

National Educators' Workshop: Update 2003

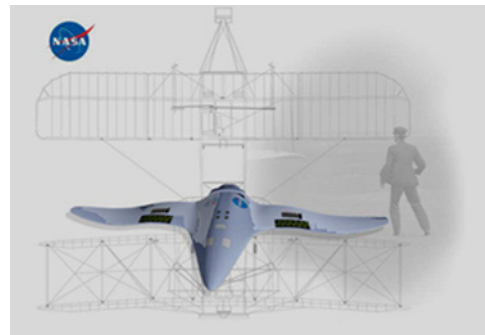
Standard Experiments in Engineering, Materials Science, and Technology

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Century of Powered Flight

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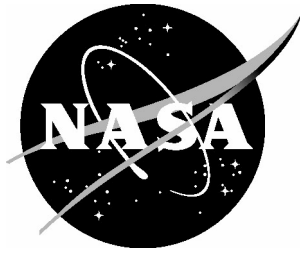
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PREFACE

Organizers of the 18th Annual NEW:Update 2003 were invited to join NASA in its celebration of the Centennial of Controlled, Powered Flight by Orville and Wilbur Wright on December 17, 1903. The Flight 100 theme guided the Organizing Committee to structure activities that provided a historic perspective to take a glimpse back at the remarkable accomplishments of the Wright Brothers as was so ably presented in Bob Ash's, "Uncovering the Secrets of the Wright Brothers". For those of us lucky enough to enjoy warm, torrential rains of Kitty Hawk to witness attempts to recreate the Wright's amazing feat of flight at the December 17, 2003, program, we gained an even greater appreciation of the tenacious voyage the Wright's undertook to finally achieve success in human aspirations of desire to fly with the birds. As these workshop proceedings reveal, a historic view of flight set perspectives for gaining insights into aeronautics and aerospace structures and materials now and into the future as presented by Darrell Tenney and Alan Miller at the Virginia Air and Space Center. Our next venues at NASA Langley Research Center, Thomas Jefferson National Accelerator Facility and the Applied Research Center provided NEW:Update 2003 participants with valuable experiences in structures and materials and related sciences and technologies.

NEW:Update 2003 was built on themes, activities, and presentations based on extensive evaluations from participants of previous workshops as we continued efforts to strengthen materials and technical education. About 200 participants witnessed demonstrations of experiments, discussed issues of materials science and engineering (MS&E) with people from education, industry, government, and technical societies and heard plenary sessions on leading edge developments from experts in their fields. Participants also engaged in valuable mini workshops in state-of-the art laboratories of Langley, Jefferson Lab and the ARC. Faculty, in attendance, represented high schools, community colleges, smaller colleges, and major universities. Undergraduate and graduate students also attended and presented.

With the sponsorship of the newly formed National Institute of Aerospace, this year we inaugurated a special series of events for precollege teachers. Even though hurricane Isabel presented obstacles for full participation, the teachers gained valuable resources and ideas to strengthen their teaching of science and technology as a result of visiting Langley Labs, gaining interactive experiences with problem-solving activities and obtaining a wide range of resources including the unique Langley Structures and Materials kit of specimens that all NEW:Update 2003 participants received. This kit, designed and constructed by NASA Langley technicians as extra duty, was the jewel among many resources educators took away for use as a multiplier of the NEW: Update treasures of technical concepts, pedagogy and laboratory experiments and classroom demonstrations.

Another inaugural event, the brain-child of Zoubeida Ounaies and sponsored by the Biologically Inspired Materials Institute - NASA URETI, was a very successful student poster competition. This event helped gain participation by a significant number of students from regional universities and college students as well as students from across the USA, who also presented papers and demonstrated laboratory experiments, provided valuable input to discussions and helped with our mission of motivating students to strive for excellence.

NEW:Updates continue because of involvement by bright and busy people who squeeze “one more task” into their hectic schedules in order to insure that American education advances thus spurring innovation which helps cement US world leadership in science and technology. Even in a strong economy, gaining funds for educational activities is a challenge. During times of a weak economy, as we experienced during the past few NEW:Updates, the challenges grow. NEW:Updates approach a 3rd decade as a result of vital support from our major sponsors and the many supporters who provide key in-kind assistance and funding. Our local hosts were keys to quality events. Organizers coordinated the many scientists, engineers, professors and other staff, by providing funding, opening their facilities, developing presentations and activities.

NEW:Update 2003 participants saw the demonstration of about fifty experiments and aided in evaluating them. We also heard updating information relating to materials science, engineering and technology presented at mini plenary sessions. The national NEW:Update 2003 Organizing Committee, listed in this conference proceeding, tackled numerous challenges to keep NEW:Update 2003 on track, relevant and full of valuable resources, yet very affordable to participants.

This publication provides experiments and demonstrations that can serve as valuable aids to faculty who are interested in useful activities for their students. The material was the result of years of research aimed at better methods of teaching technical subjects. The experiments, developed by faculty, scientists, and engineers throughout the United States and abroad, add to the collection from past workshops. They include a blend of experiments on new materials and traditional materials.

Experiments underwent an extensive peer review process. After submission of abstracts, selected authors were notified of their acceptance and given the format for submission of experiments. Experiments were reviewed by a panel of specialists through the cooperation of the International Council for Materials Education (ICME). Comments from workshop participants provided additional feedback, which authors used to make final revisions, which were then submitted to the NASA editorial group for this publication.

The ICME encourages authors of experiments to make submissions for use in the *Journal of Materials Education (JME)*. The *JME* offers valuable teaching and curriculum aids including instructional modules on emerging materials technology, experiments, book reviews, and editorials to materials educators. See *JME* subscription information on 1100.

Critiques were made of the workshop to provide continuing improvement of this activity. The evaluations and recommendations made by participants provide valuable feedback for the planning of subsequent NEW:Updates. NEW:Update 2004 will be held at Arizona State University and Phoenix Area industry on October 16 - 20. The growing number of hosts can be seen on our website <http://MST-Online.nsu.edu>. Click on NEW:Update 2004 for developing information. Join us in beautiful and historic Phoenix in October, 2004, to visit one of the nation's incubators of emerging science and technology and a wonderful environment full of ever changing vistas.

NEW:Update 2003 and the series of workshops that go back to 1986 are, to our knowledge, the only national workshops or gatherings for materials educators that have a focus on the full range of issues

on strategies for better teaching about the full complement of materials, manufacturing and related technologies. Displays by publishers, technical societies, and equipment suppliers add to the workshop's value.

The second edition of *Experiments in Materials Science, Engineering & Technology, (EMSET2)* CD-ROM with over 400 experiments from NEW:Updates, is another example of cooperative efforts generated as a result these annual workshops. The primary contributions came from the many authors of the demonstrations and experiments for NEW:Updates. Funding for the CD came from both private industry and federal agencies. Please see the attached information for obtaining the CD.

Special thanks goes to those on our national Organizing Committee, management team, hosts, sponsors, and especially those of you who developed and shared your ideas for experiments, demonstrations, and innovative approaches to teaching.

The Organizing Committee hopes that the experiments and technical updated material in this publication will assist you in teaching about materials science, engineering and technology. We would like to have your comments on their value and means of improving them. Please send comments to Jim Jacobs, School of Science and Technology, Norfolk State University, 700 Park Avenue, Norfolk, Virginia 23504 or e-mail to dplacaire@nsu.edu.

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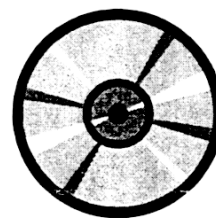
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For more than a decade, the National Educators' Workshops have enabled educators to participate in seminars of peer-reviewed experiments and demonstrations in materials science, engineering and technology. Following each workshop, these papers were published in an annual compendium, with the generous support of NASA.

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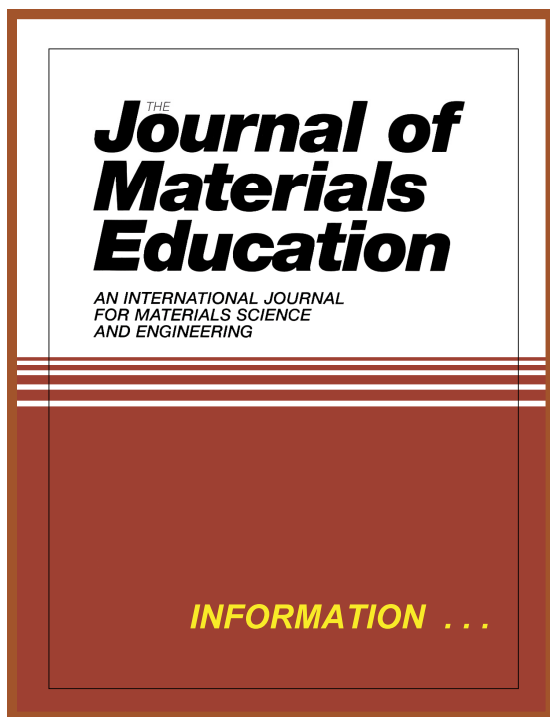
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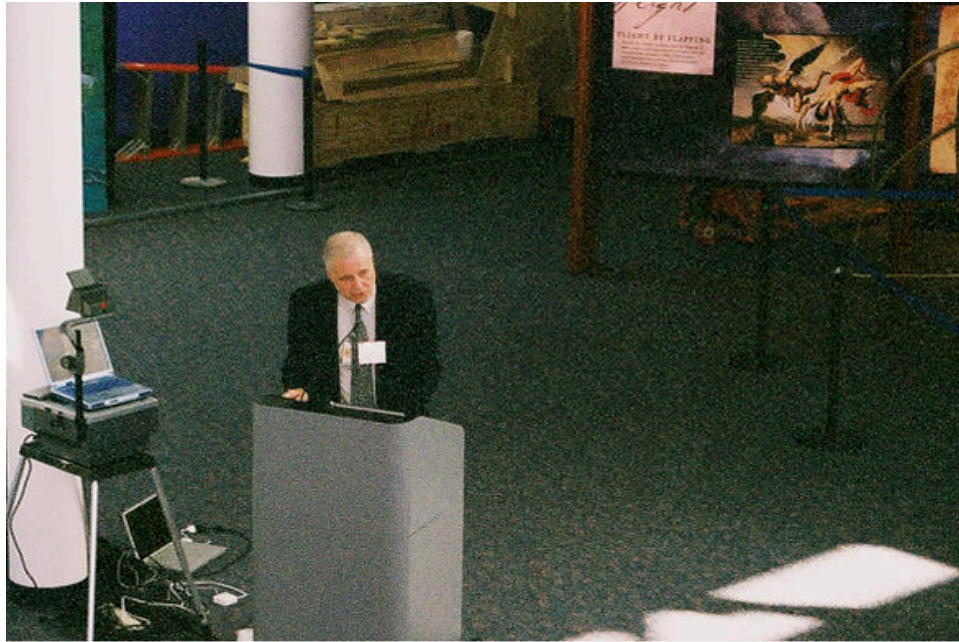
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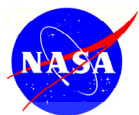
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6 Strategic Enterprises - One NASA

NASA's Vision

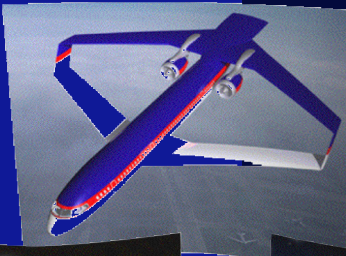
- To improve life here
- To extend life to there
- To find life beyond

NASA's Mission

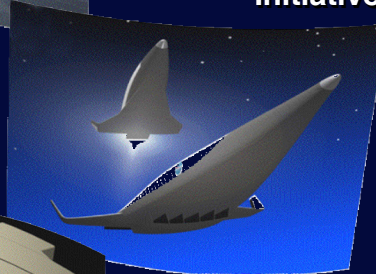
- To understand and protect our home planet
 - To explore the universe and search for life
 - To inspire the next generation of explorers
- ...as only NASA can

Aerospace Technology Enterprise Strategic Themes

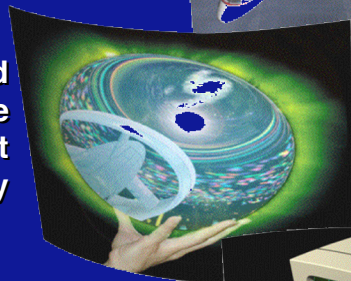
**Aeronautics
Technology**



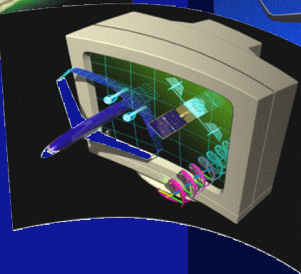
**Space Launch
Initiative**



**Mission and
Science
Measurement
Technology**



**Innovative Technology
Transfer Partnerships**



Aeronautics Technology

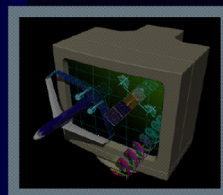
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**Aeronautics
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**Space Launch
Initiative**

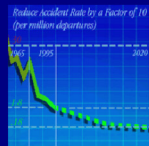
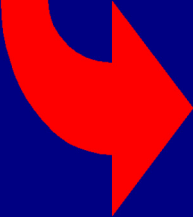


**Innovative Technology
Transfer Partnerships**

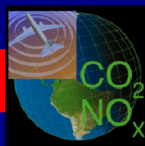


**Mission and Science
Measurement
Technology**

Aeronautics Theme Objectives



**Protect Air
Travelers and
the Public**



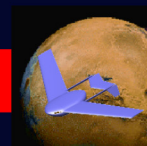
**Protect the
Environment**



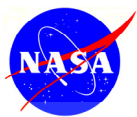
**Increase
Mobility**



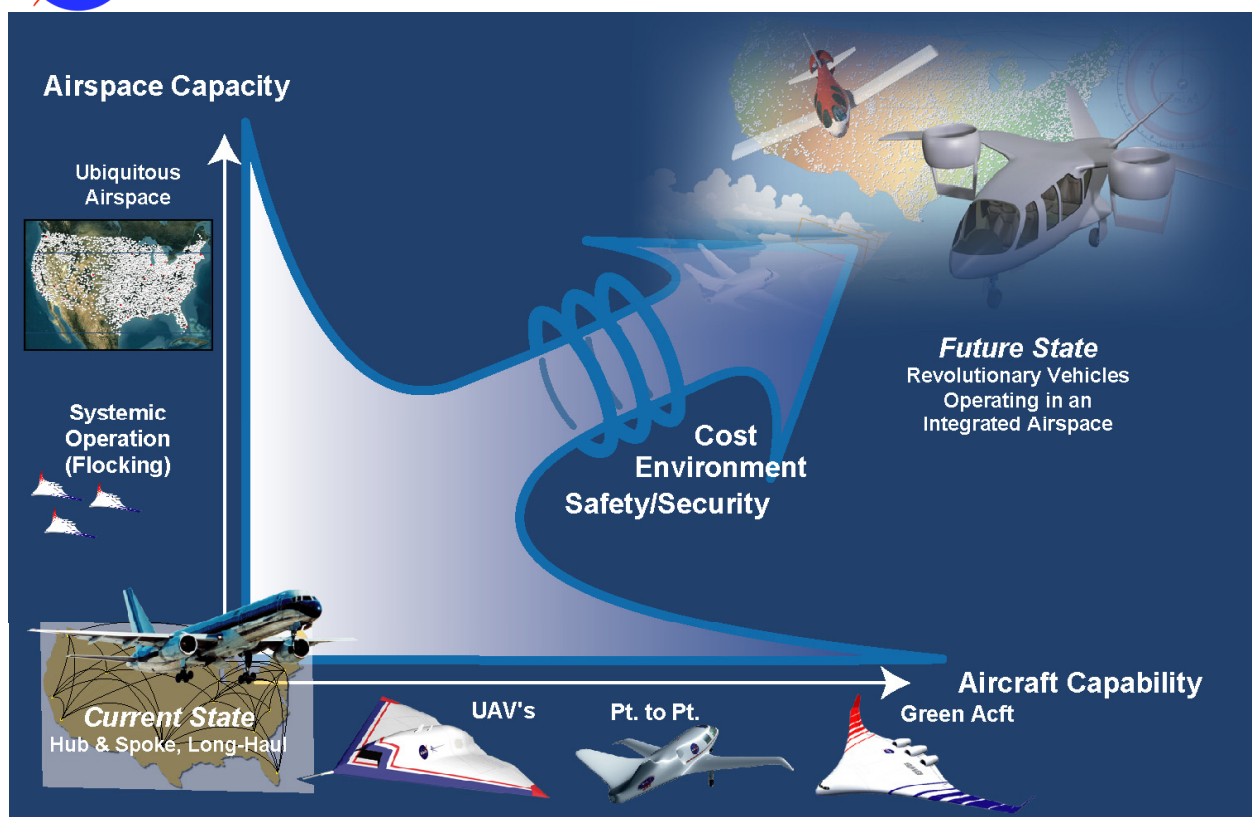
**Protect the
Nation**



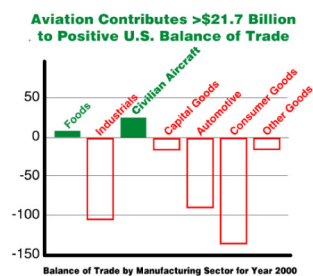
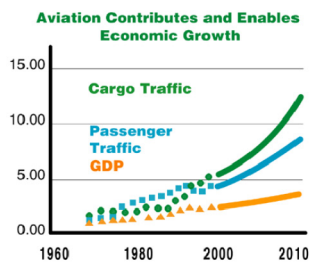
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Integrated Advancements in Airspace and Vehicles



Aviation is Critical to Society

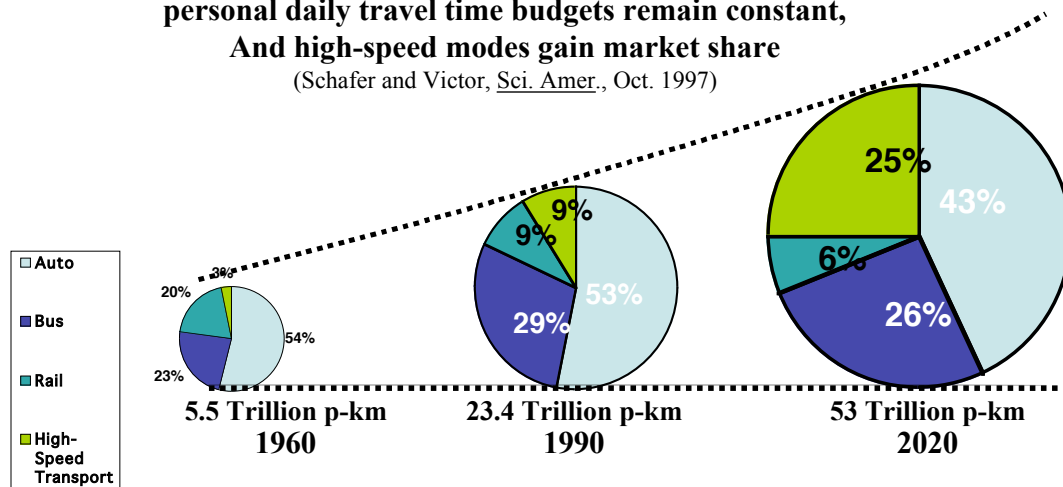


Aviation Extends and Accelerates the E-Commerce Revolution



Global Trends in Transportation Mode Market Shares

**As *per capita* income rises, *per capita* annual travel rises,
personal daily travel time budgets remain constant,
And high-speed modes gain market share**
(Schafer and Victor, *Sci. Amer.*, Oct. 1997)

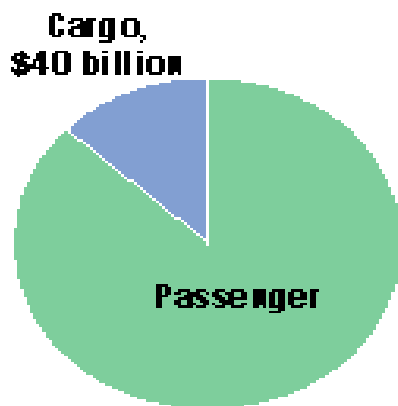


Demand for transportation, especially high-speed air travel, will soar beyond supply early in the 21st century.
The demand for air travel in 2020 could exceed the volume of ALL auto travel in 1990.

