Gluhareff Pressure Jet Engine: Past, Present and Future

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This paper is an historical overview of one of the more unrecognized technologists and classes of jet engines the technical community has known. Although not featured in any classic text of yesteryear or today, the engine was first reduced to practice more than 50 years ago. The engine as a whole and enabling components have been covered in several patents, flown thousands of times and boasts a total production run in the thousands. The paper outlines the history of the engine's inventor, Mr. Eugene M. Gluhareff, starting from his education at Rensselaer Polyetchnic Institute, moving through Sikorsky Aircraft Corporation and finally ending up in private business. The basic physics of the engine is also explained along with its similarities to other athodyds and several profound differences. The paper outlines the current state of pressure jet engines of this family and describes new improvements which continue to add performance to this dark horse of the jet engine family.

Nomenclature

f	=	fuel-to-air ratio
m_a	=	mass flow rate of air
m_f	=	mass flow rate of fuel
η_i	=	inlet total pressure conversion efficiency
P_o	=	stagnation pressure of flow
P_{oa}	=	stagnation pressure of airflow
P_{of}	=	stagnation pressure of fuel

I. The Inventor: Eugene M. Gluhareff

A. The Formative Years: Russia, Emigration, Rensselayer, United Aircraft Corporation

EUGENE M. Gluhareff was born in St. Petersburg, Russia in 1916 to a family of landed technologists and educators. After emigrating to the United States with his family via Finland in the early 1920's, he enrolled in Rensselaer Polytechnic Institute in Troy, New York where he earned a Bachelor's Degree in Aeronautical Engineering in 1942. Shortly after graduating, he joined United (Sikorsky) Aircraft Corporation of Bridgeport, Connecticut. where his Father, Michael worked as a Senior Engineer. He and several other Gluhareff family members helped unravel many of the stability and control and performance issues with the VS-300 and R-4 helicopters. Eugene, Michael and Serge Gluhareff helped form the core of of Sikorsky's early engineering team. Figure 1 shows a variant of the VS 300 hovering with Igor I. Sikorsky at the controls and several of the Gluhareff family members and Col. Charles Lindberg observing.

Fig. 1 VS300 with Igor Sikorsky at the Controls & 3 Gluhareff Family Members in Attendance (courtesy: Gluhareff Family Archives)

During these formative years, major questions on helicopter stability and

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control, aerodynamics and propulsion were being explored. Several of the most pressing issues were related to rotor solidity and methods of propulsion. The first patent protecting the R-4 rotor system, including feather, flap and lag motions as well as integral lag dampers is attributed to Eugene.[1,2] The reader will note that these patents contain many of the features found in the first and formative rotorcraft texts which arrived a decade later, including clear vector positions for centrifugal forces, blade drag, lag angle and resultants. Even as early as 1944, he and the rest of the Sikorsky team were working tricky issues of lag dampers, bump stops and resonance.[3] As vibration issues plagued many rotorcraft of the 1940's, he patented isolation systems for rotorcraft and even advanced blade trim mechanisms employing flexible trailing edges.[4,5] Clearly the Sikorsky Engineers were working to pick apart blade dynamics and performance both analytically and experimentally and Eugene was at the heart of this team.

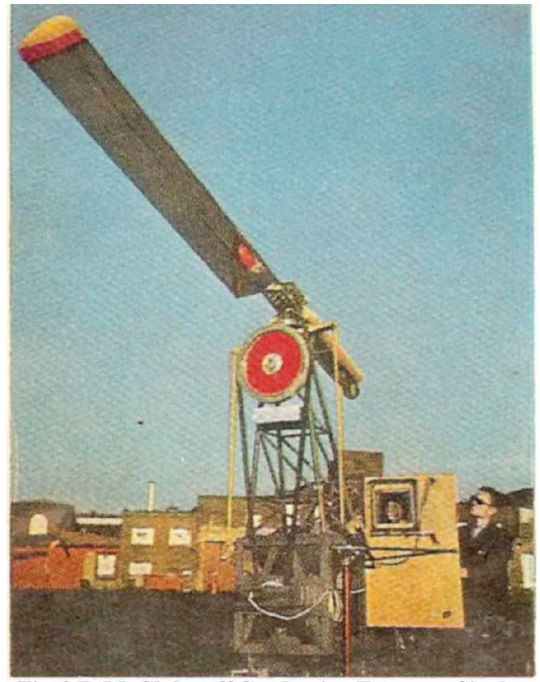

Fig. 2 E. M. Gluhareff Conducting Tests on a Single-Bladed Rotor for SikorskyAircraft (1946)
(Gluhareff Family Archives)

