EXPANDING THE REALM OF POSSIBILITY

Total Impulse Gauge (TIG) for Measurements of Multi-Phase Flows in Blast Waves

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  - TIG development sponsored by the Naval Surface Warfare Center, Dahlgren Division, Contract No. N00178-00-C-1020, TDL18.

Outline

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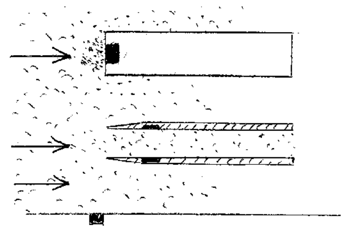
- Approach
- Gauge Construction and Characterization
- Applications and Results
  - Reactive Material Impact
  - Aluminized Explosives
  - DIME (Dense Inert Metal loaded Explosive)
- Summary and Recommendations

Introduction

- **Multi-phase flows in explosive blast waves:**
  - **Condensed phase particulates entrained in high velocity gas of an expanding blast wave.**
    - “Dusty” flows in nuclear air blast.
    - High velocity inert or reaction product particulates accelerated by the expanding detonation reaction product gases from inert loaded explosives or from friable case materials.
  - **Potential to significantly increase the impulsive loads imparted to a target over and above the gas phase loads alone.**
- **Simultaneous measurements of gas phase pressure and impulse and condensed phase impulsive loads, as well as differentiating between them are problematic, particularly for *free-field* probes.**
  - *Free-field probe measures a fundamental property or characteristic of the flow, as opposed to the effects of the flow.*

Introduction (cont'd)

- **GREG/SNOB Gauges:**
  - **GREG:** $P_G = P_0 + \phi\, C_G$
  - **SNOB:** $P_S = P_0 + \phi\, C_S$
  - **Overpressure:** ΔP



P_0 = Gas Stagnation Press; C_G, C_S = Dust Reg. Coeff.

IF C_G, C_S = 1, 0 *AND* $u_a = u_p$ (Ideal Case), *THEN:*

Air: P_S, $\Delta P \rightarrow M$, $Q = ½\, \rho_a u_a^2$

Dust: P_G, P_S, $Q \rightarrow \phi = \rho_p u_p^2$, $K = \rho_p / \rho_a = \phi / 2Q$

- **C_G, C_S dependent on *M* and dust particle size distribution. Flow conditions need to be known explicitly to calibrate *free-field* probes.**

Approach

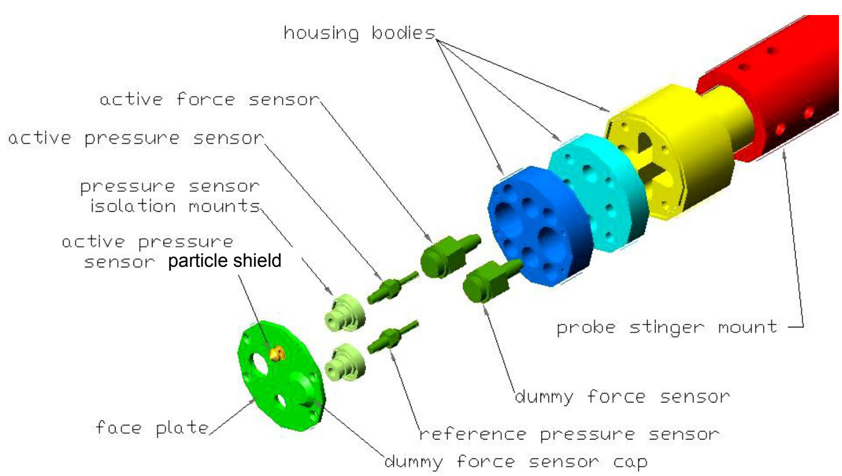
- Total Impulse Gauge (TIG) Concept:
  - Simultaneously measure both the gas phase pressure/impulse and condensed phase impulsive loads at a point (or points) on a *target* subjected to the multiphase flow.
    - *i.e.,* C_G, C_S are dependent on the target itself, not the probe body.
  - Quantitatively differentiate between gas phase loads and condensed phase loads.
    - $P_S = P_0$ = Stagnation Press. at measurement point (effective C_S must be zero).
    - $P_G - P_S = \phi$ at measurement point.
  - Evaluate target dependent effects of flow as opposed to a fundamental property/characteristic of the flow itself.

