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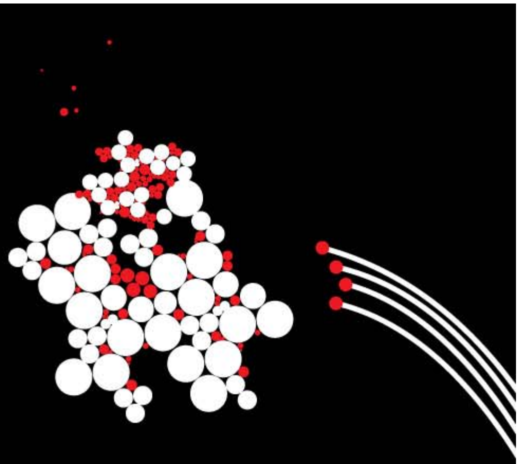
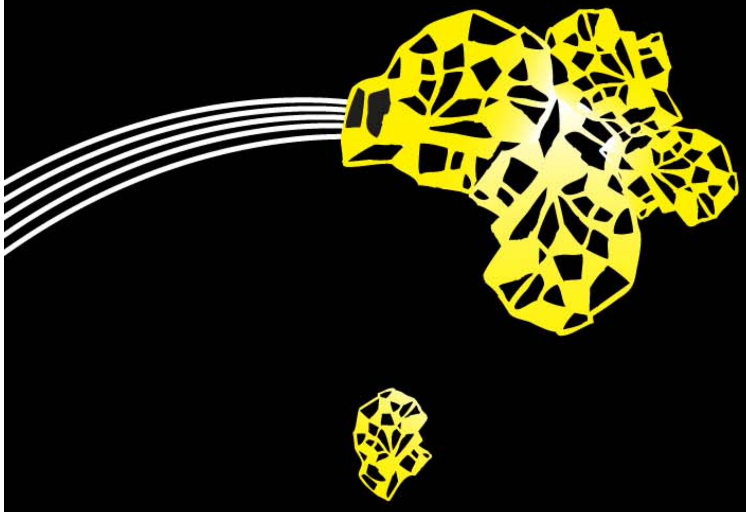


Combustion Dynamics in Gas Turbine Engines

Jim B. W. Kok

Reddy Alemela, Juan Carlos Roman, Mehmet Kapucu, Can Altunlu, Mina Shahi



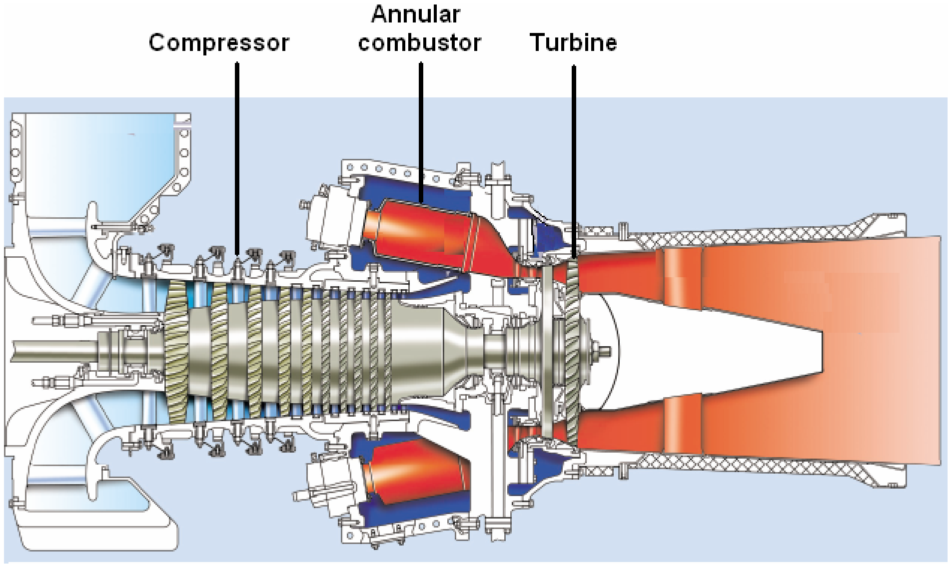
Outline

- Introduction Combustion Dynamics
- LIMOUSINE
- Limit cycles in a Generic combustor

Gas Turbine Engines for Power Generation, gas fired

1950: increase efficiency	diffusion flames
1980: decrease NOx	premix flames
1990: control stability	lean premix flames
2010: life time	very lean flames, high power density

Siemens SGT100



Acoustic Wave Propagation Equation in a fluid in motion

- Sound generation by turbulent flames:
- Originates from the fluctuating heat release in the flame.

- Explained by volumetric expansion in flame.

- fluctuating heat release in turbulent flames is complicated due to the interaction of turbulence, mixing, combustion and pressure fluctuations.

The thermo acoustic source term

Sir James Lighthill:

Propagation of pressure fluctuations:

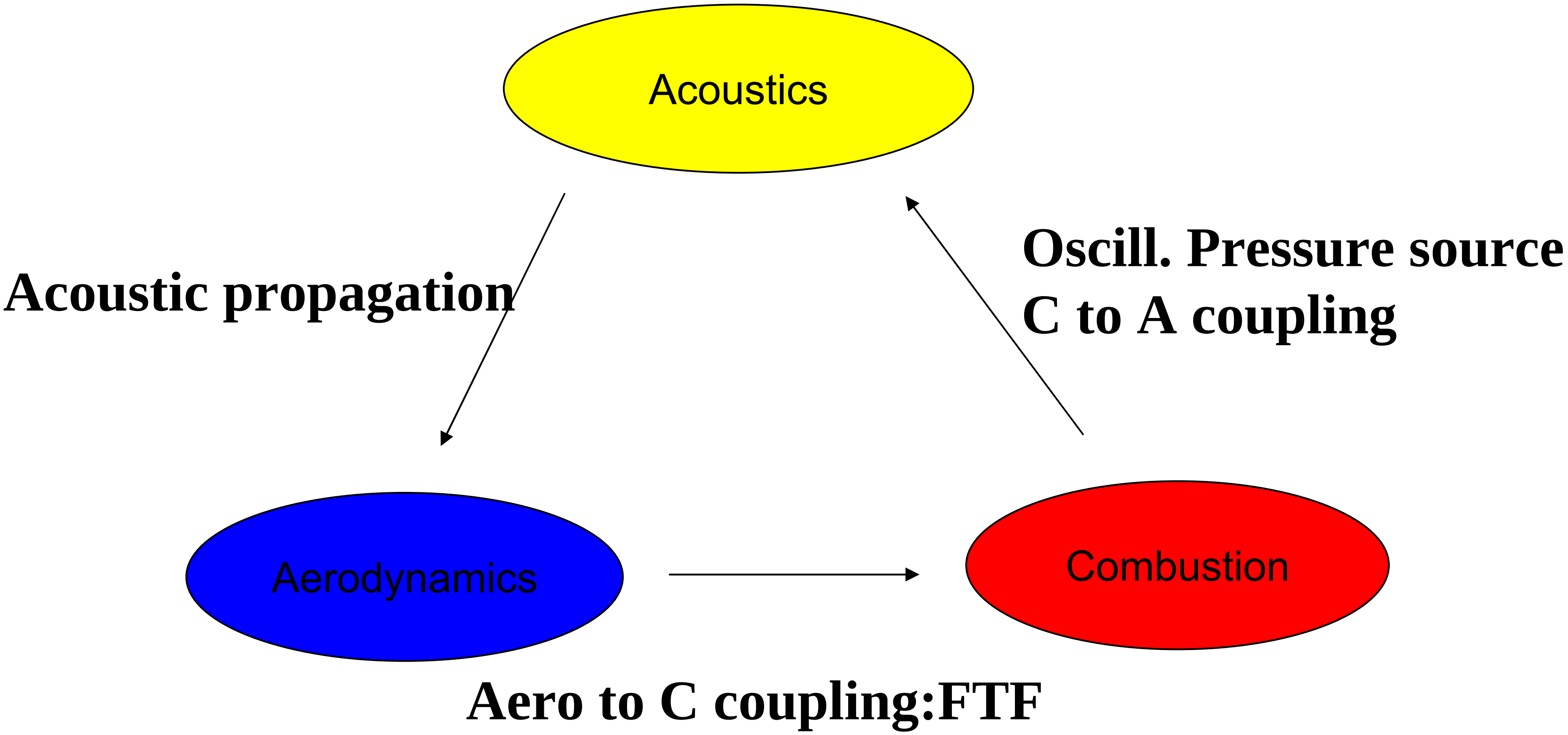
$$\frac{\partial}{\partial t}\left(\frac{1}{c_0^2}\frac{\partial P}{\partial t}\right)-\nabla^2 P =$$

