CSIR Emerging Researcher Symposium, CSIR Convention Centre, October 2012

# Flow features that arise due to the interaction of a plane shock wave with concave profiles

PhD by David MacLucas

Supervised by Prof. BW Skews

Flow Research Unit

Wits University

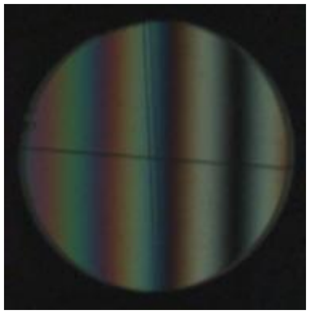
FLOW

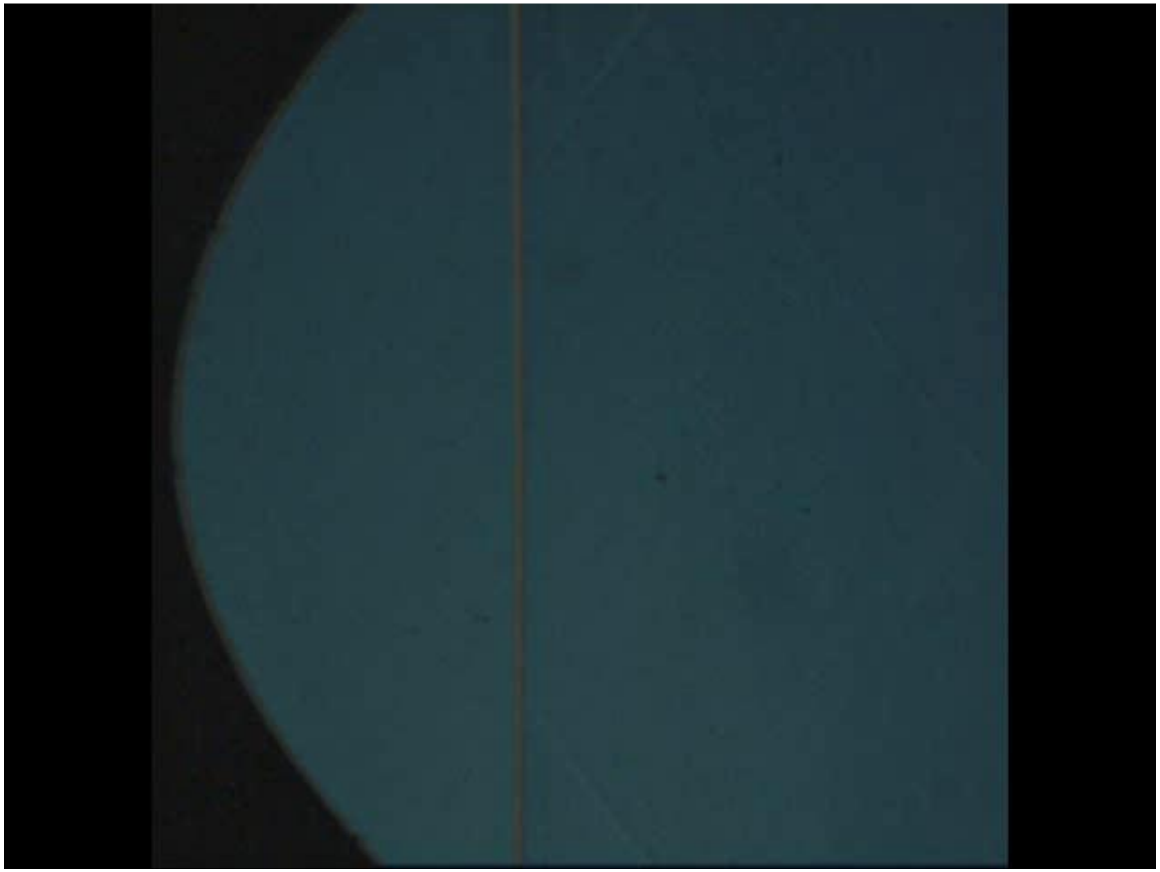
our future through science

# Presentation outline

- Introduction to shock wave focusing
- Numerical and experimental setup
- Results
- Conclusions

# Introduction: Shock wave focusing





Shearing interferometry flow viz. of the interaction of a plane Mach 1.2 shock wave with a blended profile.

