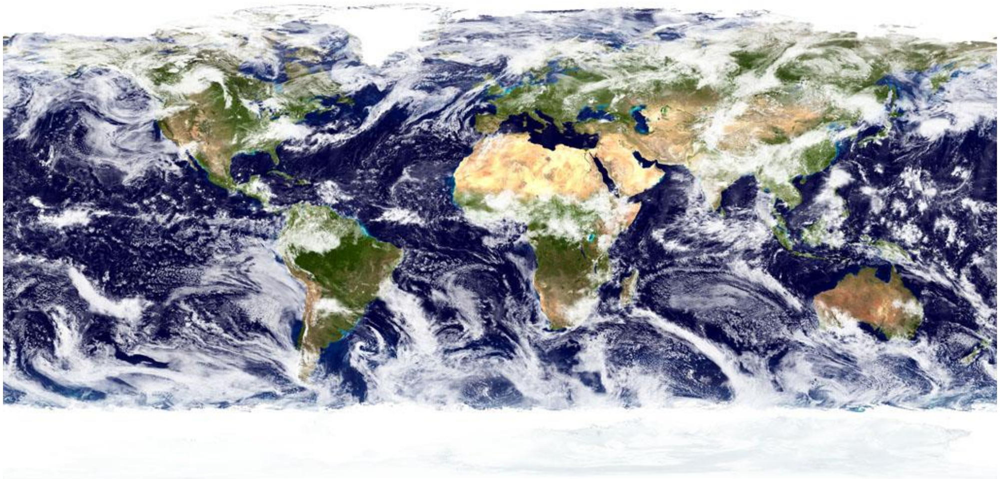

Global Change

as Demonstrated by Aviation
Climate, Resources, Globalization, and Demographics

Teaching Materials

for Upper-level Classes at the Bavarian *Gymnasium*

Geography

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"Teacher in Business" 2012–13

Translation by MTU Aero Engines
Munich 2013

The Purpose of These Teaching Materials

Global Change: Globalization, Climate Change, Resources, Demographics …

Upper-level geography classes at Bavaria's *Gymnasium* address the megatrends of both the present and the future. Such trends are changing the world we live in – and creating new challenges for companies. These teaching materials, taking MTU Aero Engines as an example, show how Germany's high-tech mechanical engineering industry is helping to shape the future. Geography, as a "centering subject" combining business, social, and ecological aspects, provides an overall perspective.

Material ready for use

The teaching materials are intended to complement and concretize the information found in standard geography textbooks. They are presented so as to be immediately useful. Moreover, they are compatible with the current teaching curriculum at Bavarian *Gymnasium*, and they incorporate the competence orientation soon to be required by the curriculum initiative "LehrplanPlus." Relevant command words in the review questions at the end of each section account for all three required areas (description, justification, assessment). The course booklet is accompanied by a solutions booklet for teachers.

A person wishing to get to know MTU Aero Engines and its contexts in brief may choose to read these materials as a brochure. Courses may work through them by curriculum topic, downloading individual chapters (see Table of Contents) and combining them into an integrated lesson plan. The materials may also be used to prepare for the *Abitur*, or as the basis for a presentation, project, or exam.

Hands-on Industry

Industry, commerce, and technology should not be treated in geography classes solely at the meta-level. In these teaching materials, MTU Aero Engines' industrial processes and products are carefully illustrated by means of concrete examples, so that their geographical implications may be properly understood. Some basic, easily understandable information about the functioning of an aero engine, for instance, opens a door to a world of interesting and geographically significant issues. At the same time, bridges appear to interdisciplinary projects, especially projects combining geography with the sciences (chemistry and physics) or with mathematics.

University Orientation

To give students some orientation with regard to their higher education and career choices, these materials quote from interviews with professionals whose work requires the same knowledge and skills that are imparted in the geography classroom. At MTU Aero Engines, such professionals include engineers of various fields, market strategists, purchasing agents, chemists, and human resource specialists. The teaching materials are therefore also an opportunity to get to know some of the many paths leading to employment in the industry. Students and teachers are invited to inform themselves about careers at MTU, and to contact the company's HR development team over social media. School classes may even be able to tour the MTU factory grounds or invite an MTU employee to visit their school.

Good Prospects for Aviation

Aviation has the world on the move: As of 2013, there are around 37,000 aircraft in service, from business jets to wide-body planes. Airlines currently host 2.5 billion passengers per year, and the trend is rising. Four million people are traveling in airplanes at any given moment.

Enjoy discovering the fascinating world of the aviation industry as an example to help your Geography classes to comprehend global change!

Contents – Booklet by Chapters

Contents – Chapters by Curriculum Relevance

1 Global Player from Germany – The Example of MTU Aero Engines

Through the 20th century and the beginning of the 21st, MTU Aero Engines has risen to become Germany's leading aircraft engine manufacturer, witnessing many developments along the way. BMW Flugmotoren GmbH was founded in 1934 in Ludwigsfeld, to the northwest of Munich. The Motoren- und Turbinen-Union (MTU) is that company's direct legal successor. It was formed in 1969 through a conglomeration of the former aircraft engine divisions of BMW, MAN, and Daimler-Benz. MTU's business was still 80 % military into the mid-1990s. With the spread of globalization, however, the company shifted its focus towards developing, producing, and maintaining engines for commercial aircraft. Now, as of 2013, this area accounts for 84 % of the company's turnover (F1).

MTU's target is growth with a stable EBIT margin (Earnings Before Interest and Taxes). The company also wants to reach the turnover mark of six billion euros by the year 2020. In pursuing these goals, MTU takes advantage of its independent position within the global aero engine industry (F2).

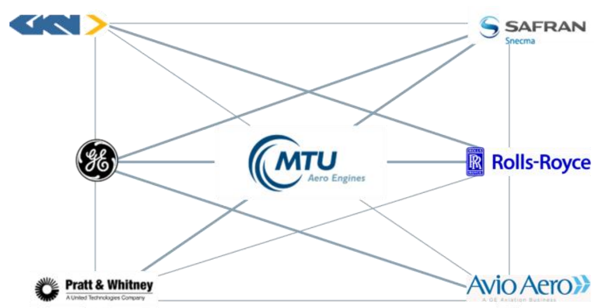
OEM Business

OEM stands for "Original Equipment Manufacturer." In the aero engines industry, this term refers to manufacturers who market their products under their own names. The biggest OEMs are Pratt&Whitney, General Electric, and Rolls Royce. Every company in the aero engine industry specializes in certain core competencies, using them to contribute to the joint "programs" in which new aero engine families are developed. The result is a series of shifting alliances. For instance, MTU is Pratt&Whitney's partner in the PW-1000G program, to which it contributes leading technology in low-pressure turbines, high-pressure compressors, and high-tech production processes. This program has led to the development of the most environmentally friendly aero engine currently on the market. MTU is likewise involved in programs with the other OEMs.

The aero engine industry's direct customers are aircraft manufacturers. An aero engine's scheduled price is, on average, around 10 million U.S. dollars. An aircraft manufacturer will generally offer at least two types of engine for each of its airliner models. Thus an airline purchasing a new Airbus A320neo can choose between the PW1000G and a competing product. The aircraft manufacturers Bombardier, Embraer, and UAC have also chosen to offer their jets with engines from the PW1000G family. Ultimately, an aero engine manufacturer must serve the interests of the airlines; it does so by offering the most reliable, economical, and silent product it can. After all, the two engines of an aircraft of the above type account for about one third of its total price.

2012 Fiscal Year	Turnover	Adjusted EBIT
OEM business: engines, commercial and military	2,106	265
MRO business: commercial maintenance	1,306	112

F1: Key financial figures in millions of euros (source: MTU Aero Engines)



F2: Structure of the international aero engine industry (source: MTU Aero Engines)

MRO Business

MRO stands for "Maintenance, Repair, and Overhaul." It's an abbreviation used to refer to the aero engine maintenance business. Developing a modern, large-model aero engine takes an average of five years and costs around 1 billion U.S. dollars. The manufacturer breaks even only after about 15 years of sales. In order to capitalize on its technological competence sooner, and throughout the lifecycle of aero engines, MTU has positioned itself as the world's largest independent provider of MRO services. The major inspection of a V2500 engine – the standard propulsion system of the A320 aircraft family since the 1990s – takes about two months, and an aero engine's scheduled price is approximately 1.5 million U.S. dollars.

The MRO business also includes maintenance of industrial gas turbines (IGTs), which are derived from aircraft engines. These turbines are used to generate electricity in power plants, for instance, or as propulsion systems in hovercraft. By far the most important market for IGTs, however, is oil and gas platforms, where they act as a power supply.

- Participates in the global competition
- Enjoys a leading position in its industry (technological, qualitative, innovative leader)
- Exerts influence on politics and market mechanisms
- Has subsidiaries around the world
- Has financial power like that of a small country

F3: Characteristics of a "global player"

F4: MTU Aero Engines and MTU Maintenance locations, including joint ventures, representative offices, IGT service centers, and consortium memberships (source: MTU Aero Engines)

Review

R1: Does MTU Aero Engines qualify as a "global player"? Consult Figure 3 and your textbook. Assess.

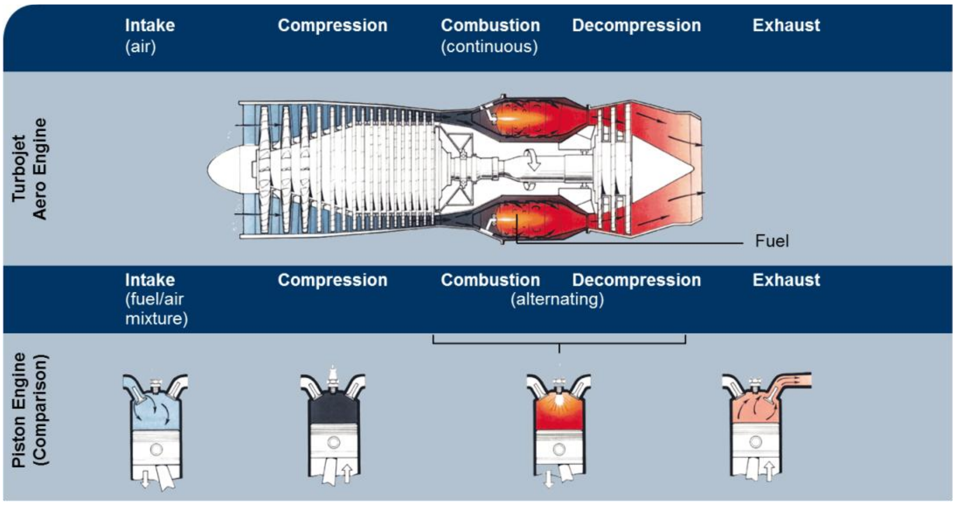
R2: How globalized is the commercial aero engine business? Research where the aero engine and aircraft manufacturers named in this chapter have their headquarters. Also research the headquarters of Boeing, MRJ, and Cessna. Explain your answer.

R3: Aero engines are transported to MRO locations over long distances – from an airline's base on the Persian Gulf, for instance, to MTU Maintenance in Hanover. The transport alone can cost more than 10,000 U.S. dollars. Does transporting engines over such long distances make sense? Assess this practice from an economic and from an ecological perspective.

R4: Why are MTU's IGT service centers (F4) located where they are? Consult relevant atlas maps. Thoroughly justify your answer.

2 Atmosphere and Aviation

2.1 Workings of an Aero Engine

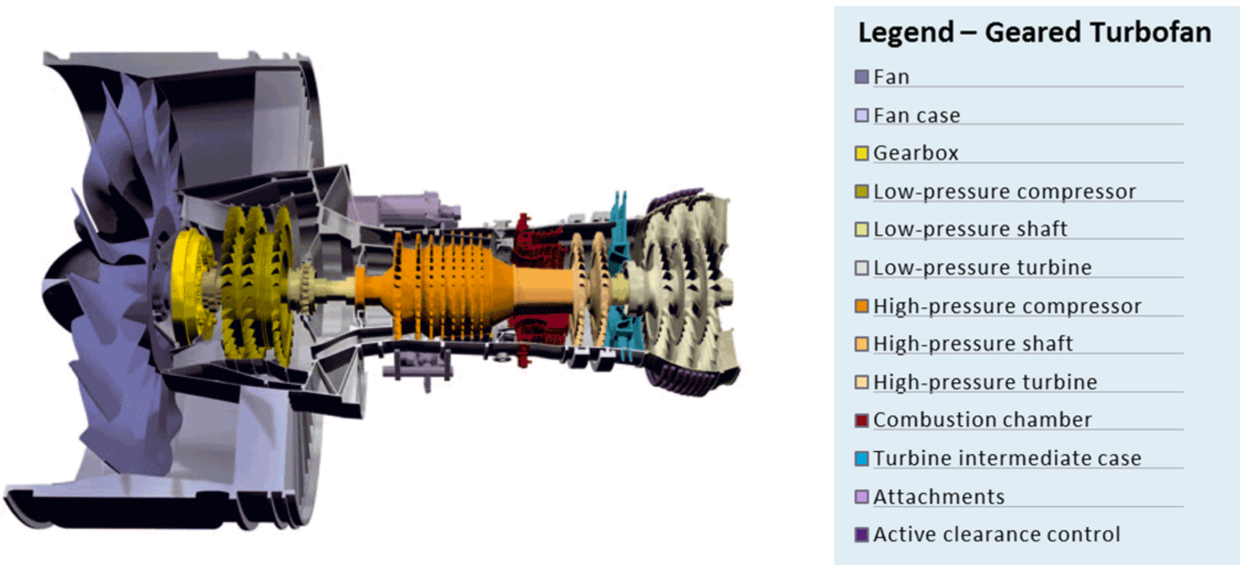


F1: How a turbojet engine works: a cross-section (source: MTU Aero Engines)

A turbojet engine functions by a simple principle (F1).

The low- and high-pressure compressors draw in air and compress it. In the process the air heats up. It is then fed into the combustion chamber, where jet fuel (kerosene) is injected. The result is an air/fuel mixture that is burning continuously, and the gas expands dramatically as its temperature rises. The gas now shoots through the high- and low-pressure turbines, causing them to rotate as it flows over the turbine blades. This provides the energy to drive the various compressor stages, which are connected to the turbine by a shaft. Single-flow turbojet engines of this kind were used widely until the 1960s.

In a modern turbofan engine (F2), the components of a turbojet make up the engine core, while an additional fan with large blades is installed in front of the compressor stages. This fan is driven by the low-pressure compressor via a shaft. Acting like a propeller, the fan accelerates the air coming in from the front. Only about 1/10 of that air reaches the engine core; the other 9/10 make up the bypass flow, which produces most of the thrust. A bypass engine – that is, a turbofan – achieves a much higher degree of efficiency than an engine with only one flow. Figure 2 shows the PW1000G, built by a consortium that includes MTU. This engine represents an advancement on the turbofan, namely the geared turbofan. The addition of an epicyclic gearbox allows the fan to rotate more slowly than the low-pressure turbine, resulting in greater fuel efficiency and reduced engine noise.



F2: Cross-section of a turbofan engine (PW1000G) with an integrated reduction gearbox
(source: Pratt&Whitney/MTU Aero Engines)

www.mtu.de/en/take-off/how_engines_work/index.html

2.2 The Influence of Temperature and Atmospheric Pressure

An aircraft in flight is kept in balance by four forces (F3). The engine provides the thrust, and is also involved in generating the lift. That's because lift has a positive correlation not only with air density and wing surface area, but also with the velocity of the oncoming airflow. Without aero engines, a modern airliner would overcome neither the force of drag (air resistance) nor the force of gravity.

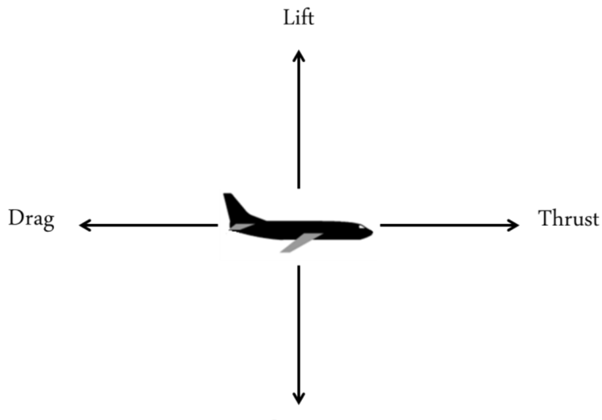
An airliner spends most of any given flight at its cruising altitude, between 9,000 and 11,000 metres. The majority of its fuel will be consumed at this height and under these atmospheric conditions (F6). Development engineers therefore design aero engines to attain their maximum efficiency at cruising altitude, making them as economical as possible. Yet the aircraft also has to be able to generate maximum power during takeoff and the subsequent climb, and during landing the engines are responsible for sharply reducing the aircraft's thrust. Thus every aero engine has three important design points corresponding to the three flight phases of takeoff, cruise, and landing.