Instantaneous thermo acoustic source term:

$$-\frac{\gamma-1}{c_0^2}\frac{\partial}{\partial t}\left(\dot{Q}\right)$$

Question: Is it that simple ?

Acoustic/aerodynamic/combustion feed back loop



Acoustics

Acoustic propagation

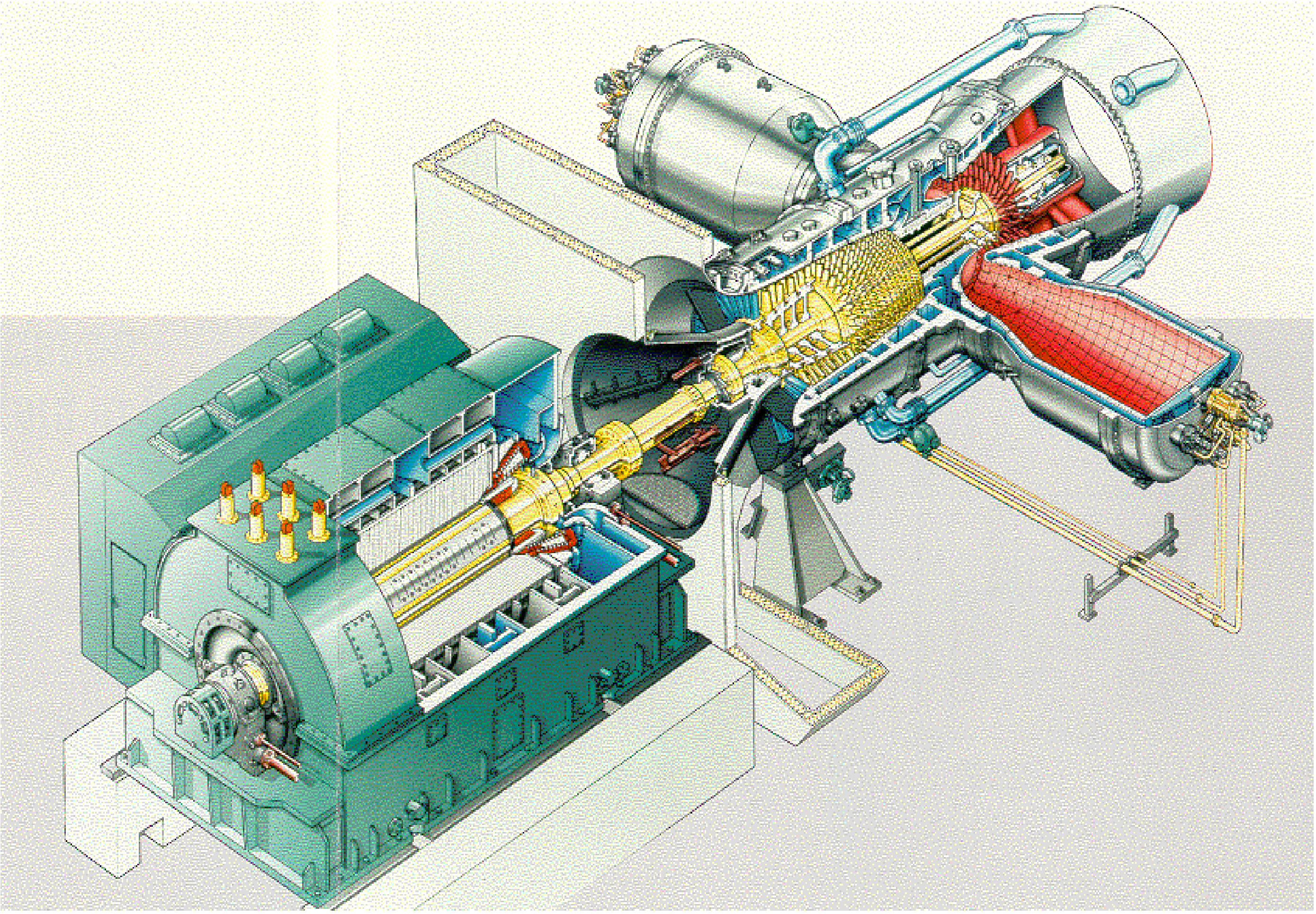
Oscill. Pressure source
C to A coupling

Aerodynamics

Combustion

Aero to C coupling:FTF

Siemens V94.2/ SGT5-2000E, 200 MW
Buggenum 1995
Puertollano 1998



Combustion Dynamics research UT

PhD projects Combustion Dynamics

1995 Syngas/Buggenum	S.Klein
2002 DESIRE	J. van Kampen/R. Huls
2004 HEGSA	S. Pater
2006 FLUISTCOM	A. Pozarlik
2008 LIMOUSINE	5 PhD's

2000	Klein, S.A.	On the acoustics of turbulent non-premixed flames
2006	Kampen, J.F. van	Acoustic pressure fluctuations induced by confined turbulent premixed natural gas flames (Cum Laude)
2007	Jager, B. de	Combustion and noise phenomena in turbulent alkane flames
2007	Pater, S.G.J.	Acoustics of turbulent non-premixed syngas combustion
2010	Pozarlik, A.	Combustion, acoustics and vibration in premixed natural gas turbine combustors

Limousine Project: Marie Curie/ITN

- Limit cycle Oscillations in:
- Combustion-Acoustics-Vibration-Heat Transfer-Fatigue

- 17 PhD students
- 3 Post Docs
- 5 work packages: Analytical, Numerical, Experimental, Control, Fatigue
- 6 work shops

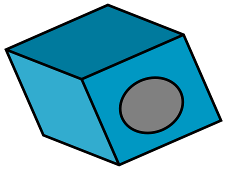
- Twente/Keele /Imperial College/Zaragoza/Brno
- CERFACS/DLR/ANSYS
- IftA/Siemens/Electrabel

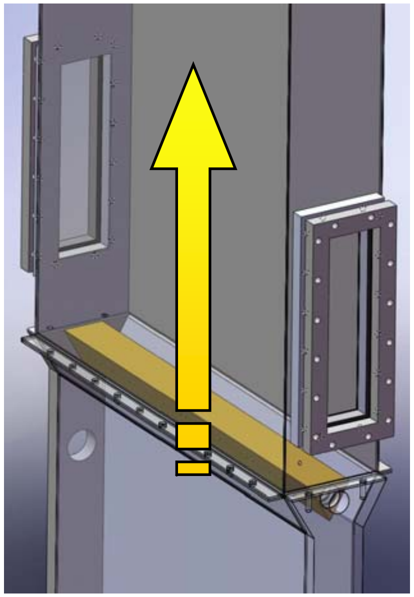
LIMOUSINE PROJECT

- Study of high amplitude processes in a generic atmospheric combustor:
- NG 60 kW/air factor 1.4/bluff body=wedge stabilized
- Rig in 5 copies at UT/IC/DLR/Zaragoza/Ifta

