INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING
ISSN (ONLINE): 2321-3051
Vol.4 Issue 4,
April 2016
Pgs: 48-75

CFD ANALYSIS ON MANIFOLD AND FABRICATING IT IN ADDITIVE MANUFACTURING

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Abstract

Additive Manufacturing (AM) is the process of making objects from 3D model data by joining materials layer by layer, as opposed to subtractive manufacturing methodologies, such as traditional machining. The term Additive Manufacturing includes a wide range of technologies, such as: laser sintering, FDM, stereolithography, and many more. These technologies are used in a wide range of industries from the automotive, consumer electronics, and consumables sectors as well as being used for aviation applications. In addition to producing objects using AM, we would also use two AM-related software's. The design will be done for jet engine exhaust manifold in software and then manufacturing by FDM in 3-D printer using CURA software and then analyzing it n CFD and Ansys software's respectively in order to calculate the flow properties.

1. Introduction

Additive Manufacturing, or AM. AM covers an extensive range of processes and technologies that go beyond simple 3D printing (or even rapid prototyping, as it was first known when construction focused on the sole production of prototypes). To provide better perspective on this ever-evolving spectrum of industries, we aimed to include a broad array of AM techniques and processes that are not typically highlighted within the industry. Developed by Material connexion's award-winning consulting team, think lab, we have curated a resource that provides digestible, enjoyable and insightful access to this amazing new manufacturing tool. Through our extensive materials knowledge and experience working to innovate the world's leading products through material solutions, we have produced a report that captures every aspect of AM's diverse evolution. In this personal use, medical, industrial, consumer products, aerospace, architecture, automotive, military, fashion, food and art, all in a palatable format that is suitable for both the introductory reader and seasoned professional. The report aims to bring you a fuller understanding of the breadth of both the machine and material types used in

AM, and provides an overview of the industries it is impacting. We incorporated highly visual graphs, easy-to-understand schematics and breathtaking images that give full license to this often very beautiful method of manufacturing. The directories of material and machine types and their respective suppliers and producers serve as an essential reference for anyone hoping to better understand AM and start making things through the process. Both a visual and written glossary eliminate the burden of having to log onto Wikipedia every time you come across a new term. We have also included interviews with a number of pioneers in the field and numerous case studies to highlight the true variety of what is being developed and produced. All of this has been made possible by a team well accustomed to making technical jargon digestible—so read on and give yourself a head start in truly understanding what many have called the next Industrial Revolution.

3D printers in Additive Manufacturing:

In a perfect world, 3D printing would be used to manufacture parts on demand, quickly and cheaply. There is little to no scrap and parts can be produced remotely. Such a device could open up many opportunities for an A&D company. Early prototypes and demonstration units could be fabricated quickly, with minimal investment in part-specific tooling. Production units could be produced on demand, avoiding expensive setups or large quantities of safety stock. Spares could also be produced on demand, even in Battlefield Theater, significantly reducing the amount of inventory throughout the entire service supply chain.

Materials. Today's 3D printers are currently limited to using only a handful of engineered materials, mostly plastics and a few metals. Innovation is occurring most quickly in plastics, because they are easier and cheaper to work with than metals. But the plastic materials are generally of low quality and not suitable for most production products due to their limited strength, toughness, surface quality, and UV degradation properties. Recently, a number of companies have introduced machines capable of 3D printing parts made out of metal. These machines are more complex and expensive than their counterparts because they involve using lasers to melt metal powder to build the parts up. Nevertheless, manufacturers have demonstrated their ability to build parts out of steel, aluminum, and titanium. Several aerospace leaders are experimenting with powder melting technologies to build engine blades and other specialty components.

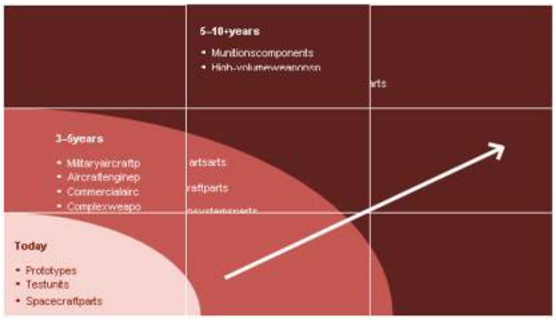
- **Costs.** Today's 3D printing technology is also more expensive than traditional manufacturing alternatives. 3D printing machines, particularly metal producing machines, are expensive. Laser melting machines cost from $500K to millions of dollars each. They are complex pieces of capital equipment on par with sophisticated machine tools in regard to operating environment (vacuum or gas-filled chambers) and control software. 3D printing machines are also slower than the current manufacturing alternatives. It takes thousands of beads to build up a metal part one layer at a time, and most metal parts take hours or even days to build. And powder metal feedstock is up to 30 times more expensive, by weight, than its bulk counterpart.

These costs will come down with time and volume of production, but there are some physical limits, such as the speed of laser melting, that will ultimately define the inherent cost structure of metal 3D printing.

• **Structural integrity.** Lastly, laser-melted parts are metallurgic ally different from machined parts. By its nature, laser melting introduces voids and a different metallurgical grain structure within the fabricated part. The structural integrity of these parts may be sufficient for some applications, but not for others. Much testing will be needed to demonstrate where a laser-melted part can be used and where it cannot. Alternatively, electron beam additive manufacturing is currently under development and capable of creating void-free and structurally sound parts comparable to today's machined parts. But this process usually creates near-net shapes, which often require post-process machining, a costly secondary step subject to all of the geometric
Limitations that traditional machining operations impose.

Current applications

Despite the current limitations, 3D printing is catching on in the A&D industry. A&D Leaders recognize the unique capabilities of 3D printing and are seeking ways to exploit These capabilities. GE recently acquired Morris Technologies, a precision engineering services firm specializing in advanced fabrication techniques such as laser melting, electron beam melting (EBM), and other 3D printing applications.1 Boeing is using 3D printing to fabricate plastic interior parts out of Ultem and nylon for prototypes and test evaluation units. Boeing is also using 3D printing technology to rapidly fabricate tools for making composite parts.2 Pratt & Whitney is investing millions in an advanced additive manufacturing center in collaboration with the University of Connecticut.3 NASA is using 3D printing to fabricate parts for its rocket engines.4 As with any new technology



In theory, intellectual property (IP) theft is also a concern. Counterfeiters can reverse engineer parts using laser imaging technology, then 3D print replicas without payment to the design data owner. Although possible, the incentives for IP theft, particularly in the A&D industry, are minimized by 3D printing economics. Unlike music or movies, the marginal cost of 3D printing is not negligible. And the available market is small and fairly sophisticated. So although it is technically possible to 3D print counterfeit parts, it's not any more convenient than using currently available machining technologies.

