T5.5 Case study Problem- Based Learning (PBL)

Title of Case Study / Problem-based learning case

Integrating Quality Assurance, Quality Control and Traceability in Aerospace & Defence Additive Manufacturing Production

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Background:

An anonymised aerospace supplier has produced a lightweight Ti-6Al-4V bracket by Powder Bed Fusion Laser Beam (PBF-LB) for installation in an aircraft environmental control system. The design has passed prototype functional testing, but the first qualification build has produced results that raise concerns about internal integrity. Management wants to proceed to serial production as quickly as possible, while the customer requires a technically justified qualification decision and a credible recovery plan.
The manufacturer works under an aerospace quality management system and has prepared a preliminary AM Procedure Specification (AMPS). However, the qualification file contains open questions concerning parameter validation, process monitoring, post-processing, traceability, acceptance criteria, repeatability and the relationship between coupon results and the final component. You are part of the Quality Assurance team appointed to lead the qualification recovery review. Using ECSS-Q-ST-70-80C as the principal reference, you must determine the component safety class, assess the available evidence, compare technically viable recovery routes and recommend the most efficient strategy that protects product integrity and supports timely industrialisation.

Open-ended PBL challenge: Develop and defend a qualification recovery strategy rather than simply identifying nonconformities. Your team must make justified assumptions, identify missing evidence, establish component-specific acceptance criteria, compare alternative recovery approaches, and present a recommendation to the customer. Different solutions may be valid when they are technically coherent, risk-based and supported by evidence.

(note: This case is fictional and anonymised for educational use. All company, part and batch identifiers are illustrative)

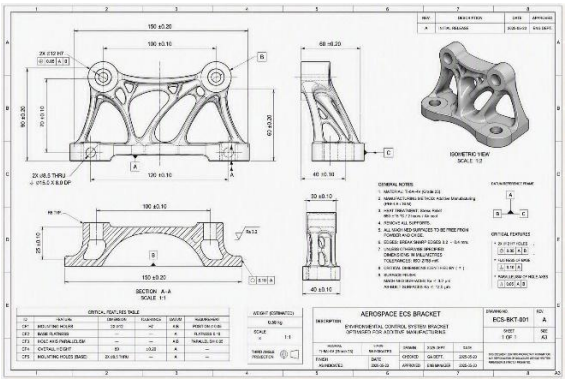
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Illustration of the case study

Component	Lightweight titanium aerospace bracket
Material	Ti-6Al-4V powder
Process	Powder Bed Fusion Laser Beam, 400 W fibre laser
Build volume	250 × 250 × 300 mm
Powder batch	P-2026-001, virgin powder
Nominal particle size	20-60 µm
Production intent	Qualification before serial manufacturing



Note: this is a fictional image to illustrate the case study

Preliminary build parameters - unvalidated values to be critically assessed

1. Data preparation	2. Powder release	3. PBF-LB build	4. Stress relief	5. Support removal	6. CNC & finishing	7. Final inspection

Preliminary build parameters

Parameter	Recorded value
Layer thickness	40 µm
Laser power	285 W (preliminary value; validation evidence not provided)
Scanning speed	1 250 mm/s
Hatch spacing	0.11 mm
Chamber oxygen level	< 100 ppm
Build orientation	Bracket inclined 35° to build plate
Witness coupons	Three, built with the component

Post-processing route

- Stress relief while attached to the build plate.
- Removal from build plate and support removal.
- CNC machining of critical interfaces.
- Surface finishing.
- Final dimensional and integrity inspection.

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Important note: The numerical values and provisional acceptance criteria are fictional educational data. ECSS-Q-ST-70-80C does not prescribe universal density or porosity limits for this component. You must determine whether the proposed limits are suitable and justify component-specific criteria using intended function, loading conditions, defect morphology and location, inspection capability, fatigue implications and the selected safety classification. The same should be performed for density.

Qualification results from first build

Test	Provisional acceptance criteria	Result
Relative density	≥ 99.8%	99.65%
Ultimate tensile strength	≥ 900 MPa	920 MPa
Yield strength	≥ 830 MPa	850 MPa
CT porosity	< 0.20%	0.35%
Dimensional deviation	± 0.20 mm	± 0.12 mm

Technical challenge

Prepare a concise, evidence-based QA review and qualification recovery proposal. Use ECSS-Q-ST-70-80C as the main reference and identify relevant complementary standards or customer requirements. State assumptions, distinguish mandatory evidence from recommended improvement, and clearly separate containment, root-cause investigation, corrective action and requalification.

