

Identifying Disturbance Sources in Shear Flows Using The Degenerate Unmixing Estimation Technique (DUET)

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DEPARTMENT OF
AEROSPACE ENGINEERING

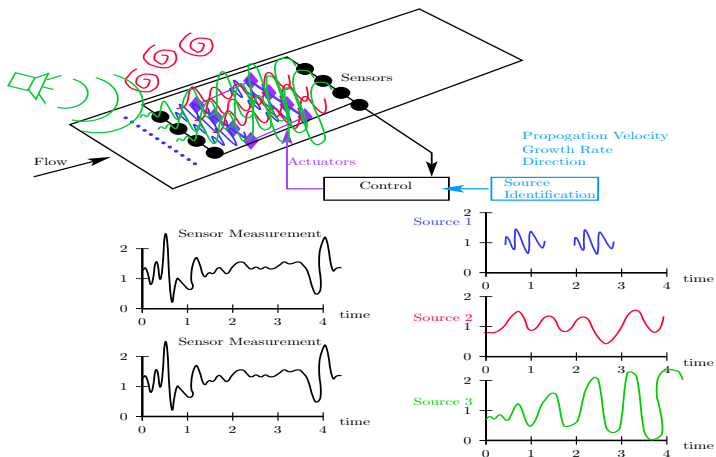
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8 May 2017

Objectives

Source Definition

Signal recorded by the sensor due a single physical disturbance source.



Cocktail-Party Problem



Image source:

<https://www.sciencenews.org/blog/science-ticker/3-d-printed-device-cracks-cocktail-party-problem>

[Cherry, 1953],[Haykin & Chen, 2005].

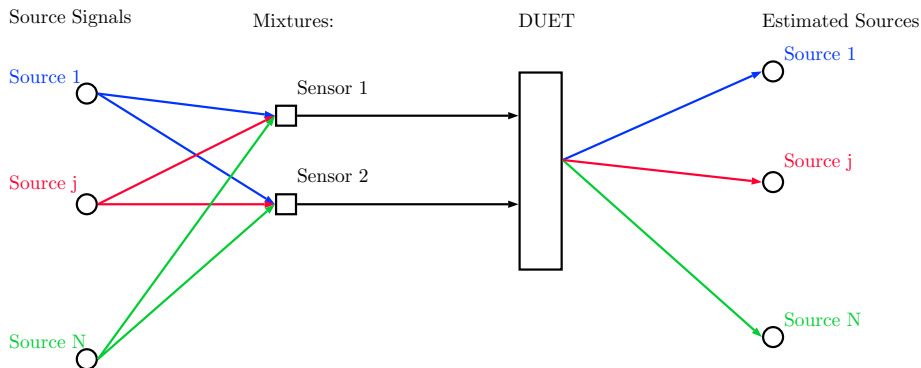
Blind Source Separation



► Image sources

The decoupling of unknown signals that have been mixed in an unknown way

Degenerate Mixtures (More sources than mixtures)



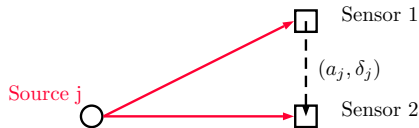
DUET -Degenerate Unmixing Estimation Technique
[Rickard 2007]

DUET Assumptions

Anechoic mixing model

$$x_1(t) = \sum_{j=1}^{N_s} s_j(t)$$

$$x_2(t) = \sum_{j=1}^{N_s} a_j s_j(t - \delta_j)$$

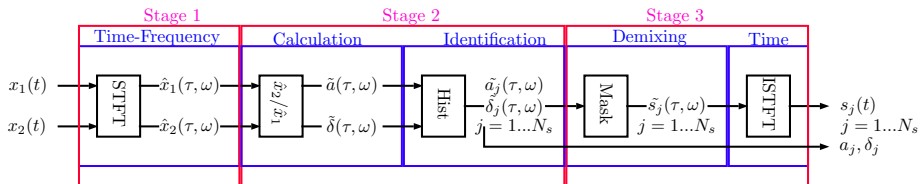


Windowed-disjoint orthogonality

$$\hat{s}_j(\tau, \omega) \hat{s}_k(\tau, \omega) = 0, \quad \forall \tau, \omega, j \neq k.$$

$$\hat{s}_j(\tau, \omega) = F^W[s_j](\tau, \omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} W(t - \tau) s_j(t) e^{-i\omega t} dt.$$