Product quality. Product quality is the Achilles' heel of every production technology. Laser melting has improved significantly over the past several years, but it still produces parts with micro-voids and heat-induced stress. Equipment manufacturers are continuing to improve the deposition quality of this technology, but it will probably never be void-free, thus limiting its use to non-critical load-bearing parts. Electron beam melting has emerged as a higher quality alternative to laser melting. The very high-energy density of the electron beam technology enables it to produce fully dense, void-free parts. Electron beam technology is increasingly being used in the manufacture and repair of turbine blades .

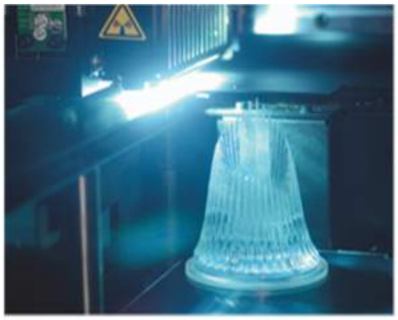
State of Industry:

With the explosive growth of Additive Manufacturing (AM), claiming to offer an accurate industry overview can be dangerous. There is staggering diversity in new breakthroughs and innovation within the field, which evolves on an almost weekly basis. The number of individuals, groups and companies that have joined this "revolution" have made covering the news in AM a daunting game of "catch-up." The diverse types of materials, processes and applications that AM offers make it difficult to even categorize as one industry.

Food, human organs, prosthetics, houses, cars, weapons, clothing, toys—what other industrial process can manufacture such a wide range of products across such varied business sectors?

What other new innovation has so quickly superseded many well-established manufacturing processes? Unlike other recent "revolutions" such as nanotech or biotech, AM is inherently accessible, with costs, technical knowhow and raw material resources readily available. As such, it dovetails nicely with the recent maker movement, resulting in an evolution of machines and knowledge that is exponential compared to other industries. It is going to be an exciting next few years as the growth of this industry continues. Forbes estimates that the "3D Printing industry will reach $3.1 billion worldwide by 2016." One can only imagine what new solutions this incredible technology will bring. It is important to note that a critical milestone in the evolution of AM for part production (both prototype and finished product) is the expiration of patents. The original Fused Deposition Modeling (FDM) patent owned by Stratasys expired in the mid 2000's, leading to the development of MakerBot, the maker movement's white knight, and other desktop and professional machines using a similar process. Additionally, the main selective laser sintering (SLS) patent held by 3D Systems expired earlier this year, potentially opening up this area of AM to competitors, which could result in explosive growth for this section of the market.

Despite these patent expirations, Stratasys and 3D Systems remain the main players in the market, and will likely continue to dominate due to both companies' aggressive acquisition models. 3D Systems is countering the inevitable challenge of its loss of patent rights for SLS by purchasing a number of AM related technologies, material suppliers and software developers, totaling over 40 companies in the past three years. These include material producers such as Huntsman's photopolymer division and RPC Ltd. from Switzerland, as well as makers of consumer products such as Bits from Bytes in the UK and BotMill from Florida. 3D Systems subsumed these companies for the production of a desktop alternative to MakerBot's line of Replicators— the Cube, an FFF printer for consumers that retails from $1-5K.



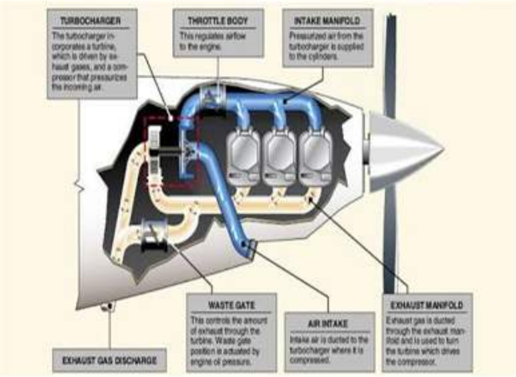
Stratasys sold their first FDM in 1991, and currently ships the largest number of professional AM machines (75,818 machines as of December 31, 2013). In 2012, the company merged with Objet, an Israeli AM company that produces polyjet (light polymerized) machines, and also introduced the first multi-material printer, the Connex500, in 2007. In June 2013, the company purchased MakerBot, enabling it to capitalize on the burgeoning FDM market. Due to FDM's reliance on lower-melting-point plastics, and its relatively poor surface resolution, many in the industry thought the process to be inherently limiting when considering engineering and industrial applications. However, users seem to disagree, citing FDM's reliability and simplicity, the ability to tinker with and hack the process and, of course, the lower machine cost.

This technology is strikingly different from many other industrial processes in that it is used on a personal, home, workshop or lab level by hundreds of thousands of "makers," who, by experimentation—and probably a lot of failure— have expanded and diversified the types of things that can be done with a machine. Indeed, it was Janne Kyttanen, through his design label Freedom of Creation (FOC) in 2000, who first saw the potential of using these machines for anything other than industrial purposes. Kyttanen pioneered the 3D development of lighting, jewelry, tableware, and yes, tchotchkes. (3D Systems acquired FOC in May 2011.). Despite the ability to create modular parts that can be pieced together, one of the major limitations of these types of AM machines has been the constraint in size. Everything has to be printed within the confines of the box. It is intriguing then to see the beginnings of a movement that utilizes robots, some of which are mobile, to expand the maximum size of printed parts by removing the “box” altogether. “You can integrate a lot of components into a single part now,” said Richard Beckett, a London-based architect/designer and co-founder of Syn. De.Bio (Synthetic Design Biotopes), an online forum that aims to disseminate new bio-digital work that is emerging at the crossroads of design, biology and engineering. “So you can leave cavities for auto pipes, you can print door handles straight into doors; the notion of the architectural component is changing. I think that’s more interesting than the formal geometry. There’s something nice about being able to integrate all of these various systems that we see as separate, into one. “From Dirk Vander Kooij’s use of car manufacturing robot arms to print chairs, to the “Minibuilder” robots that print objects many times their size by moving around on caterpillar treads, these “outside the box” techniques allow for much greater freedom of form that cannot be achieved using traditional box-type printers

There are still limits on this new area of robot printing that mimic other AM techniques, including speed and resolution. However, these innovations show that one limitation size has been overcome.

2. Project Description

Manifold: The manifold pressure gauge is an engine instrument typically used in piston aircraft engines to Measure the pressure inside the induction system of an engine. A good pilot is always learning right? Well, since writing this post I have learned that the manifold pressure gauge is really NOT about pressure but about suction! Think about it. Your whole engine (especially the cylinders) is a big vacuum pump. Every time the piston drops into the "intake" stroke it is literally pulling or sucking air into the cylinder. Your manifold pressure gauge is actually reading suction not ram air pressure. That's why at idle power your manifold pressure gauge might read 10 or 12 inches when the outside ambient pressure is 30 inches. Your engine is literally starving for air! It is creating a vacuum or negative pressure inside the intake manifold. The induction system of Couse being the air / fuel mixture that is between the throttle and the cylinders.



