Circular Economy: Designing Aerospace Parts for Reuse, Repair, and Recycling

Following: Value Engineering in the Aerospace Industry: Balancing Performance, Cost, and Innovation

Introduction

Our earlier discussion outlined how Value Engineering (VE) optimizes aerospace products and systems, striking a careful balance between performance, safety, and cost over the full lifecycle. At its core lies the simple but powerful equation, Value = Function ÷ Cost. While VE focuses on delivering essential capabilities at the lowest possible expense, the industry now faces a pressing additional requirement, greater sustainability and resource efficiency. This brings us directly to the Circular Economy, an approach that builds on established VE principles. It involves designing components and systems so they can be reused, repaired, refurbished, remanufactured, or recycled. The goal is to keep materials and their inherent value in active use for as long as possible, while significantly cutting waste and reducing long-term expenditure.

This stands in clear contrast to the traditional “linear economy” model, where items are made, used, and then discarded. Under the circular framework, aircraft, engines, satellites, and individual parts are treated as reusable assets rather than one-off products. In aerospace, where materials are high-grade, costly, and require significant energy to produce, circular design is far more than just an environmental choice, it makes strong commercial sense, aligning perfectly with the VE objective of minimizing total lifecycle costs.

Core Principles of Circular Economy in Aerospace

Circular practice in aerospace is guided by the 10 Rs framework, which maps closely to the priorities of value engineering:

1. Rethink & Reduce, simplify designs, minimize material use, and avoid unnecessary complexity, standard practices within VE.
2. Reuse, deploy parts again in the same or different aircraft without extensive processing.
3. Repair, rectify faults to restore full functionality and extend service life.
4. Refurbish, clean, inspect, and upgrade items to return them to a condition matching new specifications.
5. Remanufacture, disassemble, rebuild, and test components to meet original performance standards.
6. Repurpose, adapt existing parts for new roles or applications where they can still deliver value.
7. Recycle, recover raw materials to manufacture new aerospace-grade products.
8. Recover, extract usable materials or energy from what remains once other options are exhausted.
9. Refuse, avoid specifying materials or designs that cannot be easily recovered or processed later.

10. Redesign, develop products and systems specifically with circularity in mind from the very start.

These principles reinforce the core tenets of VE, prioritizing function over form, taking a long-term view of costs, and seeking continuous improvement. The key difference is that the circular economy explicitly targets material retention and waste reduction as major drivers of value.

Design for Circularity: Key Strategies & Applications

Just as VE applies at every stage, from concept and design to manufacturing, operation, and retirement, circular thinking must be embedded from the earliest design work. Below is how it operating in practice, illustrated with industry examples:

1. Design for Disassembly & Modularity

One of the biggest obstacles to reuse or recycling is complexity. Where parts are bonded, welded, or permanently joined, they often become waste at the end of their operational life. Circular design addresses this through:

A. Modular construction, systems built as independent sections that can be removed, replaced, or upgraded separately. For instance, modern satellites and jet engines use modular payloads, battery packs, and avionics units, meaning only the affected section needs servicing rather than the whole system.

B. Standardized fasteners and connections, avoiding custom fittings reduces the number of specialized tools required and cuts labor time during maintenance or dismantling, directly lowering costs, which is a central VE objective.

C. Clear identification, marking materials and alloys clearly speeds up sorting and processing later, ensuring that recovered materials retain their maximum possible value.

Industry Example, the Airbus-led PAMELA project demonstrated that by planning for disassembly during the design phase, between 85% and 90% of an aircraft’s total weight can be recovered or reused, compared to just 50% to 60% for older models.

2. Material Selection: Balancing Performance, Cost, and Recyclability

Value engineering already guides material selection based on strength, weight, and cost. The circular economy adds recoverability as a vital selection criterion:

A. Closed-loop metals, titanium, aluminum, and steel can be recycled repeatedly without losing their structural properties. Today, recycled titanium costs roughly 30% to 40% less than virgin material and requires approximately 95% less energy to produce. Airbus currently recycles over

460 tons of titanium scrap annually, feeding it back into the production of new airframe components.

B. Advanced composites, historically difficult to recycle, newer thermoplastic and improved thermoset materials are now engineered to allow reprocessing. In 2026, Airbus successfully converted a composite pylon cowl from a retired A380 into a certified new component for the A320neo, proving that high-value reuse is achievable even for complex materials.