Approach (cont'd)

- Constraints
  - Based on commercial off the shelf (COTS) transducers
    - Endevco or Kulite piezoresistive pressure transducers for severe thermal environments.
    - PCB 208 series piezoelectric force/impact transducers.

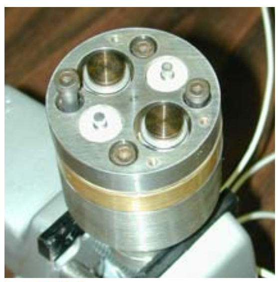
Gauge Construction

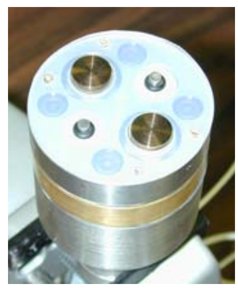
- TIG Gauge Components



Gauge Construction (cont'd)

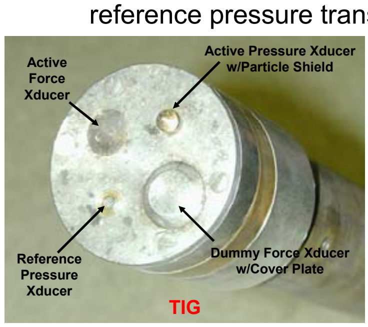
- TIG Gauge Assembly (Mod 3)





Gauge Characterization

- **Shock Tube Testing**
  - **Low pressure tests in PVC tubes with pistol blanks and rifle cartridges for drivers.**
    - Evaluate and optimize pressure transducer particle shield.
    - Evaluate force transducer performance relative to active and reference pressure transducers in "clean" air shocks.



Mod 3 TIG w/ Reference Pressure Xducer installed

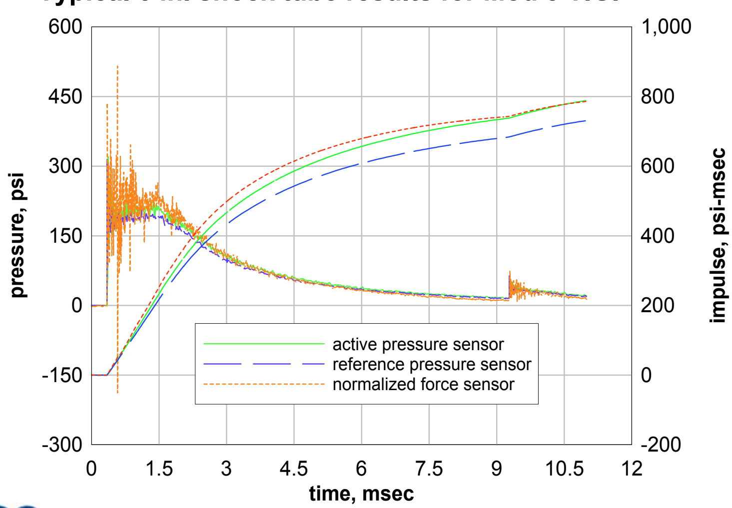
Particle Shield Configurations

Gauge Characterization (cont'd)

- **Shock Tube Testing**
  - **High pressure tests in ARA 6 in. gas driven shock tube.**

Gauge Characterization (cont'd)

- **Shock Tube Testing**
  - **Typical 6 in. shock tube results for Mod 3 TIG.**

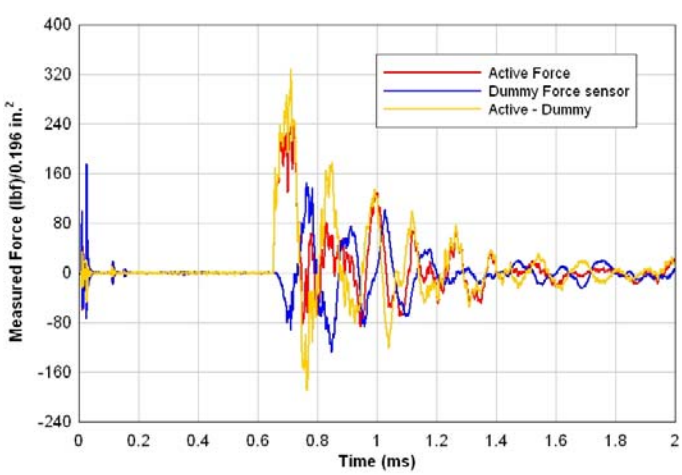


Gauge Characterization (cont'd)

- **Shock Tube Testing**
  - **Observations on Mod 3 TIG gauge performance**
    - Effects of active pressure transducer particle shield on indicated pressure compared to measured reference pressure and force appear to decrease as shock pressure and impulse increased. Indicated impulse values from each transducer were within ≤10% of each other.
    - Some leakage of pressure into the dummy force sensor cavity was observed in the higher pressure, longer duration 6 in. shock tube tests.

