

Micrometeorology and the Jet Engine*

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(Translated by KIM Kyuri††)

Introduction

This paper is an *attempt* at examining the structure of the jet engine from a micro-meteorological perspective. I stress that it is an attempt. For one, I am yet to come across such an endeavor, and two, because although this paper addresses the convergence between the natural sciences and engineering, it ultimately remains to be a work in the humanities, more specifically “machine critique.” Investigating science and technology (S&T) from a humanities perspective may seem somewhat inadequate or inappropriate. Nevertheless, the rise of academic departments devoted to the history and philosophy of S&T in many universities across the world is evidence that epistemic, ontological, and ethical aspects of S&T cannot be fully addressed cannot be fully addressed without borrowing the insights and methodologies from the fields of history, philosophy, and other humanities. This research takes this further by “critiquing” S&T through a rather unfamiliar method called machine critique. Machine critique, a concept developed by myself, is an intellectual activity aimed at investigating the meaning of machines. The objective of machine critique is to ask historical and philosophical questions by examining the structure of the machinery itself. This does not, however, call for an external approach whereby machines are examined using epistemologies extraneous to the machines. Rather, it entails closely studying the machine as it is and deducing the meaning of its structure and function, as an art historian would examine the artwork itself and derive meaning from it.¹

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¹ Lee Young June 이영준, *Gigye bipyeong: Han inmunhakja-ui gigye munmyeong sanchaek* 기계비평-한 인문학자의 기계문명 산책 (Machine Critique: A Social Scientist's Stroll through Machine Civilization) (Hyunsil Book, 2007); idem., *Pegaseoseu 10,000 mail* 페가서스 10000마일 (Pegasus 10,000 Miles) (Workroom Press, 2012). I am currently preparing a second manuscript on machine critique.

The limitations of a critique coming from a social scientist vis-à-vis a specialist in natural sciences or engineering are clear. For instance, a critical bottleneck for the former arises when s/he encounters equations. Faced with equations, which are symbolic of scientific knowledge, the social scientist's cognition is brought to a halt. This applies not only to complex equations but to those as simple as $F=ma$ as well. This high school physics-level equation is succinct in itself, but if one were to explain it further and lay out theories on force, mass, and acceleration, the social scientist find her/himself in a completely dark and unknown territory. In addition, terminologies specific to the field also present themselves as challenges. On one hand, terminologies embody abstruse concepts that are difficult to grasp, and on the other, they encompass contexts and nuances specific to that field of expertise. In other words, terminologies reflect exclusivity, and a social scientist who is not a member of the scientific community is unable to fully access the contexts and nuances attached to expert terminologies. This limitation is one that can be somewhat overcome by coming into contact with people in the field, but expert terminologies are not independent articles. They are more like clouds that group together to form a larger whole, which in turn creates an exclusive "expertise" that is elusive to those on the outside. For instance, the fact that one has become familiar with a few terminologies in the field of printing, such as *harikomi* or *hongake*, does not ensure her/his ability to understand the inner workings of the printing industry.

Being part of a given field or community, however, does not guarantee complete familiarity of the field either. Knowledge exists as manifold layers, and only by grasping all the layers can we truly say that we understand our subject matter comprehensively. Moreover, these manifold layers refer not only to the multiple, *vertical* layers but also to horizontally-placed layers. In other words, knowledge is comprised of "upstairs," "downstairs," and "next-door," hence knowledge that scholarship seeks is both multi-layered and multi-dimensional. Scientific knowledge, for instance, includes those produced within scientific communities as well as those produced externally. Science exists not only as scientific phenomena, but are simultaneously historical, social, and philosophical. Thus, to understand science is to understand these many layers of science. It would be impossible to assess the problems posed by Hwang Woo-suk's stem cell research without a proper understanding of research ethics; it would be impossible to appreciate the novelty of a given scientific discovery without a strong background in the history of science. Certain knowledge is better appraised by those looking in from the outside.

This is why we need a critique on S&T. Despite the limitations in probing into deeper layers due to the lack of specialized, technical knowledge, machine critique can provide new perspectives towards S&T. Examining it through sets of external but fresh set of eyes can reveal aspects that were previously unseen by its technical experts. In this spirit, this research attempts to converge two distinct subjects—micrometeorology and jet engines. The attempt of a social scientist to converge the two topics based on a relatively shallow understanding of both fields, compared to the

collaboration of technical specialists in the two areas, may sound as absurd, or even dangerous, as someone who has barely any culinary training attempting to fuse Italian and Japanese cuisine. The attempt to bring micrometeorology and the jet engine together despite these obvious limitations is because it is through unconventional ventures such as this that will prompt new understanding and knowledge, and ultimately provide new insights for scientists and engineers to further their horizons.

A critique is not thoroughly objective. Unlike quantitative analyses in S&T, critique involves analysis that includes the subjective opinions of the examiner, as well as the debates sparked by differences in opinions between different examiners. Critique, therefore, is fluid knowledge.

