CHROMALLOY

The PMA Advantage:

Quality, Compliance, and Cost Savings for Engine Operators

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Chromalloy PMA Snapshot

- Use of Chromalloy's Parts Manufacturer Approval (PMA) parts can offer significant cost savings to customers compared to Type Certificate Holder (TCH) parts.[1]
- Chromalloy offers over 62 Federal Aviation Administration (FAA) approved PMA parts and has sold over 400,000 parts worldwide with over 6 billion part flight hours, all without any Airworthiness Directives (AD).[2]
- PMA parts are designed, developed, and manufactured following rigorous engineering processes with FAA regulatory oversight and certification.[3]
- The FAA has strict regulatory requirements for non-TCH applicants to develop and manufacture equivalent replacement parts for aircraft engines.[4]
- Chromalloy's PMA parts maintain the same or higher quality standards as TCH parts and are equivalent to TCH parts in form, fit, function, capability, and durability.
- The FAA conducts an extensive review of each element of the design and Chromalloy's ability to manufacture under its quality system demonstrating compliance with FAA regulations before approving PMA parts.[5]
- For complex PMA parts that are not licensed by the TCH, the FAA requires applicants to follow a strict "Test and Computation" methodology to ensure parts are equivalent in form, fit, function, capability, and durability.[6]
- PMA parts provide an alternative supply chain, reducing the risk of delays in engine overhauls due to, for example, TCH supply chain constraints.
- The use of PMA parts and DER repairs can offer substantial customer savings for a mid-life engine over time.[7]

The Economics of Using Chromalloy PMA Parts

Chromalloy's PMA parts are designed, developed, and manufactured following a rigorous engineering and regulatory process set forth by the FAA which governs the development and certification of PMA parts.[8] This process ensures that Chromalloy's PMA parts are equivalent to TCH parts in form, fit, function, capability, and durability. The FAA's certification process promotes regulatory compliance to the airworthiness standards for PMA articles through their regulatory oversite responsibility.[9]

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[1] https://www.chromalloy.com/solutions/#parts

[2] https://www.chromalloy.com/chromalloy-secures-faa-approval-of-cfm56-lpt-vane-up-change-pma/

[3] 14 Code of Federal Regulations (14 CFR) Part 21, Certification Procedures for Products and Articles, Subpart K, Parts Manufacturer Approvals.

[4] AC33-8 Guidance for Parts Manufacturer Approval for Turbine Engine and Auxiliary Power Unit Parts under Test and Computation.

[5] 14 CFR Part 21, Subpart K, Parts Manufacturer Approvals. See also, FAA Order 8110.42, which has been in place since 1995.

[6] 14 CFR § 21.303(5), FAA Order 8110.42D.

[7] https://www.chromalloy.com/solutions/#parts

[8] 14 CFR Part 21, Certification Procedures for Products and Articles, Subpart K, Parts Manufacturer Approvals.

[9] 14 CFR Part 21, Subpart K, Parts Manufacturer Approvals. See also, FAA Order 8110.42, which has been in place since 1995; 14 CFR § 21.303(5), FAA Order 8110.42D.

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Cost Savings Using PMA Parts

Chromalloy's new PMA parts are typically available to its customers at a lower price than the relevant TCH's published price. Despite the typically lower cost, PMA parts maintain the same or higher quality standards. Chromalloy's records demonstrate that it currently maintains over 62 FAA approved PMA parts and has sold over 400,000 parts worldwide with over 6 billion part flight hours without any ADs.[10] A key advantage to PMA parts is that they are typically manufactured with tighter tolerances than TCH parts and, therefore, may result in improved engine performance and higher repair yields over time. Combining Chromalloy's PMA parts and FAA approved Designated Engineering Representatives (DER) repair solutions, Chromalloy can offer its customers substantial savings per shop visit. For legacy engines, Chromalloy offers a suite of FAA approved DER repairs and PMAs that can generate substantial savings on shop visit costs. [11] With other mid-life engines, shop visit cost savings can continue to grow as additional new PMA parts and proprietary DER repairs are developed and brought to market.

