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Engine & Engine Simulation Manual

Garrett / AlliedSignal TPE331-10R-513C Turboprop

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C212-200

*For Simulation Use Only

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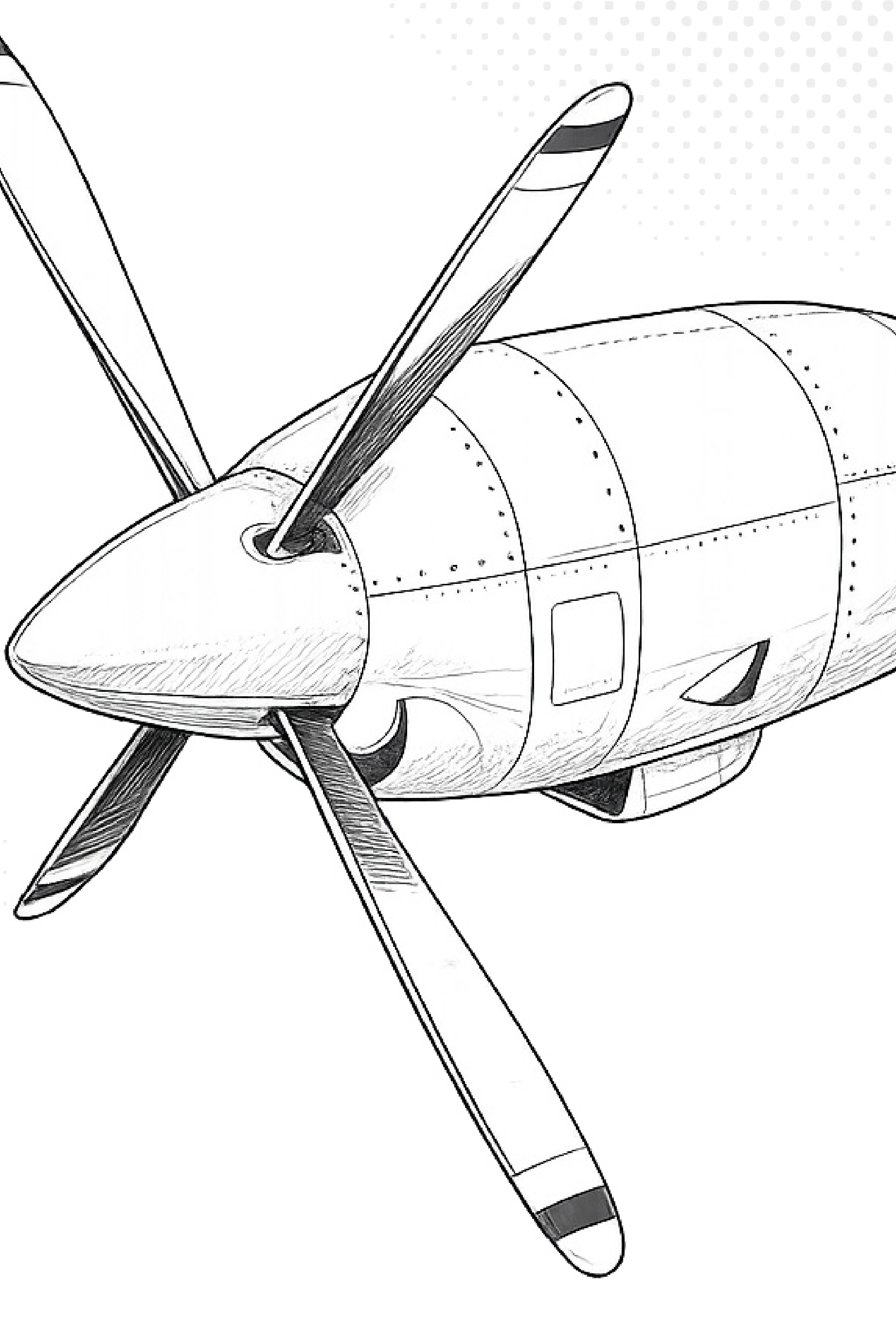
Engine Systems

This section introduces the Honeywell TPE331-10R engine installed on the Project MAX C212-200.

The following chapters cover the engine's main systems, normal operation, cockpit controls, and operating limitations to provide a clear understanding of engine operation before flight.



1. THE TPE331-10R ENGINE

This section introduces the Garrett/AlliedSignal TPE331-10R turboprop engine installed on the C-212-200, based on the relevant information from the Aircraft Operation Manual (AOM). It provides an understanding of the engine's design, operating characteristics, and control system behavior, establishing the technical foundation for Part 2, which explains how these systems have been reproduced within Microsoft Flight Simulator.

