Multi-Disciplinary Aircraft Synthesis/Design and Large-Scale Mission Based Optimization

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Multi-Disciplinary Aircraft Synthesis/Design

Mission based advanced tactical fighter aircraft synthesis/design optimization

- 453 optimization degrees of freedom for the propulsion, environmental control, fuel loop, vapor compression/PAO loop, airframe subsystems
- 481 DOF without airframe subsystem (AFS-A) DOF

Mission Profile

Thermal Management System

Some of the highly coupled subsystems include the propulsion subsystem (PS), fuel loop subsystem (FLS), vapor compression/PAO subsystem (VCP/PAOs)

Optimal variation of take-off weight with aircraft DOF

Aircraft system-level Optimization Response Surfaces

Subsystem Weight Optimization with AFS-A DOF: degrees of freedom included

Objective Function Effects on Aircraft Optimal Synthesis/Design

Five different objective functions/figures of merit were investigated: take-off weight (1); energy destruction and exergy fuel loss in the PS and ECS (2); energy destruction and exergy fuel loss in the PS, ECS and AFS-A (3); thrust efficiency (4); and thermodynamic efficiency (5).

Optimum fuel weight with and without AFS-A degrees of freedom for objectives 1, 2, and 3 where objective 1 is gross take-off weight, objective 2 is energy destruction plus fuel energy loss excluding the exergy destruction rate in the AFS-A, and objective 3 is exergy destruction plus fuel energy loss plus the exergy destruction in the AFS-A.

The exergy-based objective 3 is clearly superior

Morphing Aircraft Synthesis/Design Optimization

A simple turbopet engine model is used in the initial feasibility study. The results prove to be very promising. An aircraft design using a low bypass turbopet is currently under study.

2-D Geometries morphed: wing length, wing sweep, root chord length, tip chord length

Mission-based optimization: the plane is flown from takeoff to landing

Integrated Mission Hypersonic Aircraft Design Optimization

Hypersonic air-breathing aircraft are optimized using three different objective functions: one energy-based and two energy-based (weight of fuel and thermal efficiency). Quasi-three-dimensional models of the vehicle and its subsystems (airframe and propulsion) are developed for the optimization. A total of 8 design and 6 operational optimization degrees of freedom are used.

Comparison of Optimization Results with Standard Design

Each successive iteration of the ILGO optimization process produces a lighter subsystem weight, and an overall lower take-off weight.

Optimal Fuel Tank Temperature vs. Time

Mission segments with horizontal tank temperatures indicate the fuel used to cool the TMS was overheated and burned at a rate that required cooling.

Large-scale optimization showed a ram air heat exchanger for the hot PAO loop could be eliminated by using the fuel tank as a heat sink for the PAO loop without exceeding the vaporization temperature of the fuel.

Comparison of Optimization Results with Standard Design

Take-off weight reduced by 1406 lb compared to Mattingley et al.

Fuel weight reduced by 513 lb

Comparison with and without Airframe DOF

Airframe degrees of freedom allow the optimization to find the optimum airframe configuration for the entire mission.

Improvements in all performance measures were observed after optimization.

Integrated-Single- and Integrated-Mission Vehicle Optimization

The impact of an almost indis-tinguishable boundary between engine and aircraft results in a vehicle in which slight changes in one sub-system profoundly affect the other. This presents a severe challenge for integrated mission-level synthesis and optimization.

Inviscid exergy destruction around the aircraft results in the mission-optimized designs or recharge times.

Unique MIA geometries could potentially allow the fuel cell stack to be placed in non-traditional locations such as the wings and tailplane inside the aircraft. Placing the fuel cell stack in non-traditional locations would allow for larger fuel tanks, packaging, and longer flight times without significantly changing current designs or recharge times.

Using a combination of first-principle and semi-empirical models as well as synthesis/design optimization techniques and breakthrough technologies, current traditional geometries could also be viable options for MAVs. The fuel cell stack proposed by M.M. Hensch, M.Y. Wang, K. Bhata, and C.Y. Wang and shown in the right is a design using such a geometry. This design uses gravity and battery forces to feed the fuel, through flow for smaller, lighter, and more effective fuel cell systems for MAV applications by eliminating the need for pumps and the ensuing parasitic losses as well as balance of plant volume requirements.

CFD Exergy Destruction Calculations in Aircraft Aerodynamics

Exergy analysis has proven to be a very useful synthesis/design tool in lumped parameter type of systems analysis and design approach. The former are in general unable to compete with the latter not just from a performance but also a mission completion standpoint.

Initial results show that CFD methods may provide useful exergy analysis tools for aircraft synthesis/design in the future.

Fuel Cell Propulsion in MAV Synthesis/Design

The Center for Energy Systems Research is collaborating with Luna Innovations, Inc. to determine the feasibility of implementing fuel cell technologies in Micro Air Vehicles (MAVs). Both unique and traditional proton exchange membrane (PEM), direct methanol (DM), and DPA (direct formic acid) fuel cell geometries and configurations are being modeled and tested.

New ways of making the electrolyte materials and fabricating the membrane-electrode assemblages as well as assembling and integrating the multiple cells and stacks into the body of the aircraft are being studied.

Innovative tubular fuel cell cores developed by Microlink Corp. are being examined as potential candidates for use as propulsion units in MAVs. Microcells core picture is from www.microlink.com.

Based on the latest battery technology, the MAV above is the current world record holder for longest flight time of a MAV. This was accomplished by designing the wings to function as batteries.