Manifold vacuum, or engine vacuum in an internal combustion engine is the difference in air pressure between the engine's intake manifold and Earth's atmosphere. Manifold vacuum is an effect of a piston's movement on the induction stroke and the choked flow through a throttle in the intake manifold of an engine. It is a measure of the amount of restriction of airflow through the engine, and hence of the unused power capacity in the engine. In some engines, the manifold vacuum is also used as an auxiliary power source to drive engine accessories and for the crankcase ventilation system. Manifold vacuum should not be confused with venture vacuum, which is an effect exploited in carburetors to establish a pressure difference roughly proportional to mass airflow and to maintain a somewhat constant air/fuel ratio. It is also used in light airplanes to provide airflow for pneumatic gyroscopic instruments.

Uses:

1) This low (or negative) pressure can be put to uses. A pressure gauge measuring the manifold pressure can be fitted to give the driver an indication of how hard the engine is working and can be used to achieve maximum momentary fuel efficiency by adjusting driving habits: minimizing manifold vacuum increases momentary efficiency.

2) A weak manifold vacuum under closed throttle conditions shows that the butterfly valve or internal components of the engine (valves or piston rings) are worn, preventing good pumping action by the engine and reducing overall efficiency.

3) Vacuum is often used to drive auxiliary systems on the vehicle. Vacuum assist brake servos, for example, use atmospheric pressure pressing against the engine manifold vacuum to increase pressure on the brakes. Since braking is nearly always accompanied by the closing of the throttle and associated high pressure.

Types of Manifold:

Exhaust manifold: An engine part which collects the exhaust gases from multiple cylinders into one pipe.

Hydraulic manifold: A component used to regulate fluid flow in a hydraulic system, thus controlling the transfer of power between actuators and pumps.

Inlet manifold or "intake manifold": An engine part which supplies the air or fuel/air mixture to the cylinders.

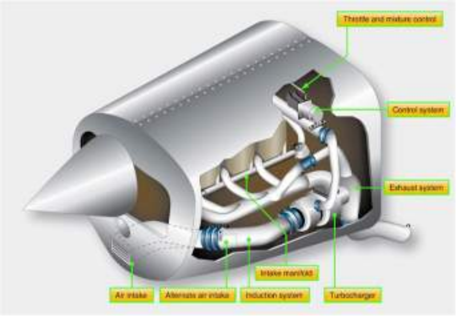
Manifold (scuba): In a scuba set, connects two or more diving cylinders.

Vacuum gas manifold: An apparatus used in chemistry to manipulate gases.

Many edge pipe pieces

Exhaust manifold of Aircraft Engine:

In automotive engineering, an exhaust manifold collects the exhaust gases from multiple cylinders into one pipe. The word manifold comes from the Old English word manifold (from the Anglo-Saxon manig [many] and feald [fold]) and refers to the folding together of multiple inputs and outputs (in contrast, an inlet or intake manifold supplies air to the cylinders).



Exhaust manifolds are generally simple cast iron or stainless steel units which collect engine exhaust gas from multiple cylinders and deliver it to the exhaust pipe. For many engines, there are aftermarket tubular exhaust manifolds known as headers in US English, as extractor manifolds in British and Australian English, and simply as "tubular manifolds" in UK English. These consist of individual exhaust head pipes for each cylinder, which then usually converge into one tube called a collector. Headers that do not have collectors are called zoomie headers.

The most common types of aftermarket headers are made of mild steel or stainless steel tubing for the primary tubes along with flat flanges and possibly a larger diameter collector made of a similar material as the primaries. They may be coated with a ceramic type finish (sometimes both inside and outside), or painted with a heat resistant finish, or bare. Chrome plated headers are available but these tend to blue after use. Polished stainless steel will also color (usually a yellow tint), but less than chrome in most cases. Another form of modification used is to insulate a standard or aftermarket manifold. This decreases the amount of heat given off into the engine bay, therefore reducing the intake manifold temperature. There are a few types of thermal insulation but three are particularly common:

1) Ceramic paint is sprayed or brushed onto the manifold and then cured in an oven. These are usually thin, so have little insulator properties; However, they reduce engine bay heating by lessening the heat output via radiation.

2) A ceramic mixture is bonded to the manifold via thermal spraying to give a tough ceramic coating with very good thermal insulation. This is often used on performance production cars and track only racers.

3) Exhaust wrap is wrapped completely around the manifold. Although this is cheap and fairly simple, it can lead to premature degradation of the manifold.

Exhaust Scavenging:

When an engine starts its exhaust stroke, the piston moves up the cylinder bore, decreasing the total chamber volume. When the exhaust valve opens, the high pressure exhaust gas escapes into the exhaust manifold or header, creating an 'exhaust pulse' comprising three main parts:

EXHAUSTION SYSTEM OF AN AIRCRAFT:

THE FORCED INDUCTION CYCLE:

Figure 1 shows how forced induction works. The forced induction device has a rapidly spinning impeller that sucks in ambient air. The impeller accelerates the incoming air centrifugally, from the center to the edge of the chamber. Although the air at the rim is moving very quickly — close to the speed of sound — it does not increase in pressure or temperature.

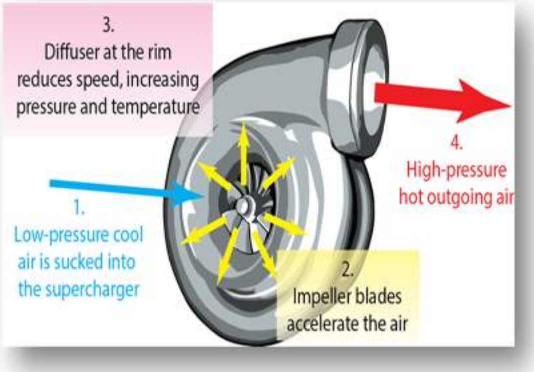


Figure 1: Forced Induction with a Supercharger or Turbocharger

Source: Raymond Panko (Ray@Panko.com).

At the edge of the chamber, fixed diffuser vanes slow the air, as Figure 2 illustrates. As the air slows, its pressure increases, following Bernoulli's principle. The air now has the higher density the engine needs.

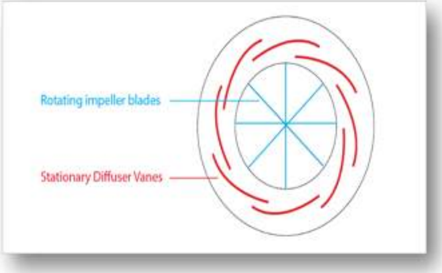


Figure 2: Impeller and Diffuser Vanes

Source: Raymond Panko (Ray@Panko.com).

The Intercooler

In accordance with the Ideal Gas Law, however, the denser air is also hotter. If this hot air is mixed with gasoline and fed directly into the cylinder, the engine might be able to handle it. However, beyond some point, the hot charge will detonate prematurely, reducing engine efficiency or even damaging the engine. If detonation occurs, the air must be cooled before it reaches the carburetor, manifold, and pistons. There are three ways to do this.