OVERVIEW

The C-212-200 is powered by two Garrett/AlliedSignal TPE331-10R turboprop engines. Each engine is rated at 900 SHP under sea-level, static, standard-day conditions at 100% RPM, with output increasing to 925 SHP when the Automatic Power Reserve (APR) system is active. Power is transmitted through a four-bladed Dowty Rotol R.334/4-82-F/13 constant-speed propeller featuring both feathering and reverse-pitch capability.

The TPE331 is a single-shaft, or fixed-shaft, turboprop engine in which the compressor, turbine, reduction gearbox, and propeller are mechanically connected to a common shaft. Unlike a free-turbine design, the gas generator and propeller cannot rotate independently. This characteristic defines the engine's operating philosophy and is fundamental to understanding its control system.

Because shaft speed remains essentially constant throughout normal operation, engine power is controlled primarily by varying propeller blade angle rather than by changing RPM. The propeller governor continuously adjusts blade pitch to regulate engine load while maintaining the selected rotational speed. This operating principle forms the basis of the control systems discussed in Section 3, including Propeller Governing mode, Beta mode, and the Under- and Overspeed Governor systems, all of which are designed around the fixed-shaft configuration of the TPE331.

The power plant, taken as a whole, comprises six subsystems:

- Power group assembly — compressor, combustion section, turbine section
- Engine control system — FCU, propeller governor (PG), propeller pitch control (PPC)
- Engine oil system — lubrication, cooling, torque sensing, chip detection
- Engine fuel system — pumps, FCU, nozzles, flow divider
- Engine starting and ignition system
- Propeller and reduction gearbox

POWER GROUP ASSEMBLY

Air enters the engine through an inlet located beneath the inlet housing before passing into a two-stage centrifugal compressor. The first-stage impeller compresses the incoming air and directs it through an interstage crossover duct to the second-stage impeller, where it is compressed further before entering the combustion section.

The engine incorporates a single reverse-flow annular combustion chamber that surrounds the turbine section, allowing the engine to maintain a relatively compact design while reducing external casing temperatures. Within the combustor, compressed air is mixed with atomized fuel supplied by the fuel nozzle and manifold assembly. During engine start, fuel is delivered only through the primary nozzles. Once combustion is established, the secondary nozzles are introduced to support normal engine operation. Two igniter plugs provide ignition during the start sequence, after which combustion becomes self-sustaining and the ignition system is automatically de-energized.

The resulting combustion gases expand through a three-stage axial turbine, which extracts the energy required to drive the compressor, reduction gearbox, and propeller through the engine's single-shaft arrangement. To maintain acceptable operating temperatures, a portion of the compressor discharge air is diverted to cool the turbine rotors before the exhaust gases are discharged around the tail cone.

PROPELLER & RPM CONTROL

Because the TPE331 is a fixed-shaft engine, constant-speed operation is achieved by balancing engine power against propeller load, rather than by decoupling the two. Four control elements do this job in pairs:

- Manual Fuel Valve (MFV) and Underspeed Governor (USG) — inside the Fuel Control Unit (FCU), control power (fuel flow)
- Propeller Pitch Control (PPC) and Propeller Governor (PG) — at the rear of the gearbox, control propeller load (blade angle)

There are two distinct modes of operation, and understanding the difference between them is the crux of this whole system:

1. Beta Mode (ground operation)

In Beta mode, propeller blade angle is controlled directly by the Power Lever (PL) through the Pitch Positioning Cam (PPC). Unlike normal flight operation, blade angle is determined by the physical position of the Power Lever rather than by the propeller governor. Oil pressure from the engine lubrication system is boosted by the Propeller Governor (PG) and metered by the PPC in proportion to Power Lever position. This pressurized oil is routed through the beta tube to the propeller hub, where it positions the blades accordingly. A pressure switch installed in the oil line between the PG and PPC illuminates the green BETA annunciator whenever this hydraulic control path is active.

Engine speed remains independently governed while operating in Beta mode. The RPM Lever adjusts the Underspeed Governor (USG), allowing the selected engine speed to be set between approximately 65% and 97% RPM. The Fuel Control Unit (FCU) then automatically schedules the fuel flow required to maintain the selected RPM as propeller load changes. Beta mode is used exclusively for ground operations, including taxiing and reverse-pitch braking during the landing roll.

The Power Lever quadrant incorporates four primary reference positions:

- **FULL REVERSE** – Commands maximum reverse blade angle with the corresponding fuel flow.
- **GROUND IDLE (G.I.)** – Produces minimum engine torque and is the required position for engine start when the propeller blades are engaged on the start locks.
- **FLIGHT IDLE (F.I.)** – Establishes the minimum fuel flow and torque permitted for flight operation while serving as the boundary between the ground and flight operating ranges.
- **TAKEOFF** – Commands maximum available engine power.

