Analysis of LBM/VLES Data Related to the Source Diagnostic Test Cases

Sheryl Grace

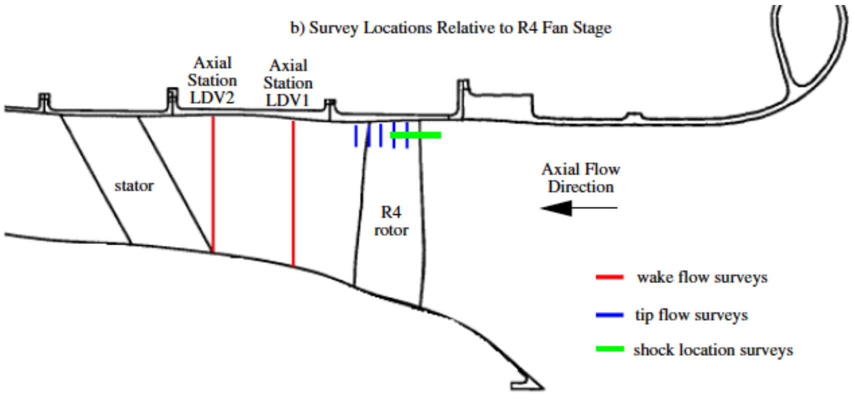
Mechanical Engineering

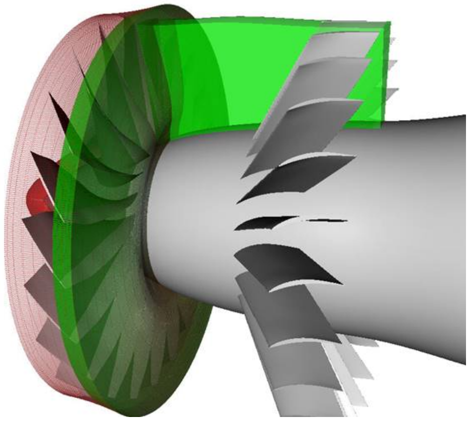
Boston University

(with cooperation of Ignacio Gonzalez-Martino & Damiano Casalino)

November, 2020

Tasks: in support of improving low-order modeling





1. Determination of turbulence isotropy
2. Determination of length scales
3. Turbulence spectrum
4. Analysis of flow field for other rotor speeds.
5. Analysis of streamwise evolution of flow.
6. Analysis of unsteady vane surface pressure

1. Determination of turbulence isotropy

Previously, difference between two run methods : rotor tripped, refined rotor grid

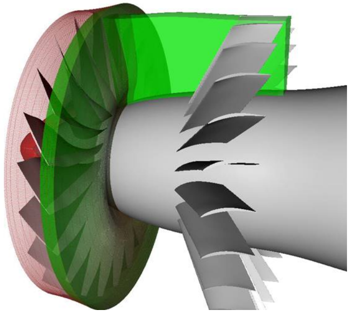
Tripped rotor case : baseline wavy vane

Refined rotor case : low-noise vane

In this presentation : only on refined rotor grid with low-noise vane

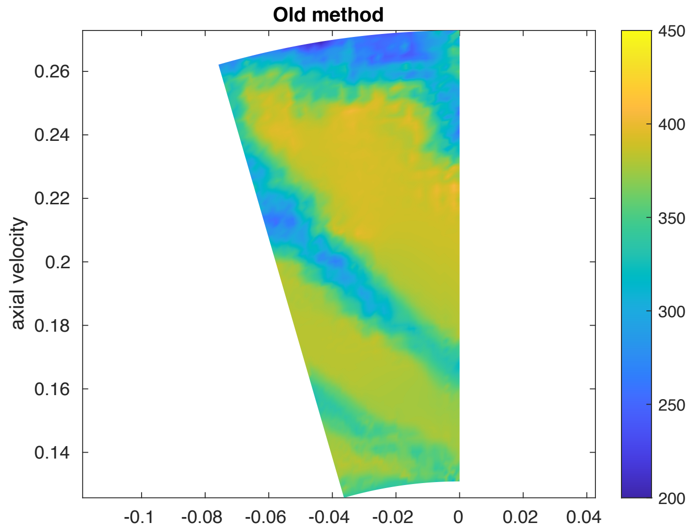
Data analysis progress

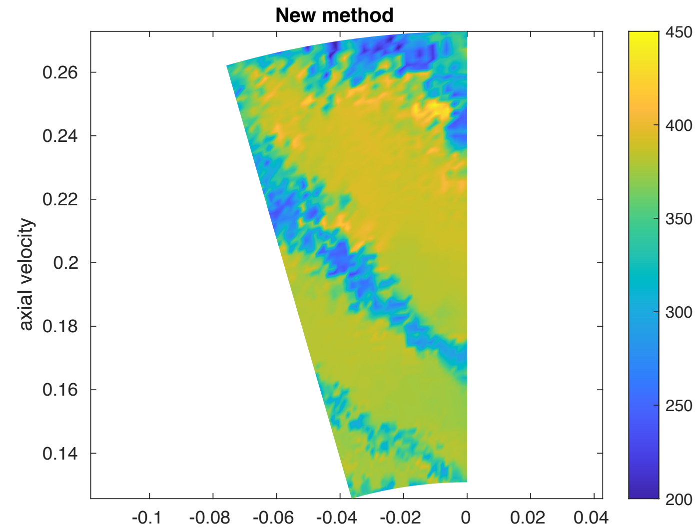
- Probes that match experimental locations were saved during computation
- Volume file was saved – some averaging and every other time increment
  - Data is extracted from the volume file
  - Extraction method continues to be modified, tested, ...

