Quick
Start

From 0 to 30,000 revolutions
in 2.6 seconds

How do you start a helicopter engine so fast that it can be used as a redundant safety engine for emergencies? The Chair of Turbomachinery and Flight Propulsion at the Technical University of Munich uses regulated compressed air to reduce the start time by up to 90%.

For safety reasons, modern helicopters generally have two turboshaft engines. This redundancy ensures that if one of the engine fails, the other engine provides the necessary power to maintain the helicopter flight or to begin a precautionary landing procedure. Therefore, multi-engine helicopters generally have excess engine power as the combined performance of both engines is usually required only during take-off and landing, while flying at high speeds, and during the ascent. At all other times, the simultaneously running engines operate only in a partial-load range, in which the fuel consumption is comparably high (figure 1). An optimized strategy for operating the engines now intends to lower fuel consumption.

Idea: Reducing the Fuel Consumption

The plan is to switch off one engine in a controlled manner (intended single-engine operation, ISEO). This requires a higher power output of the remaining engine, which improves the specific fuel consumption. As a result, fuel consumption and exhaust gas emissions decrease. This procedure is particularly useful for longer flights at continuous speed, for example, for supply flights to offshore platforms or long overland connecting flights. Research shows that up to 21% of fuel can be saved at the current state of technology.

Problem: Loss of Power

Since only one engine is used when flying in ISEO mode, this also entails a reduction in flight safety. If the running engine causes any problems, the second, previously inactive, engine cannot take over immediately, because starting the engine can take up to 26 seconds with a standard starter generator. During this start phase, the main rotor of the helicopter continues to rotate only in autorotation. This means the rotation is caused merely by the air flow of the descending helicopter. At the same time, the helicopter significantly loses altitude. Assuming that the typical rate of descent is 15 m/s, this can be more than 400 m.

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It is only after this time span that the restarted engine provides sufficient power again. The loss in altitude, which must be taken into account when flying in ISEO mode, means a limitation to the usable flying range and could be avoided by a faster engine start.

Solution: Reducing the Engine Start Time

Smaller helicopter gas turbines are usually started with a battery-operated electric motor. Because this type of starter system is optimized for weight, it can only provide a limited acceleration torque for the shaft of the core engine, the gas generator. The transmission gear between the electric motor and the engine is not designed for higher torques. Thus, to shorten the start phase of the engine, other methods are needed. One of the concepts directs a powerful jet of compressed air to the trailing edges of the radial compressor blades of the core engine to quickly stimulate shaft rotation (figure 2). This method is very effective, because most turboshaft engines in helicopters have a large leverage at the core engine shaft.
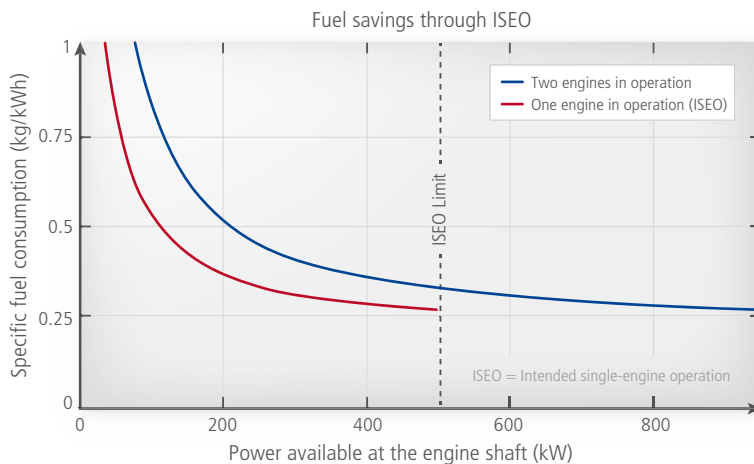
Objective: Reliable Self-Start

It is vital that the quick-start system is completely reliable. In addition, the reduction in start time must be significant enough to justify the additional weight of the quick-start system in the overall ISEO concept. Aside from the analytical calculations, the research team at the university also carries out experiments with this type of system. For this, it uses an Allison 250-C20B turboshaft on a testbed in the Chair's laboratory. For the first functionality test, a modified radial compressor enclosure was designed with five integrated de Laval nozzles (specially shaped nozzles for high air flow speeds). At first, a 13-bar compressed air supply on the testbed provided the nozzles with air. In a second step, a 200-bar compressed air tank was used.

