

# NEXT ENGINEERS

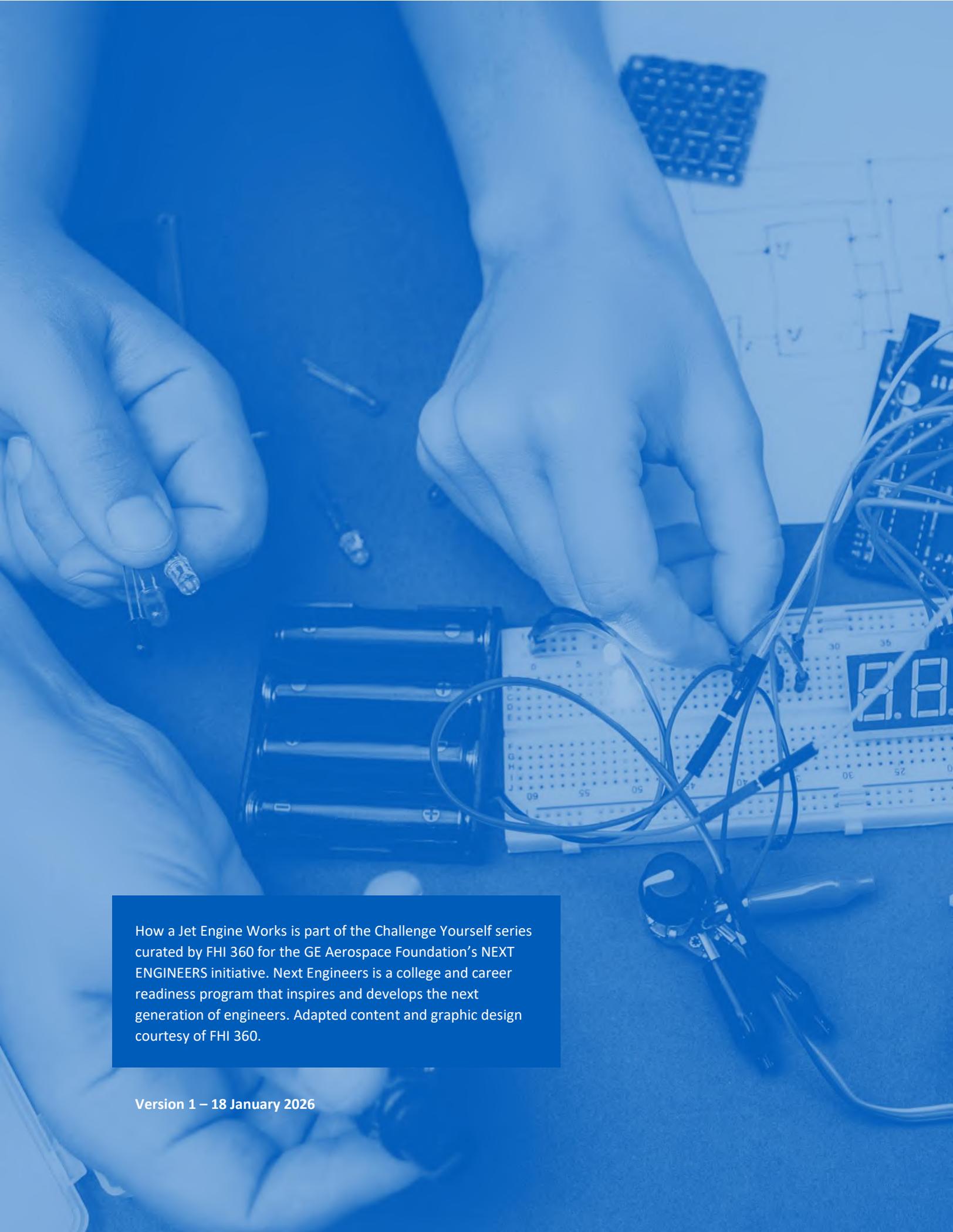


CHALLENGE YOURSELF

## Extreme Machine Part 1: How a Jet Engine Works Aeronautical Engineering



NEXT ENGINEERS



How a Jet Engine Works is part of the Challenge Yourself series curated by FHI 360 for the GE Aerospace Foundation's NEXT ENGINEERS initiative. Next Engineers is a college and career readiness program that inspires and develops the next generation of engineers. Adapted content and graphic design courtesy of FHI 360.