Task	Focus	Required output
1	Safety classification and requirements	Propose and justify the component safety class with reference to ECSS-Q-ST-70-80C section 5.2.2. Translate the classification and intended service conditions into applicable assurance and verification needs.
2	AMPS and evidence gaps	Define the critical AMPS content and assess whether the available qualification evidence is sufficient, explicitly listing missing or uncertain evidence.
3	Acceptance criteria	Establish and justify suitable density and porosity acceptance criteria. Consider loading, fatigue, defect type, size and location, CT capability, coupon representativeness and customer requirements.
4	Root-cause investigation	Develop a prioritised investigation of both density and CT porosity results, using a structured method such as Ishikawa plus 5 Whys or fault-tree analysis. Identify hypotheses, evidence required and decision points.
5	Recovery options	Compare at least three recovery routes, for example measurement confirmation, parameter/process optimisation, and redesign or post-process mitigation. Assess technical risk, lead time, evidence burden and impact on qualification.
6	Corrective action and verification	Recommend the preferred route and define controlled trials, additional tests, process adjustments, verification activities, effectiveness criteria and requalification scope.
7	Traceability and process control	Define controlled variables and an end-to-end traceability strategy covering digital files, equipment, powder, people, coupons, post-processing, inspection, and final parts.
8	Decision, risks, and customer recommendation	Recommend approve, conditional development approval, or reject pending corrective action. Provide a risk register and a concise customer-facing justification, including residual risks and conditions for serial release.

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Please perform a QA review covering Tasks 1-8 and a justified component safety classification. Also, please propose an AMPS structure and evidence-gap checklist, including:

- Component-specific acceptance-criteria rationale.
- Root-cause analysis and comparison of at least three recovery routes.
- Prioritised corrective-action and requalification plan with verification gates.
- Traceability matrix, risk register and customer recommendation.
- Traceability matrix.
- Risk register.

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Alternative solutions may receive full credit when technically coherent, risk-based and supported by the case evidence and applicable requirements. The model solution below describes an expected reasoning process, not a single mandatory answer.

Detailed solution/ process

1. Safety classification and requirements, and 2. AMPS and evidence gaps

The learner should first propose a safety classification under ECSS-Q-ST-70-80C section 5.2.2 and justify it from the bracket function, credible failure consequences and available system-level information. Because the case does not provide a complete failure-hazard assessment, a defensible answer should state assumptions and identify customer confirmation as a qualification gate. The selected class should drive the rigour of process qualification, inspection, acceptance and change control.

AMPS minimum content

- Scope, part/family identification, controlled document number, revision and approval authority.
- Applicable customer, regulatory, drawing and material requirements.
- Qualified machine identification, configuration, software version, maintenance and calibration status.
- Feedstock specification, batch identification, receiving controls, storage, handling and reuse rules.
- Approved digital workflow, including CAD, build preparation, parameter-set and build-file revisions.
- Build layout, orientation, support strategy, layer thickness, laser power, scan speed, hatch spacing and atmosphere limits.
- Pre-build checks, in-process monitoring, interruption rules and deviation management.
- Post-processing sequence, qualified equipment, time/temperature limits and subcontracted-process controls.
- Witness specimen plan, inspection methods, acceptance criteria, release authority and record-retention requirements.

Evidence evaluation and interim disposition

Serial production release is not justified on the present evidence. The immediate disposition should be containment of the affected build and authorisation, at most, of controlled development or recovery trials. The final decision must follow confirmation of the measurement results, agreement of component-specific acceptance criteria, completion of the root-cause investigation and successful requalification. Learners may recommend different recovery routes but must define explicit evidence-based release gates.

3. Variables to control and record

- Machine ID and configuration; laser status; recoater condition; platform condition and calibration.
- Powder batch, condition, reuse count, sieving/mixing history, storage and exposure conditions.
- Build-file and parameter-set revisions; orientation; supports; nesting and coupon locations.
- Layer thickness, laser power, scan speed, hatch spacing, scan strategy and preheat conditions.
- Oxygen level, gas type/flow and relevant environmental conditions.
- Build interruptions, alarms, operator interventions and in-process monitoring outputs.
- Complete post-processing route, equipment IDs, cycle records and inspection/test reports.