After the climb out, the airliner begins the cruise phase, but even during this phase the aircraft continues to gain altitude. At the beginning of the jet age, the cruise phase was arranged as one continuous cruise climb (F4). Today, most flight routes only allow for a step climb. This means that the aircraft, after first attaining a relatively low flight level (e.g., 9,000 m altitude = FL 300, or a flight level of 30,000 feet), proceeds to climb to higher flight levels by a series of steps.

Aero engine performance has a positive correlation with air pressure but a negative correlation with temperature and inlet velocity at the air intake (F8). Atmospheric conditions are most apt for cruise flight in the range of the tropopause, an altitude of about 11,000 m. Here, above the clouds, the air is extremely dry, which accounts for the excellent visibility passengers enjoy at such altitudes (F7).

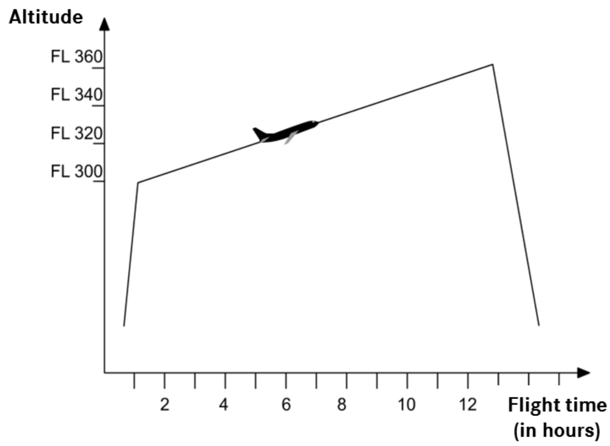
- Maximum takeoff weight: 78 t
- Maximum fuel capacity: 24 t (30,190 l)
- Maximum flight range: 6,150 km
- Service ceiling: 12,130 m
- Cruising speed: 840 km/h
- Maximum number of passengers: 150–180
- Fuel consumption at cruising altitude: 2,700 l/h

F6: Basic data for an Airbus A320 (source: Wikipedia)

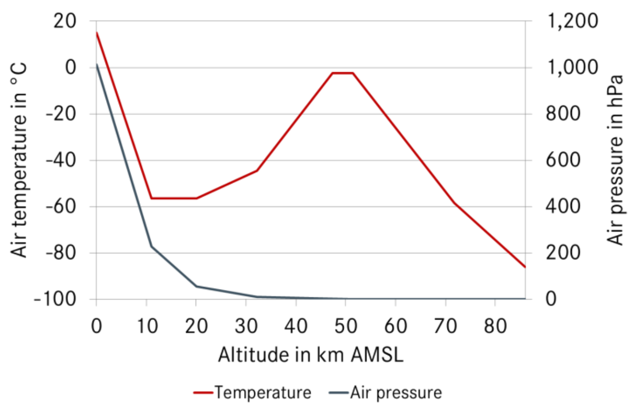


$$\overrightarrow{F_G} = m * \vec{g}$$

F3: An aircraft at the equilibrium of forces



F4: Cruise climb (source: Wikimedia)



F5: Air temperature and atmospheric pressure in the troposphere and stratosphere

Interview with Dr.-Ing. Thomas Uihlein
(Technology Transfer Manager)

The polar-front jet stream, which flows through the tropopause at cruising altitude, speeds up flights from North America to Europe. How does the jet stream affect an airplane's engines?

It gives the airplane tailwind and allows it to reach cruising speed with less fuel. The functioning of the aero engine itself is not affected.

But in 2010 there was another earth science phenomenon along the North Atlantic route which did have a big effect on turbojet engines: the eruption of the Eyjafjallajökull volcano in Iceland. Volcanic ash can cause damage to compressor and turbine blades. Sand and dust also take a toll on aero engines. We research these factors at MTU and develop coating processes to protect our blades.

Dr. Uihlein, you wrote your doctoral thesis on corrosion and surface engineering in aero engines. You've registered more than 100 patents. As an honorary professor you teach aero engine technology at the Brandenburg University of Technology Cottbus-Senftenberg. Why did you decide to get involved with academic teaching?

I have fun working with tomorrow's engineers. Theory and practice should always be in contact, especially because the research and development of aero engines is always pushing the limits of our technical capabilities. That's why a large number of MTU employees are active in teaching. Even the head of our engine research and development division holds lectures at the Institute of Flight Propulsion at the Technische Universität München.

With whom does MTU Aero Engines collaborate on research?

The list is long. Within our region alone, we work with the Technische Universität München, the Universität der Bundeswehr München, the German Aerospace Center, and Bauhaus Luftfahrt. Elsewhere we cooperate with the University of Stuttgart, the RWTH Aachen University, the Leibniz Universität Hannover, and various Fraunhofer Institutes. If you're a young engineer and you decide to come work for MTU, there are quite a few paths open to you.

Thrust is the product of the mass current and the change in airstream velocity, that is, the difference in velocity between the outgoing and the incoming airstreams:

$$\text{Thrust [N]} = \text{change in momentum} = \text{mass current [kg/s]} \times \text{change in velocity [m/s]}$$

The velocity of the incoming air is at its lowest and the acceleration of the air at its highest when the aircraft first begins moving from a standstill.
The mass of the airflow is dependent on its volume and has a positive correlation to air density. Air density in turn depends on temperature and pressure: the lower the air temperature and higher the pressure, the greater the air density. All these factors go into the following equation:

$$\text{Thrust [N]} = \text{volume velocity [l/s]} \times \text{density [kg/l]} \times (\text{velocity}_{\text{outlet}} \text{ [m/s]} - \text{velocity}_{\text{inlet}} \text{ [m/s]})$$

With a turbofan engine there are two different masses that can be accelerated. The hot-air stream passes through the core engine, while the cold-air stream is merely accelerated by the fan. To determine the total thrust, one adds together the individual thrusts of these two airstreams.

F7: Basic physics of aero engine thrust

F8: High visibility over the Antarctic (source: Wikimedia)

The influence of humidity and water, whether in the form of drops or ice crystals, is negligible under normal conditions. Temperatures of over 400 °C prevail inside the compressor, while in the combustion chamber temperatures range from 1,300 °C to over 2,000 °C. Any water in the air evaporates immediately. Crossing weather fronts likewise has no major effect on the thrust of an aero engine, as the difference in atmospheric pressure is generally less than 100 hPa. The airplane's sensors do measure these parameters so that the control system can continually optimize the fuel feed, but in terms of engine performance, passing from the takeoff to the cruising phase is a much more significant change than passing from one atmospheric pressure formation to another.

Even at cruising altitude, there is enough oxygen available for the engine to burn fuel. The low partial pressure of oxygen at high altitudes can cause a person to experience altitude sickness, for instance when mountain climbing above 4,000 m. An aero engine, however, is designed for high-altitude conditions. The quantity of oxygen present in the air is perfectly sufficient, since the relative concentrations of the air's major components remain the same within the homosphere, which extends to an altitude of 80 km and in some places as high as 120 km. This means that an aero engine at cruising altitude has plenty of oxygen to continue burning fuel. After all, the proportion of oxygen in the air at high altitudes is about 21 % – the same as at sea level.

Review

R1: Why does an airplane continue to gain altitude throughout a long commercial flight? Justify your answer.

R2: Why is an airplane's ascent during cruise flight generally executed as step climb rather than a cruise climb, even though the latter would conserve more fuel? Explain.

R3: Redraw Figure 4 to show a step climb encompassing four flight levels.

R4: Why are atmospheric conditions most suitable for cruise flight at an altitude of 11,000 m? Explain.

R5: What other advantages does a cruising altitude of 9,000 to 11,000 m offer as opposed to a lower altitude of, say, 2,000 to 5,000 m?

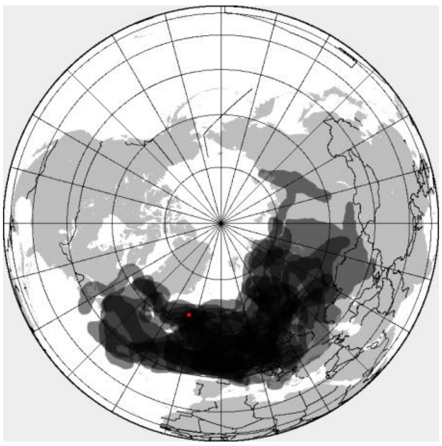
2.3 The Influence of Volcanic Ash

As it draws in air, an aero engine also takes in small airborne particles. If those particles are volcanic ash, the engine's compressor and turbine blades may be damaged. In early 2010 large quantities of volcanic ash were discharged into the atmosphere through the eruption of the Eyjafjallajökull volcano in Iceland, reminding many people of the KLM Flight 867 incident that had demonstrated the dangers of volcanic ash for air traffic before (F1).

In a series of eruptions lasting from April 14 to mid-June 2010, Eyjafjallajökull released approximately 140 million m^3 of volcanic ash (F2). Ash plumes rose to 8,000 m, in places even as high as 9,000 m. A large portion of European airspace was closed to traffic from April 15 to 20. Only two days after the first eruption, the ash had reached Polish airspace – and was still spreading (F3). There was concern that aircraft, if allowed to fly, might face damages similar to those suffered by KLM Flight 867 in 1989. Air traffic returned to normal only towards the end of April. By then the aviation industry had suffered turnover losses of around 2 billion euros, with 100,000 flights cancelled and 10 million passengers affected. The European air-traffic control authority, Eurocontrol, introduced the three-zone model (F4) on May 4, 2010 so that uniform regulations could be applied during similar situations in the future. It is impossible to obtain constant measurements from across the entire European airspace; thus the spread of an ash cloud is calculated using meteorological models. However, due to isolated eddies, such forecasts are marred by an uncertainty factor of up to 2000 percent. So it is generally recommended that pilots simply avoid flying through visible ash clouds at any time. But in Central Europe, the critical value for airborne ash – the value at which airplanes must remain grounded – was reached neither before nor after May 4. So, if we are to ensure air traffic safety while at the same time avoiding unnecessary stoppages, our current methods for identifying dangerous concentrations of ash in the atmosphere will require significant improvement.

On December 15, 1989, a Boeing 747-400 belonging to KLM was on its way from Amsterdam to Tokyo with 245 people on board. The plane was approaching its scheduled stopover in Anchorage, Alaska, beginning its descent for landing, when at an altitude of about 8,500 m it entered what appeared to be a raincloud. In fact it was an ash cloud produced by the eruption of Mount Redoubt about an hour earlier. Particles found their way into the cockpit along with a sulfuric odor, and the pilot reversed course, climbing again to escape the cloud. Within a minute all four of the airplane's CF6-80 engines had failed. The ash was impeding the flow of air through the engines' compressors, causing a flameout in the combustion chambers. All measuring instruments failed, and the airplane began to glide. It continued in that state for twelve minutes, all the while losing altitude. Finally, at a height of around 4,000 m, the pilot managed to restart the two left engines. Fifteen minutes later – the plane had meanwhile fallen to within 2,000 m of the ground – the two right engines were restarted. By now the windshield was so badly scratched from the oncoming ash particles that the crew could see only through the side windows. Yet they managed to land in Anchorage, and the Boeing 747 was subjected to a thorough inspection. Eighty kilograms of volcanic ash were found in each of the four engines. The airplane as a whole had suffered 80 million U.S. dollars' worth of damage.

F1: KLM Flight 867 (Image: Wikimedia)



F3: Areas affected by the ash cloud between April 14 and April 25, 2010 (source: Wikimedia)

F2: Ash cloud from the Eyjafjallajökull volcano on April 17, 2010 (source: Wikimedia)

Although it has become standard to refer to it as “ash” due to its fine material structure, volcanic ash is in fact not a combustion residue. Rather, it is made up of small particles. The particles arise when lava or already hardened rock is torn apart by a volcanic eruption. Most of the stratovolcanoes around the circum-Pacific Ring of Fire explode in this way, as was the case with the powerful eruptions of Mount St. Helens in 1980 and Mount Pinatubo in 1991.

The eruption of Eyjafjallajökull brought 14,000,000 m^3 of liquid lava to the surface in addition to volcanic ash. The ash was formed as the rising magmatic material came into contact with the glacial ice coating at the volcano’s surface. The extreme temperature difference caused the rock to explode in a phreatomagmatic eruption.

Volcanic ash particles can impair an aero engine in a number of ways. They can erode compressor blades, altering the blades’ shape and surface roughness (an effect similar to the one seen in Figure 6). The resulting loss in aerodynamic efficiency causes the engine to consume more fuel and emit more CO_2. The melting point of volcanic ash, furthermore, is generally well under 1,000 °C. When it reaches the turbine, it becomes viscous and can stick to the surface of the blades (F5). If this molten mass is produced in sufficient quantities, it may block the airflow and provoke an engine failure. The probability of an engine standstill is greater still if the turbine blades have cooling air holes. When the holes become blocked with molten ash, the blades begin to overheat and will eventually be destroyed.

Review

R1: Why did air safety officials pronounce a general flight ban after the eruption of Eyjafjallajökull, even though the ash cloud did not rise high enough to affect cruising altitude (9,000 to 11,000 m)? Justify your answer. Present multiple safety considerations.

R2: Execute a roleplaying scenario in which air-traffic control authorities and airline representatives argue about the flight ban during the first days after the spread of the ash cloud.

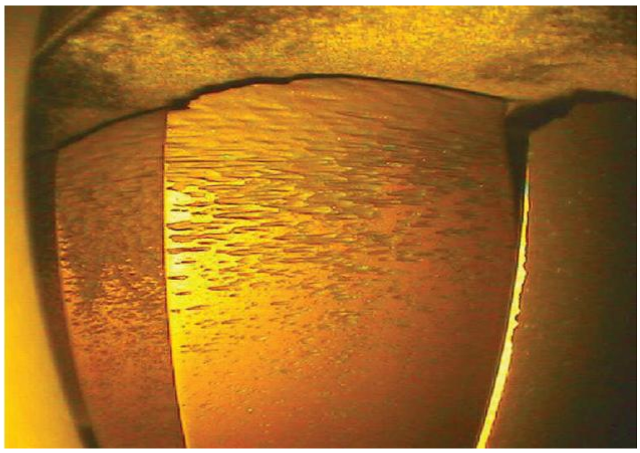
R3: Estimate which flight routes are most at risk from volcanic ash (tephra). Consult sources on historical and current volcanic activity as well as Figure 12.
Links: earthquakes.volcanodiscovery.com;
www.volcano.si.edu/weekly_report.cfm

R4: Track the route of flight KLM 867 and the non-stop connection between Amsterdam and Tokio on a relevant atlas map. Why has the direct route (without a stopover) been possible only since the beginning of the 1990s? Explain!

Zone	Ash Concentration	Rule
3	>2 mg/m³	No-fly zone imposed within a 110 km radius
2	0.2–2 mg/m³	Inspection intervals shortened
1	<0.2 mg/m³	No restrictions

F4: Eurocontrol’s three-zone model (source: Wikipedia)

F5: Turbine blades with a crust left behind by molten volcanic ash (source: MTU Aero Engines)



F6: A blade that has been eroded by aeolian sand during use in the Middle East (source: MTU Aero Engines)

2.4 The Influence of Aeolian Sand

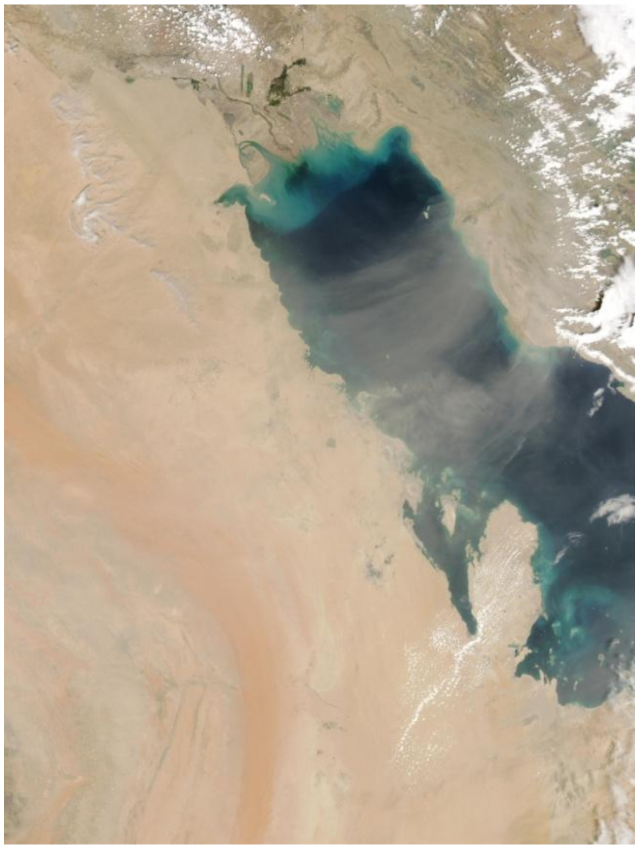
Aeolian sand also takes a toll on aero engines. In the arid, sparsely vegetated regions of the low and middle latitudes – regions which are in fact spreading due to ongoing desertification – winds can carry sand even to higher altitudes (F7). Because of its high melting point, aeolian sand does not leave a residue in an engine's turbine, but it does have an erosive effect as it passes through the compressor. This effect is similar to sandblasting (F6).