Cost Savings Example

As a cost savings example, a PMA blade may be priced at 70% of a TCH's Catalog List Price (CLP). This scenario allows for that 30% difference to be a direct savings. In a typical replacement of 80 blades (which are fully replaced every 18,000-20,000 cycles), the use of PMA blades would provide a customer with an average savings of $408,000 per overhaul (for example, TCH 2025 CLP = $17,000 per blade X 80 parts in a set = $1,360,000. If the PMA cost is 70% of CLP, that equals $952,000 per set of blades).

Supply Chain Improvements

Airlines, MROs, and leasing companies oftentimes encounter delays in engine overhauls. One contributing factor stems from a strained TCH supply chain for replacement parts. When end users only have a single provider for a given part, capacity constraint risks increase the potential to disrupt or even shut down the supply chain without feasible alternatives. Diminished service life of parts due to quality escapes, service bulletins, or ADs in recent years have caused single source forging suppliers to consume raw materials and forgings in increased amounts, thus resulting in part supply shortages. PMA parts, however, offer alternative options to alleviate supply chain risks from single source parts and support timely engine overhauls.

Type Certificate Holder's Focused on New Engines

Another factor contributing to mid-life engine overhaul delays surrounds each TCH's focus on newer engines with nearly all those engines including maintenance and warranty agreements. For example, certain components have a shorter time on wing and, therefore, require overhaul sooner than expected. This stresses the TCH supply chain producing parts supporting newer engines, thus creating delays for customers with mid-life or legacy engines. Chromalloy's PMA parts offer a separate supply chain that is essentially entirely vertically integrated, thus alleviating delays often found in the TCH supply chain.

Regulatory Compliance Requirements

The FAA maintains strict regulatory requirements for non-TCH applicants to develop and manufacture equivalent replacement parts for aircraft engines. This process outlines the requirements to develop equivalent replacement parts. For complex PMA parts that are not licensed by the TCH, the FAA requiresthat applicants follow a strict "Test and Computation" methodology[12] to ensure parts are equivalent.

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[10] https://www.chromalloy.com/chromalloy-secures-faa-approval-of-cfm56-lpt-vane-up-change-pma/

[11] https://www.chromalloy.com/solutions/#parts

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The process follows 8 steps:

1. Develop an agreed Part Specific Certification Plan (PSCP) with the FAA.[13]
2. Complete a safety assessment of the part and operating environment.[14]
3. Use reverse engineering to create design specifications for the PMA.[15]
4. FAA approval of PMA design and test plans.[16]
5. Develop production processes to meet the design requirements.[17]
6. FAA approval of production parts as conforming to design.[18]
7. Final part and specimen testing to confirm equivalency between PMA and TCH parts.[19]
8. FAA review of all test data and final PMA approval.

Part Specific Certification Plan (PSCP)

The PSCP defines and documents the requirements and tasks for FAA approval of a PMA.[21] Once the PSCP is accepted by the FAA, it documents the commitment between the FAA and the PMA applicant. FAA resources are planned and committed for the project's completion using the projected milestones within the PSCP.

Prior to completing the PSCP, Chromalloy performs a full assessment of the TCH certification and completes a comprehensive Failure Modes and Effects Analysis (FMEA). The certification assessment and FMEA are then used by Chromalloy and the FAA to evaluate and finalize the PSCP which can impact the manufacture of a PMA part.

Safety Assessment

The FAA requires that the PMA applicant conduct a safety assessment pursuant to 14 CFR Part 33, § 33.75 - Safety Analysis. This can include a review of fleet history, known failure history and failure modes, part change progression, service bulletins related to the part, and part repair history and yields. Chromalloy typically works with multiple airline partners and customers to extract extensive fleet and operational data for the part.

Regulatory Framework for PMAs

Chromalloy's PMA design process follows the FAA regulatory framework consisting of regulations,[22] Orders, and Advisory Circulars (AC). AC33-8—Guidance for Parts Manufacturing Approval of Turbine Engine and Auxiliary Power Unit Parts under Test and Computation—provides guidance on demonstrating compliance with regulations for the development of complex gas turbine parts. AC33-8 also provides detailed templates for typical gas turbine components—listing relevant characteristics critical to functionality, part/system failure modes to be considered, and methods of risk mitigation and control. The template for a cooled turbine blade includes 84 items for consideration of substantiating data, testing to demonstrate equivalence, and showing compliance for certification.

