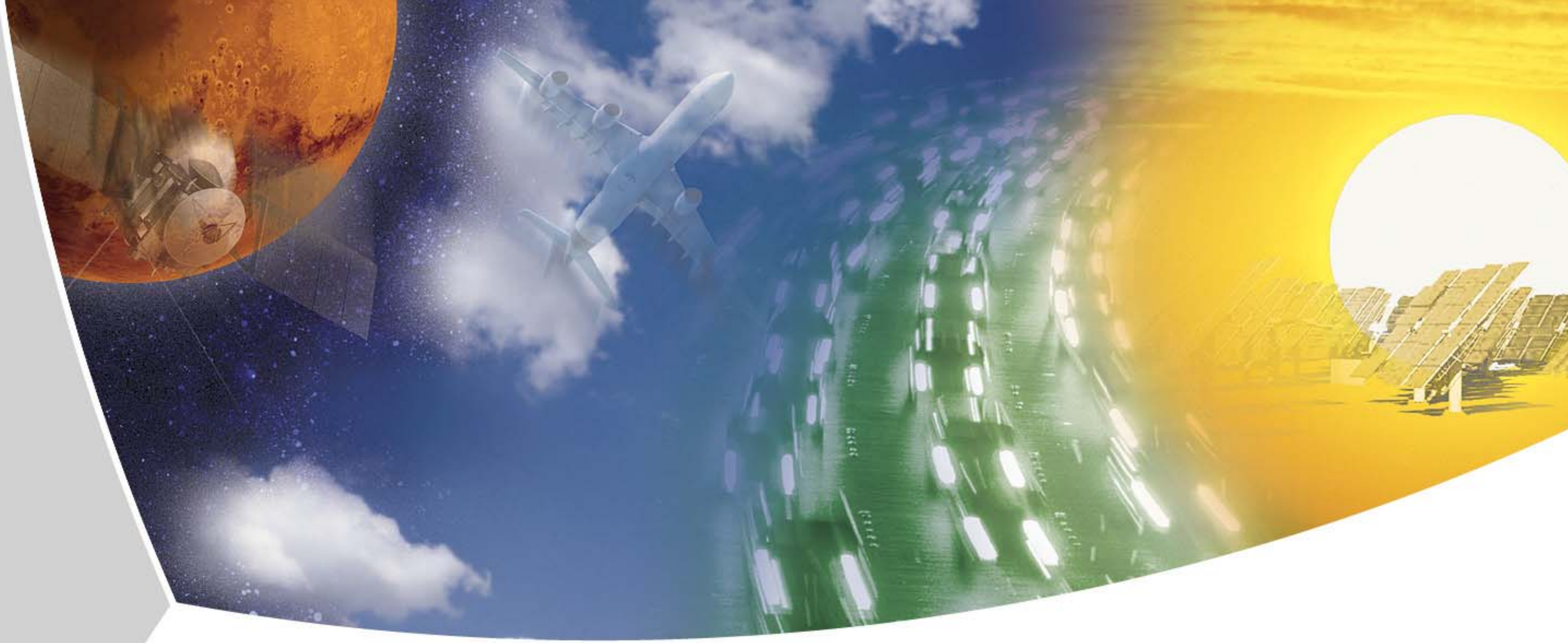

Conditionally Averaging of Pressure Data from HART II

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HART II Workshop in Phoenix, AZ, May 8, 2006

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
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Introduction

Motivation: Scatter of vortex position in PIV data suggest scatter of BVI in pressure data

Approach: Analysis of blade pressure data from HART II for

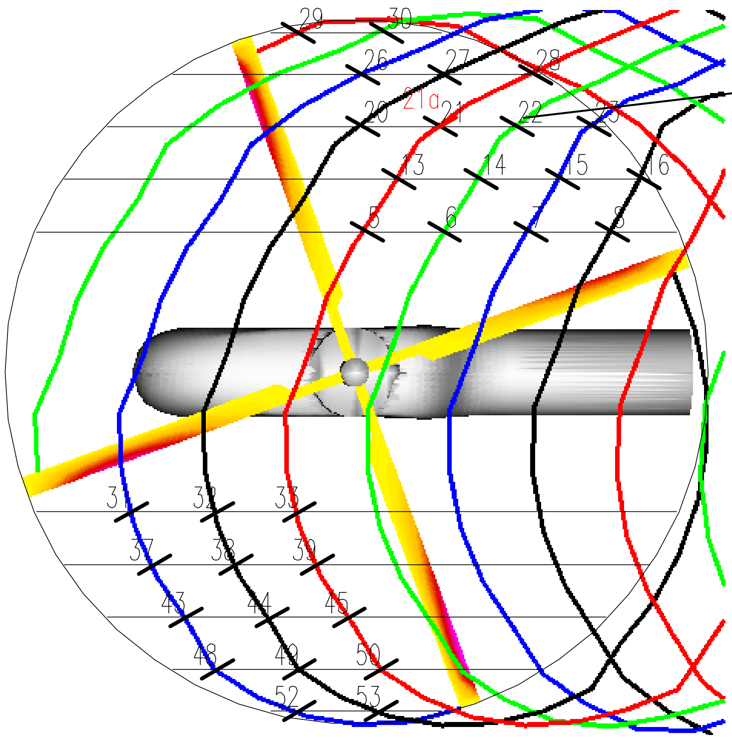
Base Line (Dpt 128), Minimum Noise (Dpt 413), Minimum Vibration (Dpt 413)