If an engine is used regularly under these conditions, the wear on the metallic surfaces of the compressor blades is such that it must be serviced and repaired three times more frequently than an engine used, for instance, in Central Europe. A "shop visit" – which can cost up to 1 million U.S. dollars with a large aero engine – becomes necessary after only 3,000 h of running time, rather than the standard 10,000 h. The logistic burden is also tripled, since the engine must be flown to its service location – from Dubai, for example, to MTU Maintenance in Hanover – and in the meantime the airline needs a substitute engine.

If the eroded blades aren't replaced, fuel consumption, CO_2 emissions, and strain on the turbine will all increase, while the performance of the engine will decrease. For commercial flights that means a rise in travel time; for military aircraft, it means less maneuverability during an operation – which is especially critical if the aircraft is forced to land on a dirt strip (F8). Regardless of whether the engine is used in a commercial or a military aircraft, regular exposure to sand can weaken the blades so much that they may even break, provoking an engine failure.

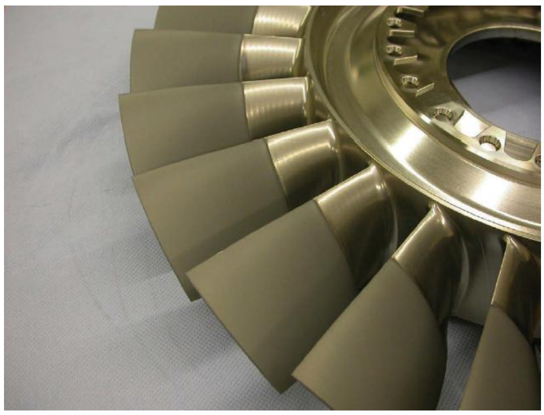
At MTU, a team of researchers led by Dr. Thomas Uihlein has examined and compared the relative influences of sand and volcanic ash on compressor materials. They collected their ash samples shortly after the eruption at Eyjafjallajökull (F10). The sand came from the grounds of an airport in the Middle East (F11).

Trial runs on the test bench demonstrated that the compressor blades' rate of erosion depends on the base materials they're made of, the conditions they operate under (flow velocity, temperature, angle of impact), and the morphology of the particles in question. Generally, volcanic ash was shown to be more abrasive than aeolian sand. MTU has developed the coating process ERCoat^{nt} (F9) to protect blades from particles of all kinds as well as from high temperatures. Although the company earns money servicing and repairing engines, it still has an interest in preventing engine damage. Dr. Uihlein: "With the coating we can increase the life expectancy of blades and blisks by 200 to 300 percent. That conserves valuable resources and represents a genuine benefit for our customers."

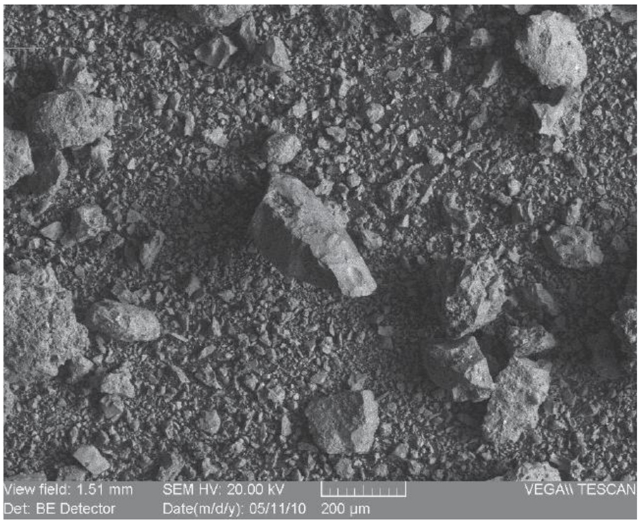


F7: Sandstorm over the Persian Gulf (source: NASA)

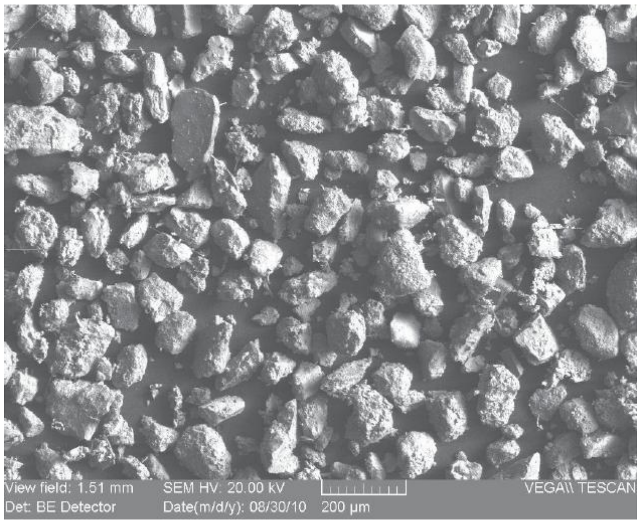
F8: A400M on a sand runway (source: Airbus Military)



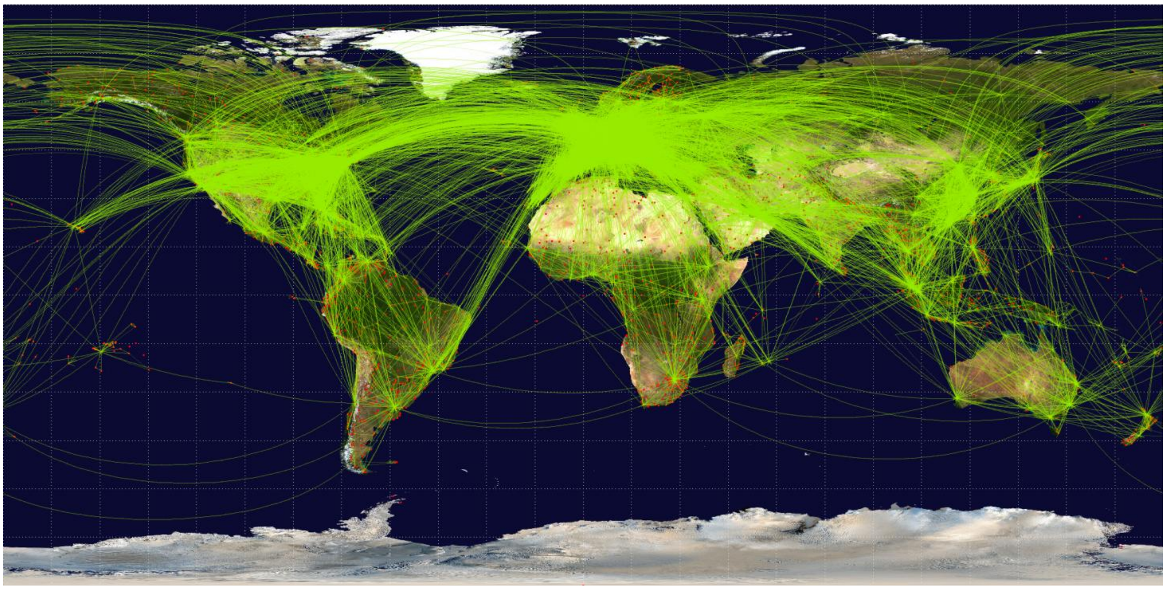
F9: Blisk treated with the ERCoat^{nt} process (source: MTU Aero Engines)



F10: Volcanic ash from Eyjafjallajökull under a scanning electron microscope (source: MTU Aero Engines)



F11: Aeolian sand from the Middle East under a scanning electron microscope (source: MTU Aero Engines)



F12: Air traffic schedule for June 2009 (source: Wikimedia)

Review

R1: What geographic location is depicted in the satellite image (F7)? Draw a sketch showing this region in its physical-geographical surroundings. Use relevant atlas maps to determine the season in which the image was taken.

R2: Describe the volcanic ash and aeolian sand in Figures 10 and 11 with regard to their relative shapes and particle sizes. Support your observations by describing the conditions under which each of these substances was formed. Why is the abrasive effect of volcanic ash stronger than that of aeolian sand? Justify your answer.

R3: Which regions and commercial flight routes are most affected by aeolian sand? Assess. Consult relevant atlas maps and Figure 12. Also consider the growth of air traffic, paying additional attention to the regions where strong growth is expected.

R4: Where do the German and U.S. militaries currently have troops and aircraft deployed in assignments abroad and/or combat missions? Do research. Estimate the relative threat of erosion by aeolian sand at each location.

R5: How do volcanic ash and aeolian sand affect aero engines? Provide a brief summary of the effects of each, and assess which represents the greater threat for routine aviation.

3 Water and Energy Use at MTU Aero Engines Headquarters in Munich

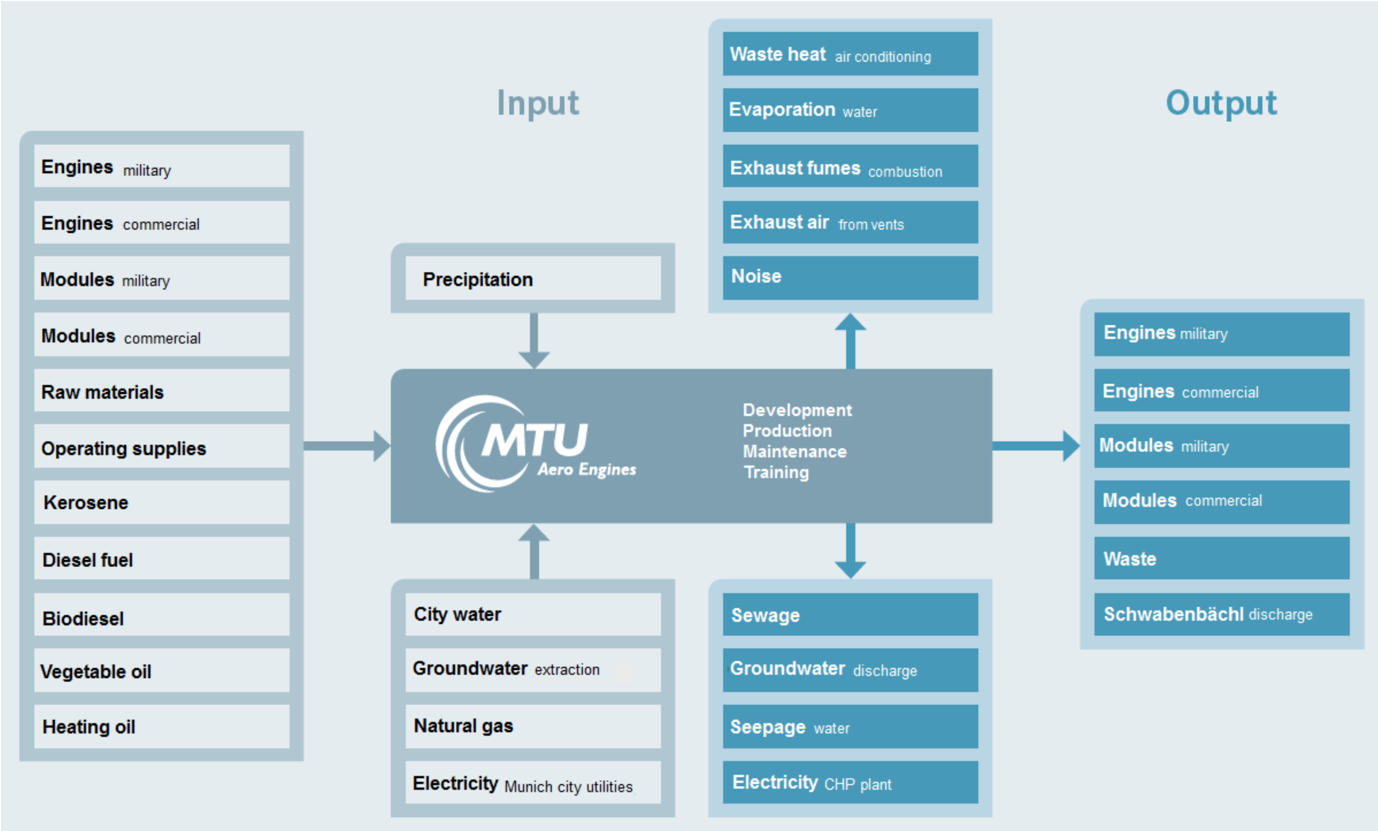
3.1 Local Conditions

MTU Aero Engines' corporate headquarters is located just outside Munich. Here, north of the Allach Forest, BMW began building up its aircraft engine division in 1936. After being taken over by the motor vehicle and machine manufacturer MAN in 1965, that division emerged in 1969 as an independent company: the Motoren- und Turbinen-Union (MTU). Since then, the northwestern section of the site (F1) has belonged to MAN, which produces trucks and buses there. The southeastern half, bordering on the A99 and Dachauer Straße, is the headquarters of MTU Aero Engines. MTU employs about 4,600 people at this site, which spans approximately 500,000 m^3, and although the company is represented internationally, its board of directors and management are based here. Research and development, production, inspection, and marketing of commercial and military aero engine components and subsystems can be found here as well. Military aero engines are also assembled and serviced at this site.

Figure 2 is a qualitative depiction of an input-output analysis. It shows the materials, unfinished parts, energy sources, and other supplies the company takes in, and what it makes from them in turn.

Engines are sent here for inspection and maintenance, and industrial gas turbines for service. All these processes require kerosene. MTU produces components using resources, operating supplies, and utilities. The components are then combined with modules arriving from elsewhere to form larger subassemblies or whole engines. The factory's water and energy needs are supplied from a number of sources. When a complete engine undergoes final assembly at MTU, it is shipped directly to an aircraft manufacturer; when only a module is assembled, it is shipped to one of MTU's engine manufacturing partners. Solid waste and wastewater are properly disposed of and, like emissions, kept to a minimum. The factory's combined heat and power (CHP) plant feeds electricity into the public grid.

F1: Satellite image of MTU's Munich headquarters (outlined in blue) and surroundings
(Source: Bavarian Administration for Surveying – www.geodaten.bayern.de)



F2: An input-output analysis for MTU's Munich headquarters (source: MTU Aero Engines)

Review

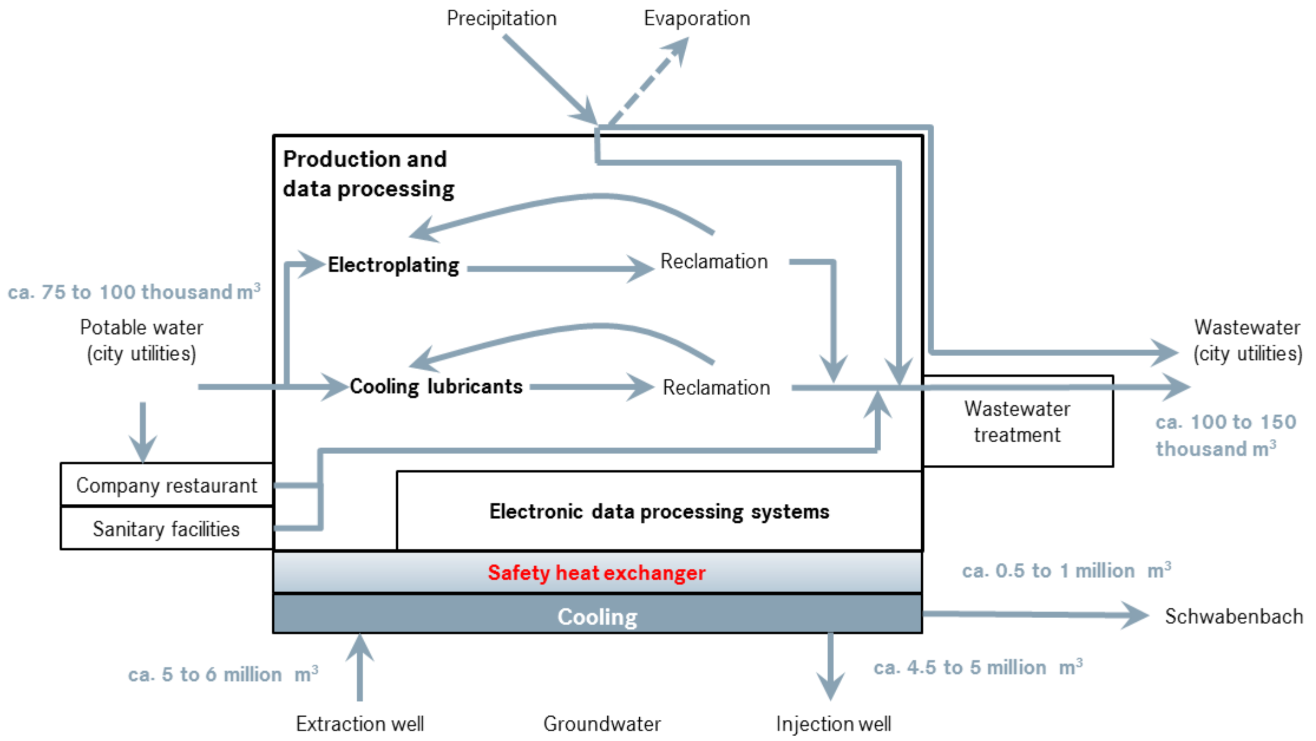
R1: Locate the MTU factory grounds (F1) on a small-scale atlas map or (with your teacher's permission) using your mobile phone.