DUET Algorithm



Numerical Study: Linear Stability Model of Measurement



$$x_i = \sum_{j=1}^{N_s} s_{ij}, \quad i = 1, 2, \dots, N_x.$$

The source s_j recorded by sensor x_i is denoted by $s_{ij} \equiv [s_j]_{x_i}$.
TS wave sources

$$s_{ij} = |\tilde{q}_j([l_y]_{x_i})| e^{-\alpha_{im_j}([l_x]_{x_i} - [l_x]_{s_j})} \cos(-\omega_j t + \phi_{t_{ij}}),$$

$$\phi_{t_{ij}} = \alpha_{r_j}([l_x]_{x_i} - [l_x]_{s_j}) + \beta_j([l_z]_{x_i} - [l_z]_{s_j}) + \phi_j([l_y]_{x_i}) + \phi_{t_{0j}}.$$

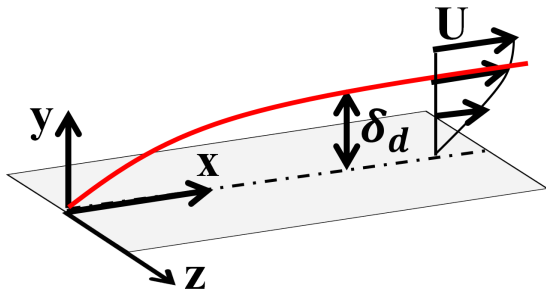
WP sources

$$s_{ij} = A_{j,[l_y]_{x_i}} \Re \left\{ \sum_{\omega_n=\omega_0}^{\omega_N} \sum_{\beta_k=\beta_0}^{\beta_M} \exp \left\{ i \left[\alpha_{x_{s_j}, \omega_n, \beta_k} ([l_x]_{x_i} - [l_x]_{s_j}) + \beta_k [l_z]_{x_i} - \omega_n t \right] \right\} \right\}.$$

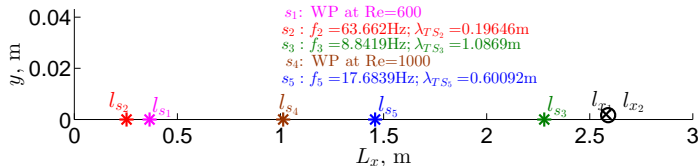
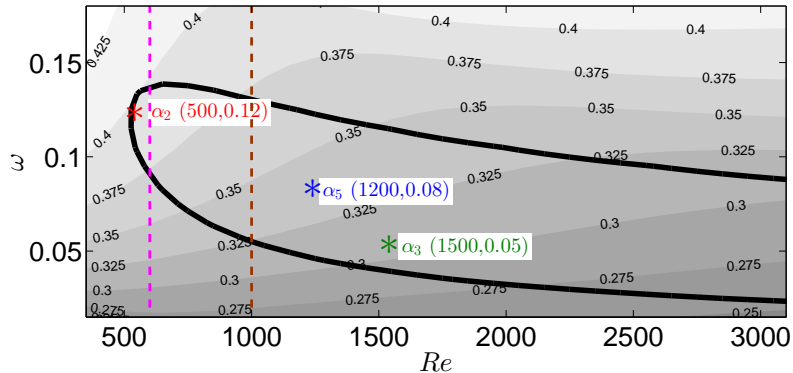
Numerical Study: Blasius Flow

Simulation settings:

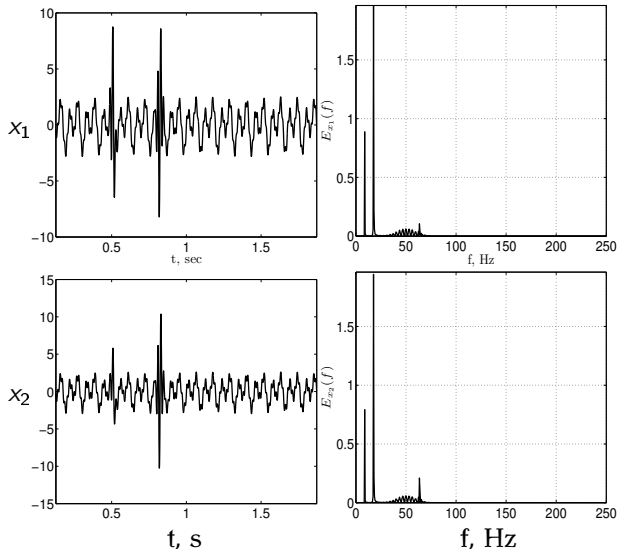
- ▶ 2D disturbances
- ▶ Spatial case with (complex α and real ω)
- ▶ Kinematic viscosity of air ($\nu = 0.15 \cdot 10^{-4} \text{ m}^2/\text{s}$)
- ▶ $U=5 \text{ m/s}$