Machine Taxonomy

To enter inside the machine in order to critique it as a social scientist rather than an engineer is a challenging task. The “inside” of a machine refers to the specialized knowledge and logic comprising the machinery. To anyone who is not trained professionally, their understanding of the machinery declines drastically when faced with scientific equations. Therefore, a machine critic cannot address the machine from a technical standpoint. Alternatively, an engineer cannot analyze the machine as would a machine critic, as they also cannot fully address the historical, philosophical, and anthropological aspects of the machine. Even though engineers can investigate the inner workings of a machine, they cannot fully address the external elements. Engineers are able to build and operate machines that are useful to society, but are unable to engage in a complex debate over why a given society came to require that specific machinery, or trace the historical roots of the machine across time and space. Moreover, it is even more difficult for the engineer to tease out the subtle nuances in the machines’ influence over people, society, and culture. That is the role of the critic. A machine is made up of not only its inner—technical knowledge and logic—workings, but also its external elements—such as man’s desire for machinery, the culture of externalizing this desire, societies made up by machines, the temporal axis of history, and so on. These are the aspects with which a critic is concerned. This, however, does not mean that the machine’s internal and external aspects separate from each other.² It is only that critics concern themselves

² Many intellectuals argue that technology is social—for instance, Paul Virilio, who wrote gloomily and pessimistically about the influence of speed on modernity in *Vitesse et politique essai de dromologie* (Paris: Editions Galilée, 1977); Bruno Latour, who studied the alliance between the human and non-human in “On Actor-Network Theory: A Few Clarifications Plus More than a Few Complications,” *Soziale Welt* 47:4 (1990), 1-14; Donald MacKenzie’s work on the social process that led to increased accuracy of ballistic missiles, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, MA: MIT Press, 1990); and Jonathan Crary,

of the social aspects of the machine civilization holistically rather than as individual parts. Put differently, it is easy to talk about how the demand for mobile phones is social. It is more challenging, however, to explain how the specific designs for its batteries and antennae are social. The latter requires a certain degree of understanding of the inner workings of the machines.

A critic's means to discuss the details of a machine without specialized knowledge in mechanical engineering is through ontology. In this paper, I apply the method of machine taxonomy, which involves imposing certain criteria in order to examine the ontological characteristics of the machines. For example, as biological taxonomy assesses how different species are related to each other based on their traits and characteristics, machine taxonomy aims to categorize machines according to certain criteria and create new combinations of relationships. It is similar to how in biological taxonomy, deer are classified as Artiodactyla due to the shape of their hooves. The aircraft is an aerodynamic phenomenon, and we could further distinguish machines by whether or not they require air, like we do for aerobic and anaerobic bacteria. Distinguishing machines in this manner can better reveal certain qualities of machines. The piston engine and the jet engine require air, unlike the rocket engine. Many objects found in our daily lives like the pencil and eraser are able to function in the absence of air. Then what about computers? A computer's computational abilities can function anaerobically, but its fans will be futile in the absence of air. Without their cooling effect, the computer will continue to heat up, resulting in lower efficiency and shortened lifespan of the machine. The computer, therefore, is a closer relative of the jet engine than the rocket engine.

As structuralist and anthropologist Claude Levis-Strauss categorized cultures of indigenous tribes between raw and cooked depending on their system of signs and symbols, machine taxonomy can be useful in externally examining machines and their traits.³ This categorical understanding of machines is especially meaningful when we consider the wide range of machines invented and produced in the modern times that stir air. Not only are there machines fitted with fans that stir through air, but even more stationary machines are equipped with parts that stir air, from ventilation fans themselves, to air conditioners, refrigerators, aircraft, and computers. Cooling fans are also pervasive in industrial machines. At first glance these machines have their fans as a common denominator, but a closer look reveals significant differences. For instance, the common household cooling fan and the turbofan jet engine are both fitted with fans with rotating blades, but the difference in size, shape,

who wrote about the social development of visual technologies in *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century* (Cambridge, MA: MIT Press, 1992).

³ For more on Levis-Strauss's work, see *Tristes Tropiques* (New York : Atheneum, 1961) and *From Honey to Ashes: Introduction to a Science of Mythology, Volume 2* (Chicago : University of Chicago Press, 1973).

materials used, application, history, and philosophy behind the two fans are insurmountable. Strictly ontologically speaking, the jet engine is fundamentally related with the most primitive of machines invented to stir air—the handheld fan. But once we take the other factors into consideration, the two are completely unrelated machines from an ontological standpoint. Machine taxonomy may seem like it takes only the external aspects of a machine into consideration, but it categorizes machines based on their characteristics, hence also gives weight to their inner workings.

Meteorology is a unique knowledge-machine that deals with air. It develops and implements means to observe, forecast, and even control the flow of air. In this sense, the jet engine and meteorology have something in common. Needless to say, meteorological information plays a significant role in navigating aircraft. For the purpose of this paper, however, I am interested in the relationship between meteorology and the jet engine at the micro-level. Of interest is the changes of air within a specific, micro-level space—the inside of the jet engine—that is on a completely different level to what standard meteorology is used to examining. In sum, this paper aims to examine how air is sucked into a jet engine, is compressed, and explodes to escape the combustion chamber, thereby turning the turbines to create kinetic energy on one hand, while examining micrometeorologically the changes in the speed, temperature, pressure, and density of the air.

Applications of Micrometeorology

Examples of applications of micrometeorology are abound. They exist virtually everywhere the atmosphere exists. There can be several applications of micrometeorology: air pollution meteorology (how do pollutants spread and travel through air, how do industrial and agricultural activities produce air pollution, how should expulsion of pollutants be managed for facilities such as power plants),⁴ mesoscale meteorology (urban boundaries and heat islands, land and sea breezes, mountain and valley breezes, and whirlwinds), synoptic scale meteorology (atmospheric forecasting and long-term weather forecasting), agricultural and forest meteorology (effect of atmospheric environment on plants and vice versa, soil and atmosphere), urban planning and management (flow of air around buildings, impact of air conditioning, and heating on the weather, road conditions), physical oceanography (forecasting the state of the sea, modelling oceanic circulation, impact of weather on ocean navigation, and electric wave transmission).⁵

A closer look at the body of research interestingly reveals that micrometeorology was applied in seemingly disparate topics, ranging widely to cover forestry, urban

⁴ Joe R. Eagleman, *Air Pollution Meteorology* (Lenexa, KS: Trimedia, 1996).

