

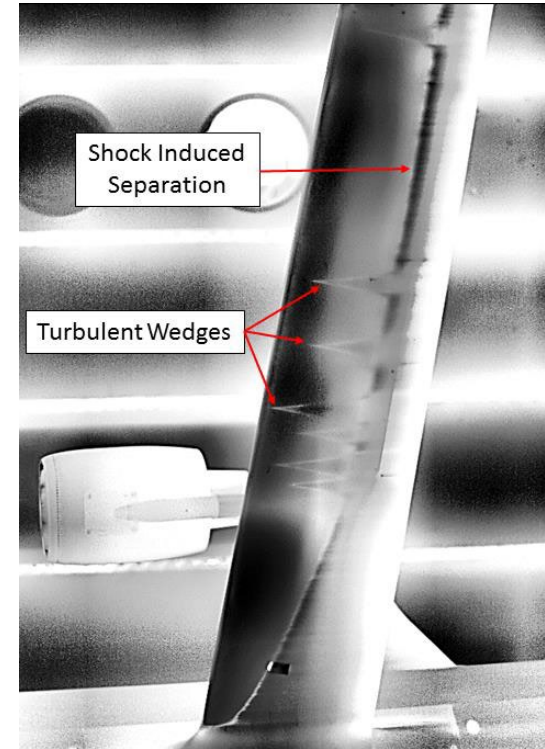
Infrared Reflection Removal in Wind Tunnels using Polarization Theory

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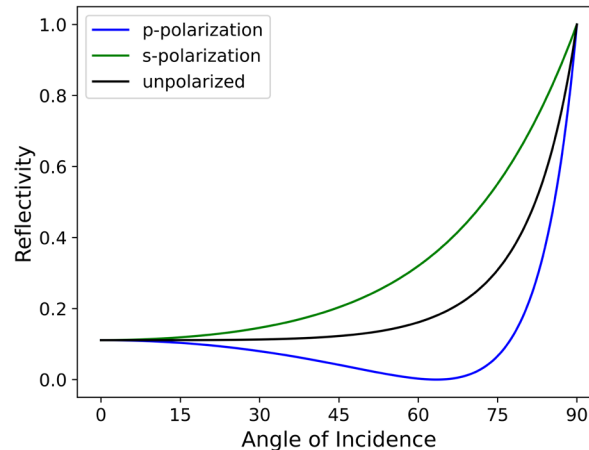
Infrared Radiometry in Wind Tunnels

- Useful for IR flow visualization
 - Can identify boundary layer transition, shock impingements, flow separation, etc
- Not useful for temperature measurement
 - Emission looks identical to reflection
 - Significant portion of signal is from reflection



Quantitative Reflection Removal with IR Polarization

- Reflectivity is different for p-polarization and s-polarization
- Reflectivity is a function of angle of incidence
- Need only simple prior information



Quantitative Reflection Removal with IR Polarization

- System of equations to separate emission and reflection
 - Need p- and s-polarized images

$$\begin{aligned} E_p &= (1 - \rho_p) \tau \left(\frac{E_e}{2} \right) + \rho_p \tau \left(\frac{E_r}{2} \right) \\ E_s &= (1 - \rho_s) \tau \left(\frac{E_e}{2} \right) + \rho_s \tau \left(\frac{E_r}{2} \right) \end{aligned}$$

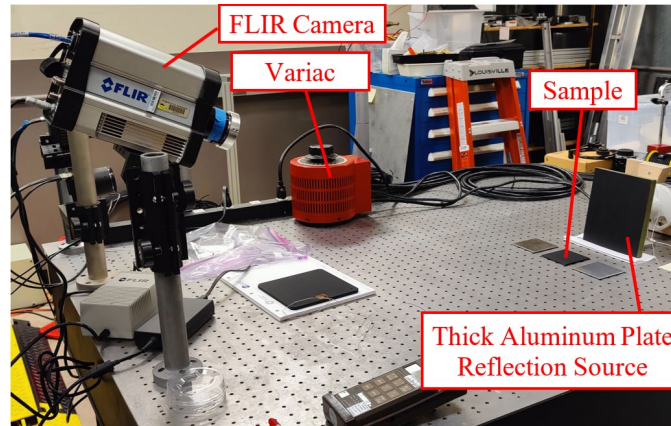
Experiment

- Tested 3 samples representative of common materials in wind tunnels
 - Bare Aluminum
 - Flat, Black, Polyurethane Paint
 - Pressure Sensitive Paint (PSP)