Indicators of Demand

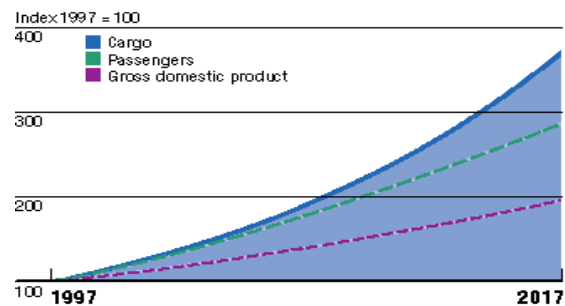
Air Cargo Growth

Air cargo revenues are \$40 billion per year



(Source: Boeing, 2000)

Air cargo traffic is expected to triple and outpace passenger growth in next 20 years



There are Major Issues in Aviation



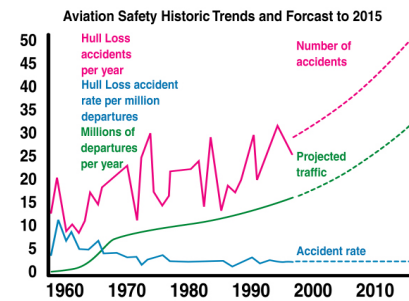
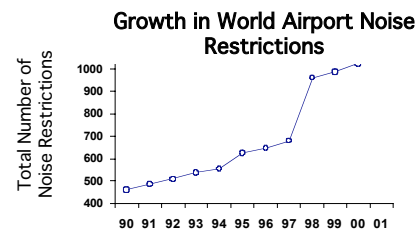
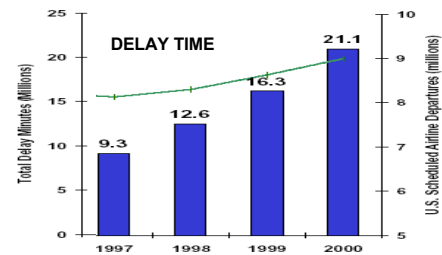
**Capacity
Limits**



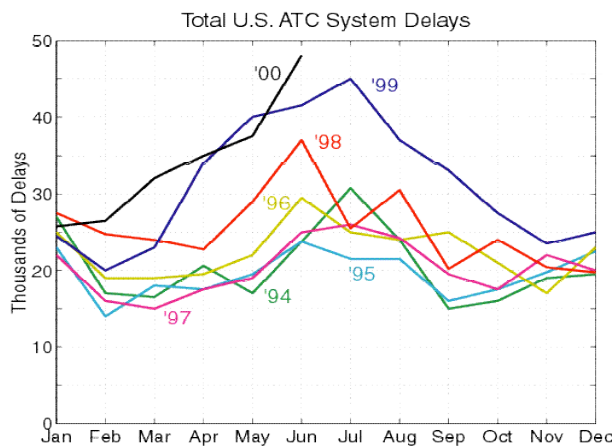
**Noise
&
Emissions**



**Safety
&
Security**



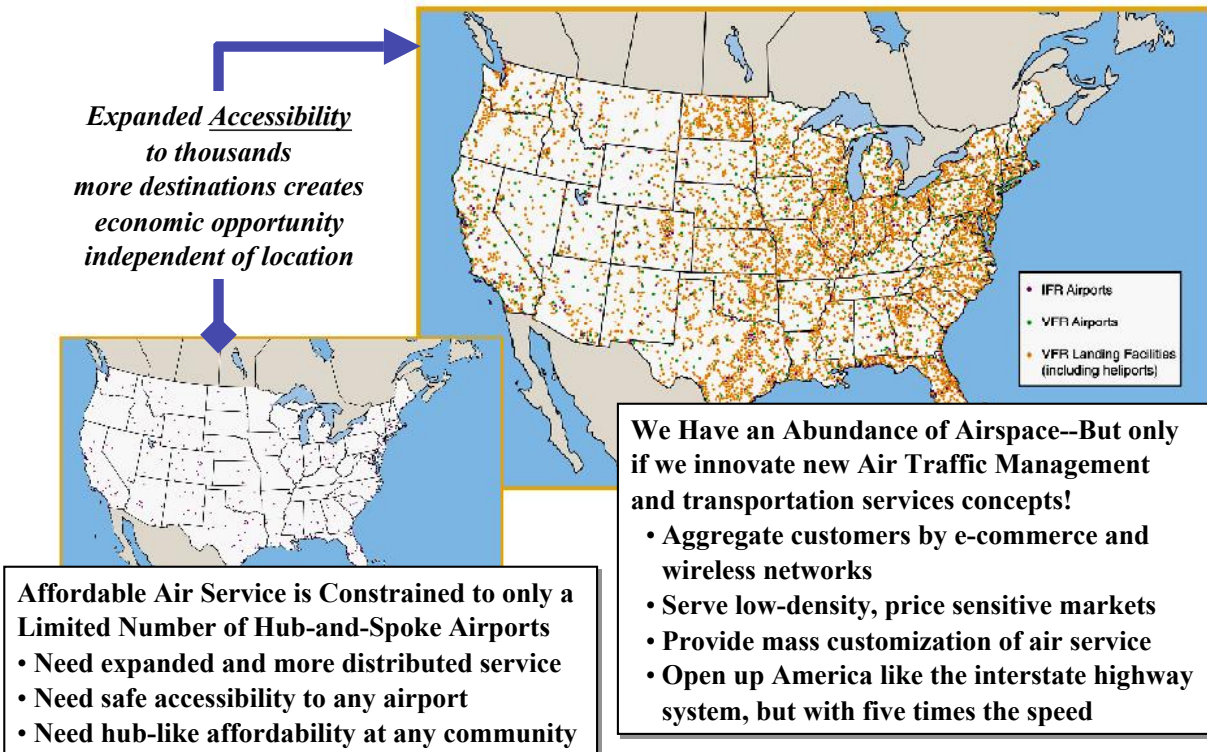
Congestion is an Issue



Highways are not the solution



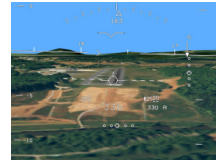
On Demand (Airspace and Airports are Abundant, not Scarce)



Safety

Today's Challenges:

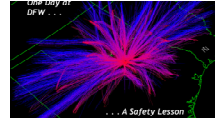
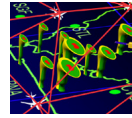
- Limited Visibility
- Human Error
- Component Failures
- Weather Hazards
- Hidden/Emerging Risks
- Asymmetrical Threats



- Synthetic Vision Provides Visibility in all Conditions



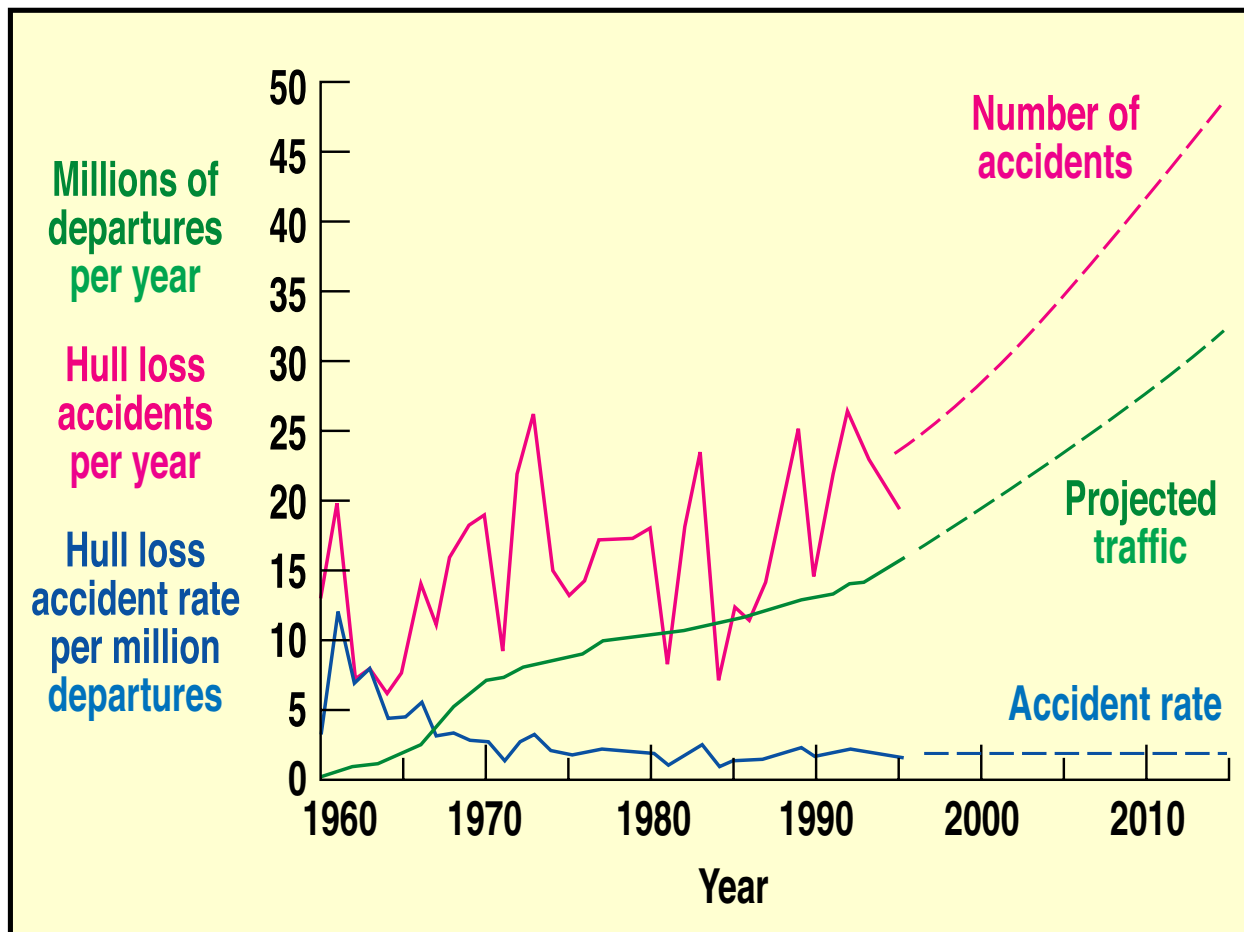
- Human-Centered Designs
- Self-healing, Fault Detection and Reconfigurable systems
- Weather Precisely Known



- Aviation Risks Monitored and Managed

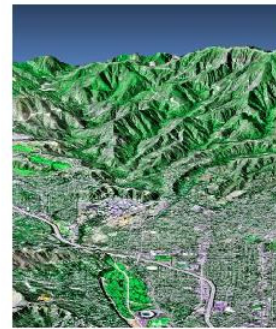
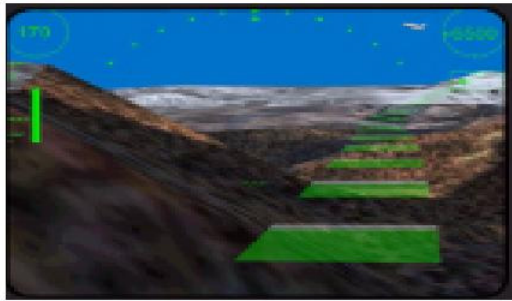


- “Refuse to Crash” Digital Terrain Technology



Synthetic Vision

Example of How Technology Will Transform Aviation



Safety

Controlled Flight into Terrain
Approach & Landing
Loss of Control
Runway Incursion



Efficiency

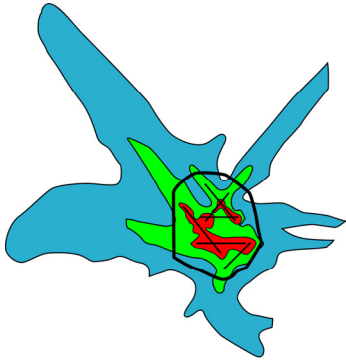
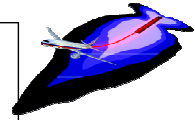
All Weather
Visual Departures &
Visual Approaches
Visual Spacing

Accessibility

Virtually any runway end or heli-pad in the nation becomes accessible in near-all-weather, without traditional ground infrastructure expense



Environmentally Friendly Aircraft



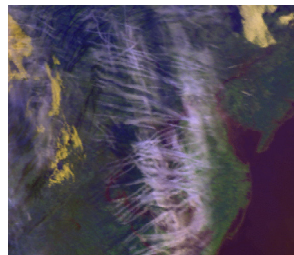
Noise within airport boundaries

Constrain objectionable noise to within airport boundaries



Smog-free

Minimize the contribution of air vehicles to the production of smog



No impact on global climate

Minimize the impact of air vehicles on global climate

Noise Reduction

Today's Challenges:

- 825 (and growing) airports with noise restrictions
- \$4B (and growing) to condition homes
- To keep noise inside airport boundaries
- Understanding the sources of noise
- Integrate emerging materials, structures, flow control technologies

Future Opportunities:

- Revolutionize How Citizens View Airports

People Impacted

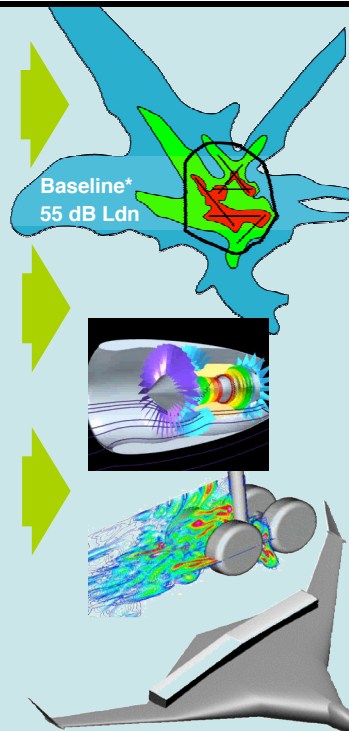
Baseline*	620,000
-10 dB	55,000
-20 dB	0
Airport Boundary	

- Eliminate Noise by Design

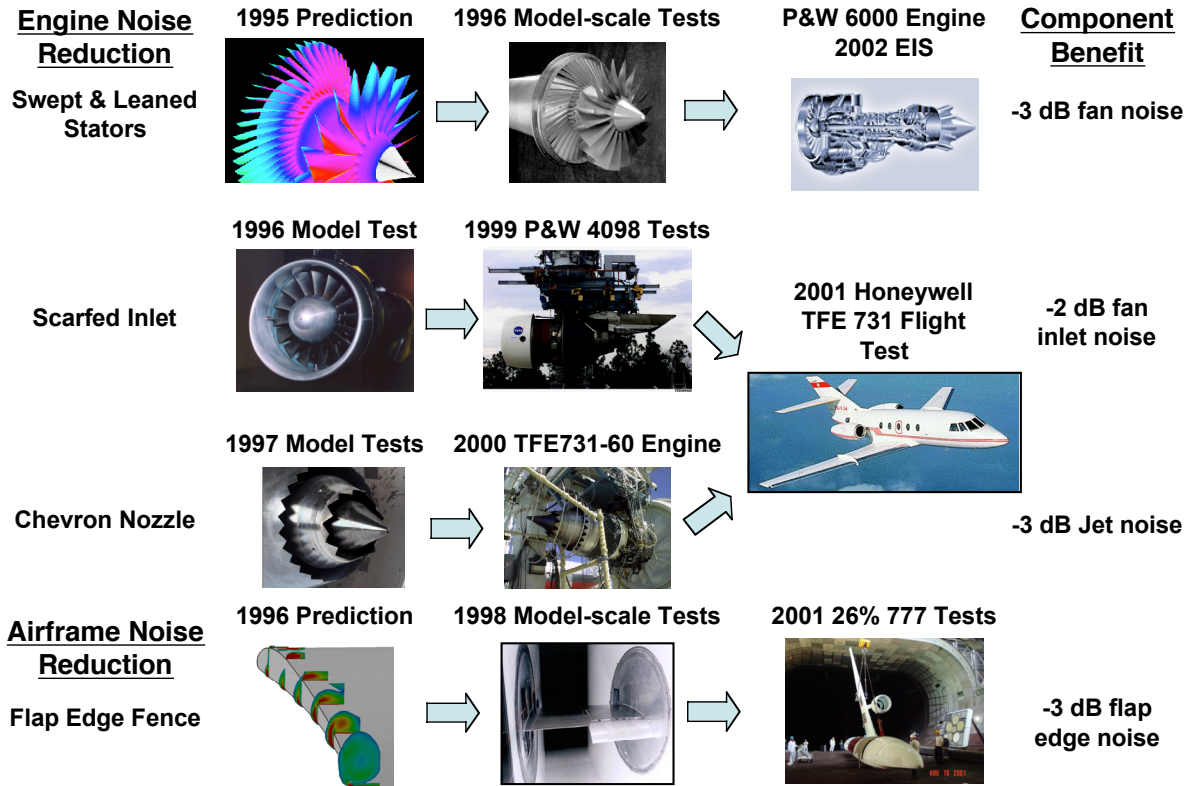
- Quiet Design Engines, Landing Gear, and Airframes

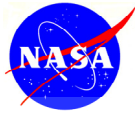
- Revolutionary Vehicles (BWb)

* DNL 55 is the EPA outdoor noise exposure level "requisite to protect the public health and welfare with an adequate margin of safety".