If the detonation problem is not too great, the aircraft can use higher-octane gasoline. (In automobiles today, if you use gasoline with too low of an octane rating, your engine might knock. This is detonation.) In the 1930s, a typical rating for aviation gasoline was 87 octane. Many countries continued to use 87-octane gas during the war. Thanks to pre-war work at Shell Oil that involved Jimmy Doolittle, the United States entered the war with 100-octane avgas, although producing and distributing this high-quality fuel to combat units often fell behind needs. Theoretically, gasoline cannot go above 100 octane, which is effectively pure octane. However, performance can still be increased by adding other substances. The United States produced a considerable amount of 130 "performance number" gasoline during the war.

A more comprehensive way to reduce detonation is to use an intercooler, which is essentially a radiator. Figure 3 shows that the intercooler sits between the forced induction device and the engine. Radiators are heavy, and an intercooler requires the addition of tubing between the three devices involved.

Figure 3: Intercooler

Source: Raymond Panko (Ray@Panko.com)

One way to reduce detonation for brief periods of time was water injection. Water (usually mixed with methanol) was injected into the engine with the air/fuel charge. This reduced the temperature considerably, making the air even denser. However, the added coolant disrupted combustion to some extent. The charge did not burn completely, and the exhaust contained black smoke. This disruption must be very brief or the engine would stop working. Consequently, water injection was used only for brief periods of time, such as take-off or emergency combat boost.

Superchargers and Turbochargers

There are two types of forced induction devices. They differ in how the impeller's rotation is powered. The first is the supercharger, in which the engine itself powers the impeller via a short drive shaft. Figure 4 shows that the supercharger usually presses directly against the engine.

Figure 4: Allison V-1710 with Single-Stage Supercharger

. Source: Ray Panko. Photo taken of the Allison V-1710 engine at Pacific Aviation Museum Pearl Harbor

The second type of forced induction device is the turbocharger, which is also called a turbo-supercharger. In turbos, the impeller is powered by the engine's exhaust. High-performance aircraft engines produce very hot, fast, high-pressure exhaust gas. The exhaust spins a turbine, which drives the impeller. (With engines that did not use turbochargers, it was common to direct the exhaust backward, giving extra thrust that might boost the aircraft's forward speed by five miles an hour or more.)

In theory, turbochargers are better than superchargers. A supercharger "steals" power from the engine, lessening its benefit. For example, if a supercharger increases engine performance by 200 horsepower but requires 50 horsepower from the engine to drive its impeller, the net gain will only be 150 horsepower. In contrast, the exhaust gas that drives turbochargers is essentially free energy. This is not entirely true, but back pressure from the turbine does not substantially reduce engine power. This is why modern cars use turbochargers instead of superchargers. (As air pressure decreases, in fact, back pressure from the atmosphere itself decreases; the exhaust actually becomes faster as altitude increases.)

Unfortunately, it is difficult to handle pressurized, fast, and very hot exhaust gas. Special materials were needed, and these were underdeveloped during World War II. Turbocharger production was difficult throughout the war, and reliability was a frequent issue. World War II was a few years too early for turbos in terms of materials science. Turbochargers also require a great deal of heavy tubing to contain the hot gas flows. This tubing carries the hot engine exhaust to the turbocharger and delivers the compressed air back to the engine. When an intercooler is used, the amount of plumbing increases considerably. In a bomber, there is room for this piping. In fighters, the amount of piping needed is a serious design issue. Figure 5 illustrates the large and complex piping in a turbocharged bomber engine.

Figure 5: Turbocharger tubing in a bomber engine

Turbocharger

Source: Ray@Panko.com. Photograph taken at Duxford.

Speeds and Stages

All combat aircraft in World War II used superchargers. However, a single stage of supercharging was effective only up to about 16,000 feet. One solution was to use two stages of supercharging. Each stage had its own impeller, diffuser, and horn. These were placed in series, the first stage feeding into the second. At lower altitude, one second stage was bypassed by the pilot to prevent over boost. As the first stage became insufficient during a climb, that stage was kicked back into the flow.

Although combat aircraft all used supercharging for the first stage of forced induction, some used a turbocharger for their second stage. Given production difficulties, turbocharging was much more expensive. Also, while two stages of supercharging were sometimes possible without an intercooler, turbocharging almost always required an intercooler.

Another way to deal with the need for very different pressure boosts at lower and higher altitudes was to give superchargers multiple speeds. This required a gear and clutch assembly controlled by the pilot. Some British Merlin superchargers had three speeds. The German DB 601 and DB 605 engines used in most Bf 109s carried this trend to the logical extreme. Using fluid coupling with the engine, their superchargers could vary boost smoothly over a considerable range. These adjustments, furthermore, were handled automatically by a barometric-based control. This freed the fighter pilot to concentrate on his opponent.

Of course, having two or more speeds does not rule out also having two stages. Some of the later Merlin engines had two supercharger stages, each with three speeds. For the Fw 190, the BMW 801R under development at the end of the war had a two-stage, four-speed supercharger.

Uses in American Aircraft

F4F with a 2-Stage, 1-speed Supercharged Pratt & Whitney R-1830 Engine

The first fighter in the world to use a two-stage supercharger was the Grumman F4F-3 Wildcat, which used the Pratt & Whitney R-1830 Twin Wasp radial engine. The unsuccessful XF4F-2 prototype used the R-1830-66 engine with a single-stage supercharger. Its performance was not good enough. For the F4F-3, Grumman switched to the R-1830-76 and R-1830-86 engines. Both had two-stage superchargers. This allowed all production Wildcats to perform at high altitudes from the beginning of the war in the Pacific. The heavy F4F burned copious amounts of fuel getting up to altitude, but in combat, altitude is life. From the first combat between Wildcats and Zeroes at Coral Sea to the battles in November at Guadalcanal, postwar analysis found that the F4F had a roughly 1:1 kill ratio against the vaunted Zero [Tillman 2001].

Figure 6: Grumman F4F Wildcat powered by an R-1830 engine with a two-stage supercharger U.S. Government photograph. http://en.wikipedia.org/wiki/File:F4F-3_new_pitot_tube_of_later_model.jpg.

Merlins and Spitfires

Although we focus on American aircraft, the British Merlin engine's evolution exemplifies how rapidly forced induction improved during the war. In addition, of course, the American P-51 Mustang became a great fighter only after it received license-built British Merlin engines.

Rolls-Royce Merlins, which were named after a type of falcon rather than the magician, had 1,650 cubic inches of capacity. This made them slightly smaller than Allison V-1710s. In addition, Merlins had 12 cylinders in a V configuration, while Allisons had 10. In general, barring supercharging, they were very comparable. However, supercharging made all the difference in the world.

In England, the Merlin engines that powered the Battle of Britain Spitfires had single-stage, single-speed superchargers. It was not until the Merlin Mk XX that a second speed was added, but not a second stage. When Stanley Hooker took over supercharger design at Rolls-Royce, he realized that air flows in the existing Merlin superchargers were imperfect. He improved them, and this resulted in a new single-stage two-speed supercharger for the Merlin Mk 45.[1] This new design allowed output to be raised to 1,515 hp at 11,000 feet. The Royal Air Force put this new engine into the Spitfire Mk V airframe just in time to battle the new Bf 109F, which began to appear in large numbers in early 1941. Compared to the Battle of Britain Bf 109E, the “Fredrick” had a completely redesigned wing and cooling system. It had improved fuselage aerodynamics and a somewhat more powerful engine.