Video shot at 330 kfps using a NHK prototype high-speed camera.

FLOW

CSIR
our future through science

# Research motivation

- Focus studies concentrated on a limited group of both cavity profiles and depth-to-aperture ratios
  - Identify new focus patterns and focus mechanisms
- Limited understanding of shock focus mechanism in blended profiles.
  - Determine the efficiency of various shock focus mechanisms
  - Tailor both the focus pattern and focus mechanism with the addition of an inlet profile.
- Improved flow visualisation techniques capable of providing both qualitative and quantitative information
  - Quantitative information would aid in understanding the variation of shock strength affecting shock focus process

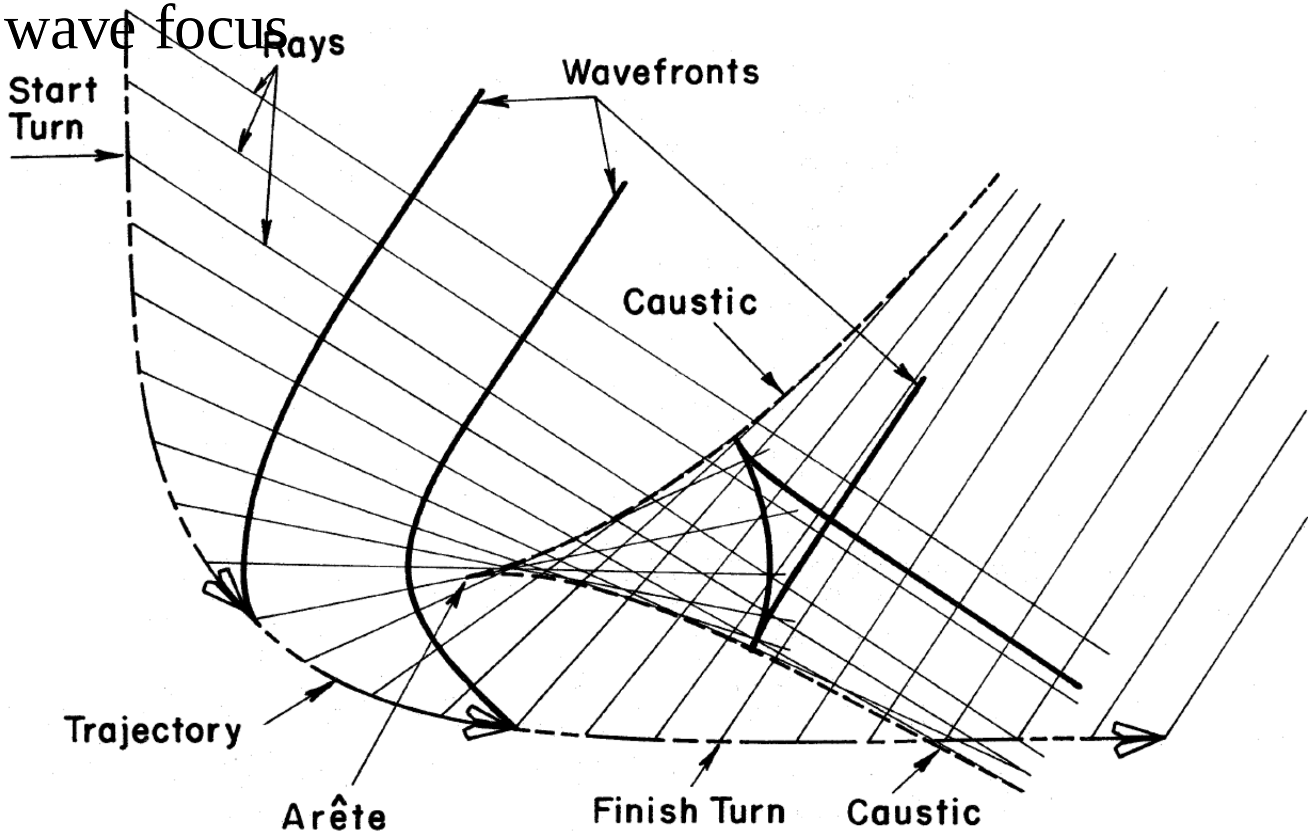
FLOW

CSIR our future through science

# Research applications

## The focus of sonic booms

- Extracorporeal shock wave lithotripsy
