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MODELING OF CIRCULAR ECONOMY STRATEGIES FOR CFRP-MADE AIRCRAFT

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ABSTRACT

In a circular economy, recycling of materials at the end of a product's life cycle is a key issue. This paper discusses the sustainability impacts of different recycling strategies for CFPR-made aircraft and how they weigh up against alternative measures such as waste reduction and lower material consumption in the manufacture of the product. The analysis includes environmental and cost impacts for different strategies and market scenarios. A quantitative system dynamic simulation of the life cycle of an aircraft program is used. The subject of the life cycle simulation model is the CFRP mass flow, CO2 emissions and associated costs. In addition, the effects of R&T investments in new technologies for recycling and waste prevention as well as the reduction of material consumption were investigated.

1 MOTIVATION AND PROBLEM DESCRIPTION

In a circular economy, the product life cycle is extended by recycling the product's materials as much as possible and minimizing waste by keeping materials in the system and using them again and again. Recycling technologies for materials at the end of a product's life cycle are key. Alternatively, avoiding waste or using less material in the manufacture of the product can also contribute to the goal of waste reduction.

New materials such as CFRP (carbon fiber reinforced plastic) play an important role in improving product performance in operation, e.g. by reducing weight. But these new materials also require new recycling technologies and new concepts for reuse in a circular economy. Technical challenges arise from the immature technologies for CFRP recycling, whilst commercial challenges include the difficult to predict economic parameters for industrial goods like aircraft with long life cycles of more than 25 years. Investments in the development of recycling technologies will only pay off in the future, but today's product design decisions will have a major impact on the life cycle: the choice of new product materials (e.g. CFRP or metal) on the required recycling technologies and new lightweight designs on the material consumption during manufacturing.

Modeling and simulation are required to show the complexity and interdependencies of technical, economic and political aspects to support decision-making. The following problems need to be solved: modeling the flow of CFPR material within the system from supply through production, operation and recycling loop or disposal, modeling the resulting CO2 emissions along the flows, the associated costs through CO2 pricing and investments, simulating the life cycle of the product program from production ramp-up to ramp-down and phase-out, and finally presenting and comparing the results for multiple scenarios.

2 CASE STUDY OF THE CFRP-MADE AIRCRAFT LIFE CYCLE MODELING

The focus of this study is to determine the impact of recycling strategies for CFRP-made aircraft on total CO2 emissions and associated life cycle costs. New aircraft designs using CFRP materials, e.g. for parts of the fuselage and wings, have advantages in terms of their technical performance (fuel consumption, maintenance). The required recycling technologies or alternative concepts for the reuse of the CFRP material from production (waste) and from the product after 25 years of operation (scrap) are still immature and subject to research. Inputs for the analysis are the amount of CFRP material required per aircraft, the production rate along the 25-year program life, the CFRP recycling and disposal rate, and the CO2 emissions from CFRP procurement, production, recycling and disposal processes. Over the life cycle of the aircraft program of approximately 50 years, process technologies and associated CO2 emissions may also change, as may the CO2 price set by policy makers. Additional R&T investments will affect the speed and quality of maturation of recycling technologies and/or the amount of CFPR material required per aircraft.

The objective of simulating multiple scenarios of the 50-year life cycle of a new CFRP-made aircraft program is to understand and compare the impacts on CFRP procurement, CO2 emissions and costs along the life of the aircraft program.

3 SIMULATION APPROACH

The analysis of the life cycle of the CFRP-made aircraft program, and in particular its sustainability, uses a quantitative system dynamics modeling approach implemented in Anylogic. The core of the model is a stock and flow model of the CFRP material in the system. The stocks represent the positions of the CFRP material within the life cycle and the flows represent the processes associated with the CFRP material such as procurement, production, recycling and disposal. Feedback loops model the circular effects of recycling CFRP material and/or life cycle design decisions. Linked to the core model are two additional stock and flow models that represent CO2 emissions and costs incurred along the life cycle. Core system variables are CFRP material per aircraft, production rate, recycling and disposal rate, CO2 emissions for the modelled processes, and CO2 prices and technology investments. These system variables are time-dependent functions and may change over the simulation time. The modelled system boundaries are the supply of CFRP materials on the input side and the disposal of the CFRP material after reuse.

The output of the simulation are performance indicators for the entire life cycle of the aircraft program from the first aircraft production to the retirement of the last aircraft whose CFRP material was processed. Of interest are the CO2 emissions, the CFRP materials required, and the costs caused by the CO2 emissions, the recycling processes and the disposal.

To support the embedding of the analysis in a broader decision-making framework, data input and result output are realized via Excel files and can also be used in a cloud environment as provided by Anylogic.

4 RESULTS AND CONCLUSIONS

The study shows the ability to model and simulate complex systems and their behavior along the complete life cycle of long-lasting products like aircrafts. By means of the developed system dynamics model, interdependencies and effects between technical factors such as the recycling rate and technology maturity of different recycling and disposal processes, policy decisions such as CO2 pricing, and business strategies such as R&T investments in recycling versus and/or less material consumption can be shown.

In this study a number of input data sets were defined to explore different possible scenarios of technological and CO2 policy evolution for a novel CFRP made aircraft program. Of interest were the sum and ratio between R&T investments for lightweight design and CFRP recycling technologies maturation in an early aircraft program life cycle stage for the overall sum of CO2 emissions and their life cycle CO2 cost effects for alternative CO2 pricing scenarios.

The outcome of the study can be used as an input for R&T strategy development related to circular economy technologies.