⁵ S. Pal Arya, *Introduction to Micrometeorology* (San Diego: Academic Press, 1988), 23.

planning, cultural assets, and apparel. This indicates that micrometeorology can also be applied to examining the internal mechanisms of the jet engine and acceleration.⁶

⁶ For more on the different sub-fields within micrometeorology, firstly environment and organisms, see Sin-gyu Kang, “Bokjabhan jise-ui salimeseo-ui migihuwa toyanghwan-gyeong, toying-hoheup-e daehan moyeong yeongu” (Modeling Microclimate, Soil Environment, and Soil Respiration in a Rugged Forest Landscape) (Ph.D. Dissertation, Seoul National University, 2001); Hongqing Yao, “Iyujadonsa-ui migihuga daegioyeommuljil-e michineun yeonghyang” (Effects of Microclimate on Aerial Emissions in Swine Nursery House) (MS Thesis, Seoul National University, 2010); Sae Ro Mi Mun, “Misegihuga yuhaesikmul-e michineun yeonghyang” (The Implication of Microclimate on Harmful Plants, *Ambrosia artemisiifolia* and *Humulus japonicas*) (MS Thesis, Seoul National University, 2011); Jae Won Lee “Migihu jojeolgibeobeul jeogyonghan suwonyeong jogyeong gibonseolgye” (Microclimatic Landscape Design for Suwon Railway Station) (MS Thesis, Seoul National University, 2003). For apparel-related studies, see Jun Hee Park, “Uibokgihuwa boollyeokgwa-ui gwallyeonseong yeongu” (A Study on the Relationship Clothing Microclimate and Thermal Insulation of Clothing) (MS Thesis, Seoul National University, 2004); Il Na Son, “Uibokgihubyeonhwa-e ttareun jugwanjeong hanseo gamgakgwa cheonjojeol baneunggwau gwallyeonseong” (Relationship between Thermal Sensation and Thermoregulatory Responses According to Clothing Microclimate) (MS Thesis, Seoul National University, 2010); So Young Kim, “Uibokgihuwa naehannaeyeolseonggwa-ui gwallyeonseong” (The Relationship Between Clothing Microclimate and Cold/Heat Tolerance) (Ph.D. Dissertation, Seoul National University, 2005). For cultural assets, see Sun Myoung Lee, “Seosanmaaesamjon bulsang-ui jeongmil huesondo jindangwa migisanghwangyeong yeonghyang bunseok” (Detailed Deterioration Diagnosis and Microclimatic Effect Analysis of the Seosanmaaesamjon bulsang (Rock-carved Triad Buddha in Seosan), Korea) (MS Thesis, Kongju National University, 2007); Dario Camuffo, *Microclimate for Cultural Heritage* (Amsterdam: Elsevier Science, 1998).

Hongqing Yao studied the effect of pigsties on air pollutants explained that he “measured the air pollutants emitted from a pigsty, and examined the effect of microclimate on the concentration of dust particles, microbes in the air, and malodorous materials. As the objective of the study was to control the amount of air pollutants in the sty, it is expected that an understanding of the correlation between microclimate and air pollutants can contribute to decreasing the latter by manipulating the former, and ultimately to inform guidelines for sty management and operation.”

In a paper on the landscape design of Suwon Station, Jae Won Lee limited his scope of examination to a specific region to examine the changes in the microclimate within a city, and to propose detailed measures. He points out the importance of landscape design and planning in creating a pleasant environment, as well as a means to solve the problem of heat islands in urban settings. He examined temperature, humidity, the direction and speed of wind, amount of sunlight, and albedo as variables affecting the climate, and proposes grassland, wind, packaging materials, appropriate installation of facilities as ways to moderate the climate.

Studies on apparel can be an example of application of micrometeorology at the smallest scale. Jun Hee Park studied the relationship between clothing climate and insulation by trying on different garments at 15°C and examining how insulation and clothing climate affect each other. Through this experiment, she demonstrated the impact of clothing climate as an environment on health and thermal sensation. The study is unique in that it calculated insulation capacity of different garments by measuring clothing climate and physiological responses, and examined the correlation between microclimates inside the clothing, insulation, and amount of clothing.

Another field where micrometeorology has been applied is that of cultural assets. A characteristic of cultural assets is that they exist in a given place semi-permanently, exposed to shifting artificial environmental factors. They are especially vulnerable to constantly changing level of

Aircraft as a Meteorological Phenomenon

This paper essentially considers the aircraft as a meteorological phenomenon. Here, the term “aircraft” refers not to specific models such as DC3, but to some combination of the variables such as air, metal, and speed. The phenomenon of ‘flying’ is due to a lifting force, which is entirely created by air. The aircraft is a metallic machine but it cannot operate in the absence of air. Since the air or atmosphere through which the aircraft travels are in constant flux, the aircraft is in essence flying through meteorological phenomena. In the process of inventing and developing the aircraft, humans have created new dynamic meteorological phenomena. The impact of aircraft on the quality and state of the Earth’s atmosphere has been so significant that the invention of the aircraft signified the beginning of a new era. Phenomena such as turbulence or eddies,⁷ boundary layer separation,⁸ and shock waves,⁹ which occur in proximity to the aircraft, take place exclusively in the presence of an aircraft, hence need to be addressed as distinct micrometeorological phenomena.



Figure 1. Wake vortex turbulence forming around an aircraft

humidity and temperature, hence it is interesting to see that micrometeorology has been applied in research towards their preservation.

⁷ This phenomenon takes place as part of the fluid flows in the opposite direction of the main flow, causing a whirlpool-like eddy. A short counter-directional flow is created behind the object. This phenomenon is best observed in a rapidly flowing stream, behind a large rock pointing out of the water. Another example of turbulence is a whirlpool. The concept applies more to gases than liquids. In gases, there are no empty spaces (vacuums) but only areas of low pressure, but the backward flow makes the gas move in circular motion.

