Research Project Management
Highlights and Impacts

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Presentation to

Sandia National Laboratory
Combustion Research Facility
Livermore, California

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A partial list of research activities
- Liquid fuel spray and DISC engine
- Swirl-stabilized combustor (gas turbine engine)
- Interacting-jets/sprays: Simultaneous reduction of soot & NOx emissions
- Supercritical combustion in cryogenic rockets
- Combustion instability in liquid rocket engines
- Nanotechnology, optics, and chemical reaction

Conclusions
Liquid Fuel Spray: DISC Engine

- Objectives
  - Develop diagnostics in dense spray
  - Characterize dense spray region
  - Length and shape of the dense core
  - Database for modeling and simulation

- Organizational Impact
  - Maintained leading position in the field
  - Secured follow-up funding
  - Visibility in the national and international community
  - Role model in research excellence
  - Close collaboration between modeling/simulation and experimental teams in the same building (laboratory)
Key Technical Results & Impacts

- Winner of the *Arch T. Colwell Merit Award* from SAE (only to top 1% of all publications each year)
- Innovative electrical conductivity approach for both length and shape of the dense-spray region
- One of the two known such measurements in the world at the time (the other: Hiroyasu et al., Japan)
- Modeling and simulation code validation (KIVA)
- Core length proportional to square root of density ratio
- Previous measurements overestimated the length
- Theoretical and experimental results in good agreement
- Used for engineering design purposes
- Path from fundamental research to applications

Chehroudi et al. Equation

\[
\frac{L_{\text{core}}}{d_{\text{jet}}} = \left[ \beta_0 + c' \left( 1 - \frac{\beta_0}{c'} + 9 \left( \frac{\beta_0}{c'} \right)^2 /8 \right)^{-1} \right] \left( \rho_l / \rho_g \right)^{1/2}
\]
Swirl-Stabilized Combustor 

- Objectives
  - Designed and built facility from the ground up
  - Mechanism of swirl stabilization
  - Pollutants formation
  - Spray characterization under both reacting and nonreacting flows
  - Experimental data for modeling and simulation
  - Visualization & laser diagnostics

- Organizational Impact
  - Decorated the department’s only advertising brochure: an effective marketing impact
  - Attracted additional funding
  - Used for research and education
  - Attracted other colleagues for collaborative research and proposals
  - 1 PhD and 3 MS
Key Technical Results & Impacts

- **CRC Handbook of Fluid Dynamics** as significant example of applied engineering research done on the subject with many commercial applications (W. Bachalo)
- Journal of Fluids Engineering: *Data Bank Contribution*
- Effects of reacting flow on spray characteristics
- One of the earliest data set in the literature
- Recirculation zones and their interactions
- Stability zone characterization
- Anatomical features were named and distinguished under both cold and reacting flows
- Design guidelines were proposed
Interacting-Jets/Sprays: Simultaneous soot & NOx reduction

- **Objective**
  - Feasibility of an innovative concept for simultaneous reduction of soot and NOx
  - Innovation at the interface
  - Fundamental understanding of the interacting sprays

- **Organizational Impact**
  - Enhanced visibility in innovative idea generation
  - Advanced engine laboratory for both research and education
  - Attracted funding from the industry (GM and Ford)
  - Patent filed
  - A number of publications
  - Motivated other researchers in the world to explore similar strategy
  - 2 PhD and 4 MS
Key Technical Results & Impacts

- The concept based on physical intuition has been proven.
- Led to follow-up studies throughout the world.
- Interacting-sprays concept appears to be complementary to other competing approaches.
- Laser diagnostics including Exciplex method revealed the nature of the interaction.
- Interaction at the right time and right place achieved the desired effects.
- Stronger interactions between the two injection pulses (i.e., spray/spray impingement) early within the ignition delay period was critical to reduction in smoke (or soot) formation.
- For effective NOx reduction the second injection pulse should start near the ignition delay period to lower local burned and burning gases temperatures.

Simultaneous soot & NOx reduction potential of the interacting-sprays are shown.
Objective
- Understand combustion under high pressures including supercritical conditions
- Fundamental understanding of cryogenic liquid propellant atomization
- Database for modeling and simulation

Organizational Impact
- Improved design tools
- Continued funding through AFOSR
- Earned one of the prestigious AF awards: the Star Team Status (implications: secured funding for 5 years no matter what)
- Built international reputation for the group
- Opened up national & international collaborations
- Expanded into another program: Combustion instability
- Enhanced sense of pride and teamwork
- NASA funding via AFRL, ATC, JPL joint proposal
- 1 PhD jointly with Penn State, 1 postdocs, 1 visiting faculty
**Key Technical Results & Impacts**

- **Outstanding Technical Publication Award**
  - In recognition of performance and outstanding achievement to the Air Force Research Laboratory, Space & Missile Propulsion Division, 2002

