Progress in Burner Design Using Additive Manufacturing with a Monolithic Approach and Added Features
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Feasibility study about AM financed by the FFG and the BMVIT (Contract 862837)
Contents

• Background and incentives
• The rePorT technology
• Advanced fuel injection
• Advanced burner design
• Conclusions
Background of this project

• rePorT stands for „Instrumented burner ports for advanced monitoring of the injection in the combustor of an aeroengine“

• emootion stands for Engine health monitoring and refined combustion control based on optical diagnostic techniques embedded in the combustor

• is supported by the FFG and the BMVIT in the frame of the aeronautic programme "TAKE-OFF“ (Contract 850454, 861004).
Incentives

Current:
Injection and burner separately

• Liquid, multipoint fuel injection system with detailed metering and possibly control systems embedded in each burner
• Monolithic 2 staged-premixed burner

Vision:
a compact, low emission, high performance gas turbine burner concept

• Monolithic:
  – one part replaces many
  – combines the best trade-off from previous
  – optimum weight & volume
• Integrative
  – air feed
  – fuel feed
  – thermal management
  – embedded instrumentation
  – additional features
  – advanced injection
Background of this project

**Paper GT2018-75165:** Air flow monitoring using the pressure loss in the burner *with focus on the swirl stage*

- Front plate
- Modular construction with instrumentation
- Venturi shape vs. flashback
- Several fuel injection/staging configurations
- Several swirlers
Background of this project

Design of a
- monolithic burner
- liquid fuel injection ramp

AM by
- SLA
- SLM with Inconel 718

Patent: A50516/2019
Background of this project

This paper separate study of:
- liquid fuel injection
- premixed 2-staged burner
Background of this project

Final demonstrator all integrated:
- fuel and air management
- measurement p,T
- injection ramp
- ignition
- swirl
Background of this project

Support the conventional air and fuel metering

Global core air is known from the engine’s operation

with metering and possibly control systems embedded in each burner

Fuel in

FMU

PRV

Spill flow

Gear Pump

BURNERS

Collected spill flow
Contents

• Background and incentives
• State-of-the-Art and rePorT Technology
• Advanced fuel injection
• Advanced burner design
• Conclusions
State-of-the-Art

For each fuel stage

- Assumption of an even distribution of air and fuel in each burner
- Frequently maintenance intervals
- Health of each burner is unknown

Strong heat transfer due to the hot compressed air and the heat of the combustor

$\rightarrow$ UNCONTROLLED / INHOMOGENEOUS HEAT UP OF THE FUEL
• Larger fuel flows prevent from coking
• Fast detection of engine malfunctions
• Computation of TET
• Adaptive maintenance
Instrumented fuel injection

Activates one single ramp

Fuel Feed

On-off Valve

Fuel interface input / output

Instrumentation

ΔP

T

INJECTION NOZZLE / RAMP

Fuel injection

Feedback

• Normal or faulty injection
• Burner health

• Prevent fuel from flowing back
• Discharge function

• Cooling the instrumentation
• Collected at reservoir
Contents

• Background and incentives
• State-of-the-Art and rePorT Technology
• Advanced fuel injection
  – Injection ramp
  – Test results
• Advanced burner design
• Conclusions
Injection Ramp

Combined:
- Manifold
- Heat exchanger
- Multipoint injector

Fuel spray

Spill flow
Non-reactive tests
**Injection hole test**

<table>
<thead>
<tr>
<th></th>
<th>1 Round hole, D 0.5 mm, S 0.196 mm²</th>
<th>2 Square hole, same surface S</th>
<th>3 Square hole, same as before slanted 45°</th>
<th>4 Elliptic hole, same surface, D1 0.8 mm, D2 0.32 mm</th>
<th>5 Elliptic hole, same as before but slanted 90°</th>
<th>6 Round hole, surface $\sqrt{2}S$</th>
<th>7 Round hole, surface $\sqrt{2}S$</th>
<th>8 Round hole, S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image1.png" alt="Image 1" /></td>
<td><img src="image2.png" alt="Image 2" /></td>
<td><img src="image3.png" alt="Image 3" /></td>
<td><img src="image4.png" alt="Image 4" /></td>
<td><img src="image5.png" alt="Image 5" /></td>
<td><img src="image6.png" alt="Image 6" /></td>
<td><img src="image7.png" alt="Image 7" /></td>
<td><img src="image8.png" alt="Image 8" /></td>
</tr>
</tbody>
</table>

Width of ramp = 10mm  
Number of holes = 14  
Reference diameter = 0.5mm

No clear advantage of shaping the holes elliptic or square.
Contents

• Background and incentives
• The rePorT technology
• Advanced fuel injection
• Advanced burner design
  – Premixed, staged burner
  – Full instrumentation
  – Results
  – AM design details
• Conclusions
Premixed, staged burner

- **Pilot burner**
  Maintain main’s flame combustion

- **Flow conditioner**
  Additional swirl

- **CBO4**
  Monolithic design

- **Swirler**
  Generation of swirl stabilised flame

Indicative thermal power
7.6 kW

Venturi Factor near 5
AM design details

- Printed from bottom to top
- Integrated support structure into the design
  - Heat exchanger function
  - Holding structure for instrumentation
  - Swirl function through spiral inside burner
- hardly realisable with conventional production methods
  - Crown details
  - integrated Swirler and
  - other design details
Full instrumentation

