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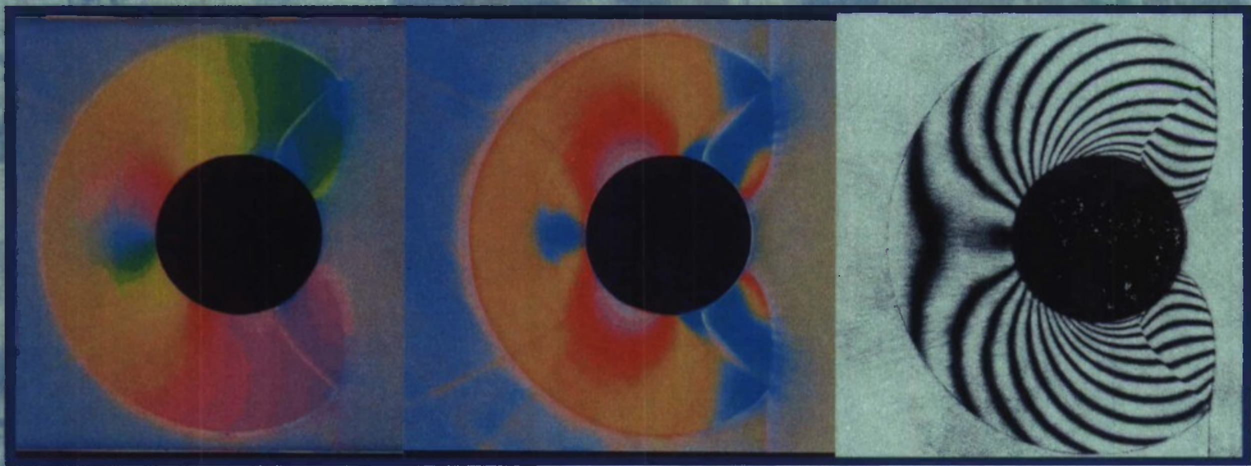
ISISWR-3

Third International Symposium on Interdisciplinary Shock Wave Research



March 1-3, 2006
Canberra, Australia

UNSW@ADFA

Book of Abstracts

School of Aerospace, Civil and Mechanical Engineering
University of New South Wales / Australian Defence Force Academy

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The Third International Symposium on Interdisciplinary Shock Wave Research

ISISWR-3

is hosted by the

**School of Aerospace, Civil and Mechanical Engineering,
University of New South Wales / Australian Defence Force Academy,
Canberra, Australia.**

Welcome to Canberra, and welcome to UNSW@ADFA !

This is the third installment of the International Symposium on Interdisciplinary Shock Wave Research. The previous two meetings were held in Matsushima, Japan, and Sendai, Japan. The focus of this conference is to bring together scientists and researchers from quite different technical backgrounds, with shock waves and their applications being the common denominator. This meeting stresses, as the title indicates, the multidisciplinary aspect of shock wave research.

The contributions will cover traditional areas like shock and blast wave research - that is, shock waves in gaseous media - but will also be related to shocks in solids and liquids or in multiphase materials. This includes the application of shock waves in medicine, but also fundamental material science such as the behaviour of materials under shock compression.

The previous meetings have been very fruitful by deliberately bringing people of different expertise and background together to share their knowledge and understanding of a basic phenomenon in nature:

– the shock wave.

Canberra, March 1, 2006

Harald Kleine (chair ISISWR-3)

ISISWR-3 will be held in lecture room LT3, Lecture Theatre South (building 30 on the map). Signs will be posted along the two main paths leading to this building.

Delegates staying at Olims hotel or coming by public transport will be dropped off at the bus stop at the ADFA roundabout (yellow circle). Walk down towards the administration building (no. 1 on the map), turn left, pass the library (building 13), the ICT centre (building 14) and the School of Humanities and Social Sciences (building 29). The main entrance to Lecture Theatre South is on a small plaza facing the School of Aerospace, Civil and Mechanical Engineering (buildings 17-20).

Delegates coming with their own car will most likely find a parking spot on the Senior and Junior Ranks carparks (P1 on the map), from which they can walk down past the Officers Mess (building 6) either towards the administration building or, as a shortcut, between the library and the ADFA café complex (building 33) until they reach the ICT centre. From then on, the path is identical to the one taken by people coming by bus.

Lucky delegates might be able to find a parking spot on the larger car park P2. In this case, access to the lecture theatres is quite straightforward – a straight path from the underpass between buildings 20 and 21 followed by another underpass through building 32 (Lecture Theatre North) leads you directly to the plaza from which the entrance of the Lecture Theatre South building can be seen.

Access to ADFA is via Northcott Drive, which can be entered from the Northeast via Fairbairn Avenue (the most likely route for anybody coming from outside of the ACT) or from the West via Constitution Avenue in Russell (not shown on the map). Northcott Drive has only one side road, the entrance to ADFA.

Delegates coming from Sydney:
Leave the Remembrance Highway immediately after passing the ACT border to Majura Road (direction Fyshwick, Queanbeyan). Majura Road leads you to the airport (on your left) and eventually to a T-intersection with Fairbairn Avenue. Turn right at this intersection and go straight until you reach a roundabout (just visible on the upper edge of the map). Turn left there onto Northcott Avenue.

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K. Takayama (Tohoku University, Japan)

Acknowledgement

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Air Force Office of Scientific Research
Asian Office of Aerospace Research and Development

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Special Acknowledgement

The preparation of conferences like this requires a lot of time and effort, as anybody who has ever organised one will know. It is virtually impossible to attend to all tasks without the help of dedicated assistants. Many of these often unsung heroes spend hours and days looking after the many details that such meetings inherently have, and without them, many a conference would have ended a lot less successful than they did. I consider it therefore appropriate to acknowledge the contributions of

(in alphabetical order)

Mrs. Vera Berra – for organising some of the stationery supplies found in the conference bag

Dr. Martha Patricia Butrón Guillén – for the patience she has had with her husband, and for her support in preparing the conference bags

Mr. Dirk Dullinger – for his work on the Book of Abstracts

Mr. Graham Doig – for his assistance in the registration process and technical support in the lecture theatre

Mrs. Jill Gordon – for taking care of the formal duties of registration and conference paperwork and for organising all things related to food for this meeting

Ms. Laura Kristina Kleine Butrón – for making her father smile in various periods of stress and for packing all the pens and notepads into the conference bags

Mrs. Carol O'Brien – for looking after the hotel reservations and all internal finances

Mr. Jamie Purdon – for the various pick-up and shuttle services provided to the conference delegates

Mrs. Danica Robinson – for giving the conference chairman useful advice and hints, even though he certainly qualifies as one of the stress factors in her role as Manager of the Research Office

Schedule ISISWR-3
(created February 28, 2006)
LT3, Lecture Theatre South

Each presentation has been allocated a duration of 30 minutes, including discussion.

Wednesday, March 1 2006

9h30 Bus transfer from Olims to ADFA

9h45 Registration opens

10h30 Welcome

10h45 **Session 1: Shock Wave Phenomena and Applications (I)**
Chairman: L.F. Henderson
K. Takayama:
Recent progress of medical application of shock wave research in TUBERO
N. Thadhani:
Shock compression of powder mixtures for materials synthesis and reaction energetics studies
B. Skews, H. Karnovsky:
Surface jets resulting from a shock-accelerated submerged surface

12h15 Lunch

13h45 **Session 2: Shock Wave Phenomena and Applications (II)**
Chairman: B. Skews
K. Ohtani, D. Numata, S.H.R. Hosseini, M. Sun, K. Takayama, A. Abe, M. Katayama, T. Kobayashi, K.Otomo:
Study of rock drilling by laser-induced underwater shock waves
G. Doig, A. Neely, T. Barber, E. Leonardi:
Initial numerical and experimental investigations into shock/ground and shock/vehicle interactions around a supersonic land speed record car
J. Purdon, N. Mudford, H. Kleine:
Supersonic projectiles in the vicinity of solid obstacles

15h15 Afternoon Tea

15h45 **Session 3: Shock Interaction With Materials**
Chairman: K. Takayama
L.F. Henderson:
Polar analysis of two-dimensional shock interactions in a general class of materials
Y. Horie, S. Case:
Mesodynamics of shock waves in polycrystalline materials
N.C. Holmes:
Using heterodyne velocimetry in impact experiments