MODEL COMBUSTOR

SET-UP AND SENSORS

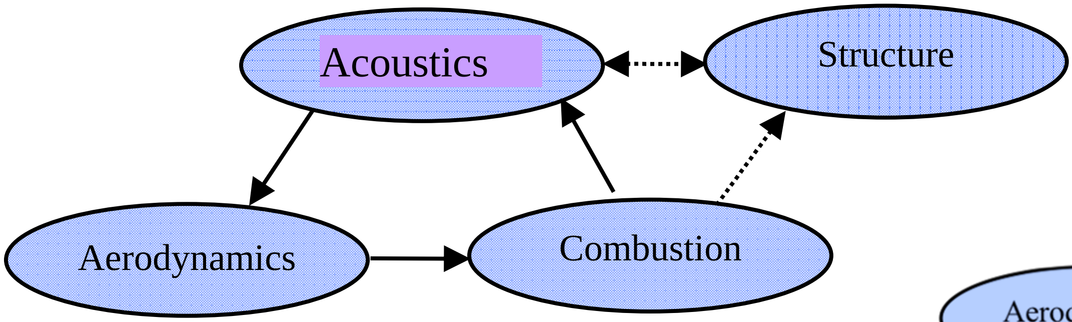




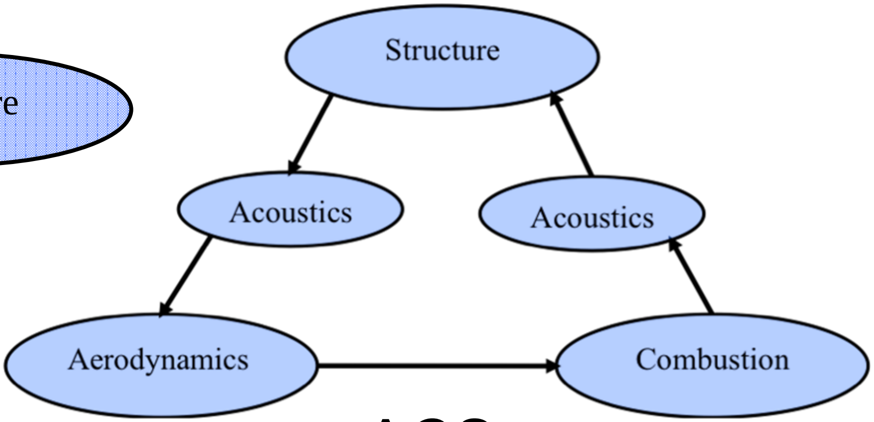
Pressure Transducer	**Pressure waves**
Laser Doppler Vibrometer	**Wall vibration**
CCD Camera	**CH* Luminescence**
Thermocouple	**Temperature field**

INSTABILITY MECHANISM

OF THE THERMOACOUSTIC OSCILLATIONS



ACA



ACS

→ Active Link

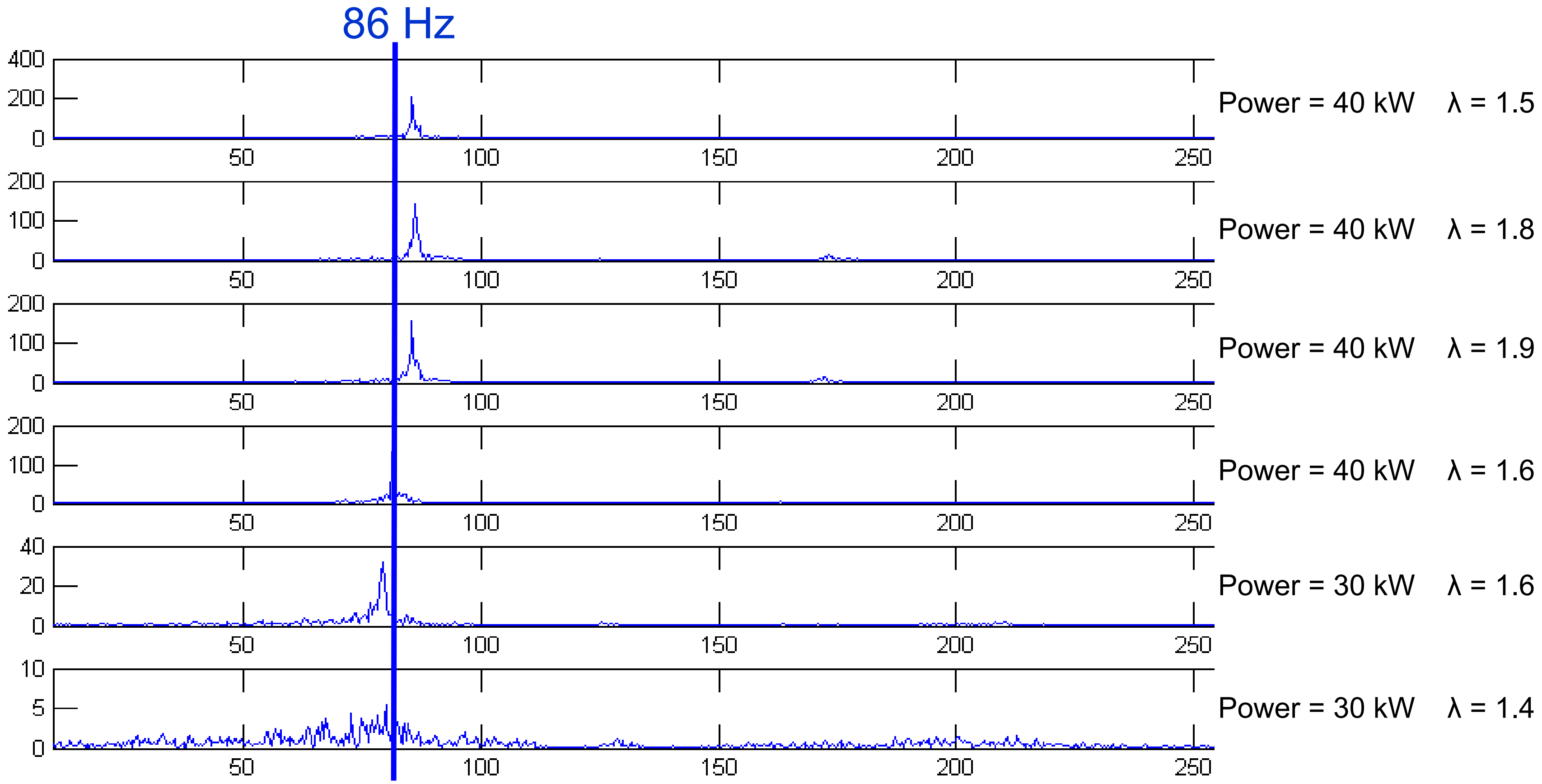
⇢ Passive Link

McManus, Poinsot, Candel, **1993**.
Lieuwen, Torres, Zinn, **2001**.