- Blast wave focus



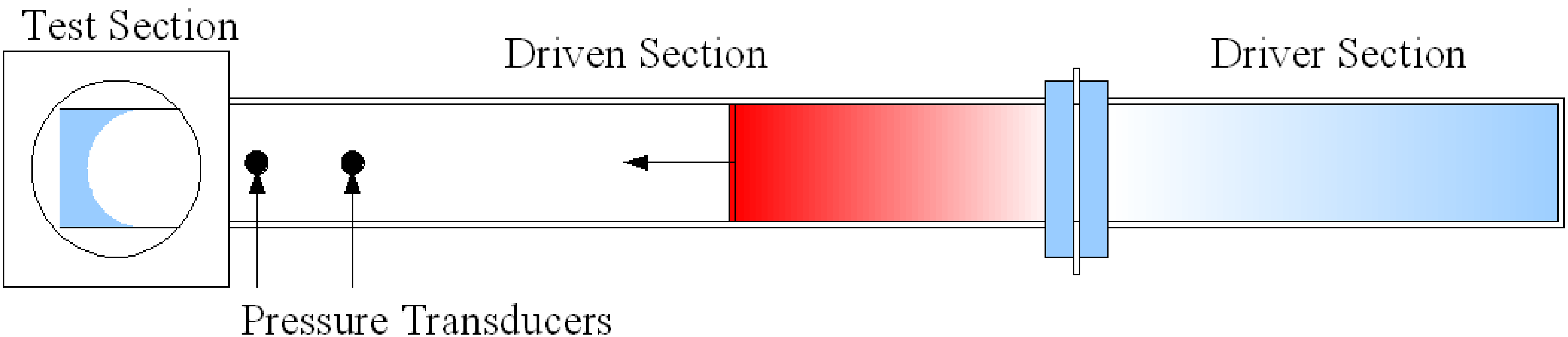

Kulkarny, V.A. (1975) The focusing of weak shock waves. PhD submitted to CAL Tech, Pasadena California.

# Research Objectives

- Conduct numerical testing of various cavity profiles using a suitable computational fluid dynamics package
- Validate the numerical scheme experimentally
- Identify variation in shock focus patterns and focus mechanism numerically and experimentally.
- Identify the effect of cavity shape on the shock induced pressure distributions
- Implement a qualitative and quantitative flow visualisation system

# Experimental Setup

- Test section measures 150 x 75 mm
- Air is used as the test gas
- Atmospheric pressure is approximately 933 mb
- Shearing interferometry flow visualization – measures horizontal density gradient only
- Images captured on a NHK high-speed camera (712 x 412 pixels)