Requirements and Challenges

Handling the high air pressures and optimizing the reaction time of the engine control unit poses exceptional challenges. On the one hand, every hundredth of a second counts during the quick start. On the other hand, the controlled components

1 High-pressure turbine: Depressurizes the hot gas from the combustion chamber and subsequently drives the compressor and, via a transmission, the attachments. Maximum rotational speed approximately 50,000 rpm.

2 Low-pressure turbine: Depressurizes the hot gas after the high-pressure turbine and subsequently uses a transmission to propel the helicopter rotors. Maximum rotational speed approximately 30,000 rpm; continuous power: 298 kW.

3 Compressor: Consists of six axial stages and a radial power stage. Maximum air rate approximately 1.5 kg/s; maximum pressure build-up: 1:7. Supplies compressed air to the combustion chamber.

4 Pot-shaped combustion chamber with injection elements and ignition plug.

5 Fuel metering unit, controlled by the dSPACE system.

6 Electric starter motor for the normal engine start.

7 Exhaust gas diffusor, depressurizes the exhaust gas to the ambient pressure.

8 Electromagnetic eddy current brake, controlled by the dSPACE system. Simulates helicopter rotors and subsequently the power requirements of the helicopter.

9 Air supply of the engine.

10 Bottle of compressed air (max. 230 bars, 15 l), supplies the compressed air required for a quick start.

Figure 1: Instead of two engines working at an unfavorable partial load, only one engine works at a higher load when using ISEO, which means it operates in a more fuel-efficient range. As a result, operating only one engines achieves the same performance as two simultaneously operated engines and uses less fuel.

Fuel savings through ISEO

— Two engines in operation
— One engine in operation (ISEO)

ISEO Limit

ISEO = Intended single-engine operation

Specific fuel consumption (kg/kWh)

Power available at the engine shaft (kW)

must work quickly and accurately. The calculated quick-start time is only three seconds, during which the engine accelerates from standstill to 30,000 revolutions per minute. This corresponds to 60% of the designed rotational speed of the core engine. During this interval, the controller must perform various control and monitoring tasks. They include controlling the fuel release valve when a certain rotational speed is reached or sending the signal for closing the compressed air valve, for example. Safety-critical values, such as the gas temperature at the rear of the combustion chamber, must also be monitored. Since the test operation requires setting
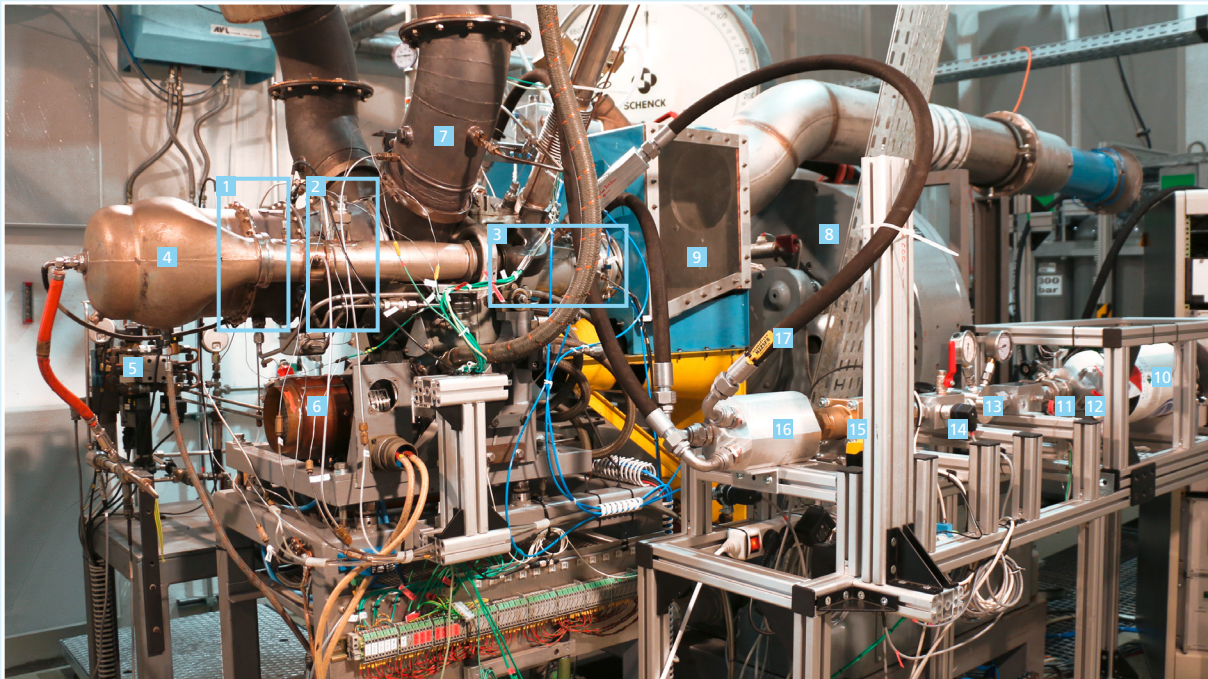
Figure 2: Overview of the testbed with the Allison 250-C20B turboshaft engine.