In the mid- '40's, Eugene worked many projects for Sikorsky, but one of the most interesting was a single-bladed, counterbalanced rotor for the R-4. It was on this project that he cut his teeth on rotor counterbalance designs and unraveling rotor efficiency as a function of blade geometry, solidity etc. Figure 2 shows the 1946 single-bladed test stand of United (Sikorsky) Aircraft Corporation with Eugene at the controls. It was from some of these formative experiments that unusual configurations of rotorcraft were born including a single-bladed variant of the R-4 (Fig. 3). Eugene spent hundreds of hours experimenting with different geometries of blade and counterbalances. The result was the first of several patents related to single bladed rotors.[6-7]

With the groundwork laid, Eugene launched into the unsettled area of rotorcraft propulsion. Although he had begun experimenting with valveless pulsejets as early as 1946 on various test rigs, his first rotorcraft with such an engine took to the air in October of 1950. Certainly, the concept of tip-jet propulsion was not new as it dated all the way back to 1915 with the work of Papin and Rouilly and continued in both the US and Nazi Germany through The War.[8] Still, the idea of putting a valveless pulsejet on the tip of a rotor blade was sensational at the time, to say the least. This propulsion method allowed the net torque transferred to the airframe to drop by orders of magnitude, thereby bringing many benefits to the overall design. Its many other attractive qualities included negligible transmission weight, extremely inexpensive engine costs, high reliability, low inspection and maintenance costs and light weight. Because of its extreme simplicity and robustness, CAA certification time and expense was also reduced. Indeed, the Hiller 8RJ2B tip-ramjet became the first jet engine of any category to be certified on a civil aircraft in the US.[9] Still, there were challenges which came mainly in the form of noise, starting and gross inefficiencies associated with the engine class. Indeed, some positive (and yet unintentional) press followed the highly proprietary project. As is

Fig. 3 Single-Bladed Variant of Sikorsky R-4
(Gluhareff Family Archives)

Fig. 4 Sikorsky "Flying Experimental Test Stand" with Eugene Gluhareff, October 1950 (Ref. 10)

often the case with the press, it was speculated that "... a highly classified Air Force project..." was underway.[11] Not surprisingly, the earsplitting noise of an unshielded valveless pulsejet was enough to bring a reporter to a knothole in a fence where he witnessed (and subsequently reported about) several flight tests. Although lost to the public at large, this report is important because it described the functionality of the engine which required no prerotator as was the case with most other engines of the day. Because the tanks used pressurized fuel and (according to Ref. 11), the "...rotor immediately sprang to life." it indicates that Eugene had begun to understand the role of fuel pressure in his revolutionary family of jet engines.

Fig. 5 North American XA-5 Top Sergeant (Ref. 13)

Because all subsonic pulsejets of the day lost propulsive efficiency at tip speeds which were compatible with efficient flight and equivalent shaft power generation, the overall efficiency of the craft was compromised at best. Although Eugene flew the Sikorsky test stand of Fig. 4 in 1949 and with respect to the other tipjet powered aircraft of the day it performed well, it was not enough to convince United (Sikorsky) management that this path should be pursued. It was at this point that a strategic decision was made both by Corporate Management and by Eugene Gluhareff: Part ways and part propulsive methodologies. This corporate philosophy has rippled all the way into modern times as the company has only dabbled in a handful of tip-propulsor projects between 1950 and today, which, in hindsight, was the correct decision for economic competitiveness.