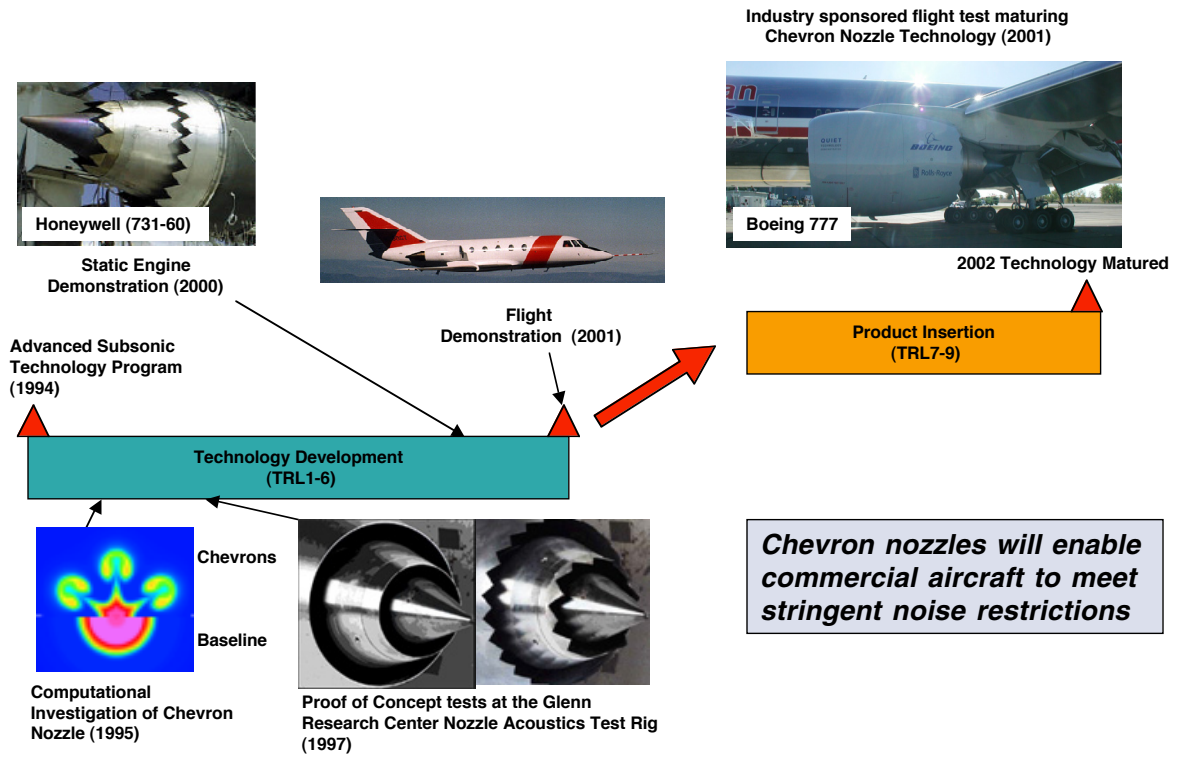


Technology Discovery, Maturation, and Implementation





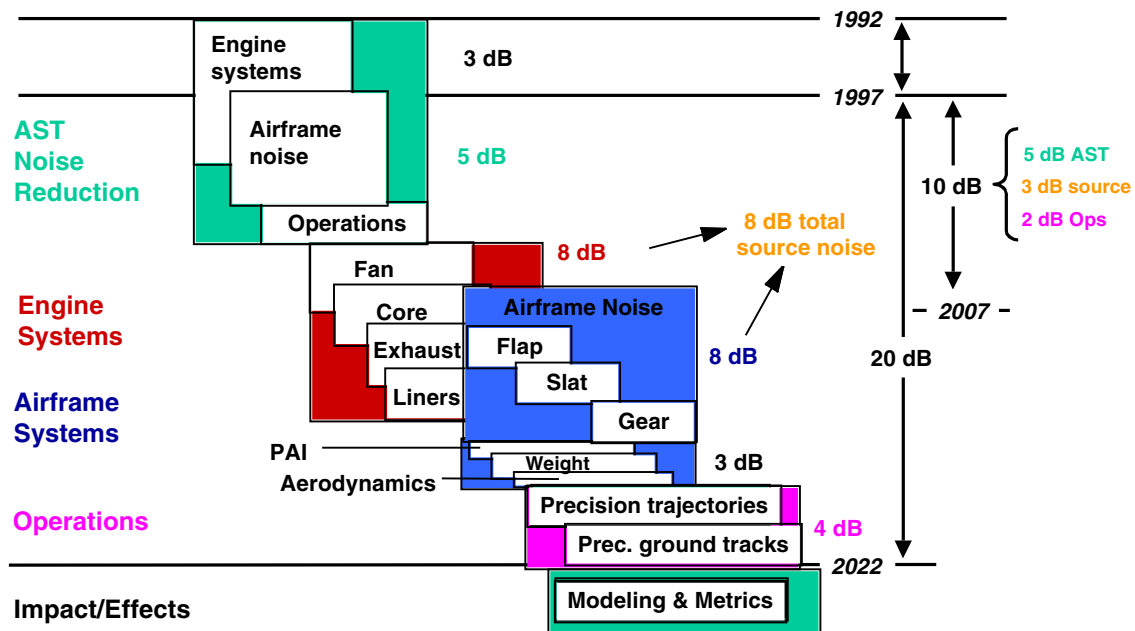
Chevron Nozzle Technology for Engine Noise Reduction



Noise Reduction



Gap Analysis: Technical Challenges, Objectives, and Investment Areas



Environment



- **Reducing CO₂ emissions by 50% and NOX emissions by 80% in 25 years will require radically new propulsion and airframe concepts**
 - **CO₂ reduction directly related to fuel burn**
 - Smart vehicles, structures and active flow control technology to reduce drag, improve propulsion/airframe integration and optimize performance
 - Advanced propulsion systems (e.g. fuel cells)
- **NOX reduction related to combustion properties/design and fuel burn**
 - Advanced materials and designs for turbines, fans, and compressors
 - New combustion cycles
- **Operational environmental issues with painting, de-icing, etc.**
 - Application of riblets/coatings & smart wing de-icing systems

Other Environmental Issues

- **Deicing**

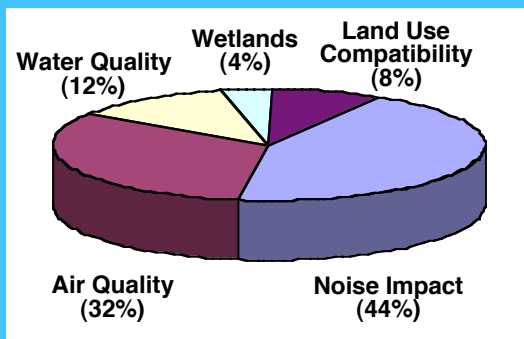
- **New systems required to stop runoff of harmful chemicals**
- **Some European cities using Infrared heating**

- **Painting**

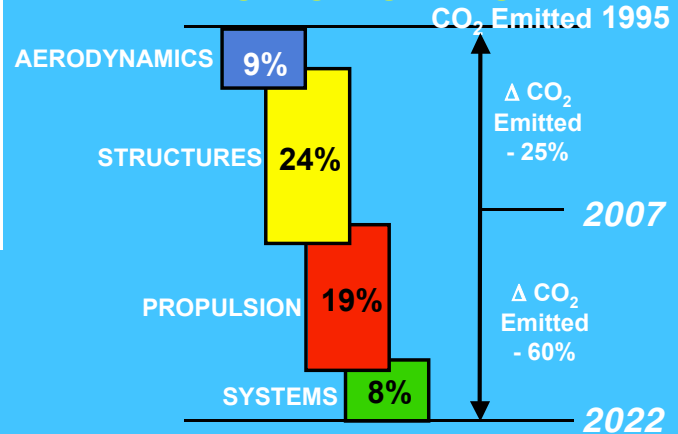
- **Some manufacturers are flying unpainted aircraft off the assembly line to remote locations for painting**

Issues and Technologies: Emissions

GAO SURVEY OF FUTURE ENVIRONMENTAL IMPACTS ON AIRPORTS



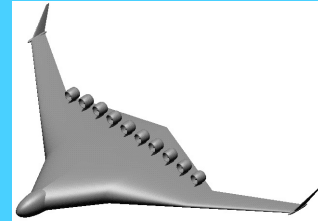
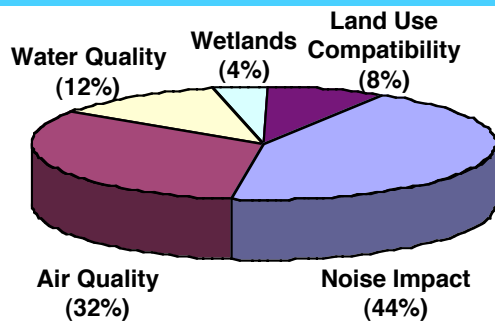
BREAKDOWN OF TARGET OPPORTUNITIES



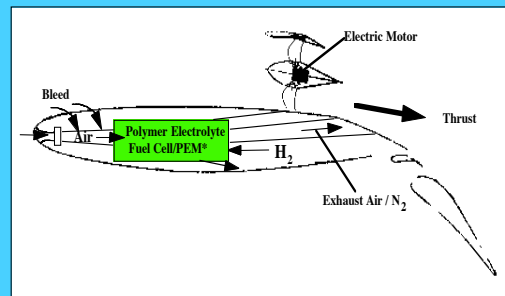
Issues and Technologies: Emissions Impact on 21st Century Mobility

Possible Future Technologies

GAO Survey of Future Environmental Impacts on Airports



Quiet-Green Blended Wing Body Concept

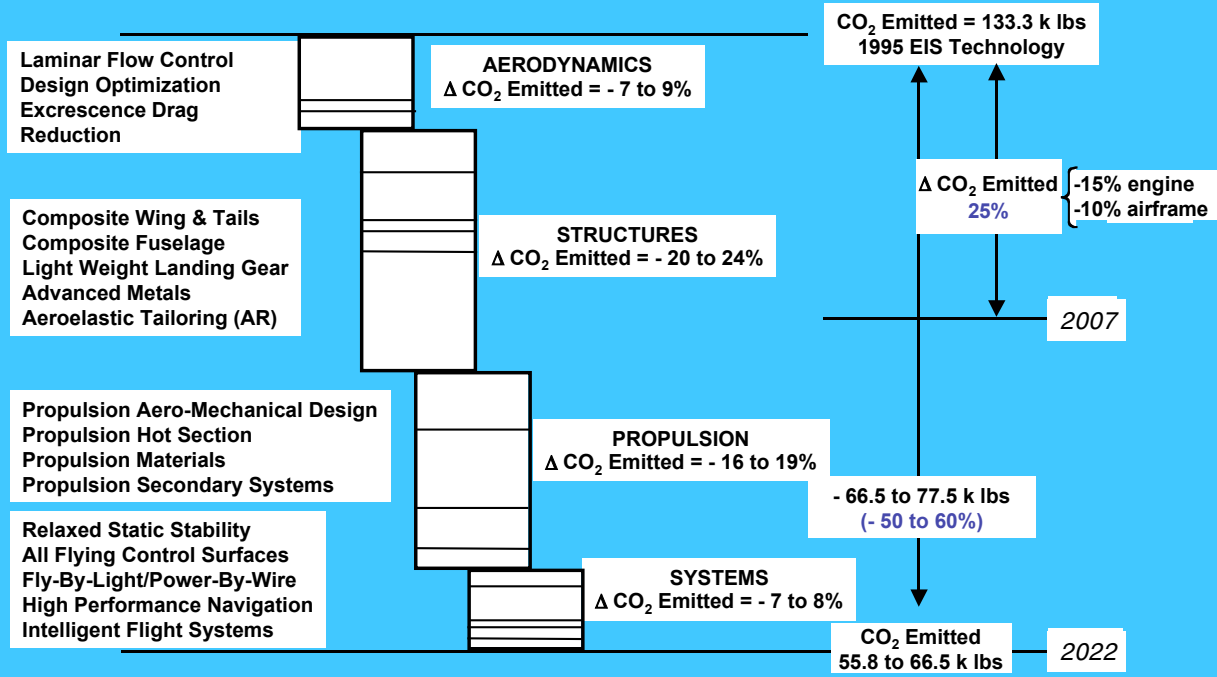


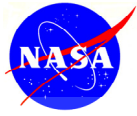
Electric Aircraft Concepts

Emissions - Fuel Burn “Waterfall” Scenario-Based Vehicle Technologies

325 PAX CONVENTIONAL SUBSONIC TRANSPORT

2-Engine, 6500 nmi Design Range, 10000 ft Field Length





Aircraft for Public Mobility



More Convenient

Expand access to aviation to more locations and make it available on-demand



...without compromising safety

More Affordable

Make air travel available to the entire population



Faster

Increase the speed of air travel

Indicators of Demand

Regional Jet Growth

- New regional jets fly faster and farther and are adding new direct connections
 - 550 RJs in use by end of 2000
- Older 19-seat turboprops used by regional airlines declining
 - down 40% in last decade to 405 in 1999
- However, fewer cities are being served as airlines consolidate markets for profitability



Canada and Brazil are the leading makers of regional jets.

A New Generation of Revolutionary Light Jet Products

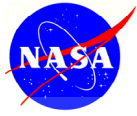
- Strong Growth between 1994-1999
 - Billings up 235%
 - Deliveries up 172%
 - 636 Business & Corporate jets (\$7.9 B) delivered in 1999
 - In comparison, 287 fighter planes (\$9.7 B) delivered in 1999
 - Strong export market (>30%)
- Several new model jets
 - From low (<\$1M) to high (>\$40M) products
 - New engines stimulate new aircraft development
- New Aircraft Revolutionize the Cost of Speed
 - \$1.00/aircraft mile (total for 5 passenger jet travel)
 - Ultimately propeller travel becomes obsolete
 - On-Demand jet trips become affordable for most travelers



*New Quiet, Affordable
Small Jet Engines*



Safire S26



Highway in the Sky (HITS)



Graphically intuitive pilot interface system that provides a general aviation aircraft operator with the attitude and guidance inputs required to safely fly an aircraft in close conformance to air traffic procedures.



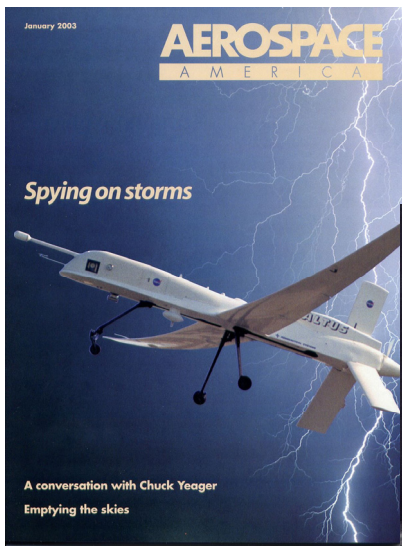
A multi function display showing a moving map and the path to any destination is available to the operator.

