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

Title of Case Study / Problem-based learning case

Full Cycle PBF LB Development – from Feasibility and Generative Design to Functional Validation of a Drive Roller Flange.

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Based on / adapted from: CEI drive roller flange case study (https://www.ceigroup.net/)
(note: CEI is a Portuguese company that develops advanced industrial equipment for cutting, automation and production processes, delivering reliable solutions for demanding international markets).

Background:

The drive roller flange is a structural component used in a mechanical drive and roller support assembly. It interfaces between the drive roller and the rest of the system, with high demands on alignment, stiffness and geometric repeatability. The original component was designed for conventional subtractive manufacturing and produced using S235 steel by waterjet cutting, turning, CNC milling, pickling, metallization and painting. A significant part of the volume of the original flange does not contribute directly to the final mechanical function. This created the motivation to re-engineer the component for PBF-LB (Powder Bed Fusion – Laser Beam) additive manufacturing, using generative design and topology optimization to reduce mass while preserving all critical interfaces, hole positions and structural load paths.

The case is therefore not merely a process substitution. It is a full-cycle development:

- feasibility study,
- material selection,
- generative design,
- structural simulation,
- PBF-LB manufacturing,
- post-processing and machining,
- dimensional and functional validation,
- economic evaluation.

Key data of the original component

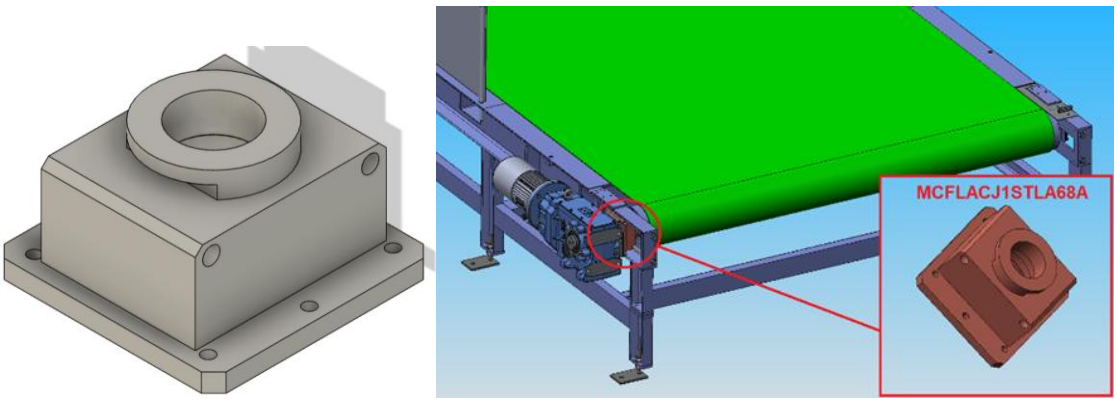
Item	Detail
Original material	S235 steel
Original mass	11.4 kg
Original volume	1425 cm^3
Conventional process	Waterjet cutting, turning, CNC milling, pickling, metallization, painting
Manufacturing time	≈ 16 hours
Annual production	20 parts/year
Functional role	Drive roller interface, alignment, stiffness, repeatability

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Illustration of the case study



Original drive roller flange (left) and assembly view (right)

Technical challenge

The problem-based learning challenge is:

1. What analyses and tests can you perform to determine the feasibility of converting the drive roller flange from conventional manufacturing to PBF-LB?
    - Identify functional requirements, load cases and critical interfaces.
    - Determine whether generative design can reduce mass without compromising stiffness, strength or alignment.
2. Read scientific articles on PBF-LB of M300 maraging steel and generative design for structural tooling/components.
    - Check printability, mechanical properties, residual stress, distortion and post-processing requirements.
    - Compare M300 with 316L for this application.
3. After the feasibility study, determine what tests could be performed to pass functional validation successfully.
    - How can this be tested on small samples?
    - Additional constraint: there is no time for extended fatigue tests. Use static simulation, tensile testing, hardness, dimensional inspection and functional trials as proxies.
4. Decide the final design and manufacturing route.
    - Compare conventional machining, PBF-LB, DED-LB and DED-Arc.
    - Select the best compromise between mass reduction, structural integrity, manufacturability and cost.

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Detailed solution/ process

1. Functional requirements and constraints

The main requirements for the drive roller flange are summarised below.