B. The Move West to California: American Helicopters, Private Business, Air Force Support

Fig. 6 Eugene Gluhareff Hovering in the MEG-1X (1959)
(Courtesy Gluhareff Family Archives)

In early 1951, Eugene and family moved to Manhattan beach, California where he worked as a Project Engineer on the American Helicopters Top-Sergeant, a valved pulsejet powered helicopter.[12] This was followed by stints as a preliminary designer on the XH-26 Jet Jeep and the RH-1 Pinwheel tip-rocket powered rotorcraft. Reports from the day verify that the noise from the unmuffled engines continued to be "earsplitting" and from a military standpoint became the major reason why they were not acquired in appreciable numbers. In 1953 at the urging of his wife, Alla, he went into business for himself, forming The Gluhareff Helicopters Corporation. In 1955 he partnered with Robert McCulloch to develop a portable helicopter for a military competition. The MEG-1X, MEG-2X and MEG-3X (Flying Platform) for the US Air Force were final deliverables on the project. As part of this project, the tipjet engines were improved substantially and showed greater propulsive efficiencies than any that had come before, enabling out of ground effect hover endurances in excess of an hour. Figure 6 shows Eugene hovering in the MEG-1X. Figure 7 shows him in the MEG-2X.

Fig. 7 MEG-2X (Gluhareff Family Archives)

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Some of the more unique properties of these new engines were that (like all pressure jets), they could be started without a prerotator, but more importantly, that they gained in propulsive efficiency with increasing airspeed up to compressible limits and they were smoothly throttlable from just 30% through 100% rated thrust levels.[12] It was this property that distinguished them from earlier pulsejets and accordingly made them better suited to tipjet propulsion and perhaps even economically competitive with other rotorcraft propulsion means. Of course, although two operational properties were improved dramatically, the noise continued to be a challenge with 128db being generated by one of the small 20lb thrust engines at 10 ft. Although the progress was dramatic and commercial viability seemed inevitable, the lack of a sponsor lead him to other corners of the Aerospace industry.

C. Corporate/Government Aerospace Engineering Positions & Back to Private Enterprise

In 1960 he joined the US Navy at the US Naval Ordnance Test Station, China Lake, California. From 1960 to 1963 he progressed from a GS-12 to a GS-14 as an Aerospace Engineer working on rotary-wing drones. In the Fall of 1963 he joined Douglas Aircraft Company, Missile and Space Division, Huntington Beach, California as a design engineer working on the Saturn V rocket. He was an integral member of the engineering team which launched the first 4 Saturn rockets and was in charge of the sequence of events from launch through parking orbit. He also performed data verification and post-mission orbit analysis. Following the termination of the S-4 stage he was transferred to the Long Beach division as a Senior Design Engineer in the Advanced Systems Group. As part of the Special Projects group he designed and tested subscale rocket engines for two years. His expertise in rocket design lead him to the Ejection Seat Group where he became a specialist in Rocket Stabilization Systems for Air Force Ejection Seats and capsules.[12]

Fig. 8 Eugene M. Gluhareff Holding a G8-130 Engine (Gluhareff Family Archives)

In late 1972 he left steady Government/Corporate employment once again and went back into private business making jet engines and derivative products. His EMG Engineering Company of Gardena, California allowed him to focus his efforts on improving his engine and for the following decade he developed quite a following of "pressure jet enthusiasts."

Popular Mechanics ran a cover article on his Yellow Jacket Hovercraft in March of 1971. His jet-powered go-cart was featured in the May 1973 issue of *Science and Mechanics* and *Mechanics Illustrated* featured his G8-2 jet engine as their cover story in January of 1975. This period of his life was one of the most productive as he designed, built, tested, produced and marketed an entire family of pressure jet engines from 5 to 130 lb of static thrust.

D. The Final Years: Hesperia, California

In 1981 he was diagnosed with terminal cancer and moved to a small ranch just outside of Hesperia, California. In 1982 his cancer went into remission and he redoubled his efforts to develop ever more powerful engines. In 1984 he finished his comparatively "giant" G8-2-350 and G8-2-700 engines with 350 and 700 lb of static thrust respectively. As with earlier years, he maintained a small revenue stream by placing 'Build Your Own Jet Engine" advertisements in the back of magazines like *Popular Mechanics* and *Popular Science*. In addition to selling blueprints, plans, individual engines as completed devices and kits, he also developed a "Teaching Stand." This educational stand has been one of the longer lived legacies because it sports an extremely loud jet engine which typically thrills both science educators and students alike. Indeed, roughly 1/3 of Eugene's engine-related revenues came from the sale of teaching stands. Unlike turbines or piston engines, it has no moving parts so the danger of blade loss, which is of primary concern in this letigious time. Maintenance headaches associated with rotating

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machinery and high oil levels are nonexistant, making it well suited to science instructors with little time to worry about such things. It is little wonder that to this day, several original Gluhareff engines are maintained and run by educational institutions for recruitment and education purposes. Figure 9 shows the original Teaching Stand and a crowd of youngsters gathered around an original (now 20 year old) G8-2-20 mounted on a portable demonstration stand during a K-12 science education exercise in May of 2007.