HITS
c. 2002

***Demonstration of the
AGATE Highway In The
Sky (HITS) in a General
Aviation Aircraft***



Emerging New Applications for Composite Structures



UAV Systems

Operational



RQ-1 Predator



RQ-2 Pioneer



RQ-5 Hunter

RQ-5 Hunter/TRW/IAI/Army					
Weight	Length	Wingspan	Ceiling	Radius	Endurance
1,600 lbs	20 ft	29.2 ft	15,000 ft	144 nm	11.6 hrs
Payload Weight: 200 lbs					

Developmental



RQ-4 Global Hawk



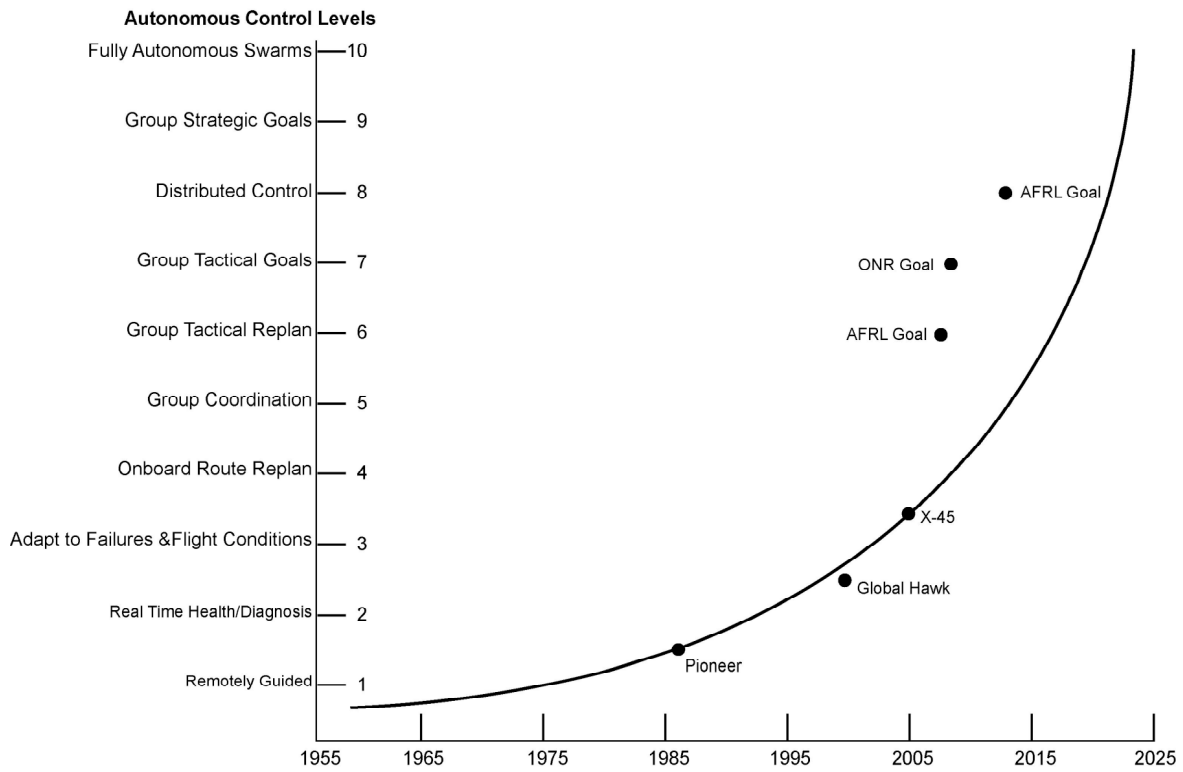
Fire Scout



RQ-7 Shadow 200

RQ-7 Shadow/AAI/Army					
Weight	Length	Wingspan	Ceiling	Radius	Endurance
327 lbs	11.2 ft	12.8 ft	15,000 ft	68 nm	4 hrs
Payload Weight: 50 lbs					

Autonomous control Level Trends



Source: Unmanned Aerial Roadmap 2000-2025





Personal Air Vehicle (PAV) Sector (Goal Based)

Ease of Use Equivalent to Automobile

- Blunder resistant controls, co-pilot on a chip, obstacle avoidance, etc...
- Seamless integration of airspace communication, navigation and surveillance

Improved Propulsion

- Engine-out robustness
- Efficient, simplified propulsors
- Alternative cycle engines
- Propulsion-airframe integration

Affordable Ownership

- Certification of automotive processes
- Lean design and manufacturing
- Advanced software certification
- Health monitoring systems
- Design to certification toolsets

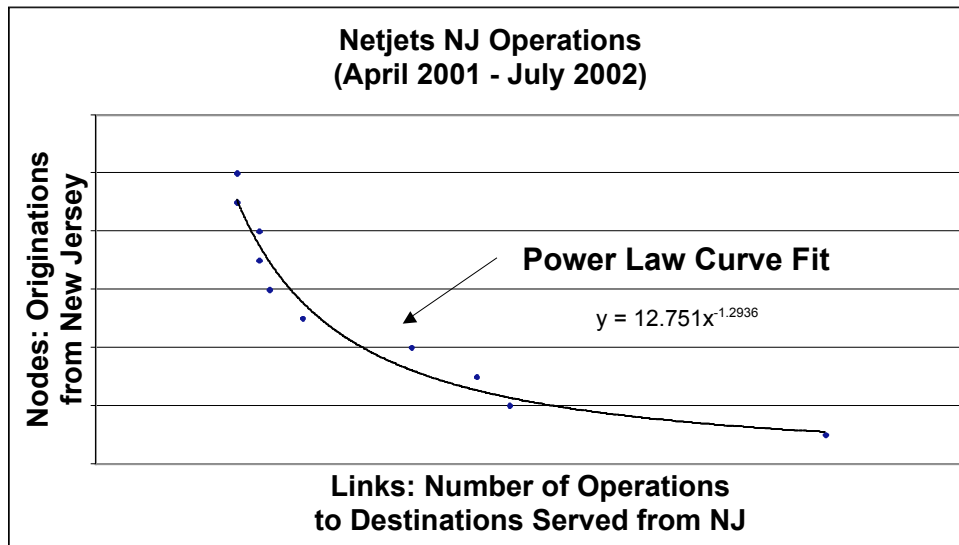
Low Community Noise

- Engine noise management systems
- Quiet propulsors

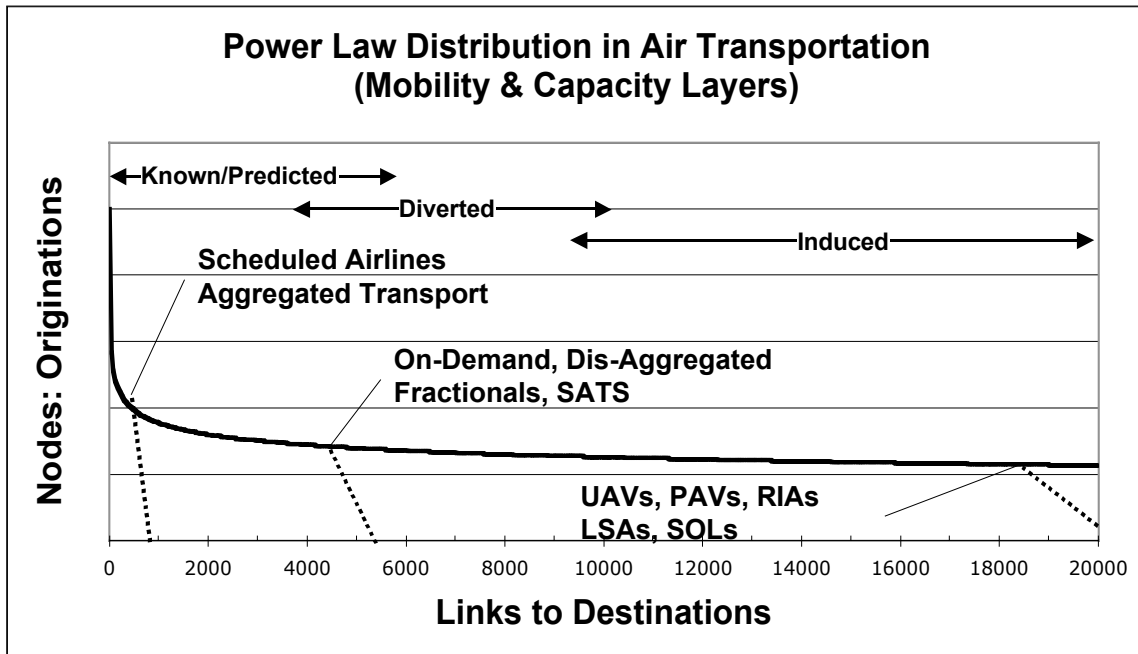
Lower Weight Systems

- Durable, damage-tolerant structures
- Minimum gage materials and design
- Active control simplified high-lift

Scale-Free Distribution of NetJets Operations



- The links (operations) from a few of NetJet's nodes in NJ to their top ten destinations from NJ nodes (originations) follow a power law distribution.
- For NetJets, this distribution of nodes with links extends out to about 1250 airports annually.

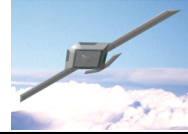


Small World Behaviors in Air Transportation Topologies

- Hub-and-spoke exhibits single-scale (truncated)
- Regional jet operations exhibit single-scale (truncated)
- SATS Jet-taxi operations (5,000 airports) exhibits broad scale
- Self-operated rural/regional PAVs exhibits broader scale
- Intra-urban PAVs approach scale-free



Air Vehicles for New Missions



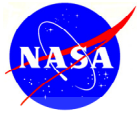
Science platforms

Develop innovative air vehicles for science missions in the earth's atmosphere and beyond



Hazardous environments

Enable uninhabited air vehicles to fly in hazardous environments



HALE UAV for Earth Science Measurements

Goal: Long-endurance, high altitude, unmanned flight



ERAST program begins (1994)

Technology Development (TRL1-6)

Pathfinder (1995)



Reached 50,000 ft during a 12-hr flight

Helios (2001)



Reached 96,000+ ft



Mobile Imaging Demonstration (2002)

Technology Demonstration (TRL7-9)



Cloud-free images of coffee plantation obtained after 4-hr loiter showed areas ready for harvest.



Superior Air Power



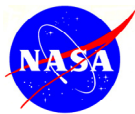
Technological superiority

Cooperatively develop technologies that enable air superiority

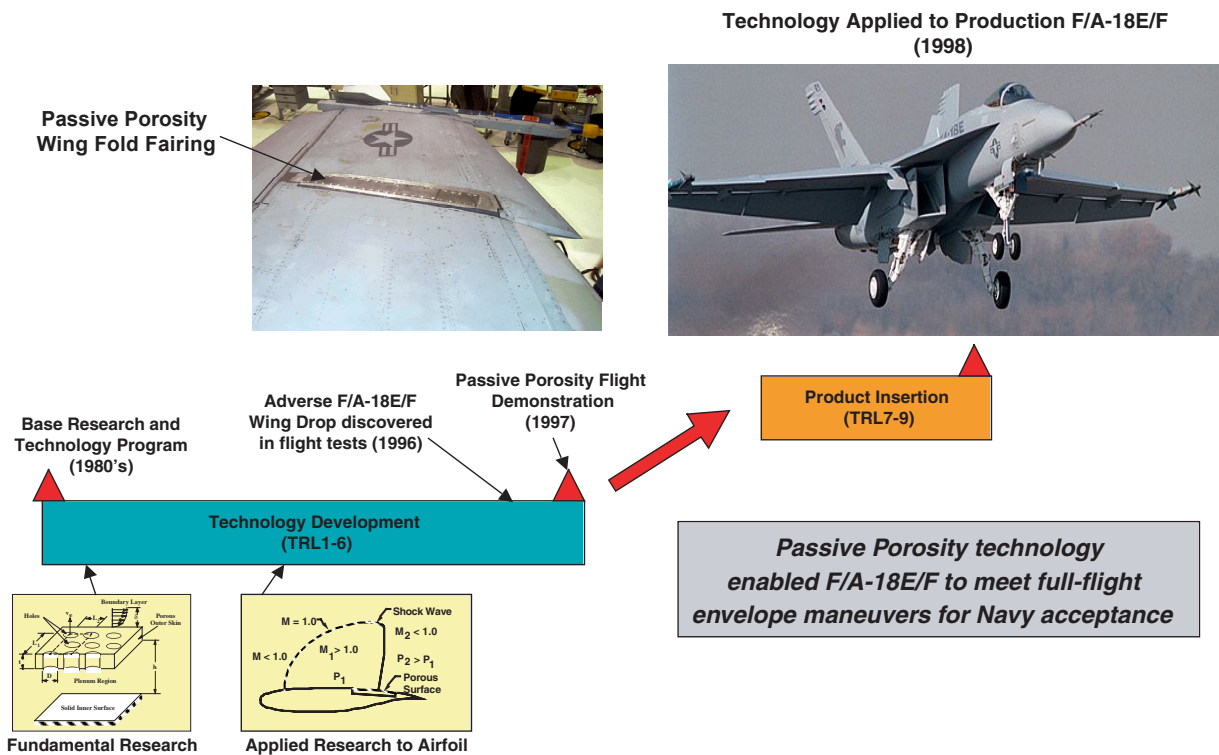


Partners in freedom

Support the development of advanced military aircraft



Passive Porosity Technology for F/A-18E/F Wing Drop





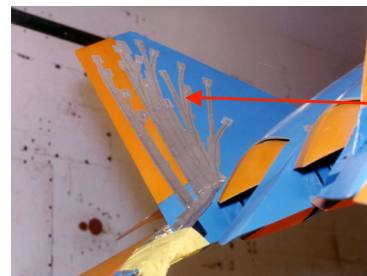
Support of DOD Programs - F-22

F-22 Tail Buffet Survey



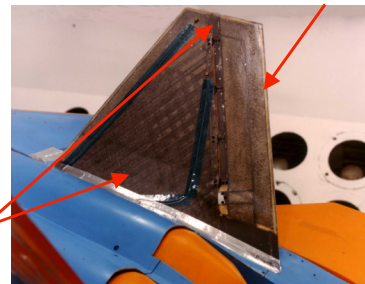
13.5% Scale F-22 in
LaRC Transonic Dynamics Tunnel

Port Fin - Rigid



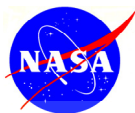
Pressure
Transducers

Starboard Fin - Flexible



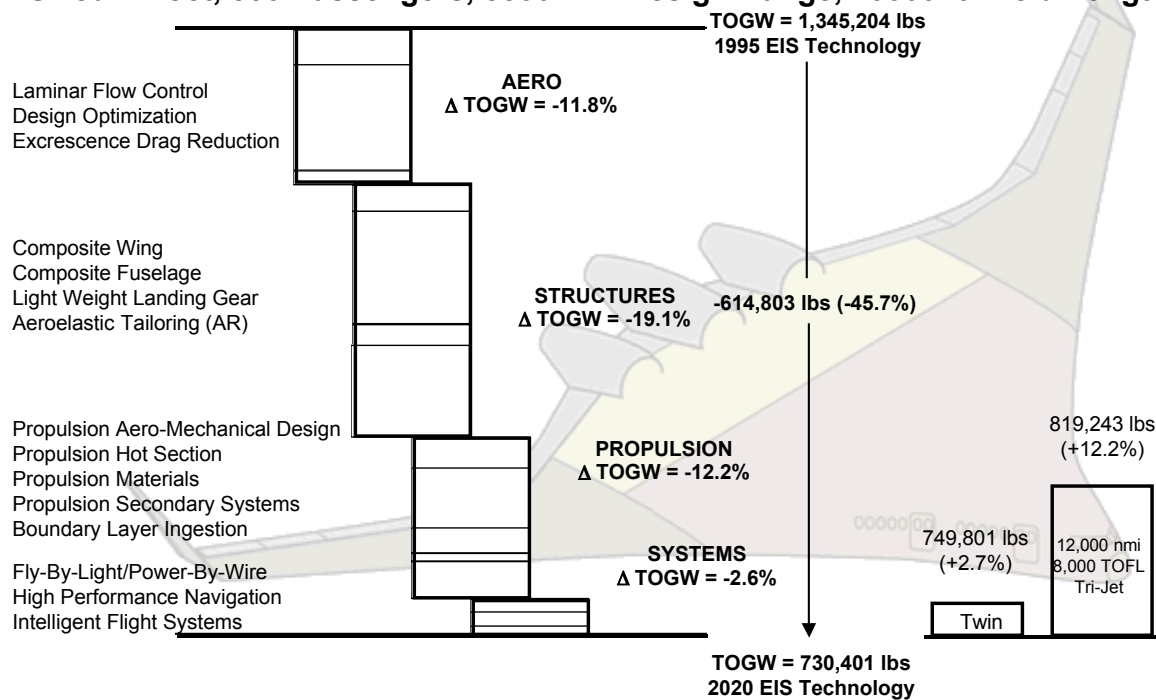
Active
Rudder

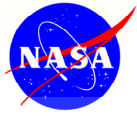
Accelerometers



LONG HAUL/HIGH CAPACITY BWB SUBSONIC TRANSPORT

Sized Tri-Jet, 800 Passengers, 8500 nmi Design Range, 10000 ft. Field Length





Vehicle Sectors



Subsonic

Vehicle capabilities defined
within each sector



Supersonic



**Personal Air
Vehicle**

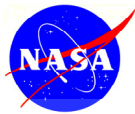


**Uninhabited
Air Vehicle**

Technology goals defined
to support capabilities



**Runway
Independent
Aircraft**



Innovative Vehicle Concepts to Identify Key Technology Requirements



Minimum environmental impact, maximum efficiency

Clean Transport



Strengthen national security through rapid deployment and global reach

Global Strike



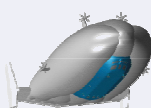
Conduct extended science and exploration missions

Planetary Flight Vehicles



All hour access to any location without noise disturbance

Santa Monica at Midnight



Global reach and on-demand delivery

Global Reach Transport



Rural, regional, and intra-urban transportation

Personal Air Vehicle



Rural and regional economic growth, time critical transport

Heartland Express



Automated refueling capability, ultra-long endurance, wide speed range

Tanker



Enables city center access in all weather

V/STOL Commuter



Expands the use of existing airport infrastructure

Extreme STOL Transport



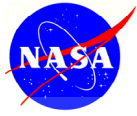
Reduce passenger flight time by at least a factor of 2