The arrival of the Fw 190 in late 1941 made even these engines obsolete. Fortunately, Rolls-Royce was ready with a two-stage, two-speed supercharger for its engines, and beginning with the Mk 60 series. These engines powered the Spitfire Mk IX, which restored British parity with the best German fighters. These two-stage supercharged Merlin’s came considerably later than the two-stage R-1830. In compensation, this delay allowed the Mk 60 and engines to have not only two stages but also two speeds and eventually three speeds for greater pilot control.

The P-40

Before the war, the U.S. Army Air Forces were enamored with turbocharging for the second stage of forced induction, even for fighters. Before the P-40, the Army had Allison add a turbocharged second stage to its V-1710. Curtis used this engine in its XP-37 prototype. As Figure 7 shows, adding room for the turbocharger and its tubing led to an enormously long nose. In fact, the XP-37 looked more like a child’s cartoon than a military aircraft. Its long nose turned ordinary takeoffs and landings into near-death experiences. In combat, pulling lead on a target would have been nearly impossible because the target would be obscured by the nose during sharp turns. In any case, the turbocharger proved unreliable. A similar project to put a turbocharger in the P-39 prototype also floundered because of poor reliability.

Figure 7: XP-37 with second-stage turbocharger

3. INLET MANIFOLD OF A JET ENGINE

INTRODUCTION

An Inlet manifold is the part of an engine that supplies the fuel/air mixture to the cylinders. The primary function of the intake manifold is to evenly distribute the combustion mixture to each intake port in the cylinder head. Even distribution is important to optimize the efficiency and performance of the engine. It may also serve as a mount for the carburettor, throttle body, fuel injectors and other components of the engine. Due to the downward movement of the pistons and restriction caused by the throttle valve, in a reciprocating spark ignition piston engine, a partial vacuum (lower than atmospheric pressure) exists in the intake manifold. This manifold vacuum can be substantial, and can be used as a source of automobile ancillary power to drive auxiliary systems: power assisted brakes, emission control devices, cruise control, ignition advance, windshield wipers, power windows, ventilation system valves, etc.

This vacuum can also be used to draw any piston blow-by gases from the engine's crankcase. This is known as a positive crankcase ventilation system. This way the gases are burned with the fuel/air mixture.

It has long been realized that the design of air intake manifolds has a large effect on the performance of reciprocating engines. The unsteady nature of the induction means that the effect of the manifold on charging and discharging is dependent on the engine speed. The manifold must be designed to enable the engine to ingest air (Pulkrabek, 2004), and thus the inside diameter of the manifold must be able to accommodate the bulk air flow in order to avoid low volumetric efficiency. On the other hand, if the manifold flow path is too restrictive, the desired high air velocity.

FUNDAMENTALS

This section highlights the basics of the engine system that the intake system is designed for. It specifies the scope around which this particular study of the intake system design is carried out. INTERNAL COMBUSTION ENGINE An internal combustion engine is one in which the engine has a combustion chamber in which a mixture of fuel and oxidizer is ignited to generate power. It is particularly characterized as an engine in which the working fluid is being ignited and expanded to gain mechanical energy that can be harnessed. This is opposed to external combustion engines in which the working fluid and the combustion elements are kept separated. There are many different types of internal combustion engines available in the market, mostly of the reciprocating type, although there are others such as the rotary Wankel engines that are popular among today’s automotive manufacturers. The engines used in the FSAE competition are primarily piston-type reciprocating engines, and while the competition is dominated by race cars sporting inline-4-cylinder engines, the team has been using a V-twin for the last three years, particularly for its advantage in power-to-weight ratio. Among reciprocating engines, there is also a distinction between the four-stroke spark ignited engine we use, as compared to two-stroke engines or pressure-ignited engines such as the Diesel engine.

TURBULENCE

The carburettor or the fuel injectors spray fuel droplets into the air in the manifold. Due to electrostatic forces some of the fuel will form into pools along the walls of the manifold, or may converge into larger droplets in the air. Both actions are undesirable because they create inconsistencies in the air-fuel ratio. Turbulence in the intake causes forces of uneven proportions in varying vectors to be applied to the fuel, aiding in atomization. Better atomization allows for a more complete burn of all the fuel and helps reduce engine knock by enlarging the flame front. To achieve this turbulence it is a common practice to leave the surfaces of the intake and intake ports in the cylinder head rough and unpolished.

Only a certain degree of turbulence is useful in the intake. Once the fuel is sufficiently atomized additional turbulence causes unneeded pressure drops and a drop in engine performance.

VOLUMETRIC EFFICIENCY

The design and orientation of the intake manifold is a major factor in the volumetric efficiency of an engine. Abrupt contour changes provoke pressure drops, resulting in less air (and/or fuel) entering the combustion chamber; high-performance manifolds have smooth contours and gradual transitions between adjacent segments. Modern intake manifolds usually employ runners, individual tubes extending to each intake port on the cylinder head which emanate from a central volume or "plenum" beneath the carburettor. The purpose of the runner is to take advantage of the Helmholtz resonance property of air. Air flows at considerable speed through the open valve. When the valve closes, the air that has not yet entered the valve still has a lot of momentum and compresses against the valve, creating a pocket of high pressure. This high-pressure air begins to equalize with lower-pressure air in the manifold. Due to the air's inertia, the equalization will tend to oscillate: At first the air in the runner will be at a lower pressure than the manifold. The air in the manifold then tries to equalize back into the runner, and the oscillation repeats. This process occurs at the speed of sound, and in most manifolds travels up and down the runner many times before the valve opens again.

The smaller the cross-sectional area of the runner, the higher the pressure changes on resonance for a given airflow. This aspect of Helmholtz resonance reproduces one result of the Venturi effect. When the piston accelerates downwards, the pressure at the output of the intake runner is reduced. This low pressure pulse runs to the input end, where it is converted into an over-pressure pulse. This pulse travels back through the runner and rams air through the valve. The valve then closes. To harness the full power of the Helmholtz resonance effect, the opening of the intake valve must be timed correctly, otherwise the pulse could have a negative effect. This poses a very difficult problem for engines, since valve timing is dynamic and based on engine speed, whereas the pulse timing is static and dependent on the length of the intake runner and the speed of sound. The traditional solution has been to tune the length of the intake runner for a specific engine speed where maximum performance is desired. However, modern technology has given rise to a number of solutions involving electronically controlled valve timing (for example Valvetronic), and dynamic intake geometry. As a result of "resonance tuning", some naturally aspirated intake systems operate at a volumetric efficiency above 100%: the air pressure in the combustion chamber before the compression stroke is greater than the atmospheric pressure. In combination with this intake manifold design feature, the exhaust manifold design, as well as the exhaust valve opening time can be so calibrated as to achieve greater evacuation of the cylinder. The exhaust manifolds achieve a vacuum in the cylinder just before the piston reaches top dead center.The opening inlet valve can then—at typical compression ratios—fill 10% of the cylinder before beginning downward travel. Instead of achieving higher pressure in the cylinder, the inlet valve can stay open after the piston reaches bottom dead centre while the air still flows. In some engines the intake runners are straight for minimal resistance. In most engines, however, the runners have curves...and some very convoluted to achieve desired runner length. These turns allow for a more compact manifold, with denser packaging of the whole engine, as a result. Also, these "snaked" runners are needed for some variable length/ split runner designs, and allow the size of the plenum to be reduced. In an engine with at least six cylinders the averaged intake flow is nearly constant and the plenum volume can be smaller. To avoid standing waves within the plenum it is made as compact as possible. The intake runners each use a smaller part of the plenum surface than the inlet, which supplies air to the plenum, for aerodynamic reasons. Each runner is placed to have nearly the same distance to the main inlet. Runners whose cylinders fire close after each other, are not placed as