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[12] AC33-8 Guidance for Parts Manufacturer Approval for Turbine Engine and Auxiliary Power Unit Parts under Test and Computation.

[13] https://www.faa.gov/sites/faa.gov/files/aircraft/air_cert/design_approvals/dah/ePSCP_guide.pdf.

[14] FAA Order 8110.42C Para. (b).

[15] FAA AC 21.303-4 para 26.

[16] FAA Order8110.4C.

[17] https://www.faa.gov/sites/faa.gov/files/aircraft/air_cert/design_approvals/dah/ePSCP_guide.pdf

[18] AC 21.303-4 para 27 (c).

[19] FAA AC 21.303-4 Para. 25.

[20] 14 CFR 21.3109(a).

[21] https://www.faa.gov/sites/faa.gov/files/aircraft/air_cert/design_approvals/transport/CPI_guide.pdf, at paragraph 1.3.5.

[22] 14 CFR Part 21 and Part 33.

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Reverse Engineering and Creation of the PMA Design

Chromalloy measures a statistically significant sample size of TCH parts with highly accurate reverse engineering techniques to characterize certain aspects of the part design and operational characteristics. Reverse engineering includes the development of an engine airflow system model with engine part dimensional and test data. This allows Chromalloy to, for example, use system-level airflow and computational fluid dynamics analyses to define the operating environment around the part, such as local temperature distribution and cooling system pressures. Tolerances developed by reverse engineering are typically more restrictive than the TCH part design drawings and specifications.

Chromalloy's reverse engineering process is extensive and comprehensive in that it includes:

- Structure.
- Shapes and tolerances.
- Alloy chemistry and microstructure.
- Characterization and statistical evaluation of airflow tolerances, including measurement of individual airflow distributions, pressures within the part, and cooling hole dimensions.
- Coatings chemistry and application methods.
- Crystallographic orientation (single crystal parts only).
- Dimensions and detailed tolerances for all part features.
- Frequency response across all engine operating conditions.
- Any other relevant characteristics of the part as defined in the PSCP or Chromalloy's proprietary reverse engineering processes.

The process replicates the critical design and operational features of the TCH part, including pertinent material properties, to ensure the PMA design exhibits the same or better service experience and durability as that of the TCH part. Chromalloy then creates, for instance, design drawings and specifications to ensure the PMA part performs equivalent to or better than the TCH part. As part of the design process, Chromalloy also evaluates the PSCP and reverse engineering data to create detailed test plans. Generally, more than a dozen test plans are developed to support Chromalloy's PMA applications.

FAA Approval of PMA Design Specifications and Test Plans

Upon completion of reverse engineering and the proposed design, Chromalloy submits the design documentation and test plans to the FAA for approval. The FAA's review is extensive and includes an evaluation of reverse engineering data for completeness, compliance with the PSCP, consistency with the Safety Assessment, and compliance with FAA regulations and guidance. FAA approval is required before the PMA application is permitted to move forward.

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Part Characterization

The PMA design process begins with the characterization of a sample of new TCH parts. This includes measurement of geometry, weight and moment weight, modal frequency and mode shapes, cooling airflow (flow and pressure distribution, and overall capacity), alloy and coating properties, chemistry, microstructure, application method, and functional characteristics, evaluation of surface finishing, and application of anticipated NDT inspections (e.g., dimensional, FPI, Xray, UT, grain etch, and Laue). The data is used to establish nominal design requirements and production inspection tolerance limits.

For example, alloy microstructure and thermal cycles are characterized by using a combination of metallurgical evaluation and property testing (e.g., tensile, creep, and fatigue) using specimens from TCH parts. During PMA manufacturing process trials, the same metallurgical and property testing is applied to PMA trial parts. PMA test results then feed back into the design requirements for alloy processing and heat treatments.