17h25 Bus transfer to Olims

Schedule ISISWR-3
(created February 28, 2006)
LT3, Lecture Theatre South

Thursday, March 2 2006

9h00	Bus transfer from Olims to ADFA
9h15	**Session 4: Shock Wave Interactions** **Chairman: A. Neely** T. Saito, M. Sun, K. Takayama: Studies of time-dependent drag forces of shock wave loaded spheres M. Omang, S. Børve, J. Trulsen: Shock collisions in 3D using the Regularized Smoothed Particle Hydrodynamics method (RSPH) for cylinder symmetry L. Janicke, S.L. Gai: Organized motions in a supersonic mixing layer
10h45	Morning Tea
11h15	ISWI meeting
12h45	Lunch
14h00	Excursion: Mt. Ainslie (Canberra's most prominent viewpoint), Canberra Exhibition at Regatta Point, Guided tour through Parliament House (with the possibility of a rare 'behind the scenes' look)
17h00	Bus transfer to ADFA and Olims
18h00	Bus transfer to Banquet
18h30	Symposium Banquet at The Meeting Place, Kamberra Wineries, Northbourne Avenue, Lyneham
21h30	Bus transfer to Olims

Schedule ISISWR-3
(created February 28, 2006)
LT3, Lecture Theatre South

Friday, March 3 2006

9h00 Bus transfer from Olims to ADFA

9h15 **Session 5: Hypersonics (I)**
Chairman: S. Gai
N.R. Mudford, S.L. Gai, A.T. Goldsworthy:
Boundary layer chemistry and surface heat flux at interplanetary mission speeds
A.K. Stumvoll, R.R. Boyce:
Re-entry body drag – shock tunnel experiments and CFD calculations compared
M. Furudate, I-S. Jeung, S. Matsuyama:
Nonequilibrium He-H_2 flow field behind shock wave over blunt body

10h45 Morning Tea

11h05 **Session 6: Shock Wave Visualisation**
Chairman: N.R. Mudford
S. O'Byrne, P.M. Danehy, A.F.P. Houwing:
An experimental investigation of the effect of shoulder radius on the hypersonic laminar near wake flow
R. Faletič, A.F.P. Houwing, R.R. Boyce:
Tomographic reconstruction of shock layer flows
A.J. Neely, Z. Chia, S. Chittleborough, H. Kleine:
Initial studies on the performance of shock vector control as a method for fluidic thrust vectoring using a small-scale experimental rig
G.S. Settles, H. Kleine:
The art of shock waves and their flow fields

13h05 Lunch

14h30 Closure

15h00 Bus transfer to Olims

Recent progress of medical application of shock wave research in TUBERO

K. Takayama
Tohoku University Biomedical Engineering Research Organization
2-1-1 Katahira, Aoba-ku, Sendai, 980-8577 Japan

E-mail: takayama@ifs.tohoku.ac.jp

Under collaborations with the School of Medicine, Tohoku University, we have been working for medical applications of shock wave research. Recent progress in exploitations of a laser induced water jet device applicable to the revascularization of cerebral thrombosis and a result of its animal experiment will be presented. A development of an actuator induced water jet dissection device and a result of its preliminary animal experiment. We understand that the characteristic of micro-pumps used this dissection device is governed by that of micro-pumps. The inception of micro-cavitation bubbles in the micro-pumps and unsteady water flows in capillary tubes of 0.030 mm diameter are found to play decisive role in their performance. We initiated a laser ablation assisted drug delivery system (DDS) and have been working for its clinical applications. Under the collaboration with biologists in Tohoku University, we introduced DNA coated gold particles into onion cells and successfully obtained gene expression in onion cells. Although its characteristics should be optimized, our system is comparable with DuPont's Biolistics and Oxford University's Powder Ject. It is a critical issue in shock application to medicine to discover the induction of a substance in shocked cells. For this purpose spatially and temporally well controlled shock loading in cells is needed. Hence, we are developing a micro-shock focusing device by underwater explosions of micro-gram silver azide crystals. Primary results of micro-underwater explosions will be presented.

Shock compression of powder mixtures for materials synthesis and reaction energetics studies

Naresh N. Thadhani
School of Materials Science and Engineering,
Georgia Institute of Technology
Atlanta, GA 30332-0245

E-mail: naresh.thadhani@mse.gatech.edu

Shock compression of powders is of considerable interest for materials synthesis applications due to possibilities of forming new compounds with non-equilibrium compositions, chemically and/or physically altered structures, or for simply making bulk compacts in which the metastable or ultra-fine grain size of the precursor particles is fully retained. The shock-compression response of powders is significantly different from that of solid-density or distended (cellular) solids, since a large amount of energy is dissipated in the processes of void annihilation and overcoming inter-particle interactions. The stresses at points or surfaces of contact are significantly greater than the mean applied stress, which can lead to heterogeneous deformation at interparticle regions, plastic flow and sliding at contact surfaces, shear localization in particle interiors, as well as fracture and dispersion of fragments. Exploitation of these challenging and unique effects is what makes it possible to utilize shock compression of powders for synthesis of novel materials. Likewise, the shock compression of reactive (intermetallic-forming or thermite) powder mixtures is of interest for capitalizing on the release of heat of reaction associated with compound formation, for applications relevant to energetic materials. This presentation will provide an overview of our work on shock compression of intemetallic-forming powder mixtures for investigating the shock-initiation of chemical reactions. While prior work has suggested that the criterion for reaction is most probably mechanochemical in nature, in which shock loading environment plays a larger role than absolute shock energy input, the mechanisms responsible for intimate mixing of fresh reactants and subsequent compound formation are however still unclear. The discussion will focus on the understanding of shock-induced reaction initiation criterion based on results of *in-situ* stress and shock velocity measurements in the regime of the crush-strength of the powder mixture. The effects of the intrinsic and extrinsic properties of reactant materials on shock-initiation of reaction (or its lack of) will be described. Understanding of these effects is essential for control (implying encouraging or discouraging) of shock-initiation of chemical reactions in powder mixtures for applications relevant to synthesis of novel compounds as well as for their uses in energetic materials.

Surface jets resulting from a shock-accelerated submerged surface

B. W. Skews, H. Karnovsky
Flow Research Unit
University of the Witwatersrand
Johannesburg, South Africa.

Fax: +27 11 3397997 E-mail: bskews@mech.wits.ac.za

It has been found that concentrated free-surface water jets can be formed by rapidly accelerating a plate positioned below the water surface. The early work demonstrating this effect used a shaped metal disk accelerated by repulsion from an electrically powered coil, driven by an electric current of 6000A at 8000V (Mortimer et al. 1995). The original intent of the work was to use small water jets in a materials sorting application, by impulsively impacting selected particles, thereby causing them to be deflected from the main particle stream. The electrical environment required in that implementation is not conducive to safe operation so a shock tube driven system is explored in this work.

A number of plate arrangements were selected. A simple gas shock tube is mounted vertically below a water tank with the end of the driven section interfacing with the water and fitted with a variety of flexible terminations which allow the end plate to move upward into the water bath as indicated in Fig. 1. Various mounting systems were explored and pressure fields established using a needle hydrophone.

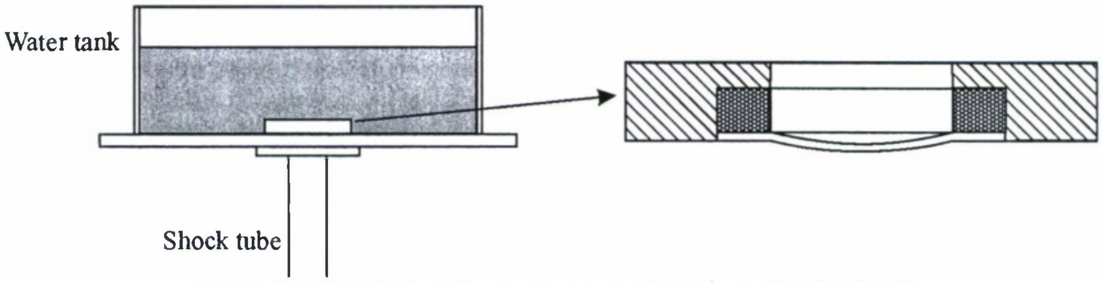

Figure 1. Water bath and support arrangement above the shock tube

The early version had the parabolic-shaped plate seated on an elastic ring of foam with the edge sealing done with silicone. Although good water jets were obtained this arrangement was not robust enough to survive more than a few tests. In the second version a metal flexible bellows was used at the end of the shock tube, but inferior jets were produced. This resulted from the larger inertia and the jets were generally smaller, broader, and less coherent. A set of typical results for the foam-mounted case are given in Fig. 2. Some simulations were done using Autodyne, which correlate reasonably well with the images.