"180-degree intake manifolds"....Originally designed for carburettor V8 engines, the two plane, split plenum intake manifold separates the intake pulses which the manifold experiences by 180 degrees in the firing order. This minimizes interference of one cylinder's pressure waves with those of another, giving better torque from smooth mid-range flow. Such manifolds may have been originally designed for either two- or four-barrel carburettors, but now are used with both throttle-body and multi-point fuel injection. An example of the latter is the Honda J engine which converts to a single plane manifold around 3500 rpm for greater peak flow and horsepower. "Heat Riser"....now obsolete, earlier manifolds ...with 'wet runners' for carburetted engines...used exhaust gas diversion through the intake manifold to provide vaporizing heat. The amount of exhaust gas flow diversion was controlled by a heat riser valve in the exhaust manifold, and employed a bi-metallic spring which changed tension according to the heat in the manifold. Today's fuel-injected engines do not require such devices.

Variable-Length Intake Manifold (**VLIM**) is an internal combustion engine manifold technology. Four common implementations exist. First, two discrete intake runners with different length are employed, and a butterfly valve can close the short path. Second the intake runners can be bent around a common plenum, and a sliding valve separates them from the plenum with a variable length. Straight high-speed runners can receive plugs, which contain small long runner extensions. The plenum of a 6- or 8-cylinder engine can be parted into halves, with the even firing cylinders in one half and the odd firing cylinders in the other part. Both sub-plenums and the air intake are connected to an Y (sort of main plenum). The air oscillates between both sub-plenums, with a large pressure oscillation there, but a constant pressure at the main plenum. Each runner from a sub plenum to the main plenum can be changed in length. For V engines this can be implemented by parting a single large plenum at high engine speed by means of sliding valves into it when speed is reduced.

As the name implies, VLIM can vary the length of the intake tract in order to optimize power and torque, as well as provide better fuel efficiency.

There are two main effects of variable intake geometry:

- **Venturi effect** - At low rpm, the speed of the airflow is increased by directing the air through a path with limited capacity (cross-sectional area). The larger path opens when the load increases so that a greater amount of air can enter the chamber. In dual overhead cam (DOHC) designs, the air paths are often connected to separate intake valvesso the shorter path can be excluded by deactivating the intake valve itself.
- **Pressurization** - A tuned intake path can have a light pressurizing effect similar to a low-pressure supercharger due to Helmholtz resonance. However, this effect occurs only over a narrow engine speed range which is directly influenced by intake length. A variable intake can create two or more pressurized "hot spots." When the intake air speed is higher, the dynamic pressure pushing the air (and/or mixture) inside the engine is increased. The dynamic pressure is proportional to the square of the inlet air speed, so by making the passage narrower or longer the speed/dynamic pressure is increased.

Manifold Heat Control

Most engines have automatically operated heat controls which use the exhaust gases of the engine to heat the incoming fuel-air charge during starting and warm-up. This improves vaporization and mixture distribution. When the engine is cold, all of the exhaust gas is deflected to and around the intake manifold "hot spot". As the engine warms up, the thermostatic spring is heated and loses tension. This allows the counterweight to change the position of the heat control valve gradually so that, at higher driving speeds with a thoroughly warmed engine, the exhaust gases are passed directly to the exhaust pipe and muffler. In the ram induction system, there is a heat control chamber in each manifold to operate the automatic choke and to heat the fuel mixture after warm-up. A heat control valve in each exhaust manifold will by-pass the exhaust gas through an elbow to the intake manifold heat control chamber. Heat outlet pipes then carry the gas down to the "Y" connector under the heat control valve. Heat control is regulated by a coiled thermostatic spring mounted on the exhaust manifold. A counterweight is mounted on the other end of the heat control valve shaft and this counterweight, in conjunction with the thermostatic spring, operates to close and open the heat control valve.

Ram Induction Manifolds

The ram induction manifold system consists of twin air cleaners, twin four-barrel carburettors and two manifolds containing eight long tubes of equal length (four for each manifold). This system was designed by the Chrysler Company to increase power output by in the middle speed range (1800-3600 rpm). Each manifold supplies one bank of cylinders and is carefully calculated to harness the natural supercharging effect of a ram induction system. By taking advantage of the pulsations in the air intake column caused by the valves opening and closing, sonic impulses help pack more mixture into the combustion chambers. In the Chrysler system, the air-fuel mixture from each carburettor flows into a chamber directly below the carburettor, then passes through the long individual intake branches to the opposite cylinder bank. The right-hand carburettor supplies the air-fuel mixtures for the left-hand cylinder bank, and the left-hand carburettor supplies the right cylinder bank. The passages between the manifolds are interconnected with a pressure equalizer tube to maintain balance of the engine pulsations. Distribution of the fuel should, therefore, be as even as possible. This depends greatly upon the design of the intake manifold. Dry fuel vapour is an ideal form of fuel charge, but present-day fuel prevents this unless the mixture is subjected to high temperature. If the fuel charge is heated too highly, the power of the engine is reduced because the heat expands the fuel charge. Therefore, it is better to have some of the fuel deposited on the walls of the cylinders and manifold vents. Manifolds in modern engines are designed so that the amount of fuel condensing on the intake manifold walls is reduced to a minimum. In a V-8 engine, the intake manifold is mounted between the cylinder heads. The L head engine's manifold is bolted to the side of the block, and the I-head manifold is bolted to the cylinder head.

Air Intake Manifold

The air intake manifold ensures the **optimal filling** of the engine cylinders with a suitable mass of comburent consisting of **fresh air and recirculated exhaust gases**. The intake manifold also carries out the function of integrating other engine **supply control functions**: fuel supply, fuel anti-evaporation system control, and engine operation point control. Hence, the air intake manifold can also carry out the function of engine supply mechatronic module, with the following advantages: compact size, cost, and assembly on the engine.