Passages for the thermocouples
Pilot inlet
Main inlet
Differential pressure ports for the air mass flow rate measurement
Quick connectors

Instrumentation ports
Fuel and air feed swirl generation
Pilot-crown

Measurement of differential pressure
Results

- Atmospheric conditions
- Speed measured from part to full load
- Measurement error high at part load
Conclusions

• First fully integrated burner was 3D printed
  – Very thin walls (0.4mm) for support structures
  – Integrated instrumentation
    • Ignition
    • Pressure loss and temperature measurement
• 3D printed ignition ramp and the burner are successfully tested separately
• Integration of multipoint injection ramp into the burner can be done in the next step
• Whole system could provide an advanced monitoring and combustion system
Thank you for your attention!

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Mathematics to Shapes

- From equation to the shape

Analytical Mathematics

Library of Shapes

Numerical Mathematics

Sizing Parametrics & Plots

CFD

CAD

Design Optimisation

SINGLE SHAPES

Production

MATLAB
Mathematic to shape
Steps in 3D production of mock-ups

**Plastic wire model:**
check out the feasibility of the printing process

**Resin model:**
check out the aerodynamics and internal liquid flows

**Final burner made up of Inconel 718,**
ready for combustion application
3D printed Burner
3D-printed fast connectors for the gas supply / pressure instrumentation / ignition

- Differential pressure ports for the air mass flow rate measurement
- Passages for the thermocouples
- Pilot inlet
- Main inlet
- Quick connectors
Detail pilot crown
Metering point facing the crown

Anti-Froude profile of the pilot stage for flow relaxation

Ignitor
Detail Spirale
1. The ignition flame is started with a spark plug.
2. The pilot gas is turned on.
3. The ignition flame transmits to the pilot flame. Ignition is turned off.
4. The pilot and main gas are adjusted. Ignition sequence successful.
INJECTION AND DIFFUSION
The initial temperature of the fuel is even better, leading to:

- Better quality of the mixture
- Better Combustion

FLOW IN

HOT AIR

SPILL FLOW OUT

INJECTION AND DIFFUSION

-> BETTER COMBUSTION
<table>
<thead>
<tr>
<th>Nr.</th>
<th>Geometry</th>
<th>Diameter</th>
<th>Surface</th>
<th>Comments</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Round hole</td>
<td>0.5 mm</td>
<td>0.196 mm²</td>
<td>#1 Reference case with 0.5mm supposedly round holes. All 14 jets active</td>
<td>14 round holes, this object is the reference</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Little</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Square hole</td>
<td>0.433 mm</td>
<td>0.196 mm²</td>
<td>#2 All 14 jets active. The square pattern is well visible. At least 5 streams parallel</td>
<td>Same surface as 1) Side parallel to the border</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Qualitatively the best of the serie for low flow rates</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Square hole</td>
<td>0.433 mm</td>
<td>0.196 mm²</td>
<td>#3 Expected to be better than 2) but actually not really. 4 parallel streams</td>
<td>Same surface as 2) With sides inclined 45 degrees compared to the border</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hole #13 from outlet is partly plugged</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Elliptic hole</td>
<td>0.8 mm</td>
<td>0.201 mm²</td>
<td>#4 Very similar to 1), with stream #13 plugged (visible on the picture left)</td>
<td>Same surface as 1), with an elliptic hole where the long side is parallel to the long border. D1=D2*square root(2)</td>
</tr>
<tr>
<td>5</td>
<td>Elliptic hole</td>
<td>0.320 mm</td>
<td>0.201 mm²</td>
<td>#5 No spray</td>
<td>Same as 4) but with the short side parallel to the border. This hole could not be printed properly and was therefore plugged.</td>
</tr>
<tr>
<td>6</td>
<td>Round hole</td>
<td>0.595 mm</td>
<td>0.278 mm²</td>
<td>#6 Holes #13 and 14 are plugged. No real benefit versus #1)</td>
<td>Same as 1) with the surface multiplied by square_root(2)</td>
</tr>
<tr>
<td>7</td>
<td>Round hole</td>
<td>0.658 mm</td>
<td>0.340 mm²</td>
<td>#7 9 parallel streams. All jets active. Qualitatively better than 1)</td>
<td>Same as 1) with the surface multiplied by square_root(3)</td>
</tr>
<tr>
<td>8</td>
<td>Round hole</td>
<td>0.707 mm</td>
<td>0.393 mm²</td>
<td>#8 10 parallel streams. All jets active. Qualitatively the best spray of the serie adapted to large flows.</td>
<td>Same as 1) with twice the surface</td>
</tr>
</tbody>
</table>
1. Application of the powder layer
2. Melting of the powder
3. Lowering of the base plate

LAYER N
LOOP TO LAYER N+1

Machine Farsoon FS121M:
- Platform Dimensions: 120mm x 120mm x 100mm
- Yb-fiber Laser 200W with a diameter of 40 - 100 µm

Inconel 718 (Pulver AMPO L718):
- Particle size: 15-45 µm
- Bulk density: 8,2 g/cm³
- Porosity < 0,1%
- Building rate: 5,5 cm³/h (1 swirler ~ 10 hours)