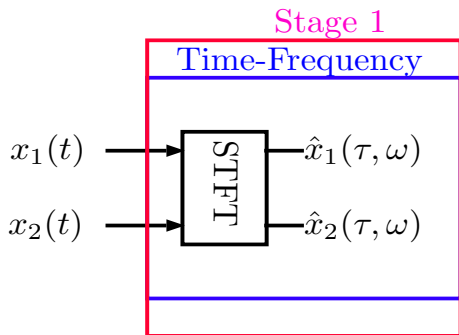
Numerical Study: Blasius Flow



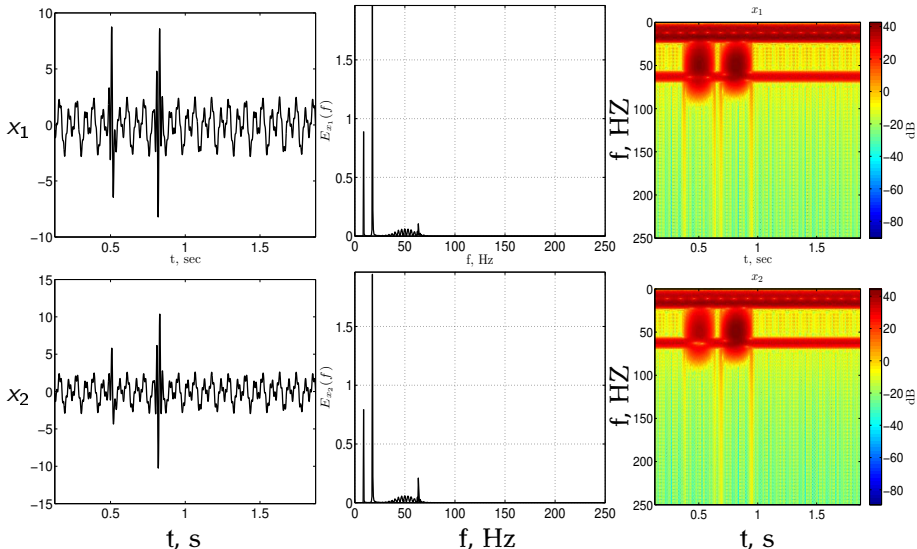
Numerical Study: Simulated Mixtures



Numerical Study: Simulated Mixtures

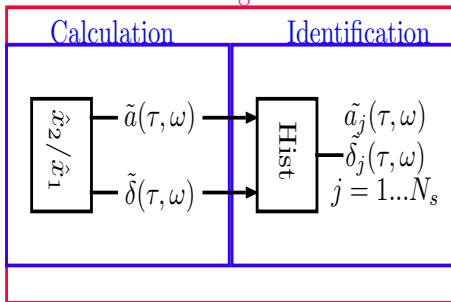


Numerical Study: Simulated Mixtures



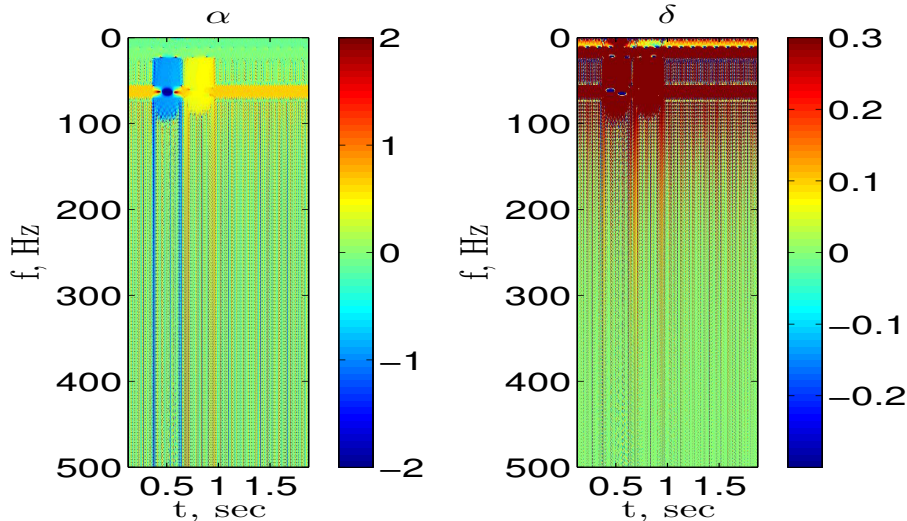
Numerical Study- Identification by DUET

Stage 2



Numerical Study- Identification by DUET

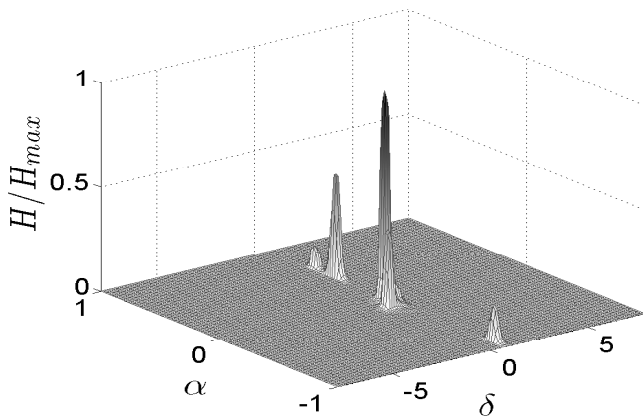
Mixing Parameters



Numerical Study- Identification by DUET

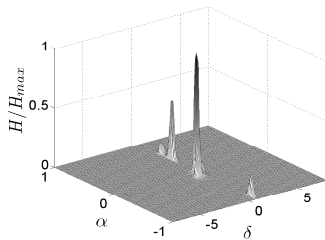
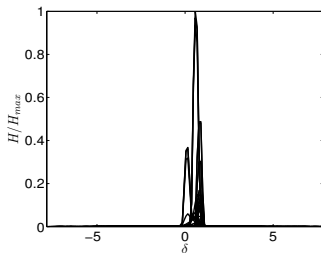
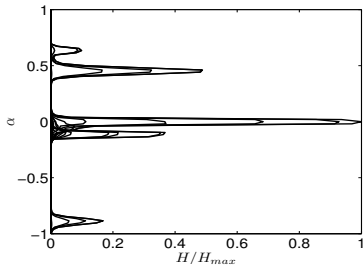
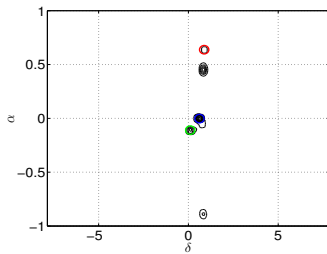
DUET Histogram

$$H(\alpha, \delta) := \iint_{(\tau, \omega) \in I(\alpha, \delta)} |\hat{x}_1(\tau, \omega) \hat{x}_2(\tau, \omega)|^p \omega^q d\tau d\omega.$$