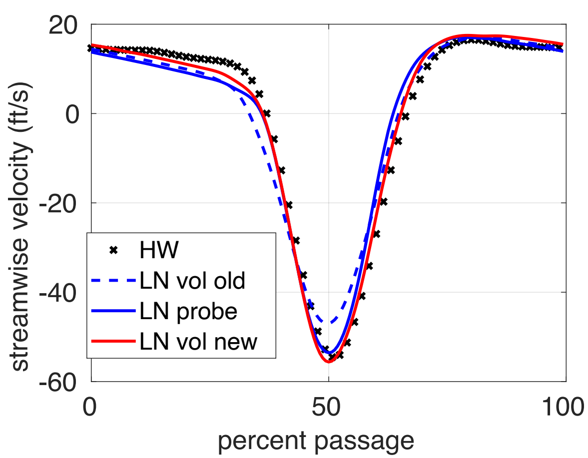


1. Determination of turbulence isotropy

Data analysis progress

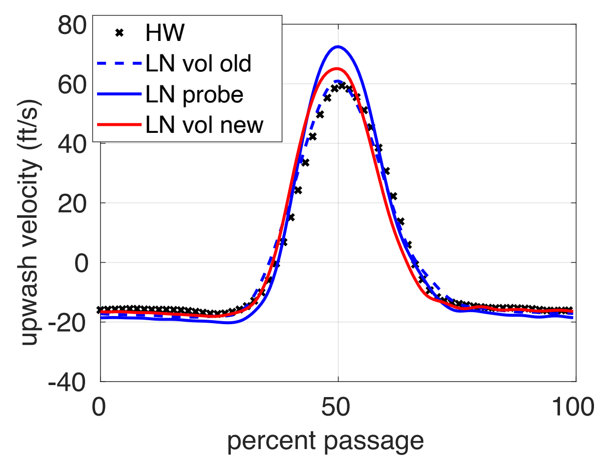






New extraction method closer to computational probe data

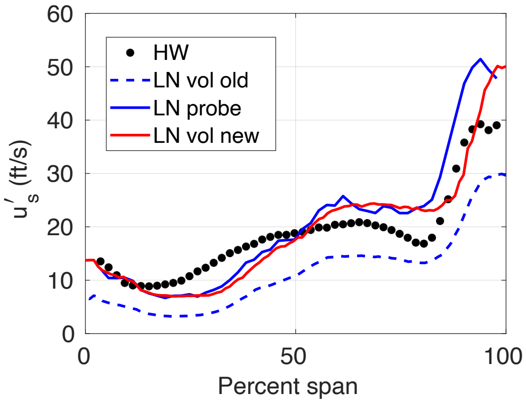
Mean taken out

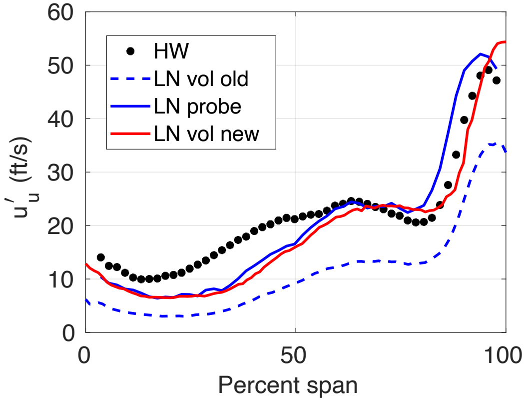


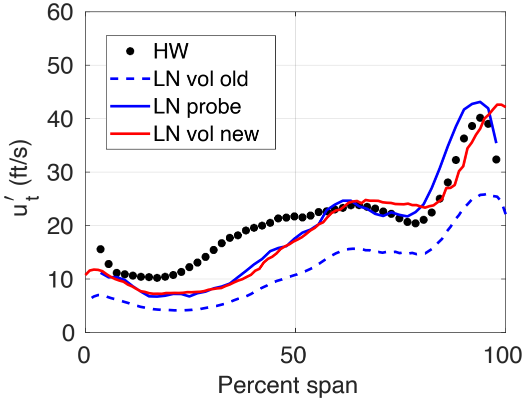
1. Determination of turbulence isotropy

Data analysis progress

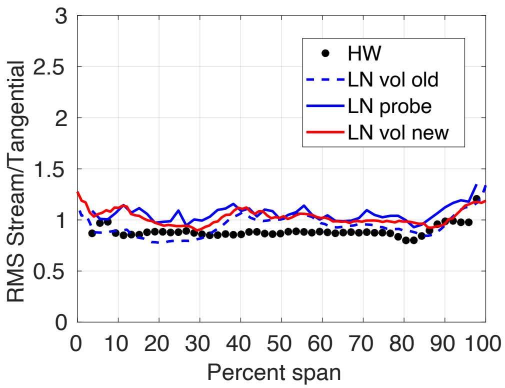
New extraction method closer to computational probe data
Some location issue with probe locations

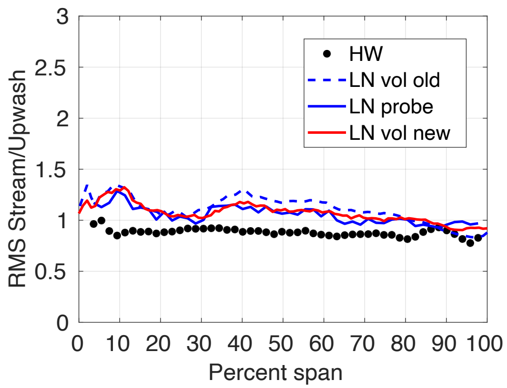


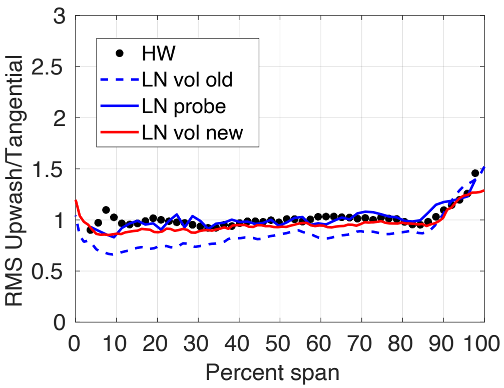




Ratios : Stream/other EXP < 1. Stream/other LBM > 1.
Not perfectly isotropic, but very close except at 90-100% (tip) and 0-5% (hub)







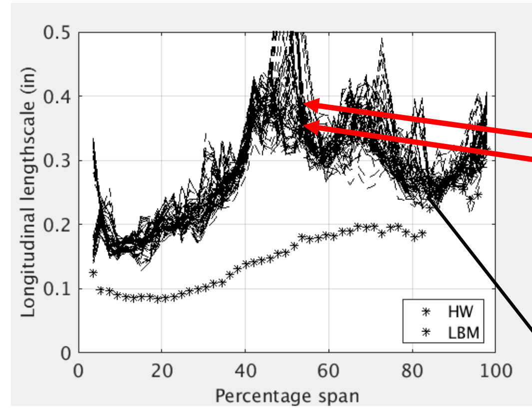
2. Determination of length scales

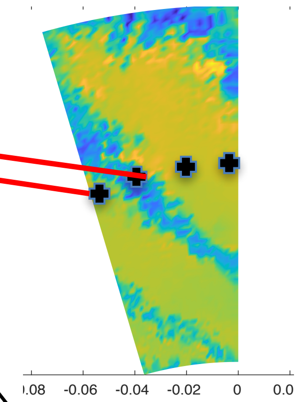
Streamwise, longitudinal lengthscale

Obtained using stationary probe method with Taylor's hypothesis

$$L_{s_i} = \overline{U_s} \int_0^\infty \frac{\overline{u_i'(\tau) u_i'(\tau + t)}}{u_i'^2} dt$$

LBM data predicts larger length scales. Some uncertainty due to difference based on circumferential location