The range between **GROUND IDLE** and **TAKEOFF** corresponds to positive blade angles, while the range between **GROUND IDLE** and **FULL REVERSE** commands negative blade angles. From **FLIGHT IDLE** forward to **TAKEOFF** is the normal flight operating range, whereas movement from **FLIGHT IDLE** aft to **FULL REVERSE** is reserved for ground operation. To prevent inadvertent selection of the ground range during flight, the Power Lever quadrant incorporates a mechanical gate and stop that prevent the lever from being retarded below **FLIGHT IDLE** unless intentionally overridden.

2. Feathering & Negative Torque System (NTS)

The feathering valve, located at the rear of the reduction gearbox, may be actuated either hydraulically by the Negative Torque Sensing (NTS) system or manually by the pilot. When activated, the valve relieves hydraulic pressure acting on the propeller piston while simultaneously blocking pressure from the Pitch Positioning Cam (PPC). With hydraulic pressure removed, the propeller return spring drives the blades toward the feathered position.

Negative torque occurs when the airflow forces the propeller to drive the engine instead of the engine driving the propeller, resulting in a windmilling condition. The NTS system is designed to limit the amount of negative torque transmitted through the drivetrain by automatically increasing blade angle toward feather. Following a sudden in-flight power loss, this action reduces propeller drag before a complete feathering sequence occurs. During a windmilling air start, the NTS system also provides continuous blade angle modulation to maintain an appropriate level of negative torque while the engine accelerates.

The Aircraft Operation Manual (AOM) considers the NTS system a safety-critical component and requires it to be fully serviceable before flight. Certified takeoff distance and single-engine climb performance assume that the system will automatically reduce propeller drag following an engine failure during or immediately after takeoff.

STARTING LATCHES: The propeller is spring-loaded toward full reverse, held at ~0° by two spring-loaded starting latches until sufficient RPM builds enough centrifugal force to release them. Full reverse pitch must be selected on ground shutdown specifically so those latches re-engage for the next start.

ENGINE FUEL SYSTEM

Fuel is supplied from the aircraft tanks through the fuel shutoff valves to the engine-driven pump assembly, which consists of a boost pump and a high-pressure pump separated by a bypass filter. From there, fuel is delivered to the Fuel Control Unit (FCU), where it is metered according to engine operating requirements. To prevent fuel icing, a thermostatically controlled anti-ice valve diverts a portion of the high-pressure fuel through an oil-to-fuel heat exchanger whenever fuel temperature falls below 5 °C.

The FCU incorporates three primary control devices, each responsible for a specific operating regime:

1. **Underspeed Governor (USG)** regulates engine speed between approximately 65 ±1% and 97% RPM during Beta mode. It prevents the engine from accelerating above the RPM selected by the pilot.
2. **Manual Fuel Valve (MFV)** meters fuel flow to control engines power throughout the operating range. It functions in both Beta and Propeller Governing (PG) modes and is the component directly actuated by the Power Lever while operating in PG mode.
3. **Overspeed Governor (OSG)** serves as an independent safety device. In the event of a propeller governor malfunction, it limits engine speed to approximately 103% to 105% RPM by reducing fuel flow.

After leaving the FCU, fuel passes through the enrichment valve, the Torque Limiting and Temperature Limiting (TTL) valve, the fuel flow transmitter, and the engine shutoff valve before reaching the flow divider. The flow divider distributes fuel to the primary and secondary fuel manifolds, which supply ten dual-orifice fuel nozzles. During engine start, fuel is delivered only through the primary manifold. Once combustion is established, both the primary and secondary manifolds are supplied for all normal phases of operation.

The engine shutoff valve opens automatically when a speed switch senses approximately 10% RPM during engine start and remains open throughout normal operation. Fuel flow may be interrupted either electrically by selecting the cockpit **FUEL** switch to the OFF position or mechanically by operating the emergency shutdown lever.

LIMITS & INSTRUMENTATION

The figures below are the AOM's operating limits for the -10R as installed in the C-212-200.

RPM LIMITS

Condition	% RPM
Takeoff / Maximum Continuous	100.0
Maximum Cruise	98.0
Normal Cruise	96.1
Minimum In-Flight Cruise	96.0
Continuous Overspeed	101.0
Transient, max 5 min	101.5
Transient, max 30 sec	105.5
Transient, max 5 sec	106.0
Never Exceed	>106.0

CAUTION: Operation between 18% and 28% RPM should be avoided except transiently during start and shutdown — this band is also where windmilling is outright prohibited (see below).