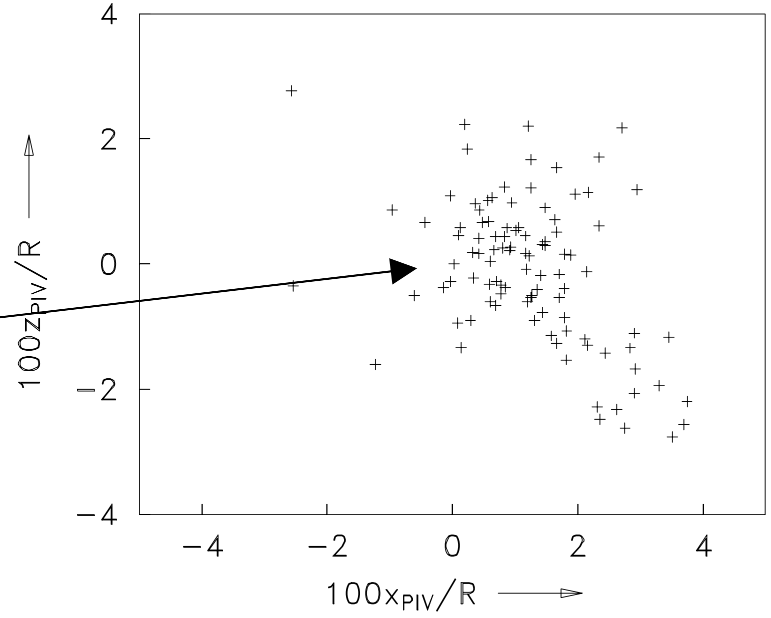
CnM^2 originally was computed by DLR Göttingen using simple averaging of 80 revolutions

Former data: biased by defect sensors

Now: Defect sensors are corrected respectively replaced
Conditionally averaging is applied to all individual time histories

PIV analysis: vortex position





Scatter of data vertically indicates BVI miss-distance fluctuations (amplitude)

Scatter of data horizontally indicates azimuthal scatter of BVI events ±1.3deg

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Effect of scatter on simple averaged data

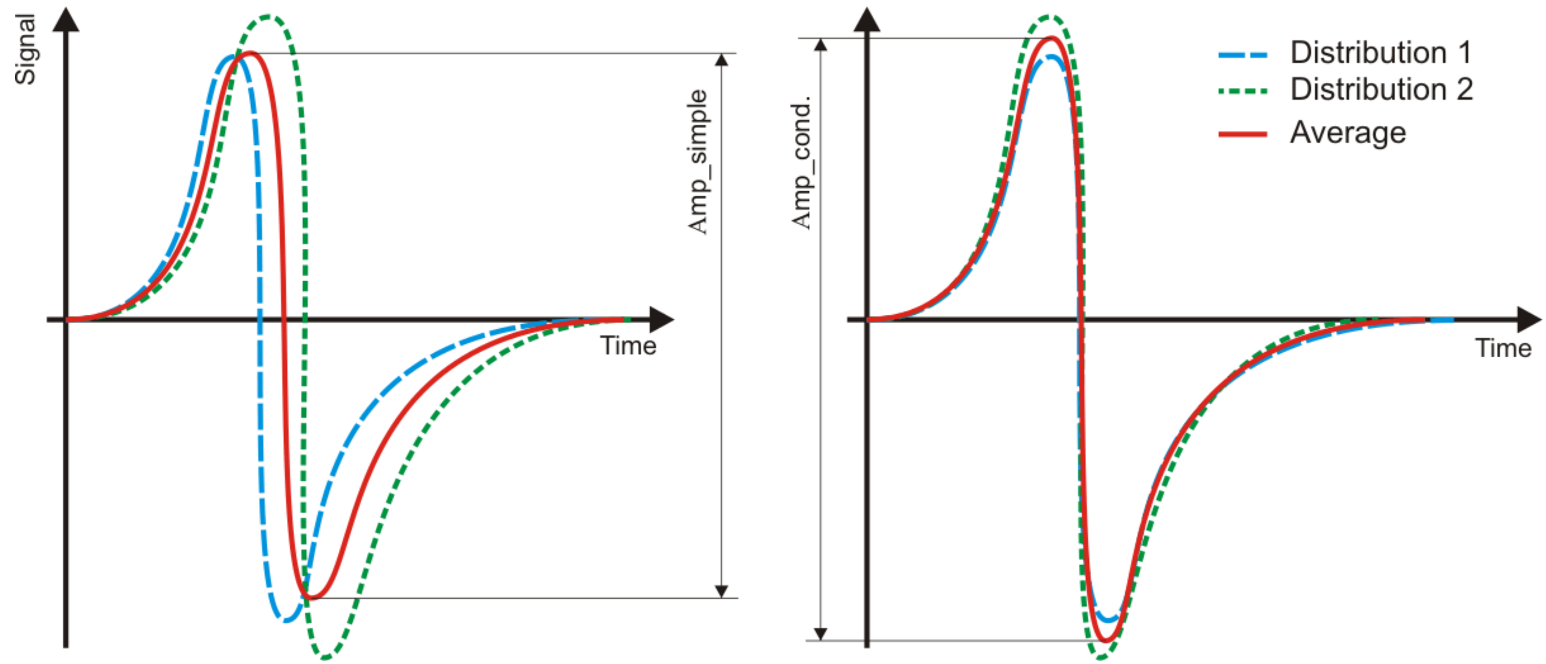
PIV:

- Unrealistic large vortex core radius and unrealistic low swirl velocity
- Conditionally averaging needed!