Requirement	Specification
Mechanical	Minimum tensile strength 350–500 MPa (equivalent to S235). Support 5000 N + gravity in multiple positions and directions. Safety factor ≥ 2.5.
Thermal	Operating temperature 15–55 °C.
Dimensional	Machining required only for central bore (bearing and seal housing). Roughness Ra 0.5–5.0 µm. Minimum optimized wall thickness 0.5 mm.
Material compatibility	High corrosion resistance equivalent to conventional pickling + metallization + painting.
AM technology	PBF-LB. Proposed materials: 316L stainless steel or M300 tool steel.

The redesign had to preserve the original functionality, hole locations and main structural elements. The selected development route used PBF-LB with M300 steel, supported by generative design.

2. Material and process selection

Two main materials were considered:

Material	YS (MPa)	UTS (MPa)	Comments
M300 / DIN 1.2709	1850 (age hardened)	1916 (age hardened)	High strength, good for mass reduction, sufficient corrosion resistance for the working environment.
316L / DIN 1.4404	500	680	Lower strength, better ductility and corrosion resistance.

M300 was selected because it allowed a significant mass reduction while maintaining a high safety factor. The working environment – water with stone residues, pH 7–8, 15–55 °C – did not require the full conventional surface protection cycle. This eliminated pickling, metallization and painting.

3. Generative design and topology optimization

The generative design and topology optimization study was carried out using Autodesk Fusion (Generative Design workshape). Several configurations were studied with different safety factors (2.5, 2.75, 3) and critical support angles (20°, 30°, 40°). The minimum wall thickness was fixed at 0.5 mm, and the service load was 5000 N + gravity.

Configuration	Mass (kg)	Volume (cm^3)	Mass reduction
Original machined S235 part	11.4	1425	–
Generative alternative (example)	≈ 6.5	–	≈ 43%
Case #12 – selected solution	7.2	896	37%
Other alternatives	7.0–7.5	–	38–42%

Case #12 was selected as the best compromise between mass reduction, structural integrity and manufacturability. Although lighter alternatives existed, Case #12 provided a more balanced solution for the CEI operating context.

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4. Structural simulation and validation

Structural validation was performed for both the conventional and additive versions under identical conditions: 5000 N force, gravity (9.807 m/s²), and fixed functional surfaces.

Configuration	Maximum displacement (mm)	Maximum stress (MPa)
Original machined version	0.002	19.054
Additive version – Case #12	0.01	48.285

The results show no significant increase in displacement or stress. The optimized geometry maintains the relevant structural behaviour despite the 37% mass reduction. The maximum stress in the M300 version is far below the yield strength of the age-hardened material, giving a safety factor of approximately **2.75**.

5. Redesign, over-thickness and post-processing

The additive design included over-thickness allowances on all surfaces to be machined, especially the central bore, threaded holes and base. This is essential because PBF-LB surfaces rarely meet the required tolerance and roughness directly. The design therefore allowed for:

- PBF-LB build,
- support removal,
- stress relief / age hardening,
- finish machining of critical interfaces,
- final dimensional inspection.

This approach ensures that the functional interfaces – bearing seats, seal seats and mounting holes – meet the original specifications.

6. PBF-LB manufacturing and functional validation

The first prototypes were manufactured by PBF-LB together with the gearbox support flange and the turns-counter housing with connection flange. This confirmed the maturity of the project and allowed a comparative approach between AlSi10Mg and M300 parts.

After machining, the critical surfaces were adjusted and validated. The PLA prototype was used to reproduce the original geometry for comparison, while the final M300 PBF-LB version was machined and prepared for functional validation.

7. Economic analysis

Parameter	Conventional process	Additive manufacturing (M300, Case #12)
Material	S235 sheet	M300 / DIN 1.2709 powder
Part mass	11.4 kg	7.2 kg (37% reduction)
Manufacturing operations	Waterjet cutting, turning, milling, pickling, metallization, painting	PBF-LB printing, support removal, local machining (just central bore and threads in the part produced)
Surface treatment	Mandatory (pickling + metallization + painting)	Not necessary – M300 has sufficient corrosion resistance for the working environment
Unit cost		Estimated reduction of 30–45%

The elimination of the complete surface treatment cycle is the most important cost driver, together with the mass reduction. The higher mechanical strength of M300 also allows a high safety factor without economic penalty.