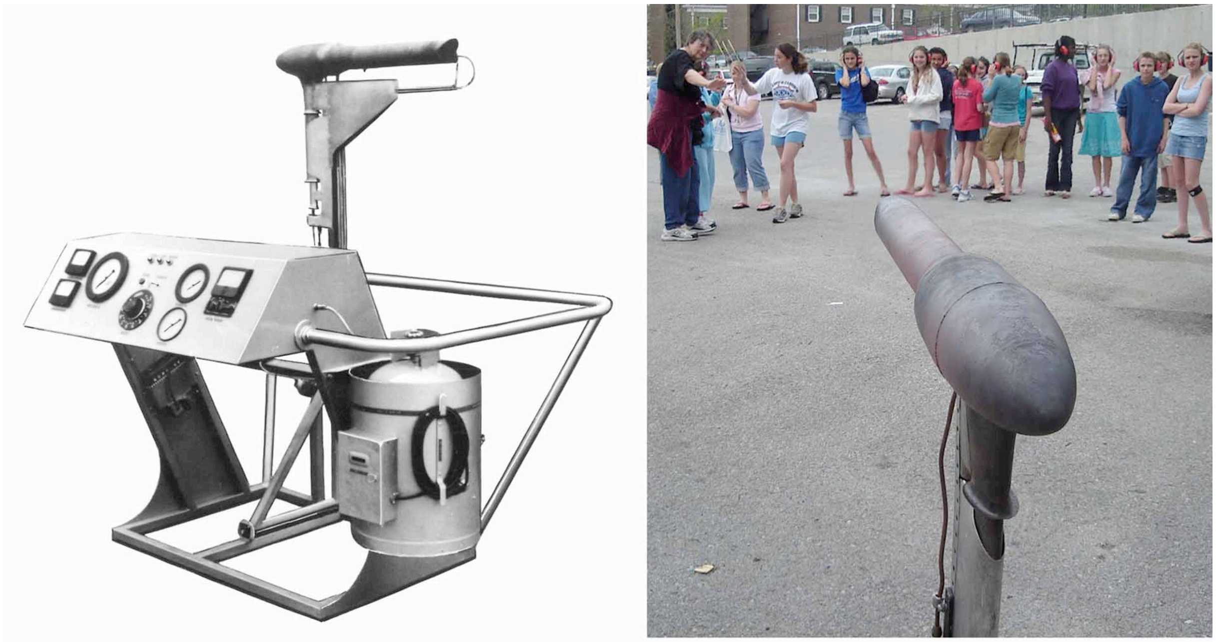

Fig. 9 Gluhareff GTS-15 Teaching Stand and Original G8-2-20 (built in 1987) Roaring at "Science Day" May 2007
(Gluhareff Family Archives and The University of Kansas School of Engineering)

After many years, Eugene finally completed his EMG-300 Tip Jet Helicopter. As with all of his projects, he showed exceptional fabrication skill and had targeted the aircraft toward the ultralight/homebuilt market. Figure 10 shows his final great creation which was just in the process of being marketed as illness overtook him once again. Production and marketing efforts were curtailed in his last years to near subsistence levels, passing away in 1994.

E. Post-Mortem and Rebirth

After Eugene's passing, his oldest son, Eugene, with the help of his mother, Alla, made an attempt to restart the family business under the name of "Jet Wind." In 2006, the youngest daughter of Eugene, Irina Gluhareff (co-author), formed Gluhareff Helicopters, LLC of Valencia, California. Although not an engineer by training, she has helped design an improved version of the most widely produced tipjet engine, the G8-2-20i which boasts several substantial advances over her Father's original oval-intake design for non-flying applications.[14] She currently works to preserve not only his memory in the website she maintains, but also his legacy by producing and marketing this unique class of engine, blueprints, plans, construction kits and a lightweight portable teaching/demo. stand for the G8-2-20i.