R2: Draw a land-use diagram showing the structure of the area depicted in Figure 1. What are the favorable and unfavorable aspects of this location from the standpoint of MTU? From the standpoint of the local population? Explain.

R3: An input-output analysis (F2) measures the supply and material flows and the emissions that a company generates within its own facilities in manufacturing its products and/or rendering its services. The analysis does not include the commuter traffic generated by the company's workers. With a partner, estimate how many total kilometers MTU's workforce commutes each year by means of private transportation. To obtain your answer, make plausible assumptions as to: the number of work days in a year, assuming that an employee is granted a total of 40 holidays and vacation days; the percentage of employees who work only three days per week, the percentage who work only four; the percentages who have, respectively, a 10 km, 30 km, or 50 km commute; the various means of transportation used for commuting, in their respective percentages; and the average sickness absence rate (percentage of employees who miss work due to illness).

R4: Outline three approaches to reducing the volume of individual motorized commuter traffic generated by MTU's employees, and discuss the feasibility of each.

3.2 Water as a Factor of Production



F1: Water budget of the MTU factory in Munich (source: MTU Aero Engines)

Most of MTU Aero Engines' demand for potable water (F1) arises from manufacturing processes, especially processes that involve electroplating or cooling lubricants.

Electroplating means that a component is first cleaned, then bathed in a coating material that helps prevent rust and wear. During this process water serves as a medium for transferring ions to the component's surface. Before the Munich drinking water can be used for this purpose, however, its salt must be removed to eliminate unwanted ions. Liquids used in the electroplating process are afterwards treated in a water reclamation plant. Of the 450,000 m^3 of water used for electroplating at MTU in 2012, only 13,000 m^3 ended up as wastewater and had to be discarded.

Cooling lubricants are required in many metalworking processes. They reduce friction between tool and component, draw away heat, and absorb dust (F2). These lubricants are made from water and various types of oil, and like water they are purified after each use. In this way they can be reused several times.

F2: Use of cooling lubricants during a deburring-milling process (source: MTU Aero Engines)

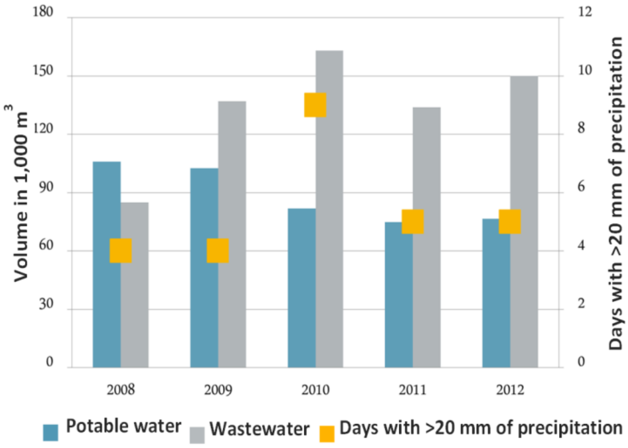
Great attention is paid not only to conserving water, but also to ensuring that when water is used, it remains clean. As the technology in this area has improved, legislators have regularly tightened the limits on hazardous substances. MTU remains well below these limits in all its operations.

REVIEW

R1: Compare the water budget at MTU (F1) with the general water cycle (textbook depiction). How does MTU's water budget differ from that of a residential or agricultural area? Describe.

R2: Look closely at Figures 1 and 3. Why is the quantity of wastewater MTU gives off greater than the quantity of drinking water it takes in? Explain.

R3: What are the advantages and disadvantages of tighter water regulations from a citizen's standpoint? From a company's standpoint? Discuss.



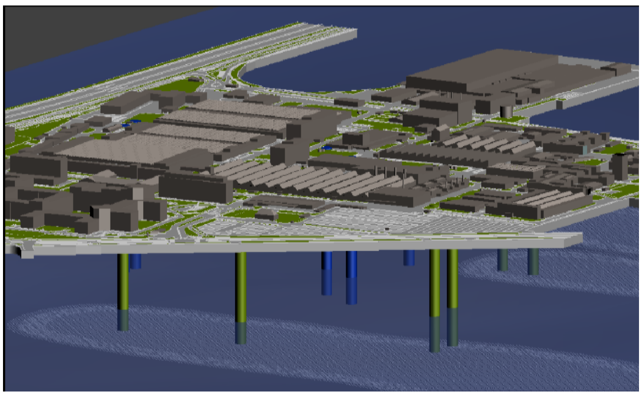
F3: Drinking water demand, wastewater, and heavy rainfall (Sources: MTU Aero Engines; German Meteorological Service of the Munich Airport weather station)

3.3 Energy as a Factor of Production and CO_2 Emissions

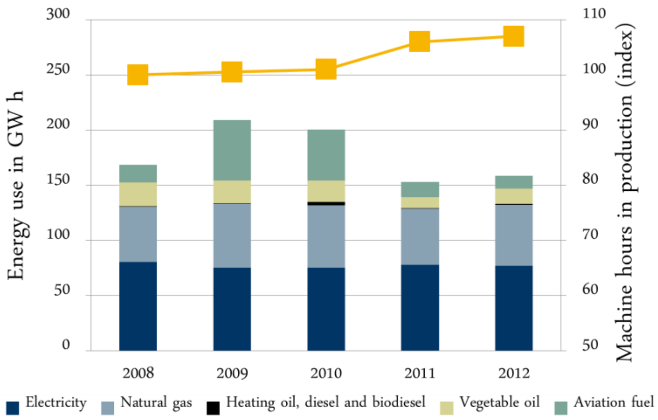
Interview with Burkhard Oesten
(Director of Environmental Protection)

Why do you use seven different energy sources?
We use electricity mostly for machines and lighting, and natural gas for heating. The small amounts of fuel oil, diesel fuel, and biodiesel we use are needed to run our emergency power supply and in-plant vehicles. Our combined heat and power plant burns vegetable oil.
Aviation fuel is required for engine testing. In 2009 and 2010 we had several engines in development which of course needed to be tested according to regulations.
If you disregard aviation fuel, our energy consumption over the last few years shows a slight downward trend.

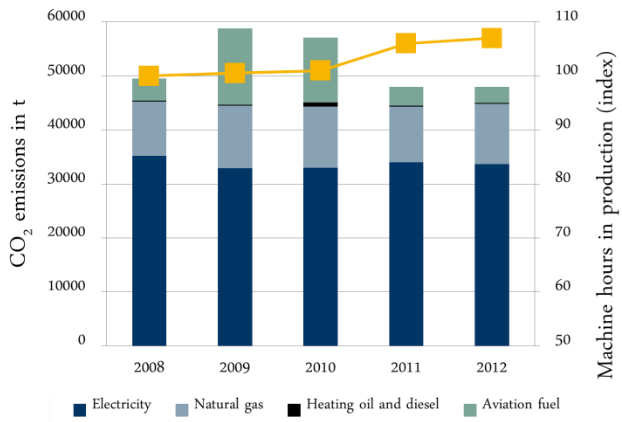
What do you do to reduce your energy needs?
We began operating our own combined heat and power plant already in 2006. It covers 15 % of our location's heating needs – and does so in a carbon-neutral way, through cogeneration. The plant economizes 7,400 tons of CO_2 per year.
We've also installed circulating heat exchangers for heat recovery in our production facilities. That measure saves 1,500 tons per year.
And of course it's helpful that we cool our data systems and several of our buildings with groundwater (F3). Compared to using electric refrigeration units, this method saves over 3,000 tons of CO_2 per year. We have our own groundwater wells. The newest, with a pump capacity of up to 140 liters per hour, was put into service in 2011. The water absorbs heat, then is pumped back into the groundwater aquifer, flowing north. The water may be heated a maximum of 6 K in the process, and its temperature when reintroduced into the groundwater current may not exceed 20 °C.



F3: Groundwater wells (blue) and injection wells (green)
(source: MTU Aero Engines)



F1: Energy use and production (source: MTU Aero Engines)



F2: CO_2 emissions and production
(source: MTU Aero Engines)

Review

R1: Look closely at Figures 1 and 2. To what extent has MTU's energy use become more efficient over time? Explain. Also, determine which key figure would be suitable for calculating MTU's energy efficiency.

R2: With a partner, develop three ideas for achieving even greater sustainability in the selection and use of energy sources at MTU.

R3: Why is vegetable oil shown in Figure 1, but not in Figure 2? Justify your answer.

R4: In 2011, around 400,000 tons of CO_2 were released at the Munich Airport by airplanes in the landing and takeoff (LTO) cycle, in other words by air traffic below 3,000 feet (source: Munich Airport 2012). On that basis, calculate how many days it took in 2011 for the same amount of CO_2 to be released at the airport as was released in MTU's engine testing during the entire year.

R5: What are the effects of heating groundwater to 20 °C? Do research, and evaluate the practice of using groundwater for cooling purposes.

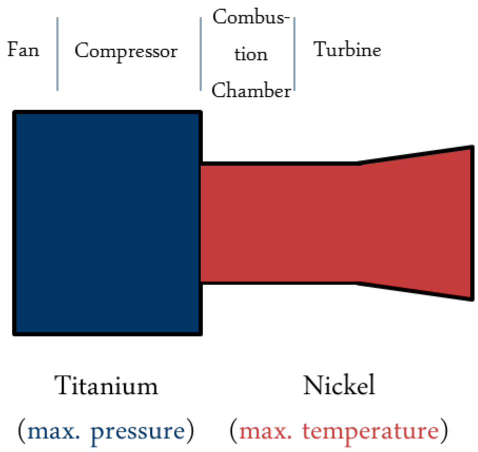
4 Mineral Resources and Aero Engine Construction

A number of materials go into building an aero engine – from alloys and several types of steel, to composite materials and even carbon-fiber-reinforced plastics. The most important mineral resources are titanium and nickel (F1).

In spite of its lower melting point, nickel is more heat-resistant than titanium. The latter quickly loses its rigidity at temperatures over 400 °C, and it reacts with oxygen starting at 880 °C. Because it has such a low density, however, titanium is utilized in the parts of an engine where temperatures are low and materials are subjected to strong dynamic stresses. Nickel, on the other hand, is used where temperatures are highest (F2).

	Titanium	Nickel
Symbol	$_{22}Ti$	$_{28}Ni$
Melting point	1,668 °C	1,455 °C
Density at 25 °C	4.50 g/cm^3	8.91 g/cm^3

F1: Basic data for titanium and nickel (source: Wikipedia)



F2: Titanium and nickel in an aero engine

Nickel offers a good example to demonstrate the importance of mineral resources for aero engine construction. Known worldwide nickel reserves are estimated at 75 million tons, while about 2 million tons are currently mined each year (F3).

About 65 % of the world's pure nickel is used in the production of high-grade steel. About 12 % go into the alloys needed to make aero engines, automobiles, and other machinery. The remaining 23 % are divided among various applications, such as the production of coins and batteries.

Country	Production	Reserves
USA	0	7,100
Australia	230,000	7 to 20,000,000
Botswana	26,000	490,000
Brazil	140,000	7,500,000
Canada	220,000	3,300,000
China	91,000	3,000,000
Colombia	80,000	1,100,000
Cuba	72,000	5,500,000
Dominican Republic	24,000	970,000
Indonesia	320,000	3,900,000
Madagascar	22,000	1,600,000
New Caledonia (France)	140,000	12,000,000
Philippines	330,000	1,100,000
Russia	270,000	6,100,000
South Africa	42,000	3,700,000
Others	120,000	4,600,000
World (rounded)	2,100,000	75,000,000

F3: Nickel production and reserves in 2012, in tons (source: U.S. Geological Survey)

F4: Nickel Rim South mine near Sudbury, Canada (source: Wikimedia)

Interview with Rudolf Michl
(Director of Purchasing and Logistic Services)

Why has the price of nickel fluctuated so strongly since the turn of the millennium?
That has a lot to do with the awakening of China. In 2003 the Chinese high-grade steel industry started gaining momentum. It expanded so rapidly that the world supply of nickel couldn't keep pace with demand. For that, new mining sites first had to be established, but meanwhile the price trend caught the attention of speculators – at the beginning of the banking crisis, they were looking to invest their capital in commodities. In the end, the rise in nickel prices was actually much more dramatic than the rise in industrial demand for nickel (F7).

And why has the price gone down again?
Production having already been expanded to the point of overcapacity, the Chinese managed to substitute pure nickel in their high-grade steel production. They discovered a way to use low-quality nickel ore deposits instead, so-called nickel pig iron. Such deposits occur naturally in Asia. So, with the growth in demand for high-grade steel having slowed, especially in China, and mining capacity at the same time having risen sharply, the nickel price began to fall. From its interim high at the end of 2010, it has now sunk back to its level of ten years ago. There is even talk of closing mines in Australia in order to reduce the supply and thus counteract the price fall.

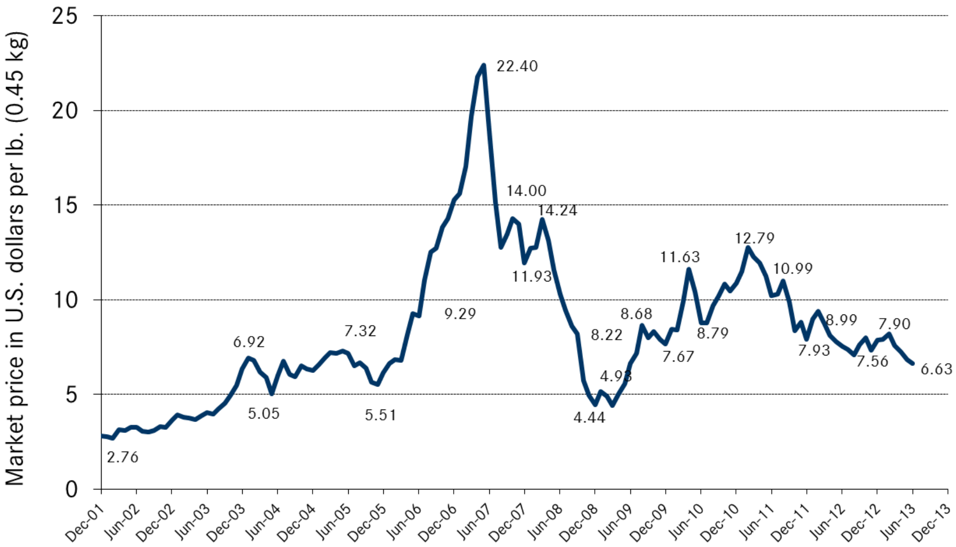
It sounds as if the acquisition of nickel is likely to be beset by uncertainties for some time to come.
We try to avoid uncertainties. MTU Aero Engines pursues an acquisition strategy based on the long term. With our providers we sign bilateral contracts that insulate us against price fluctuations and ensure that we maintain a sufficient supply. Even when prices were at their highest, we had no difficulty acquiring nickel alloys. If, however, we're facing a fundamental shortage of a certain raw material in the future, the acquisition of elements or alloys becomes more difficult. With certain rare-earth elements, the situation can become critical much faster than with nickel. If there's a material of this group which we can't expect to acquire at acceptable conditions over the coming decades, we won't include it in our new development programs. Also, we try to make ourselves less dependent on primary nickel production with our sustainable recycling program. In our production areas, for instance, we keep the chips generated during machining operations strictly separate, dividing them according to alloys. This allows them to be reintroduced into the manufacturing cycle.

You spoke of nickel alloys. What are those?
We don't use any elemental nickel (F5) in the aviation industry; instead we use alloys, which combine multiple metallic components. Alloying allows us to optimize a material's properties. One typical nickel-based superalloy is Inconel alloy 718 (F6). It's made from 52.5 % nickel, 19 % chromium, and 19 % iron, in addition to other metals. At high temperatures it resists creepage and material fatigue even better than pure nickel. This alloy can be used at temperatures of up to circa 1,300 °C. Even temperatures 200 K higher are feasible if the blades are air-cooled, meaning outfitted with tiny air holes through which some of the airstream can pass.