Blade pressure data and CnM^2:

- Unrealistic low BVI-related peak-to-peak range?
- Unrealistic large peak-to-peak azimuthal distance of BVI's?
- Conditionally averaging needed?

Differences simple vs. conditional averaging



Simple averaging:

Mean value at each azimuth position from all rotor revolutions

Conditional averaging:

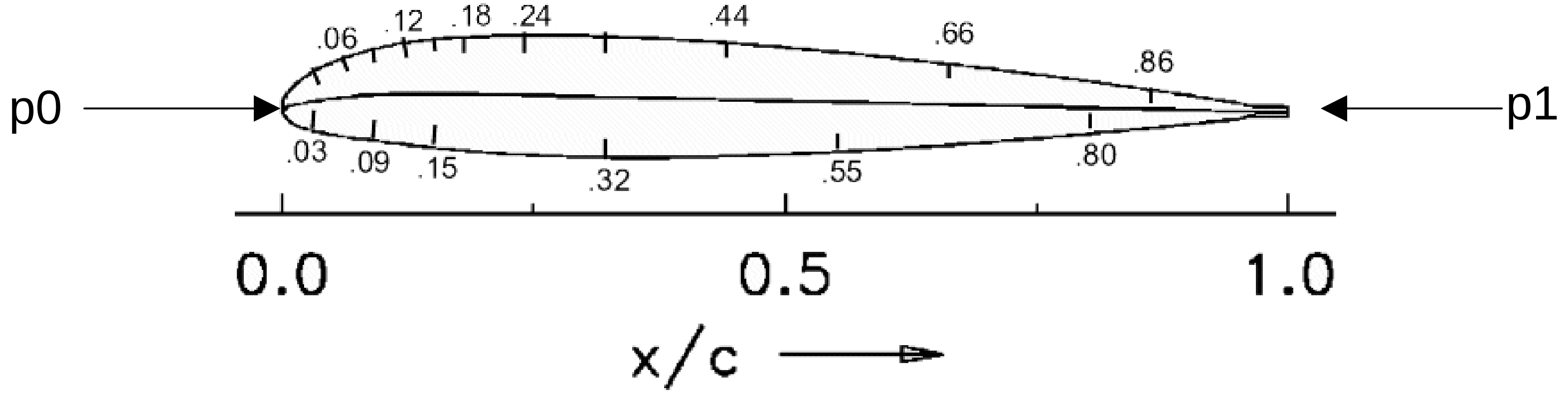
First identification of characteristics (BVI-events) followed by shifting of individual data sets to coincide with each other and a final averaging

Correction / replacement of defect sensors

Leading (p0) and trailing edge (p1) pressures were approximated to fill up the chord-wise pressure distribution

ADC 17 (low 3%) is replaced by ADC 57 (same position) of blade #4 in the BL case

ADC 21 and ADC 22 (low 55%, low 80%) are interpolated between ADC 15 and p1 in the MN as well as in the MV case



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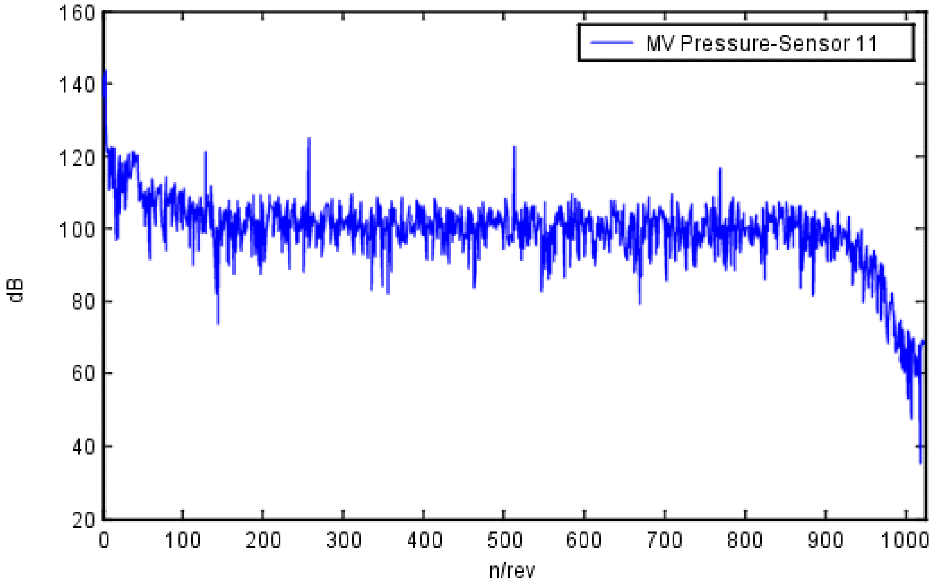
Correction / replacement of defect sensors (2)