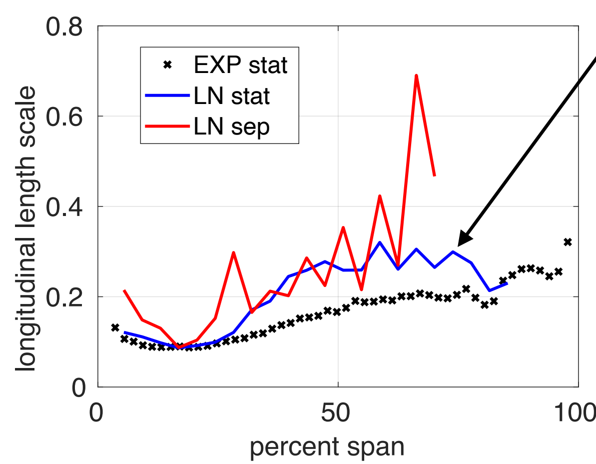


averaging

For **separation method** :

$$L_{s_i} = \int_0^\infty \frac{\overline{u_i'(s) + u_i'(s + \triangle s)}}{u_i'^2} d \triangle s$$

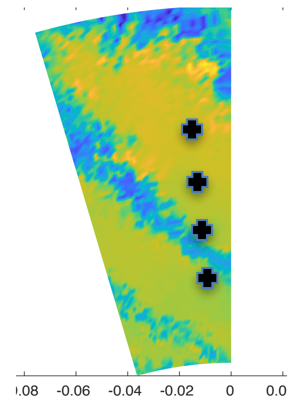
Comparison of streamwise length scale



Could average the separation way, rather time consuming!

Some agreement though between two methods for computing the lengthscale

2. Determination of length scales



Previously showed – if wake width is used, agreement closer to experiment can be obtained

So why even try to find alternative method ?

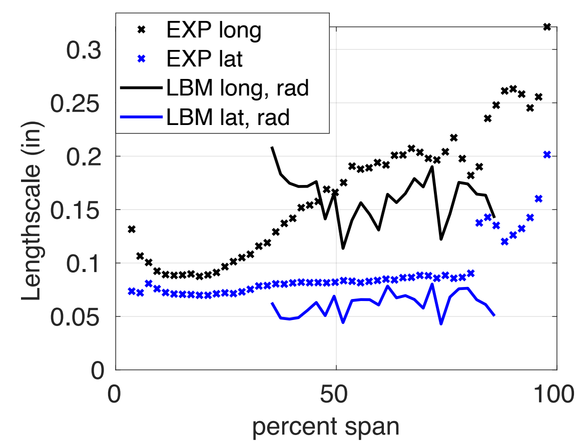
For longitudinal and lateral length scale **radial direction** :

Focus on station 1 location, radial separation ½ that in experiment, simultaneous data

Issue : choose different circumferential location, get different result
Solution : average over result integrand result from different circumferential location

r

$$L_{s_i} = \int_0^\infty \frac{\overline{u_i'(s) + u_i'(s + \triangle s)}}{u_i'^2} d \triangle s$$



Finding: radial longitudinal and lateral length scales are slightly smaller than streamwise
If we believe these results!

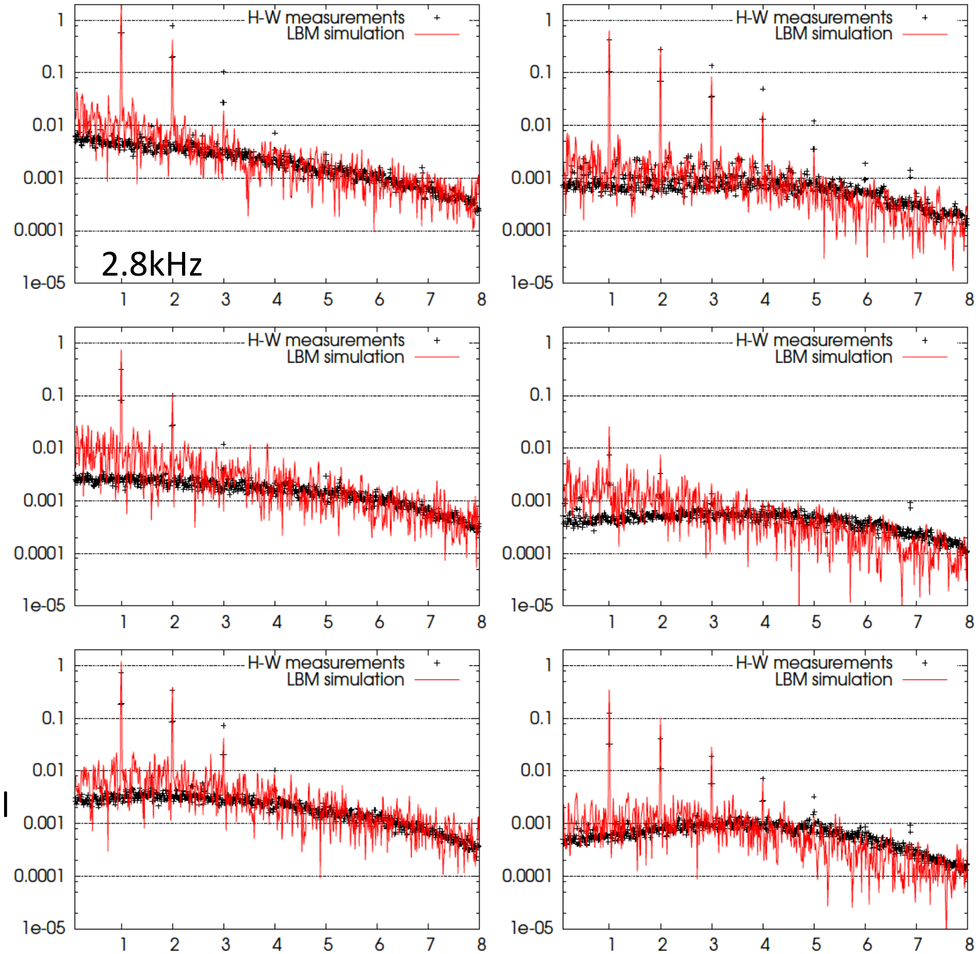
3. Turbulence spectrum

80% span | 60% span | Station 1

axial

radial

circumferential



23kHz

Direct data comparison reasonable.
Previously showed Liepmann defined with length scale matched experimental spectrum reasonably well.
Connection to length scale not useful if computational lengths scale is so different than experimental.

4. Analysis of flow field for other rotor speeds

Have agreed on additional run of sideline (take off) low-noise vane case

Have detailed method for saving data and what data

BU and 3ds still negotiating!

