area	80	0
4	Construct test bench with thrust meter	20	0
5	Construct test control panel	20	0
6	Construct centrifugal fan assembly for positive forward velocity testing	20	0
7	Procure safety equipment for all testing	20	0
8	Perform basic engine static testing & modification, incl. documentation	60	0
9	Perform engine positive forward velocity testing & modification, incl. documentation	40	0
10	Perform hydrogen fuel static testing & modification, incl. documentation	10	0
11	Perform hydrogen fuel positive forward velocity testing & modification, incl. documentation	10	0
12	Program Management (incl. status/final reports)	40	0
13	Finalize Business Plan	40	0
Task Totals	Total allocated hours by work provider	520	81

Where: PI = Principal Investigator QMC = Quality Manufacturing Corporation

The remainder of this section describes each of the major technical tasks, followed by brief specifications for the working models.

4.1 Complete Proof-of-Concept Model

All fabrication of stainless subassemblies for the Proof-of-Concept model is expected to be complete before the Phase I contract is awarded. Remaining work to complete the working model under the Phase I contract comprises procuring materials for and fabrication of the ignition and fuel delivery systems. The ignition system will consist of spark plugs (one for the Proof-of-Concept model, four for the Production Prototype), several feet of high-voltage wiring, a point set driven by a small electric motor, a capacitive-discharge type ignition circuit, and an automotive spark coil. The fuel delivery system will comprise a steel or polyethylene tank, continuous stainless or copper fuel lines and threaded fittings (all standard automotive types), an automotive type electric fuel-injection pump and fuel pressure regulator, and short lengths of high-pressure fuel rated hose for direct connection to the engine under test. A small fuel pressure gauge and a fuel rated flowmeter will be provided downstream from the pressure regulator.

4.2 Fabricate Production Prototype Model

Construction of the Production Prototype model will be a shared effort between the PI and Quality Manufacturing Corporation of Urbandale, Iowa, acting as the subcontractor. Because of Quality Manufacturing's established expertise in stainless steel fabrication and production, the laser cutting, parts forming and welding to produce all engine subassemblies will be their effort. All experimental results from basic testing of the Proof-of-Concept model will be evaluated by the PI before finalizing the design of the Production Prototype model. Dimensioned parts drawings and specifications will then be provided to the subcontractor by the PI, who will handle any questions, including requests for changes, which arise during the fabrication process. The subcontractor fully understands and accepts that the principal objective at this point is to make sure that all materials, parts, tooling and methods are exactly as needed for full-scale commercial production (except for custom tooling, such as building jigs) - the use of hand re-working to achieve proper fit is not acceptable; instead, a request for change will be submitted to the PI for subsequent redesign or other suitable resolution, before continuing with the work. All materials procurement and fabrication effort for the subassemblies will be provided by Quality Manufacturing Corporation under the Phase I contract. As a contingency plan, parts for two complete engines will be initially cut from the purchased sheet stock. All design, drawings, direction to the subcontractor and handling of requests for changes will be provided by the PI under the Phase I contract. All subsequent construction to complete and test the model such as attachment of fuel delivery and ignition systems and attachment of gauges, etc., will be performed by the PI under this contract.