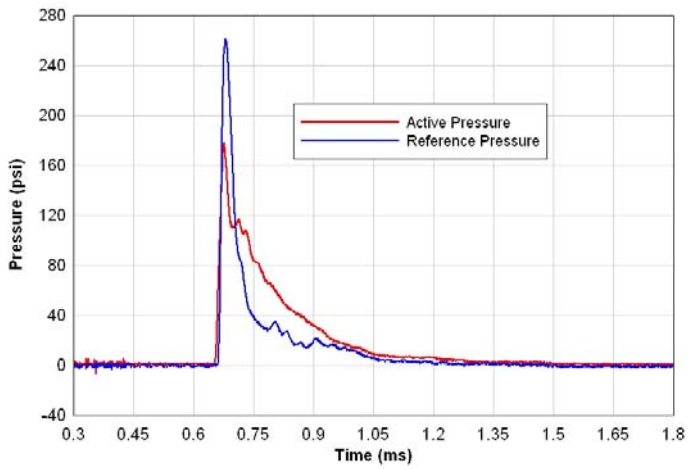
Gauge Characterization (cont'd)

- **Data Analysis**
  - Force sensors from free-field air blast test (Mod 0 TIG).



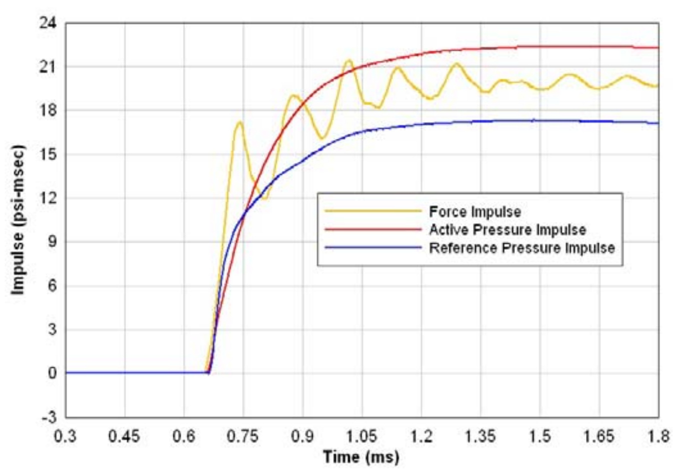
Gauge Characterization (cont'd)

- **Data Analysis**
  - Pressure sensors from free-field air blast test (Mod 0 TIG).



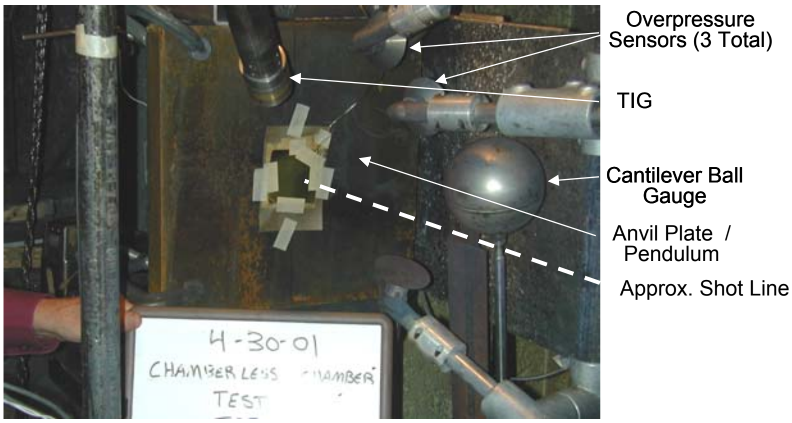
Gauge Characterization (cont'd)

- **Data Analysis**
  - Impulse from free-field air blast test (Mod 0 TIG).