Fig. 10 Eugene Gluhareff in His Last Tipjet Coptor: the EMG-300
(now in the Pima Air Museum, Tucson, AZ, Gluhareff Family Archives)

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II. The Pressure Jet Engine

A. The Market and Operating Conditions

From the description of the tipjet performance of Ref. 11, it can be seen that the earliest foundations of the G8 family of jet engines were laid in those formative experiments of the late 1940's at United (Sikorsky) Aircraft Corporation. As Eugene experimented with kerosene, butane, acetylene and propane, and observed competing designs of the day, he came to understand that several characteristics were important for the engines to be successful tipjets: i.) self starting, 2.) no coating exhaust effluents, 3.) fully throttleable, 4.) very low weight, 5.) lateral-g capable and 6.) no loss of efficiency with higher subsonic Mach numbers.

Fig. 11 Hiller YAH-32 Hornet with 8RJ2B Tip-Ramjet Engines (Ref. 15)

The importance of possessing a self-starting capability cannot be overstated as the primary competition for the engine in the late 1940's and the early 1950's was the Hiller 8RJ2B family of tip-ramjet engines. To get these engines going, a small internal combustion "prerotator" was started and attached to the rotor hub to spin the rotor up to past 50 RPM. Once the rotor was rotating at this rate, the ramjets could produce positive thrust and accelerate the rotor to full flight speed. This procedure was time consuming and required extra, specialized ground-based equipment to which the user community objected. This meant that the desired tipjet engine should be capable of producing static thrust (which pure ramjets cannot do). To make this happen, the only reasonably available classes of engines of the day which could do this were turbines, rockets and pulsejets. Turbines had trouble in that they had yet to be shrunk to a size which would be compatible with rotors (this would come later with the Williams and Continental family of tip-turbines), leaving only pulsejets and rockets. The self-starting property also meant that the engine would probably use fuel which would be gaseous under standard atmospheric conditions. The desire to minimize exhaust effluents came from operators' reports from flying tip-ramjet rotorcraft as helmets, windshields and crews became slimed in unburned kerosene residue. Because helicopters operate in many different flight states, it was desirable to have an engine which could be steadily throttled throughout the entire thrust and operational RPM range. Because pulsejets are typically tuned for only one operating condition, they are anything but fully throttleable. Their tendency to lose efficiency with increasing subsonic Mach number further retarded their utility along with deafening noise levels during operation. Because rocket engines have equivalent thrust specific fuel consumption levels which are often an order of magnitude higher than other classes of tipjets, those, too were determined to be less than ideal tipjets because of inefficiency.

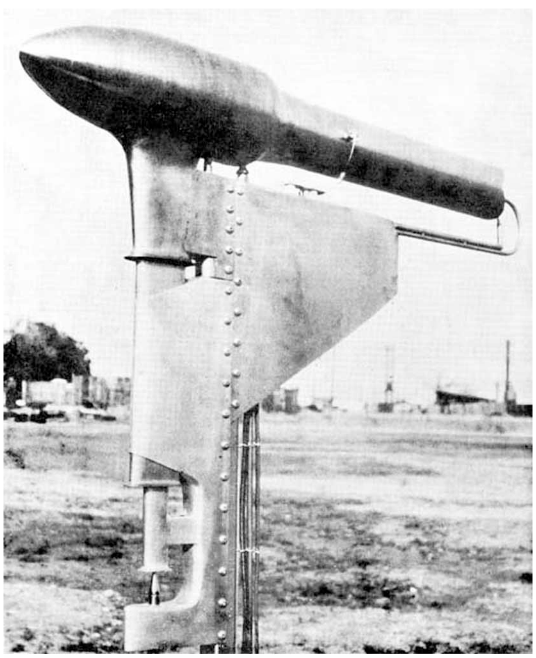
Fig. 12 Gluhareff G8-2-20 Pressure Jet Engine (Gluhareff Family Archives)

It was this collection of practical operational concerns that gave rise to the G8 family of tipjet engines. In short, Eugene had developed an engine which met all six of the conditions above and still was substantially quieter than the pulsejets. Figure 12 shows the most widely produced tipjet engine in the world: the Gluhareff G8-2-20 engine.

B. Fundamentals: Extracting the Kinetic Energy of the Fuel

Originally, Eugene used pressurized, gaseous (at STP) fuel mostly for its self-starting capability. However, he soon realized and took advantage of other properties. Because fuels such as butane, propane and acetylene can be vaporized without coking, they could be sent through a series of preheat coils prior to entry to the combustion chamber. This preheat process meant that if the fuel was handled at moderate pressure levels (above atmospheric), then substantial amounts of kinetic energy could be extracted via an air induction system. Figure 13 shows the anatomy of the G8 family of Pressure Jet engines with the fuel preheat coils lining the combustion chamber.