4.3 Construct Test Pit and Test Site Area

The next major task in preparing for testing will be preparation of the outdoor test pit and surrounding area. The pit will be approximately six feet wide by eight feet long in plan and at least 18 inches deep. An earth bank will surround the top rim of the pit so that the pit wall and bank form a sloping surface angled at about 45 degrees away from the engine test bench. Considering the small size of the models and limited fuel delivery rates, this should be more than adequate to provide effective containment for small fuel fires in case of a minor accident. Front and rear walls of the pit will be lined with concrete pavers, also sloping away at 45 degrees; the rear wall will have a fire brick facing overlaying the pavers, to act as a 'blast wall' deflecting exhaust flame projection upward. A reinforced concrete pad at least 4 inches thick and sized adequately to support the test bench and engine will be poured on undisturbed earth at the center of the pit, with four embedded studs provided to secure the test bench. Fuel tanks will never be located to the front or rear of the model engine under test, since these are the most likely directions for unintended excessive flame projection. Fuel tanks will be embedded in earth at an elevation that will keep the highest fuel level beneath the fuel spray nozzle in the engine, to prevent accidental siphoning. All ignition and fuel system electrics will operate from a 12-volt DC battery, of sealed gel type construction; the battery will be located well away from fuel tanks. The test control panel (switches, valves, etc.) and storage battery will be located to one side at a distance of at least ten feet from the engine centerline. Large face pressure gauges will be mounted near the engine on the test bench itself, facing the control panel and clearly visible to the video camera which will be used to record all test firings. A steel deflector panel, approx. three by seven feet in size, will be located to offer further protection for the control panel, fuel tanks, battery, etc. and tilted at a 45 degree angle away from the pit to provide upward deflection. All electrical and fuel line runs to and from the pit will be through buried PVC conduit.

4.4 Construct Test Bench with Thrust Meter

The test bench and panel will be a simple assembly of mild steel weldments made up of standard structural sections (angles, channels, tubes, etc.) arranged so that forward movement of the engine will lift a weight suspended on a swinging arm supported by a suitable bearing. This design means that more thrust will always be required to raise the weight further, so that the upward rotation of the weighted arm can be used as a measure (admittedly, non-linear) of thrust. A simple visual scale will be arranged to 'linearize' this measurement. It is expected that such a mechanism, once calibrated, can provide measurements to better than plus or minus 5 percent accuracy, which should be deemed adequate precision for tests at this stage of development. The lower stationary section will be bolted securely via the embedded studs to the concrete pad at the bottom of the test pit. The gauge panel will be part of the welded engine mount plate assembly so as to move with the engine and will provide solid mounting of all the pressure gauges, which will be of large face, panel mount, liquid-filled type. Mounting the gauges on the moving bed of the test bench allows them to be connected to the engine under test via short stainless lines and threaded fittings for maximum safety. Mounting for the airspeed indicator and custom-built Pitot tube assembly for intake airspeed measurements in positive forward velocity testing will also be mounted on this panel. Note that separate pressure gauge lines and Pitot tube assemblies will be required for the two different models tested.

4.5 Construct Test Control Panel

Construction of the control panel is simple, since all the pressure gauges are located on the test bench. A simple panel will be constructed to mount an ignition system switch, a fuel pump switch, a fuel delivery valve with lever, and an aircraft-style throttle lever and cable (for use in throttle testing of the Production Prototype model only), as well as a large 'panic switch' that can be used to immediately shut down all electrical power to the ignition and fuel delivery systems. Since there is no need for gauges on this panel, it seems reasonable to design it so a notebook can be supported for recording observations during tests. Construction will be of small lumber and plywood. All switches will be high-grade industrial machine types. Throttle levers for fuel valve and air throttle control (Production Prototype model only) will be purchased (if something suitable is available) or custom built from mild steel sheet; suitable levers will be of steel construction with comfortable grips and adjustable friction.

4.6 Construct Positive Forward Velocity Test Fan Assembly

For positive forward velocity testing, a large (at least 30 HP) centrifugal or axial fan will be used. The fan will be equipped with a long velocity cone and mounted on a simple rail mechanism running parallel to the engine centerline, so distance between the cone outlet and the engine air inlet can be manually varied to adjust the impingement airspeed at the engine intake. The velocity cone will be custom built of mild steel sheet metal and bolted onto the outlet flange of the fan housing. The fan mounting and rail will be custom built using standard steel sections.

4.7 Procure Safety Equipment for Tests

Because of the small size and fuel requirements of the models and the careful design and fire containment value of the test pit area and control panel, highly sophisticated safety equipment is not deemed necessary. Two fire extinguishers of suitable type will be provided, stationed at two different points near the control panel area. Vision and hearing protection will be provided for the engine operator and any test spectators present. Spectators for any given test will be strictly limited in number and stationed well away from the engine under test and the equipment area.