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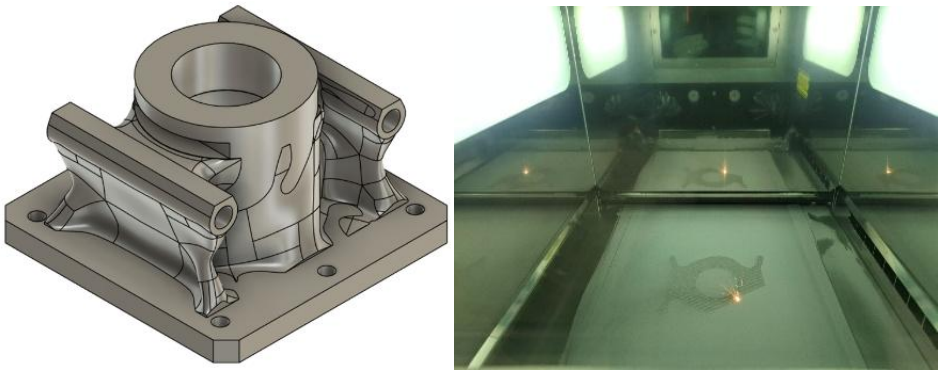
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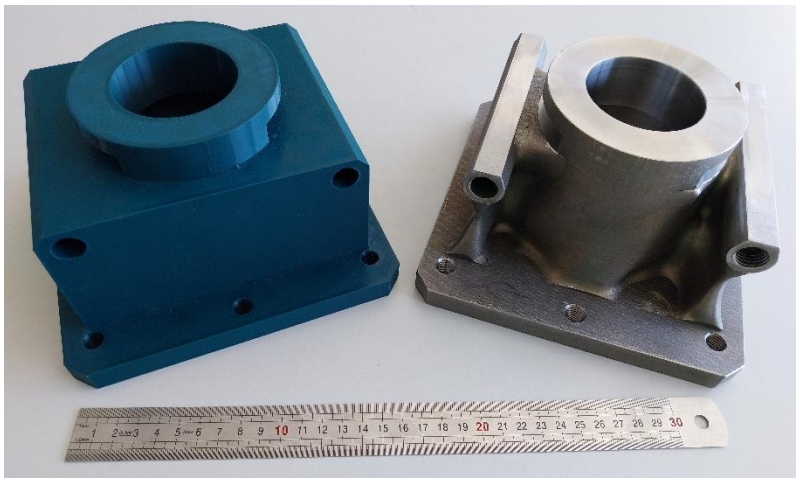
8. Conclusion

The drive roller flange case demonstrates that metal additive manufacturing, combined with generative design and careful material selection, can achieve significant mass reductions without compromising structural function. The final M300 solution with a safety factor of 2.75, 5000 N + gravity load, 0.5 mm minimum wall thickness and 37% mass reduction represent a solid compromise between performance, manufacturability and material sustainability. Simulations confirm that displacements and stresses remain within acceptable limits, and the main load paths are preserved. Industrially, the prototype evolved into a part ready for final machining and functional validation, confirming the viability of the concept in the CEI context.

Additional Pictures / Information



Selected generative design – Case #12 (left) and PBF-LB manufacturing of the drive roller flange (right).



PLA prototype vs optimized M300 PBF-LB version with machined surfaces.

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Purpose of the Elaborated Case Study

This case study bridges theory and industrial practice in full-cycle PBF-LB development. It encourages learners to:

- Analyse a real structural component and define functional requirements.
- Perform a feasibility study for additive manufacturing.
- Use AI tools to find scientific literature on M300, 316L, PBF-LB and generative design.
- Apply generative design and topology optimization to reduce mass.
- Interpret structural simulation results and compare conventional vs additive designs.
- Plan post-processing, over-thickness and machining allowances.
- Evaluate economic and sustainability benefits.
- Develop short, practical validation tests when extended fatigue testing is not possible.
- Communicate a well-reasoned engineering solution in a context where multiple valid solutions exist.

This case is particularly valuable for aerospace, defence and advanced manufacturing sectors, where lightweighting, functional integration and full-cycle qualification are increasingly important.

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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 Aersopace 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	x
AI_03	Inspection: Inspection of AM parts. Material Quality	x
AAM_01	AM: Qualification, Certification and Standards for AM in A&D	
AAM_02	AM: Quality Assurance & Quality Control for AM in Aerospace & Defence	
AAM_02/3	AM: Design of AM parts for A&D (2 courses - for DED & PBF)	x
AD_01	Digital: Introduction to Digital Technologies in Advanced Manufacturing	
AD_02	Digital: Data Acquisition and Analysis	
AD_03	Digital: Industrial Internet of Things (IIoT) 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	x
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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