A similar approach is used to define coating requirements. Microstructure, thickness, coverage, and defects are measured directly from TCH part specimens. Specimens taken from TCH parts are used for property and functional testing (e.g., spallation, oxidation, erosion, and corrosion). The same measurements and testing are conducted on PMA trial parts to define the coating process requirements (e.g., surface preparation, application method, and process parameters) and demonstrate equivalency in controlled lab tests.

Other testing and inspections are conducted on new and engine run TCH parts to support thermal/structural analysis, future Continued Operational Safety (COS) activities, and support or refine the FMEA and the PSCP.

Engine Characterization

The engine application for the PMA part is used to understand the operating conditions of the part and evaluate engine hardware that directly interface with, or could be affected by, the target PMA part through system effects. Engine operating data, systems, instrumentation, controls, and hardware are characterized. The effort is focused on modules, systems, and components that affect overall engine thermodynamics, aerodynamics, and secondary airflow characteristics, and are critical to defining external aerodynamic and thermal conditions, cooling airflow conditions, structural loading, and interfaces for the target PMA part.

Engine Analysis

Engine characterization data is used to develop an engine analytical model that couples thermodynamic, aerodynamic, and secondary airflow system models. This model is matched with engine operating data across a wide range of ambient conditions and power settings. The engine analytical model is used to understand PMA part thermal and structural boundary conditions and evaluate engine system interaction effects caused by either the target PMA part or other engine hardware.

Part Analysis

Thermal, structural, and modal analysis under engine operating conditions is conducted on the PMA part. Thermal predictions are validated using fleet inspection data and metallurgical analysis. Stress and fatigue life predictions are validated using fleet inspection data.

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Part Design

The reverse engineering process develops the information in the PMA design package, which includes nominal geometry, geometric tolerances specifications, process development, source demonstration requirements, and production inspection requirements. The design package details requirements for the PMA part to ensure that it is equivalent to the TCH part in form, fit, and function. All part requirements contained in the PSCP are subject to passing comparative testing, which demonstrates equivalence to TCH parts.

Manufacturing Process Development

Manufacturing process development begins after the PMA design is defined. This begins with Chromalloy's application of best practices, its deep gas turbine manufacturing experience, and its world-class casting, machining, and coating facilities to produce trial parts. Early trials are subjected to testing consistent with the PSCP, and the manufacturing tooling and processes are refined to achieve the design requirements and TCH equivalent functional capability. Once process development trials are complete, production PMA parts are produced to demonstrate that the PMA parts conform to the design. The trial parts and manufacturing facility are audited by the FAA's Certificate Management Service (CMS), formerly known as the Manufacturing Inspection District Office (MIDO), to verify that the PMA parts conform to the design requirements and satisfy quality system requirements.[23]

Comparative Testing

Initial PMA production parts are subjected to comparative testing to demonstrate equivalent characteristics, functionality, and capability. Typical tests include:

- Alloy coating chemistry and microstructure.
- Oxidation, corrosion, and erosion.[24]
- Cyclic oxidation/spallation.
- High-temperature component high-cycle-fatigue.
- Grain orientation.
- Alloy melting point.
- Modal natural frequency and mode shapes.[25]
- Alloy physical properties, tensile and creep.
- Surface finishing residual stresses.

PMA Production Processes

As the design is developed, Chromalloy develops production processes necessary to produce parts conforming to the design, including alloy process development, casting development, machining and hole drilling, and coating. Chromalloy validates the production requirement for each design criteria. This oftentimes includes, for example, the purchase of advanced new equipment to meet the tight tolerances required or the development of extensive tooling to support the process.

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[23] https://www.faa.gov/documentLibrary/media/Order/Order_8120.22A_w_Change_1.pdf.

[24] https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_33-11.pdf.

[25] https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC-33.83-2B.pdf.

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Once the design reports and test plans are reviewed and approved by the FAA or their designee, the PMA applicant may then manufacture a set of parts to the approved drawings and specifications.[26] This set of parts is used for final compliance testing.

FAA Approval of Production Parts

The FAA CMS group provides production approval and certification, airworthiness certification, and support certification during the design approval process.[27] After Chromalloy produces the initial production parts, CMS inspects the parts for conformance to design and reviews all quality documentation associated with the manufacturing operations. This inspection must be completed successfully before the applicant can conduct final comparative bench testing as described in the individual FAA approved test plans.