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From Fig. 13, the fuel flows into the Liquid Propane Connection. Typically, pressurized, liquid fuel enters from 10 to 300 psig and is vaporized in a set of helical preheat coils mounted within the combustion chamber. The fuel typically leaves the combustion chamber with just 5 - 8% pressure loss and preheated to 800 - 1200°F. After the fuel exits the combustion chamber, it flows down an insulated hot gas line at just Mach 0.05 - 0.2. As the gaseous propane enters the injection nozzle, it is choked down to sonic at the throat. Ref. 17 described a special fabrication process that allows the grossly underexpanded flow to produce an oscillatory Mach disk upon throat exit. It is this unsteady Mach disk that generates a high intensity acoustic standing wave in the inlet system. This standing wave has pressure antinodes located at the entrances of the 2nd and 3rd Stage Ducts with a dominant pressure node at the distal end of the combustion chamber. These low pressure regions induce airflow into the engine which in turn mixes with the fuel and burns in the combustion chamber. Although tuning is important for the intake section, the acoustic waves are detrimental to the performance of the aft portion of the engine, which is why fishtails were cut on the most advanced models (which tend not to reflect acoustic waves). Although some technologists believe the G8 to be a pulsejet, this is clearly *not* the case as the engine is fully throttleable and will run well with shortened or lengthened tailpipe sections. Of course, the trade on shortening is that combustion may not be complete and lengthening will introduce a weight penalty.

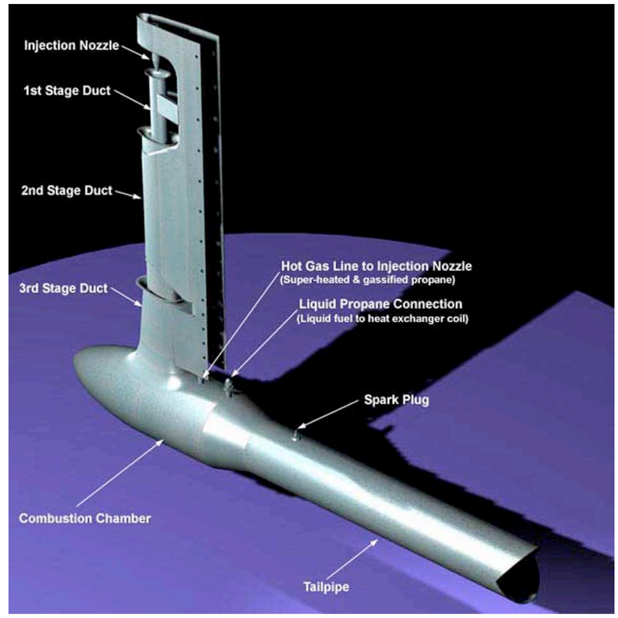

Fig. 13 Gluhareff G8 Pressure Jet Anatomy (Ref. 16)

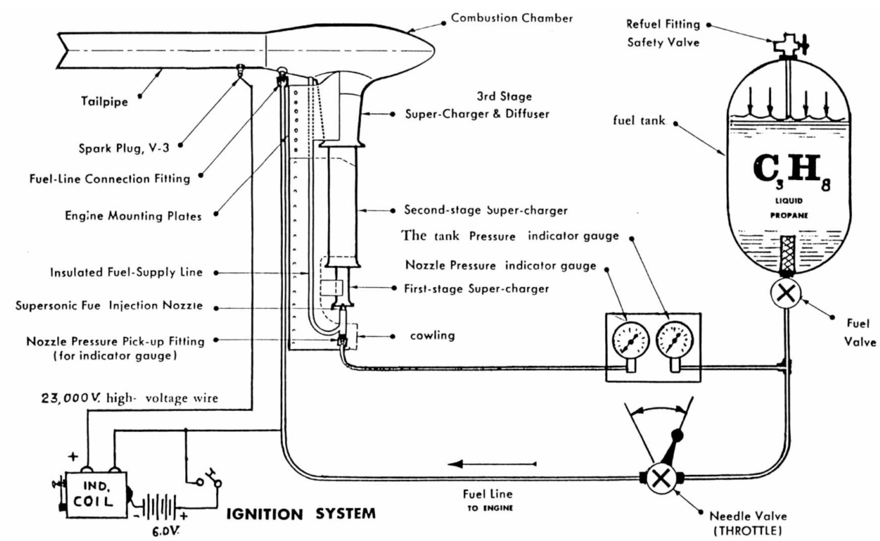

Fig. 14 G8 Pressure Jet Fuel Supply System Schematic (Ref. 12)