Supersonic Overland



High altitude observations for science and defense

High Altitude Long Endurance



Runway Independent Aircraft (RIA) Technology Goals



RIA is one of 5 vehicle sectors



Technology Areas	Goal	SOA
C _L max	10	7
L/D	16	12
Community Noise (Outside Fence)	55 EPNdB	Stage 3
Flight Controls	CAT IIIC	Special VFR
Hover Efficiency (EW/HOGE GW)	0.56	0.68
SFC	SOA -35%	SOA
Engine T/W	SOA +120%	SOA
Empty Weight Fraction	0.52	0.63
Cabin Noise	75dBA	88dBA
Cabin Vibration	0.03g's	0.10g's



Strategic Technology Focus Areas

Six long-term technology focus areas

- Key long-term investment areas
- Primary places where technology advances will occur
- Projects achieve finite steps within these areas

- *Environmentally Friendly, Clean Burning Engines*
Focus: Develop innovative technologies to enable intelligent turbine engines that significantly reduce harmful emissions while maintaining high performance and increasing reliability
- *New Aircraft Energy Sources and Management*
Focus: Discover new energy sources and intelligent management techniques directed towards zero emissions and enable new vehicle concepts for public mobility and new science missions
- *Quiet Aircraft for Community Friendly Service*
Focus: Develop and integrate noise reduction technology to enable unrestricted air transportation service to all communities



Strategic Technology Focus Areas (contd)

- *Aerodynamic Performance for Fuel Efficiency*
Focus: Improve aerodynamic efficiency, structures and materials technologies, and design tools and methodologies to reduce fuel burn and minimize environmental impact and enable new vehicle concepts and capabilities for public mobility and new science missions
- *Aircraft Weight Reduction and Community Access*
 - *Focus: Develop ultralight smart materials and structures, aerodynamic concepts, and lightweight subsystems to increase vehicle efficiency, leading to high altitude long endurance vehicles, planetary aircraft, advanced vertical and short takeoff and landing vehicles and beyond*
- *Smart Aircraft and Autonomous Control*
Focus: Enable aircraft to fly with reduced or no human intervention, to optimize flight over multiple regimes, and to provide maintenance on demand towards the goal of a feeling, seeing, sensing, sentient air vehicle



- Inherently Multidisciplinary
- Exploit vehicle flexibility and adaptability (e.g. localized and large-scale vehicle shape change)
- Colonies of distributed sensors and actuators
- A paradigm shift from
 - Steady to the unsteady world (e.g. flow control, adaptive morphing)
 - Passive to active,
 - Rigid to design for flexibility,
 - Few discrete to many distributed (e.g. sensors, control surfaces)
 - *To obtain a vehicle that is always at optimum performance.*
- *Therefore, the greatest technical challenges and opportunities occur at the intersection of disciplines*
 - *but the real barrier may be cultural, not technical*

Summary

- **Materials and structures technology advancements are required to achieve performance goals for next generation air vehicles**
- **Smart Materials and adaptive structures which enable flow control can significantly improve aerodynamic performance**
- **Advancements in process and manufacturing technologies critical to cost effective air vehicle structures**
- **Computational modeling essential to design of nano-materials and bio-inspired materials and structures**

**MATERIALS AND MANUFACTURING
TECHNOLOGIES FOR THE 21ST CENTURY**
Alan G. Miller

Chief Engineering for Structures
Boeing Materials Technology
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Alan G. Miller



Boeing Commercial Airplanes



BOEING

7E7



Integrated Defense Systems



DISCOVERING THE SECRETS OF THE WRIGHT BROTHERS

Robert L. Ash

Interim Vice President for Research
Old Dominion University
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Norfolk, Virginia 23529

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**DISCOVERING THE SECRETS OF THE
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Telephone 757-683-3460

e-mail rash@odu.edu



West Virginia and Virginia are “sandwiched” by Ohio and North Carolina! --We don’t have a dog in the fight!--

The third and fourth children of Bishop and Mrs. Wright



Bishop Milton Wright
1828-1917



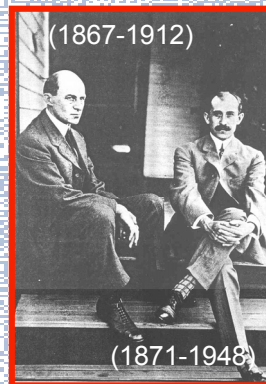
Susan Koerner Wright
1831-1889



Reuchlin Wright
1861-1920



Lorin Wright
1862-1939



Katharine Wright
1874-1929



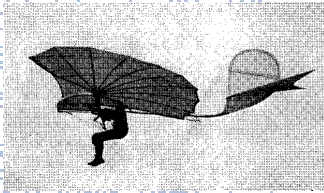
- 1883 Moved to Dayton
 - 1892 Bicycle Shop
 - 1896 Events
 - 1899 Wing warping
- Getting Serious!



Kitty Hawk, North Carolina
(1900-1905)

Otto Lilienthal's Gliders

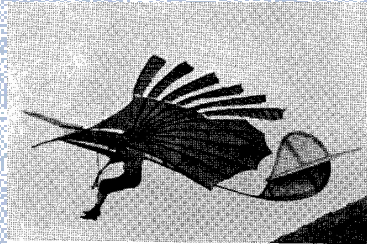
- Photography and the Press discovered aeronautics
- More than 2000 flights, using c.g. flight control



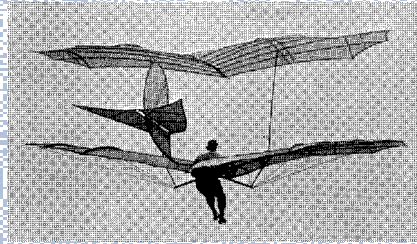
Number 11



↕ Number 13



Number 16



Lilienthal died from his glider crash injuries on August 10, 1896

Wilbur and Orville Wright--more than lucky bicycle mechanics

- ◆ Though neither graduated from high school, Wilbur completed a course in trigonometry
- ◆ Printing business 1881-1892
- ◆ Bicycle business 1892-1916



Invention of the Safety
Bicycle

- 10-million sold in US in 1890s
- Technology marvel
- Stability and Control testbed
- Wrights design and build bicycles--starting in 1896
- Business is good!

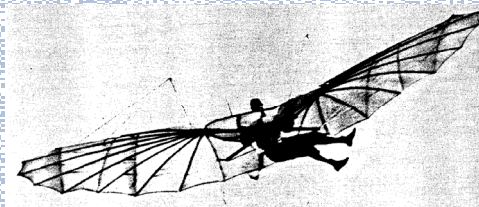
1896—A Pivotal Year

- ◆ Samuel P. Langley's steam-powered aerodrome



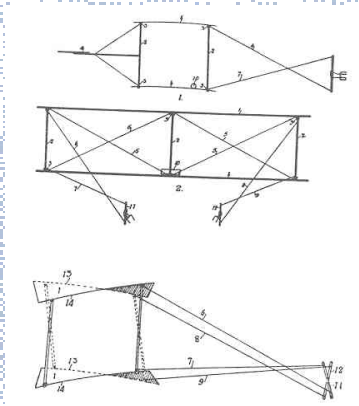
Aerodrome No. 5
Weight: 26 lbs.
Wingspan: 4 m
Cambered wings
Flew May 6, 1896
80-90 s, 2300-3300 ft.

- ◆ Lilienthal's fatal crash in August



- ◆ Orville's 6 wk. battle with typhoid fever—Wilbur was care giver.

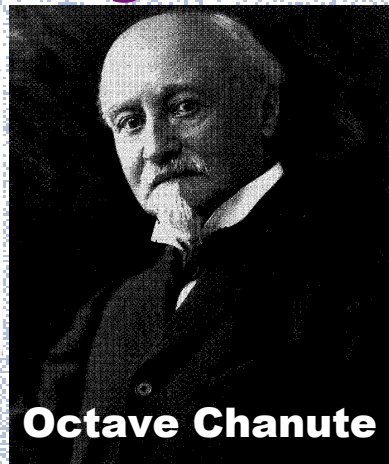
Wilbur's Idea of Wing Warping and their quest for flight.



Sketch of Wing-Warping Control Concept of 1899



1906 Patent



Octave Chanute

World aviation authority, became Wrights' mentor in 1900. (**Eclipsed by 1902**)

Learning to Fly led to Systems Engineering

- ◆ System Engineering Approach
 - Structures (Pratt Truss)
 - Integrate Controls with Airframe
 - Aerodynamics (Wind Tunnel Testing)
 - Propulsion ("Lightweight engine")
 - Efficient Propellers (Breakthrough!)
- ◆ Build it and Fly it (**Glider Systems 1st**)



1900 Glider

- Demonstrated Wing Warping
- Smaller than "design" 18' x 16'
- Unexpected angles of attack
- Few piloted flights
- Lower drag than expected

All they had to do was go back to Dayton and build a bigger glider for the summer of 1901!

1903 Machine Flight Test Program



1903 Flyer in construction

Wright Flying Machine Reproductions

- Wright Model B (3)
 - 1899 Kite
 - 1900, 1901, 1902 Gliders
 - 1903 Wright Flyer (2)
- Other Wright Reproductions
- Bicycles
 - Wind Tunnels
 - '03, '04 and 'bent end' propellers

Rochester Institute of Technology

R·I·T

Wind Tunnel Tests

- '03, '04 and 'bent end' Wright Propellers
- Model B airfoil sections
- '01 and '02 Wright gliders

Dynamometer Tests

- 1903 Wright Flyer Horizontal four
- Production Wright Vertical four



Vertical Four dynamo tests

Testing 1901 Wright Glider Reproduction in LFST in 2001

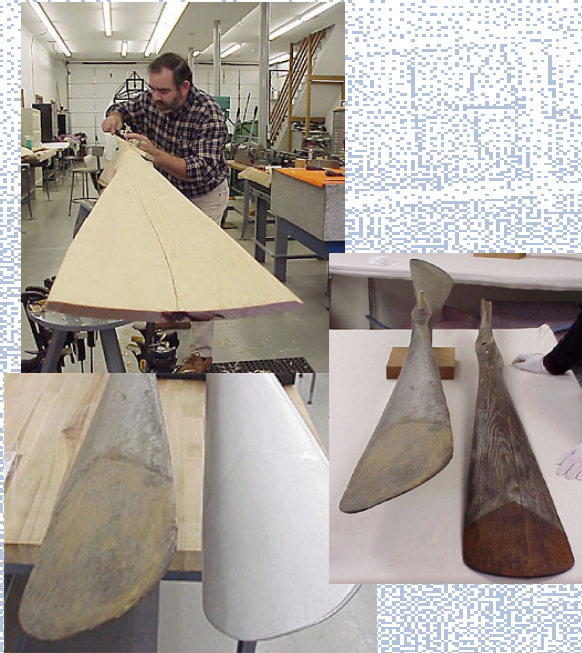




1902 Glider validated Wright Aeronautical Theories

- **Airfoil behavior consistent with wind tunnel data**
- **Three axis flight control (with hinged rudder)**
- **L/D consistent with predictions**

Reproducing a Wright Propeller



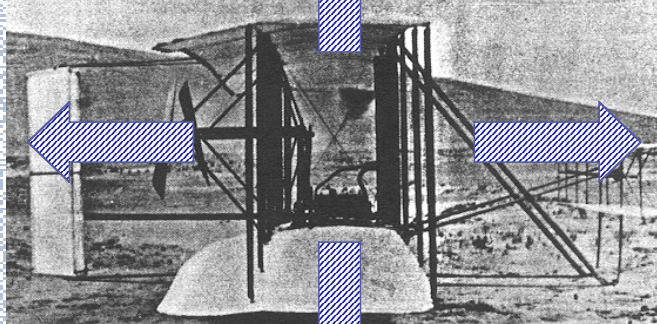
- ◆ Wright Brothers' Documentation & Photographs
- ◆ Find a Propeller
 - Digitize It
 - Correct for Aging
 - Create Templates
- ◆ Duplicate Everything!
- ◆ **Expensive**

An Exquisite Balance of Systems

- On December 17, 1903, the 4th flight covered 852 ft. in 59 seconds and sustained equilibrium flying conditions. **The actual aircraft performance can therefore be reliably analyzed on the basis of Thrust=Drag, and Lift=Weight, using original data--and an exact reproduction of the '03 Flyer.**

Drag

- Feb. 2003 ODU full-scale tests
- 2000 AIAA full-scale wind tunnel tests
- Supported by previous sub-scale data



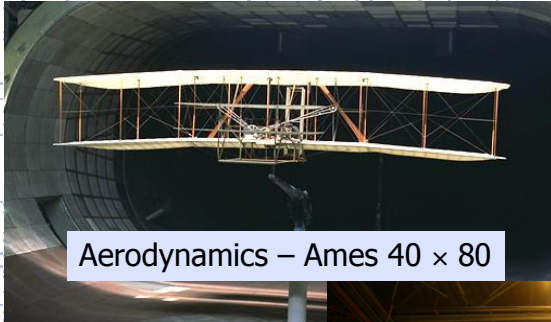
See Weight and Drag

Thrust

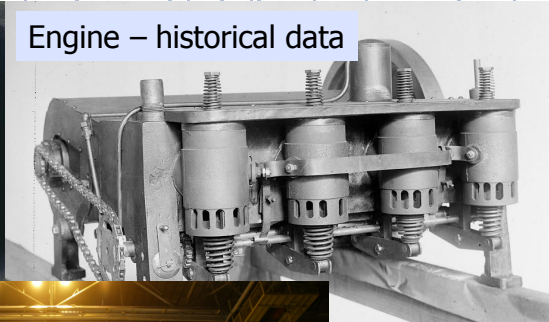
- Engine data from historical sources
- Propeller data from recent full-scale ODU/Wright Experience wind tunnel tests

Weight

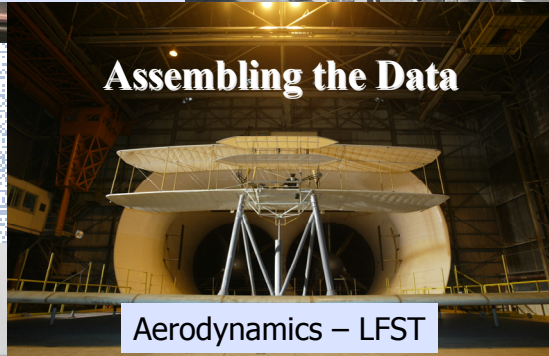
- Reliable historical data



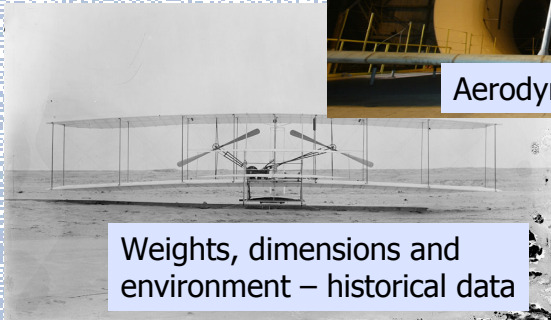
Aerodynamics – Ames 40 × 80



Engine – historical data



Assembling the Data



Weights, dimensions and environment – historical data



Propeller – ODU LFST

Aerodynamics – LFST 2002

- A Wright Experience 1903 airframe was tested in the Langley Full-Scale Tunnel, power-off and power on. Cruise conditions were fully simulated.



Preliminary Results

Measured:

- All 6 force/moments
- α & β
- Canard deflections
- Wing warp angles
- Some Flow Viz.
- Stick forces



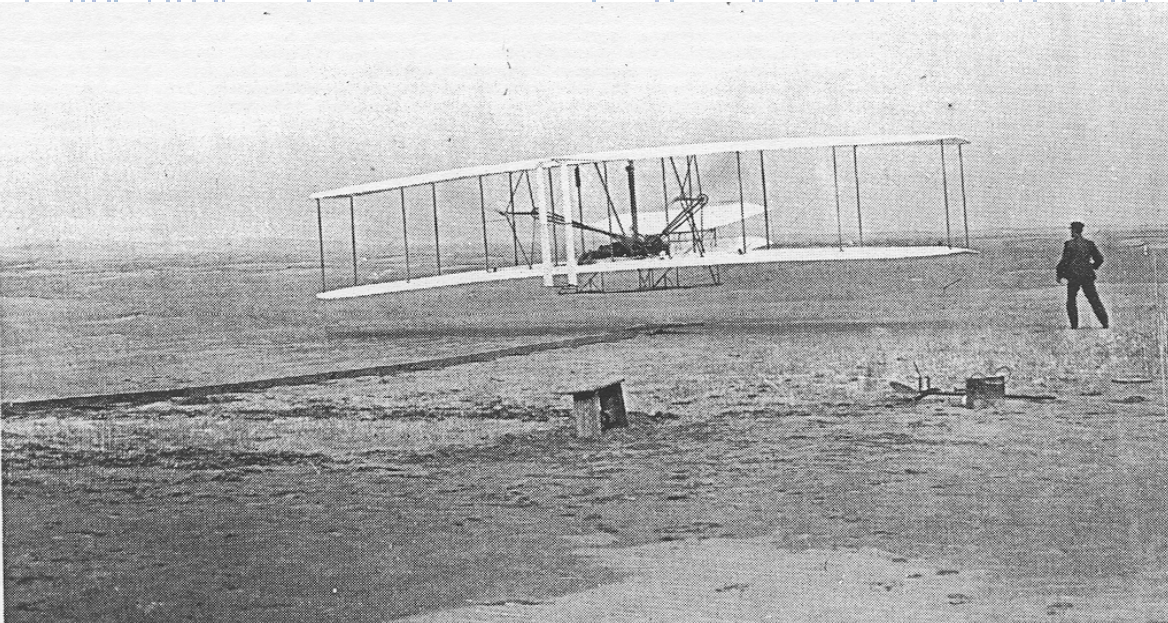
Test Conditions:

- Up to 1.2 q cruise
 - $-2^\circ < \text{AOA} < 16^\circ$
 - Up to 25° Sideslip
 - Prop. Speeds to 380 RPM
 - Full Control Deflections
- 30 hrs of tests; 6 hrs powered

- **Flight Performance: Marginal**
- **Sufficient Power for Flight**
 - More than 12 HP in flight
- **Airframe is airworthy**
- **“Sufficient” Control Authority**
- **Strongly Non-linear Aero.**

Critical Need for High-fidelity Flight Simulation

The Wrights did not consider the brief hop on Dec. 14th to be a true flight since the take-off run was downhill.