Will need no-cost extension

5. Analysis of streamwise evolution of flow

Reminder: Curious if past empirical fits are relevant. Curious if new correlations can be found

$$\frac{Wake\ deficit}{Freestream\ total\ relative\ velocity} = C_D^{\frac{1}{4}}\left(\frac{0.3675\frac{d}{c} + 1.95}{7.65\frac{d}{c} + 1.0}\right)$$

$$\frac{u'}{Wo} = \left(\frac{425\frac{d}{c}C_D^{1.5} + 0.18}{12500\frac{d}{c}C_D^{1.5} + 1.0}\right)$$

Distance from rotor trailing edge

Local rotor chord

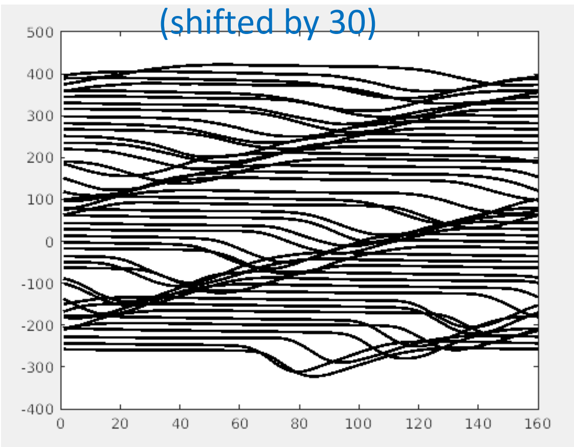
Local rotor section coefficient of drag

5. Analysis of streamwise evolution of flow

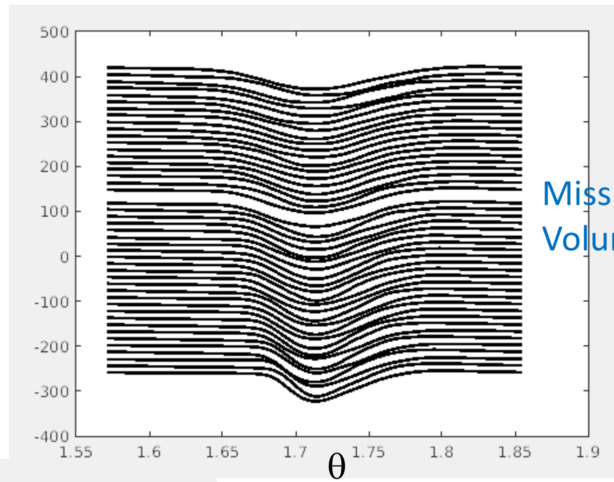
Wake tracking method developed, follow velocity deficit of average passage wake

Extrapolate back to rotor

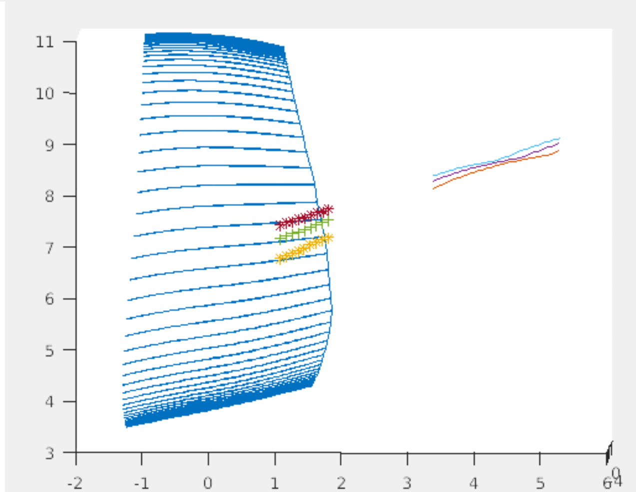
Actual wakes based on passage location (shifted by 30)



Centered for analysis



Missing location
Volume extraction fails

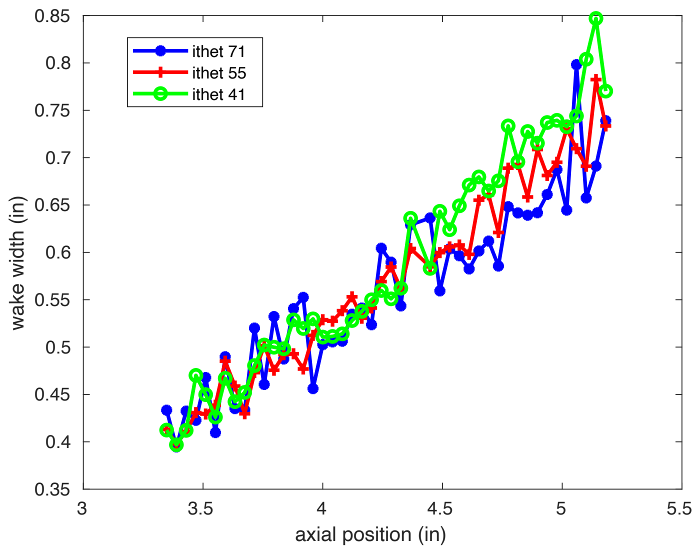


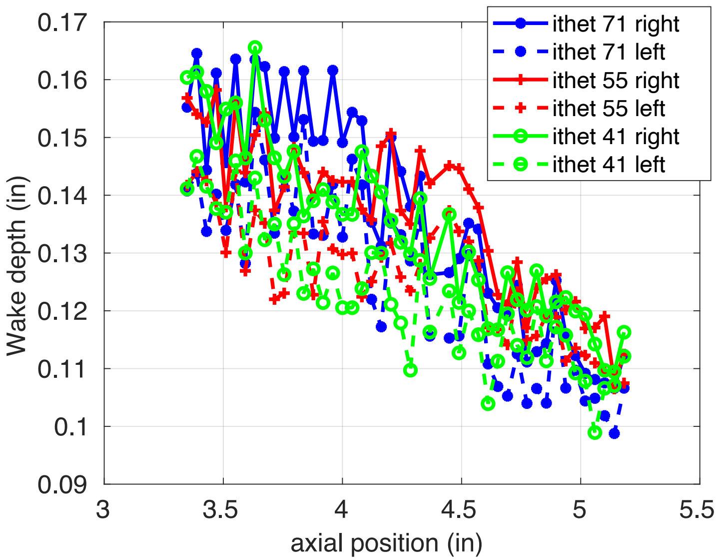
3 trajectories. Same radial and axial location at start. Different circumferential location. Slight difference in trajectory and rotor origin

5. Analysis of streamwise evolution of flow

Wake tracking method developed, follow velocity deficit of average passage wake

Extrapolate back to rotor





3 trajectories. Same radial and axial location at start. Different circumferential location. Slightly different outcomes. Overall trend same.

5. Analysis of streamwise evolution of flow

Coefficient of section drag for rotor slices, not available.

Part of data request for next series of computations. Will get the values for the approach speed as well.