In the most basic sense, Eugene had made not a pulsejet, but a ramjet with a flow induction mechanism using the fuel itself as the kinetic energy source. Because of the important role of the quality of fuel flow including (foremost) the fuel pressure, one can see that great pains were taken to properly control it. Figure 14 shows the fuel supply and ignition system for the G8 pressure jet. If one observes a simple expression for stagnation pressure at the entrance of the combustion chamber, it is easy to see the role of the fuel pressure:

$$P_o = \frac{\dot{m}_a P_{oa} + \dot{m}_f \eta_i P_{of}}{\dot{m}_a + \dot{m}_f} = \frac{P_{oa} + f\eta_i P_{of}}{1+f} \qquad \text{(eq. 1)}$$

If one assumes a typical max operational fuel pressure level of 20 atmospheres, a 1/20 fuel-to-air ratio and an inlet efficiency of just 50%, then the static combustion chamber pressure ratio is approximately 1.5. Clearly, with this low pressure ratio, the engine will not operate with a high level of overall efficiency... but, most importantly, it *will* operate. Given that a 20 lb thrust rated engine is fabricated from 0.020 and 0.030" thick stainless steel foils, its low weight and simplicity often more than makes up for its inherent inefficiency. If one compares the pressure ratio of the static G8 pressure jet to the Hiller 8RJ2B operating without losses, a static Gluhareff G8 has the combustion chamber pressure ratio equivalent to that of an 8RJ2B operating at roughly Mach 0.75 (typical for many tipjet helicopters). If one now assumes that the G8 is operating at Mach 0.75, then the combustion chamber pressure ratio increases to more than 2.25. Efficiency gains compound as the inlet total pressure conversion efficiency, η_i, is known to increase with increasing airflow. Accordingly, combustion chamber pressure ratios of approximately 2.5 are typical for G8 class pressure jets operating at design tipjet flight speeds. Clearly, this is a nontrivial improvement and departure from conventional ramjet design and operation. It is the hope of these authors that the technical community recognize a fuel-pressure augmented ramjet Brayton Cycle. Accordingly, these authors propose coining the term: "Brayton-Gluhareff Cycle" to describe a ramjet which uses the kinetic energy derived from pressurized fuel to increase the total pressure of the airflow entering the combustion chamber. A side-by-side comparison of P-v diagrams for an ideal conventional ramjet Brayton Cycle and a pressure-augmented ramjet or "Brayton-Gluhareff" cycle clearly shows the difference between these two engine types.

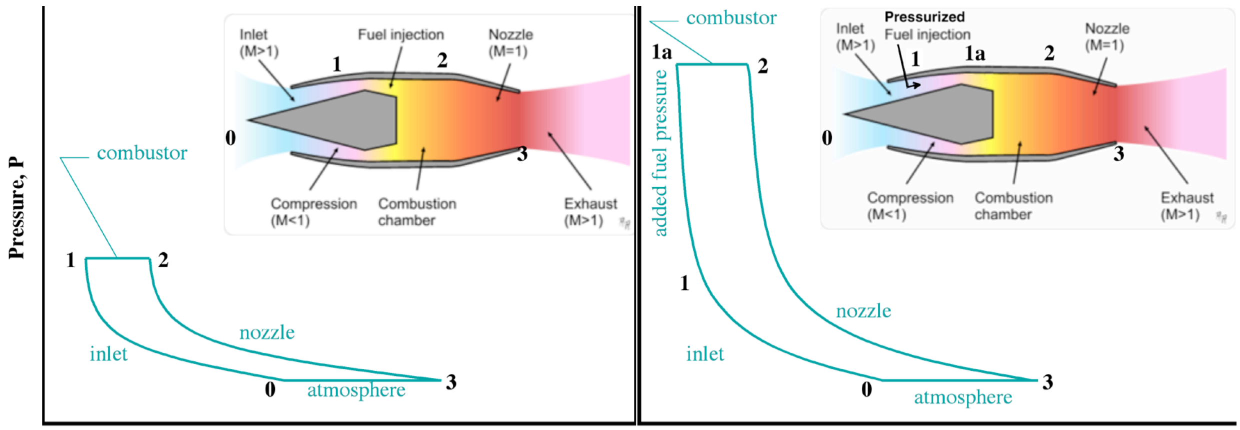

Fig. 15 Ideal Conventional Ramjet Cycle and an Ideal Fuel Pressure Augmented Ramjet Cycle P-v Diagram