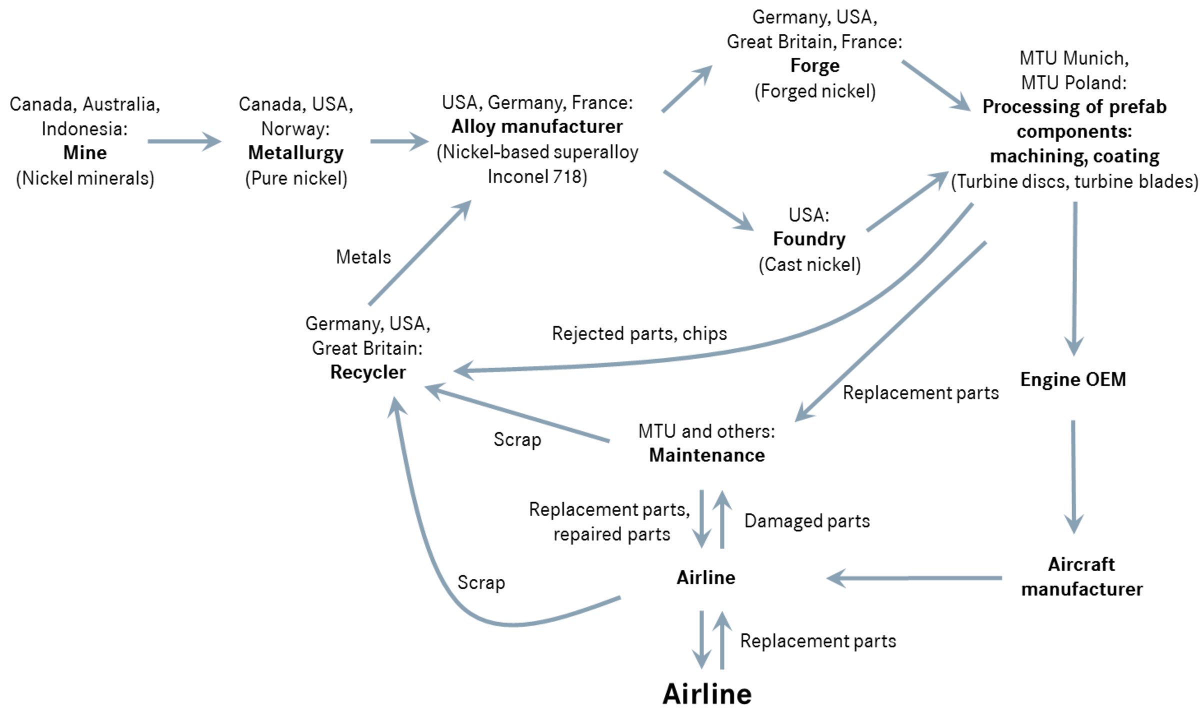
How should we picture the mineral's path from the nickel mine to the aero engine?
It's a journey with quite a few twists and turns. Take a look at the diagram (F8)!

F5: Pellets made from nickel (source: Wikimedia)

F6: Cylinder made from Iconel alloy 718
(source: Wikimedia)



F7: Price trend for nickel (source: MTU Aero Engines/MetalPrices/London Metal Exchange, average monthly values)



F8: Nickel from the mine to the recycling station (source: MTU Aero Engines)

Review

R1: Important deposits of nickel are found in central Brazil and on the Kola Peninsula and in Norilsk in Russia (F3). Locate these deposits on suitable atlas maps. What are the ecological implications of mining operations in these areas? Explain. Consider the carrying capacities of the surrounding ecosystems in your answer.

R2: Why is the volume of nickel produced in some states disproportionately large with respect to reserves (F3)? Justify your answer. Also, what are the advantages and disadvantages of this mining policy as a development strategy? Discuss.

R3: Why does the aero engine maintenance field possess great potential for the sustainable use of mineral resources? Explain.

R4: Why is it in MTU's interest to remain active in the maintenance business, with the raw materials of the metal cycle becoming ever scarcer? Justify your answer.

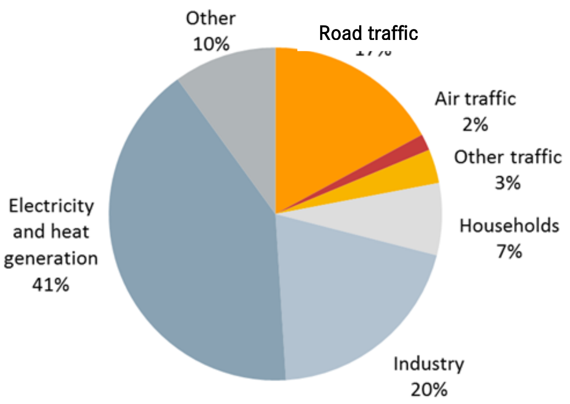
5 Energy Use in Aviation

Since 1960, when the Boeing 707 and the Douglas DC 8 heralded the jet age, the CO_2 emissions generated through civilian aviation have been reduced by 70 % per passenger kilometer. In the future it will be important to continue reducing climate-relevant emissions. There remains considerable potential for improvement in this area (F1).

The International Air Transport Association (IATA) and the European Commission's Advisory Council for Aeronautics Research in Europe (ACARE) have laid out an ambitious program for reducing CO_2 emissions in aviation between now and the year 2050 (F3). IATA intends to make the ongoing growth of air traffic carbon-neutral by 2020, and to cut all air traffic CO_2 emissions in half by 2050. To do so, it will be necessary to increase efficiency in all areas with potential for improvement. Estimates by MTU Aero Engines show that specifically the following improvements will be needed if we are to achieve these ambitious goals. (Percentages between parentheses represent the required increase in efficiency compared with the year 2000.)

- Airplane design (30 %): more efficient configuration of fuselage and wings, to the point of a flying-wing design.
- Air traffic management (20 %): Optimal use of airspace promises to shorten layovers and reduce time spent in holding patterns. It should also allow airplanes to ascend gradually (cruise climb) and descend at a constant angle (continuous descent approach), two techniques that conserve fuel.
- New aero engine technologies (50 %): concepts for improved propulsion efficiency; new thermodynamic power cycles for improved thermal efficiency
- Alternative fuels (80 % of all aviation fuel): biofuels and renewable synthetic fuels

The latter two areas show the greatest improvement potential, and there MTU is working at full steam, devising solutions for the future.



F2: Distribution by sector of the 30 Gt of global CO_2 emissions in 2010 (source: OECD/International Energy Agency 2012, "CO_2-Emissions from Fuel Combustion – Highlights")

Today's aircraft still release greenhouse gases into the atmosphere. The RFI factor (Radiative Forcing Index) represents an attempt to estimate the overall effect of air traffic on the climate. It takes into account all relevant emissions types as well as the atmospheric layer in which they were released and their residence time in the atmosphere.

Emissions that cause warming:

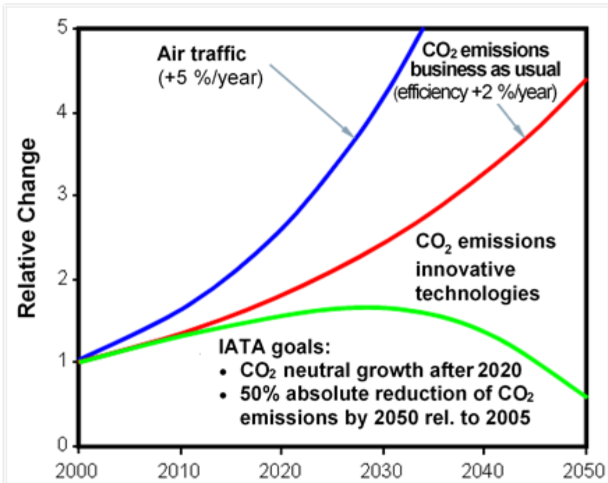
- CO_2
- Nitrogen oxides: ozone formation
- Water vapor: cirrus clouds, contrails
- Sooty particles: absorption of solar radiation

Emissions that cause cooling:

- Nitrogen oxide: decomposition of methane
- Sulfate aerosols: reflection of solar radiation

So far there are no assured research findings, but the Intergovernmental Panel on Climate Change (IPCC) estimates the air traffic RFI factor at 2.7, and similar conclusions have been reached in investigations by the German Aerospace Center (DLR). If these estimates are correct, then the effect of air traffic on the climate is in fact 2.7 times greater than the mere quantity of CO_2 emissions it produces (F2). But we can't necessarily conclude that an airplane is exactly that much more harmful than other forms of transportation. To enable such a comparison, one would have to take into account appropriate correction factors for those other transportation forms as well. They likewise emit nitrogen oxide, water vapor, and aerosols.

F1: RFI factor for aviation



F3: Program for reducing CO_2 emissions by 2050 (source: MTU Aero Engines)

New Aero Engine Technologies

The efficiency of modern turbofan engines has been improved over the last decades by increasing the bypass ratio to 1:10. This is the ratio of the main flow (air propelled by the core engine including compressor, combustion chamber, and turbine) to the bypass flow (air propelled only by the fan). Increasing this ratio has required the fan to become steadily larger. That, in turn, has made the fan's rotation steadily slower, since there is a limit to the peripheral speed the fan's blade tips can reach. This also imposes a lower number of rotations per minute on the low-pressure turbine driving the fan. The result is a loss in efficiency.

The geared turbofan technology of the PW1000G (see chapter 2, F2) is designed to fix this problem. The inclusion of an epicyclic gearbox allows the fan to rotate slowly while the low-pressure turbine, which achieves its optimum performance only at high speeds, turns at a faster rate. Thus both sections of the engine can operate at maximum efficiency simultaneously. The PW1000G hits the market in 2014, offering a 15 % reduction in CO_2 emissions.

Improved fan technologies such as the Counter-Rotating Integrated Shrouded Propfan (CRISP), which offers a CO_2 reduction of 20 %, will be available around 2025. New core engines offering a CO_2 reduction of 30 % (through heat exchangers, for instance) will come on the market starting in 2035. MTU Aero Engines is involved in the research and development of all these future technologies.

Alternative Fuels

The era of fossil fuels is coming to an end, not only because of the effect they have on the climate, but also because of market prices, which can be expected to grow continuously once we pass the "peak oil" point. Numerous fuels are being investigated as potential substitutes for our current, petroleum-based jet fuel (kerosene).

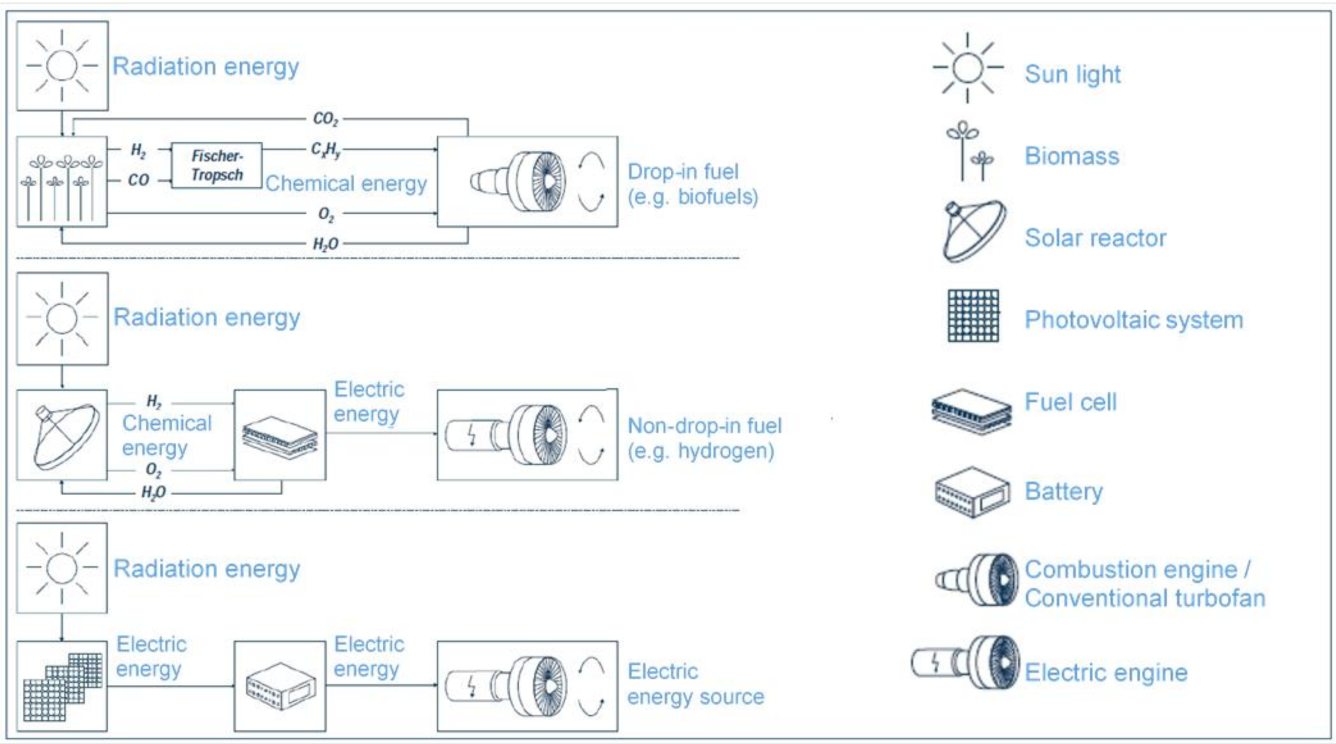
Desirable properties of an alternative fuel:

- Minimal modifications to current airplanes and aero engines
- Simple infrastructure on the ground
- Mature technology

Essential properties of an alternative fuel:

- High gravimetric energy density (specific energy) [MJ/kg]
- High volumetric energy density [MJ/l]
- Safety: low freezing point, high boiling range
- Long-term availability
- Low global-warming potential

MTU Aero Engines participates in research projects on the future of aviation through the Bauhaus Luftfahrt e.V. There, scientists are considering a number of options for propelling future aircraft (F4), including synthetic fuels from biomass (F5), solar kerosene, hydrogen fuel cells, and electric flight.



F4: Options for an alternative aviation fuel (source: Bauhaus Luftfahrt e.V.)

The first extended biokerosene experiment under real conditions was conducted from July to December 2011 with a Lufthansa Airbus 321. During these months, the plane flew a total of 1,187 times between Hanover and Frankfurt with one of its two V2500 engines running on a 50/50 blend of kerosene and biokerosene. A so-called drop-in fuel, this mixture did not require any modifications to the airplane. The 800 tons of biofuel needed for the experiment were the largest quantity of HVO (hydrotreated vegetable oil) ever produced up to that time. The resources for its production were: camelina oil from the USA (80 %), jatropha oil from Indonesia (15 %), and waste animal fat from the Finnish food industry (5 %). This research project, conducted with the cooperation of MTU Aero Engines, succeeded in demonstrating the suitability of biokerosene for everyday use. As a fuel option, however, biokerosene remains much more expensive than regular kerosene. Biokerosene will need to be economically viable if it is to have a future. We also will need to ensure that its production doesn't compete with food production, that it doesn't create ecologically undesirable monocultures, and, in the final analysis, that the complete CO_2-balance is favorable.

F5: BurnFAIR experiment, 2011 (source: MTU Aero Engines)

Biokerosene can be produced by a number of methods, including hydrotreatment of vegetable oils (HVO) and the Fischer-Tropsch process (BtL: Biomass to Liquid). These fuels, which have already been approved for use, do not require any modifications to the airplane or aero engine, since they closely resemble mineral kerosene on the chemical level. As concerns raw materials, the fuels can be made from energy crops, wood, and biodegradable waste. At present, however, we cannot be certain of the long-term availability of these materials, nor whether large tracts of land will be available where they might be produced in a consistently sustainable fashion. Substituting the whole of Europe's kerosene needs (currently 60 million tons per year) with biokerosene would require no less than 8 to 24 % of all the farmland in Europe.

A promising alternative is to use certain algae as a raw material. These microalgae are very rich in oil, reproduce quickly, and create more than 30 times more biomass per unit of area than canola. They have few special requirements with respect to cultivation land, and can be irrigated with saltwater, sewage, or even industrial wastewater. What's more, these algae absorb large amounts of CO_2 through photosynthesis. Testing facilities are already operating on Big Island in the U.S. state of Hawaii.

Solar kerosene or StL (Solar to Liquid) can also be produced with the Fischer-Tropsch process. Here, the detour via biomass is avoided by using solar energy directly, generating syngas (H_2 and CO) from CO_2 and water. Experiments in the U.S. and Switzerland have proven that solar kerosene can be made in this way. Technology that would enable production in industrial dimensions is still in development.