⁸ Phenomenon in which the air flowing along the surface of the aircraft separates from the surface as the angle of the surface changes, creating an eddy.

⁹ A compressional wave created in the air that spreads out at supersonic speed.

The subject of micrometeorological study in this paper is not the aircraft itself but the jet engine. As the term “search engine” also insinuates, engines are a source of massive power that is strong enough to lead us to a destination. Before the engine, humans could make use of natural sources of power, like water or fire, but the limitations in modulating their power, preventing accidents, or ease of use, were clear. It was only after the invention of modern engines that we could modulate power and garner it for use. It is also true, however, that the engine also led us to accidents and war, overcoming humans.¹⁰ Engines thus possess a transcendental power, and of all engines, the jet engine is the most powerful. Strictly speaking, the rocket engine generates more power physically, but the jet engine is more significant in terms of its influence on our daily lives.¹¹

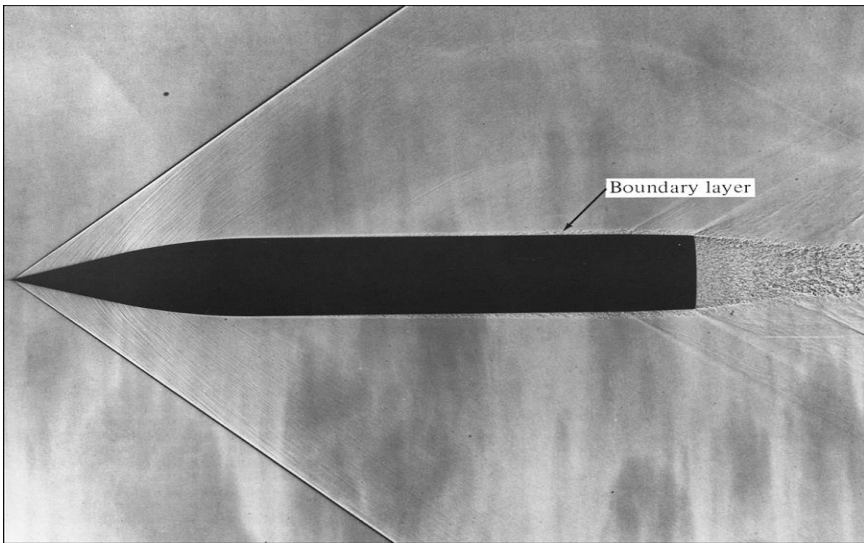


Figure 2. Boundary layer separation taking place at the surface of the aircraft. The two diagonal lines in the front are shock waves that arise when the aircraft breaks the sound barrier.

¹⁰ Whether engines themselves lead us to accidents or whether humans cause accidents is open to dispute. However, an accident involving a cow-pulled trolley with no engine and travelling at 20km/h and that of a vehicle with an engine and travelling at 100km/h are two immensely different accidents. In addition, there is also a difference in the relationship humans develop with objects. Ultimately, accidents are bigger and more dangerous because humans are in possession of engines. To borrow Bruno Latour's words, it is the “network between human and engine” that causes the accident. For more on this matter, see Latour, “On Actor-Network Theory” (cit. n. 2).

¹¹ The rocket installed on Saturn V used to send Apollo 11 to the moon had 1 million horsepower. Sonata, a widely popular vehicle, on the other hand, has 165 horsepower, and the four JT9D engines mounted on a Boeing 747 equate to 100,000 horsepower.

It would not be an exaggeration to say that the jet engine has changed how humans think about and perceive the Earth itself. Compression, expansion, and acceleration of air takes places in all aircraft, but it is in the jet engine that these phenomena are most dramatic. The invention of the jet engine came up with a completely novel way of compressing, exploding, and reigniting air to surpass the speed of sound. In order to understand how the jet engine transformed how we sense the globe, we need to understand what air travel looked like before the commercialization of jet engines.

Prior to the jet engine, the Lockheed Constellation ruled the skies. Loaded with four light R3350 piston engines each with 3,500 horsepower, it was the slimmest propeller plane and had a record of flying from London to Los Angeles in 18 hours 32 minutes in 1957. This record, however, was broken the following year by the first commercial jet liner, Boeing 707. Starting with the Boeing 707 that beat the most powerful piston engine by flying at 1000km/h, the jet liner remains the widely accepted standard for air travel. The advent of the jet engine had made the globe small enough to travel.

Of the many types of jet engines, this paper examines the turbo fan engine, which has a large bypass rate.¹² The turbo fan engine is an important subject of study because in the history of all jet engines, it is the most common and widespread, hence has transported the greatest number of passengers. In other words, the most common form of air travel today is the aircraft mounted with turbo fan engines. This is also because the turbo fan has greatly contributed to creating a sense of global space. It is used commonly in carriers like Boeing 747 and Airbus 380 that we are familiar with, because it is the most economical, makes relatively less noise, and is easier to maintain. Turbo fans are also used in military aircraft, but fighter jet engines like the GE F404 or PW F100 have a low bypass ratio, and their designs prioritize extreme functions, such as supersonic flight or high mobility combat flying, over cost-effectiveness, hence they will not be addressed in this paper. In the lineage of jet engines—which traces back to the centrifugal turbine (1930s), followed by the axial flow turbine (1940s), the turbo jet (1950s), the turbo fan (1960s-present and near future), the ramjet (undergoing tests), and finally the scramjet (in development)—the history of the turbo fan engine lies somewhere in the middle. It is also known as the most economic engine in the subsonic 1,000km/h range.¹³ Cruising speed of 1,000km/h has been set as the paradigm of air travel using jet engines to date since Boeing successfully commercialized its 707 aircraft as a passenger plane in 1956. The early retirement of the Concorde in 2003 despite its ability to travel at 2.2 times

¹² Other jet engines in this category include the historically famous JT8D, JT9D, and 4000 Series of Pratt & Whitney, GE90 and CF6 of General Electric. More recent models include the GP7000 that competitors PW and GE built together for the Airbus 380.