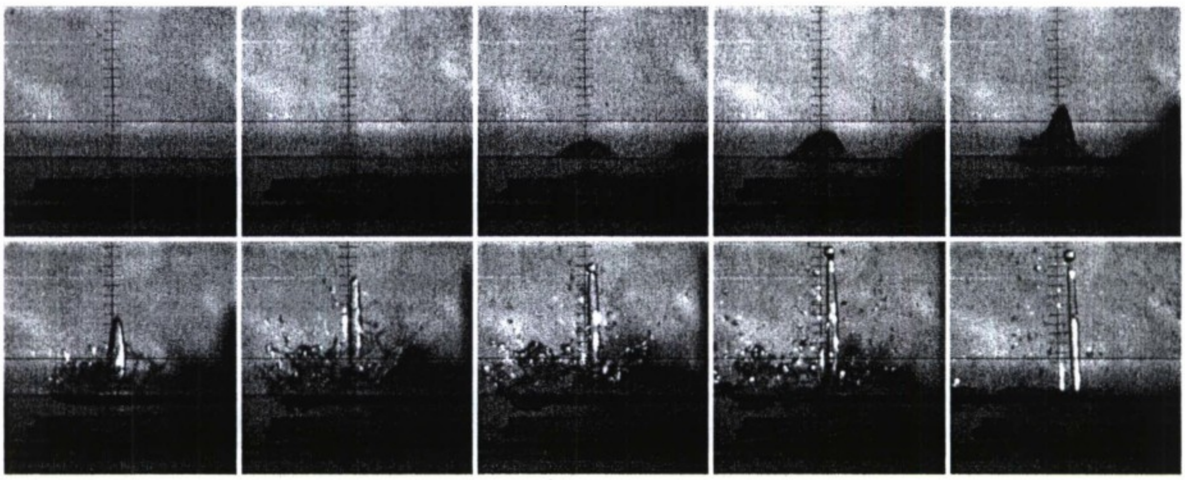

Figure 2. Development of the water jet

References

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Study of rock drilling by laser-induced underwater shock waves

K. Ohtani [1], D. Numata [1], S.H.R. Hosseini [2], M. Sun [1], K. Takayama [2]
A. Abe [3], M. Katayama [3], T. Kobayashi [4], K. Otomo [4]
[1] Institute of Fluid Science
Tohoku University,
2-1-1, Katahira, Aoba, Sendai, 980-8577, JAPAN
[2] Tohoku University Biomedical Engineering Research Organization
2-1-1, Katahira, Aoba, Sendai, 980-8577, JAPAN
[3] CRC Solution Corp.
2-7-5, Minamisuna, Koto-ku, Tokyo, 136-8581, JAPAN
[4] Japan Drilling Co., LTD.
2-4-3, Nihonbashi, Horidome-cho, Chuo-ku, Tokyo, 103-0012, JAPAN

Fax: +81-217-5037 E-mail: ohtani@rainbow.ifs.tohoku.ac.jp

Related to the laser induced shock wave research we recently became interested in application of high-power laser to rock drilling. Reed et al. (2003) used 1.6 kW pulsed Nd: YAG laser to drill a rock specimen submerged in a 2 mm thick water layer. The rock was molten rather than cracked by spalling. The molten rock surface was quickly solidified to form a glassy layer and nullified further increase of drilling effects. The elongated laser exposure time did not significantly deepen the drilling hole but simply heated up the rock specimen. We have been interested in the application of laser-induced underwater shock waves through their focusing or jet forming effects to rock drilling. Such uses of underwater shock waves are closely related to the extension of the medical applications of extracorporeal shock wave lithotripsy (ESWL) and pulsed Ho: YAG laser induced liquid jet (Takayama and Saito 2004)

This paper reports a preliminary result of laser-induced underwater shock wave applied to rock drilling. Experimental results were compared with AUTODYN numerical simulations. Time resolved shadowgraph of underwater shock wave focusing from a truncated ellipsoidal cavity is shown in Fig. 1. The ellipsoidal cavity made of brass had major radius of 35.25 mm and minor radius of 25.0 mm. Q-switched Ruby laser of 670 mJ, wavelength of 69.4 nm, 25ns pulse duration was deposited in the focal point inside the cavity. We observed the process of shock focusing to the second focal point outside the cavity and high pressure formation by using a high-speed digital video recording (HPV-1, SHIMADZU Corp., frame rate up to 1,000,000 f/s, spatial resolution of 312 pixel × 260 pixel). Consequently, the high pressures built up at the second focus point cracked the rock specimen without creating thermal damages. We plan further parametric studies by increasing laser energy in muddy sea water.

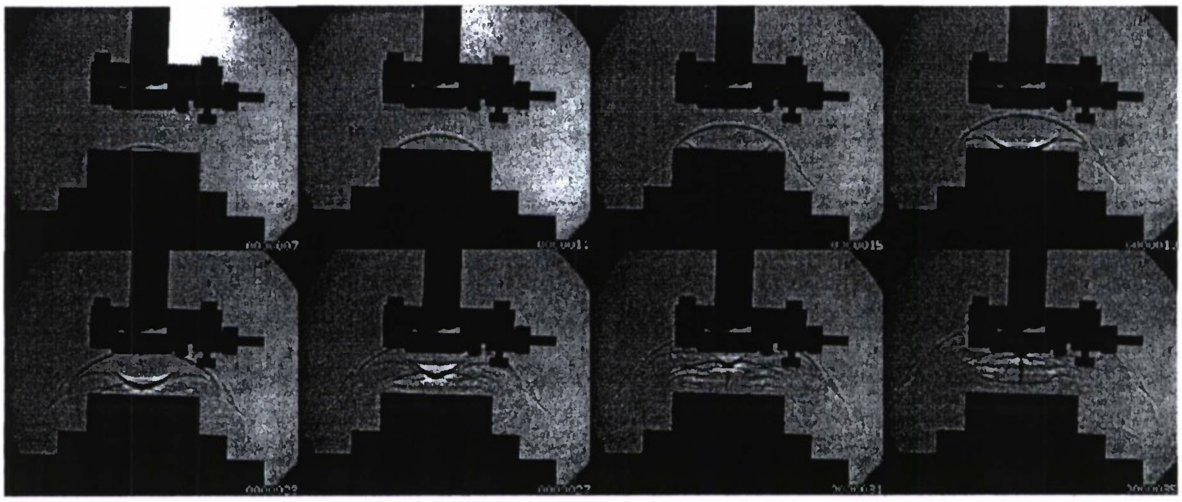

Fig. 1 Sequential photograph of laser-induced shock wave focusing from an ellipsoidal reflector in water (interframe 1μs, exposure time 0.25μs, the interval of the pictures shown above is 4 μs)

Acknowledgements This work is supported by Japan Oil, Gas and Metals National Corporation (JOGMEC).

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Takayama K, Saito T (2004) Shock wave/ geophysical and medical applications. *Annu. Rev. Fluid Mech.* **36**: 347-379

Initial numerical and experimental investigations into shock/ground and shock/vehicle interactions around a supersonic land speed record car

G Doig[1], A Neely[2], T Barber[1], E Leonardi[1]
1) University of New South Wales
Sydney Australia
2) School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia

Fax: +(61) (0)2 9663 1222 E-mail: g.doig@student.unsw.edu.au

Since the race for the World Land Speed Record entered the jet age in the 1960's, vehicles engaged in the pursuit of the fastest speed on land have operated in transonic flow conditions. Due to the formation of shock waves around and under the car at such speeds, aerodynamic considerations are of primary concern to designers planning attempts on the current mark of Mach 1.0175: the first officially-recognized supersonic land speed record, set by the British car Thrust SSC as driven by Andy Green in 1997. While the SSC team undertook novel rocket-sled testing and utilised what were at the time advanced computational fluid dynamics (CFD) techniques (Noble and Tremayne 1998) , their results were never formally published. At the time of writing, only one other substantial piece of research in the field has been undertaken let alone publicly produced (Torda and Morel 1971), but this was not a fundamental study and predated modern computational techniques. Therefore, a considerable gap in available scientific knowledge exists which this research aims to fill. The work undertaken thus far in the present study consists of wind tunnel tests on 2d and 3d models of a simple wedge-shape close to the ground, and corresponding CFD simulations using the commercial code Fluent 6.2.

The experiments were conducted in UNSW's supersonic blowdown tunnels at Mach numbers of 2 and 3. The high Mach numbers relative to the actual speeds of land speed record cars were necessary to avoid choking of the flow in the test section, but also facilitated a more straightforward assessment of techniques to properly simulate ground effect motion at supersonic speeds. In order to emulate the real life case, either the object in question must be moving over a stationary ground, or the ground must be moving at the freestream velocity (Barber et a. 2002). Neither of these options are particularly feasible, especially at a university level, and therefore some novel solutions are currently being investigated; an elevated ground splitter plate to reduce boundary layer buildup along the ground, and a supersonic version of the mirror image method have both been assessed for suitability when compared to a standard case with no special treatment of the wind tunnel boundary layers. A mixture of black and white and colour schlieren photography and videography, direct pressure readings and thermochromic liquid crystal visualisation techniques were used to gain the maximum possible insight into the flow field and the nature of the shock wave interactions.