11 Ball valve for closing the main pressure line when filling the bottle.

12 Adapter for the bottle filling valves as well as pressure and temperature measurement.

13 Adjustable pressure regulator for maintaining a fixed output pressure at the nozzles.

14 Adapter for controlled pressure release during maintenance work and for pressure as well as temperature measurements.

15 Coaxial valve for releasing the compressed air for the quick start, controlled by the dSPACE system.

16 Distributor block for the three nozzle supply lines.

17 Connecting tube of the nozzles.

> "The open and powerful dSPACE real-time systems let us use MATLAB/Simulink to quickly and efficiently implement and use new control features."
>
> *Martin Kerler, Technical University of Munich*

various quick-start parameters, a graphical user interface such as dSPACE ControlDesk is extremely beneficial, because it offers a multitude of options to configure instruments, displays, input masks, etc. (figure 4).

Predeveloping a Control System
The team at the university performed model-in-the-loop tests to test the quick-start control system beforehand. For this, they added a model for the start phase to the existing quasi-nonlinear real-time-capable state-space model of the engine in MATLAB®/Simulink®. On the basis of the measurement data, the team extended the normal operating range of the engine by a range between standstill and engine idle. They used a numerical 1-D simulation of the actual quick-start system to define the essential system values, such as quick acceleration torque, and to derive important control parameters from them, for example, the valve opening times. These values were included in additional quick-start control algorithms. Among these algorithms are also specifications for the amount of fuel that has to be injected so the core engine can be accelerated rapidly by the hot gas generated in the combustion chamber. These early tests helped solve potential problems during the fully automated quick start and validate the related control algorithms. The next step is

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to implement the quick start in the trial engine.

Setting up an Integrated Control System

For the engine control, the team at the university used a dSPACE system that consisted of a DS1007 PPC Processor Board with a dual core, a DS2103 Multi-Channel D/A Board, and a DS2002 Multi-Channel A/D Board in a PX10 Expansion Box. The 32 channels of the output and input boards provide sufficient capacity for extensive control and monitoring tasks at the engine and the quick-start system. The controller, which was modeled in Simulink, was distributed to the two cores of the processor board. One of the cores pre- and postprocesses the output and input values and monitors the engine parameters. It also integrates the virtual Simulink engine model, which thus runs simultaneously with the real engine. The second core is responsible for the actual control tasks. This way, it was possible to implement a controller update rate of 1 ms. Using dSPACE ControlDesk, the team created a graphical user interface to control and monitor the engine and

the quick-start system. The user interface also allows for changing control parameters during engine operation without having to recompile the engine controllers. For over 20 years, the combination of a regularly updated dSPACE system (hardware plus ControlDesk) and MATLAB/ Simulink has become a powerful development tool for test and research activities on the testbed at the university. The system also offers sufficient reserves for continuing development tasks, which means it can be used in the long term.