4.8 Perform Basic Engine Static Testing

All engine static tests will be under the direct personal control of the PI. Initial static tests will be 'fractional second' firings (judged as observable combustion for one second or less) using the most flow-limited fuel nozzle available for each model, after which an initial evaluation will be made and all observations noted. All static tests will be recorded on video tape as well, with imprinted date and time information clearly visible on the video record. If the brief initial test firing is successful and evokes no obvious safety concerns, the next test will be of approximately ten seconds duration unless aborted for technical or safety reasons. After each test firing, all observations will be completely recorded before initiating further testing.

Tests will be incrementally lengthened as warranted by observations until satisfactory runs of several minutes are obtainable. Once satisfactory test runs become long enough for combustion chamber temperature to stabilize, pressure values and thrust can be evaluated. Then, after allowing cooling time, the engine will be disassembled and inspected and any further observations noted. If no damage or other difficulties are observed, the fuel nozzle size will be incremented upward and another test series run in exactly the same manner. Once larger nozzles are successfully used, simple tests of fuel throttling will be attempted in order to observe the effects of limiting fuel flow with the valve. Similarly, the effects of the air throttle on the Production Prototype model will be evaluated. Obviously, any difficulties encountered in obtaining good runs may require design changes and corresponding physical adjustments to the models. This is indicated in the 'testing & modification' notations in the **Phase I Work Plan** above.

4.9 Perform Engine Positive Forward Velocity Testing

For forward velocity testing, each engine will be started as in a static test. The centrifugal fan is positioned at its most distant position from the engine intake face to begin. The fan is started, and the intake airspeed, as measured via the Pitot apparatus, is noted. Once the engine is developing full static thrust, the fan is manually moved toward the engine, increasing the measured airspeed. This continues until a significant shift in the balance between outer combustion chamber and inner combustion chamber flows is observed at the pressure gauges. Notation will also be made of changes in *net* thrust (i.e. the measured thrust *will* be reduced by the drag of the impinging air from the fan). Observed changes in the character of the exhaust flame (reflecting air/fuel mixture variation) will also be noted. What we are hoping for, at least in the Production Prototype design, is to find a (presumably high) subsonic airspeed at which all the flow through the engine is induced by normal lean combustion in the inner chamber while evolving a higher than static net thrust higher than that attained in static tests.

4.10 Perform Gaseous Hydrogen Fuel Tests

The PI is thoroughly aware of the hazardous nature and special handling requirements of gaseous hydrogen, having used hydrogen successfully in tests of underwater oxygen-cutting in the 1970s. An outdoor test setting is ideal for testing with hydrogen fuel, since there is no possibility for undetected accumulation of the odorless gas. Gas will be procured in high-pressure cylinders and delivered through a pressure-reducing regulator and appropriate piping, with a manual cut-off valve added at the Control Panel. No flexible hose will be used (except for a short link used for the actual connection to the fuel nozzles of the engine, to allow for forward movement on the test bench). All gas connections will be 'soap suds' tested for leakage prior to testing. Careful precautions against exposure to flame, sparks and hot surfaces will be taken. Procedures for the test series will be exactly as described in the preceding sections.

4.11 Specification of the Proof-of-Concept Model

Cottrill Cyclodyne Corporation has available, for this proposal, a partially completed stainless steel Proof-of-Concept working model begun by the inventor. As indicated in the work plan, only a few hours' effort will be required to finish the model. Basic specifications of this model are as follows (all dimensions are approximate):