In tandem with this study, CFD simulations of the wind tunnel experiments have been conducted. It was soon discovered that the numerical model experienced some considerable difficulty in achieving reliable results due to the multiple and complex shock reflections that occur in the space between the car and the ground, and in addition, difficulties in physically modeling the exact wind tunnel scenario (due to factors such as model vibration and deflection) were encountered, resulting in sometimes misleading data. However, the research has now reached the point where computational output can be properly validated against the experimental results, and therefore a degree of trust in the capabilities of Fluent to model the problem has emerged. Future work will incorporate more advanced, more realistic car geometries in the wind tunnel, and the computational branch of the research will now focus on simulating the real-life case of transonic flow with a moving ground.

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Supersonic projectiles in the vicinity of solid obstacles

J. Purdon, N.R. Mudford and H. Kleine
School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia

Fax: +61 2 6268 8276 E-mail: h.kleine@adfa.edua.au

The behaviour of supersonic projectiles in free flight through essentially quiescent air has been studied for more than a century (McCoy 1999), and the developed techniques, sensor-based or by visualisation, have proven to be adequate for characterising and predicting the projectile trajectory. The flow around a projectile in unobstructed free flight may with good accuracy be treated as quasi-steady so that single-shot visualisations, using schlieren and shadowgraph principles, suffice to determine the relevant flow characteristics.

One area that appears to have been insufficiently studied is the interaction of projectiles with obstacles in the vicinity of (but not in) the flight path of the projectile. The presence of such obstacles can dramatically change the temporal characteristics of the process, rendering it entirely unsteady. This significantly reduces the suitability of the previously described standard single-shot visualisation techniques, as a single image of the unsteady interaction process will normally not yield sufficient information. Because of the inherent degree of non-reproducibility of the process, series of single images, taken in different experiments, usually do not truly represent the time history of the event. High-speed cine photography, despite its long history (Fuller 1999) has so far yielded only partially satisfactory results, as spatial and temporal resolution of the high-speed recording have so far been mostly insufficient. As a result, highly transient and fully unsteady phenomena such as those occurring during the interaction of an obstacle with the flow field generated by a supersonic projectile (as opposed to the interaction with the projectile itself) are poorly documented and understood. Knowledge of these processes is often anecdotal and procedures and standards involving these processes have often been established without a scientifically thorough foundation.

One problem that highlights the lack of knowledge in this area is the prediction of the behaviour of a projectile passing in close proximity to a solid wall. In such a case the bow shock generated by the projectile may reflect from the wall and then interfere with the projectile and alter its trajectory. This is not only an intriguing problem of supersonic aerodynamics, but represents a configuration that can occur frequently in an urban warfare scenario. The need for a better understanding of such processes is therefore obvious. Anecdotal evidence claims that in such a configuration, the projectile will always deviate from its original path and turn towards the wall.

The most recently introduced new generation of novel high-speed digital video cameras, produced by SHIMADZU Japan, has provided researchers now with the ability to visualise and investigate such processes with unprecedented clarity (Kleine et al. 2005). Combining of the existing expertise in the School in devising high-quality flow visualisation systems (Kleine 2001) and the unparalleled time-resolved recording capability of the high-speed camera has provided material that will eventually yield significant insight into the dynamics of supersonic projectiles flying close to an obstacle. The results may have serious implications for safety standards and regulations regarding urban warfare training and operations.

Experimentation performed at the Australian Army's Small Arms Proofing Range has permitted free flight data acquisition to occur and will be presented on the day with a comparison to replicated supersonic wind tunnel data. The participants must be aware that while all information presented on the day will be as complete as possible this research is, however, still a work in progress.

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Polar analysis of two-dimensional shock interactions in a general class of materials

L. F. Henderson
Home address: 8 Damour Avenue, East Lindfield
Sydney, N.S.W. Australia.

Fax: +61 (612) 9416 7041 E-mail: lfh@s054.aone.net.au

The materials have *convex* equations–of-state (EOS), i.e. those whose EOS's satisfy the *fundamental derivative* $(\partial^2 P / \partial v^2)_s > 0$, where P is pressure, v is specific volume, and s is entropy. Practically all materials in a single-phase state obey this constraint (Bethe 1942), Menikoff and Plohr (1989). Other properties that will be needed include the Gruneisen coefficient Γ, and the square of the non-dimensional sound speed $\gamma \equiv a^2 / Pv$. The relations between Γ and γ are important, for if $\Gamma < \gamma$ (the *modified medium* condition) a shock polar has a unique detachment point Henderson and Menikoff (1998); another constraint ensures uniqueness of the polar sonic point, namely that $h + \frac{1}{2} a^2$ should increase monotonically along the corresponding Hugoniot adiabatic, where h is the specific enthalpy. For a material in a given state (v_0, s_0) it is shown that there is a one-to-one relation between a polar and a Hugoniot adiabatic.

The object of the paper is to bring together scattered results in the literature to build a comprehensive shock polar theory for analysing 2-D shock interactions in gases, liquids and single-phase solids. Some of the most powerful theorems will be discussed. They include the Bethe-Weyl theorem that provides the shock *admissibility conditions*, and the Triple-Shock-Entropy theorem for shock interactions. New expressions will be presented to determine the polar detachment wave angle ω_d, and the detachment angle δ_d. These are given in terms of the initial and final states of the material (v_0, P_0), (v, P), γ, Γ, and the free-stream speed q_0 of the material ahead and relative to the shock. The quantity is a constant for any particular polar, and it will also be expressed in terms of the state and material properties.

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Mesodynamics of shock waves in polycrystalline metals

Y. Horie [1], S. Case [2]
[1] AFRL Eglin AFB
Florida 32542
[2] AWE, Reading
England, RG74PR

Fax: +(1) 850-882-3540 E-mail: horie@eglin.af.mil

Analyses of plane shock waves in metals are traditionally based on the premise of laminar flow, and parallel those for gases and liquids. Even the heterogeneous deformation mechanisms such as dislocation motion and twining, that are unique to crystalline solids, are treated by a homogeneous theoretical framework. There exists, however, strong experimental and analytical evidence for non-laminar flow structure at the grain level on the scale of tens of microns. This paper reflects on the heterogeneous and non-equilibrium plane shock-structure in polycrystalline metals that are revealed by a quasi-molecular dynamic method known as DEM2. This method was initially conceived as a macroscopic extension of MD to deal with not only features such as grain boundary, crystal anisotropy, defects, and inclusions, but also fragmentation and mass diffusion that are difficult to deal with by continuum methods. The most recent development in DEM2 (Case and Horie 2005) includes the Voronoi construction of grain structure and the potential functions that are directly related to the response behavior of continuum mass at the grain level.

DEM2 calculations corroborate experimental observations by velocity interferometry (VISAR), and microscopy on post-shocked samples. These observations are (1) a non-equilibrium distribution of shock-induced particle velocity, (2) an eddy-like rotational of velocity field, (3) dynamic fracture mechanisms that are controlled by the rotational deformation. A conundrum will be discussed in dealing with the above-described heterogeneous and nonequilibrium processes using orthodox continuum thermodynamics.

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Using heterodyne velocimetry in impact experiments

N. C. Holmes
Lawrence Livermore National Laboratory

E-Mail: holmes4@llnl.gov

I will describe the use of an optical heterodyne method for velocity measurements in impact and shock wave experiments. At typical velocities of a few km/s, the Doppler shift of light reflected from a moving body is about 2 GHz. Equipment developed for the communications industry now makes measuring this easy. In fact, we now routinely use this method to measure shock arrival times and wave profiles with sub-ns accuracy with up to 16 channels, and even projectile motion to unprecedented accuracy. I will describe the data analysis method with allows us to achieve low noise, high precision, and high time resolution.