First flight, 10:35 AM, December 17, 1903

12 Pages
In Two Parts

Virginian-Pilot

True to the Democratic Party
IN VICTORY OR DEFEAT

VOL. XIX. NO. 68 NORFOLK, VA FRIDAY DECEMBER 18, 1903 TWELVE PAGES THREE CENTS PER COPY

FLYING MACHINE SOARS 3 MILES IN TEETH OF HIGH WIND OVER SAND HILLS AND WAVES AT KITTY HAWK ON CAROLINA COAST



NO BALLOON ATTACHED TO AID IT

Three Years of Hard, Secret
Work by Ohio Brothers
Crowned with Success

ACCOMPLISHED WHAT LANGLEY FAILED AT

With Man as Passenger Huge
Machine Flew Like Bird
Under Perfect Control

BOX KITE PRINCIPLE WITH TWO PROPELLERS

The problem of aerial
navigation without the use of a
balloon has been solved at last.
Over the sand hills of the
North Carolina coast yesterday

Sunday Registration and Reception

**Sponsored by
Boeing Company**

Registration



Lloyd Evans



Diana LaClaire, Martha Jacobs, Marsha Mullins

Virginia Air & Space Center Reception



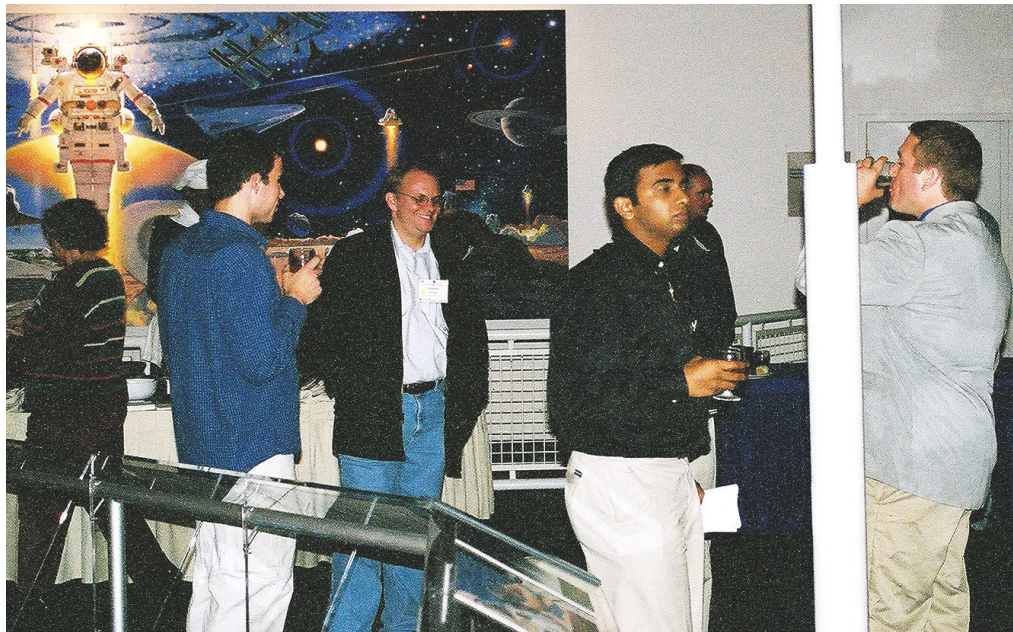
Clarence Ashe



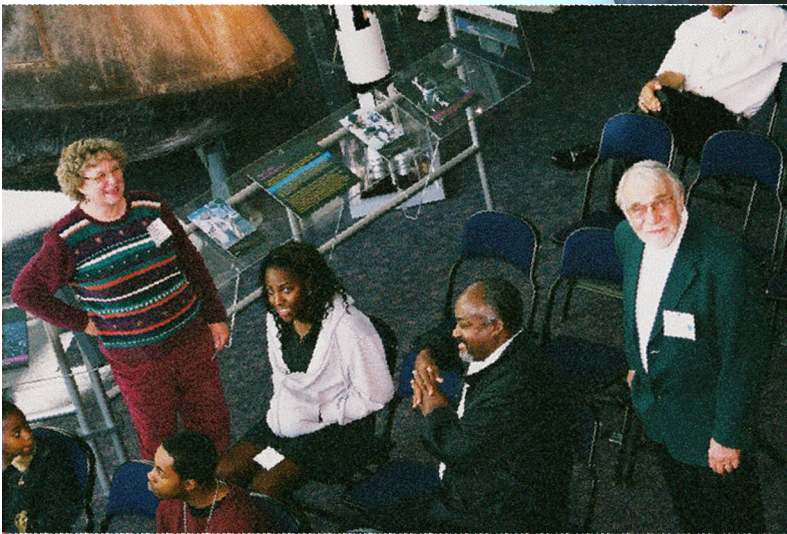
Edwin Prior, Norbert Smith







Program for Spouses



Spouses Program



Evelyn McKenney

**STRUCTURES AND MATERIALS COMPETENCY
VISION AND PURPOSE AT NASA LANGLEY
Mark J. Stuart**

Director
Structures and Materials Competency
NASA Langley Research Center
MS 121
Hampton, Virginia 23681-2199

Telephone 757-864-3492
Mark.J.Stuart@nasa.gov



Mark J. Stuart

Structures & Materials Competency Vision and Purpose

Vision

The revolutionary materials and structures technologies developed at NASA Langley Research Center meet the needs of the Aerospace Community and benefit the quality of life on Earth

Purpose

Develop and deliver useable research and technology results to meet Agency program objectives and to enable the Agency to develop future aerospace materials and structures

Areas of Expertise

-From materials synthesis to large scale structural validation-

AoE1: Materials
synthesis
& processing



AoE 2: Analytical
and computational
methods



AoE3: Structural concepts,
behavior, durability, & damage
tolerance



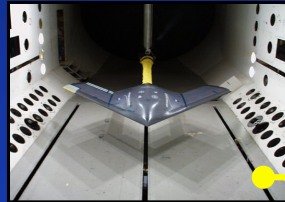
AoE 4:
Nondestructive
evaluation



AoE5: Structural
dynamics &
landing dynamics



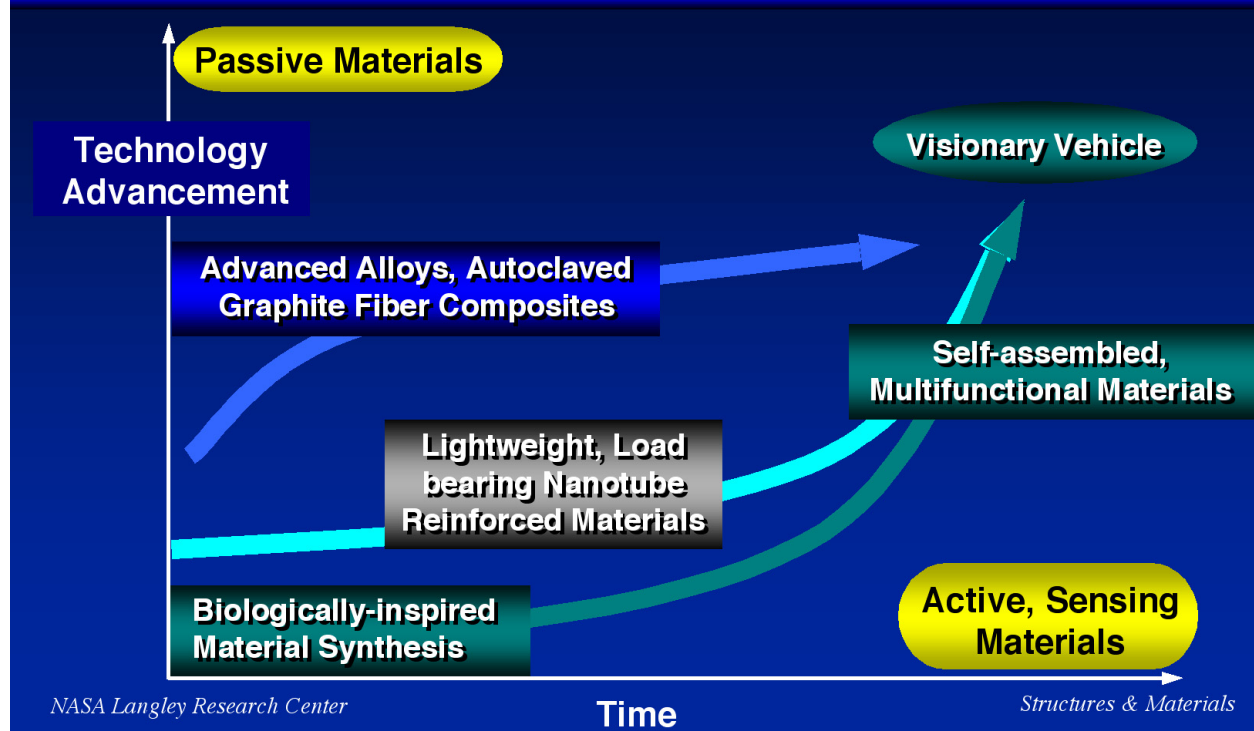
AoE6: Aeroelasticity
& unsteady
aerodynamics



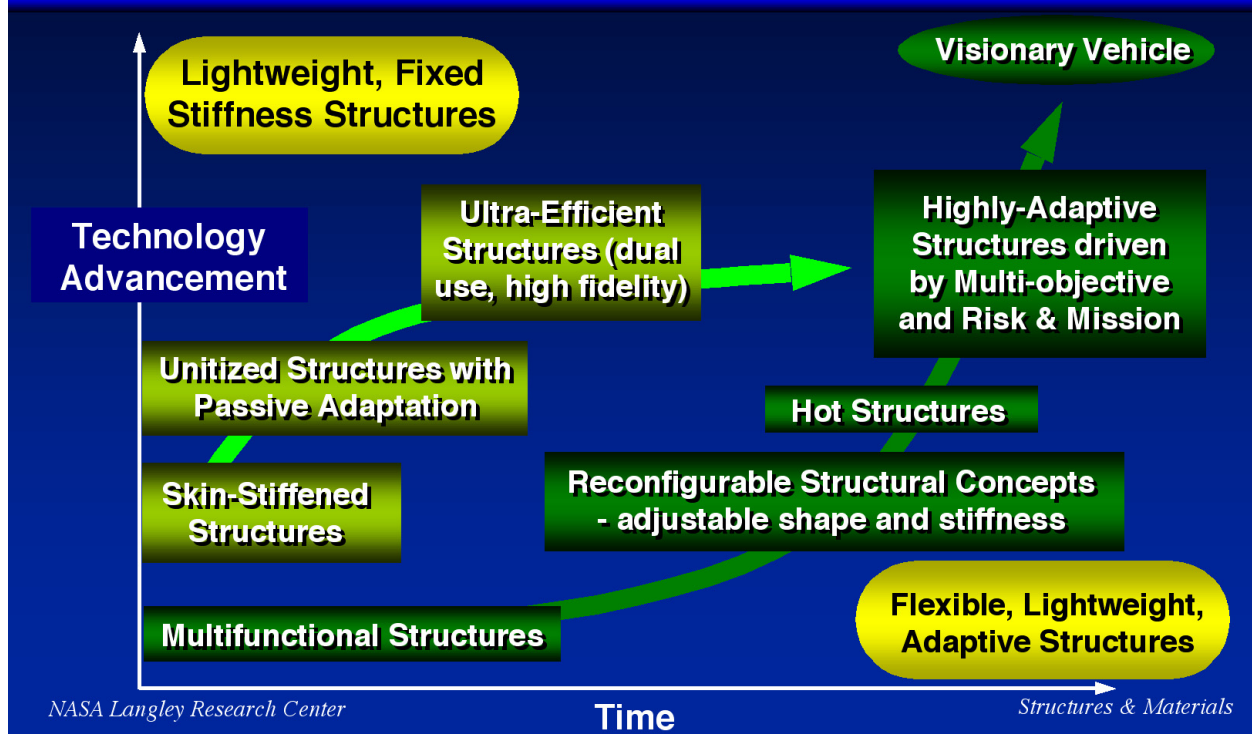
AoE7: Experimental methods
& laboratory operations



Materials Technology Development



Structures Technology Development





NASA's Vision

To improve life here,
To extend life to there,
To find life beyond.

NASA's Mission

To understand and protect our home planet
To explore the Universe and search for life
To inspire the next generation of explorers

...as only NASA can.

NASA Langley Research Center



Founded in 1917

- First civil aeronautical research laboratory

Programs

- \$737M total FY 02 budget

Facilities

- \$4 billion replacement value

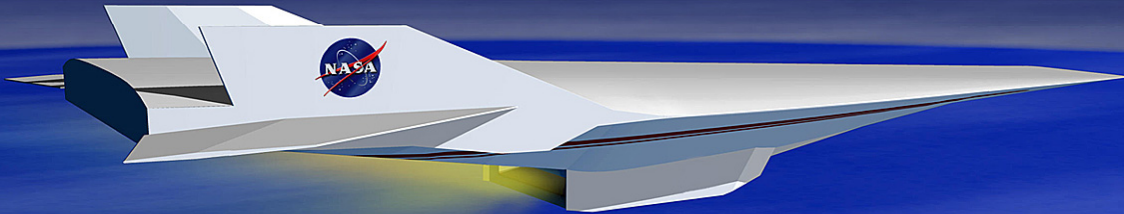
People

- 2365 Civil Servants
- 2052 Contractors

[Research & Mission](#)

Langley Mission

In alliance with industry, other agencies, academia,
and the atmospheric research community,
in the areas of aerospace vehicles,
aerospace systems analysis and atmospheric science
we undertake innovative, high-payoff activities
beyond the risk limit or capability of commercial enterprises
and deliver validated technology, scientific knowledge
and an understanding of the Earth's atmosphere



Our success is measured by the extent
to which our research results improve the quality of life

**PLASTI-BONE™: A PROPRIETARY, NEW CLASS OF
BONE IMPLANTS FOR TISSUE ENGINEERING**

Dr. Ranji Vaidyanathan

Manager, Advanced Materials
Advanced Ceramics Research Inc.
3292 East Hemisphere Loop
Tucson, Arizona 85706-5013

Telephone 520-434-6391
rkv@acrtucson.com



Dr. Ranji Vaidyanathan

Advanced Ceramics Research, Inc.

Plasti-Bone™

**A Proprietary, New Class of Bone Implants
for Tissue Engineering**

**Ranji Vaidyanathan, Ph. D
Manager, Advanced Materials**

Contact Information:

(520) 434- 6392

rkv@acrtucson.com



Business Environment

- **Increased Need for Replacement Body Parts for Aging Population**
- **Increased Use of New Materials for Tissue Engineering**
- **Within DoD, Battlefield Personnel and Aging Veterans Need Replacement Body Parts**



Total Available Market

- **Global Orthopedic Market - \$9.8 Billion in 1999**
- **\$13.6 Billion by end of 2002**
- **Tissue Engineering Market - \$80 billion-2010**



Market Trends

- **Compound Growth of 11-12%**
- **Bone Substitution and Orthobiologics Sectors Have Grown by over 450% since 1999**
- **Demographic Changes and Aging Population Will Drive the Market**



Technical Background

- **Problems with the current technology**
 - **Loss of strength of the scaffold/implant occurs before substantial mass is lost**
 - **Most resorbable materials become too weak to carry any load before bone growth, e.g., PLA/PGA**
 - **Concern about collagen based products due to source (e.g., mad cow disease)**



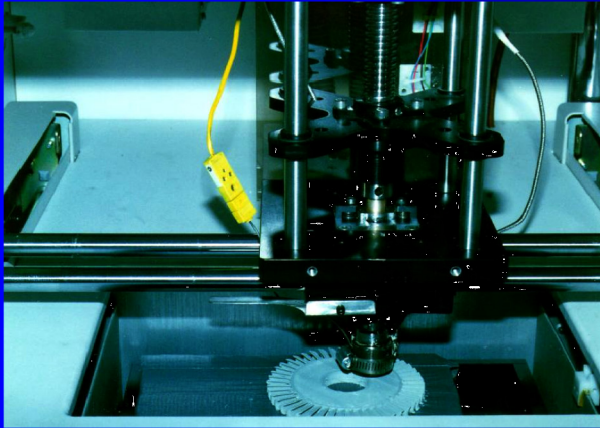
ACR Materials and Methods

- **Polymer ceramic composites to combine advantages such as toughness, high strength, biodegradability**
 - **PBT blend scaffolds produced via EFF: strength, slow degradability, and porosity**
 - **Scaffolds coated with calcium phosphate (TCP) in a polycaprolactone (PCL) binder: osteoactivity, benefits of TCP**
 - **Rapid prototyping of bone implants: custom fitted to patients, and reduced manufacturing lead time**



Processing Methods

- EFF and RP Manufacturing
 - Appropriate for high temp polymers
 - Based on tomography data
 - Reduced fabrication time



ACR PlastiBone™

6F SUNDAY, AUGUST 17, 2003 **NEWS ILLUSTRATED** sun-sentinel.com/theedge • SOUTH FLORIDA SUN-SENTINEL

Plasti-Bone, an innovative technology funded by the military, one day may be used to create custom artificial grafts to repair shattered or diseased bones.