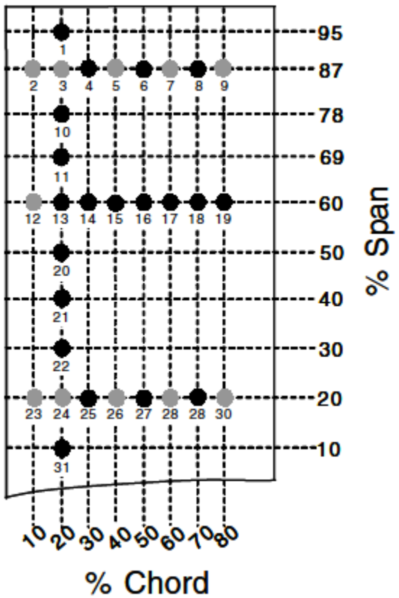
6. Analysis of unsteady vane surface pressure

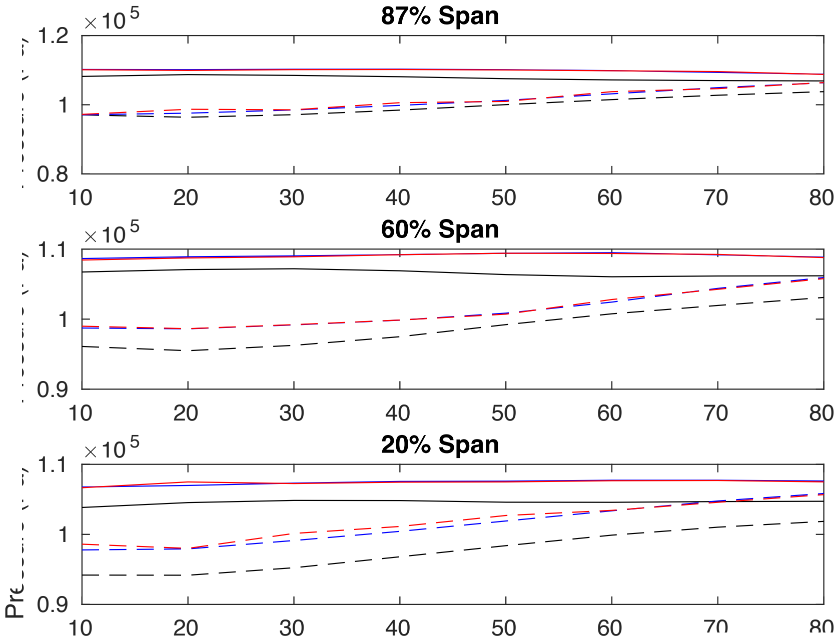
Why are we interested?

Is there a way to check the low-order model in terms of the stator response. Any ballpark information at the broadband frequencies.

Can the surface pressure give insight into how correlation of the turbulent inflow in the radial direction affects the radial correlation of the surface pressure

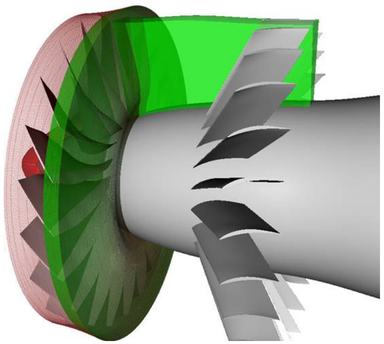
6. Analysis … vane surface pressure

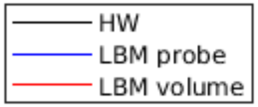


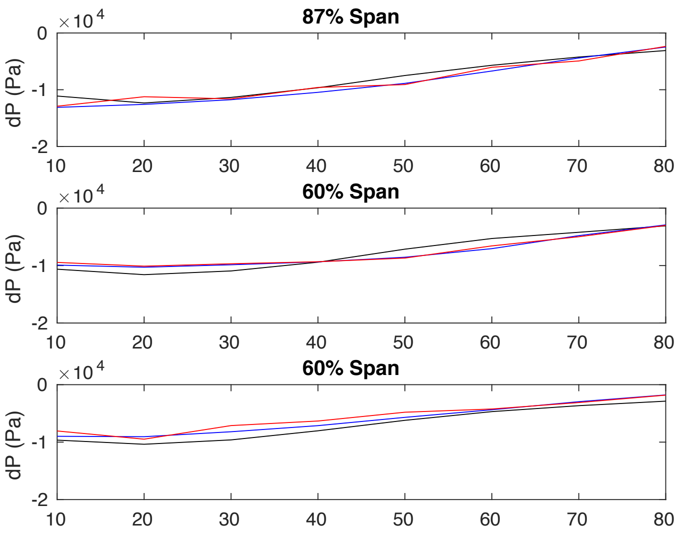


Mean pressure
On-vane probes
Off-vane volume data

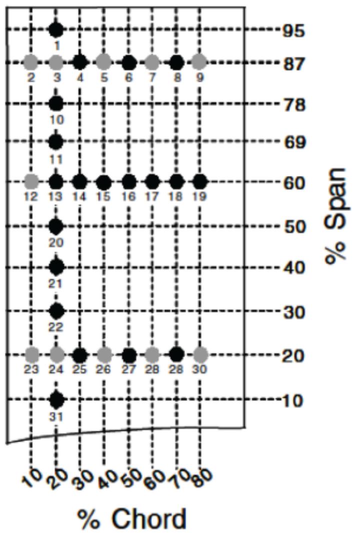
Delta pressure reasonable.
Shift in actual pressure







6. Analysis of unsteady vane surface pressure



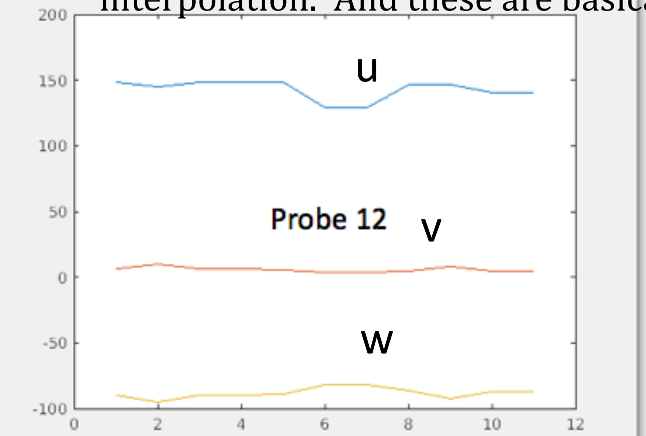
Plan is to analyze surface pressure correlations