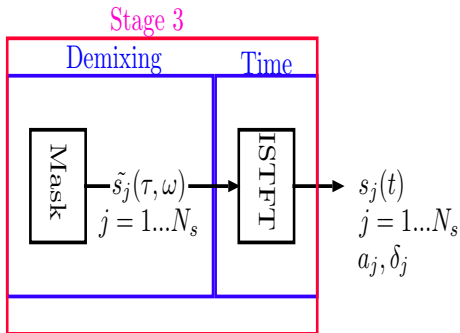


Numerical Study- Identification by DUET

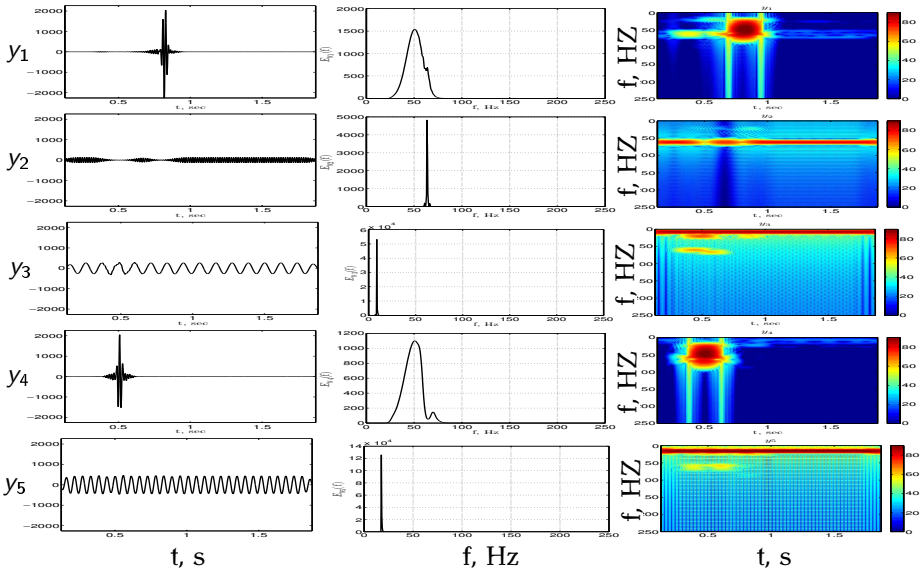
DUET Histogram



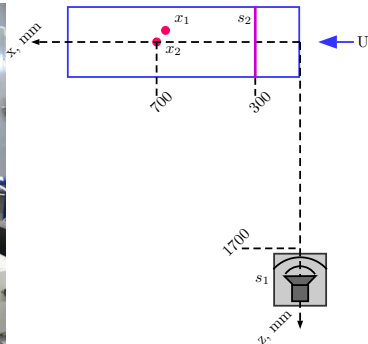
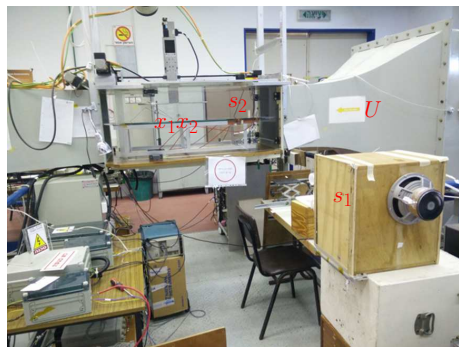
Numerical Study: Estimated sources



Numerical Study: Estimated sources



Experimental Study: Experimental Setup



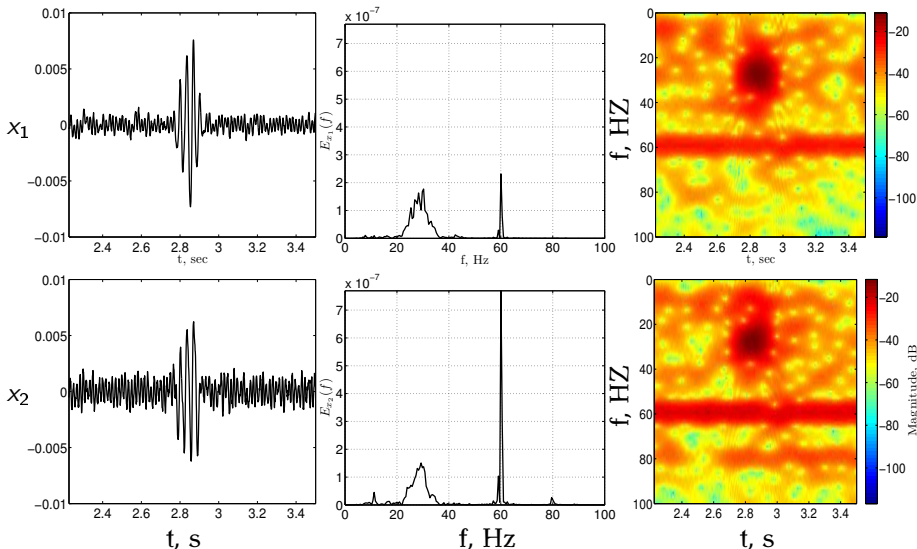
s_1 : 60 Hz by the loudspeaker.

s_2 : short pulse (50 ms) into an SDBD plasma actuator; $L_{s_2}=0.3$ m.