Isolated spikes are found at 128/rev, 256/rev, 512/rev, and 768/rev

Phenomenon was not visible in all sensor signals and not at any time

Frequencies were removed for each single time history of affected sensors

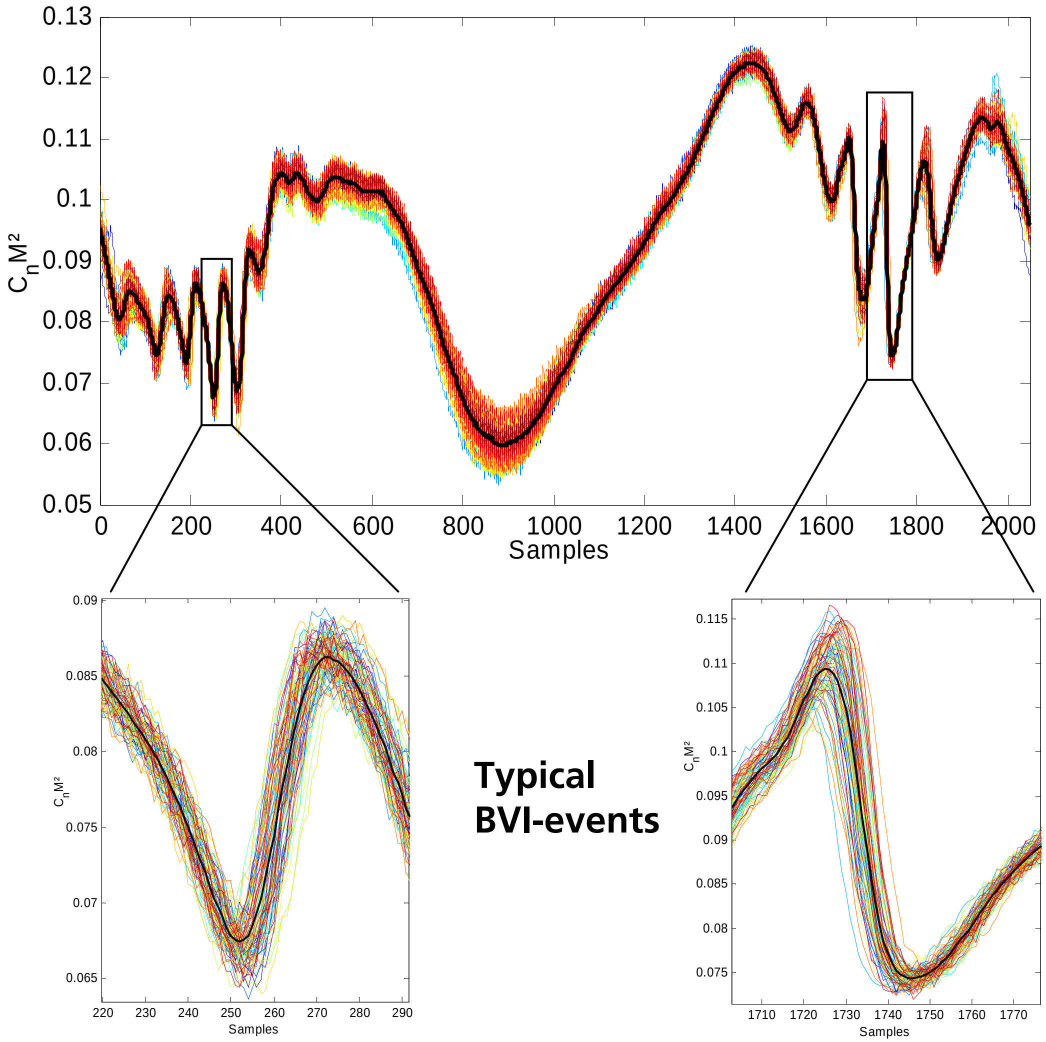


Definition of BVI events

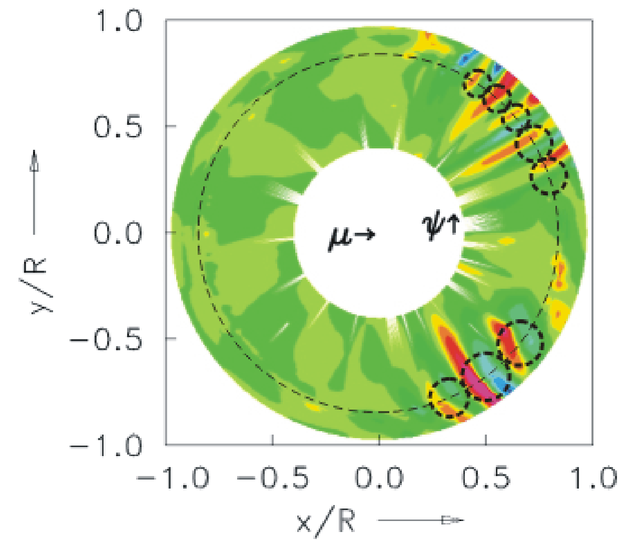
Steep increasing CnM² flank at advancing side