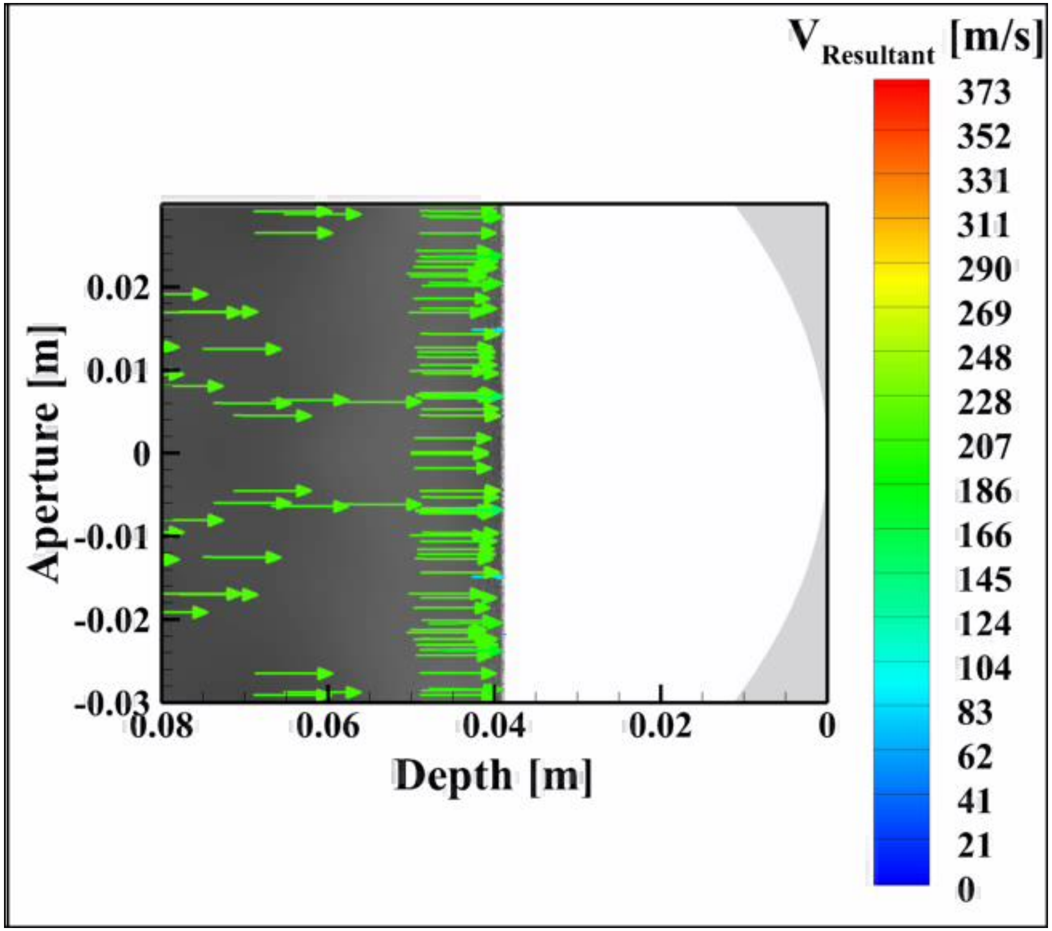


# Numerical setup

Flow Euler code by Luke Felthun:

- Adaptive dynamic triangular meshes
  - Element size calculated by maintaining global target for approximated error. Density gradient used to measure error within each cell.
- Compressible Euler equations written in terms of an arbitrary reference frame
  - Inviscid approach adequate for a transient flow of short duration.
- Finite volume vertex centred scheme with upwind flux functions
  - Numerical dissipation by upwind approach using a flux vector splitting method.
- 2nd order accuracy in space
  - Reconstruction procedure works in conjunction with a multi-dimensional limiter to reduce overshoots and oscillations of solution within a cell.
- Scheme validated experimentally

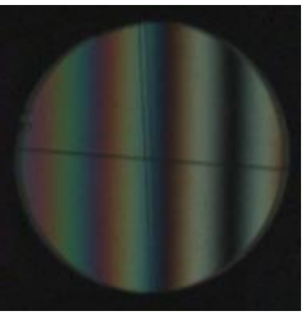
# Results: Velocity profile




Air velocity vector plot superimposed onto interferograms for a parabolic-circular compound at Mach 1.45. Vectors are scaled and coloured according to their resultant magnitude measured in the laboratory reference frame

# Results: Shock wave focusing

## Pre-focus wave behaviour




I – Plane incident shock wave

R – Reflected shock wave

F – Reflected shock of Transitioned Regular Reflection (TRR)

W – Wall shock of TRR

S – Shear layer

Shearing interferometry flow visualisation of the interaction of a plane Mach 1.2 shock wave with a blended profile.