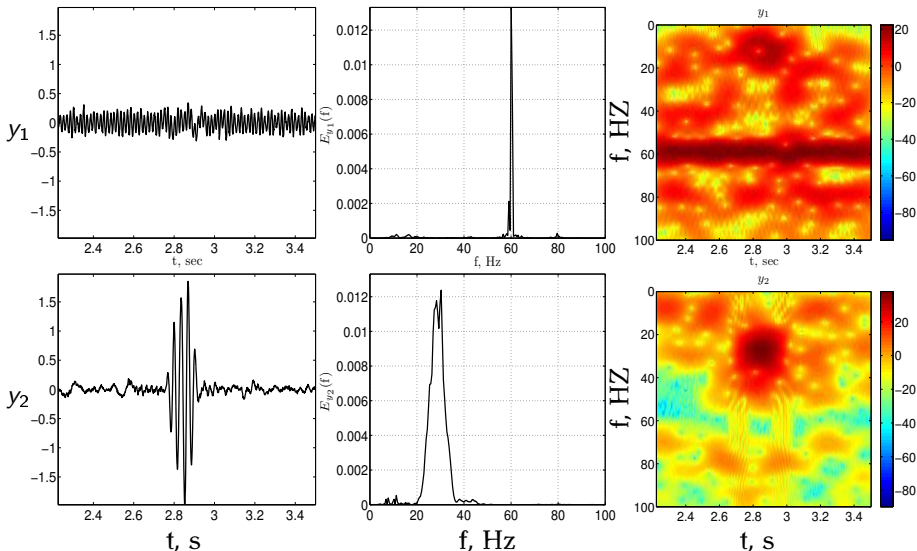
$U=4.2$ m/s.

x_1, x_2 : 1 KHz sample rate. $L_{x_1}=0.775$ m; $L_{x_2}=0.8$ m; (40 mm spanwise).

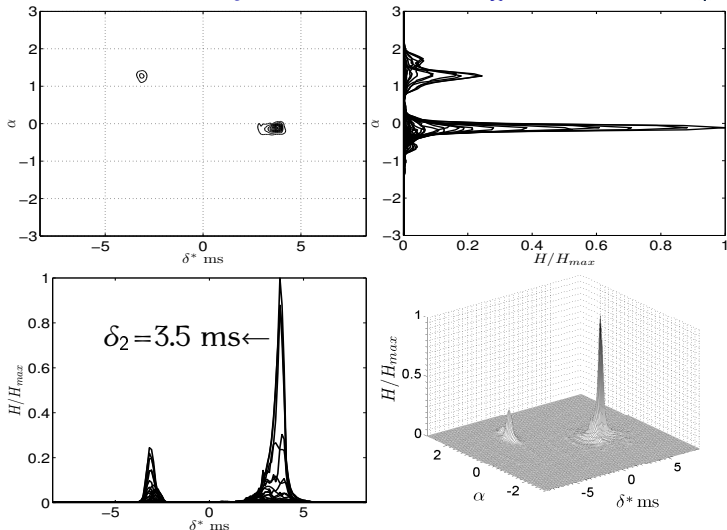
Experimental Study: Measured Mixtures



Experimental Study: Estimated sources



Experimental Study: DUET Histogram



$$c_g = \Delta L_x / \delta_2 = 1.43 \text{ m/s} = 0.36 U$$

leading edge: $0.44U$; trailing edge: $0.36U$. [Gaster, 1975]

Summary

- ▶ Flow state formulated in terms of mixture of sources.
- ▶ Sources identified in boundary layer measurements by using DUET.
- ▶ DUET can blindly discover any number of sources by using only two sensors.
- ▶ Method demonstrated numerically and experimentally.

The End





Acknowledgments

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