¹³ Subsonic range refers to speeds below the speed of sound, which travels at 1,224km/h.

the speed of sound is evidence that air travel at a cruising speed higher than 1,000km/h is not economical.¹⁴

The Jet Engine as a Micrometeorological Phenomenon

Historically speaking, the development of engines and new engines types means more than simply improvements in the functions and speed of aircraft. The improvements and transformations in engines have served as the impetus for paradigm shifts in aircraft design, for older designs are unable to withstand the speed of newer engines. It is also important to acknowledge that the most influential factors in the dramatic paradigm shift in aircraft design have been the two World Wars.

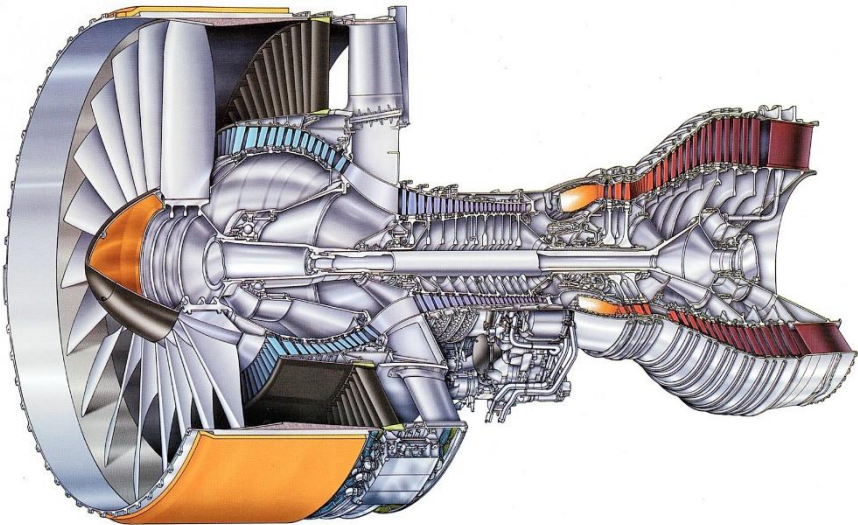


Figure 3. An archetype of an engine with a high by-pass ration, the Pratt and Whitney PW4000

¹⁴ In addition to the problem of cost, supersonic air travel is also accompanied by the problem of shock waves. The Concorde constantly produced shock waves while it travelled beyond the speed of sound, making it impossible to travel above inhabited grounds. For this reason, the Concorde's flights were limited to trans-Atlantic routes, such as Paris-New York, London-New York, and London-Washington, DC. For more, see R. E. G. Davis, *Supersonic (Airliner) Non-sense: A Case Study in Applied Market Research* (MacLean, VA: Paladwr Press, 1998).

The basic idea of the jet engine emerged quite early on in the history of aircraft, and can be traced back to when René Lorin thought of the pulse jet in 1913. Given that man's first flight was in 1903 by the Wright brothers, Lorin was ahead of his time with his ideas. His pulse engine had very few internal components, and employed an extremely simple design comprised of a vibrating plate (pulse), which opened and closed to let air in, and nozzles, which would spray fuel onto the incoming air. There are almost no moving parts in this engine making it highly efficient, but required a high starting speed in order to start the engine. This exceptionally simple structure, however, was experimental at best (and is yet to be commercialized to this day). The standard aircraft in 1913 were biplanes, made by covering cloth on wooden frames, and they could not reach a speed high enough to start a pulse jet. In the hypothetical event that it could, the structure would not have withstood the wind pressure and would have disintegrated in the sky. Lorin's ideas thus could not come to fruition. Aviation engineers, however, were well aware of the limitations of propellers even before the First World War broke out. Rotating the propellers in order to increase the speed of the aircraft caused the ends of the propellers to break the speed of sound, resulting in a steep drop in efficiency. Therefore, jet engines were futile unless the aircraft itself could be made entirely out of metal. Efforts to develop jet engines in earnest took place in England and Germany, albeit separately. In 1903, Frank Whittle in England, and in 1937, Hans von Ohain in Germany presented two slightly different types of jet engines. Ohain's jet engine was mounted on a Heinkel He178, making it the first aircraft to be fitted with a jet engine. This aircraft had a metallic body that allowed it to withstand the high speed (although its wings were made of wood). In order to invent and commercialize jet engines, they had to be accommodated by an appropriate design.

Ultimately, the matter of a jet engine's speed rested not only on the engine itself but the overall design and choice of material for different parts of the aircraft. These were all problems that arose because the body of the aircraft had to endure the new speed of air produced by the jet engine. Applying the concept of micrometeorology here, the structure of the aircraft can be seen as having accommodated a new form of air speed (speed of sound, or transonic or subsonic) that the jet engine incurred.

The matter of micrometeorology, however, is also a matter of scale. In terms of scale, a jet engine's scale is comparable to a molecule's mean free path of 10^{-7} to those of minuscule turbulent eddies of 10^{-2} - 10^{-1} to eddies of 10^{-1} -1. In this case, the application of micrometeorology to jet engines is sufficiently justified. Another rationale for applying micrometeorology to jet engines can be found in the following phrase: "atmospheric movements are governed by basic laws of physics, such as mass, momentum, and conservation of energy."¹⁵ These three laws also apply to the jet engine without question. Therefore, micrometeorological phenomena and what happens inside a jet engine are similar in nature.