Final Part and Specimen Testing

Testing is performed to demonstrate by comparative analysis that the applicant PMA parts perform equivalent to or better than the TCH parts. Testing can include side-by-side part-level comparative validation, such as frequency response, high-cycle fatigue response, and coating cyclic testing. The test methods are supported by FAA guidance and techniques prescribed in industry specifications,[28] such as ASTM and/or by ISO certified laboratories. The FAA also requires that critical test set-up and processes are witnessed by the FAA prior to the commencement of testing.[29]

Final FAA Review and PMA Application

After completion of all part-level testing, Chromalloy submits the test reports, consistent with FAA approved test plans, to the FAA for review and acceptance. Critical test setups and processes are witnessed by the FAA. The FAA must approve each test report before moving to administrative approval of the PMA application.[30]

Final FAA Approval

The FAA review process typically requires many months to obtain final FAA certification resulting in FAA design and production approval.[31]

In summary, PMA parts are designed, manufactured, and tested under a rigorous regulatory framework to demonstrate full equivalence of form, fit, function, and capability. The reverse engineering process characterizes part and engine characteristics critical to the function of the PMA part. The manufacturing process development ensures that the PMA parts will robustly conform to the design requirements and pass direct comparative testing. The direct comparative testing of TCH and PMA parts provides a more controlled and precise evaluation of part equivalence than standard engine level certification testing.

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[26] https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_21.303-4.pdf, paragraph 9b.

[27] https://www.faa.gov/about/office_org/field_offices/certificate_management_sections.

[28] FAA AC 33.83-1, Section 3.

[29] https://www.faa.gov/documentLibrary/media/Order/FAA_Order_8110.37F.pdf.

[30] 14 CFR 21.310.

[31] 14 CFR 21.311.

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Type Certificate Holder and PMA Competitive Environment

Market Competition

Competition in any market offers benefits for the end user and the industry. The ability to offer alternative solutions for gas turbine parts through PMA parts provides both the airlines and other aircraft operators cost and time savings. A TCH can hinder competition through a range of changes that can span from making minor part upgrades to changing part numbers or mating life limited components.

New Engine Sales

Each new commercial engine often has a negative return on investment for the TCH due to the high costs of design, manufacturing, and the FAA certification process. [32] Studies have shown that it may take decades for an engine model to become profitable for a TCH. A large portion of a TCH's cost recovery, however, may come through service maintenance agreements which allow the TCH to fully control overhauls, repairs, and new part sales. These maintenance agreements typically help the TCH recoup their initial investment and earn additional profits by hindering competition via sales of new replacement PMA parts.[33]

Type Certificate Holder Product Hopping

PMA parts support a robust aviation economy through pricing competition and supply chain risk mitigation. However, when faced with competition from PMA parts, TCHs may engage in non-substantive changes such as updating part numbers based on modifications to original designs, oftentimes with limited or no testing. Subsequently, TCHs can market the modifications as necessary or strongly encouraged, and even adopt the enhancements made in certain PMA parts as "new" modifications, thus rolling out "updated" parts with "updated" part numbers. Consequently, new PMA approvals are then required for non-TCHs on any TCH-updated part numbers (despite a lack of design changes), resulting in severely delayed market entry of PMA parts, in part due to the FAA's more rigorous approval process for PMA parts, including resubstantiation. Through this "product hopping" process (updating TCH part numbers to reflect minor or unnecessary updates, thus resulting in disruptive delays to PMA part approvals), TCHs can impede competition and evergreen their parts. Customers often bear the cost.

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AC33-8 Guidance for Parts Manufacturer Approval for Turbine Engine and Auxiliary Power Unit Parts under Test and Computation, FAA Advisory Circular, 2009.[35]

[32] https://leehamnews.com/2023/05/02/pontifications-engine-makers-business-model-needs-overhaul/.
[33] https://leehamnews.com/2023/05/02/pontifications-engine-makers-business-model-needs-overhaul/.
[34] https://pmaparts.org/pdf/AirlineGuideToPMA.pdf.
[35] https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_33-8.pdf.

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