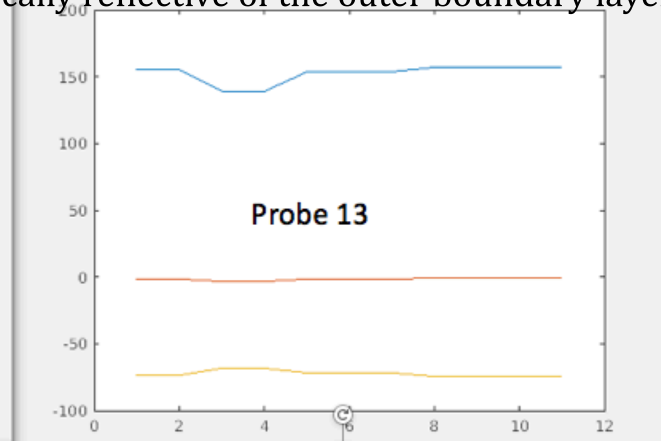
Determine propagation speeds

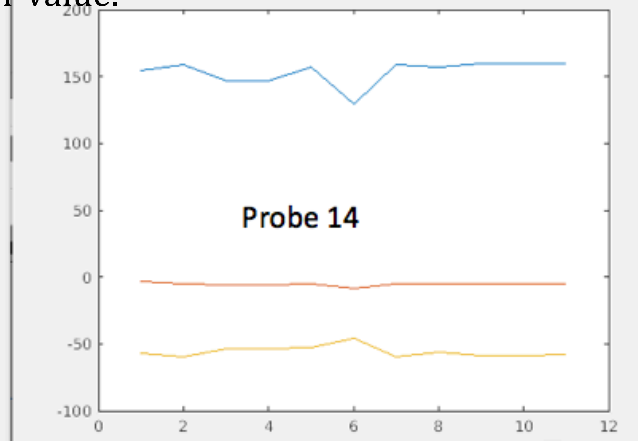
Only have probe locations and volume file from computation
New computation will have surface values

Velocity above the stator surface

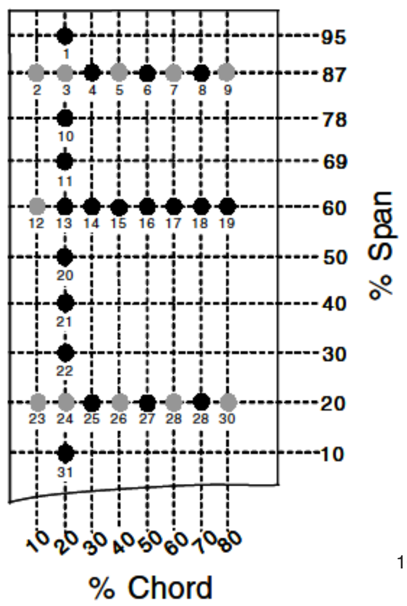
I thought I was extracting data such that four points were in the boundary layer and 2 were outside. However volume file only has values starting at edge of boundary layer. So, differences are due to the interpolation. And these are basically reflective of the outer boundary layer value.







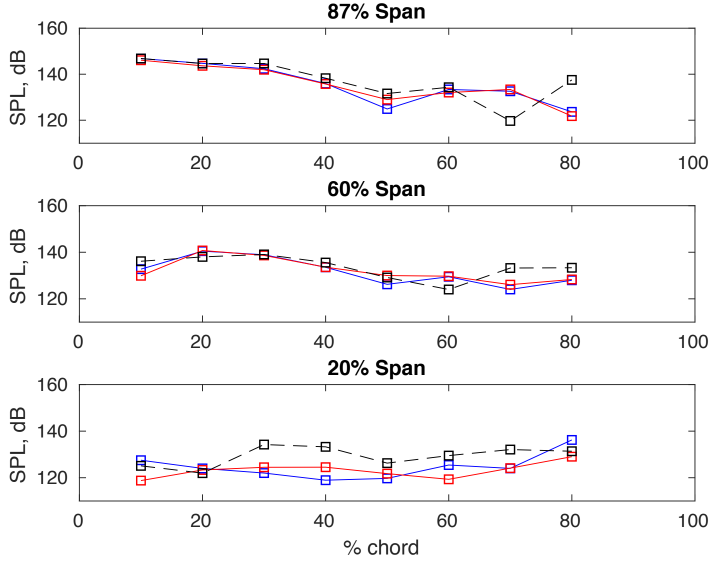
6. Analysis of unsteady vane surface pressure

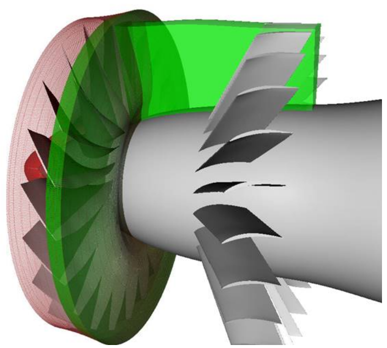


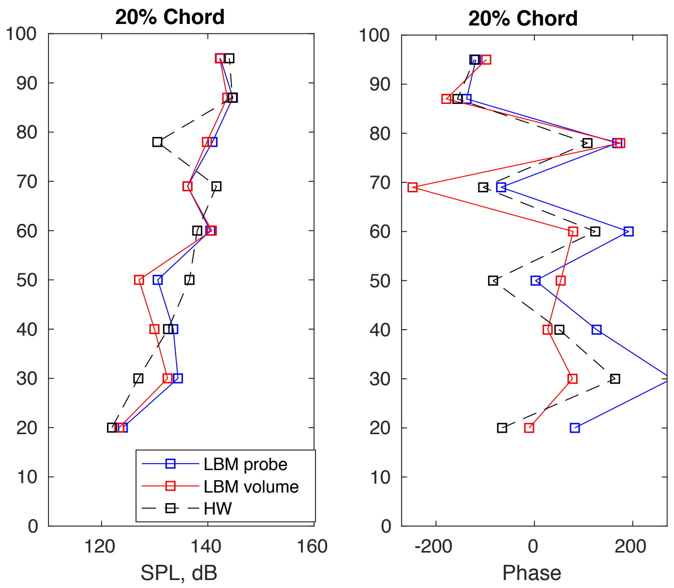
Probe at outer boundary layer contains reasonable tonal content

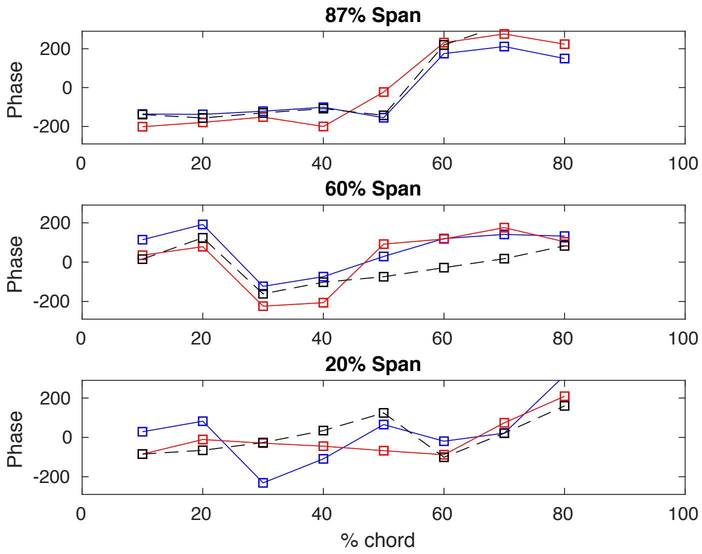
BPF from experiment, LBM probes and LBM volume file