- Physical specifications:
  - Length: 30 inches;
  - Maximum diameter: 4 inches (not including gasket flanges & heavy-duty clamps);
  - Total engine structure weight: 18 lbs (not including heavy-duty clamps);
  - Air intake clear area: 0.067 sq. ft.;
  - Outer combustion chamber cross-sectional area: 0.087 sq. ft.;
  - Inner combustion chamber cross-sectional area: 0.034 sq. ft.;
  - Exhaust nozzle throat area: 0.0218 sq. ft.
  - Construction: Welded stainless steel sanitary tubing (.045 & .065 in. thickness), stainless steel sheet for front wall & incidental small parts.
- Calculated theoretical performance (maximum static power output using liquid hydrocarbon fuel):
  - Total static thrust: 100 lb;
  - Air intake volume: 1.4 lb/sec;
  - Air / fuel ratio: 30.0 lb / lb;
  - Combustion chamber gas temperature: 2628 deg F abs;
  - Combustion chamber static pressure: 27.2 PSI abs;
  - Exhaust volume: 1.44 lb/sec;
  - Exhaust velocity at nozzle throat: 2299 ft/sec (non-critical).
  - Fuel consumption: .045 lb/sec = 23.22 gal/hr;
  - Thrust specific fuel consumption: 1.626 lb/hr/lb thrust;
  - Thrust / weight ratio: 5.56 lb/lb
  - Thrust / cross-sectional area ratio: 1145.9 lb/sq.ft

Note that several different recycling duct outlet nozzle designs may be required to achieve optimum static mode air induction; this is facilitated by providing a coupling for easy strip-down at the inlet end of the duct and a threaded connection for the nozzle at the outlet end. Another matter for experimentation is the fuel nozzle. The flow capacity can be roughly calculated based on the static thrust attempted, by assuming good combustion and a reasonable fuel/air ratio (e.g. 30 lb air / lb fuel). The spray angle must cover the principal air stream from the air intake cone into the front area of the combustion chamber; a nozzle providing a 50 degree included angle will be tried initially. Stainless steel agricultural spray nozzles delivering from 25 to over 100 degrees at moderate pressure can be inexpensively obtained, and variations will be tried if indicated by experimental results.

The proposed Patent Drawings comprising **Figures 1** through **4** in Section 2, above, show the basic layout of the Proof-of-Concept Model. While not to scale, the basic proportions and parts layout are almost exactly those embodied in the model. Flanges, gaskets and clamps do not appear on the drawings, and the outer cooling jacket shown in the drawings will not be embodied in the working model, as already mentioned. The spark plug mounting is not shown, but will be located (at least initially) a little below the midpoint of one side of the outer combustion chamber wall, just forward of the inner combustion chamber inlet. Engine mounts also do not appear in the drawings.

4.12 Specification of the Production Prototype Model

The finished Production Prototype Model will be under 48 inches in length, under 10 inches in maximum diameter, and should come in at under 30 lb total engine weight (not including any ancillary equipment such as battery, electric fuel pump and ignition voltage source). We will try to achieve 300 lbs maximum static thrust, from a combustion chamber static pressure of well under 20 PSIG.

The proposed Patent Drawings comprising **Figures 5** through **7** show the basic layout of the Production Prototype Model. Basic principles of operation in all modes are exactly the same as described for the Proof-of-Concept model, except for throttling effects, as already noted in **Section 2.2**. The principal goal in completing the Production Prototype model is to demonstrate that the entire engine can be constructed in a mass-producible form, using ordinary industrial techniques, tools and methods throughout. Machining operations will be confined to spark plug ports, a single fuel spray mounting port and a handful of small bearings for the mounting of the throttle vanes. Of particular note is the design intent that the front end and rear end shells will be mated together using a high temperature gasketed seam, without resorting to large machined surfaces. This connection will be secured with multiple threaded fasteners (not shown in the drawings) around the periphery of the shells. The inner combustion chamber will be removable through the front aperture of the rear end shell, to which it will be internally bolted. While not to scale and *sans* reference pointers, the drawings clearly show the basic proportions and parts layout. The auxiliary rotor shown in the rear exhaust cone will not be attempted in the Production Prototype model, due to time constraints; it is believed that extensive experimentation and possible modification will be required for optimal design of this subassembly (admittedly, a very essential feature of a practical production engine, as it provides the only source of auxiliary shaft power available in this design).