The intake manifold basically consists of a volume of thermoplastic material with high thermal and **mechanical resistance**, hooked up to the engine by means of duly sized conduits and made in injection moulding technology and welding of vibrating parts. The technical solutions satisfy needs in terms of **weight reduction and recyclable materials.**

Thanks to its knowledge of engines and experience when it comes to systems, Magneti Marelli Powertrain offers its customers, with delivery **times compatible with the time-to-market, “turnkey” systems** capable of meeting the following requirements: performance, fuel consumption and overall dimensions of engine vehicle applications from **2 to 12 cylinders**.

Through sophisticated virtual design techniques and advanced production technologies, Magneti Marelli can develop and manufacture complex intake manifolds equipped with electronic control systems of air and gas fluid dynamics aimed at maximizing performances, **reducing fuel consumption and CO_2** and **reducing the noise emitted by the engine.Intake Air Management for manifolds of Diesel Engines**

Managing the supply of air to the combustion chamber is a critical aspect of modern diesel engines and can impact emissions, performance and fuel economy. Combustion air management is the process that is used to ensure that the air supplied to the combustion chamber at all operating conditions meets a number of requirements including:

- A sufficient quantity of oxygen is available to ensure complete combustion,
- A sufficient amount of diluent (i.e., EGR) is present to control the combustion temperature,
- The temperature and pressure (density) of the charge air is controlled,
- Suitable bulk motion and kinetic energy is imparted to the charge air in the cylinder to support the mixing of air, fuel and intermediate combustion products, and
- The size and concentration of impurities such as dust and dirt is acceptable.

In older engine designs that did not have to meet stringent exhaust emissions requirements, air management systems could be relatively straightforward. In some cases, it was sufficient to simply ensure that the air was clean, that the flow capacity of the intake system was adequate to ensure peak torque and power objectives were met and sufficient swirl was imparted to the air as it entered the combustion chamber to support the fuel injection system in the task of mixing of air and fuel. Typically, no active control of any intake side hardware was required. Even as many engines started to adopt turbochargers and other forms of intake air compression, it was sufficient to simply ensure a proper match between the engine and compressor.

Pressure to lower emissions while maintaining or improving other engine performance parameters required that the intake air properties be better controlled and matched to suit the engine operating condition. This required the introduction more hardware to control these intake air properties. For example, waste gate control on the turbocharger was introduced to enable improved intake air boosting at lower engine speeds and to limit turbine speeds at high engine speeds, valves were introduced to mix some exhaust gas (EGR) into the intake air at some engine operating conditions, turbocharger controls become more complicated to ensure that boost and EGR requirements could be met and higher and higher intake air pressures required that the higher intake air temperatures resulting from compression be limited. All of this added complexity required that more sophisticated control systems with sensors and sophisticated control algorithms be incorporated to ensure everything functions as expected.

This paper covers the basics of pressure charging—including turbochargers, superchargers and systems with multiple compressors—as well as turbocompounding and an introduction to intake manifold design. There are a number of additional important aspects of intake air management that will be discussed in separate papers. These include:

- **Charge Air Temperature Management.** Managing the temperature of the air at the time of fuel injection in diesel engines is critical to ensure proper engine operation. There are two aspects of charge air temperature management:
  - managing high air temperature by cooling in boosted diesel engines and
  - Managing low air temperature by heating to facilitate engine start-up and warm-up at low ambient temperatures.
- **Exhaust Gas Recirculation.** Exhaust gas recirculation (EGR), the process of recirculating some of the exhaust gas back into the intake system, is an important technology that has allowed modern diesel engines to achieve very low engine out NOx emissions. As can be imagined, introducing relatively high temperature exhaust gas into the intake air can have significant impacts on the temperature and composition of the combustion air supplied to the combustion chamber. In order to ensure proper functioning of an engine with EGR, various hardware components, such as valves and coolers have to be introduced to control the flow, temperature and distribution of EGR supply and the resulting mixture with intake air. As well, turbocharger sizing and technology choices can also be affected and steps must be taken to ensure sufficient oxygen is still available for combustion and sufficient EGR flow is available at all engine operating conditions.
- **Crankcase Ventilation.** Engines with closed crankcase ventilation systems vent gases from the crankcase into the intake air system to be recirculated into the engine. This recirculated blowby must be properly managed. Also, while the recirculated gases are filtered, a small amount of oil and particulate can still be introduced into the intake system and accumulate on critical air management components such as the compressor. Over time, if a sufficient accumulation of this material occurs, it can have a significant impact on the air management system performance.

- **Control of Flow into and out of the Combustion Chamber.** From the intake manifold, the flow must be transferred to the cylinder. In four stroke engines, this is accomplished with a port located in the cylinder head with a poppet type valve to open and close the port. A different set of valve(s) controls the timing of the flow of exhaust gas out of the cylinder and into the exhaust port. Valve timing in four-stroke engines can be either fixed or variable.

  In two stroke engines, ports in the cylinder liner located near the piston's BDC location that are alternately covered and uncovered by the piston are commonly used to control intake flow. After combustion is complete, the burned gases from a two-stroke are expelled from the cylinder either through exhaust valves or a different set of exhaust ports located near the piston's BDC position. The portion of the cycle available for expelling exhaust gases and admitting intake gases in two-strokes is relatively short. Generally, the intake gases must be pressurized in order to allow the incoming air to quickly fill the cylinder and scavenge it of exhaust gases.

Turbo Manifold Design

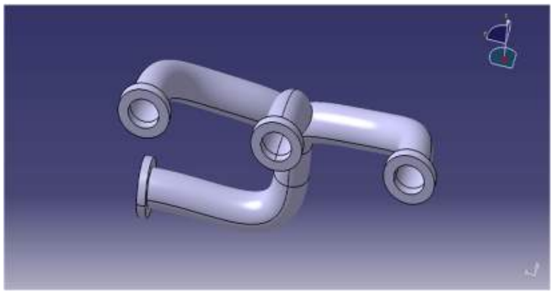
- The manifold is to direct the exhaust gases through the turbine side of the turbo.
- Manifolds are commonly built of 304 stainless steel. It is strong and resists cracking at the high temperatures that the turbo manifold will see.
- Manifold should have waste gate priority. The waste gate is what regulates the boost pressure of the compressor side of the turbo.
- Volume of runners and runner length should be optimized. For the test vehicle, a long runner manifold such as a top mount or a ram horn manifold should be used, with fluid bends not sharp angles.