Studies of time dependent drag forces of shock wave loaded solid spheres

T. Saito[1)], M. Sun[2)] and K. Takayama[3)]

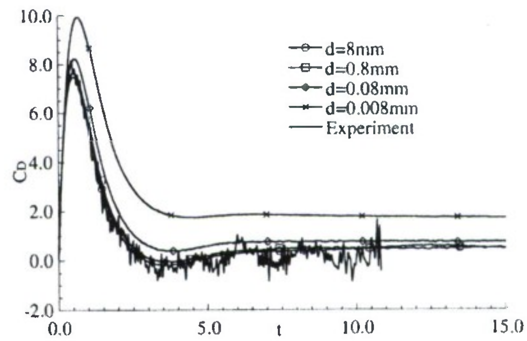
[1)] Mechanical Systems Engineering
Muroran Institute of Technology
27-1 Muroran, 050-8585Japan.
[2)] Center for Interdisciplinary Research
Tohoku University
6-3 Aramaki, Aoba-ku, Sendai, 980-8578 Japan
[3)] Tohoku University Biomedical Engineering Research Organization
2-1-1 Katahira, Aoba-ku, Sendai, 980-8577 Japan

Fax: +(81)143-46-5353 E-mail: saito@mmm.muroran-it.ac.jp

One of the important subjects of high-speed gasdynamics is the two phase flows of gaseous media loaded with small solid particles (dusty gases). The research is directly linked to many important and practical applications and numerous works on the subject have been reported over the last several decades (Rudinger 1964, Miura and Glass 1982, Igra and Ben-Dor 1988).

Recognizing the importance of the subject, our group has been involved in the studies of dusty gas flows both experimentally and numerically (Igra and Takayama 1991, Saito 2003). Experimental works of this subject are not as easy as the one with pure gases. Generation of uniform flow conditions in a dusty gas is difficult and, accordingly, the quantitative measurements of flow parameters are difficult, too. Flow visualizations also are difficult with the conventional methods due to existence of the solid particles. Therefore, computational fluid dynamics (CFD) has been a useful tool to investigate the nature of the two phase flows

One of the crucial parts of studying dusty gas flows with CFD is the drag force modelling through which the interaction between gas and solid particles are defined. Usually one of steady drag force formulae for a spherical particle is used. It may be either a theoretical or empirical one. The effect of differences in drag force models is investigated (Saito et al. 2003) and some of the results will be presented. Our recent studies both experimental and numerical showed that time dependent drag coefficient exhibits even negative values when a shock wave passes over a sphere as shown in the figure. This was attributed to complex wave interactions that take place around the object (Sun et al. 2005). The results suggest us that the employment of the steady drag coefficients may lead us to erroneous results for extremely time dependent phenomena. Discussions on this subject will also be made.



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Shock collisions in 3D using the Regularized Smoothed Particle Hydrodynamics method (RSPH) for cylinder symmetry

M. Omang [1), 2)], S. Børve [2)], J. Trulsen[2)]
[1)] Norwegian Defence Estates Agency
P.O. Box 405, NO-0103 Oslo
[2)] Institute of Theoretical Astrophysics
University of Oslo
P.O. Box 1029 Blindern, NO-0315 Oslo

Fax: +47 23 09 31 76 E-mail: momang@astro.uio.no

In Omang et al. (2005) we presented a new approach to the use of the numerical method Smoothed Particle Hydrodynamics (SPH) in situations were spherical or cylindrical symmetry applies. SPH is a numerical method for studying continuous fluid flows in which the fluid is represented by a set of interacting particles. Each particle has its own set of properties. A kernel function of characteristic width (smoothing length) h is used to describe the size and shape of each particle and the interaction between the particles. In Omang et al. (2005) kernel functions and corresponding equations of motion valid for systems with cylindrical and spherical symmetries were derived. Preliminary results showed that the new method is capable of solving typical benchmark tests to a high degree of accuracy also close to the axis of symmetry. In Omang et al. (2006) the method is further developed, and alternative kernel functions suggested, which are capable of increasing the computational speed. Based on the previous work (Omang et al. 2005, Omang et al. 2006), we here present a new set of applications, in which the method is further challenged.

The first example shows the release of a high pressurized, dense torus with a pressure and density ratio of 33, relative to the surrounding atmospheric gas. The torus has minor and major radii of 0.5 and 1.0, and a symmetry plane at z=6.0 (computational length units). The ratio of specific heat capacities is 1.4. In the flow-field, a cylindrical object of radius 1 is positioned along the symmetry axis from z=3 to z=5. When the torus is released, an expanding cylindrical shock is formed. The shock propagates outward and eventually also reaches the symmetry axis where it is reflected and the shock direction reversed. This leads to a characteristic shock reflection pattern formed on the symmetry axis. The object introduced in the flow field is observed to further complicate the reflection pattern, as the shock is reflected both from the top and side of it. In Figure 1, we have plotted the density a) and pressure b) color plot for time, t=0.8. The location with the highest density is observed to be were the reflected shock from the object interacts with the shock reflected from the symmetry axis. For the pressure plot, the highest pressure level is observed in the corner between the symmetry axis and the upper wall of the object.

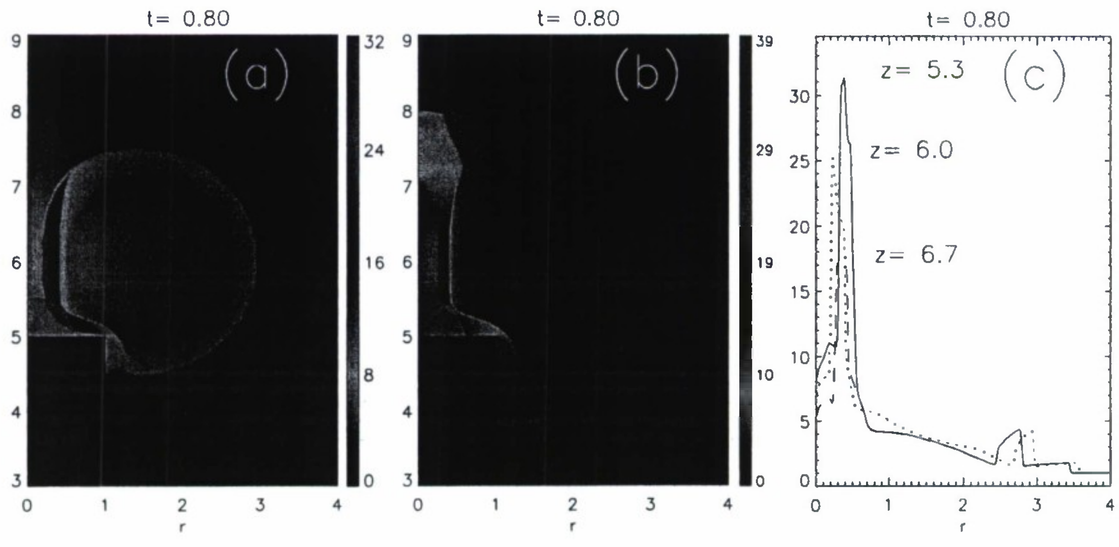

Figure 1 Density a), pressure b) and density cross section c) for z=5.3, 6.0 and 6.7 at t=0.80

In Figure 1c) we have also plotted the density profile along the radial direction for three different heights, corresponding to z=5.3, 6.0 and 6.7. A prominent density peak is observed for all three heights, with a maximum value obtained for z=5.3. The average particle number in this example was 376400 particles, for a computational domain of (r, z) = {(0,4),(0,9)} .

In our second example we look at a cylindrical shock tube partly blocked by a coaxial cylinder with radius of 1 and height of 2. The driver section is relatively short, with a diaphragm at z=1.8. Removing the diaphragm at t=0, a coaxial shock is formed, propagating along the z axis. The initial conditions are the same as for the Sod benchmark test (Sod 1978). The initial pressure and density in the driver section are both 1.0, whereas in the driven section, the density is 0.125 and the pressure is 0.1. In Figure 2a) and 2b) we present results for the density and pressure at t=1.4. When the shock reaches the end of the coaxial cylinder the shock expands creating a vortex structure at the corner. A reflection pattern is further observed as the shock reflects from the symmetry axis. In Figure 2c) a cross section plot for z=2.3, 3.0, and 3.7 illustrates how the vortex influences the density profile. In this example the average particle number was 102300 for a computational domain of (r, z) = {(0,4),(0,9)}.