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## Extreme Machine Part 1: How a Jet Engine Works

### NERD OUT

#### The Turbofan

Global air travel has become so commonplace that we seldom stop to think about the amazing thing that it is – how it's possible that enormous metal objects carrying hundreds of people at a time routinely travel thousands of miles without incident.

Right at the heart of what makes this all possible is the modern jet engine (technically, the turbofan engine) – one of the most extreme machines ever built. A single [GE90](#) turbofan, for example, can produce over 400,000 Newtons (N) of thrust, survive temperatures hotter than molten lava, and operate flawlessly for hundreds of thousands of hours, ensuring that people get where they're going safely and reliably.



The GE Aerospace GE90 turbofan engine

Image by GE Aerospace is used under fair use

<https://www.geaerospace.com/commercial/aircraft-engines/ge90>

#### How Does it Work?

So how does a turbofan engine actually work? And why is making it more efficient such a hard engineering problem?

At its simplest, a jet engine does one thing: it pushes air backwards to push the aircraft forwards. This is Newton's **Third Law** in action. If you accelerate a mass of air in one direction, you experience a force in the opposite direction. That force is called **thrust**.



#### WHAT IS A TURBOFAN?

A turbofan is a type of gas turbine jet engine that uses a large front fan, powered by the engine's core gas turbine, to move a huge amount of air. Most of the air bypasses the core with only a small portion going through the engine to be combusted. Turbofans produce a large amount of thrust efficiently, making them ideal for modern commercial airliners.



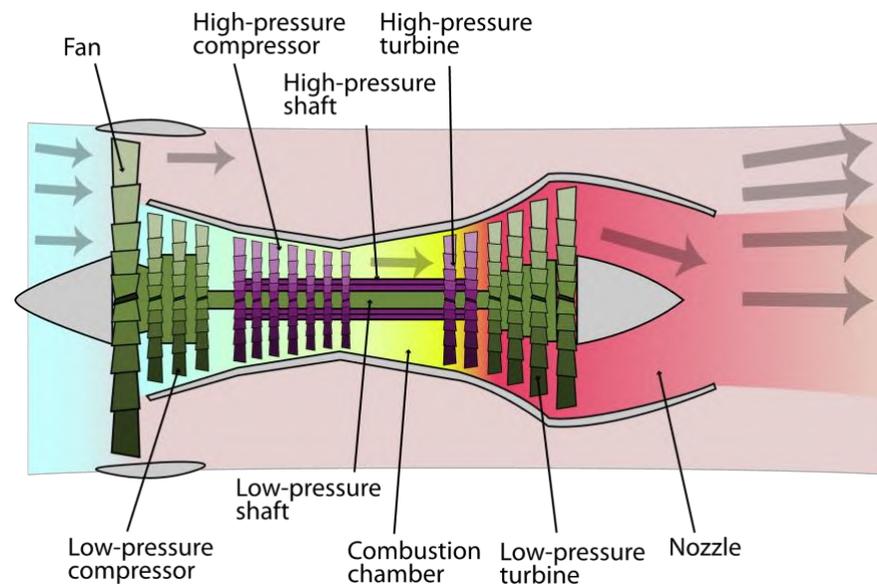
Early jet engines pushed a small amount of air very fast. Modern turbofan engines do it differently – they trade speed for mass, which turns out to be far more efficient.

A turbofan engine has two main airflow paths:

- The **combustion flow** — this is the air that goes **through** the engine’s core, including the compressors, combustor, and turbines
- The **bypass flow** — this is the air that goes **around** the core through the bypass duct

Here’s the surprising part. It might seem silly to waste all that bypass air. However, most of the thrust in a modern turbofan (80% - 90%) comes from the bypass flow, not the exhaust jet from the core. That big fan at the front is what creates the bypass flow and hence most of the engine’s thrust.

The ratio of bypass to combustion air is called the bypass ratio (BPR). Some modern turbojets, like the [GE9X](#), achieve bypass ratios of 10:1 (10 kg of air goes around the core for every 1 kg that goes through it). Generally speaking, the higher the bypass ratio, the greater the engine’s efficiency and the quieter it is.



A schematic of a high bypass turbofan jet engine  
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<https://commons.wikimedia.org/w/index.php?curid=4005530>

There are 4 key parts of a turbofan engine:

1. **The Fan:** The large fan at the front pulls huge amounts of air into the engine. As noted, some of this goes into the core but most is bypass air. This fan is driven by the low pressure turbine at the back of the engine.
2. **The Compressor:** This is the first part of the core. A series of spinning rotors squeezes (or compresses) the air entering the core to much higher pressures, each rotor adding a little more pressure. Compressing air makes it hotter and denser, something you may have noticed when using a bicycle pump. Compressed air produces far more efficient combustion.



