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Method for Simulating the Performance of a Boundary Layer Ingesting Propulsion System at Design and Off-design

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Abstract

Boundary layer ingestion has emerged as a potential propulsion concept on novel aircraft configurations for the future. As these concepts progress, preliminary design tools are required that enable the simulation of these aircraft and the rapid analysis of multiple configurations. Simulation tools for boundary layer ingesting propulsion systems tend to focus on proving performance benefits at design point. However, the simulation of aircraft configurations that utilise boundary layer ingestion requires a method to simulate the propulsion system at a range of flight conditions other than design point. A tool is therefore required to enable simulations at off-design. This research presents a work flow to simulate a boundary layer ingesting propulsion system at design and off-design. The process is intended as a tool for design space exploration and the rapid analysis of concepts at the conceptualisation phase. Boundary layer calculations have been combined with conventional 1-D gas turbine performance methods to predict performance of a propulsion system at design point. This method is then extended to enable simulations at off-design conditions for a range of flight conditions or propulsion system power settings. The formulation provides a thrust-drag representation that supports conventional aircraft simulation tools. A case study of an aircraft configuration which utilises an array of boundary layer ingesting propulsors is used to demonstrate the process. The performance of individual propulsors in the array is compared at off-design. Simulations found that, although each propulsor was sized for the same propulsive force at design point, off-design performance diverged depending on operating conditions. In addition, the performance of the propulsor array as a whole was predicted as a function of altitude and Mach number. The case study is used to draw general conclusions on the performance characteristics of a boundary layer ingesting propulsor.

Keywords: Propulsion modelling, Aircraft propulsion, Novel propulsion systems, Boundary layer ingestion

Nomenclature

δ	Boundary layer thickness (m)
δ^*	Displacement thickness (m)
$\dot{m}$	Mass flow rate (kg/s)
ρ	Density (kg/m^3)
τ_w	Shear stress (N/m^2)
A	Area (m^2)
c	Aircraft chord length (m)
D	Drag (N)
F_G	Gross thrust (N)
F_N	Net thrust (N)
h	Streamtube height (m)
P	Total pressure (Pa)
p	Static pressure (Pa)
P_{BLI}	BLI propulsion system power (MW)
P_{ref}	Reference propulsion system power (MW)
S_{wet}	Wetted surface area (m^2)
u	Axial velocity (m/s)
w	Streamtube width (m)
x	Chordwise distance from leading edge (m)
x_0	Chordwise distance from aircraft nose (m)
y	Vertical distance above surface (m)
z	Spanwise distance from centreline (m)