¹⁵ Ibid.

The Flow of Air within the Jet Engine

The changes in the flow of air within a jet engine can be regarded as a micrometeorological phenomenon. Air undergoes various changes in speed, pressure, and temperature as it flows along the complex and detailed inner structure of the jet engine. As explained above with regards to the aircraft itself, jet engines too are an aerodynamic phenomenon, for unlike the piston engine which gains its rotatory power from detonating the air-fuel mixture, the jet engine gains its thrust by sending backwards a flow of air mass. Although it is an engine that propels by burning kerosene-like fuel onto metallic parts, this backward transportation of air is at the heart of its mechanism. Therefore, it is plausible to consider the inner workings of the engine as micrometeorological phenomenon. However, rather than referring to mathematical equations, this paper will limit its scope to proposing a way to describe how a jet engine operates by drawing on the concepts of micrometeorology.

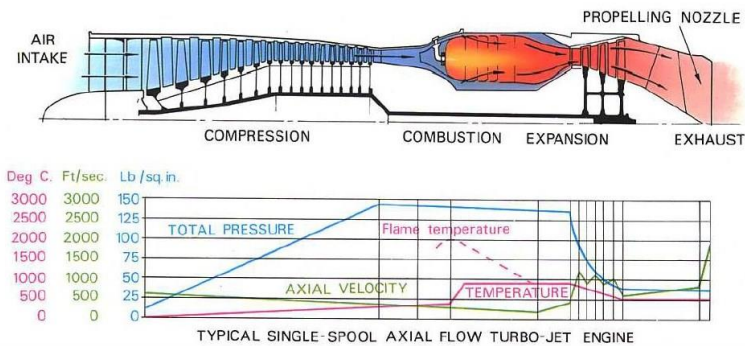


Figure 4. Diagram demonstrating the flow of air within a jet engine and the changes in temperature, speed, and pressure it undergoes. Blue represents air at low temperature, whereas red represents air at high temperature.

Air on the outside is sucked into the engine through an air inlet. This air passes through the low- and intermediate-pressure compressors, and reaches its highest pressure after passing through the high-pressure compressor. It then mixes with fuel in the combustion chamber and explodes, producing high-temperature and high-pressure air, which turns the exhaust turbine and escapes through the nozzle. The figure below depicts the changes in pressure, temperature, and speed that air undergoes in this process.

When an aircraft is still, drag is at 0. In other words, there is no resistance pulling it backwards. When the aircraft begins to move, the speed of the air being pulled into the engine increases. The faster the aircraft travels, more air enters the engine's air inlet, and the pressure created is called "ram pressure." As ram pressure increases, so does the mass of the air entering the engine, ultimately increasing the thrust of the engine.¹⁶

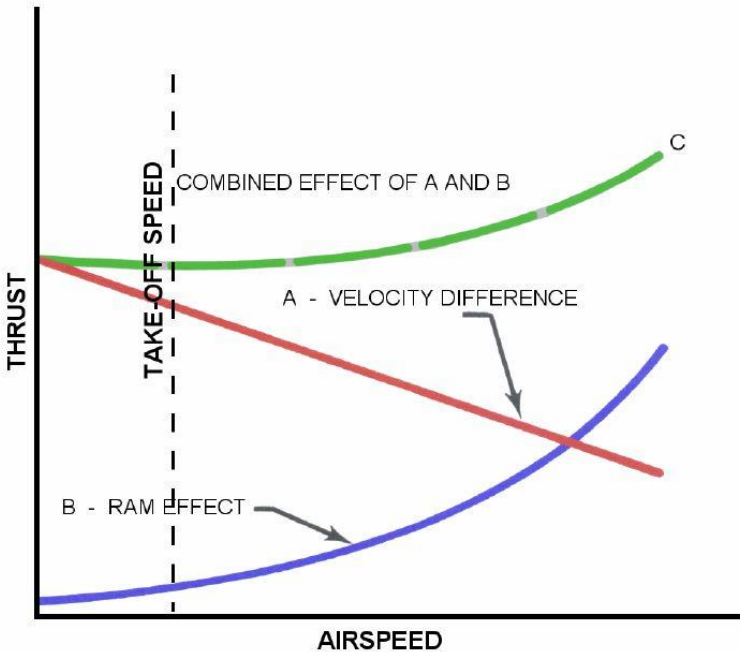


Figure 5. Graph showing the relationship between the thrust and speed of a jet engine

The speed of the air gradually increases as it passes through the compressor fans, rapidly increases when it explodes in the combustion chamber (temperature reaching up to 1,300°C), and intensifies as it turns the turbines and escapes through the exhaust nozzle. At this point the engine's thrust is directly related to the density of air; engine thrust refers to the kinetic energy of the air mass, hence it is the density of the air mass that decides the thrust of the engine. Therefore, if air density decreases due to high temperature or low air pressure, so does the thrust of the engine. An engine with a thrust of 10,000 pounds can create a thrust of 8,000 pounds on a hot

¹⁶ Mustafa Cavcar, "Jet Engine." see, <http://coursehero.com/file/26674526/cavcarpdf> (accessed on 20 August 2019).

day, but 12,000 pounds on a cold day. In addition, high altitude results in low air density and pressure, in turn reducing the engine thrust. At an altitude above 11,000 meters, the temperature no longer decreases, but air pressure continues to decline. This is why most commercial aircraft travel at a fixed altitude of 10,000m.¹⁷ On the other hand, in locations of high altitude and high temperature, like Denver, Colorado, generating enough thrust for an aircraft to take off is a matter of serious concern.