### HIGH VS LOW BYPASS

Modern commercial airlines use high bypass turbofan engines because these are quieter and more fuel efficient, especially at lower speeds. Fighter jets use low bypass (or no bypass) turbojet engines. These are noisy and less efficient but produce far higher speeds and better accelerations.



### DIG DEEPER

This is the simplified equation to calculate the thrust of a jet engine:

$$F_{thrust} = m \times (V_e - V_0)$$

where

$m$  = mass of air flow

$V_e$  = exit velocity of air

$V_0$  = intake velocity of air

By doubling the mass of air being moved, we can double the thrust of the engine.



3. **The Combustor:** Here jet fuel is sprayed into the compressed air, and the mixture ignites and burns continuously. This produces extremely hot, high-energy gas with temperatures exceeding the melting point of metal.
4. **The Turbine:** The hot, rapidly expanding gas from the combustor blows through turbine blades, spinning them. The high pressure turbine drives the compressor while the low pressure turbine behind it drives the large fan. The energy still left in this air exits the engine at high speed as exhaust, contributing to the engine's overall thrust.

This continuous, 4-stage cycle is often summarized as “suck, squeeze, bang, blow”.

Watch these videos for an excellent summary of how modern turbofan engines work.

- [How Jet Engines Work](https://www.youtube.com/watch?v=L24Wf0VITE0) (5:01)  
<https://www.youtube.com/watch?v=L24Wf0VITE0>
- [How Does a Turbofan Engine Work?](https://www.youtube.com/watch?v=7v-lyKce7U8) (3:04)  
<https://www.youtube.com/watch?v=7v-lyKce7U8>

## Engineering Trade-offs

If turbofans are so efficient and the greater the bypass ratio the greater the efficiency, why not just make them ever bigger? After all, the perfect engine would have high thrust, great efficiency, and long life, all while being quiet.

Well, because engineering, just like life, is all about trade-offs. Improving one of these things often hurts another.

Here are some of the competing goals engineers face:

- A **bigger fan** would improve efficiency, but it would also add weight to the aircraft and increase drag. Besides, how would you attach a 100 m diameter engine to an aircraft?
- **Hotter combustion** would improve efficiency, but it would shorten the life span of the engine components, making the engine more expensive to maintain.
- Using **stronger materials** would make the engine last longer, but these are more expensive and harder to manufacture, increasing the cost of the engine.

Therefore, there is no “perfect” jet engine. Every design is a balance between three crucial factors – performance, cost and reliability. These are almost always in conflict, meaning that engineering is not about maximizing everything at once. It is about **optimizing** – about making the best possible decisions under real constraints.

For example, GE Aerospace has made thousands of small, incremental changes to their jet engines over decades. Each generation, like the [GE90](#), through to the [GENx](#), and the [GE9X](#) represents successive improvements in design, materials, manufacturing, aerodynamics, cooling, and overall system integration.



### LEARN MORE

Watch the video called [Compressors – Turbine Engines](https://www.youtube.com/watch?v=CXSi4GXUojo) (7:47) (<https://www.youtube.com/watch?v=CXSi4GXUojo>) to learn more about how jet engine compressors work.



In the next articles, we'll explore three of the best ways engineers have and continue to improve turbofan engines—and the difficult trade-offs each one brings, including increasing the bypass ratio, increasing the air compression, and increasing the combustion temperature.

Visit *The Parts of a Gas Turbine* or watch the following videos for a more in-depth look at how turbojet and turbofan engines work.

- **[How a TURBOJET Engine works](https://www.youtube.com/watch?v=GrhBrhYIFdo)** (19:54)  
<https://www.youtube.com/watch?v=GrhBrhYIFdo>
- **[Turbofan Engines: How They Work and Why They're Important](https://www.youtube.com/watch?v=VBEqMpqTiIY)** (11:46)  
<https://www.youtube.com/watch?v=VBEqMpqTiIY>
- **[Turbojet vs Turbofan Engines](https://www.youtube.com/shorts/fnujLLqNAJo)** (0:43)  
<https://www.youtube.com/shorts/fnujLLqNAJo>
- **[Jet Engine Evolution - From Turbojets to Turbofans](https://www.youtube.com/watch?v=5uKmqP3kQ2A)** (13:22)  
<https://www.youtube.com/watch?v=5uKmqP3kQ2A>