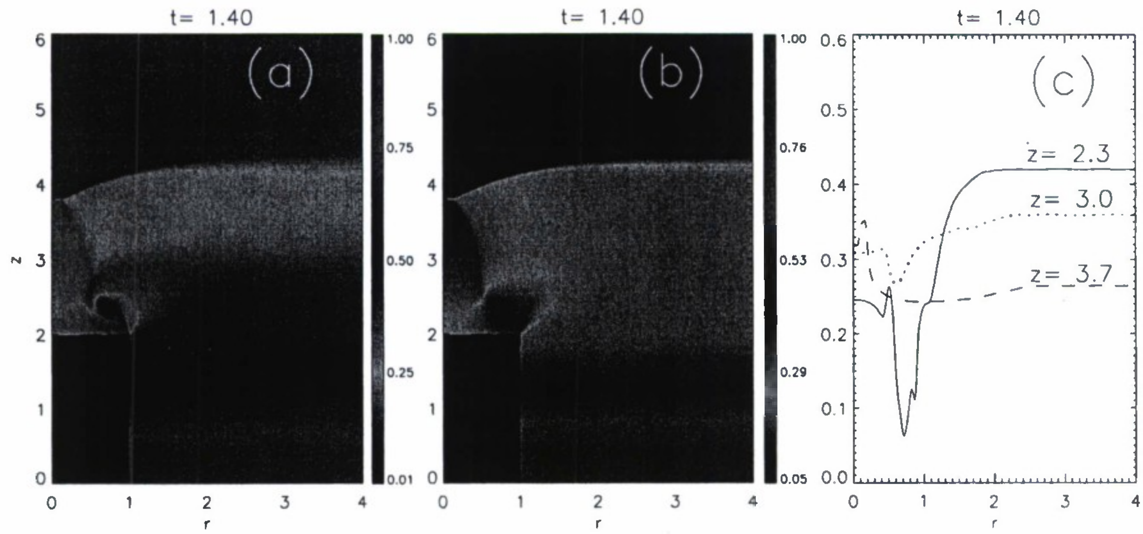

Figure 2 Density a), pressure b), and density cross section c) for z=2.3, 3.0 and 3.7 at t=1.40

For both numerical examples presented in this work we observe a high degree of accuracy, with both shocks and rarefaction waves resolved to a high degree. We also observe that the numerical noise level along the symmetry axis is low, in accordance with our preliminary results (Omang et al. 2005, Omang et al. 2006).

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Organised motions in a supersonic mixing layer

L. Janicke, S. L. Gai
School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia

E-mail: s.gai@adfa.edu.au

The paper describes an investigation into organised motions that exist in a supersonic boundary layer and a mixing layer formed by a splitter plate separating Mach 2 and Mach 3 flows.

The main feature of such a flow is the flow deflection towards the Mach 3 flow, thus producing an asymmetric mixing layer. Associated with this flow deflection are a compression shock on the Mach 3 side and an expansion on the Mach 2 side of the mixing layer. The characteristics of the flow both upstream and downstream of the splitter plate trailing edge have been investigated using schlieren photography and pitot surveys.

Typical inclined structures, previously observed in supersonic boundary layers and wake flows (Gai, Hughes, and Perry 2002) were again evident. The transition from boundary layer to mixing layer through the compression shock and expansion did not distort or diminish the strength of these structures nor markedly change their characteristics. The structures seemed to maintain their integrity as they convected downstream for at least upto 80 trailing edge thicknesses.

Just downstream of the trailig edge, presence of a distinct vortex street was noted. The vortex street was less organised and the vortices did not exhibit the same regular alternate shedding seen in the wake.

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Boundary layer chemistry and surface heat flux at interplanetary mission speeds.

N.R. Mudford [1], S.L. Gai [1] and A.T. Goldsworthy [2]
[1] School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia
[2] Royal Australian Navy.

Fax: +(61) 2 6268 8337   E-mail: n.mudford@adfa.edu.au

At space vehicle re-entry flight speeds in the Earth's atmosphere, significant molecular dissociation occurs in the shock layer about the forward region of the vehicle. At interplanetary mission re-entry speeds, significant ionisation may also occur. These reactions convert sensible enthalpy into chemical enthalpy in the inviscid regions of the shock layer. Chemical enthalpy in a gas sample may contribute to surface heating only if it is released by atomic or ionic recombination prior to heat exchange between the gas sample and the surface. Recombination may occur via homogeneous (gas phase) or heterogeneous (surface catalysed) reaction pathways in the boundary layer where the lower temperatures encourage such recombination.

Experimental results reported earlier (Mudford et. al. 1997) indicate that almost all the chemical enthalpy is released and contributes to surface heat flux in bluff body reacting flows in the ANU's T3 Free Piston Shock Tunnel (FPST) (Stalker, 1972) operating in the reflected mode at specific total enthalpies up to 20 MJ/kg. Analysis showed that homogenous recombination was the responsible mechanism.

Experiments to be reported here were carried out in air and nitrogen flows over a model of the Viking spacecraft using T3 in the straight through mode (Stalker and Mudford, 1992) over an expanded range of total enthalpies from 7 MJ/kg to 80 MJ/kg. Preliminary analysis shows that, up to total enthalpies of 50 MJ/kg, the flows behave in a similar fashion to their reflected mode counterparts, i.e. the bulk of the chemical enthalpy is retrieved and contributes to surface heat flux. At 80 MJ/kg, however, very little of the chemical enthalpy is retrieved. That is, both the homogeneous and heterogeneous boundary layer chemical reactions are frozen. The 80 MJ/kg flow results are shown in Figure 1. The measured heat fluxes of the present results, shown as open symbols, cluster around the frozen boundary layer chemistry (dashed) line, well below the equilibrium chemistry heat flux levels.

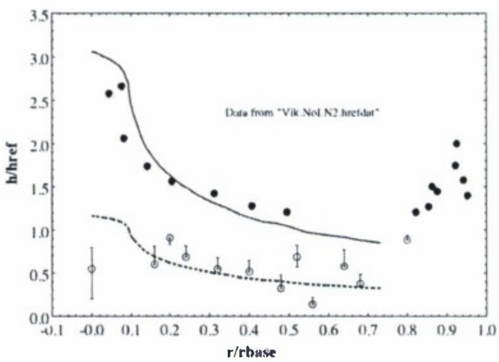

Figure 1. Normalised surface heat flux on Viking. Solid symbols: Shih and Gay's experiments (1985); open symbols: present work; solid line: equilibrium boundary layer chemistry; dashed line: frozen boundary layer chemistry.

Inger (1963) shows that adherence or otherwise to equilibrium boundary layer chemistry depends on the relevant Damköhler number. An analysis of the present data, against Inger's criteria, will be presented in the paper.

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Re-entry body drag – shock tunnel experiments and CFD calculations compared

A. K. Stumvoll [1)], R. R. Boyce [2]
[1)] Lehrstuhl für Flugantriebe – TUMünchen
D-85748 Garching, Deutschland
[2)] School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia

E-mail: r.boyce@adfa.edu.au

Hypervelocity impulse facilities have an important role in the development of hypersonic flight vehicles and their propulsion systems. Those facilities, such as free piston shock tunnels, are the only ground based option to generate such high-enthalpy flows as associated with hypersonic flight. Accomplishable test periods are usually of the order of milliseconds. Conventional measurement methods cannot be applied due to the force equilibrium rarely being established within the short duration of the test flow when measuring drag on a test model in a free piston shock tunnel. To overcome this problem, the so-called Stress Wave Force Measurement Technique was developed by Sanderson and Simmons (1991). This technique has recently been applied in the T3 shock tunnel at the Australian National University to measure axial drag on a blunt body, representing the nose shape of a typical re-entry vehicle. The hyperboloid test model, depicted in Figure 1, was 90 mm long and had a base diameter of 105 mm. Experiments were performed in argon, nitrogen and air. The test flows had specific stagnation enthalpies between 3.5 MJ/kg and 14 MJ/kg and Mach numbers varying from 6 to 13. The associated measured drag forces ranged from 280 N to 370 N. Figure 2 shows sample nozzle reservoir pressure and experimentally-determined drag time histories. The results obtained from the measurements are compared with viscous CFD simulations for each experiment. Results from the test runs and CFD-calculations were found to be of very good consistence. Apart from the low enthalpy argon condition, deviations lay within a 10%-range. Best results were obtained at high enthalpy flows with practical test periods being less than one millisecond. Figure 3 shows a sample CFD-generated Mach number contour map. The full paper will describe the experimental and numerical methods and present the results in full.