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4. Root-cause investigation, 5. Recovery Options & 6. Corrective action and verification

- **Phase 1 - Containment and data validation**: quarantine the build; open a nonconformity; confirm CT settings, segmentation threshold, resolution, and uncertainty; verify density measurement method; confirm coupon-to-part linkage; and review whether the reported difference is statistically and technically significant.
- **Phase 2 - Root-cause hypotheses:** investigate energy input and scan strategy, laser calibration and beam condition, recoater behaviour, powder morphology/chemistry/contamination, oxygen, and gas flow, build orientation and support strategy, thermal history, interruptions, and the representativeness of witness coupons. Use a structured cause-analysis method and rank hypotheses by likelihood, consequence, and ease of verification.
- **Phase 3 - Evidence plan:** for each priority hypothesis, define the data or test needed to confirm or reject it. Examples include review of machine and monitoring logs, laser calibration checks, powder characterisation, metallography, CT defect morphology and spatial distribution, fracture-surface analysis, coupon mapping and repeat measurements by an ISO/IEC 17025 competent laboratory.
- **Phase 4 - Compare recovery routes:** Route A, verify measurement and reassess justified acceptance criteria; Route B, optimise process parameters or scan strategy through controlled trials or a limited design of experiments; Route C, modify orientation/supports or introduce a justified mitigation such as HIP, followed by evaluation of dimensional, microstructural, and mechanical effects. A redesign route may be considered if local stress or possibility to inspect makes the original concept unsuitable.
- **Phase 5 - Select and verify:** compare routes against safety, technical risk, qualification evidence, lead time, cost and change-control impact. Define go/no-go gates. The preferred strategy should include controlled build trials, representative specimens, CT and metallography, tensile testing and, where relevant to the safety class and loading, fatigue testing. Compliance must be demonstrated against all agreed criteria before serial release.
- **Expected prioritisation:** first validate the apparent nonconformities and their relevance; then address high-consequence, high-likelihood process causes; only afterwards optimise or mitigate. Parameter changes must not be made informally or justified solely by achieving a higher density value.

7. Traceability strategy

Traceability object	Minimum record	Linkage
Digital data	CAD, build file, parameter set, software version, revision, and approval	Unique job/build ID
Equipment	Machine ID, configuration, maintenance, calibration, and status	Build record
Feedstock	Supplier, alloy, batch, certificates, reuse, and handling history	Build and remaining powder
People	Operator/inspector ID, competence, and authorisation	Operation sign-off
Process	Parameters, atmosphere, alarms, interruptions, and monitoring data	Time-stamped build log
Post-processing	Route, equipment, cycle records and subcontractor certificates	Part serial number
Coupons	Location, orientation, tests, and results	Build and represented parts
Final part	Serial number, inspections, disposition, and release	End-to-end history

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Standards and requirements

- ECSS-Q-ST-70-80C: Space product assurance: Processing and quality assurance requirements for metallic powder bed fusion technologies for space applications

Some examples of standards to be referenced and the purpose of its utilization:

- EN 9100 / AS9100: aerospace quality management framework and controlled production environment.
- ISO 9001: general quality management system foundation.
- ISO/ASTM 52941: acceptance tests for laser metal powder bed fusion machines.
- ISO/ASTM 52935: qualification principles for AM processes.
- ISO/ASTM 52928: powder feedstock lifecycle management.
- ISO/IEC 17025: competence of testing and calibration laboratories.
- ISO/ASTM/TS 52930: Additive Manufacturing - Qualification principles - Installation, operation and performance (IQ/OQ/PQ) of PBF-LB equipment
- ISO/ASTM 52904: Additive manufacturing of metals - Process characteristics and performance - Metal powder bed fusion process to meet critical applications
- ISO/ASTM 52920: Additive manufacturing - Qualification principles - Requirements for industrial additive manufacturing processes and production sites
- Customer, drawing, material, heat-treatment, machining, and inspection specifications applicable to the component.

8. Example risk register

Risk	Potential cause	Effect	Preventive/detective control	Expected evidence
Lack-of-fusion porosity	Insufficient or unstable energy input	Reduced integrity and fatigue performance	Qualified frozen parameters; in-process monitoring; CT	Build log and CT report
Powder contamination	Poor handling, mixing or environmental exposure	Chemistry/property variation	Batch segregation; closed handling; testing; reuse control	Powder history and certificate
Configuration mismatch	Uncontrolled file or parameter revision	Nonconforming geometry or process condition	Revision control; electronic approval; pre-build verification	Approved configuration record
Post-process deviation	Incorrect heat-treatment cycle or sequence	Residual stress or property nonconformity	Qualified procedure; calibrated equipment; cycle recording	Heat-treatment chart/certificate
Traceability break	Missing serial or coupon linkage	Inability to substantiate conformity	Unique IDs; route card; reconciliation before release	Complete manufacturing dossier

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Assessment Matrix

Scoring principle: award the descriptor score that best matches the evidence. Intermediate scores may be used where performance falls between descriptors.