The future of bone repair

Difficulty of treating severely damaged bones

Clean breaks and fractures are relatively easy to fix—they usually just need to be pushed into alignment and set with a cast.

Severely fractured or diseased bones are more difficult to stabilize—standard treatments include metal pins and rods, bone grafts, or, as a last resort, amputation. If they heal improperly, they can leave patients with weakened or shortened limbs.

How Plasti-Bone works

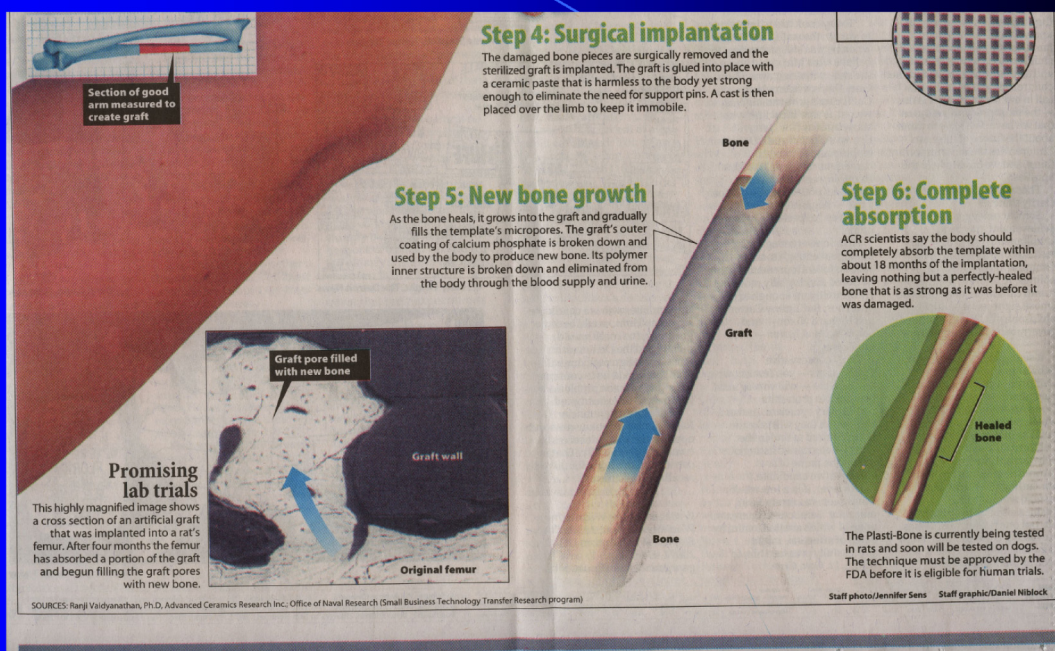
Plasti-Bone, an experimental technique developed by Advanced Ceramics Research (ACR) for the Office of Naval Research, uses a 3D printer to create custom artificial bone grafts designed to help damaged bone portions grow back as good as new.



ACR PlastiBone™



ACR PlastiBone™



Features, Advantages, Benefits

Feature	Advantage	Benefit
Osteoconductive	Increased bone cell diffusion	More rapid healing
Biocompatible	Non-toxic	Toxicity and rejection issues minimized
Bioresorbable	Complete breakdown within the body	Eliminates need to remove foreign parts
Matched properties	Similar mechanical properties to bone	Reduced risk of matrix damage during healing



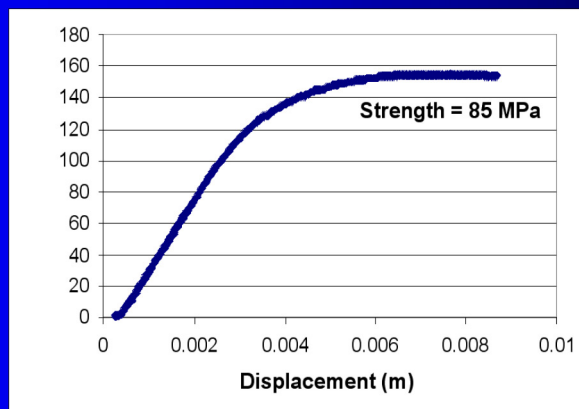
Performance Comparison

Comparison With Existing Technology		
	Benefits	Limitations
Titanium Implants (Knee, Hip, and Scofflding Systems)	~ Load-Bearing ~ Durable	~ Permanent ~ 20% Fail Rate after 10 Years ~ Reduces Functionality ~ Long Recovery Period ~ Not Patient Specific
Pastes and Powders (Biogran TM , OP-1 TM , Allomatrix TM)	~ Resorbable ~ Limited Customization Capabilities	~ Not-Load Bearing ~ Frequently Resorb Too Quickly ~ Can be Difficult in Application
PlastiBone by ACR	~ Load-Bearing ~ Resorbable ~ Patient Specific ~ Rapid Manufacturing ~ On-Site Fabrication ~ Stimulate Bone Growth	~ Restricted Use if Thickness is Under 4mm



Mechanical Performance of RP Materials

- Strength varies from 25-80 MPa depending on porosity for PBT blends.
- Modulus of PBT blend is 4.3 GPa. Comparable values for PLA are 50 MPa strength and 3 GPa modulus.
- Short term degradation did not indicate strength or modulus loss for PBT blends.

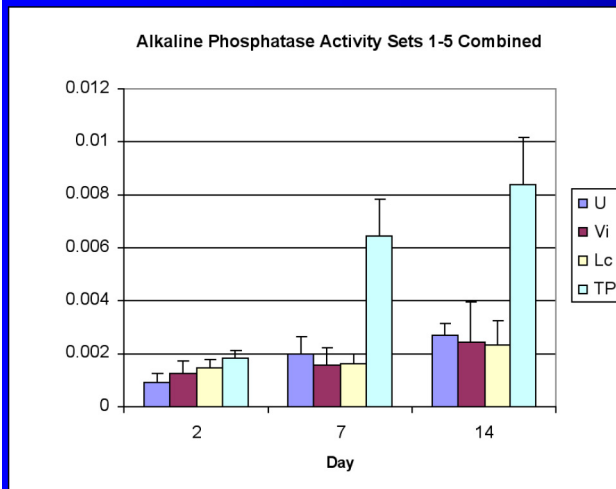


In Vitro Results

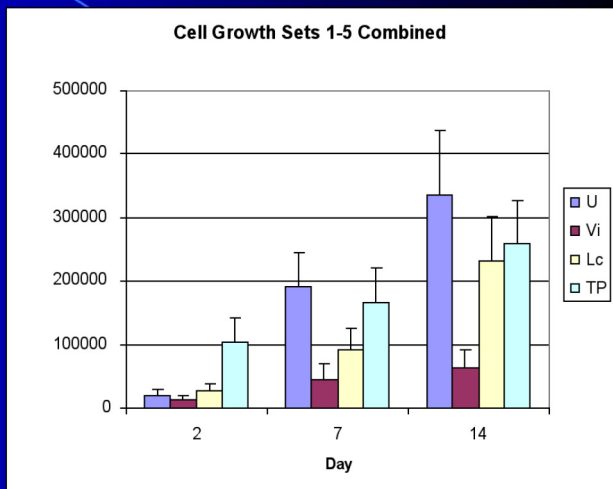


Cell growth seen through the sides of the three types of samples after 14 days

In Vitro Results



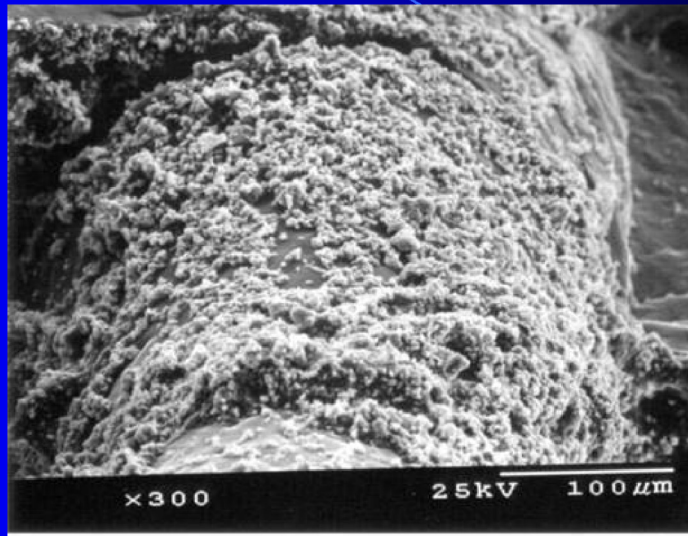
Alkaline phosphatase activity results on impregnated PBT samples after two, nine and fourteen days for all five sets



Cell growth results on impregnated PBT samples after two, seven and fourteen days for all five sets

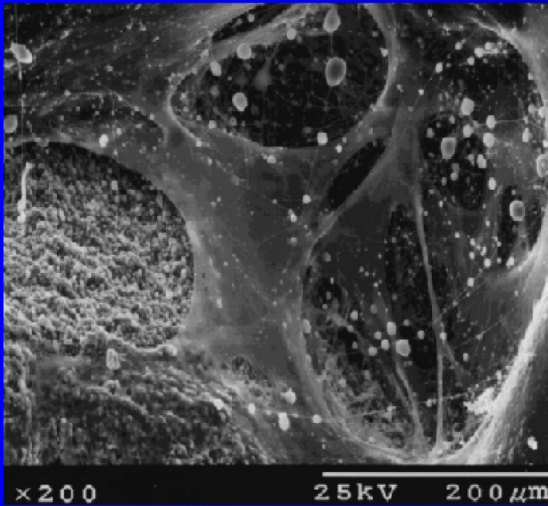


In Vitro Results

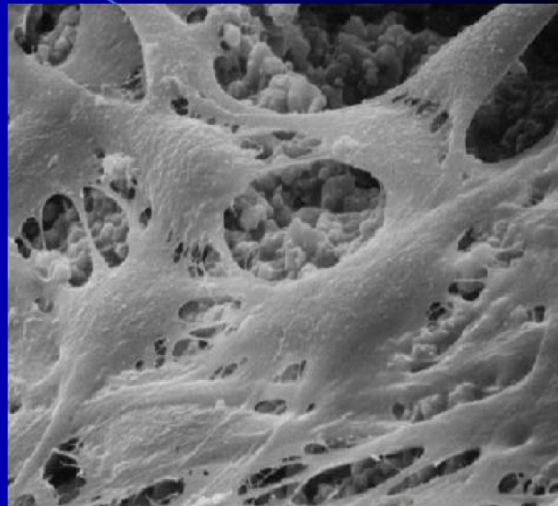


Latex Coated Scaffolds Showing a Uniform Coating

In Vitro Results



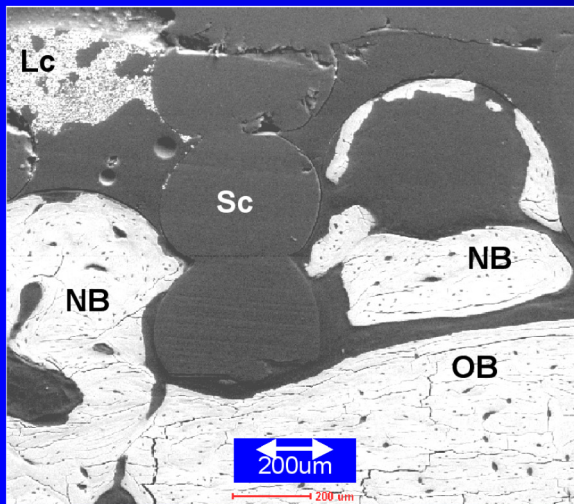
Bone derived cells growing on latex coated PBT scaffolds treated with TGF-beta1



Cartilage derived cells growing on latex coated PBT scaffolds



In Vivo Results

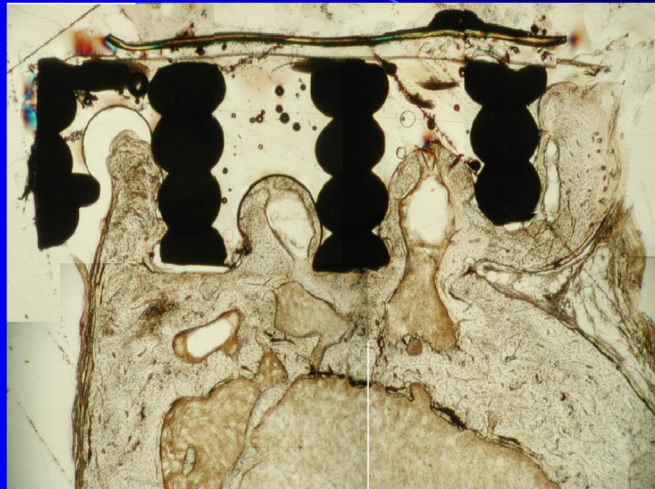


Environmental SEM of
Implant Transverse Section

- OB – Old Bone
- NB – New bone
- Sc – PBT Scaffold
- Lc – PCL/TCP Latex Remnant
- ☐ Test Coupon Attached to Femoral Surface, Allowed 4 months of Ingrowth
- ☐ Bone Ingrowth into Pores Clearly Evident
- ☐ Osteons, Haversian Canals Visible in NB



In Vivo Results



Histology montage of a bone cross-section of a test animal: The dark areas are the implant material while the light areas are the bone growth areas.



Achieved Milestones

- Developed osteoconductive, biocompatible, and load bearing bone implants
- Produced implants using flexible rapid prototyping and EFF manufacturing
- Demonstrated customized fitting for the benefit of a broad range of patients



Future Plans

- ACR will partner with companies that have an established presence in orthopedic bone substitution & revision surgery arenas:
 - ❖ FDA Approval Process Experience
 - ❖ Higher Level Animal Test Models – 6/2004
 - ❖ FDA Applications – 6/2004
 - ❖ Begin Human Trials – 1/2005
 - ❖ Secure FDA Approval and Commercialize Product – 1/2006



Expectations from Partnership

- **Pursue further R&D efforts as follows:**
 - ❖ **Perform other animal models**
 - ❖ **In-vivo imaging and develop expertise in imaging capabilities**
 - ❖ **Contacts with commercial companies, if any**
 - ❖ **Perform human trials**



Marketing & Sales Objectives

- **Establish Joint Venture and/or Licensing Agreement – 12/2003**
- **Modify Product with Partner to Meet Customer Needs**
- **Train Partner's Established Sales and Distribution Network - 2005**



TURNING STUDENTS ON TO MATERIAL SCIENCE IN HIGH SCHOOLS

Duane R. Bushey

Teacher – Material Science, Manufacturing, Construction, Material Processing
Maury High School
322 Shirley Avenue
Norfolk, Virginia 23517

Telephone 757-628-3348
dbushey@infionline.net

and

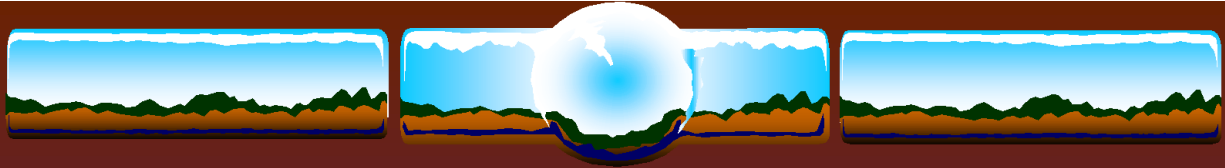
Roger Crider

Teacher – Material Science, Bio-Engineering, Bio-Technology
Landstown High School
2001 Concert Drive
Virginia Beach, Virginia 23456

Telephone 757-468-3800 ext. 2121
rlcrider@vbps.k12.va.us



Duane R. Bushey and Roger Crider

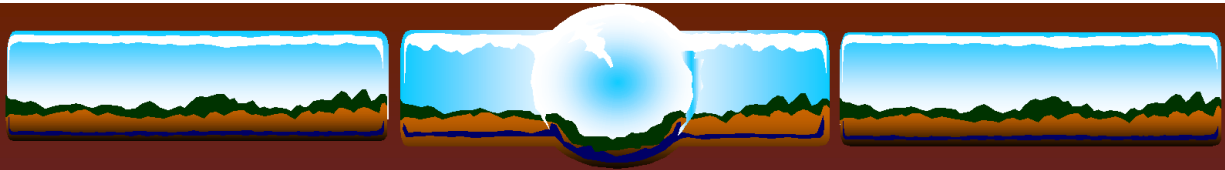


Material Science Technology

Duane Bushey – Maury HS, Norfolk

Roger Crider – Landstown HS, Virginia Beach

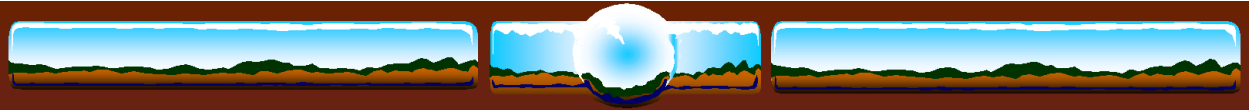
Who are you?



What Is MST?