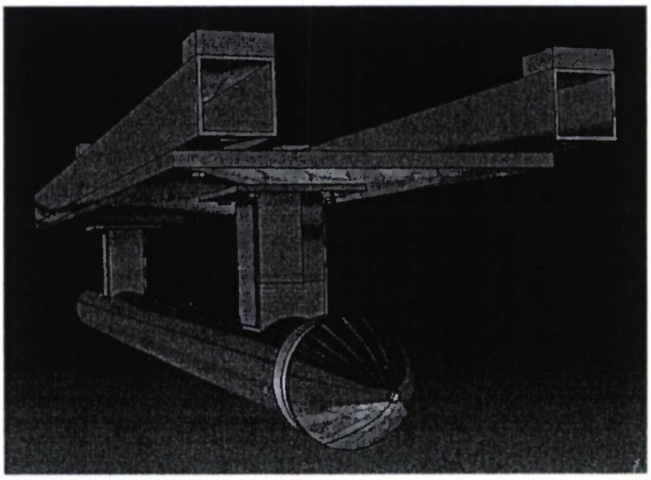

Figure 1: The experimental test article – hyperboloid re-entry body

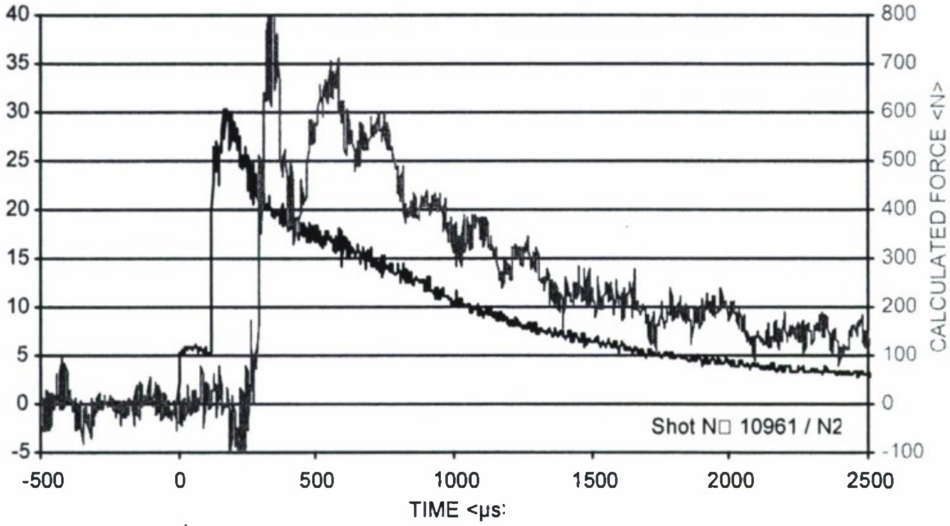

Figure 2: Sample nozzle reservoir and experimentally-determined drag time histories

Figure 3: Sample CFD-simulation (Mach number contours) of the re-entry body flowfield

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Nonequilibrium He-H_2 Flowfield Behind Shock Wave over Blunt Body

Michiko Furudate [1], In-Seuck Jeung [1], Shingo Matsuyama [2]
[1] Seoul National University
[2] Japan Aerospace Exploration Agency

Fax: +(82)-2-887-2662 e-mail: furu@snu.ac.kr

Surface recession data obtained along the Galileo Probe entry flight trajectory[1,2] have not been completely reproduced by Computational Fluid Dynamics (CFD) yet. The flight data has shown a low surface recession in the stagnation region, and a large recession in the downstream frustum region compared with the pre-flight predictions.[3] The predictions were made assuming thermochemical equilibrium. The purpose of the present paper is to investigate how the thermochemical nonequilibrium phenomena affect on the flowfield in the Galileo Probe entry flight by CFD.

The governing equations are the axisymmetric Euler equations, consisting of the global mass, the momentum, the total energy, the species mass, and the electron-vib-rot energy conservation equations. We consider 7 chemical species, H_2, H_2^+, H, H^+, He, He^+, and e. Employed chemical reaction processes and those reaction rate coefficients are summarized in Table.1. Collisional energy exchange processes between heavy particle and electron translational energies, and between heavy particle translational and vib-rotational energies are considered. A flowfield around the Galileo Probe geometry is calculated for the conditions at the altitude of 170 km of its entry flight. The gas is a mixture of 86.4% H2-13.6% He. The freestream velocity, density, static pressure, and temperature are 46.256km/s, 7.03×10-5kg/m^3, 41.2Pa and 165.8K, respectively. From the obtained steady solution of the flowfield, a radiative heat flux at the stagnation point is calculated. The absorption coefficients are evaluated by a line-by-line method using the 500 wavelength points from 750 to 15000 Å for the species H and H^+.

The calculated temperature contours are shown in Fig. 1. One can see the wide high translational temperature region behind of the shock wave, where the electron-vib-rot temperature stays lower. As seen in the mole fraction contour in Fig 2, in this region, atomic hydrogen is abundant, which is produced by the dissociation reaction. Electron mole fraction contours indicates the existence of the un-ionized region behind shock wave. The calculated value of radiative heat flux at the stagnation point is 126MW/m^2. Despite the area of ionization zone is much narrower than the reference calculation assuming thermo-chemical equilibrium, we obtain only insignificant differences in the radiative heat flux.

Table 1 Chemical reaction processes and references for reaction rate coefficients.

	Ref.
$H_2 + M \leftrightarrow H + H + M$	4
$H + e \leftrightarrow H^+ + e + e$	5
$He + e \leftrightarrow He^+ + e + e$	4
$H_2^+ + e \leftrightarrow H + H$	6
$H_2 + h\nu \rightarrow H_2^+ + e$	7,8
$H_2 + h\nu \rightarrow H + H^+ + e$	7,8

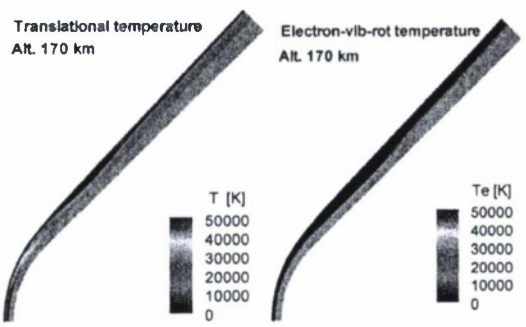

Fig. 1 Temperatures contours.

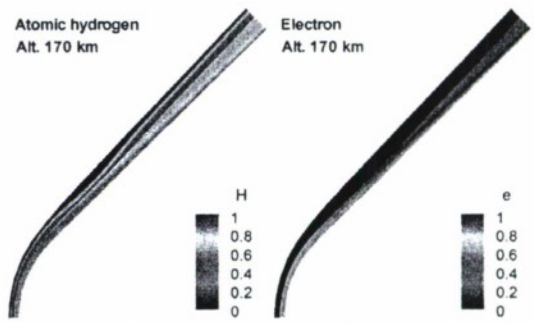

Fig. 2 Mole fraction contours of electron and atomic hydrogen

Acknowledgement

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An experimental investigation of the effect of shoulder radius on the hypersonic laminar near wake flow

S. O'Byrne [1)], P. M. Danehy [2)] A.F.P. Houwing [3)]
[1)] School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia
[2)] Advanced Sensing and Optical Measurement Branch
NASA Langley Research Center, Virginia, USA
[3)]Physics Department
Australian National University
Canberra, Australia, 0200

Fax: +(61) 262688276 E-mail: s.obyrne@adfa.edu.au

The flowfield in the near-wake of re-entry vehicles is important to re-entry aerothermodynamics because of the potential for creating vehicle instability due to transition in the free shear layer downstream of the corner (Chapman et al. 1958), and the adverse effects from the relatively high heat flux near the re-attachment point of the separated flow. As the thermal shielding in the rear of re-entry vehicles is relatively low, and sensitive payload tends to be stored in the rear of the vehicle, there is potential for payload and instrumentation damage if these factors are not accounted for in the vehicle design.

This paper presents an investigation of the effect of shoulder radius on the flowfield around a sting-mounted sharp cone with a 6-mm downstream step between the model and its mount. The wake flow for radius-to-step-height ratios of 1/60, 1/6, 1/2 and unity are investigated using planar laser-induced fluorescence visualisation, flow tagging velocimetry and heat flux measurements.

Comparisons of the four test cases will be presented, showing the differences in the general character of the flowfield, normalised heat flux and velocity distributions. Significant differences in the near-wake flowfield are apparent, mostly caused by changes in the lip shock at the rear corner of the flow, and possibly also due to transition in the free shear layer downstream of the corner. Heat flux measurements show that the corner with the smallest radius has a significantly different heat flux distribution to the other three configurations, showing a much sharper rise in heat flux on the sting surface than the other three configurations, which all have similar growth rates and peak value. The comparison is shown in Figure 1. The combination of flow visualisation and heat flux measurement provides useful extra information for postulating mechanisms for the difference in measured heat flux between these cases. Results are compared to the expected results from laminar two-dimensional computations.