Proposed new feedback loop: Acoustics is an energy carrier

PREVIOUS EXPERIMENTS

Pressure Signal Auto-spectrum for the 2 clamps situation, for same pressure transducer and different operating points

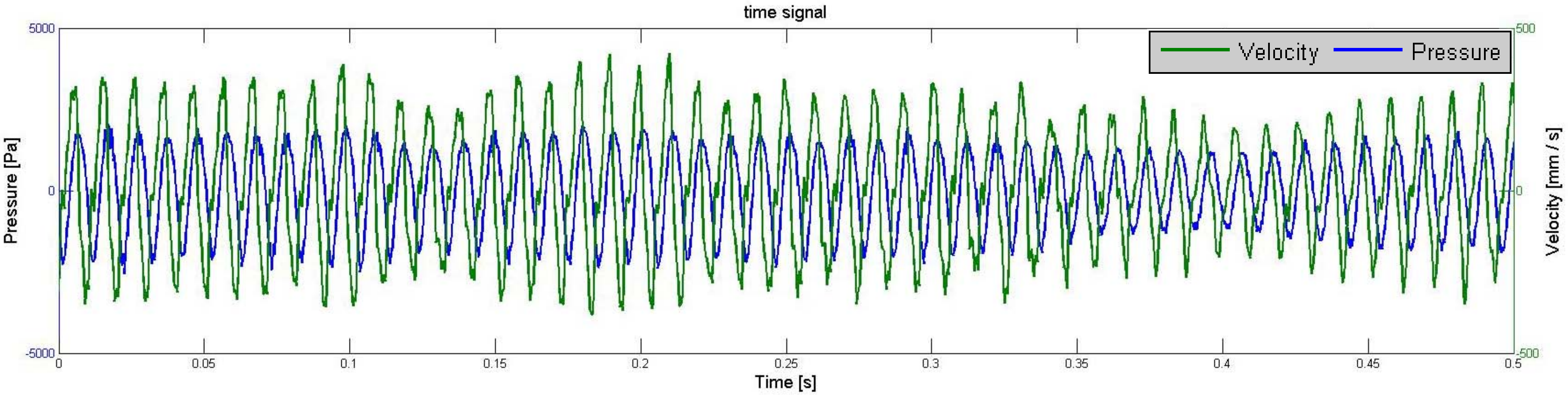


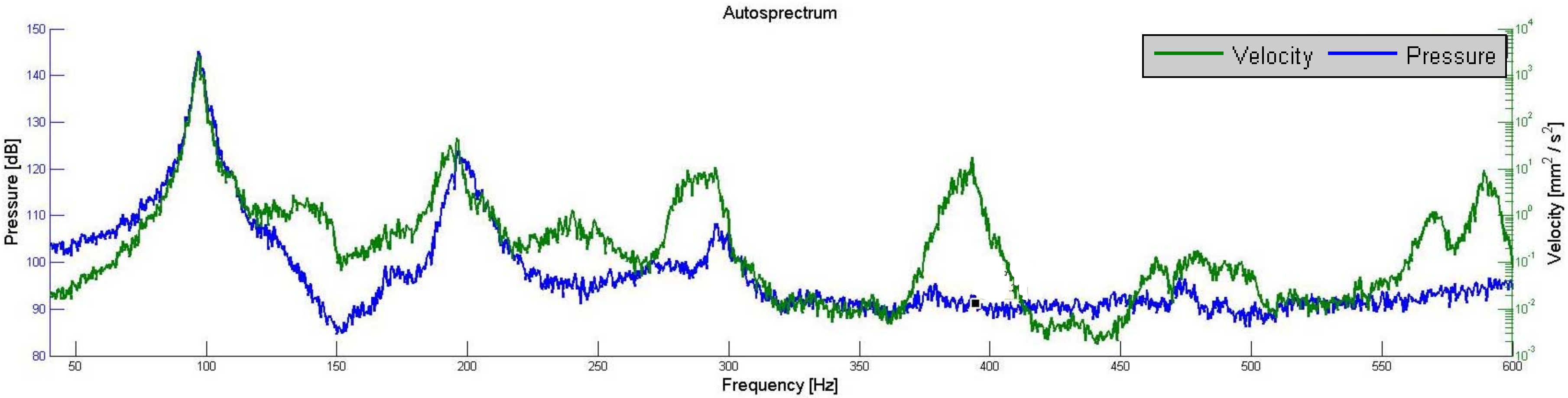
MEASURED DATA (I)

WALL VIBRATION AND PRESSURE SIGNALS

3 clamps

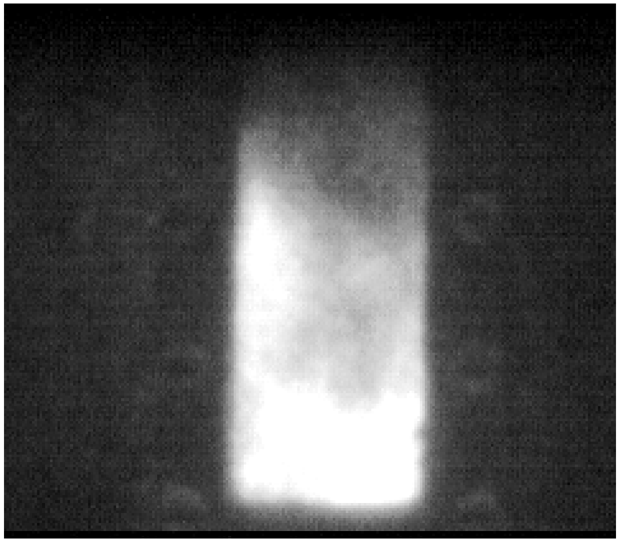
50 kW λ= 1.4





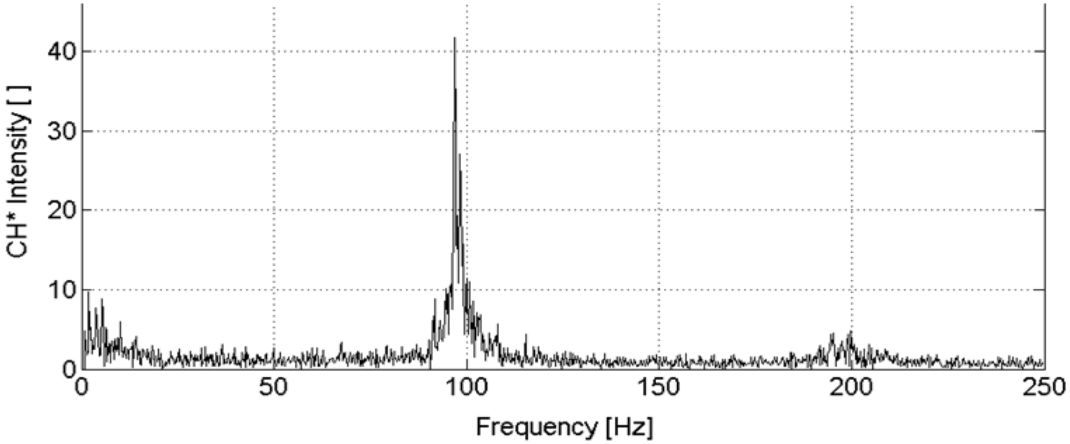
MEASURED DATA (II)