Video shot at 330 kfps using a NHK prototype high-speed camera

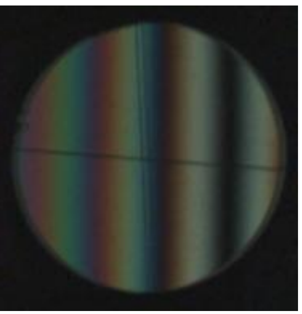
FLOW

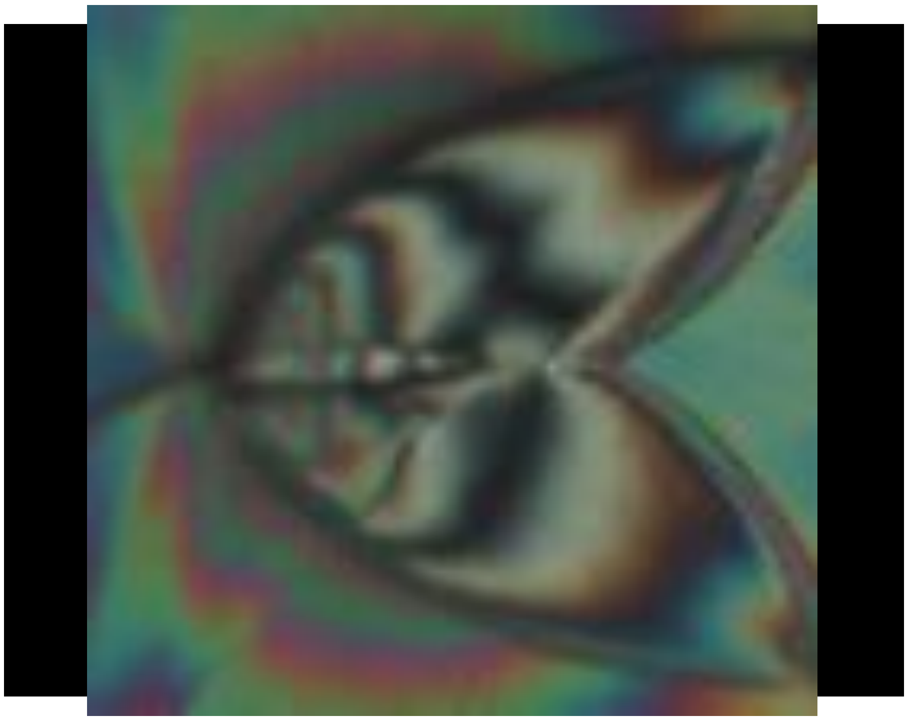
CSIR

our future through science

# Results: Shock wave focusing

## Gas Dynamic Focus





R – Reflected shock wave

W – Wall shock of TRR

P – Mach stem

M – Main reflected wave

S – Shear layer

Shearing interferometry flow visualisation of the interaction of a plane Mach 1.2 shock wave with a blended profile.

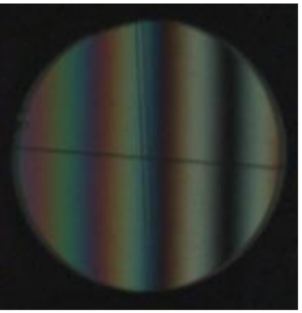
Video shot at 330 kfps using a NHK prototype high-speed camera