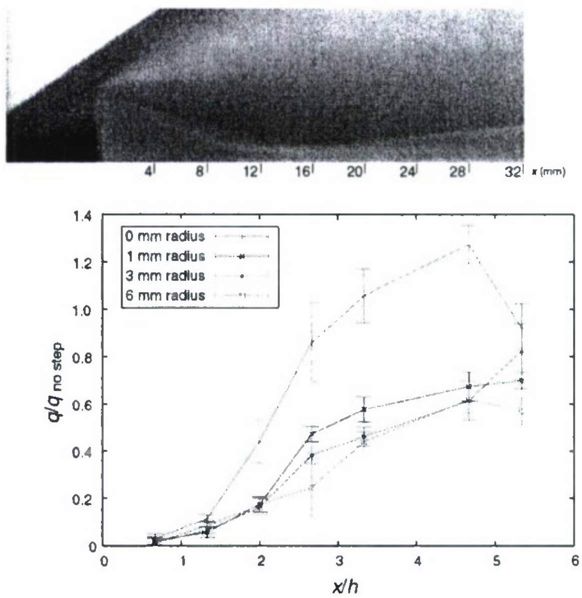

Figure 1: Comparison of normalised heat flux distributions for four values of shoulder radius.

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Tomographic reconstruction of shock layer flows

R. Faletič [1], A.F.P. Houwing [2], R.R. Boyce [3]
[1] Forum for European-Australian Science and Technology Cooperation
[2] Department of Physics, The Australian National University
[3] School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia

Fax: +(61) 2 6125 7885 E-mail: Rado.Faletic@anu.edu.au

The tomographic reconstruction of hypersonic flows faces two challenges. Firstly, techniques used in the past, such as the Direct Fourier Method (DFM) (Morton 1995, Gottlieb et al. 1998) or various backprojection (Kak et al. 2001) techniques, have only been able to reconstruct areas of the flow which are upstream of any opaque objects, such as a model. Secondly, shock waves create sharp discontinuities in flow properties, which can be difficult to reconstruct both in position and in magnitude.

This paper will present a reconstruction method, utilising geometric ray-tracing and a sparse matrix iterative solver (Paige et al. 1982), which is capable of overcoming both of these challenges. It will be shown, through testing with phantom objects described in imaging and tomographic literature, that the results are comparable to those produced by the DFM technique. Finally, the method will be used to reconstruct three dimensional density fields from interferometric shock layer images, with good resolution (Faletič 2005).

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Initial studies on the performance of shock vector control as a method for fluidic thrust vectoring using a small-scale experimental rig

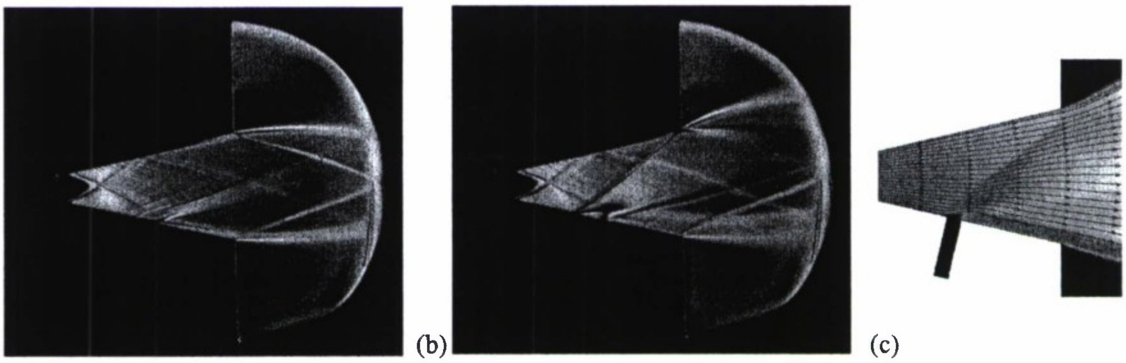
A. J. Neely, Z. Chia, S. Chittleborough, H. Kleine
School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia

Fax: +(612) 6268 8276 E-mail: a.neely@adfa.edu.au

Fluidic thrust vectoring encompasses non-mechanical fluid based methods for vectoring a jet exhaust. This work has received the most interest from those intending to apply it to either gas turbine exhaust nozzles or rocket exhaust nozzles (Deree 2003). Shock vector control uses the injection of a secondary gas stream, from the wall of diverging section of the nozzle, to induce an oblique shock wave across the nozzle exit. The core flow which crosses this oblique shock is turned towards the shock thus vectoring the exit flow. The vectoring angle can be controlled by changing the oblique shock angle which is itself controlled by the mass flow of the secondary injection.

A small scale test rig has been designed and manufactured to enable the investigation of shock vector control as a method of fluidic thrust vectoring (Chia 2005). The rig consists of small two-dimensional converging-diverging supersonic nozzle which is supplied with air from a bank of four G-size industrial gas bottles. An additional gas bottle feeds the secondary injection port which is formed by a slot in the wall of diverging section of the nozzle. The nozzle block is fitted with side windows to enable schlieren visualisation of the flow both in the nozzle and downstream of the nozzle exit.

The initial experimental program was accompanied by a numerical investigation (Chittleborough 2005) of the flow field and the results of the two were found to compare well. The initial tests were performed using cold air for both the primary and secondary flows. A range of primary nozzle pressure ratios and secondary injection pressures were investigated. It was found that the maximum vectoring angle was achieved with a secondary injection pressure sufficient to cause impingement of the induced shock at the downstream end of the opposite wall of the nozzle. Beyond this angle the reflected shock begins to deflect the flow back towards the centerline.



(a) (b) (c)

Figure 1. schlieren images of the nozzle flow with (a) no secondary injection, (b) optimum secondary injection. (c) CFD simulation of the nozzle flow with optimum secondary injection.

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The art of shock waves and their flow fields

G.S Settles [1], H. Kleine [2]
[1] Gas Dynamics Laboratory
Penn State University
University Park, PA 16802, USA
[2] School of Aerospace, Civil & Mechanical Engineering
University of New South Wales
Australian Defence Force Academy
Canberra ACT 2600, Australia

Fax: +(61) 6268 8276 e-mail: h.kleine@adfa.edu.au

Flowing media such as water and wind are primary elements of the world we live in, and as such they have always fascinated mankind. From the movement of waves in the ocean, to the impact of rain droplets on a surface, down to the pattern that milk creates when poured into coffee – flow patterns like these are part of our daily life. We may not always notice the beauty and aesthetic structure of these patterns as the encountered beauty is often elusive: most flow processes appear too rapidly to be properly perceived by the naked human eye. High-speed photography has greatly contributed to opening our eyes to such phenomena by 'freezing' rapid motions so that the structures of the moving objects can be viewed at leisure. Before photographic records became available, the recording of the patterns lay often in the hands of artists – people with extraordinary observation skills and imagination, some with and some without scientific ambitions and interests. A prime example for the former category is Leonardo da Vinci, whose sketches of vortex structures behind area changes in channels show an amazing amount of detail, even for today's standards. One of the many members of the latter group is the Japanese artist Hokusai – his woodblock print of breaking waves with a distant Mt. Fuji in the background, arguably one of his best-known works, is but one example of an artist's way of flow visualization. The link between art and physics is quite obvious in this case – in fact, it is a perpetual link that has existed throughout the centuries, even though one often only recognizes this in retrospect (Shlain 1991).

The link is not quite as obvious when it comes to the visualization of compressible flows. The basic structure of the motion of the aforementioned droplets and waves can be observed without special equipment if one has an acute sense of vision, but compressible flows not only move considerably faster but they usually also involve a transparent medium rendering the motion entirely invisible. Only with special scientific equipment and observation techniques is it possible to obtain images of these flows – therefore the visualization of shock waves and other phenomena in compressible flow can typically not be done by someone without an adequate scientific or technical background. In other words, the visual representation of such flows is primarily done by the scientist, not the artist. As such, the results of scientific flow visualization have often remained somewhat obscure – after all, the obtained images are primarily measurement records. In recent years, however, initiated by scientists who realized the artistic potential of their work, these images have often left the laboratory from which they came and found themselves displayed in exhibitions and galleries, admired not for the physical content but for their visual impact.

This paper will try to address some fundamental questions such as: Where does the aesthetic appeal of some shock wave imagery come from ? What makes these scientific measurement records pieces of art ? Which basic elements of art have shock wave visualizations and artworks such as paintings and sculptures in common ?

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INTERNATIONAL SHOCK WAVE INSTITUTE (ISWI)

Meeting held at ADFA, Canberra, Australia

March 2, 2006, 11h15

Agenda

1. Items of business from the floor

2. Guidelines for the ISWI.
   - Review of previous suggestions
   - Current implementation
   - Developments for 2006-2007

3. Web site report

4. Other communications to members

5. Conference liaison

6. Financial report

7. Recruitment of members,
   - Report on current membership
   - How to recruit
     - International committee-recruiting officer ?
     - Local (national) members (eg appoint one senior member?)

8. Nomination of Fellows
   - Suggestion of nominated fellows
   - Guidelines for nomination
     - What defines a Fellow?
     - What are the obligations of a Fellow?
     - Are they to be already members of ISWI? Or by invitation?
   - What membership fees will apply?

9. General business.