Relative phase is shown

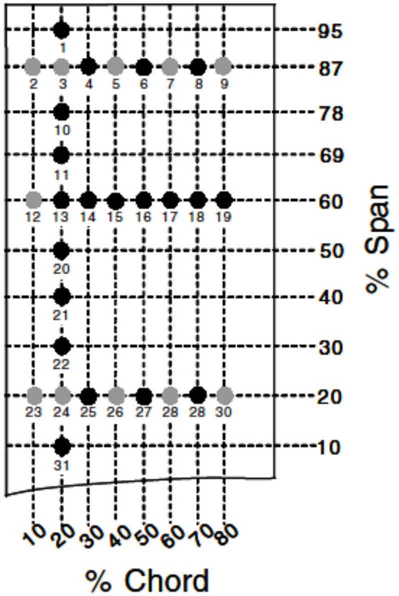






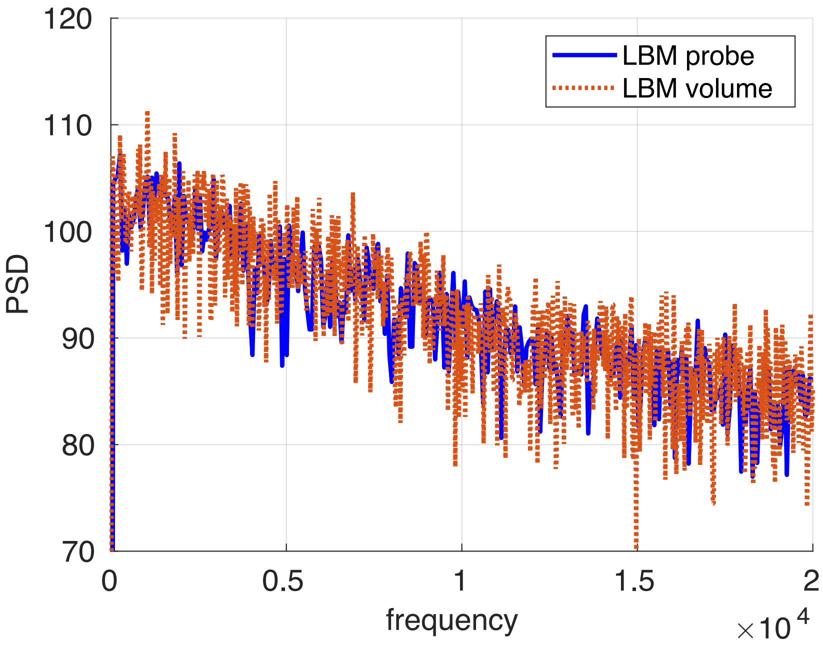


6. Analysis of unsteady vane surface pressure



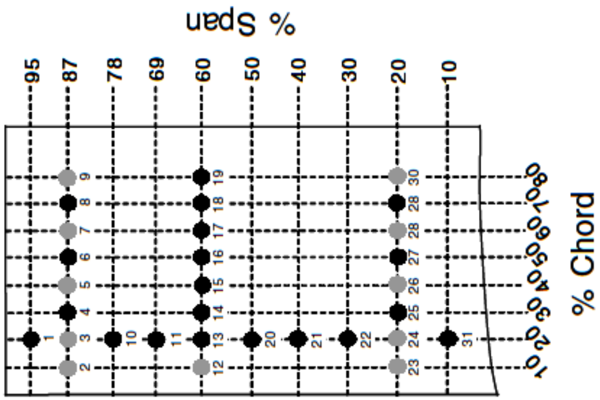
Probe 12

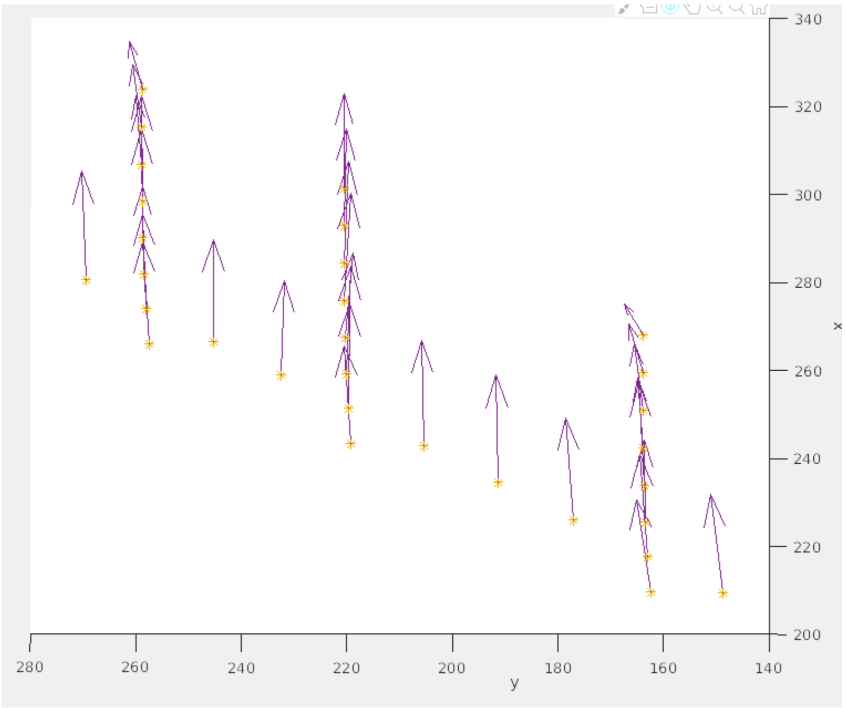
Computational probe broadband compared to computational volume point off surface



Agreement seems reasonable
Continue with analysis of wave number frequency domain

6. *Analysis of unsteady vane surface pressure*





Flow is basically chordwise
So using chordwise separation to try to find convection speed is plausible.
Then try to focus on part of signal that is propagating at acoustic speed.

