Experimental Hypersonics

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Boundary Layer Transition Mechanisms on Lifting Hypersonic Bodies

STATUS QUO

Transition Mechanisms on Lifting Hypersonic Bodies

• Stationary and traveling crossflow predicted on hypersonic vehicles • Limited experimental evidence for stationary crossflow • Little or no evidence for traveling crossflow • No flight data

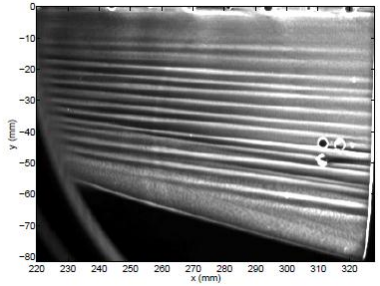
HIFiRE Flight and Ground Test

• Crossflow detected in flight • 2nd-mode N-factors measured in flight • Ground test showing stationary crossflow and possibly traveling crossflow

NEW INSIGHTS

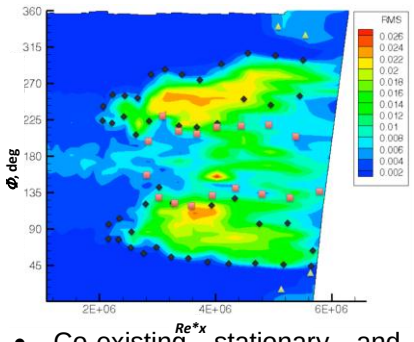
Crossflow Instability Detection

• High bandwidth pressure and heat transfer instrumentation resolves disturbances on a spinning cone at AoA • Temperature sensitive paint and oil flow visualize stationary disturbances in wind tunnel and high bandwidth pressure transducers resolve traveling disturbances



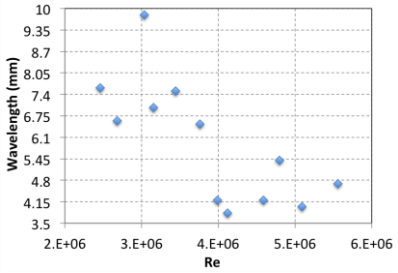
Crossflow instabilities on HIFiRE-5 in quiet windtunnel

MAIN ACHIEVEMENTS:



Pressure RMS contours and transition locations on HIFiRE-1 during descent

• Co-existing stationary and traveling vortices measured on HIFiRE-5 model in wind tunnel • Stationary crossflow vortices on HIFiRE-5 manipulated in wind tunnel with roughness elements • Descent high-AoA transition front mapped, showing crossflow instabilities, crossflow transition and attachment line transition in flight



Wavelength of crossflow instabilities measured in flight on HIFiRE-1

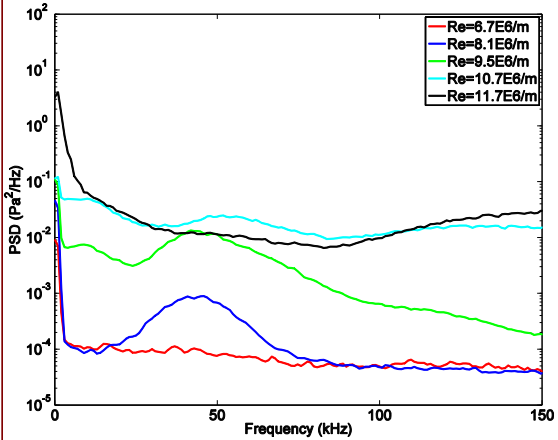
ASSUMPTIONS AND LIMITATIONS:

• Flight measurements not confirmed by computation yet • Ground tests subject to further computation and analysis to extract wave velocities and wave angles

QUANTITATIVE IMPACT

Current Impact

• Calibrated flight N-factors for second-mode transition prediction • Crossflow-induced flight transition for N-factor calibration • Quantitative wave angle measurements in wind tunnel for code validation



Power spectra of pressure measurements on HIFiRE-5 showing possible traveling crossflow instability

Planned Impact

• Provide prediction criteria for transition on lifting hypersonic bodies

Research Goals

• Derive wave angles from ground tests • Characterize wave growth in flight experiments

END-OF-PHASE GOAL

Research Will Lead to Improved Hypersonic Transition Predictions[1]

Transition Produces Radical Changes in Heating and Aerodynamics

- Objective – determine mechanisms dominating 3D hypersonic boundary layer transition
- SOA - 3D PSE, 2D PSE on planes, correlations
- What's new – combination of wind tunnel and flight experiments provides bench mark data for calibrating predictions and is also providing new insights into transition phenomena
- Risks (actually challenges) – quantitative measurements of instabilities
- Payoffs – reduced heating and improved aero performance on Prompt Global Strike vehicles

[1]Kimmel, R. L., Adamczak, D., and Brisbane DSTO-AVD Team, "HIFiRE-1 Preliminary Aerothermodynamic Experiments," AIAA paper 2011-3414, June 2011

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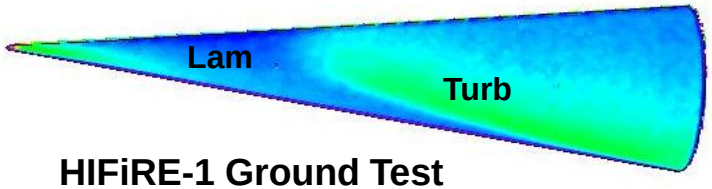
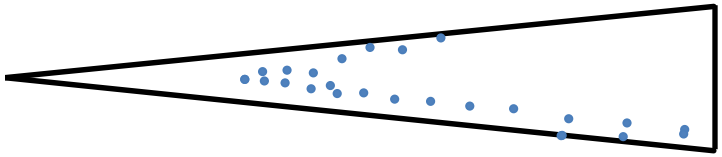
- Fellow, ASME
- Associate Fellow, AIAA
- Associate editor, AIAA Journal Spacecraft and Rockets
- PI, HIFiRE-1, -5
- Lead, Falcon HTV-2 Aerothermal IPT
- AFRL/RB Perkins Award 2009, 2011

3D, Crossflow-InducedTransition Fronts on Cones at AoA – Ground Test and Flight



HIFiRE-1 Ground Test
AoA=5

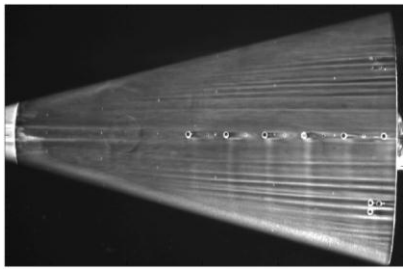
Berger, Greene, Kimmel 2008



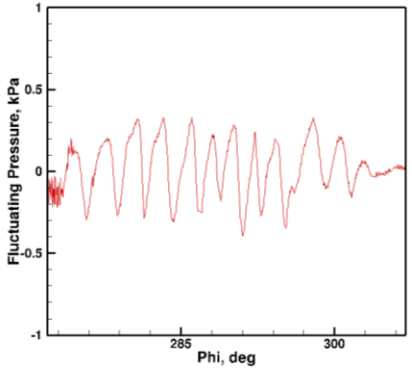
HIFiRE-1 Flight Test
AoA=5-10 deg

Crossflow Instability Measurements – Ground and Flight

HIFiRE-5 Oil Flow – Purdue Quiet Tunnel



HIFiRE-1 Crossflow Pressure Fluctuations in Flight



Ground and flight test provides benchmark data and insight into transition physics