Experiment

- Single camera
 - Polarizer rotated between batches of images
- Camera observes one sample with reflection source
 - Reflection source is spatially and temporally uniform



Reflection Measurement

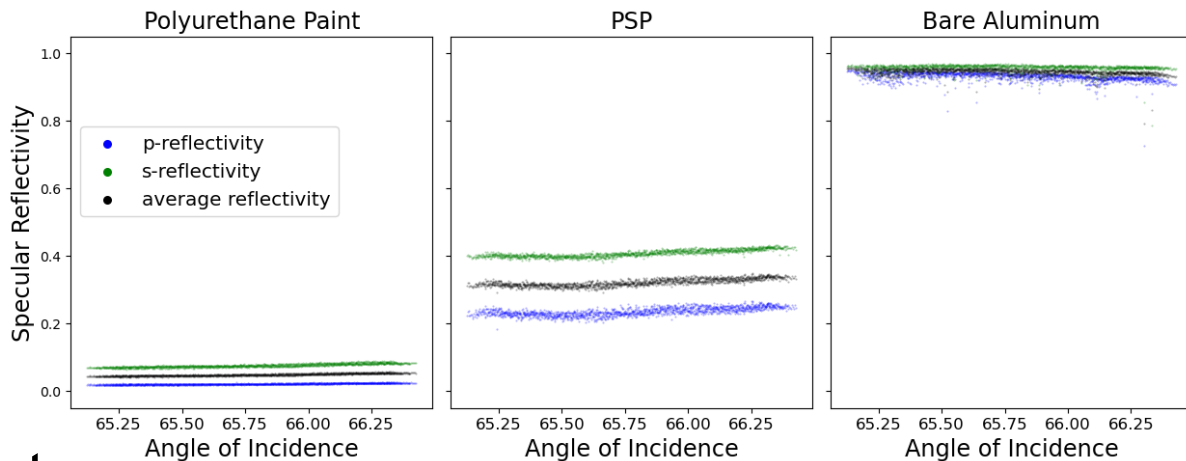
➤ Measured Reflectivity

➤ Directionally Correct

➤ s-reflectivity > p-reflectivity

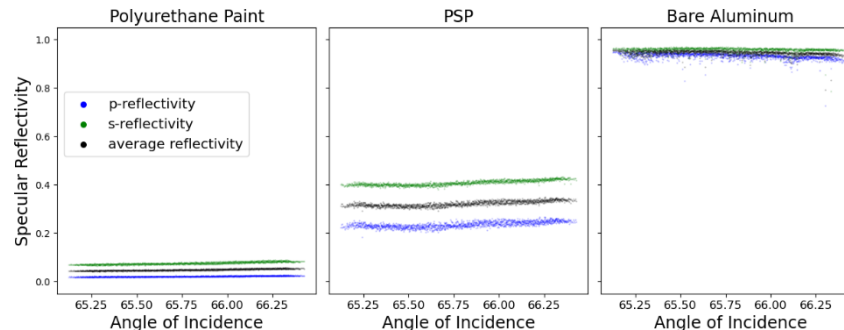
➤ Bare Aluminum > PSP > Polyurethane Paint

➤ Magnitude of reflection is wrong



Incomplete Emission-Reflection Model

- Model does not correspond to observations
 - S-polarized reflectivity is lower than expected
 - P-polarized reflectivity is higher than expected
 - Average reflectivity is lower than expected
- Diffuse reflection is likely the cause



Incomplete Emission-Reflection Model

- Adding diffuse reflection makes system of equations underdetermined

$$E_p = (1 - \rho_p)\tau\left(\frac{E_e}{2}\right) + \rho_p \alpha_p \tau\left(\frac{E_{\text{specular}}}{2}\right) + c_p \tau E_{\text{diffuse}}$$