WINDMILLING LIMITS

RPM Range	Max Permissible Time
0–5%	No limitation
5–10%	30 min
10–18%	5 min
18–28%	Prohibited
28–100%	1 min

TORQUE & EGT LIMITS

Parameter	Limit
Max torque, continuous	100.0 %TQ
Max torque, APR on (5 min)	102.8 %TQ
Torque, no maintenance action required below	104.4 %TQ (if not exceeded > 5 min)
Max EGT, takeoff / max continuous	650°C
Max EGT, starting (air/ground), 1 sec	770°C

A Torque and Temperature Limiting System (T/TL) enforces the 100% torque and 650°C EGT ceilings automatically: its computer takes inputs from the torque ring transducer, the Single Red Line (SRL) EGT controller, and RPM, and when either limit is reached it drives a torque limiter valve that bypasses metered fuel back to the pump inlet, trimming fuel supply before the limit is exceeded. The SRL controller itself removes the need for the pilot to reference correction charts — it folds in P2/P5 pressure-altitude compensation and delivers a single, constant-temperature-equivalent EGT reading. Automatic Power Reserve (APR), when armed, automatically raises the limits on the opposite engine if one engine loses significant torque — biasing the EGT limit down by 26°C (freeing up headroom to that same 26°C) and allowing torque to run 2.8% higher, while also illuminating the APR annunciator.

OIL LIMITS

Parameter	Limit
Oil pressure, green arc	70–120 psi
Oil pressure, minimum at ground idle	40 psi
Oil pressure, above 23,000 ft, never below	50 psi
Oil temperature, green arc	55–110°C
Oil temperature, red line (max)	127°C
Oil temperature, min for airstart	4°C

Instrumentation follows the same layout throughout: an RPM (tachometer) indicator per engine with a green arc 96–100%, torque indicators reading % of rated power with a green arc to 100% and an amber band to 104.4%, and an EGT indicator with a red warning light at 650°C. A CHIP DETECTOR light per engine comes on when a magnetic chip detector in the lower reduction gearbox picks up metallic particles in the oil, and an OIL PRESSURE light comes on below 40 psi.

2. ENGINE SIMULATION

This section describes how the TPE331 engine and propeller systems presented in Part 1 are represented within the simulation. It explains the modeled engine and propeller behavior, optional maintenance features, and the long-term engine management systems available through the Electronic Flight Bag (EFB).

SIMULATED SYSTEMS

The engine simulation is designed to reproduce the operating characteristics of the Garrett/AlliedSignal TPE331-10R as installed on the C-212-200. Particular emphasis has been placed on accurately reproducing the two distinct operating modes described in Part 1: Beta mode during ground operations and Propeller Governing (PG) mode during flight.

In Beta mode, the Power Lever directly controls propeller blade angle, providing the immediate response required for taxiing and reverse thrust. Once the Power Lever is advanced beyond Flight Idle, control transitions to Propeller Governing mode, where engine power is controlled by fuel flow while the propeller governor automatically maintains the selected RPM.

In addition to the core engine simulation, an optional maintenance system is available through the EFB. When enabled, the simulation tracks engine wear, oil consumption, contamination, instrument variation, and the effects of improper engine operation over time. This feature is disabled by default, allowing the aircraft to operate without persistent engine management unless selected by the user.

PROPELLER AND RPM BEHAVIOR

The fixed-shaft design of the TPE331 is reflected throughout the propeller simulation and forms the basis of the aircraft's engine handling characteristics.

1. **Beta Mode**
   With the Power Lever positioned below the Flight Idle gate, the engine operates in Beta mode. Propeller blade angle is commanded directly by Power Lever position, allowing precise thrust control during taxi, ground maneuvering, and reverse thrust operation. Engine RPM remains regulated by the RPM Lever through the Underspeed Governor within the normal operating range of approximately 65% to 97% RPM.
2. **Propeller Governing Mode**
   Advancing the Power Lever beyond Flight Idle transitions the engine into Propeller Governing mode. In this regime, the Power Lever commands engine power while the propeller governor continuously adjusts blade angle to maintain the RPM selected by the RPM Lever. Engine acceleration and deceleration are modeled with realistic spool characteristics, requiring a short period for the engine and propeller to stabilize following significant power changes.
3. **Starting, Feathering, and Windmilling**
   During engine start, the propeller blades remain secured on the start locks until sufficient engine speed is reached to release them. This prevents blade movement during the initial stages of the start sequence.