Criterion	Max	Excellent	Good	Developing	Insufficient
1. Safety classification, requirements and AMPS	18	15-18 Well-justified safety class; requirements translated into assurance measures; comprehensive, controlled and AM-specific AMPS.	12-15 Mostly complete; minor omissions that do not undermine control logic.	7-12 Several important omissions or weak AM specificity.	0-7 Generic or materially incomplete procedure.
2. Evaluation of evidence and acceptance criteria	14	12-14 Critically evaluates all evidence, identifies gaps and justifies component-specific density and porosity criteria.	9-12 Correct overall evaluation with minor omissions.	6-9 Partial comparison; misses a key nonconformity or evidence gap.	0-5 Decision not connected to the data.
3. Root-cause analysis and process understanding	14	12-14 Structured and prioritised hypotheses linked to evidence, defect mechanisms and repeatability.	9-12 Good coverage with limited omissions.	6-9 Basic list with weak linkage to repeatability.	0-5 Few variables or major misconceptions.
4. Recovery-option comparison and decision	12	10-12 Compares at least three viable routes using safety, risk, evidence, lead time and qualification impact; recommends a defensible strategy.	8-10 Defensible decision with adequate rationale.	5-8 Decision is ambiguous or only partly supported.	0-5 Unsafe/unsupported approval or no decision.
5. Corrective actions, verification and requalification	12	10-12 Clear containment, controlled trials, test matrix, decision gates, requalification and effectiveness verification.	8-10 Relevant actions with a reasonable verification step.	5-8 Actions plausible but unsystematic or weakly verified.	0-5 Unsupported parameter changes or no verification.
6. Traceability and controlled variables	12	10-12 Complete digital-to-physical chain plus prioritised process controls, unique IDs, revisions and responsibilities.	8-10 Covers most key objects and linkages.	5-8 Partial traceability with important gaps.	0-5 Minimal records; no end-to-end linkage.
7. Standards and technical justification	8	7-8 Accurate use of ECSS-Q-ST-70-80C and complementary standards; requirements linked to decisions and evidence.	5-7 Mostly relevant standards with basic explanations.	3-5 Lists standards with limited relevance explanation.	0-3 Incorrect, irrelevant or absent standards.
8. Risk assessment and professional communication	10	8-10 Well-developed risks, residual-risk logic, and a concise, persuasive customer recommendation.	6-8 Three relevant risks and generally clear communication.	4-6 Risks are generic, or controls/evidence are incomplete.	0-4 Fewer than three meaningful risks or unclear submission.

Total: ____ / 100

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AILEEN

Competence unit coverage:

	AILEEN competence units	Covered CU
AW_01	Welding: Advanced Metallic Materials in Aerospace and Defence Sectors	
AW_02	Welding: Advanced Welding Processes and Equipment in Aerospace and Defence Sectors	
AW_03	Welding: Advanced Welding Applications in Aerospace and Defence Sectors	
AW_04	Welding: Introduction to brazing technology Knowledge for quality brazed joints	
AW_05	Welding: Fundamentals of Industrial Brazing: Main Processes, Quality Standards & Applications	
AI_01	Inspection: Non-Destructive Testing (NDT) in Additive Manufacturing for metals and polymers	
AI_02	Inspection: Metrology in Additive Manufacturing for metals and polymers	
AI_03	Inspection: Inspection of AM parts. Material Quality	
AAM_01	AM: Qualification, Certification and Standards for AM in A&D	
AAM_02	**AM: Quality Assurance & Quality Control, Quality Management Systems for AM in A&D**	**X**
AAM_02/3	AM: Design of AM parts for A&D (2 courses - for DED & PBF)	
AD_01	Digital: Introduction to Digital Technologies in Advanced Manufacturing	
AD_02	Digital: Data Acquisition and Analysis	
AD_03	Digital: Industrial Internet of Things (IoT) and Advantages in Advanced	
AD_04	Digital: Artificial Intelligence and Advantages in Advanced	
AD_05	Digital: Automation and Advantages in Advanced Manufacturing	
AD_06	Digital: Potentials of Advanced Simulation and Modelling in Advanced	
AD_07	Digital: Potentials of Digital Twins and Smart Factory Automation in Advanced Manufacturing	
AD_08	Digital: Unlocking the Potential of 3D Models Beyond Technical Drawings in the Aerospace and Defence Sector	
AG_02	Green: Sustainable Design and Environmental Compliance in Aerospace and Defence	

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