Steep decreasing CnM² flank at retreating side

Best recognition of BVI-events by using the high frequency content



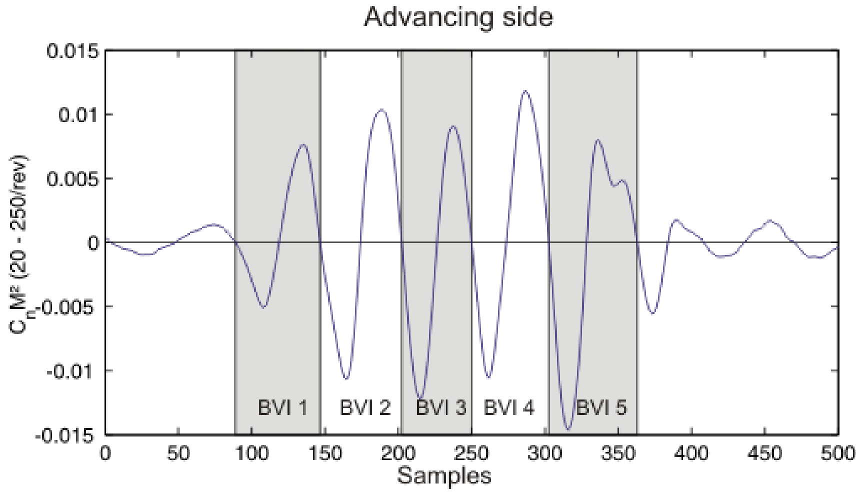
Definition of BVI events (2)

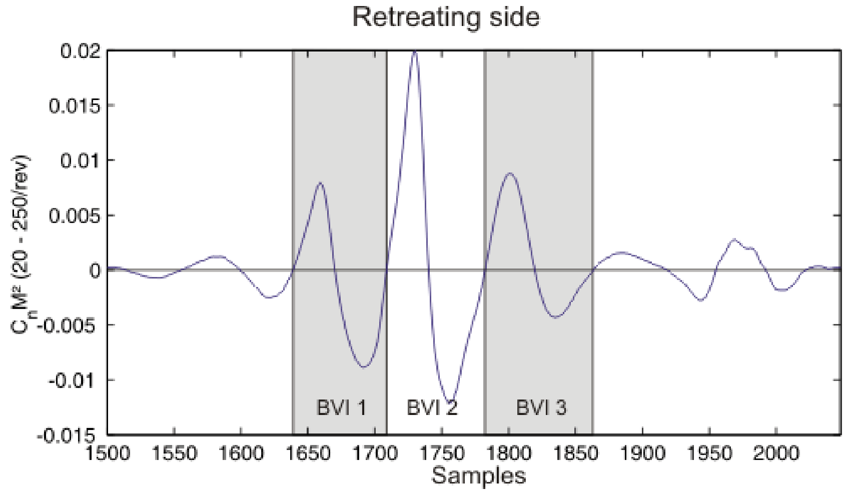


Band pass filtering between 20/rev and 250/rev of simple averaged CnM² time history

This is used as reference function for comparison with individual time histories and for BVI location selection