Hydrogen has a high gravimetric energy density, but a low volumetric energy density, meaning it requires a lot of storage space. A hydrogen-powered aircraft needs a large tank, and the tank must be thoroughly insulated to keep the hydrogen at -256 °C. With these requirements met, however, the hydrogen can be burnt directly, in a regular aero engine with a few slight modifications. Alternately, hydrogen can be used to power an electric engine via a fuel cell. In both cases a substantial amount of water vapor is released, but no CO_2. The German Aerospace Center (DLR) is already conducting experiments with a small fuel-cell airplane, although presently the plane can only carry a pilot.

Electric propulsion systems have thus far failed due to their limited energy stores. These systems must reach 10 to 20 times their current capacity before they will be viable for aviation. Yet in the last few years there have been very promising advances in battery technology.

F6: Design for an electric airplane (source: Bauhaus Luftfahrt e.V.)

Fuel	Source	Energy density	Modifications	Technology readiness level	Long-term availability	Global-warming potential
Kerosene						
BtL or HVO kerosene						
StL kerosene						
Liquid hydrogen						
Electric battery						

F7: Evaluation matrix for fuels and propulsion systems (source: MTU Aero Engines)

Review

R1: Figure 1 lists the factors that go into the aviation RFI. How does aviation affect the Earth's solar energy budget?

R2: What challenges do we face in the effort to optimize air-traffic management? Make a list.

R3: Drawing on your knowledge of both geography and physics, prepare a presentation about CRISP technology and heat exchanger propfans for an interdisciplinary sequence with the physics department.

R4: What is meant by the total carbon footprint of an energy source? Explain using the example of biokerosene.

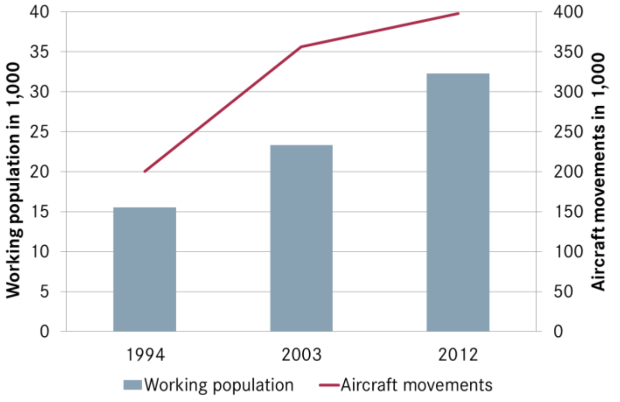
R5: Draw and fill in an evaluation matrix for the alternative aviation fuel options shown in Figure 7. Under source, write the raw materials from which these fuels are produced. In the remaining squares, enter symbols showing whether the fuels are "attractive," "semi-attractive," or "unattractive" with respect to each category.

R6: Why is the long-term global availability of raw biomass materials uncertain? Why are we unable to guarantee that these materials will always be produced sustainably on large tracts of land? Justify your answer.

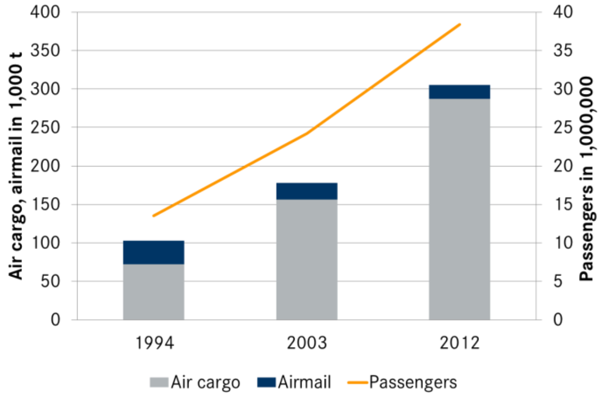
R7: Why would electric flight be particularly sustainable given sufficient technological maturity? Justify your answer.

6 Economic Dynamic in Growth Areas – The Munich Airport Region

The Munich area is among the most dynamic in Germany. An important location factor is the city's large-hub airport, "Franz Josef Strauß" (MUC).



F1: Working population and aircraft movements (source: Munich Airport)



F2: Air cargo, airmail, and passengers (source: Munich Airport)

Mode of Transportation	Km per year 2012
Airplane	24,104,632
Company car	2,082,780
Rental car	1,471,406
Standby vehicle	62,400
Train	303,709

F3: Kilometers traveled on MTU business trips

- In a survey of internationally active companies located in Germany's airport regions, 86 % responded that good airport access was an important or very important location factor for their investment activity.
- Direct international investment in Germany is concentrated in the regions Frankfurt/Rhine-Main, Rhine-Ruhr, Munich, and Hamburg – all areas that are linked to efficient airports.
- In 2007, travelers arriving by airplane and remaining at least one night in Germany spent a total of 15.6 billion euros. Their expenditures helped maintain over 390,000 German jobs.

F4: "Effects of Air Traffic" study (2008) (source: European Center for Aviation Development)

Munich's first commercial airport, founded in 1920, was located in Oberwiesenfeld, in what is now the Olympic Park. A number of companies that built airplanes or aero engines were located in the vicinity: Rapp, Otto, Rumpler, the Bavarian Aircraft Works (*Bayerische Flugzeugwerke*, BFW), and the Bavarian Motor Works (*Bayerische Motoren Werke*, BMW). BMW headquarters is still located on this site today.

As both passenger volume and the airplanes themselves got larger, it became necessary to find a new location. In 1939 the airport was relocated to Riem in East Munich, a site now occupied by the city's convention center, a shopping mall, and a park.

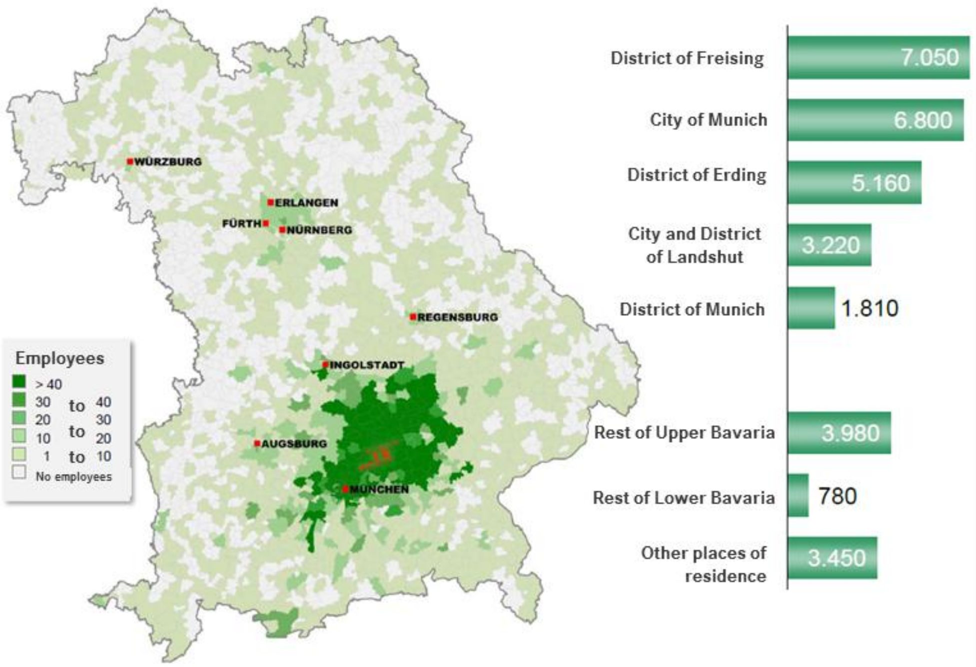
In 1963, in the wake of an airplane crash, and with air traffic volume still growing, Munich again began searching for a new airport site. The leading candidates were Mammendorf near Fürstenfeldbruck and the "Erdinger Moos", or Erding Moor, both about 35 km from downtown Munich. The planning phase got underway in 1969, and the new Munich Airport was opened in 1992. Since then it has been gradually expanded and upgraded to an airline hub. Currently the airport has a capacity of 90 aircraft movements per hour and about 50 million passengers per year.

F5: Stages in the Development of the Munich Airport

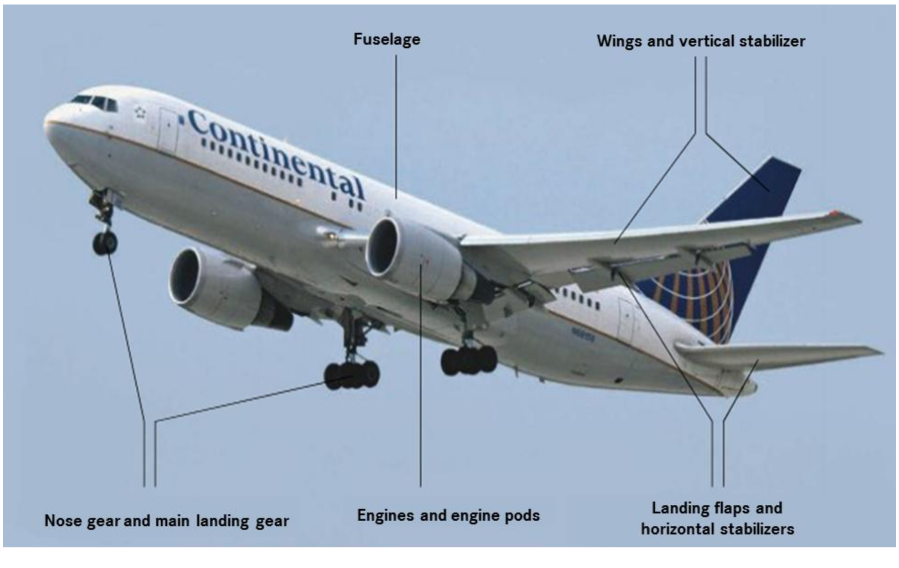
F6: Airbus A380 with four GP7000 engines at the Munich Airport (source: MTU Aero Engines)

32,250 people are employed on the grounds of the Munich Airport. In 2012 their gross total wages were 1,386 million euros, which converts to an average gross income of 42,965 euros per person. The nationwide average income for workers in their industry (called "transport support services") was considerably less – only 33,216 euros.
Of the 32,250 workers at the airport, about 8,200 are employed by the Munich Airport Group (Flughafen München GmbH, or FMG) and about 10,800 by the Lufthansa Group. A total of 552 companies are represented on the airport grounds, not counting the approximately 200 companies with more than 4,000 employees at the nearby "MUC Airport Business Park Hallbergmoos," nor the mailing and shipping center operated by the Deutsche Post, nor the industrial parks in nearby communities such as Schwaig and Eitting.

F7: Munich Airport workers in 2012 (source: Munich Airport)

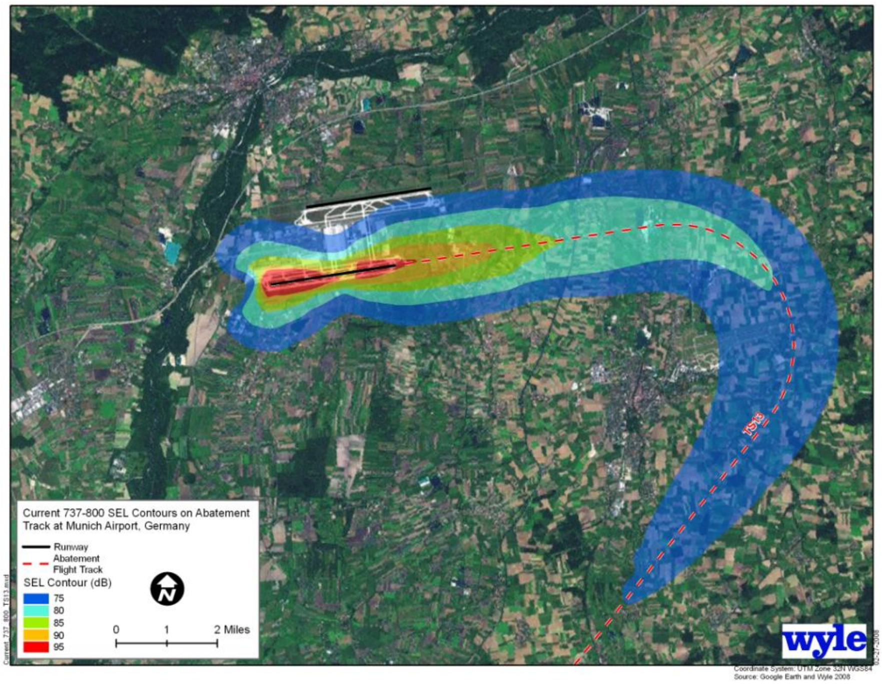


F8: Munich Airport workers' places of residence in 2012 (source: Munich Airport)

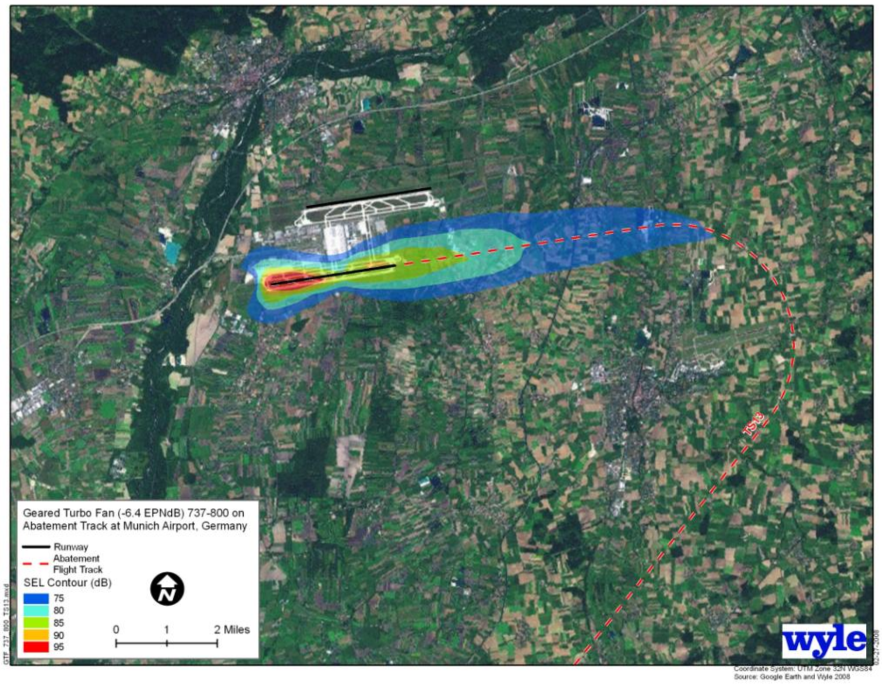


F9: Typical sources of airplane noise (source: MTU Aero Engines)

An airplane landing at almost any airport in the European Union or the USA will have to pay noise charges. Noise limits are continuously being tightened. The primary source of airplane noise, aside from the landing gear, fuselage, and wings, is the engines (F9). Geared turbofan engines – such as the new PW1000G which MTU Aero Engines is engaged in – not only reduce audible engine noise by 50 %, but also reduce an airplane's noise footprint (the ground area affected by the noise) by a full 70 % (F10).



F10: Noise contours – the approach of an ordinary airplane compared to that of a new airplane with geared turbofan engines (source: MTU Aero Engines)



Review

R1: Find indicators for economic dynamic in the greater Munich area on suitable atlas maps.

R2: Figure 5 discusses where Munich's airport has been located at different points in time. Why were these locations chosen? Justify your answer by reference to a suitable urban development model.

R3: Look closely at Figure 2. What trends do you see for air cargo, airmail, and passenger volume since 1994? Discuss with a partner.

R4: Figure 3 shows the distribution of business-related travel at MTU Aero Engines according to mode of transportation. Why are the kilometers distributed as they are? Explain.

R5: What positive and negative effects does the airport have on its surroundings? Compile a list of pros and cons with a partner. Be sure to indicate whom the airport is in each case helping or harming.

R6: Figure 8 shows where the Munich Airport's workers live. Interpret the geographic distribution.

R7: Interpret Figure 10. With the aid of an atlas, draw a land-use diagram for the area depicted. Does geared turbofan technology have the potential to reconcile supporters and opponents of Munich-area air traffic (cf. R5)? Evaluate.

R8: Use the "STANLY Track" application (www.dfs.de) to chart flights at the Munich Airport currently under 3,000 feet.

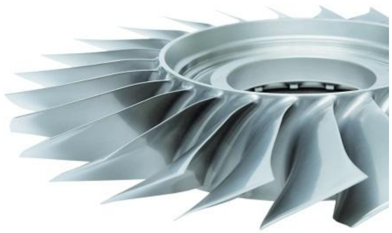
7 Location Decisions in a Globalized World

7.1 Blisk Production at MTU Aero Engines in Munich

MTU developed the geared turbofan engines of the PW1000G family in cooperation with the American manufacturer Pratt&Whitney (cf. chapter 2, F2). The essential innovation is a gearbox that allows the fan to turn more slowly than the low-pressure turbine. This reduces kerosene consumption and CO_2 emissions by at least 15 % and audible noise by around 50 %. Although the PW1000G doesn't go into regular production until 2014, airlines had already placed over 3,000 orders by mid-2013.