CHEMINLUMINESCENCE HIGH SPEED IMAGES



3 clamps

50 kW λ= 1.4



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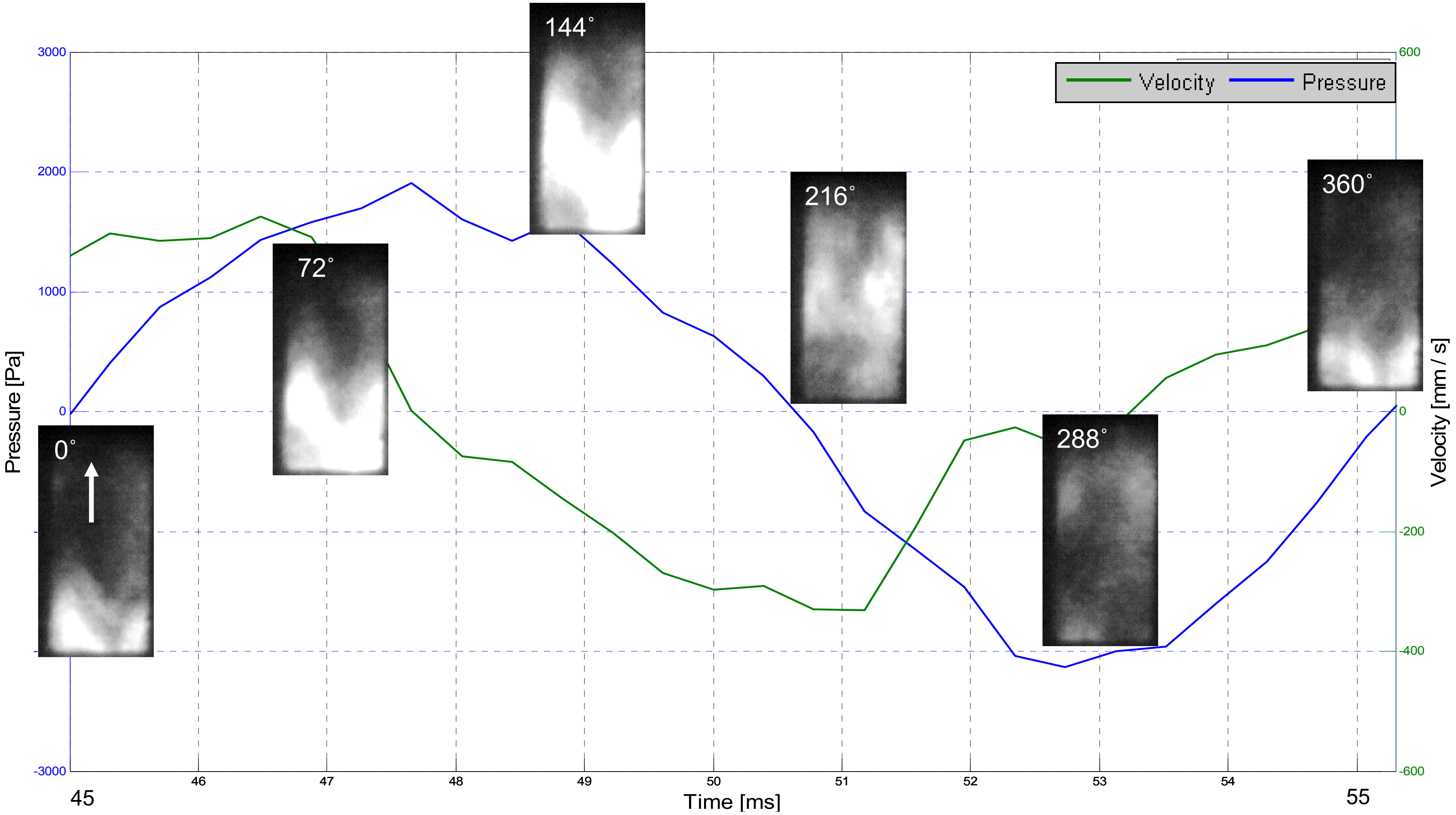
MEASURED DATA (III)

ONE LOOP ZOOM IN

3 clamps

50 kW λ= 1.4



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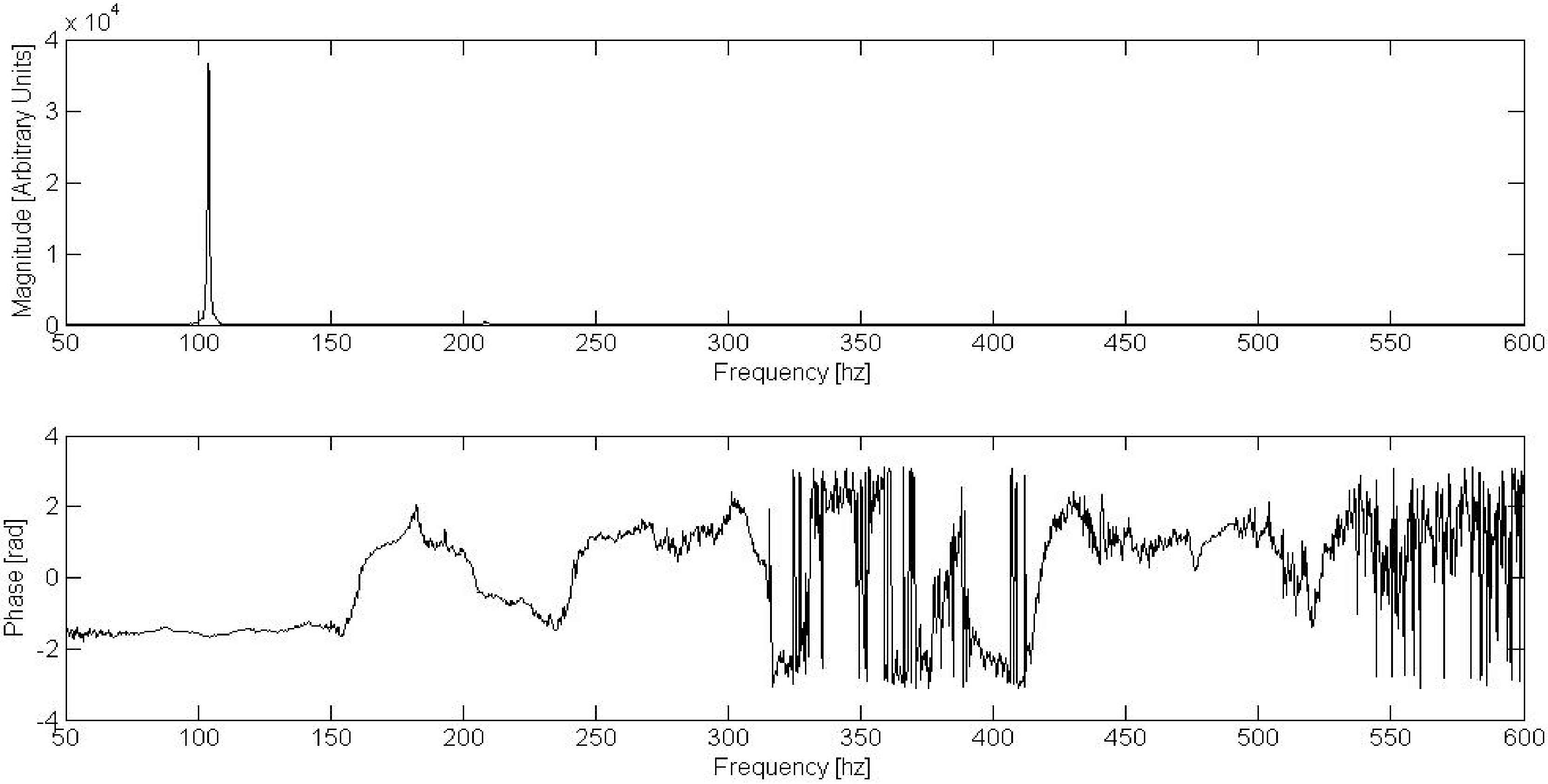
MEASURED DATA (V)