Example: BVI locations Minimum Vibration





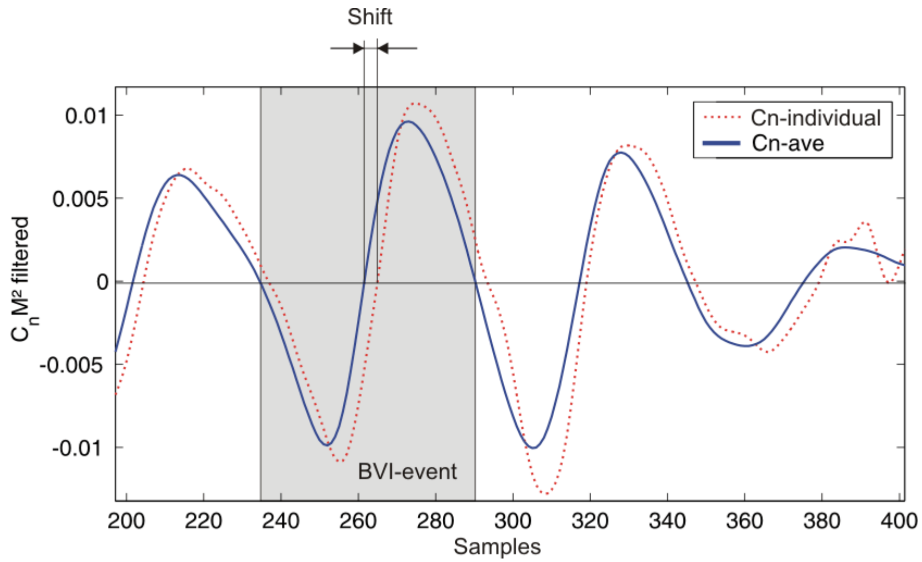
Convolution of time histories

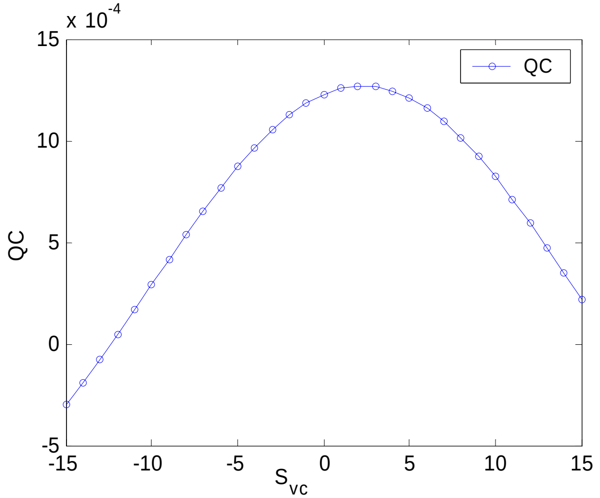
Shift of each single time history obtained by comparison with simple averaged one

Use of convolution functions, each in the range of the according BVI-event

Quality criteria (QC) by convolution

Maximum of QC (by 2nd order polynomial) defines optimal shift





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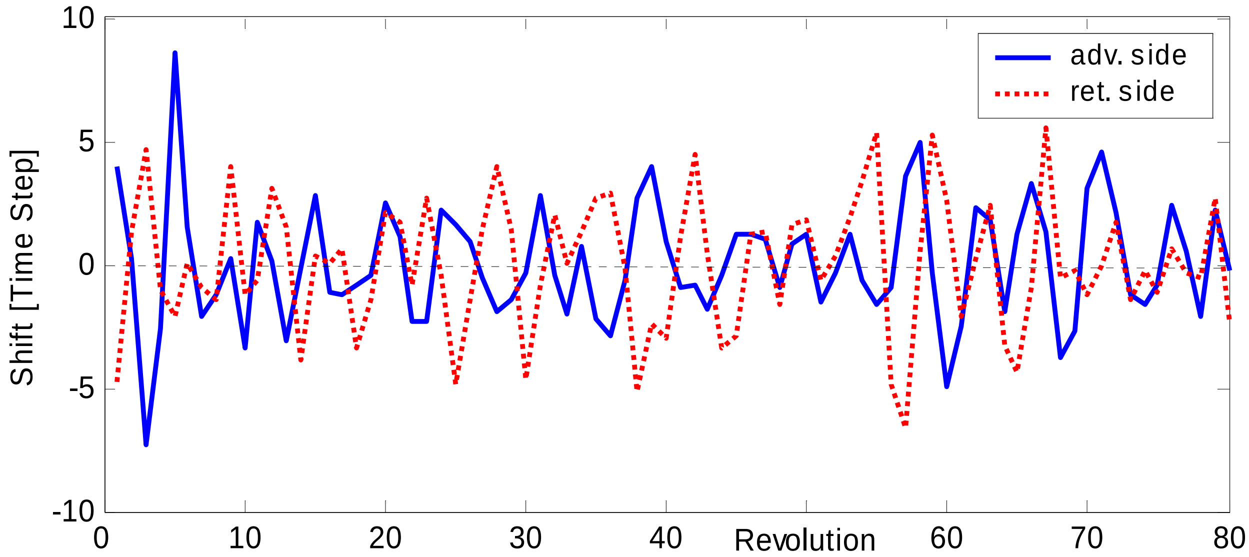
Shift results

Within one revolution all BVI events have the same shift values

Shift values differ between ± 5 samples ($\Delta\Psi$ = ±1 deg), despite of 2 outliers in MV case

No dependence between shifts of advancing and retreating side

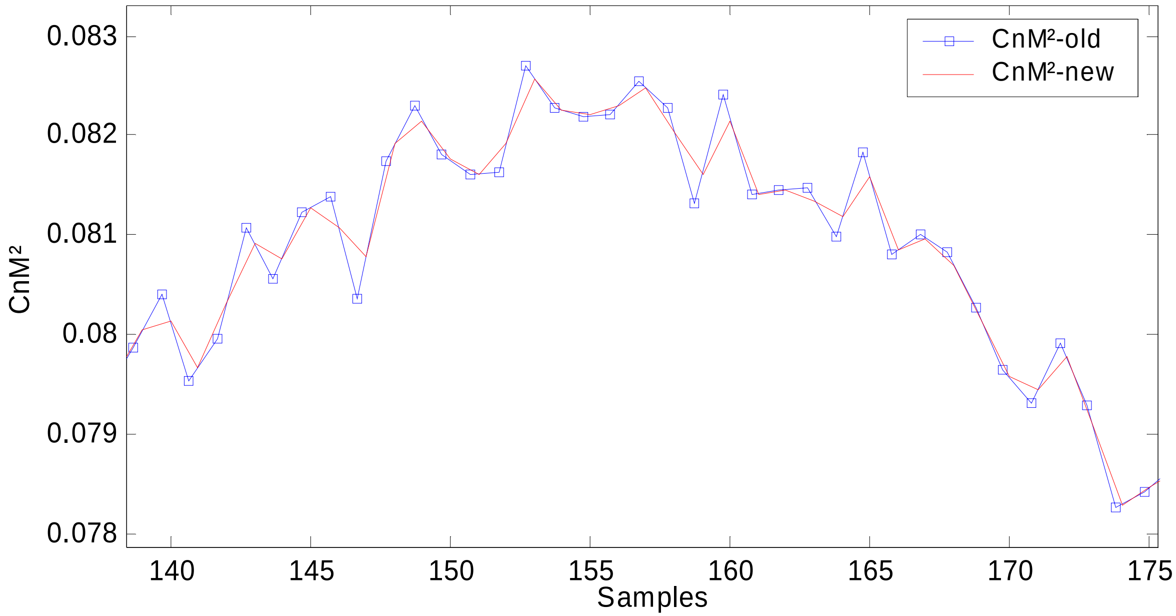


Averaged shifts of BVI events of MV case

Correction of time histories

Correction of phase shift by linear stretching / compression between two BVI reference points