   Feathering behavior follows the operation described in Part 1. Manual feather selection and Negative Torque Sensing (NTS) operation are both simulated. Following an in-flight power loss, the propeller automatically moves toward feather to reduce aerodynamic drag. Windmilling characteristics are also modeled, with propeller RPM and blade angle responding to aircraft airspeed and engine condition.

   For consistent engine starts, the Power Lever should be returned to the reverse range before engine shutdown, allowing the propeller to settle correctly onto the start locks for the next start.

ENGINE HEALTH

Each engine maintains an internal health value that represents its overall mechanical condition. Although this value is not displayed directly, it influences engine performance, reliability, and starting characteristics over time. The system is intended to simulate gradual engine wear across multiple flights rather than the effects of a single operation.

As engine health decreases, fuel efficiency is gradually reduced, requiring more fuel to produce the same power output. Once engine health falls below approximately 35%, the probability of an in-flight flameout increases progressively. An engine that reaches zero health is considered failed and will no longer operate until maintenance is performed.

Engine health does not recover automatically. Restoration requires maintenance through the EFB, as described in Section 12.
Reduced engine health may also affect engine starting characteristics. Worn engines are more susceptible to failed start attempts, prolonged start sequences, and elevated temperatures during engine start, making proper operating technique increasingly important.

EXTENDED ENGINE SIMULATIONS

Extended Engine Simulations is an optional realism feature available through the EFB Maintenance page. The feature is disabled by default. When disabled, engine indications and performance remain consistent with the standard aircraft simulation.

When enabled, each engine develops its own operating characteristics throughout its service life. No two engines are identical, and individual differences persist until the engine is replaced.

The simulation models the following long-term characteristics:

- Small but persistent differences between the left and right engines in exhaust gas temperature (EGT), oil pressure, oil temperature, and fuel flow. These characteristics are established when an engine is created and differ each time a replacement engine is installed.

- Progressive variation in engine indications as operating hours accumulate. Older engines gradually diverge further from nominal values than newly installed engines.
- Environmental aging based on operating conditions. Engines exposed to prolonged operation in hot climates, low-altitude environments, or coastal regions may exhibit additional indication drift over time.
- Gradual sensor aging, introducing small fluctuations and measurement variation independent of the engine's mechanical condition.
- Permanent EGT indication degradation following engine overtemperature events. This effect is not completely removed by routine engine repair and remains part of the engine's operating history.

OIL SYSTEM

Oil quantity is dynamically simulated throughout engine operation rather than remaining fixed.

During engine start, a portion of the oil supply enters the lubrication system, resulting in a temporary reduction in tank quantity. During normal operation, oil quantity decreases gradually as the engine consumes oil. Consumption increases slightly when operating at elevated temperatures.

Each engine is assigned an individual seal condition when created or replaced. Seal condition remains unchanged throughout the life of that engine and determines its baseline oil consumption rate. Engines with good sealing characteristics consume very little oil, while others may exhibit noticeably higher consumption despite otherwise normal operation.

Operating with insufficient oil quantity accelerates engine wear and negatively affects overall engine health. Oil quantity should therefore be monitored regularly, particularly during extended flights or long-term aircraft operation.

CONTAMINATION AND CHIP DETECTION

Both the reduction gearbox and engine oil accumulate contamination during normal operation. The rate of contamination depends on engine operating conditions and the environments in which the aircraft is used.

Contamination accumulates more rapidly during prolonged operation at or near maximum rated power and during taxi or ground operations on unpaved surfaces such as grass, dirt, gravel, or similar terrain. These operating conditions are fully supported by the simulation but will increase long-term engine wear when encountered frequently.

The **CHIP DETECTOR** annunciator monitors contamination together with overall engine condition. A built-in hysteresis prevents the indication from cycling rapidly as contamination approaches the activation threshold. Once illuminated, the annunciator normally remains on until engine condition is restored through maintenance.

ENGINE MAINTENANCE

Engine condition is monitored and managed through the EFB Maintenance page. Two maintenance actions are available for each engine.

Replace Engine installs a new engine and completely resets its operating condition. Engine health, oil quantity, operating hours, and contamination are restored to new-engine values. When Extended Engine Simulations is enabled, the replacement engine receives a newly generated operating profile, including unique baseline values for engine indications and long-term characteristics.

Repair Engine restores the existing engine without replacing it. Engine health is returned to near-new condition, and accumulated contamination is removed. However, the engine retains its identity, including operating hours, environmental history, and the unique indication characteristics established when it entered service. This behavior is intended to represent an overhaul or major maintenance event rather than a complete engine replacement.

For users operating a persistent aircraft across multiple flights, these maintenance actions provide long-term management of engine condition and reliability while preserving the operational history of each engine.