No materials have been procured for this model, so all materials procurement will be under this proposal as part of the subcontractor agreement. As indicated in the work plan, construction and testing of this model will comprise a significant effort; fabrication of the mechanical assemblies will be almost entirely by the subcontractor. It is assumed that the test pit and test stand prepared for the proof-of-Concept model will still be usable for testing, with a different set of engine mounts being the only needed modification. Basic specifications of this model are as follows (all dimensions approximate):

- Physical specifications:
  - Length: 42 inches;
  - Maximum diameter: 9.5 inches (including outer cooling shell);
  - Total engine structure weight: 28 lbs;
  - Air intake clear area: 0.33 sq. ft.;
  - Outer combustion chamber cross-sectional area: 0.349 sq. ft.;
  - Inner combustion chamber cross-sectional area: 0.230 sq. ft.;
  - Exhaust nozzle throat area: 0.087 sq. ft.
  - Construction: Welded 316 stainless steel sheet (.065 & .125 in. thickness), 316 stainless steel sanitary tubing for recycling duct, various small incidental parts 316 stainless throughout.
- Calculated theoretical performance (maximum static power output using liquid hydrocarbon fuel):
  - Total static thrust: 300 lb;
  - Air intake volume: 4.2 lb/sec;
  - Air / fuel ratio: 30.0 lb / lb;
  - Combustion chamber gas temperature: 2629 deg F abs;
  - Combustion chamber static pressure: 26.9 PSI abs;
  - Exhaust volume: 4.33 lb/sec;
  - Exhaust velocity at nozzle throat: 2299 ft/sec (non-critical).
  - Fuel consumption: .135 lb/sec = 69.67 gal/hr;
  - Thrust specific fuel consumption: 1.626 lb/hr/lb thrust;
  - Thrust / weight ratio: 10.71 lb/lb
  - Thrust / cross-sectional area ratio: 609.5 lb/sq.ft

It is presumed that the final recycling duct outlet nozzle design will have been established as a result of experimentation with the Proof of Concept Model. The principal difference in this area is that in the Production Prototype, the recycling duct and nozzle are entirely "built in" as part of the central "fin" which runs in a vertical plane through the front of the air intake shell. Attachment to the fin walls will be via plug welds through the fin walls at fairly close intervals (approx. every 2 inches). The forward velocity cone transitions from a straight-sided form at the combustion chamber to the required circular cross-section where it blends into the recycling duct below the bottom of the air intake shell. The fuel nozzle will again require some experimentation, since much greater capacity will be required for this model, although the principles of selection should be well established by earlier work with the smaller model.

Part 5 - Related R/R&D

Reference book - ***Introduction to Gas-Turbine and Jet Propulsion Design***, by C. A. Norman and R. H. Zimmerman, Harper & Brothers, New York, 1948. While this work is dated, it covers all the basic gas relations and other theory needed for reaction engine design as well as gas turbine theory, and even the rudiments of rocketry. All of the theoretical calculations on the Cyclodyne engine design were done using the equations in this book, implemented by the proposed PI as a convenient Java applet.

Patent searches - Two separate searches were done by our Patent Attorney during development of the Cyclodyne design., resulting in about two dozen examples of relevant prior art. All these patents claim some version of air induction by recycled flow of a fraction of the exhaust gases. None of these examples teach an induction geometry which automatically adjusts the device from recycled flow to pure ramjet flow as forward velocity increases. All relevant patents discovered are now expired.

Part 6 - Key Personnel and Bibliography of Directly Related Work

The following brief resumé introduces the proposed Program Manager / Principal Investigator proposed by the Cottrill Cyclodyne Corporation for Phase I. The table in the initial portion of **Part 4** of this proposal specifies the hours allotted for each task to be done by the Principal Investigator.

Name:	Larry Cottrill
Years Experience:	No direct vocational experience in aviation powerplant design; over 25 years experience in computer programming, systems design, technical drawing and technical writing, and more recently, Web site development; over 30 years experience avocationally in amateur radio (long inactive), electronics design and construction, optical system design, lens and mirror production (inactive), simple woodworking, metalworking, welding and oxygen cutting, diving (long inactive; included underwater oxygen cutting) private aviation (currently inactive) and designing and flying model aircraft, including pulsejet-powered models.
Position:	Director of Product Development & Acting CEO, Cottrill Cyclodyne Corporation
Education:	One and one-half years at Drake University, Des Moines, Iowa, 1965-1967, majoring in Astronomy.
SBIR Assignment:	Principal Investigator and Program Manager. Mr. Cottrill will be the Principal Investigator and also manage the NASA SBIR Phase I powerplant development effort. He will coordinate all interaction between the company and the subcontractor and be responsible for all technical design, testing, record keeping, reporting and documentation. Mr. Cottrill will devote a minimum of 20 hours per week of his time to the NASA SBIR project.