Integer sample indices → Real indices → Interpolation necessary

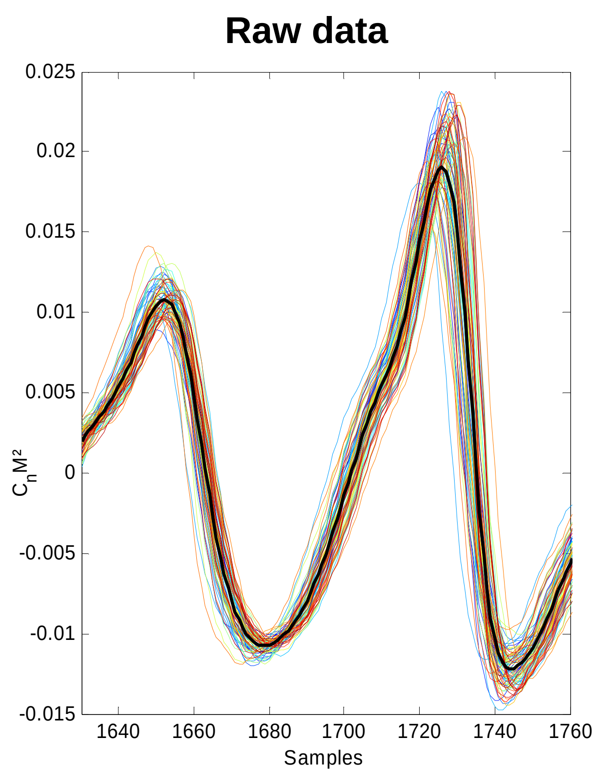


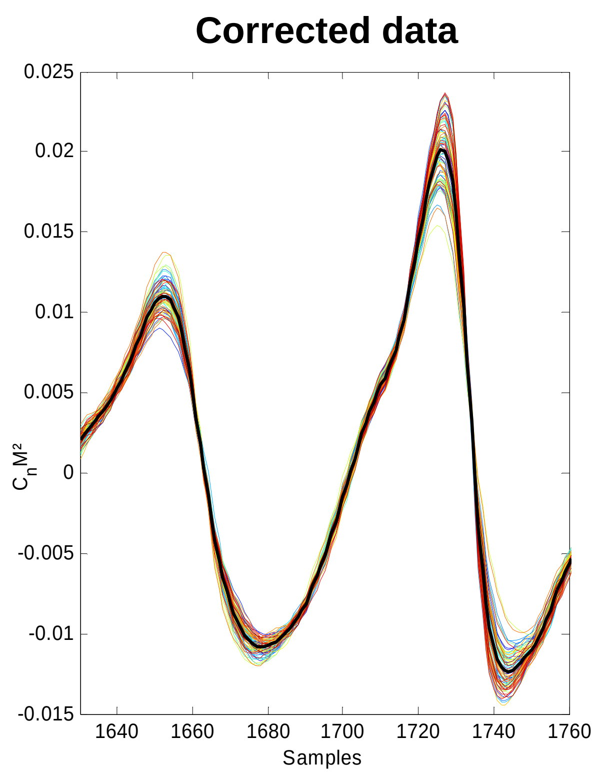
Corrected CnM² time histories BL case, Interpolation for integer indices