C. Performance and Physical Characteristics

Although the G8 pressure jet family of athodyds as currently operated will never reach performance levels like those of high bypass ratio turbofans or modern turbojets with compressor pressure ratios in excess of 30, they will have a place in the technical community because of their elegance and functionality. If one examines published data, it can be seen that for a family of athodyds that are throttleable, generate static thrust and increase in efficiency with increasing Mach number, their performance is not bad:

Table 1 Geometry and Subsonic Performance Summary of Gluhareff G8 Family of Jet Engines[12]

Engine	Max. Static Thrust (lb)	Length (in)	Lateral Dimension to Burner CL (in)	Combustion Chamber Dia. (in)	Tail Dia. (in)	Weight (lb)	Thrust-to-Weight	Static SFC (lbf/(lbf-hr))	Dynamic SFC (lbf/(lbf-hr))
G8-2-5	5.2	22	15.5	3	2	1.5	3.5	n/a	n/a
G8-2-20	23.5	36	25.5	5	3.5	5.5	4.3	4.8	1.67
G8-2-40	43	38.5	27.5	6.5	5	11	3.9	4.6	n/a
G8-2-80	82	45	36	8.5	6.5	21	3.9	4.2	n/a
G8-2-130	137	48	37	9	7	24.5	5.6	1.33	n/a

Clearly the numbers above show that the G8 family of pressure jets work and work fairly well subsonically, especially when one looks for athodyds operating between Mach 0.5 and 0.9. Given that the engines operate without the complexities associated with rotating turbomachinery, there is an opportunity to modify the G8 family of engines with supersonic inlets and nozzles. Such modifications would, doubtless, open up new opportunities for designers of missiles, munitions and UAVs.

III. Future

Clearly, the technologists and marketplace of today will have a hard time keeping up with the vision and technical skill of Eugene Gluhareff. Figure 16 is just a small sample of many concepts he laid out over his profound and highly productive life. Although this paper describes his contributions primarily to the field of endoatmospheric, subsonic aircraft propulsion, he had many other unique ideas for industrial and commercial systems ranging from citrus grove heaters to strange and unusual methods of travel.

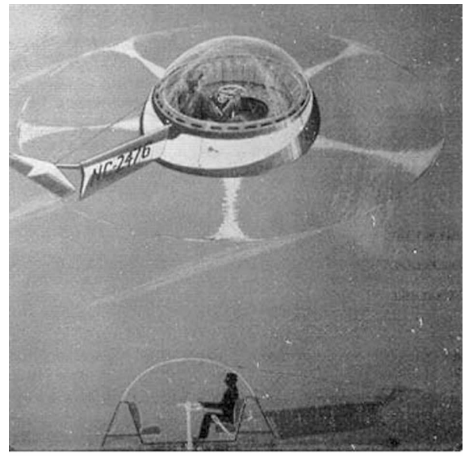

Fig. 16 Gluhareff Air Car Concept (1959)
(Gluhareff Family Archives)

The future for this class of engine is indeed bright as the opportunities for integration into subsonic and supersonic missiles, munitions and UAVs are undeniable. There exists a raft of new product lines which should spring from this powerplant as this class of engine is capable of starting from a static launch and efficiently progressing through the high supersonic flight regime. Of course, to do so, further modeling and performance improvements are needed, especially with respect to operating the engine at ever higher fuel pressure levels.

Perhaps the greatest contribution to society at large that can be made by the engine is simply in science education. Because it operates on a modified Brayton cycle, it is an ideal primer for undergraduate-level propulsion classes. Its allure to high schoolers is readily apparent by the throngs of thrilled youngsters who line up to see decades old pressure jets run to this day.

Acknowledgments

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