CROSS SPECTRUM BETWEEN WALL VELOCITY AND PRESSURE

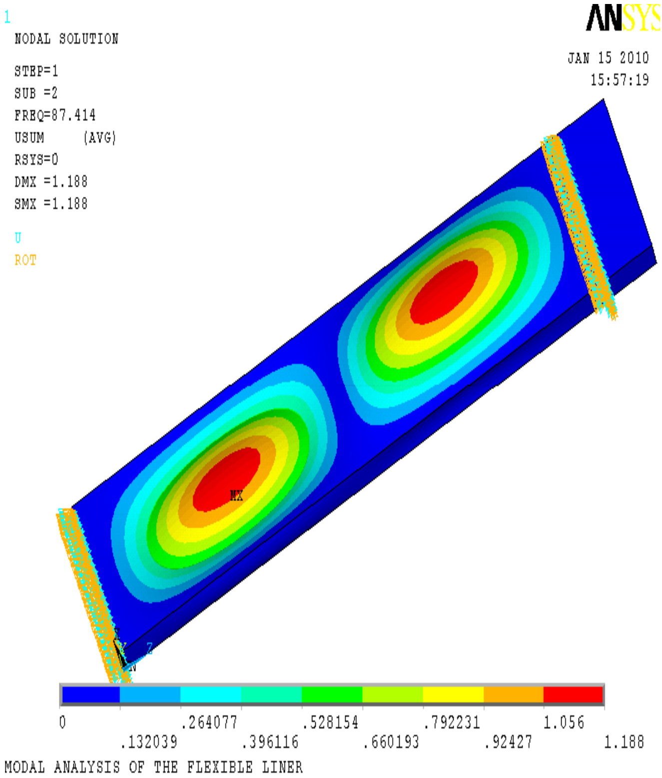
3 clamps

50 kW λ= 1.4

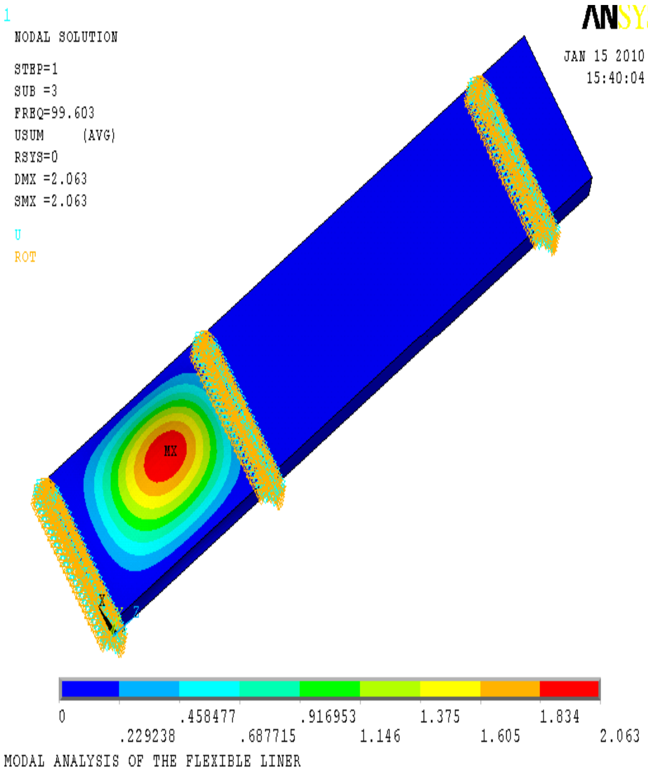


FEM MODAL ANALISYS

FOR DIFFERENT CLAMPING CASES



86 Hz



100 Hz

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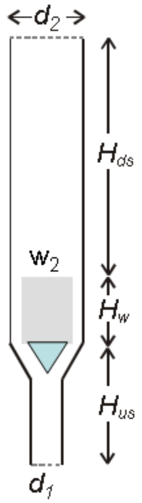
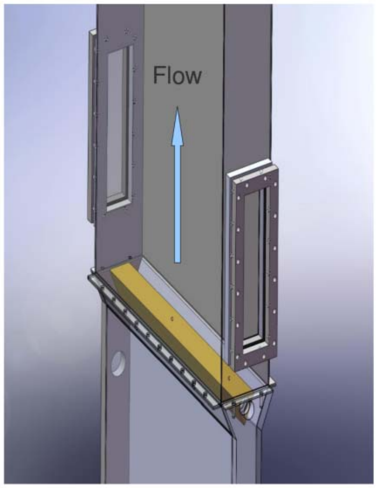
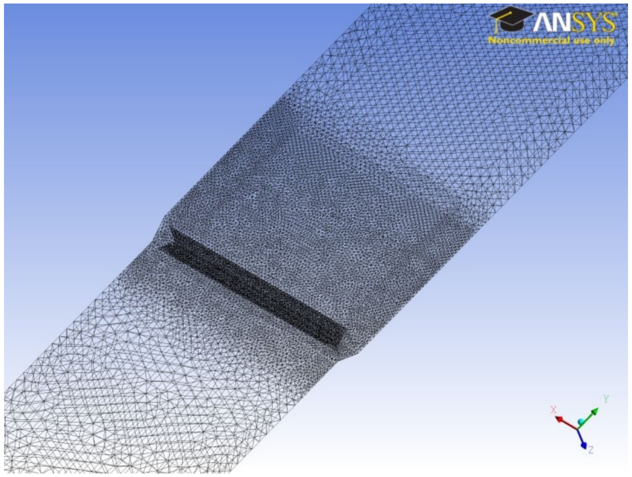
Limousine Combustor Geometry







H_{us} height upstr*[mm]*	322
H_{ds} height downstr *[mm]*	1066
Wedge side W_2 *[mm]*	21.2
Upstr air velocity *$m\ s^{-1}$]*	3.02, 1.51
Cold flow Reynolds nr	5000
Combustor power *[kW]*	40, 20
d_1, d_2 *[mm]*	25, 50

Mesh Details:

- Highly refined mesh close to the wedge
- Total number of mesh elements = 950,000
- Minimum mesh size=1mm

Numerical Models & Boundary Conditions

- Combustion Model : PDF Flamelet Model with Zimont Correlation for turbulent burning velocity
- Turbulence Model : k-ω SST for Steady State Simulations

  SAS-SST (LES like model) for Transient Simulations

All the conservation equations are solved with high resolution schemes

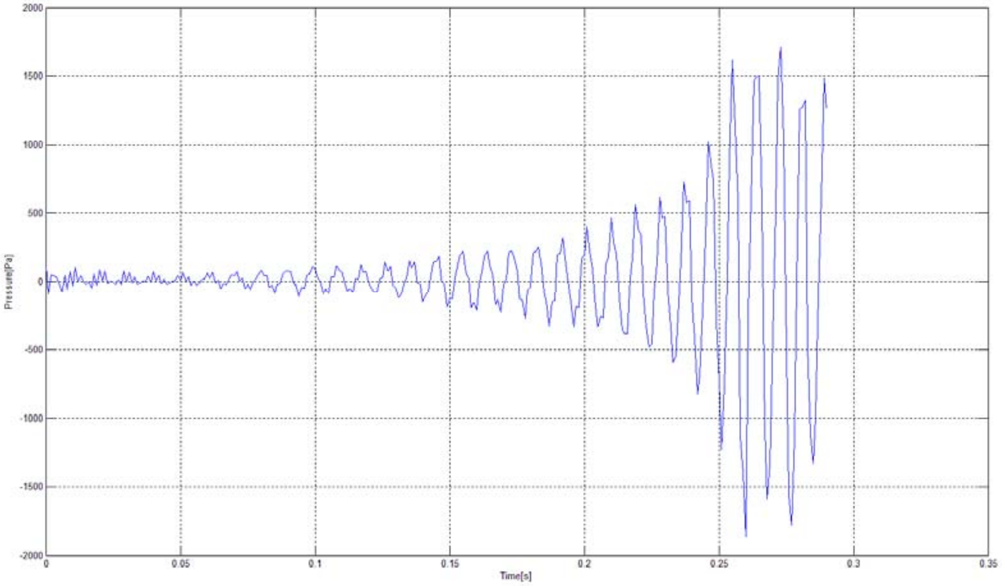
Boundary Conditions:

Air inlet: specified by velocity U=3.02, 1.51[m/s]

Fuel inlet: specified by mass flow rates $\dot{m}$ = 3.64E-04, 7.27E-04 [kg/s]

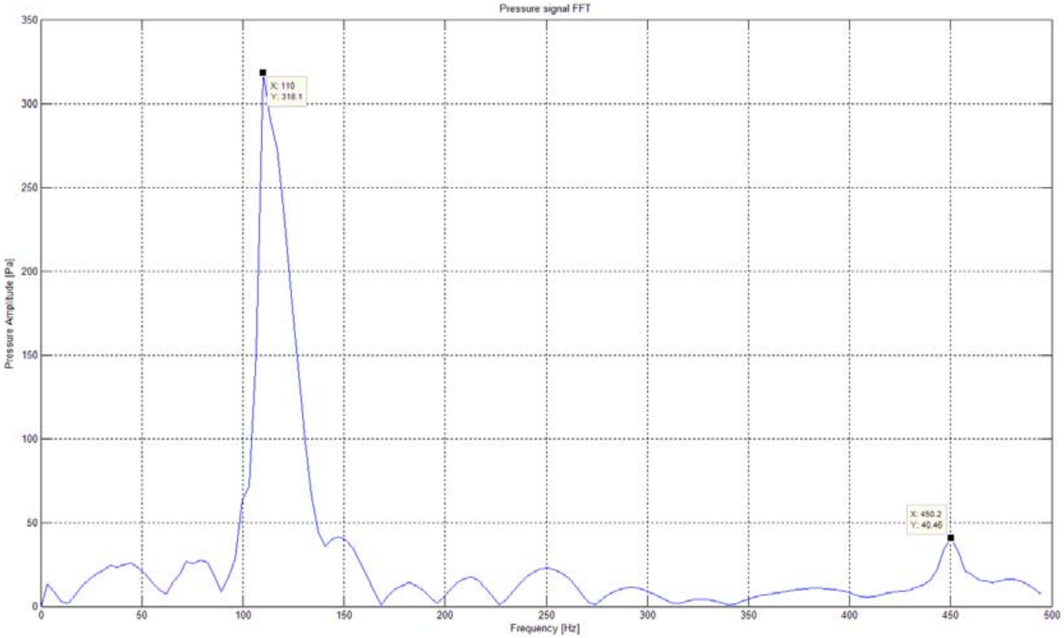
No pre-heating both inlet temperatures at 300[K]

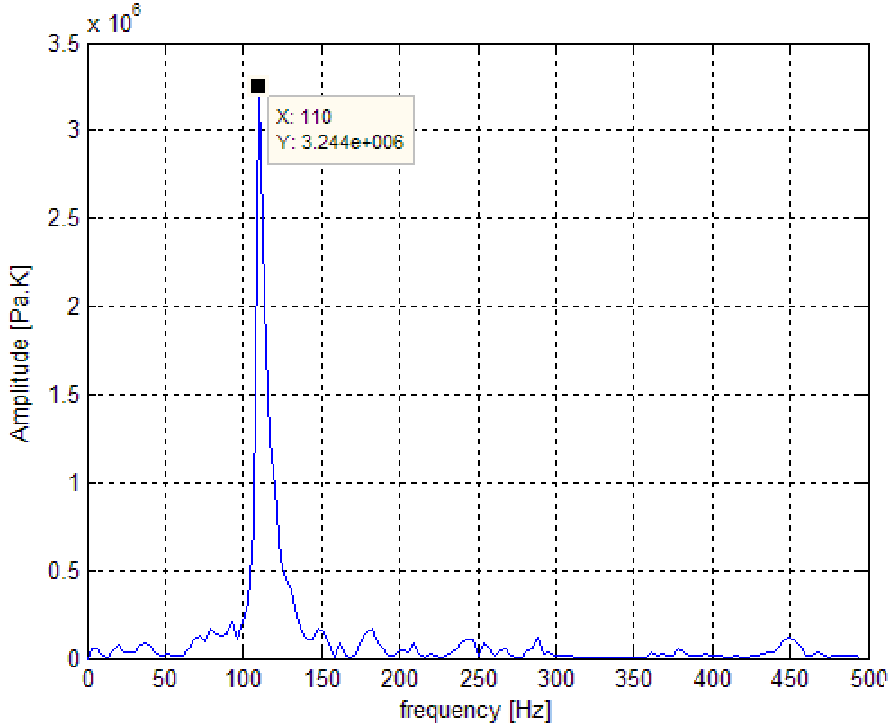
Outlet: standard outlet pressure condition