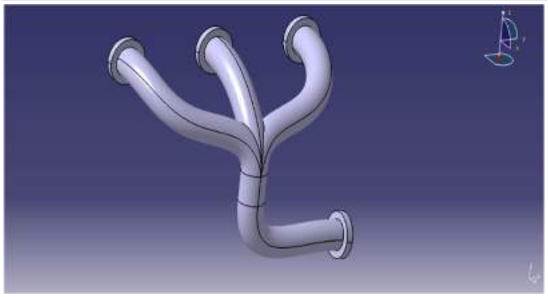
Prototype Intake Manifold Design

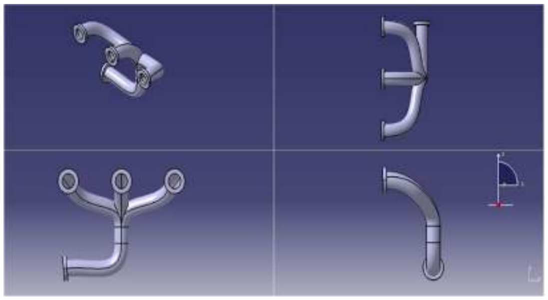
- Explain plenum size of Victor X manifold and runner length/shape.
- Going to use a Edelbrock 65mm throttle body on both intake manifolds.
- Plenum size to be 1.25% of the motor size. Which would put the plenum size to be around 2.5L
- Utilizing constant surface area through the entire runner length.
- Runner/Plenum intersection will have a bell-mouth shape given by the relation of throat diameter to the radius of the inlet to the runner. The relation is Inlet diameter = 3 x Runner Diameter.
- The plenum acts as a resonance chamber. Each reflection from the from the resonance chamber adds more (energy, tone, amplitude) to the sound wave.

- The idea is to get these maximized waves to the valves so they enter the motor with increased energy, which in some cases can be over atmospheric pressure.

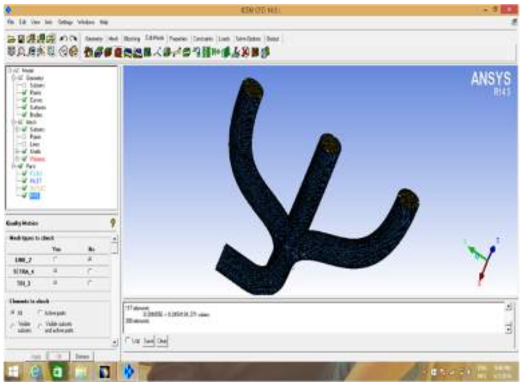
DESIGN OF MANIFOLD IN CATIA V5:

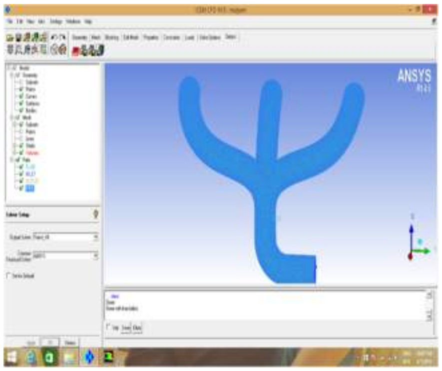






CFD ANALYSIS ON MANIFOLD OF AIRCRAFT ENGINE:

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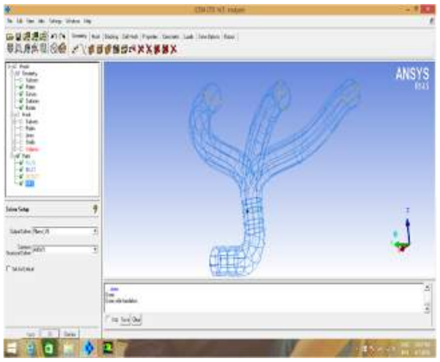
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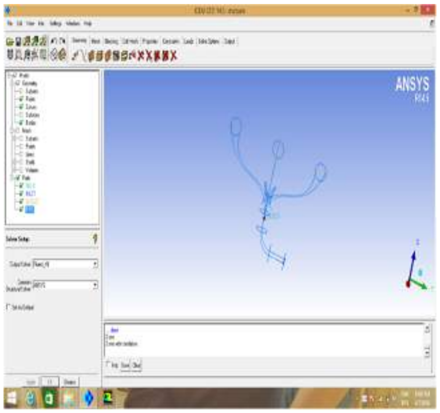
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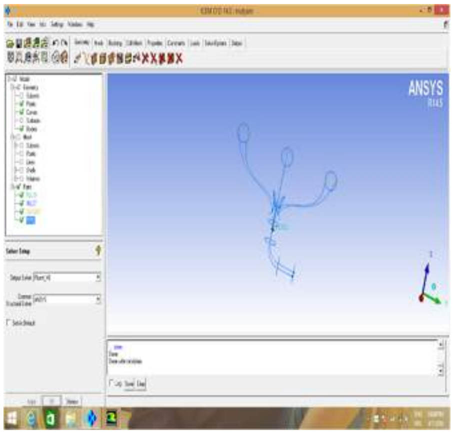
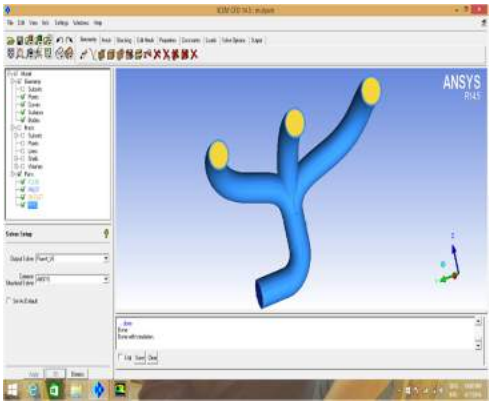
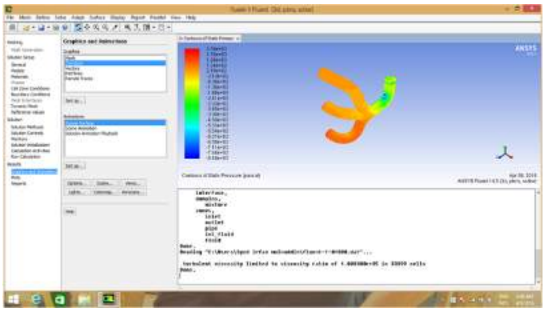
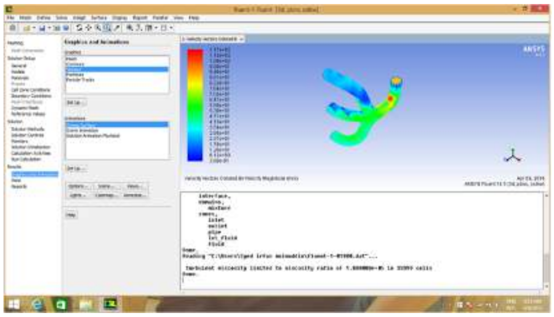




ANSYS RESULTS OF MANIFOLD OF AIRCRAFT ENGINE:





FABRICATED USING 3D PRINTING

CONCLUSION:

In this project Additive Manufacturing includes a wide range of technologies, such as: laser sintering, FDM, stereolithography, and many more. And technologies are used in a wide range of industries from the automotive, consumer electronics, and consumables sectors as well as being used for aviation applications. In addition to producing objects using AM, we would also use two AM-related software's. In this project we the designed the jet engine exhaust manifold in software and then manufacturing by FDM in 3-D printer using CURA software and then analyzing it n CFD and Ansys software's respectively in order to calculate the flow properties.

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