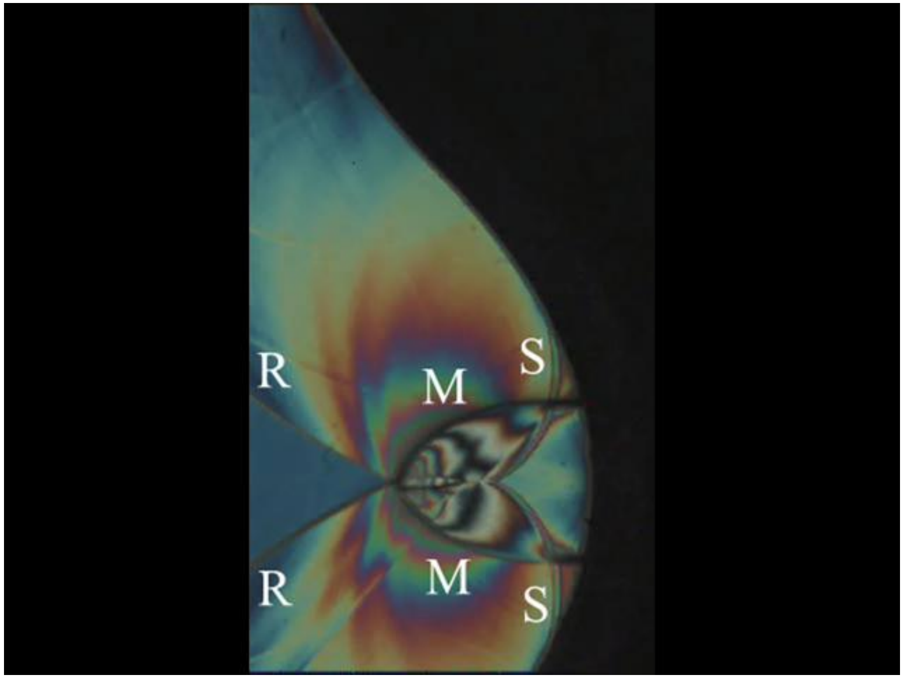
FLOW

CSIR our future through science

# Results: Shock wave focusing

## Post-focus wave behaviour






R – Reflected shock wave

P – Mach stem

M – Main reflected wave

B – Shear layer of P-R-M MR

S – Shear layer

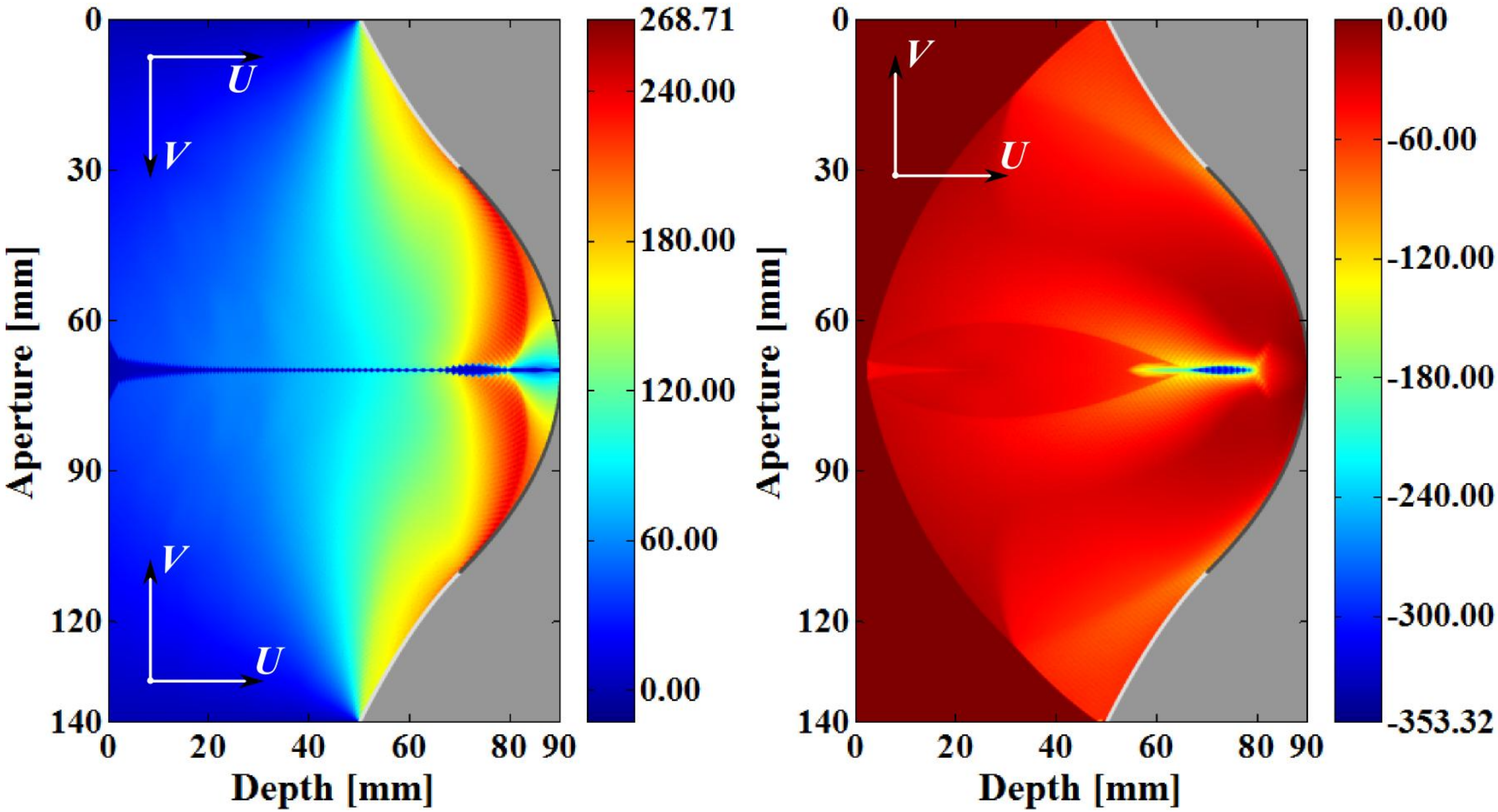
Shearing interferometry flow visualisation of the interaction of a plane Mach 1.2 shock wave with a blended profile.