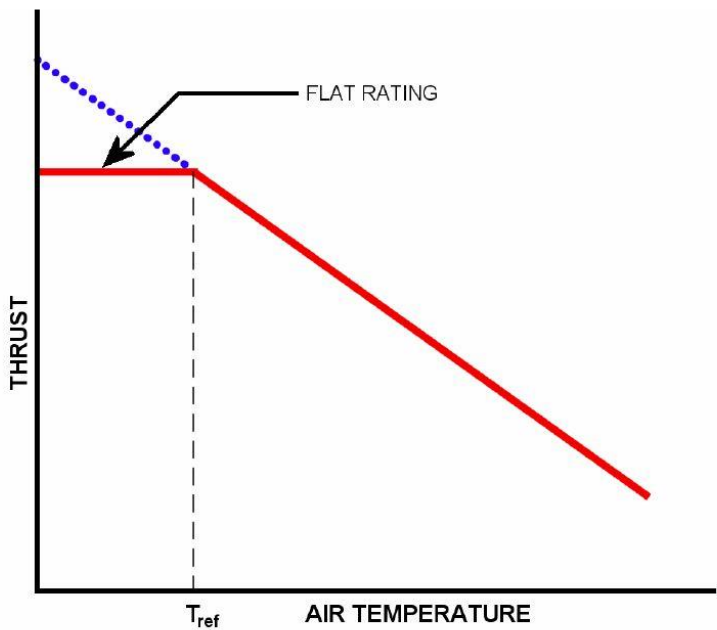


Figure 6. Graph showing the relationship between external temperature and thrust of a jet engine

A description of the micrometeorological environment within a jet engine needs to address the unique condition of acceleration it causes. The jet engine is the first air breathing engine to be invented, and the speed of the air it sucks in (A_v) affects the speed of the aircraft (V_v), and the speed of the aircraft in turn affects the amount and speed of the air flowing into the engine. The jet engine thus possesses a unique

¹⁷ Ahmed F. El-Sayed, *Aircraft Propulsion and Gas Turbine Engines* (Boca Raton: CRC Press, 2017).

structure whereby it creates a self-reinforcing cycle in which the aircraft continues to gain speed and the engine's output and fuel efficiency increases. This is a very unique course of acceleration, distinct from other types of engines, and the very form of acceleration that was critical in shaping our perception of the world as a global village.

To examine the individual parts of a jet engine where micrometeorological phenomena can take place:

- The air inlet—A large amount of air must be allowed to enter in a smooth stream. The amount of air that the inlet takes in determines the performance of the jet engine, hence is a critical factor. The structure of the inlet must be designed and built with care as excessively high flow of air past the inlet to the point that it breaks the speed of sound can ruin the intricate components within the engine.
- Low-, intermediate-, and high-pressure turbines: Air is compressed and gains speed as it passes through the compression turbines made up of numerous rotating fans.
- Combustion engine: Kerosene-like fuel is sprayed onto the high-pressure air escaping from the compression turbines, leading to an explosion that produces high-pressure and high-speed gas. This is a critical component in the jet engine gaining thrust.
- Exhaust turbine: The air escaping the combustion engine turns the exhaust turbine. Because the axis of the exhaust turbine is connected to the compression fans at the front of the engine, rotation of the exhaust turbine results in that of the compression turbines.
- Exhaust nozzle: The speed and temperature of the exhaust gas greatly contribute to the noise made by the engine. Due to strict environmental regulations, aircraft that cannot meet noise pollution standards cannot be operated. The design of the exhaust nozzle, therefore, is critical in ensuring both output power and reduction of noise. Rather than plain nozzles, chevron-patterned nozzles are currently preferred.

The most important phase in the flow of air through the engine is the when it creates thrust. What is just as important, however, is controlling and maintaining a steady performance. In order for any engine to maintain performance, it must also maintain an even temperature. An engine is constantly overheated as a result of the continuous combustion of fuel and air. Therefore, without adequate cooling, the performance of the engine drops, and the metal components undergo thermal transformation making them less durable. Whereas motor vehicles on the road usually use piston engines that use water coolants, jet engines are usually air-cooled. Being able to properly pass air through the different parts of a jet engine to cool them down is therefore just as important as gaining thrust.

The turbine blades are constantly exposed to high-speed air at over 3,000°C, flying out of the combustion chamber, and are thus prone to damage. Fan blades are therefore cooled down by making a small ventilation hole on the inside of the blades. All machines, from a motor vehicle to an electric component, become less efficient, undergo structural change, and become less durable when they reach a certain temperature, so cooling is an integral part of their operation. The flow of air is ultimately what maintain the durability and functionality of fan blades.