Correction results

Correction leads to identical BVI locations for each single time history

Maximum and minimum peaks are at the same location



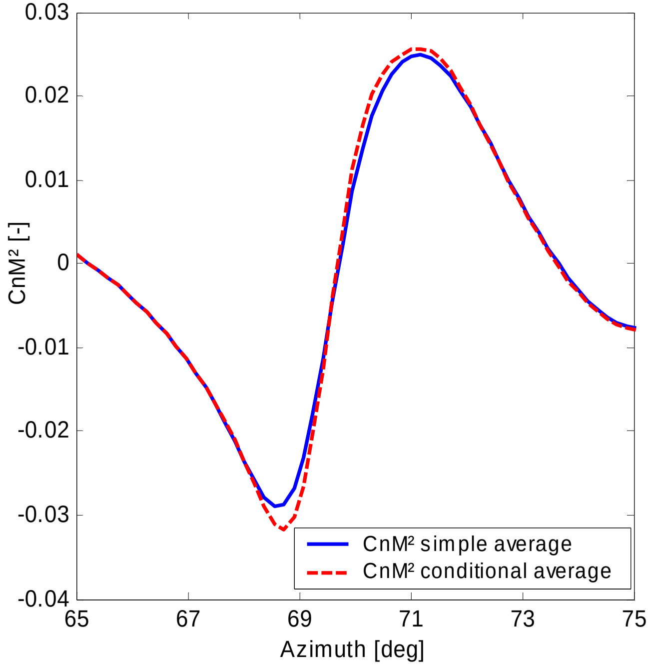


Comparison of simple and conditionally averages

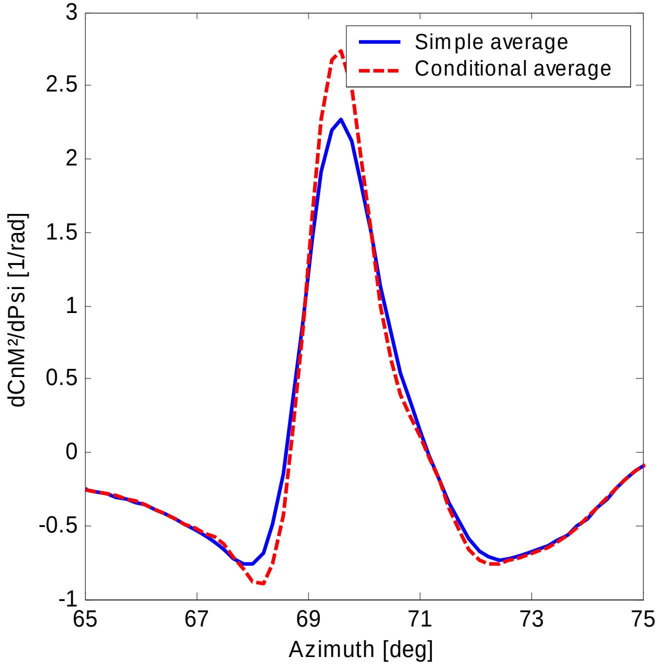
Conditional averages show larger CnM² amplitudes at the BVI events in any flight case

Peak-to-peak azimuth distances are mostly reduced

CnM² - band pass filtered (20-250/rev), MN adv. side



dCnM²/dψ - band pass filtered (20-250/rev), MN adv. side



Comparison of simple and conditionally averages (2)

CnM² amplitude differences

Flight case	Amplitude difference	BVI 1	BVI 2	BVI 3	BVI 4	BVI 5	BVI 6	BVI 7
BL, advancing side	$\Delta C_n M^2 \cdot 10^{-4}$	3.9	5.0	6.2	8.3	6.5	2.0	**0.5**
	%	6.4	5.3	4.7	4.3	3.7	3.4	2.2
BL, retreating side	$\Delta C_n M^2 \cdot 10^{-4}$	0.5	3.0	12.3	5.7			
	%	0.6	1.4	3.9	4.4			
MN, advancing side	$\Delta C_n M^2 \cdot 10^{-4}$	6.7	7.1	1.3	**35.7**	3.2	3.8	
	%	8.4	8.1	1.6	6.7	3.2	4.2	
MN, retreating side	$\Delta C_n M^2 \cdot 10^{-4}$	0.9	8.5	14.7				
	%	0.6	2.2	5.4				
MV, advancing side	$\Delta C_n M^2 \cdot 10^{-4}$	9.6	12.0	12.6	11.3	10.4		
	%	7.7	5.7	5.9	5.1	4.6		
MV, retreating side	$\Delta C_n M^2 \cdot 10^{-4}$	4.8	17.8	5.1				
	%	2.9	5.6	4.4				

Comparison of simple and conditionally averages (3)

CnM² peak-to-peak azimuth distances (0.6 samples equal to 0.1 deg)

Flight case	Peak-to-peak azimuth distance	BVI 1	BVI 2	BVI 3	BVI 4	BVI 5	BVI 6	BVI 7
BL, advancing side	Δ sample	-1.2	-0.6	-0.4	-0.8	-0.4	0.0	-0.2
	%	-4.6	-2.3	-1.7	-3.7	-1.9	0.1	-1.0
BL, retreating side	Δ sample	0.0	-0.4	-0.8	-1.2			
	%	-0.1	-1.3	-4.5	-4.2			
MN, advancing side	Δ sample	-1.5	**-1.8**	-0.7	-1.1	-0.3	-1.3	
	%	-4.4	-7.8	-1.8	-7.3	-1.3	-3.4	
MN, retreating side	Δ sample	**0.1**	-0.2	0.1				
	%	0.3	-0.7	0.3				
MV, advancing side	Δ sample	-0.4	-0.1	0.0	-0.8	-0.2		
	%	-1.3	-0.5	0.0	-3.0	-1.2		
MV, retreating side	Δ sample	-0.8	-0.3	-0.6				
	%	-2.6	-1.2	-0.4				

Summary

1. Defect pressure sensor signals were replaced or interpolated
2. All individual time histories were analyzed and time shifts at dominant BVI events were computed.
3. Linear stretching / compression was used between BVI events.
4. Conditionally averaging leads to increased amplitudes and to smaller peak-to-peak azimuth distances, compared to simple averaging. Major effect in the gradient: up to 20% increase or even more.
5. For further investigations of CnM^2 data the conditionally averaged time histories should be applied, especially for acoustic purposes.