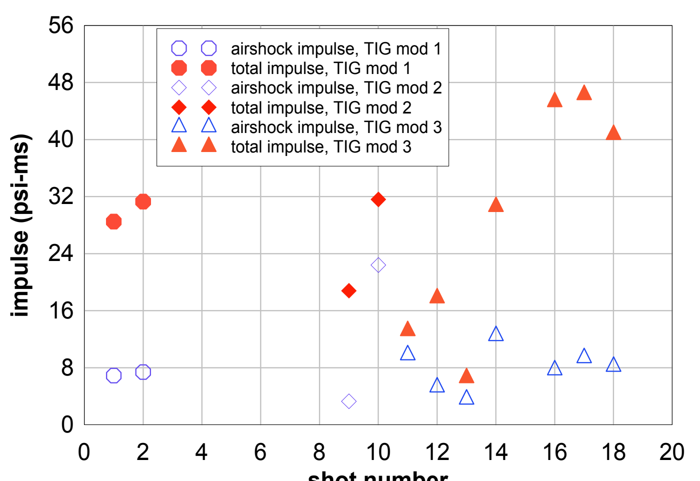
Applications and Results

- Reactive Material Impact Study (NSWCDD)
  - TIG gauge used to evaluate multi-phase flow effects in the backsplatter produced by high velocity impact of reactive material projectiles on a steel plate.



Applications and Results (cont'd)

- Reactive Material Impact Study (NSWCDD)
  - Representative results

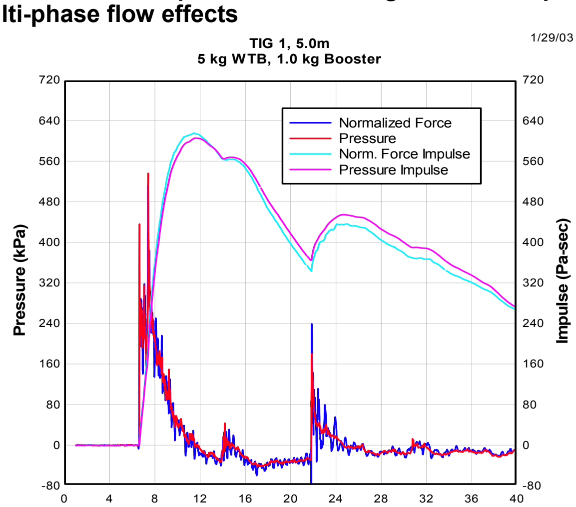


Applications and Results (cont'd)

- Aluminized Explosives (TSWG)
  - Mod 3 TIG in mounted in wall

Applications and Results (cont'd)

- Aluminized Explosives (TSWG)
  - Result—force and pressure sensors give same response, no multi-phase flow effects



Applications and Results (cont'd)

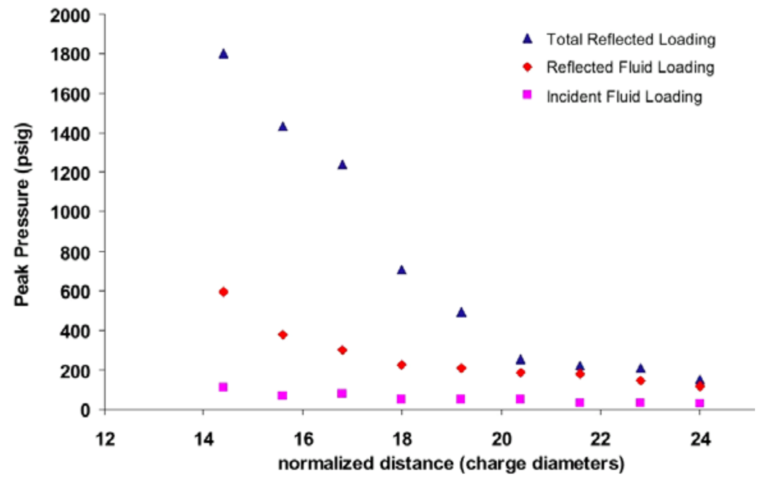
- **Aluminized Explosives (TSWG)**
  - **Observations on gauge performance:**
    - Low frequency baseline drift observed for both the active and dummy force sensors—thermal effects a possibility (thermal environment was severe), but unlikely, especially for the dummy sensor.
    - Electrical grounding of the normally isolated force sensors to the gauge body via conductive gases in the explosive fireball, and/or build-up of electrical charge on the gauge body itself were thought to be the source.
    - Electrically grounding the gauge body at a point near ground zero significantly reduced baseline shifts, but did not completely eliminate them.