Experience: Prior to founding Cottrill Cyclodyne Corporation, Mr. Cottrill partnered with Mr. Steve Johnson of Des Moines, Iowa, in founding Cottrill Optical Company which was in active operation from 1974 through 1982 and specialized in small computer integration and programming for engineering, and in commercial, industrial and architectural/engineering photography. Prior to and during that time, Mr. Cottrill was a draftsman for Brooks, Borg and Skiles, Architects and Engineers of Des Moines, Iowa, one of the foremost A&E offices in the state. While assigned to the Structural Engineering Department, he also worked extensively with Mechanical and Electrical Departments as well, and served in various capacities with a startup Civil Engineering Department that later became an independent enterprise. During this time with BB&S, Mr. Cottrill learned computer programming in several languages and eventually developed many design programs for the engineering departments, which necessitated learning basic principles and design methods of all the engineering disciplines. Also, during his time at BB&S, he successfully hand built one of the original series Altair 8800 microcomputers and in doing so, developed machine language proficiency along with some digital hardware design skills. He also worked for Mr. Dick Howard, an air conditioning consultant, as part of a small team which re-balanced the air conditioning system of the home office building of The Des Moines Register, one of the largest dual duct / dual fan systems in existence at that time. He worked with an electrical engineer, Mr. Ray Whitmore, on the development of a digital water sampler timer, performing all the circuit board negative preparation and darkroom work on that project, which was both technically and commercially successful. Since October of 1982, Mr. Cottrill has been employed by Wells Fargo Financial Information Services (currently as Operating Systems Engineer 4), performing various programming and Intranet Web Site implementation functions. He is the sole inventor of the Cyclodyne air-breathing reaction powerplant design which is the subject of this Phase I proposal.

Part 7 - Relationship with Phase II or other Future R/R&D

Cottrill Cyclodyne Corporation's final report will attempt to demonstrate to NASA our commitment to the development and marketing of this powerplant product and the ongoing development of this and related future designs. Our intent is for the Phase I work to be a thorough refinement of the design of the product and a demonstration of the production prototype as identified in Part 1 of this proposal. We expect Phase II work to complete the process of refinement of the prototype design into a full commercial product capable of manufacture without reliance on exotic materials or methods and provided with full technical and user documentation, ready to market to the whole Civil Aviation airframe designer audience. The special emphases of Phase II development will be usability, maintenance, reliability and safety issues. It is also hoped that the FAA Powerplant Certification process can begin as early as possible during Phase II.

As noted below in Part 8, the company has at this writing no manufacturing facility, no management structure, no human resources on payroll, and no active investment of risk capital. It is anticipated that Phase II will be a time of putting together the beginnings of some of these resources and starting to build a small but real aerospace manufacturing company, even if this involves establishing short-term or continuing partnerships with established industrial manufacturers in the region (not necessarily aerospace companies). It is assumed that Phase I success can be leveraged to build investor confidence so that capitalization will be provided before or during Phase II. Obviously, there is no guarantee that this will be possible; however, I believe that once the design concept is proven using demonstrable working models and the patent rights are secured, the main risk barriers to investors will have been resolved, leaving product liability potential as the only major negative consideration.

Part 8 - Company Information and Facilities

Cottrill Cyclodyne Corporation is temporarily headquartered in rural Mingo, Iowa. The company is a new start-up; at this writing, Mr. Larry Cottrill is the only employee and serves without compensation as Director of Product Development and Acting CEO. There are no capital investors at the time of this proposal.