Video shot at 330 kfps using a NHK prototype high-speed camera

FLOW

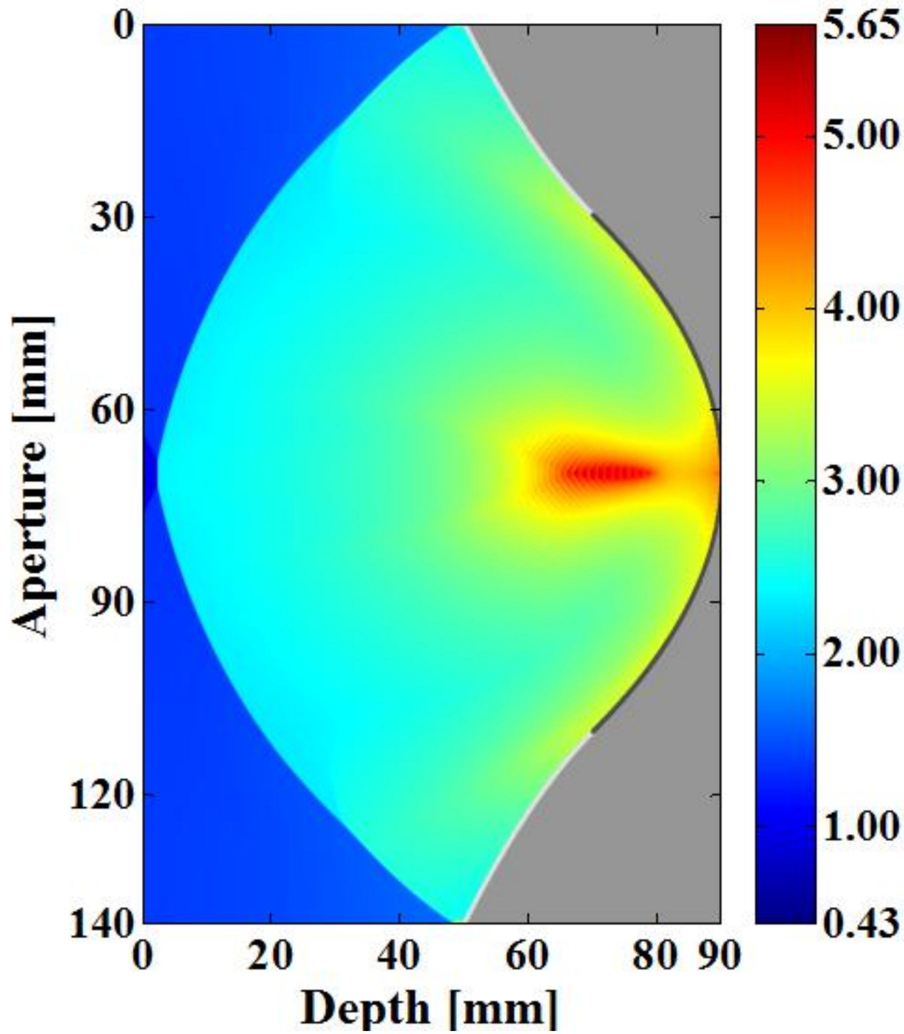
CSIR our future through science

# Results: Velocity profile




Map of maximum V and minimum U velocity **history** for the interaction of a plane Mach 1.45 shock wave with a compound profile

# Results: Pressure profile




Map of maximum pressure amplification **history** for the interaction of a plane Mach 1.45 shock with a compound profile

# Conclusions: Principal flow features

- Strong compression field developed behind the reflected shock wave R as system is near/at focus
  - Compression field shown to shape R
  - Reflected shock wave R is shown to direct air into focal region

- Strong horizontal gradients observed behind the Mach stem P
  - Minimum U velocity plot illustrates substantial velocities in the focal region
  - Results also illustrate non-uniform expansion behind shock wave M

- Peak pressure amplifications observed within focal region
  - Peak pressure amplification reaches a maximum at the start of focus
  - Peak pressure amplifications drop rapidly outside of the focal region

- Weak expansion fields found behind triple point
  - Maps of maximum V velocity history illustrate strong upward flows behind the triple point of the Mach reflection that nears focus

FLOW

CSIR
our future through science

# Acknowledgements


- Prof. Beric Skews and Dr C Law
- Prof. H Kleine of University of New South Wales
- Project Fluxion and Dr I Gledhill
- National Research Foundation for KIC grant