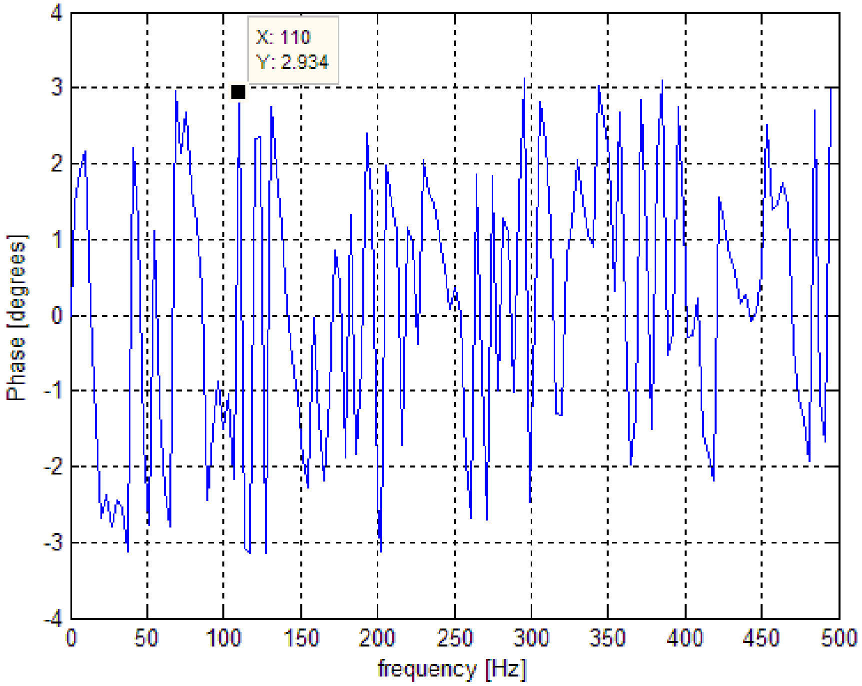
Pressure spectrum FFT for 40kW case

Pressure peak at 110 HZ

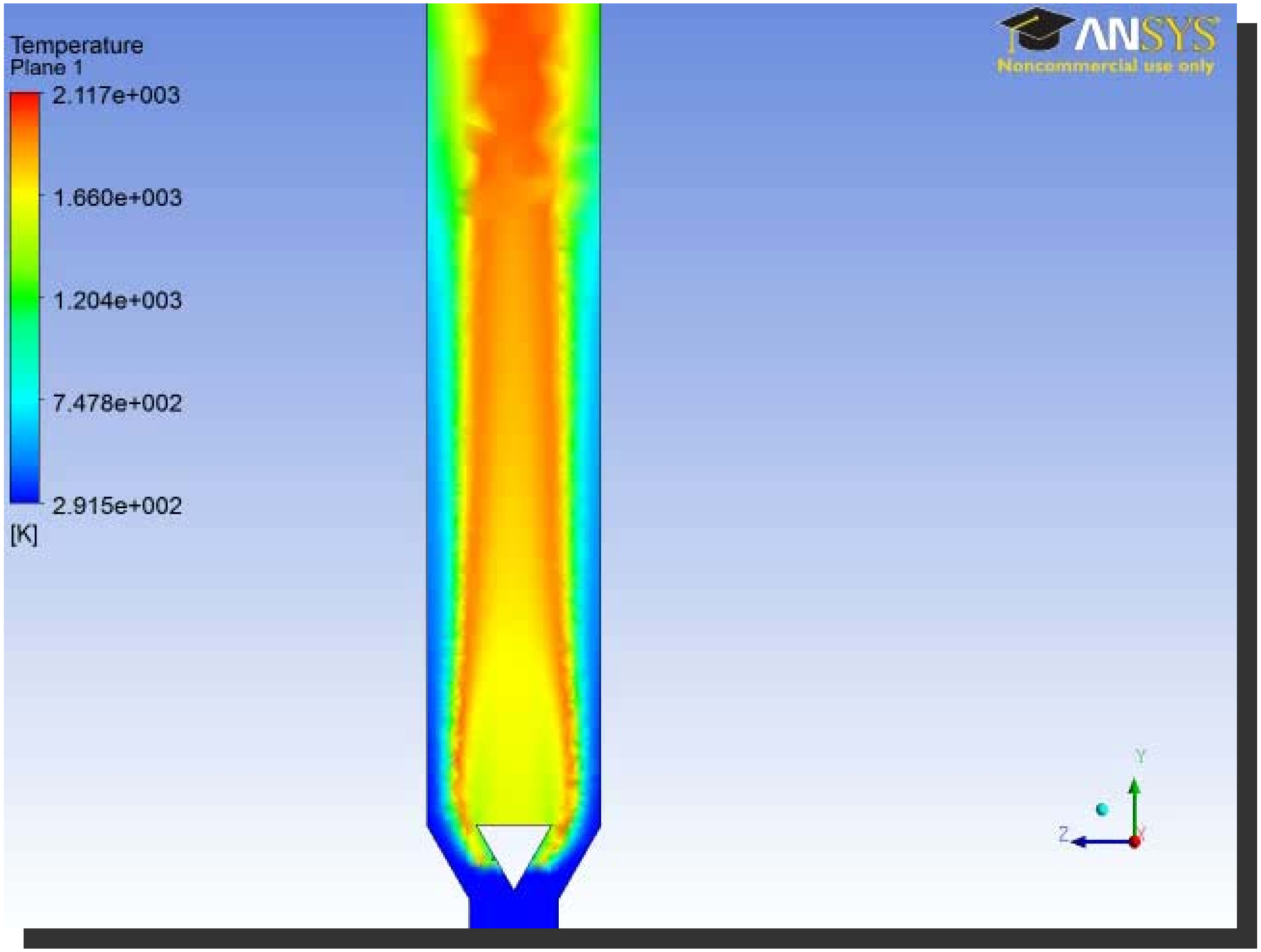




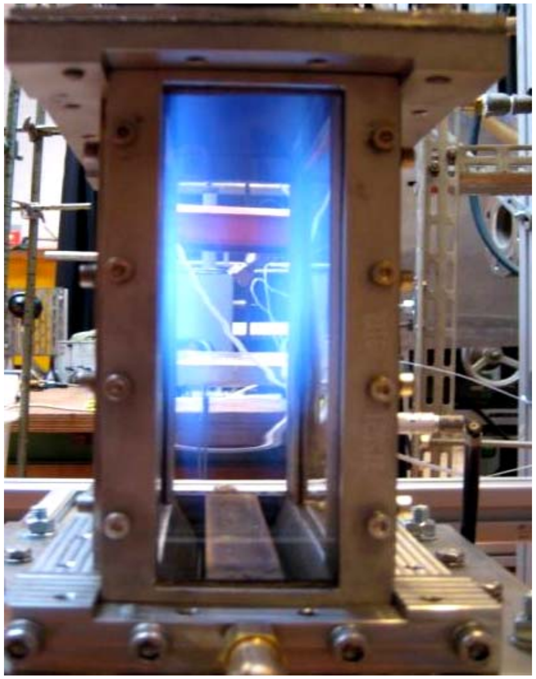
Pressure temperature cross spectrum for 40kW case

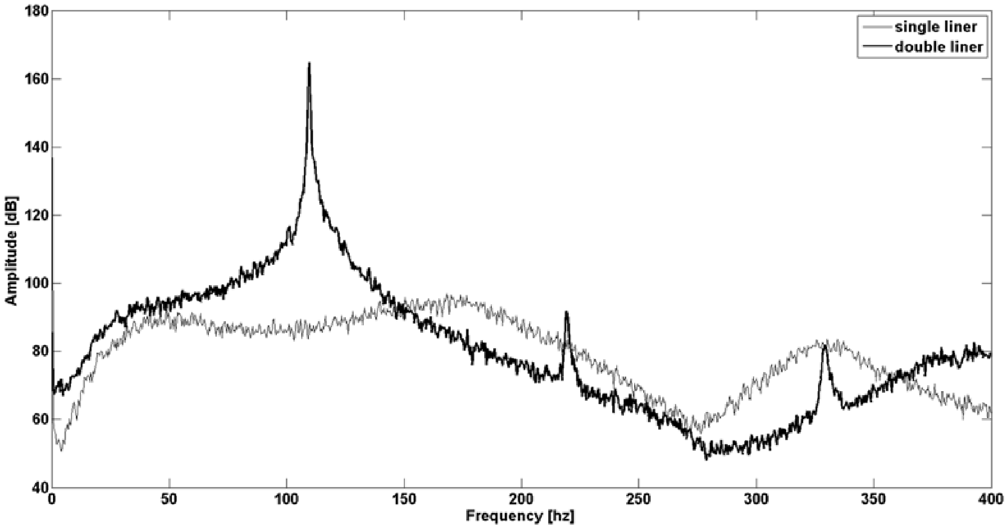


Transient time video of temperature field at mid-plane of the combustor



Rigid wall: Frequency doubling.





Acoustic Eigenfrequencies:
¼ wavelength, ¾ wavelength: 110, 330 Hz
NOT: ½ wavelength at 220 Hz

$\rho = \rho(P, s, y_i)$

Propagation equation for pressure oscillations in fluid in motion

---

Detailed derivation using $\rho = \rho(P, s, y_i)$:

$$\frac{\partial}{\partial t}\left(\frac{1}{c^2}\frac{\partial P}{\partial t}\right) - \nabla^2 P = \nabla^2[(\rho \underline{u}\underline{u}) - \underline{\underline{\tau}}]$$

$$-\frac{\partial}{\partial t}\left(\frac{\alpha}{c_P}\left(\rho\sum_{i=1}^{N}\left(\frac{\mu_i}{W_i} + y_i\right)\frac{Dy_i}{Dt} + \nabla.\underline{q} + (\tau : \nabla \underline{v})\right)\right) + \frac{\partial}{\partial t}\left(\left(\underline{u}\nabla\right)\left(\rho - \frac{P}{c^2}\right)\right)$$

At high amplitude: frequency doubling!

ACKNOWLEGDES

The authors would like to acknowledge the funding of this research by the EC in the Marie Curie Actions – Networks for Initial Training, under call FP7-PEOPLE-2007-1-1-ITN, Project LIMOUSINE with project number 214905.

CONCLUSIONS

- Autonomous Vibration at 86 Hz was recorded in the first set of experiments for all operating conditions. (does not agree with ACA loop)

- All the sensors (CCD camera, Laser Vibrometer and Pressure Transducers) measure identical frequency. The flame is the source of the sound, but the frequency is determined by the vibration of the walls.

- Changes in stiffness change frequency of the system. FEM modes were in agreement with measurements.

- **In Limit cycle operation Frequency Doubling Occurs: nonlinear processes**