Cottrill Cyclodyne Corporation was registered as a for-profit corporation in the state of Iowa on 02 November 2000. The Corporation is dedicated to exploiting the anticipated growing demand for small, simple, lightweight jet aviation powerplants and the established and growing market for jet engines for use in miniature vehicles (principally, scale and speed model aircraft). The Corporation was founded by Mr Larry Cottrill (the proposed Principal Investigator). The Corporation office space is presently located in the home of Mr. Cottrill in a rural area near the town of Mingo, in central Iowa. The company owns no manufacturing facilities or equipment, and only the most basic facilities for research and development are available (equipment for metal working and light welding, handling small volumes of compressed gases, etc.). Commercial success for this company is based on the following premises:

- There is an expanding interest in small jet powerplants for civil aviation, which will become a significant market in the near future as practical, low cost designs become readily available;
- There is an existing and expanding experimenter market for small, low cost, lightweight jet powerplants;
- There is also an existing and expanding hobbyist market, demanding miniature jet engines more practical than current design offerings;
- Central Iowa offers a good environment for light manufacturing, in terms of availability and quality of the labor pool, materials procurement, availability of facilities, access to shipping, good Central US location, and other factors;
- There is a recognized need for high quality jobs and training for skilled workers with physical disabilities;
- Capitalization can be readily obtained once patents are secured and working models are available to demonstrate the technical viability, manufacturability and uniqueness of the proposed design.

Metal work on the models (except for the work done by the subcontractor) will be basically a home garage operation using hand tools for metalworking and an ordinary oxyacetylene welding outfit. The proposed PI has attained adequate proficiency in oxyacetylene welding of types 304 and 316 stainless to perform any minor experimental modification work needed on the working models. Welding is done using Type 308 stainless filler rod with a fluoride-based high-temperature flux to prevent oxidation at the weld site. Neat welds of more than adequate strength have been consistently produced, showing reinforcement and 'ripple' similar to typical aircraft welding done on 'chrome-moly' alloy tubing. The small amount of machining required on a few parts will be done by the subcontractor or done by the PI using equipment that can be cheaply rented in the area. Subcontractor welding will be performed using MIG or TIG type electric methods. The most critical subcontractor subtask will be precise cutting and forming of stainless sheet metal sections for the Production Prototype subassemblies so they will fit with sufficient precision for good welding to be achieved. None of this work will be of a quality that could not be expected to be achieved in normal standard practice; in other words, good modern industrial shop practice, not 'laboratory' grade work, is expected for successful execution of the models.

There is no suitable indoor facility for testing, so all test firing will be done outdoors. Plenty of good weather is available in the late spring, summer and early fall months in Central Iowa. The period from December through March is generally unsuitable. Testing procedures and safety provisions are discussed in **Part 4**. Spectators at firings will be strictly limited in number and located a safe distance from the engine under test. All participants in tests, including spectators present, will be equipped with vision and hearing protection.

Part 9 - Subcontracts and Consultants

Subcontractor - Quality Manufacturing Corporation of Urbandale, Iowa, is well-known throughout the Midwest as a top-quality fabricator of steel, stainless, and other metal products needed in a variety of industries. They specialize in laser cutting of metals, machining, and welding, working basically in a parts subcontractor role for major industrial manufacturers such as John Deere. They are capable of large-scale production runs as well as efficient, economical production of single-quantity specialty assemblies. They are experienced in procurement of certified materials. They would appear to be an excellent business partner for Cottrill Cyclodyne Corporation to help get us rapidly into powerplant production in the future. Quality Manufacturing Corporation's agreed responsibilities will be the laser cutting, parts forming and welding to produce all engine subassemblies for the Cyclodyne Production Prototype working model, as detailed in **Section 4.2**. Their total estimate for work under Phase I is summarized as follows:

Total hours: **81.03** Total subcontract price: **$ 9232.70** Total participation (cost basis): **14.5 %**

The subcontractor's certification of their intent to do the work is attached following **Part 9.C** at the end of the Postal Submission copy of this proposal.