Results of the First Test Runs

The aim of the first test runs on the engine with an independent 200-bar compressed air supply system was to achieve a fast and above all safe and reproducible engine start. The time interval during which compressed air nozzles are switched off is particularly interesting, because the compressor of the engine moves towards normal operation in only a few milliseconds. After the first test run, the team adjusted a few parameters, which lead to a stable transition from the non-stationary acceleration process to stationary idling. The quick-start system

1 Display of the engine state
2 Display of the fuel consumption
3 Alert display for engine parameters
4 Control of the engine in an emergency
5 Normal control of the engine
6 Activating/deactivating the quick-start system
7 Activating/deactivating the ignition plug
8 Activating/deactivating the electric starter motor
9 Selecting model- or hardware-in-the-loop simulation
10 Selecting the source of the compressed air
11 Selecting normal or quick start
12 Selecting the control of the engine: helicopter simulator or test bench
13 Setting the engine limits
14 Display panel for warnings regarding important engine parameters
15 D/A display for commands sent to the engine and the quick-start system
16 A/D display for input measurement values for the FADEC (full authority digital engine control)
17 Control panel for the bleed air valve
18 Control panel for the electromagnetic eddy current brake
19 Control of the pump detection logic
20 Additional displays and selection elements for the FADEC

Figure 3: Comparison of a normal start (red) and a quick start (green) of the gas turbine. A quick start reaches 60% of the maximum speed within 2.6 seconds. Compared to the 26 seconds required by a normal start, this reduces the start time by 90%.
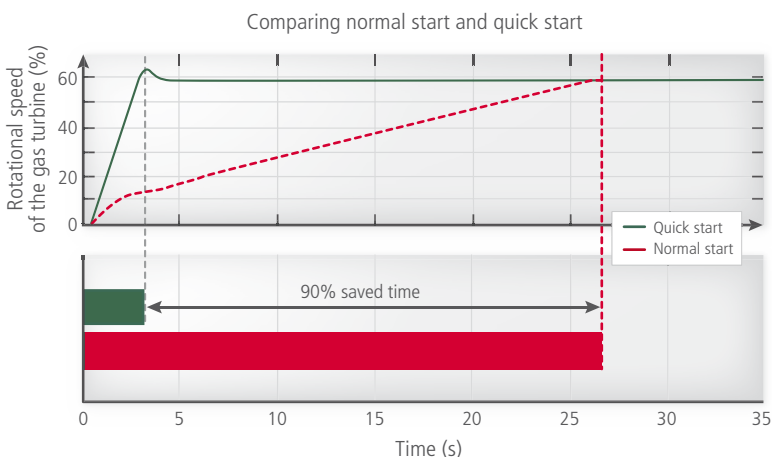
reduces the engine start time by 90% at a typical ambient temperature of 20 °C, i.e., from 26 to only 2.6 seconds. At the same time, the core engine accelerates to 30,000 revolutions per minute. The pressure inside the compressed air tank decreases from 200 to 100 bar and 1.52 kg of compressed air is consumed.

Summary and Future Prospects

This test run was able to reliably implement quick engine starts for a 300 kW turboshaft engine with an independent compressed air supply. The start times achieved exceed the predicted values and theoretically can be reduced further. The focus of ad-

Figure 4: The graphical user interface of dSPACE ControlDesk clearly displays the extensive control and display parameters for the engine tests.

> "dSPACE ControlDesk lets you clearly display all measurement values and control parameters that are relevant for operating the engine. The great flexibility of ControlDesk lets you implement new ideas fast."
>
> *Martin Kerler, Technical University of Munich*

Martin Kerler
Martin Kerler was a research associate at the Chair of Turbomachinery and Flight Propulsion at the Technical University of Munich, Germany, until the end of September 2017.

ditional research is now on thermodynamic combustion processes during quick start, the influence of the system operation on wear and tear and the life cycle, and emulating a complete helicopter powertrain. Moreover, the university team wants to test compressed air systems with higher pressures and a new nozzle geometry. The goal is to test a weight- and volume-optimized variant that can be integrated into a helicopter. The dSPACE system used for the entire development and test process has proven itself and contributed significantly to the success of the tests. ■

Martin Kerler,
Technical University of Munich