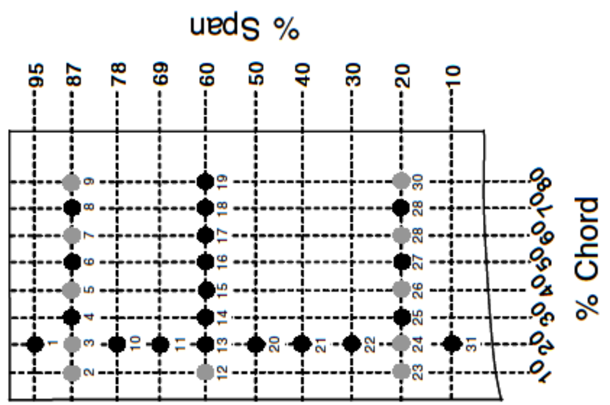
6. Analysis of unsteady vane surface pressure

INVESTIGATION OF THE WALL PRESSURE WAVENUMBER-FREQUENCY SPECTRUM BENEATH A TURBULENT BOUNDARY LAYER WITH PRESSURE GRADIENT

Edouard Salze, Christophe Bailly, Olivier Marsden & Daniel Juvé
Laboratoire de Mécanique des Fluides et d'Acoustique
École Centrale de Lyon
36 avenue Guy de Collongue, 69134 Écully cedex, France
christophe.bailly@ec-lyon.fr

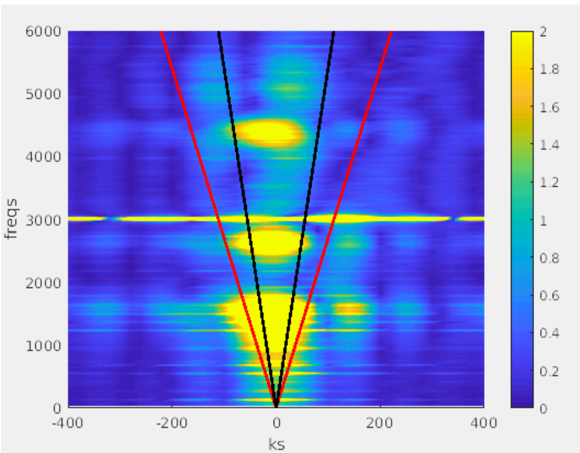
$$R(\boldsymbol{r},\omega) = \lim_{T\to\infty} \frac{2\pi}{T} E\left[\hat{p}(\boldsymbol{x},\omega)\hat{p}^{\star}(\boldsymbol{x}+\boldsymbol{r},\omega)\right]$$

$$\Phi_{pp}(\boldsymbol{k},\omega) = \frac{1}{(2\pi)^2} \iint R(\boldsymbol{r},\omega) e^{-i\boldsymbol{k}\cdot\boldsymbol{r}} d\boldsymbol{r}$$

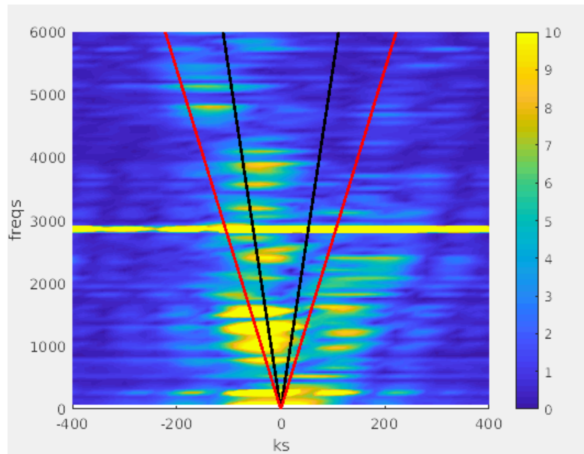


6. Analysis of unsteady vane surface pressure

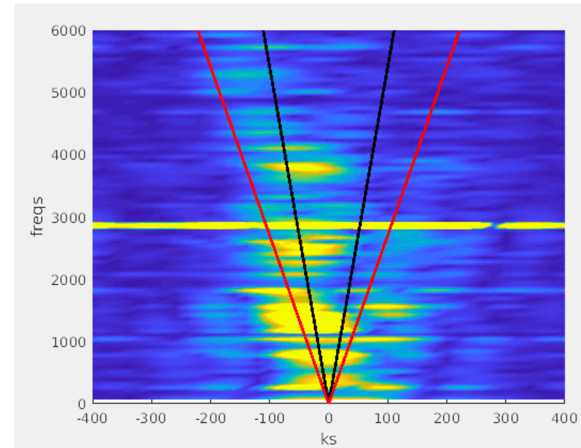
Experimental probes



Computational probe



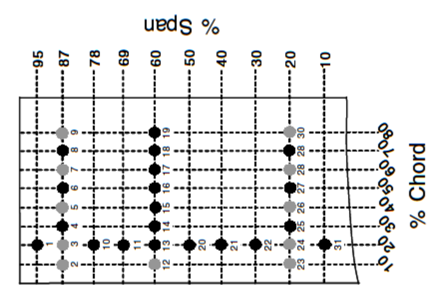
Computational volume



Near the vane: temperature is ~290K and Mach number is ~0.5 → flow speed ~ 170 m/s

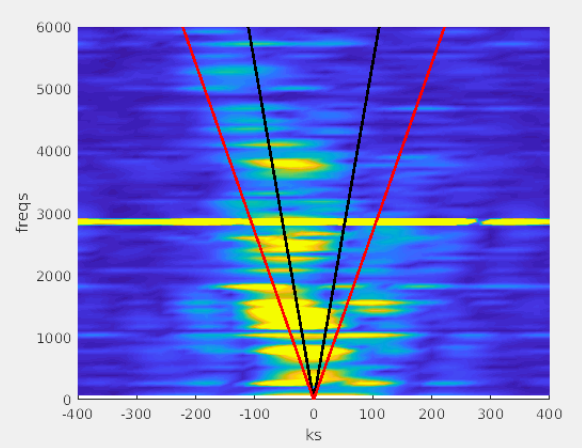
Black lines are $k_1 = \pm\ 2\ pi\ f/\ 340$ and red lines are $k_1 = \pm\ 2\ pi\ f/\ 170$

60% span, with fixed correlation point near leading edge

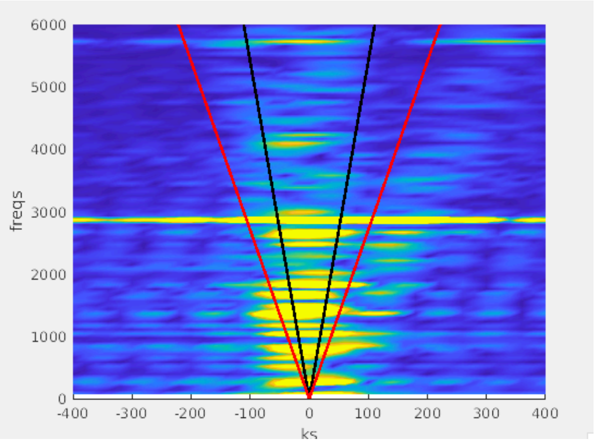


6. Analysis of unsteady vane surface pressure

Computational volume



Computational volume
Denser set of points



Still probably 10 times distance between points that is needed. Resolution in volume file not enough.

Need to determine if surface file has enough resolution.

Also, need to determine if something can actually be learned from this

Summary

Continue to make progress with the analysis of the computational data

Computational data is plentiful but has some deficiencies

Would like thoughts on separating the acoustic pressure on the vane
new run will have surface file saved