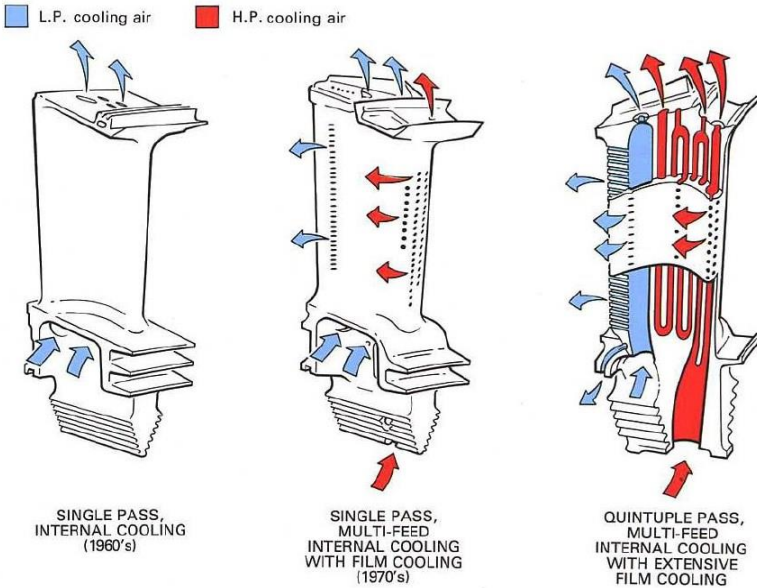


Figure 7. Air flowing through fan blades of a jet turbine for cooling

Fan blades, however, are not the only parts that require cooling. The components like the turbo shaft, gear box, and bearing all require cooling. Otherwise, they undergo thermal expansion, resulting in decreased accuracy and durability. When turbine blades experience thermal expansion, the space between them and the casing become narrow, causing surface abrasion. To avoid this from causing trouble, the turbine blades have a fixed life expectancy. The key consideration in cooling is to ensure that the components do not overheat to the point that they cause safety issues. Maintaining a constant air flow is important in cooling. About one-fifth of the air

that enters the inlet is used for this purpose. This implies that the flow of air inside a jet engine is far from simple, and is micrometeorologically complex.¹⁸

With continuous cooling, the components are able to withstand the heat even if the interior temperature of the engine rises above melting point. Proper cooling of the turbine discs when heat is transferred from the turbine blades prevents thermal deformation and overexpansion of the discs. The method used for cooling, not just its form, also influences the lifespan of the turbine blades. It is the flow of air within the turbine blades that matters. Prior to the 1960s, a single hole was bored into the blades to pass cold air through, known as the single pass internal convection method. Since the 1990s, several holes have been introduced, called the multi-pass internal cooling method. This increases cooling efficiency and enables cold air to be distributed evenly throughout the entire blade. The speed of the air that passes through the turbine and heading for the exhaust nozzle is between 220m/s to 370m/s. Air traveling at supersonic speed causes damage due to friction, hence air speed is regulated by building wider exhaust nozzles. Exhaust gases are maintained at a speed 0.8 times that of sound.

Conclusion: The Air Breathing Engine, the Interface between the Environment and Humans

“Air breathing engine” originally refers to both piston engines and jet engines. These two types require air to function, whereas rocket engines do not. The jet engine, moreover, is a distinct form of engine, both structurally and historically, in that it creates a self-reinforcing cycle of acceleration using the air it sucks in. How we as humans view the world—not just the abstract concept of the world, but tangible questions like, how big is the world, how far is New York from Seoul, what is needed to carry out a business transaction across the two cities, can we travel quickly and safely on a honeymoon trip to Prague?—are all matters closely connected to the jet engine. The jet engine is thus an interface that mediates multiple variables. The term “interface” originates from the field of computer science and is a software-centered terminology, but this paper aimed to draw on the concepts of micrometeorology for a material-centered examination. In other words, it investigated how the jet engine as an interface reacts under different atmospheric conditions and mediates humans and the environment.¹⁹

¹⁸ Rolls-Royce Public Limited Company, *The Jet Engine* (Chichester, West Sussex: Wiley, 2015), 85.

¹⁹ In *Gammophone, Film, Typewriter—Writing Science*, Friedrich Kittler, a prominent media studies scholar in the twenty first century, uses the term “mediality” to explain not how a medium is connected to certain thoughts or intentions, but to examine when and how the material characteristics comprising the medium become manifest. This concept can be applied to the jet engine.

To conclude, due to limitations in delving into the technical details of micrometeorology, here are some different scenarios on what can happen when an engine sucks in air, using real-world examples:

1. When a Cessna aircraft becomes airborne, oxygen level drops hence the fuel to air ratio needs to be increased.
2. A ship engine cools down by pumping up cold sea water, but it faces difficulty near the equator where the sea temperature rises.
3. In 2004, when the cargo ship MV Selendang Ayu was stranded in Alaska, an U.S. Coast Guard helicopter approached the ship in an attempt to save the crew members. The helicopter, however, crashed after waves carried water into the air inlet, killing its crew.
4. Helicopters have difficulty maintaining output power when the air is too cold.
5. Air density is closely related to the engine's thrust, so when air density is too low, the water injection method can be used to increase air density and thrust.

If meteorology ultimately refers to the study of the flow of air and the atmosphere, the various aerodynamic phenomena that arise around the aircraft and jet engine can be regarded as micrometeorological phenomena. Convergence of knowledge in the fields of aeronautics and meteorology can open up new horizons for both fields.

Appendix: Further Studies

- Is there a concept in meteorology analogous to engine thrust? Or, what forces or power cause movements that are produced as a result of action and reaction? (For instance, the power that causes typhoons?)
- Can the definition of meteorology be reduced to the study or knowledge on the state of fluids (temperature, density, velocity, direction)?
- In what ways are the atmosphere as environment different or similar to the jet engine, which is an enclosed environment? Is the jet engine a down-sized version of the atmosphere, or a completely new creation? (We could consider the jet engine as a completely new phenomenon in that air cannot flow faster than sound in the natural atmosphere. However, air should not travel faster than sound within the jet engine, making it closer to nature.)

Abstract

This paper is an attempt at examining the structure of the jet engine from a micro-meteorological perspective, in order to further develop the emerging methodology of “machine critique.” As an outsider of science and engineering, a social scientist can probe into the deeper layers of complex machines, which will lead to fresh perspectives. This paper will merge the two seemingly unrelated subjects, micrometeorology and jet engines, which will provide new insights for scientists and engineers to further their horizons. Ultimately, this paper interprets the jet aircraft as a micro-meteorological phenomenon. This will allow us to perceive the air-breathing engine as the interface between humans and their surrounding environment.

Keywords: micrometeorology, jet engine, machine critique, machine taxonomy, aircraft