Part 10 - Commercial Applications Potential

It is assumed here that the proposed design is fully scalable from miniature embodiments (using carburetion mode fuel delivery only) up to full-size powerplants suitable for large airframe installations. That being assumed, there is a wide range of commercial applications potential. A limited list of potential commercial markets (listed roughly from smallest to largest product scale) follows:

Scale & speed model vehicle hobbyists - Scale modelers using jets (principally in aircraft and racing boats) need a more affordable and lighter weight product than miniature turbojets and a more efficient and safer product than currently available pulsejets. A miniature Cyclodyne engine equipped with the positive draft cooling shell would practically eliminate the fire hazard that has always plagued scale models (i.e. designs where the engine is fully enclosed). For speed modelers, a version of the engine without the cooling shell would offer almost as light weight as current pulsejets but much better thrust/weight ratio, especially at current world record speeds (around 400 MPH), where pulsejet efficiency drops off dramatically.

Full-scale experimental aircraft builders - There are now some serious jet powerplant offerings for experimental 'homebuilders', but they are still far too expensive (around $50,000 per unit) for most experimenters to consider. The Cyclodyne engine scaled for similar static thrust would be lighter in weight, and should be profitably marketable in single quantities at a significantly lower (and perhaps much lower) end-user price due to its low cost to manufacture. This would have the effect of reviving and expanding a once vital segment of the civil aviation market, even before FAA certification can be obtained. This would be one of the first market penetration attempts for the company; it should be one of the easiest markets to impact, since there are highly targeted marketing channels already in place such as journals, air shows, etc. and since the target market is generally open to exciting new things to try.

Civil Aerospace Industry - The civil aviation industry will find many attributes of the Cyclodyne design to be advantageous over currently available conventional powerplant designs. Claims that will be interesting to designers as well as civil aviation operators include:

- Absence of internal rotating shaft, turbine and compressor resulting in low overall powerplant weight, no internal bearings to lubricate or maintain, no lubricating oil or other engine fluids needed, no vibration or thrown vanes due to out-of-balance conditions, total absence of mechanical torque, extremely low total parts count, and high level of immunity to damage by inhaled objects;
- Higher thrust/weight and thrust/cross-sectional area ratios;
- Dramatic increases in thrust and efficiency with increasing airspeed after takeoff;
- Lean burning and relatively low fuel consumption per unit thrust at high flight speeds;
- High immunity to intake icing under cool, humid conditions;
- Cool running exterior shell at all speeds and power settings;
- Vibration-free operation at all power settings;
- Choice from a wide selection of cheap fuels with no, or very minor, engine modification;
- High scalability to cover a wide range of applications, from personal jets to airline transport aircraft;
- Very low cost of procurement;
- Very low ongoing maintenance costs over time (all regular maintenance performed from the engine exterior - full stripdown rarely needed).

Military Aviation - All of the points just mentioned would be of importance to one degree or another in the case of military design and operation, but in addition, the issue of throttle response comes into play particularly in regard to jet fighter class combat aircraft. The absence of a large spinning mass within the engine means that thrust will vary with throttle setting in an almost 'inertialess' manner; a combat pilot could snap the throttle back and in a fraction of a second have drag exceeding thrust by several hundred pounds. Study of the flight safety and physiological implications of this kind of pilot-induced action are far beyond the scope of this proposal but should be kept in mind for future investigation.

Cottrill Cyclodyne Corporation plans to make use of its business plan developed as part of Phase I to obtain venture capital. We have met with several potential private investors who are enthused about this project, but we have so far obtained no risk capital investment. As the sole current stockholder, I cannot offer any realistic possibility of self-capitalization for a business of such large potential size, complexity, and market impact in the unlikely case that no outside venture capital is obtainable.

Part 11 - Similar Proposals and Awards

Cottrill Cyclodyne Corporation has no current active proposals submitted to Government agencies. No further proposals will be submitted during 2001 if awarded a contract by NASA. The company has not received any Government award for work related to the powerplant design currently proposed. Cottrill Cyclodyne Corporation has not received previous NASA SBIR awards.