Applications and Results (cont'd)

- **Aluminized Explosives (NSWCDD)**
  - **Mod 3 TIG mounted in 3 ft wide X 8 ft high steel plate**
  - **Tests at variable distance from aluminized explosive cylinders, 2.5 in. dia. x 2.5 in. lg.**

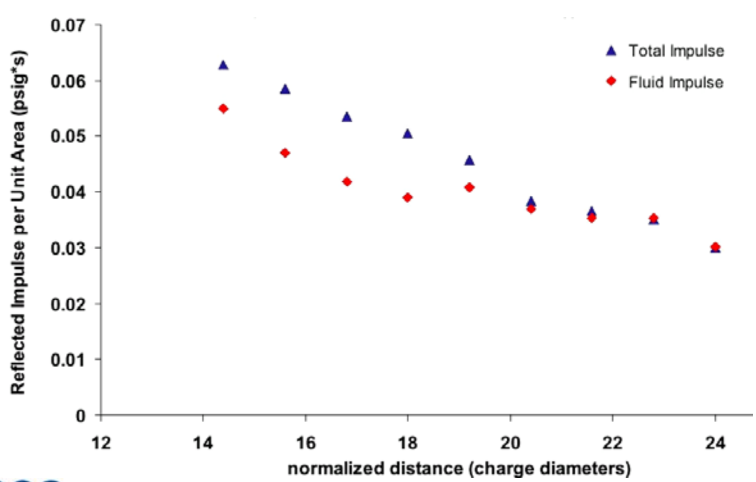
Applications and Results (cont'd)

- **Aluminized Explosives (NSWCDD)**
  - **Peak pressure results summary**



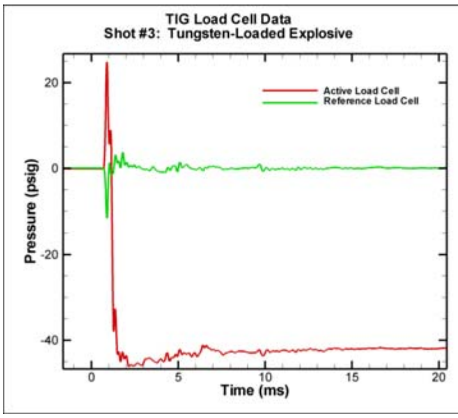
Applications and Results (cont'd)

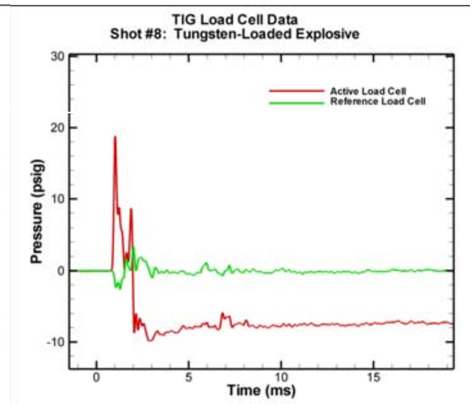
- **Aluminized Explosives (NSWCDD)**
  - **Impulse data summary**



Applications and Results (cont'd)

- DIME—Dense Inert Metal-loaded Explosives (NSWCDD)
  - High explosives containing up to 85 wt. % tungsten powder.
  - Enhanced impulsive loads over a limited area.





Applications and Results (cont'd)

- DIME—Dense Inert Metal-loaded Explosives (NSWCDD)
  - Observations on gauge performance
    - Baseline shift after initial shock was consistently present on the active force sensor only.
    - Grounding, charge build-up, etc. considered—but no ill effects on dummy sensor were apparent.
    - Impact of dense, high velocity particles on the hardened steel impact surface of the active sensor may have over-ranged and damaged the sensor in an earlier test.
    - Subsequent attempts to "soften" the impact surface were not effective—was damage done by then?

Summary and Recommendations

- **Current TIG Development Status**
  - **The current TIG design has been successfully demonstrated in several applications.**
    - The piezoelectric force transducers have performed well, and exhibit frequency response and fidelity comparable to the piezoresistive pressure transducers.
  - **Although not fully optimized, the data has been physically consistent, and most sources of anomalous performance have been identified, and fixes either implemented or planned.**

Summary and Recommendations (cont'd)

- **Future Development Requirements**
  - **Optimize particle shield configurations**
    - Test results indicate that configuration specs will be dependent on the pressure levels to be measured.
  - **Isolate dummy force transducer from any pressure effects**
  - **Resolve force transducer electrical grounding issues**
  - **Evaluate effect of force sensor impact surface/particle interactions.**
    - Are collisions elastic, inelastic, in-between?
    - Variation of impact surface materials to mimic target surface properties.