Airlines will be using the PW1000G primarily with the Airbus 320neo (i.e., "new engine option"), the Canadian Bombardier C-Series, and the Brazilian Embraer E-Jet. MTU Aero Engines' contribution to the PW1000G program is the high-speed low-pressure turbine and four stages of the high-pressure compressor. Development engineers at MTU have achieved particularly high levels of efficiency with the low-pressure turbine; the company was awarded two German innovation prizes for it in 2013. MTU will be outfitting the high-pressure compressors in these engines with blisks (blade-integrated disks).

A blisk, manufactured from a single piece of material, is both more resilient and lighter than a traditional disk with separate blades. Blisks also eliminate the work of loading blades into discs (F1).



F1: Blisk for the PW1000G engine
(source: MTU Aero Engines)

F2: Work stations at the lathe/milling machines
(source: MTU Aero Engines)

Interview with Jürgen Eschenbacher
(Director of Business Development and Geared Turbofan Programs)

What makes blisk production at MTU so special?
For years now we've manufactured blisks in medium-sized lots for the Eurofighter engine EJ200, so here in Munich we have extensive technological experience. Now we face the challenge of gearing up our production level to 3,000 blisks per year for the commercial aviation market. The demand from the airlines has exceeded our expectations.

Why did MTU decide to build a new production facility?
Our customers expect top quality and absolute delivery reliability. To produce in large lots while still meeting these requirements, we developed an optimized production concept around a new, 10,000 m^2 blisk facility. It's laid out along the lines of our flexible manufacturing system (F2 and F3). In this system, the movement of components between machines is controlled by a computer, and offices are arranged so that blisk developers, programmers, production planners, and quality inspectors all sit next to one another. This allows them to pool their extensive experience and ensure that our production flow remains stable at all times. And we've managed to do all this not least because of clever project management.

Can't that all be done abroad?
We looked into potential locations abroad. But there we can't be sure to achieve the same lead time and production capacity we have here. Munich also has very good local infrastructure in its favor, as well as all the benefits of the Munich/Augsburg aviation cluster. There are specialized suppliers here, companies with which we already have good business relations, and in Germany our work on fuel-saving engines is supported by the aviation research program of the Federal Ministry for Economics and Technology. Our technology experts also maintain a dialog with local universities.

F3: New blisk facility (source: MTU Aero Engines)

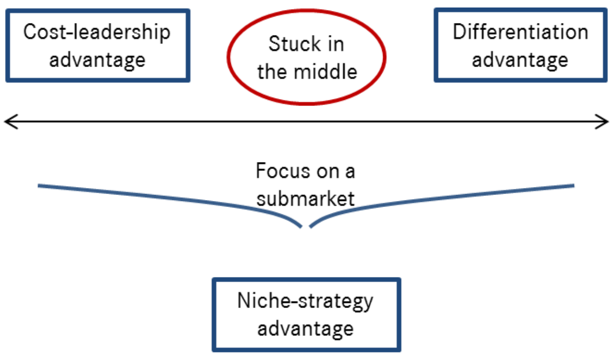
Competitive Advantages according to Michael Porter

Basic Strategies

According to Michael Porter, aerospace engineer and Professor of Business Economics at Harvard Business School, a company can choose one of three basic competitive strategies (F4).

A company that chooses the "cost leadership" strategy arranges its production in order to make a standardized product (a mass-produced article) more cheaply than its competitors do. If the company wants to turn its cost advantage into a price advantage for its customers, it must content itself with a narrow profit margin. But the "cost leader" that gains a large market share can still achieve above-average profitability through high sales volume. In the automotive industry, some manufacturers in low-wage countries try to achieve success in this way.
If a company follows the "differentiation strategy," it offers unique products that have special value for demanding customers. Its customers in turn are ready to pay a price premium. The company's products command a higher profit margin than its competitors' products do; thus the company can be profitable even with a relatively low sales volume. Most German automakers follow this strategy with their premium brands.
A manufacturer that successfully follows a "niche strategy," on the other hand, focuses its efforts on a submarket. If the competition on that market is weak or nonexistent, the "niche" manufacture can reach the status of "cost leader" while still offering a highly differentiated product.

If, however, a company attempts to occupy the middle ground between cost leadership and differentiation, it will be able to offer its customers neither a better price than its competitors do, nor any special value. Such a company will achieve low profitability at best. Porter calls this situation being "stuck in the middle." A company may find itself in falling into this dilemma if it fails to protect its cost or differentiation advantages in the face of a changing competitive environment.

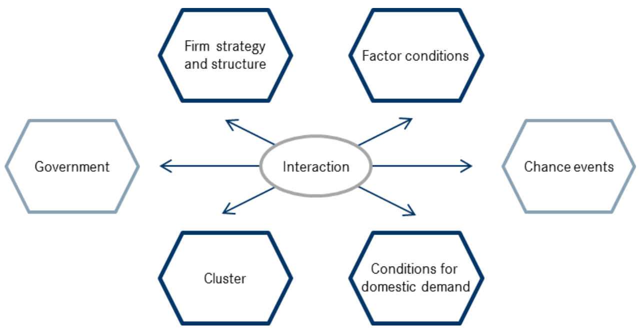


F4: Competitive strategies according to Porter

National Competitive Advantages

Whether a company will be successful in its attempts to implement one of these basic strategies, ultimately depends on business conditions at its production site. Such conditions do not only vary within states but also in the international scale. In his "diamond model," Michael Porter identifies six economic-geographic factors that have a significant influence on a country's competitiveness as a business location.

- Factor conditions: access to factors of production
    - Skilled workers
    - Raw materials and energy resources
    - Specialized knowledge: experts and research institutes
    - Capital (at low capital costs)
    - Infrastructure for transportation and communication
- Conditions for domestic demand: discerning customers on the domestic market drive demand for innovation and quality
- Related and supporting industries: innovation is fostered by geographic clusters
- Company strategy, industry-specific structure: innovation is fostered through competition
- Government: subsidies, stimulus programs, legal certainty, legislation
- Chance events



F5: Porter's "diamond model" of national competitive advantages

Review

R1: Why did MTU choose Munich as the best place to locate its blisk production? Give a thorough explanation along the lines of Porter's theory of competitive advantages.

R2: What institutions, besides MTU, make up the Munich/Augsburg aviation and aerospace cluster? Do research. Name at least five other companies and three research institutes.

R3: Give a presentation about university degree programs in Aviation and Aerospace Engineering. Be certain to touch on the importance of this field for the German economy.

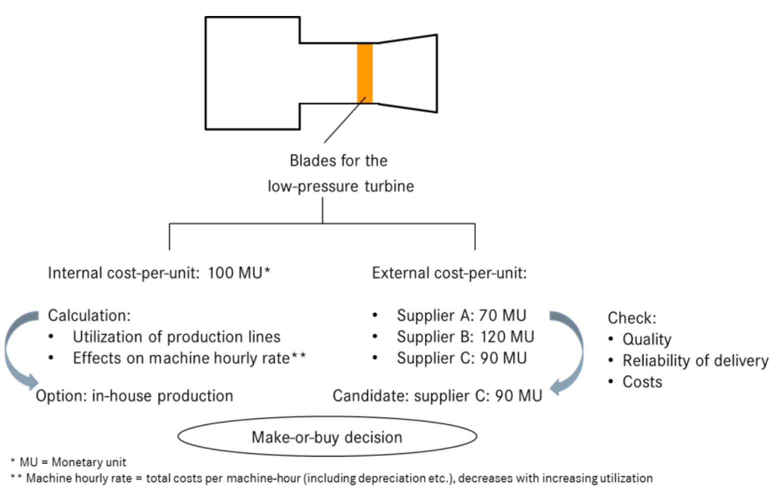
7.2 Production Strategy

Interview with Peter Kühnl
(Office of Resource Planning)

It's my understanding that standard products are built abroad, where costs are lower, and technologically advanced products here in Germany. Is that correct?
In essence that's true. The components, processes, and facilities we work with here in Munich are all in the high-end range. You call that level-one technology. However, in order to make the final products we deliver to our customers, we also need certain components of a lower technology category – level two (F2). Components at this level typically require a greater degree of manual labor.

Do these supplier products come from low-wage countries?
Not low-wage countries in the traditional sense. They do have to produce at level two, which isn't trivial. Our suppliers in Mexico, Israel, and the USA can do things more economically than we can here in Germany, while still working at the quality level we demand.

So those kinds of suppliers are responsible for everything at MTU that isn't cutting-edge?
It's not as simple as that. We also make level-two products ourselves if they're among our core competencies. We want to keep that know-how here within our own four walls. Besides, buying level-two parts elsewhere isn't necessarily more economical than producing them in Munich. When facing a "make-or-buy decision" (F1), we carefully examine offers from potential suppliers and see what we can expect in terms of product quality and delivery reliability. After all, we have to answer for those parts with our customers. In some cases we decide to produce the parts ourselves even though the unit price would be cheaper coming from one of our external providers. We do so especially in situations where outsourcing would leave our own personnel and machines at MTU underutilized. Personnel, machines – they generate fixed costs.



F1: Global resource planning (source: MTU Aero Engines)

And the level-one parts are only produced in Munich?
With some level-one components, we buy some of our stock from external suppliers. That's called "second source." It allows us to retain our own systemic and core competencies, while also attenuating fluctuations in demand – and therefore in production – by raising or lowering the quantity we purchase from suppliers. Ultimately, this method helps us optimize the cost efficiency of our production here in Munich: by keeping our workload constant, we avoid expensive conversion phases. We produce the majority of our blisks in our new facility in Munich, for example, but at the same time we purchase a smaller quantity from our American supplier. That gives us some "breathing room" in meeting market demand.

Does purchasing from external suppliers have an effect on the employment situation at MTU Munich?
Yes, a positive one. By outsourcing our level-two production, we free up personnel capacity to use in level-one production. That reinforces MTU's overall competitive position. And since we're successful, we can continue to hire new workers in Munich.

Review

R1: Make a decision tree showing MTU's options for producing or purchasing parts. On the basis of your sketch, discuss the following assertion: "In international comparison, Germany is too expensive as a place of business."

R2: What advantages does MTU's newly built Polish location offer in terms of production strategy? Explain. Make reference to your decision tree (R1) in your answer.

F2: Level-two components: vanes installed in the low-pressure turbine of a V2500 (source: MTU Aero Engines)

7.3 Setting Up MTU Aero Engines Polska

In 2007, MTU Aero Engines decided to establish a new production location – outside Germany, but somewhere in Europe (F1). Its choice fell on Rzeszów in Poland. This location now mostly handles tasks requiring a high degree of manual labor (F2, F4). One such task is the assembly of low-pressure turbine modules for the V2500 engine. This example demonstrates how the manufacturing processes performed at MTU are in fact only one step in a globalized chain of production (F3).

F1: Construction phase in Rzeszów (source: MTU Aero Engines)

Location
- At the airport, on the outskirts of Rzeszów (regional capital of southeast Poland; 170,000 inhabitants; "Aviation Valley")
- Transport hub, near Ukraine and Slovakia

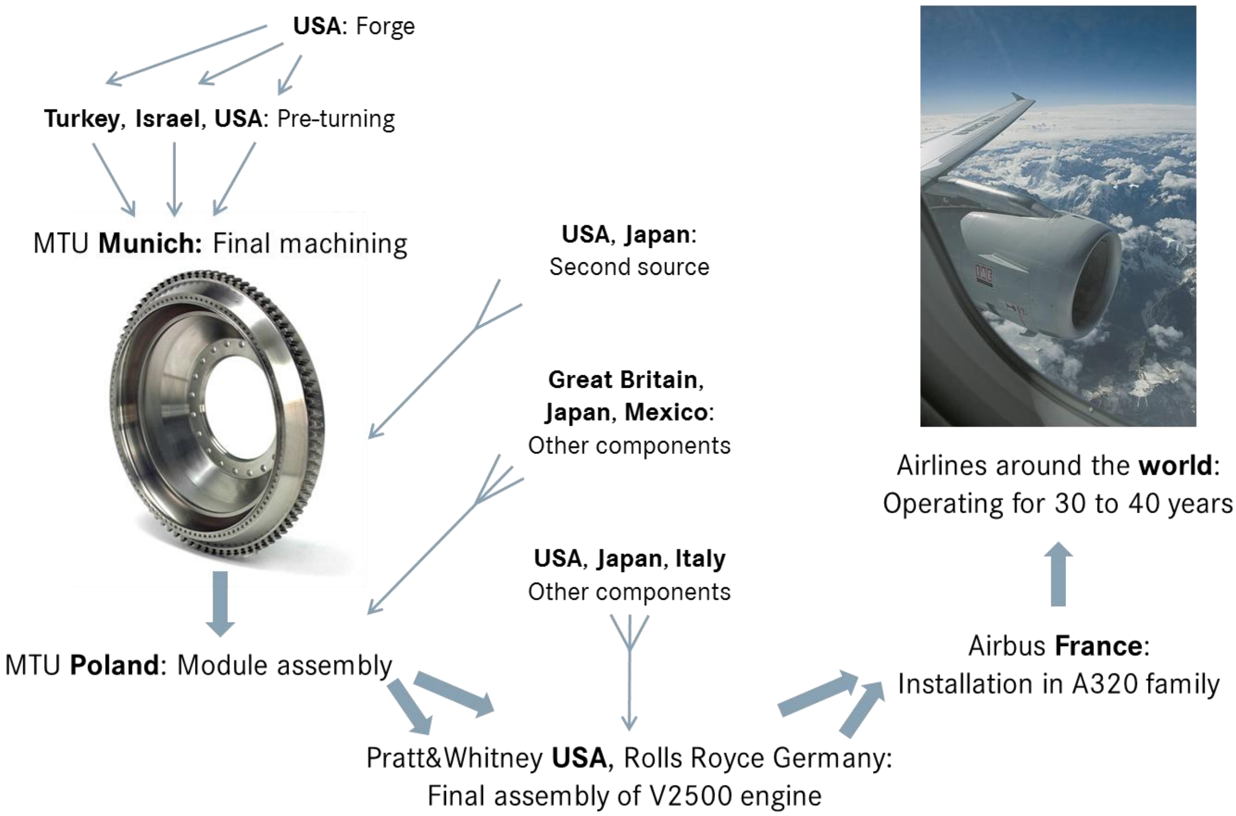
Establishment and expansion
- Built on a "greenfield" site in 2008–2009; over 50 million euros invested
- Expansion in 2013–2014; 40 million euros invested
- Employee totals: 250 (2009); 500 (2013); 750 (planned for 2020)

Production
- Turbine blades, preliminary work, module assembly
- State-of-the-art machinery

Aero engine repairs
- Hydraulic lines
- Central warehouse for certain parts

Development
- Construction of fixtures
- Installations for engine testing
- Software
- Center of excellence for uncooled engine blades

F2: MTU Aero Engines Polska



F3: Globalized chain of production: low-pressure turbine discs for V2500 engines (source: MTU Aero Engines)

Interview with Leonhard Fürg
(Project Manager, MTU Polska Expansion)

How did you proceed with the selection of a location?
We based our decision on a "filtering process" (F6). We decided it would be either Poland or Romania doing research from our desks. Then we began to narrow the selection down to individual regions. We wanted a place that had a university of technology, other companies in the aviation industry, and an international airport within one or two hours' drive at most. After applying these criteria, we had three economic areas left to focus our attention on: Kronstadt (Braşov, Romania), Breslau (Wrocław, Poland) and Rzeszów (Poland).

What did you do when you went to these regions?
We stayed multiple days in each place and looked at available properties, considering how appropriate they would be for our purposes and seeing what sort of infrastructure they have. Of course, meetings with local administrators were also on the agenda, and we spoke with university professors and vocational schools about the supply of suitable personnel. We contacted other companies that had invested in these places and asked them to share their experiences. Finally, we estimated the relative attractiveness of each location for our workers. All these factors were evaluated with a decision matrix (F5). Then we presented our top candidates to MTU's chief technology officer, and that's how Rzeszów was finally chosen.