- **Best Technical Publication Award**
  - For outstanding and lasting contributions to aeronautical and aerospace sciences, AIAA, 2000

- **First time Achievements**
  - Quantitatively demonstrated that jet growth rate (hence, mixing appetite) under supercritical conditions behaves like incompressible variable-density gaseous jets
  - Consolidated jets, sprays, mixing layers data for up to 4 order of magnitude
  - Fractal analysis of the supercritical jets
  - A physics-based model

- **Implications for modeling and simulations**

- **Methodology to reconcile results from Raman and shadowgraphs**

- **Raman data was used for temperature profiles**

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**Chehroudi et al. Model Equation**

\[
\Theta = 0.27 \left( \frac{\tau_b}{\tau_b + \tau_g} \right) + \left( \frac{\rho_g}{\rho_l} \right)^{0.5}
\]

**Growth rate of single jets as a tangent of the visual spreading angle versus the chamber-to-injectant density ratio. Data taken by Chehroudi are indicated by an asterisk (*) in the legend.**

**Comparison of the spray growth rate measured by Raman and shadowgraph methods.**
Combustion Instability: Liquid Rocket Engine

- **Objective**
  - Nature of the acoustic field / injector interaction
  - Develop understanding under high pressures including supercritical conditions
  - Data for modeling and simulation

- **Organizational Impact**
  - Led to continued funding by the AFOSR
  - Contributed heavily towards formation of combustion stability program by the Air Force
  - Established as one of the leading research groups in high pressure combustion instability
  - Enhanced collaborations with university and industry
  - Contributed towards next generation of combustion stability design tools
  - 1 PhD jointly with UCLA, 1 postdoc, 1 visiting faculty

Supercritical facility for study of combustion instability in cryogenic liquid rocket engines

Appearance of the combustion instability intentionally induced by sudden injection of nitrogen
Combustion Instability

- **Key Technical Results & Impacts**
  - **Best Paper Award**
    - Liquid Propulsion Subcommittee, Joint Army-Navy-NASA-Air Force (JANNAF)
  - **Marshall Award**
    - Best publication of the year, ILASS_America
  - A **Unified Injector Sensitivity Theory** for combustion instability was proposed
  - Opened up a new perspective on the instability at supercritical pressures
  - Theory is consistent with all available cold and reacting flow results

Comparison of Chehroudi’s cryogenic coaxial-jet dark-core length measurements with all other relevant core length data in the literature versus momentum flux ratio.

Consecutive frames from high-speed movies for a coaxial injector similar to those used in Space Shuttle main engine with the acoustic driver off (rows 1, 3, and 5) and on (rows 2, 4, and 6) at ~3kHz.
Nanoscience, Optics, & Chemical Reaction

● Objective
  ■ Light-activated volumetrically-distributed ignition of gaseous and liquid sprays: A paradigm shift in ignition technology
  ■ Explore potential for ignition-induced instability
  ■ Understand photo-physics of the phenomenon
  ■ Feasibility in applications of carbon nanotube, graphene, or other nanostructured materials for ignition/combustion

● Organizational Impact
  ■ The only group in the world harnessing the applications of this new phenomenon
  ■ Led to active participation in the AFRL Nanoscience and Technology (NST) Strategic Technology Team (STT)
  ■ Secured seed fund leading to a 5 year funding for the program through AFOSR/NST
  ■ Created & managed multidisciplinary collaboration (university/government/industry)
  ■ 2 MS students (Purdue Univ & AF Academy) & 1 postdoc
Key Technical Results & Impacts

- Distributed ignition of a host of fuels in gas phase
- Distributed ignition of liquid fuel sprays
- Publicity by the *New Scientist* magazine
- Minimum ignition energy measured for the first time, being 40 times less than any competing method
- Light wavelength effect was of secondary importance (within visible and NIR range)
- Preliminary work on photoacoustic
- First principles, state of the art, density functional methods were used to understand the iron/oxygen interaction at the cluster level and see if O$_2$ faces a barrier as it approached Fe$_n$ clusters.
- Potential application for the next generation of the highly-efficient and environmentally-clean HCCI engines
- Two patents filed at the USPTO
- True autoignition control in homogenous fuel/air mixtures

A great candidate for LDRD at Sandia
Conclusions

- Award-winning and trend-setting scientific contributions with a broad range of applications
- User-inspired and boundary-spanning basic research with a clear path to application
- Time-tested, sustained, high-quality, innovative research work
- Effective leadership, management, and teamwork
- Wide network in academia, industry, and government
- Multidisciplinary research activities
- Broad-spectrum of research management experience with diversity in scope and scale
- Multi-organizational collaborative research at the national and international levels
- An innovative, dependable, and visionary professional/leader with entrepreneurial skills, who envisions, develops, markets and improves methods/processes to achieve desired results within schedule and budget

Questions ?