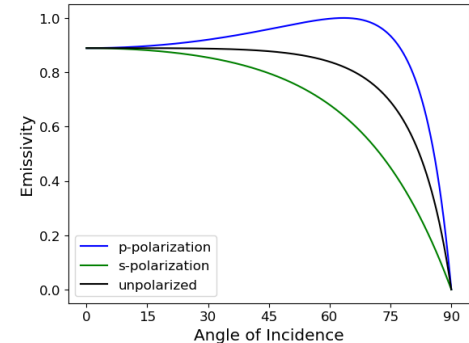
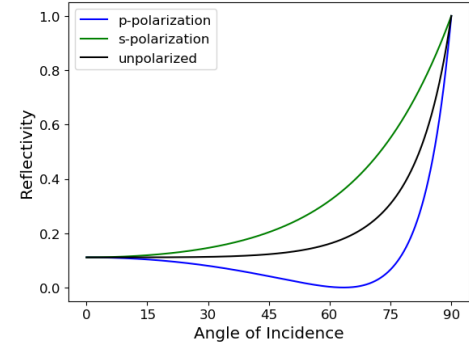
$$E_s = (1 - \rho_s)\tau\left(\frac{E_e}{2}\right) + \rho_s \alpha_s \tau\left(\frac{E_{\text{specular}}}{2}\right) + c_s \tau E_{\text{diffuse}}$$

Specular
Reflection
Proportion

Diffuse
Reflection

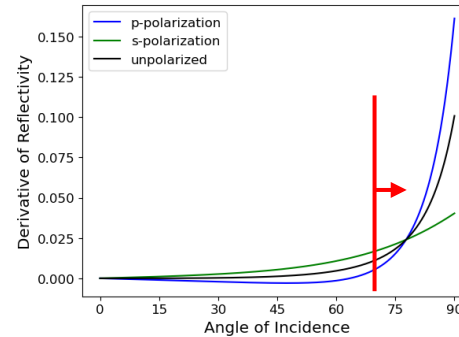
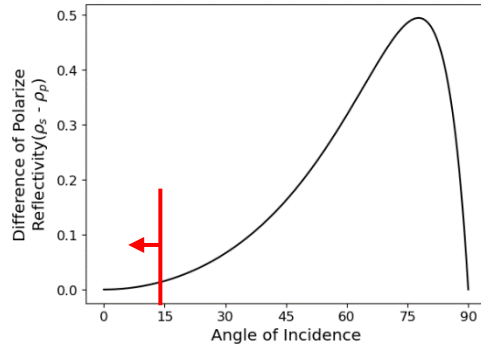
Mitigation

- Reduce diffuse reflection with mirror-like surface finish
 - Possible for bare aluminum and polyurethane paint
 - Not possible for PSP
- Leverage p-polarization for reduced reflectivity and increased emissivity



Limitations

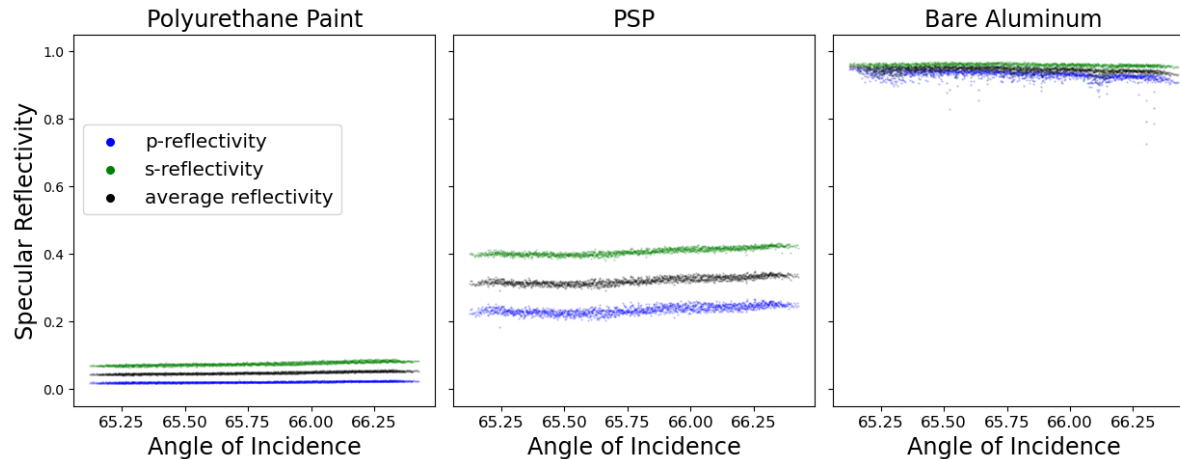
- Method unstable for low and high angle of incidence
 - Difference between polarized reflectivities is small for low angles
 - Polarized reflectivity is sensitive to angle at high angles



- Reduced signal through polarizer
- Implementation difficulties

Conclusion

- Method shows promise
 - Directionally correct
- Small changes to samples or setup could enable success





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