Passive Hypersonic Transition Control by Means of Ultrasonically Absorptive Thermal Protection Materials (UAT)

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2017 Annual Review for the AFOSR High Speed Aerodynamics Portfolio and the ONR Hypersonics Portfolio
Motivation

- shock pattern dominated flow
- boundary layer transition
- shock-shock and shock-BL interaction
- thermo-chemical effects
Motivation

- DLR SHEFEX

Additional/Critical Heating

- shock pattern dominated flow
- boundary layer transition
- shock-shock and shock-BL interaction
- thermo-chemical effects
Motivation

- Ultrasonically Absorptive
- Thermal Protection

\[ f = 200 - 400 \text{ kHz} \]
\[ \lambda = 9.6 - 4.8 \text{ mm} \]
General Design Approach for UAT

Stability Analysis / Acoustic Theory

Targeted Material Design

Operating Conditions of Interest

Validation by means of Wind Tunnel Testing

Acoustic Bench Testing
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Targeted Material Design
Manufacturing
Liquid Silicon Infiltration (LSI)

CFRP
- stacked 2d hybrid fabrics
- T < 250° C

C/C
- T > 900° C
- non stable fiber decomposes

C/C-SiC
- liquid silicon infiltration
- T > 1420° C

RTM*, Hot Press, Autoclave

Pyrolysis

Si Infiltration

* Resin Transfer Moulding
Microstructure*

- micro Computer Tomography scan using a high resolution μCT-System
- channel structure along the two fiber directions
- C/C-SiC channel surface smoother than in the C/C state, caused by the SiC which coated the entire channel

C/C

C/C-SiC

OCTRA - Optimized Ceramic for Hypersonic Application with Transpiration-cooling, Christian Dittert and Marius Kütemeyer, HTCMC9 and GFMAT2016, June 26 – 1 July, Toronto, Ontario Canada
Porosity

- ID- Code:
  PH (Autoclave),
  I (RTM),
  HP (hot press)

- porosity measurements following DIN 51918 (Archimedes principle)

- C/C intermediate state: porosity up to 45 vol.%

- C/C-SiC between 10 vol.% and 25 vol. %
Pore size distribution C/C -> C/C-SiC

- C/C PH2499
  - dV/dlog(D) (mm$^3$/g, D)
  - rel. pore vol. (%)

- C/C SiC PH2499
  - dV/dlog(D) (mm$^3$/g, D)
  - rel. pore vol. (%)

- C/C I770
  - dV/dlog(D) (mm$^3$/g, D)
  - 'classic' C/C pore vol. (%)
  - rel. pore vol. (%)

- C/C SiC I770
  - dV/dlog(D) (mm$^3$/g, D)
  - 'classic' C/C pore vol. (%)
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  - rel. pore vol. (%)

Graphs showing pore size distribution and relative pore volume for C/C and C/C-SiC materials.
Pore size distribution C/C -> C/C-SiC

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  - dV/dlog(D) (mm$^3$/g, D)
  - rel. pore vol. (%)

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  - dV/dlog(D) (mm$^3$/g, D)
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  - rel. pore vol. (%)

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- C/C-SiC I771
  - dV/dlog(D) (mm$^3$/g, D)
  - rel. pore vol. (%)

pore diameter (nm)
Pore size distribution C/C -> C/C-SiC

- Pore size can be influenced
  - by the CFRP-process
  - and by the used resin

- Pores smaller than $10^4$nm are closed after silicon infiltration

- Remaining pores arise from the decomposed fibers
Pore size distribution C/C -> C/C-SiC

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Ultrasonic Absorption Properties
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\[ R = \frac{A_{\text{porous}}}{A_{\text{solid}}} \]

Diagram showing ultrasonic absorption properties through porous walls.
Ultrasonic Absorption Properties

**Reflection Coefficient Sample I771-2 (1st WP)**

- **125 kHz (L)**
- **125 kHz (R)**
- **220 kHz (L)**
- **220 kHz (R)**
- **292 kHz**

**C/C**

- **$f = 197$ kHz**
- **$f = 373$ kHz**

**Optimized C/C**

- **$f = 125$ kHz**
- **$f = 300$ kHz**
- **$f = 490$ kHz**

**Graphs**

- Y-axis: $R$ [-]
- X-axis: pressure [x10$^5$ Pa]
Linear Stability Analysis

to support wind tunnel model design
Chosen test condition

\[ R_{\text{nose}} = 2.5 \text{ mm} \]
\[ R_{\text{em}} \sim 4 \cdot 10^6 \text{ m}^{-1} \]
\[ \text{Ma} \sim 7.5 \]

C/C material properties

<table>
<thead>
<tr>
<th>( \frac{R_{\text{trans,porous}} - R_{\text{trans,smooth}}}{R_{\text{trans,smooth}}} )</th>
<th>Exp.</th>
<th>LST</th>
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</thead>
<tbody>
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<td>0.15</td>
<td>0.13</td>
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Numerical results based on local theory
Numerical results based on local theory
Numerical results: comparison local / non-local theory

necessary porous C/C surface: 500 – 900 mm
Conclusion

➢ **Targeted Material Design**
  • first UAT samples manufactured
  • three different manufacturing processes used
  • first optimization loops to improve sample homogeneity

➢ **Acoustic Bench Testing**
  • test bench is up and running
  • first UAT sample tested
  • recent results are very promising
  • post-processing routine extended and improved

➢ **CFD (LST)**
  • porous surface boundary condition included
  • ready to support wind tunnel model design as soon as all material properties available

➢ **Next**
  • Wind tunnel model design with the most promising UAT candidate