C. Avoid mixed materials, combining different metals or incompatible coatings makes recycling far more expensive. VE teams now favor families of compatible materials to ensure value is preserved at the end of service life.

3. Extending Life: Repair, Refurbishment & Remanufacturing

The most effective circular strategy, both environmentally and economically, is keeping parts in service for longer. This delivers the highest value, as it avoids the cost and resource use associated with manufacturing new items entirely.

A. Repair, instead of replacing an entire component, only the damaged section is fixed. For example, landing gear assemblies can be repaired 5 to 7 times over a typical 30-year operational life, saving operators between 70% and 80% compared to purchasing new units.

B. Remanufacturing, used parts are fully disassembled, restored, and tested to meet original performance standards, often incorporating upgrades or improvements. CFM International, a leading engine manufacturer, remanufactures key components, reducing energy use in production by around 80% and material costs by roughly 50%.

C. On-wing servicing, modern designs allow maintenance or upgrades without removing major systems from the aircraft. This cuts downtime and reduces operational costs, both clear benefits aligned with VE principles.

Economic Impact, the global market for reused and refurbished aircraft parts is valued at over $2 billion annually, with fleet operators saving millions of dollars through the use of certified second-life or remanufactured components.

4. End-of-Life: Recycling & Material Recovery

Even when parts can no longer be reused, their underlying material value remains significant. Circular design ensures this value is fully captured:

A. Specialized dismantling, facilities such as Airbus's center in Tarbes or Boeing's Aircraft End-of-Life Solutions safely decommission aircraft, recovering engines, avionics, and high-grade structural metals for reintroduction into the supply chain.

B. Advanced recycling technologies, new processes break down carbon fiber composites to recover clean, usable fibers. These are then reintroduced into production for new aircraft, unmanned aerial vehicles, or high-performance automotive parts, creating a true closed-loop system.

C. Circularity in space, satellites are increasingly designed to allow on-orbit servicing, refueling, or robotic disassembly. This not only prevents space debris but also allows defunct spacecraft to serve as a source of raw materials for future missions, an approach actively promoted by the European Space Agency's Clean Space initiative.

Why Circular Economy is Essential for Aerospace Value Engineering

1. The circular economy is not a separate concept, it represents the natural evolution of value engineering, offering distinct, measurable benefits:

2. Lower Total Lifecycle Cost, reuse and recycling reduce reliance on costly raw materials and energy-intensive manufacturing. A remanufactured engine typically costs 40% to 60% less than a new equivalent, while delivering identical performance and reliability.

3. Uncompromised Safety & Performance, just as with traditional VE, circular strategies never compromise on standards. All reused, repaired, or recycled components must meet strict aerospace certification requirements before returning to service.

4. Meeting Sustainability & Regulatory Targets, airlines, manufacturers, and governments are under growing pressure to lower emissions and reduce waste. Circular practices can reduce the carbon footprint of components by up to 90% compared to production from virgin materials.

5. Strengthened Supply Chains, by recycling critical materials such as titanium, nickel alloys, and rare earth elements, the industry reduces its exposure to supply shortages or global price volatility, an important risk mitigation measure.

6. Enhanced Asset Value, aircraft and systems designed with circularity in mind retain their resale value better, as their constituent parts and materials remain valuable long after the original unit is retired.

Future Trends: VE + Circular Economy + Digitalization

The next phase of value engineering will integrate circular principles with advanced digital tools:

1. Digital Twins, detailed virtual models track every component's history, material composition, and remaining service life. This data enables precise decisions on whether to repair, refurbish, or recycle, ensuring maximum value is always extracted.

2. Additive Manufacturing (3D Printing), this technology uses recycled metal or polymer powders to produce spare parts on demand. It eliminates waste from traditional machining processes and removes the need for large inventories, aligning perfectly with both VE and circular goals.

3. Modular Space Systems, future satellites are being designed like modular building blocks. This allows them to be upgraded, refueled, or repaired while in orbit, extending mission durations from a typical 15 years to 30 years or more.

Conclusion

Value engineering transformed the sector by shifting the mindset from “design first, save later” to “design for value from the start”. The Circular Economy completes this transformation by adding a further dimension, “design for the next life, and the life after that.”

By systematically engineering parts and systems so they can be reused, repaired, or recycled, the industry achieves the core objective of VE, delivering maximum function and safety at the lowest total cost, now with the added benefit of minimizing environmental impact. In aerospace, where every kilogram of weight and every dollar of expenditure is scrutinized, circular design is far more than a passing trend, it is the future of value.

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