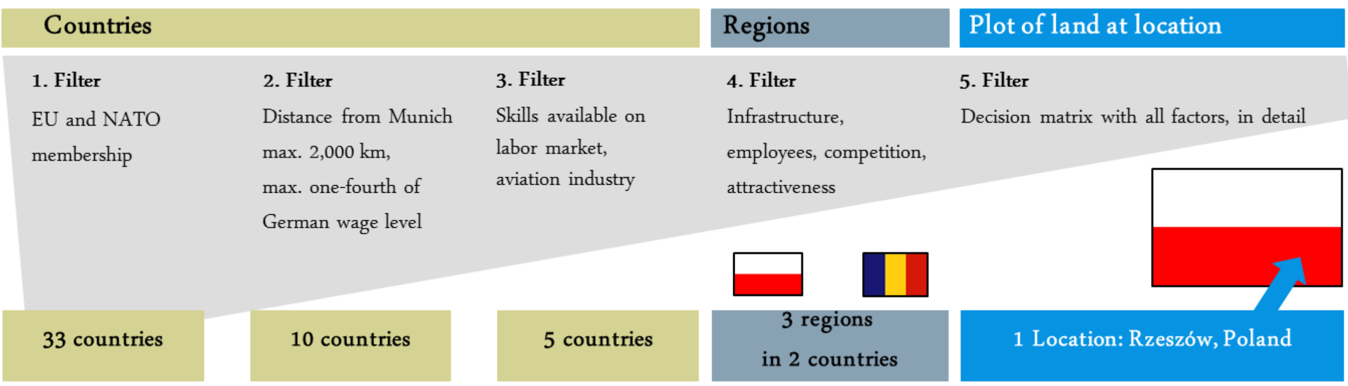
How did you find suitable personnel?
The universities and vocational schools in and around Rzeszów produce suitable graduates. These schools offer degrees in both metals engineering and aviation engineering, since other companies in the aerospace industry are also present in the area (Pratt&Whitney, Sikorsky, Snecma). Even so, after opening the new factory we gave our 250 new MTU employees from Poland six months of training in Munich. Here they got to know our technologies, systems, and processes. That was of course a big investment, but in the end it paid off.

F4: Assembly of engine blades (source: MTU Aero Engines)

Is MTU in Rzeszów an attractive employer?
You bet! We offer our employees wide-ranging benefits, expert training, and performance-based pay. The Polish applicants we get speak good English, and many have spent time working abroad. They look forward to coming to Munich for training because they're eager to learn to use the latest technology. We've also set up a center of excellence for the development of uncooled blades at MTU Polska, making it that much more attractive to our Polish specialists.

Criterion	Weight	Location A	Location B	Location C
1. Infrastructure	8	7	9	...
Land				
Supply and waste management, energy				
Transport infrastructure				
2. Human resources	10	8	7	...
3. Economic area	6	7	8	...
4. Attractiveness of location	4	9	3	...
5. Costs	9	6	8	...
6. Incentives	9	7	8	...
Total		331	346	...
Rank		7	6	...

F5: Decision matrix for the location choice (excerpt) (source: MTU Aero Engines)



F6: Filtering process for the location choice (source: MTU Aero Engines)

REVIEW

R1: How many direct flights are offered at the Rzeszów Airport? Where to? Does the city enjoy a good position within the highway grid? Evaluate Rzeszów's accessibility by airplane and commercial truck from MTU's locations in Munich, Hanover, and Berlin.

R2: Of all the chains of production at MTU, which is the longest? Determine your answer with the aid of Figure 3 and a suitable atlas map. (Measure from the forge, to MTU, to the aircraft manufacturer, disregarding "second source" manufacturers and external component suppliers.) When you've found the longest chain, estimate its total length in a straight line.

R3: What ecological or economic problems could result from MTU's globalized chain of production? Work with a partner to compile a list, then compare your list to the problems in the globalized textiles industry, where most production steps are performed in developing countries (see your textbook).

R4: Justify the criteria applied in the first filter of Figure 6. Why are they appropriate?

R5: Why did MTU consider it essential that other aviation companies be present at its future location, even though it now has to compete with those same companies for workers? Justify your answer.

R6: Review the first column of Figure 5. What specific points would MTU need to consider within each of these categories? Also, discuss how the categories are weighed (second column).

R7: Execute a roleplaying scenario based on the following situation: A politician in Rzeszów is demanding that local wages be raised to the level of wages in Munich. A representative of the companies in the region is offering a moderate wage raise of 5 % per year. Divide into two groups, one for each position. Collect arguments as a group, then choose a representative to argue your group's position. Also, choose one student to moderate.

8 Megatrends as Driving Forces of Aviation

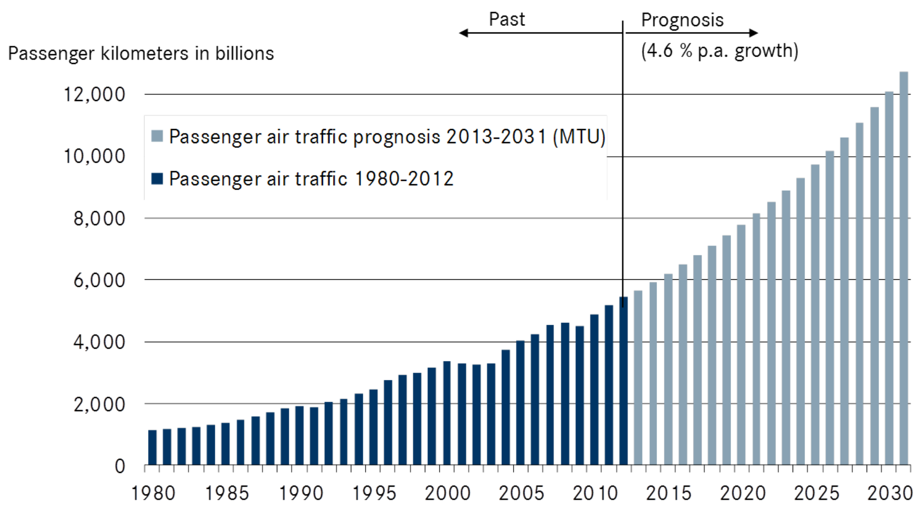
The strength of the global aero engines business depends on the number of passenger or cargo kilometers that are flown, since that is what generates demand for new aircraft and engine maintenance services. The projection for the period from now to 2030 (F2) is very promising. It is based on the assumption that current global megatrends (F1) will continue to shape our world in the future.

It has become clear that these trends are altering the balance of the world economy, shifting its focus towards the Asia-Pacific region (APac) and the Middle East (ME). These are also the regions expected to see the greatest growth in air traffic (F3). In the examples of China, India, and the Gulf Region, one can see how MTU Aero Engines is working to shape the future of aviation.

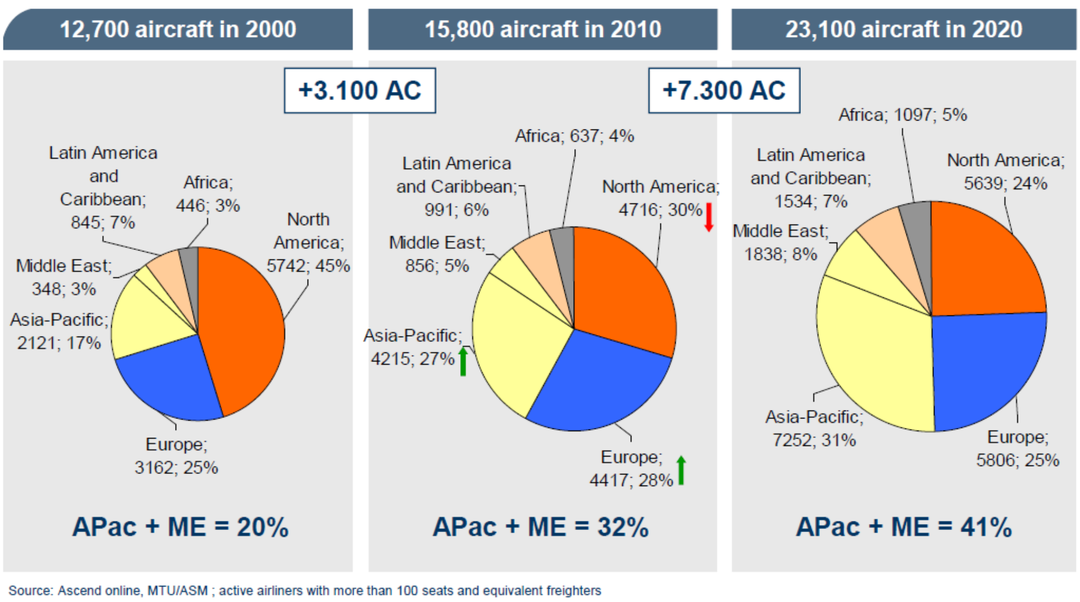
Global megatrends are defining the challenges and opportunities of the future.

- Population growth
- Demographic shift
- Urbanization
- Growing prosperity
- Modern communications technology (digitalization)
- Global trade relations
- Climate change and strains ecological damage
- Scarcity of resources
- Fossil-free automobility and aviation

F1: Global megatrends



F2: The global aero engines business (source: MTU Aero Engines/ASM March 2013, Ascend; note: passenger and cargo aircraft with turbofan engines (passenger and cargo planes, regional jets))



F3: Fleet development follows wealth and population: shift to the Asia-Pacific and the Middle East (source: MTU Aero Engines)

China

In 2003 MTU founded a joint venture with China's largest airline, China Southern. Now China Southern's engines, as well as those of other airlines, are receiving maintenance services (MRO = Maintenance, Repair, and Overhaul) at a new location in Zhuhai, near Macau. Through this location MTU can profit directly from the Asian air traffic boom.

Since 2010, MTU has been developing new suppliers in China, too. It purchases die-cast parts there, and has final processing done on engine blades. A shift has occurred in this respect since the year 2000 – away from the US, via Israel, towards Mexico and China. New suppliers strive to internalize the aviation industry's high level of quality-consciousness, while existing MTU employees receive intercultural sensibility training to deal appropriately with cultural differences, language barriers, and other work mentalities. It is crucial that the immediate cost advantages of producing in China are not canceled out by follow-up costs due to quality problems, which entail more shipping expenses and business trips.

MTU is also profiting from a growing passenger and cargo volume in China, which is generating a strong demand for aircraft. The growth in Chinese aviation, by international standards a disproportionately fast development, would not have been possible without the intensive expansion of infrastructure that took place there starting in the 1980s. Much of the demand for travel originates in the middle class, and in China the middle class is growing rapidly. By 2020, 80 % of flight demand will fall in the category of flights up to 1,700 km. This is the range the massive passenger currents will move in when traveling around China and Southeast Asia – between major cities or back and forth to regional tourist destinations. Specially enhanced versions of the Boeing 737 and the Airbus 320 will be launched in 2016 to meet this demand. These aircraft will dominate the market for a long time to come, and they can be purchased with engines made in part by MTU. The Chinese airplane project Comac won't be flying before 2018, and aero engines made in China won't be available for everyday use before 2020. But when the Chinese aviation industry does take off, MTU, with its long-standing, successful market presence, will be well positioned as a strategic partner.

Review

R1: Draw a structure diagram showing the influence of megatrends (F1) on air traffic.

R2: Why is China important for MTU? Explain.

R3: Why are foreign airlines not allowed to make direct investments in Indian ones? Justify this policy by reference to a specific development strategy.

R4: Does it make sense that taxes on kerosene in India should be high? Discuss.

R5: How plausible are the plans for the "World Central International Airport"? Give reasons for an optimistic and reasons for a pessimistic view.

India

The middle class is expanding in India, too, and its growing purchasing power represents an enormous potential: "If Indians did fly only a third as much as Americans do per capita, that would be an air travel market of 700 to 800 million passengers per year, rivaling that of the U.S.," says IATA Director General Tony Tyler.

In reality, Indian airlines suffered a joint loss of 2.5 billion U.S. dollars in 2012. They're also sitting on a mountain of debt – 20 billion dollars' worth. And there's no solution in sight, since Air India, as India's state-owned airline, uses its government subsidies to offer extremely low ticket-prices. Other airlines can't be profitable in such an environment, especially since the government levies high taxes on kerosene. Moreover, foreign airlines are prohibited from directly buying shares in Indian ones. A further obstacle is the lack of infrastructure. India's few large airports are often overburdened, many major cities have only outdated facilities (F4), and aside from Delhi, the country has no hub. Since India is only now gradually expanding its infrastructure, MTU won't be looking to invest there until around 2018.

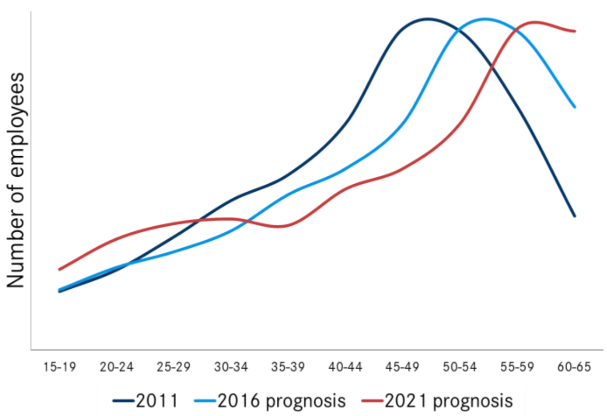
F4: International Airport of Kochi/Cochin, an Indian agglomeration of 2.1 million residents
(source: Wikimedia)

The Gulf Region (Middle East)

The Gulf Region has used its geostrategically convenient location to position itself as an important hub of air traffic. From here, destinations in North America, Europe, Africa, North Asia, East Asia, Southeast Asia, Australia, and South Asia can all be reached with connections. The "World Central International Airport" is currently under construction in Dubai. In 2025, when it reaches its final stage of expansion, it will have five airstrips and a total capacity of 160 million passengers and 12 million tons of cargo per year.

R6: Can the airport project help the United Arab Emirates overcome its dependency on petroleum production? Evaluate.

9 The Demographic Shift

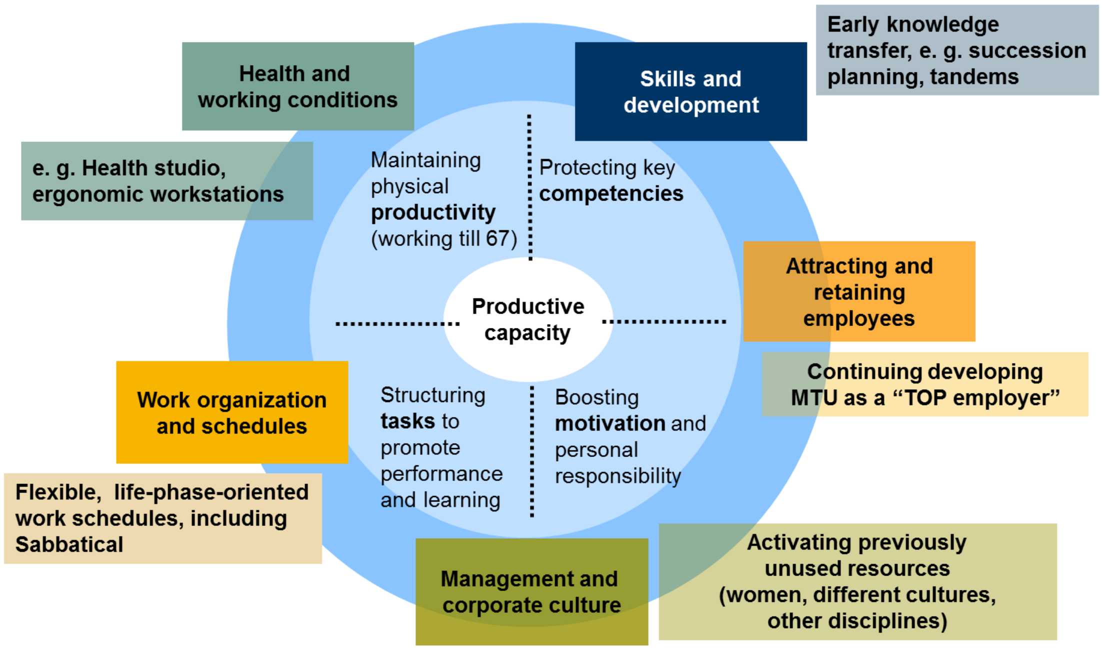


F1: Employees at MTU Aero Engines Munich divided by age group (2011, with projections for 2016 and 2021) (source: MTU Aero Engines)

The demographic shift in Germany is beginning to show its effects within companies' workforces (F1). German companies are facing a number of challenges as a result, all of which can be seen clearly in the example of MTU Aero Engines in Munich. Four spheres of activity are essential (F2):

- Maintaining productivity
- Protecting key competencies
- Boosting motivation and personal responsibility
- Structuring tasks to promote performance and learning

A company can engage its full productive capacity only when its employees can make full use of their potential. One feature of MTU which is unusual for an industrial enterprise is that it only hires employees with professional training or a university degree. MTU is reliant on qualified recruits. Women currently make up only about 15 % of the company's workforce.



F2: MTU's spheres of activity in response to the demographic shift (source: MTU Aero Engines)

The quality of MTU's employee benefits has been recognized by a series of employer awards (F3). MTU uses social networks as a way of attracting new employees and forging closer ties with current ones.

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F3: Employer awards MTU has received

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F4: MTU's presence on social networks

REVIEW

R1: Interpret the age structure at MTU (F1) with the aid of the demographic transition model. What trend can the company expect to see in the future?

R2: What challenges is MTU facing as a result of the demographic shift, and how do its human resources policies (F2) propose to solve them? Explain.