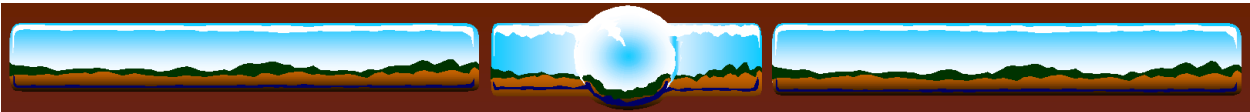
With appreciation to:

**Kathi Medcalf, Debbie Goodwin,
Andy Nydam, John Rusin**



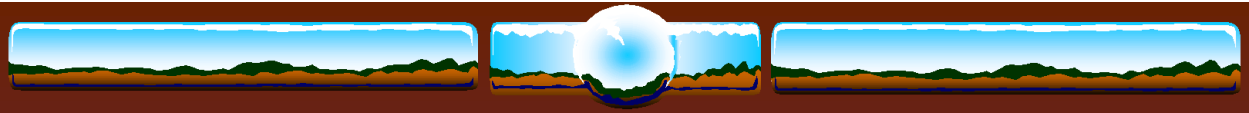
Material Science

- ❖ The science of “stuff”
- ❖ Multidisciplinary approach
- ❖ Chemistry, physics, engineering
- ❖ Designed for “team approach”
 - ❖ Science and technology teacher
- ❖ Hands-on, minds-on



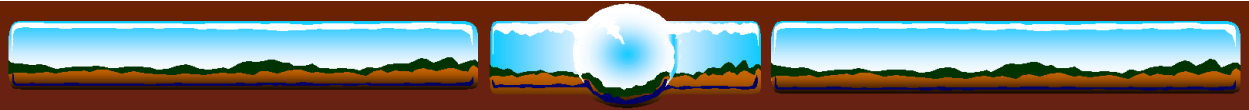
Units

- ❖ Introduction: general properties of materials
- ❖ Metals
- ❖ Ceramics and glass
- ❖ Polymers
- ❖ Composites



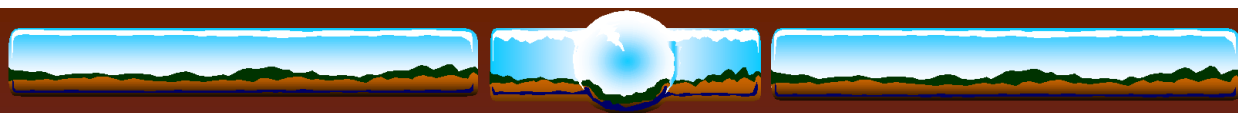
Prevailing Concepts

- ❖ Use journal
- ❖ Apply concepts throughout all units
- ❖ Look at “stuff” from micro to macro
- ❖ Learn why and how “stuff” does what it does...by understanding the properties of the “stuff”



How is it Offered?

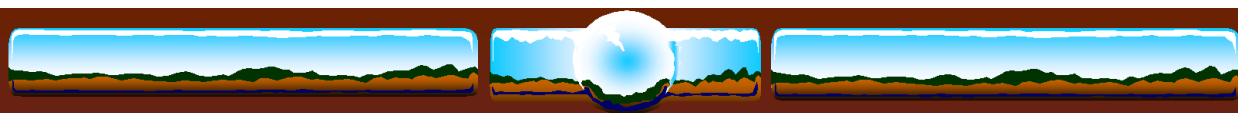
- ❖ Dedicated “stand-alone” class
- ❖ Incorporate into traditional science class
- ❖ Incorporate into technology classes
- ❖ Modules
- ❖ Other



Solids

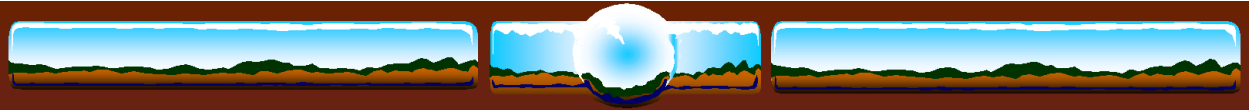
- ❖ Importance of materials science and technology.
- ❖ Solids are typically separated into four categories.
- ❖ Simple chemistry including chemical bonding, the periodic table, and oxidation-reduction.
- ❖ Crystal structures, physical properties.
- ❖ How metals are claimed from their ores.
- ❖ Importance of maintaining a student journal and keeping good records is stressed.





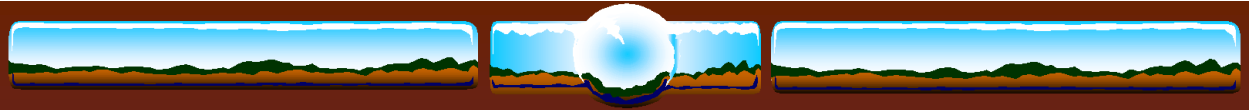
Solids Activities

- ❖ Material safety data sheets (MSDS)
- ❖ Identification of materials
- ❖ Formation of crystals
- ❖ Destructive testing
- ❖ Reactivity series of metals
- ❖ Oxidation/reduction of copper



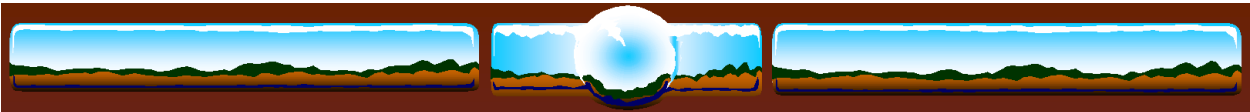
Metals

- ❖ Introduce the properties and historical developments of metals.
- ❖ Investigate mechanical properties of metals along with the effects of heat-treating.
- ❖ Study alloys and alloying techniques along with phase diagrams.



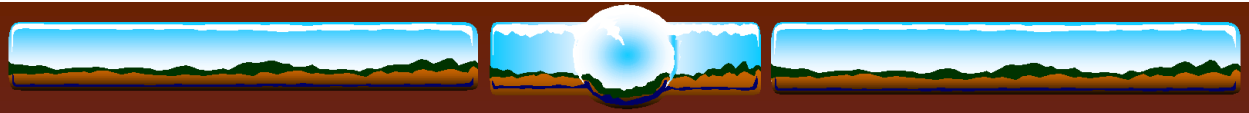
Metals

- ❖ Study testing of metals and manufacturing processes.
- ❖ A major project is the making of sterling silver jewelry using the process of lost wax casting.



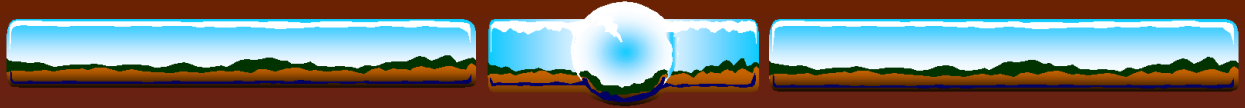
Video Clip

❖ Len Booth – Rolling Copper Wire



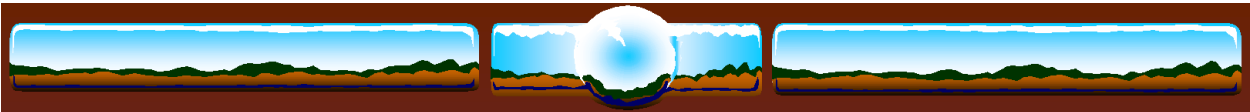
Metals Activities

- ❖ Rolling a coin
- ❖ Drawing a wire
- ❖ Alloying copper and zinc
- ❖ Cost of a penny -
- ❖ Making a light bulb
- ❖ Making tin-lead solder
- ❖ Annealing copper
- ❖ Powder metallurgy
- ❖ Lost wax casting



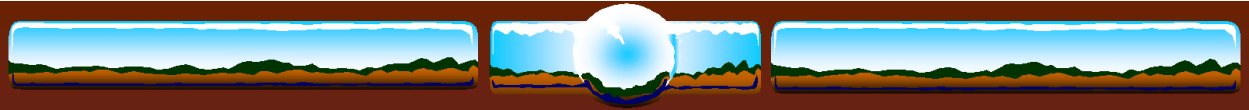
Ceramics & Glass

- ❖ Learn that most ceramics are crystalline solids.
- ❖ Study properties related to the ionic or covalent bonds that hold them together.
- ❖ Learn that glass has different properties than most ceramics due to the amorphous structure of glass.
- ❖ Study processes used to manufacture ceramics including a stained glass and a Raku pottery project.



Video Clip

❖ Len Booth – Glass Bending & Blowing



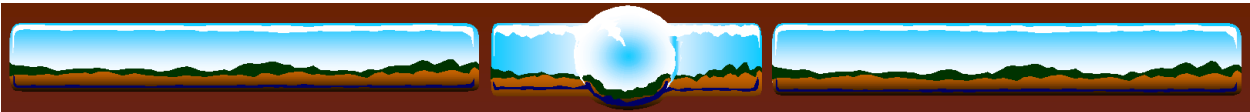
Ceramics & Glass Activities

- ❖ Forming, firing, and glazing clay
- ❖ Thermal shock
- ❖ Glass bending and blowing
- ❖ Glass batching and melting
- ❖ Dragon dribble/dragon tears
- ❖ Coloring glass
- ❖ Stained glass project
- ❖ Making Raku
- ❖ Ceramic slip casting



Polymers

- ❖ Study synthetic polymers and their chemistry.
- ❖ Include the classification of polymers along with how they are altered chemically or with additives.
- ❖ Emphasize concerns with recycling.
- ❖ Review the chemical changes brought about by cross-linking.
- ❖ Include historical developments and manufacturing processes.



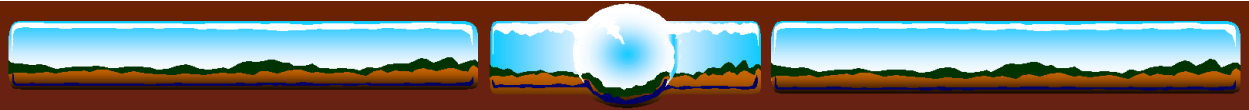
Video Clip

❖ Len Booth – Nylon



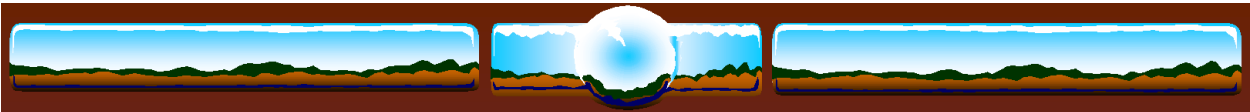
Polymer Activities

- ❖ Cross-linking a polymer (slime)
- ❖ Polymer identification
- ❖ Making nylon 6-10
- ❖ Latex rubber ball
- ❖ Memory in polymers
- ❖ Epoxy resin cast
- ❖ Polymer foam creations



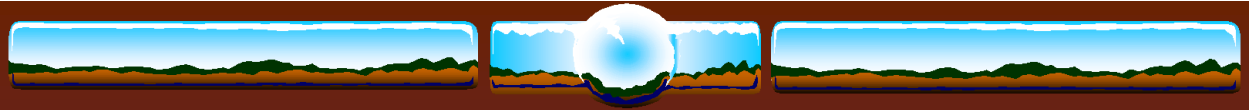
Composites

- ❖ Describe and categorize types of composites.
- ❖ Emphasize strength-to-weight ratios including strength measuring, testing, and altering.
- ❖ Use wood and concrete as two traditional composites to introduce many concepts.
- ❖ Discuss fiber reinforced composites including those containing graphite and Kevlar fibers.



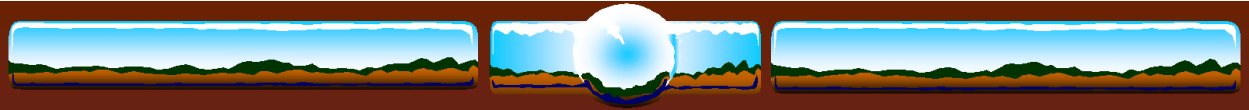
Video Clip

❖ Dr. John Rusin – Simple Stressed-Skin Composite



Composite Activities

- ❖ Stressed-skin composites
- ❖ Plaster of Paris matrix composite
- ❖ Compression and tension in a bending beam
- ❖ Laminated wood beams
- ❖ Using Portland cement to make & test concrete
- ❖ Hand lay-up of a glass fiber reinforced polymer

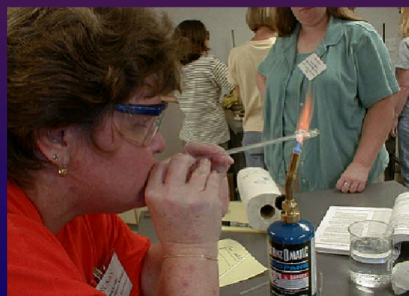


And finally.....

- ❖ This is only a partial listing of the experiments and projects.
- ❖ Many teacher demonstrations are also included in the curriculum.
- ❖ Major themes weave from one unit to the next making it easier for the students to make connections and applications.



MST is FUN!!!



**UNIVERSITY-INDUSTRY INITIATIVES TO ENHANCE
AND IMPROVE ENROLLMENT OF K-12 STUDENTS
INTO SCIENCE AND ENGINEERING PROGRAMS**
Dr. Ranji Vaidyanathan

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Dr. Ranji Vaidyanathan

**University-Industry Initiatives to Enhance and Improve
Enrollment of K-12 Students into Science and
Engineering Programs**

**R. Vaidyanathan
Advanced Ceramics Research, Tucson, AZ**

**National Educator's Workshop
October 19-22 2003, Hampton, VA**



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University-Industry Initiatives to Enhance and Improve Enrollment of K-12 Students into Science and Engineering Programs

Highlights

- University-industry partnership
- Started with Summer Engineering Academy, 1999
- Included Computer Aided design (CAD), Rapid Prototyping (RP) and manufacturing
- Annual program
- For high school students – nationwide
- Modified to include middle school students and teachers
- ONR funded Institute for SME Education Center



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Benefits to Students from Summer Engineering Academy

- Fun during the summer break
- Exposure to college campus and manufacturing companies
- Provide an idea about opportunities in engineering
 - ✓ Preferably, in Materials Science and Engineering
- Hands on experience
- Short projects



University-Industry Initiatives to Enhance and Improve Enrollment of K-12 Students into Science and Engineering Programs

Benefits to university-industry

- A recruiting tool for the university and the local industries
- Helping the community
- Social implications
- Improve the recruitment of women and under-represented minority students into engineering programs.



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Teaching

- **General concepts of engineering**
 - ✓ **Aerodynamics, Materials Science, Materials Selection, Rapid Prototyping, CAD**
- **Use of CAD**
- **Producing RP models**
- **Testing a model in a wind tunnel**
- **Analyses of data and feed back**
- **Group Presentations to friends and families**



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Student statistics for 1999-2003 SEA program

Program Year	# of Applications	Selected		Female Candidates	Underrepresented Minority Candidates
		Freshman/Sophomore	Junior/Senior		
1999	200	35	47	14	17
2000	390	52	40	54	40
2001	400+	45	46	43	43
2003	400+	94		31	56

- ✓ Program supported by 5 undergraduate counselors.
- ✓ Program supported by internal funds in 1999; supported by a \$25,000 GTE grant for 2000-2001.
- ✓ Program currently supported by funds from Intel.
- ✓ Funds used for secretarial help, CAD seats and counselor salaries.



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Materials Science and Engineering topic

- 30-45 minutes presentation
- Describe
 - Different classes of materials
 - Career opportunities
 - Where do materials engineers work
 - What do they do
 - Why should we learn about materials
 - End with rapid prototyping.



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Sample slides from Materials Engineering presentation



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Here's a short quiz...

- What percent of engineering majors are Materials Science & Engineering majors?
- What percent of the advances in technology are limited by materials?

The Answers.....

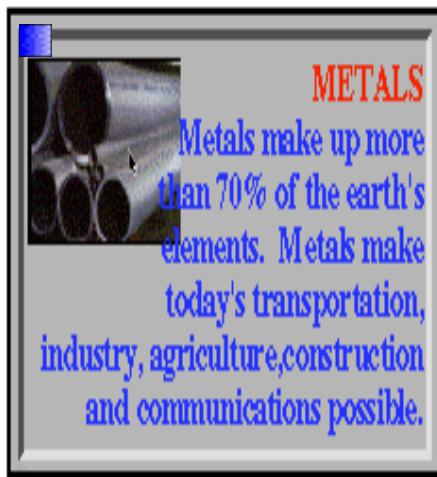
- Only 2% of all engineers are Materials Science & Engineering majors.
- Obvious, but 100% of the advances in technology are limited by advances in materials.



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What does Materials Engineering cover?



- For example, covers different types of materials
- Metals
- Ceramics including glasses
- Polymers



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Where are the career opportunities?



- ☐ Materials based technologies (**Plastics, glasses, semiconductors**)
- ☐ Frontier technologies (**Semiconducting materials, materials for communications**)
- ☐ Emerging technologies (**Environmental, biomedical engineering, composites**)
- ☐ Consumer technologies



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What do Materials Engineers do?

ENGINEERING

Developing new ways, new materials and new processes.
(Selection, Process, Application and Analysis Engineering)

RESEARCH

Discovering the basic knowledge that can benefit other engineers and society.



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Why are Materials Special?



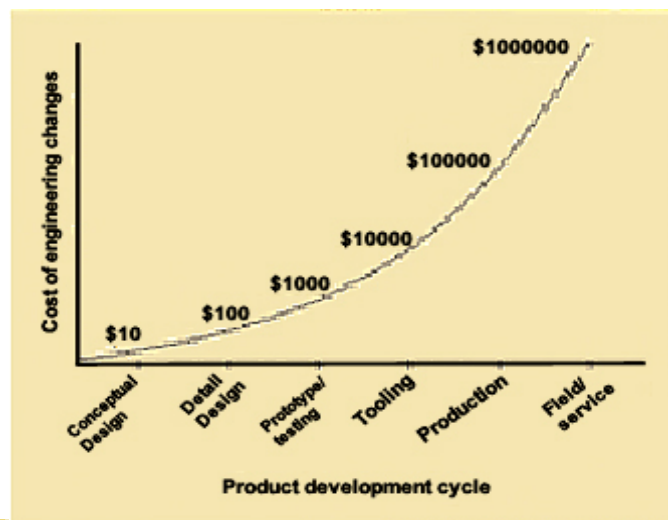
☐ Because materials.....

- ✓ Are beautiful!...
- ✓ Can take you to far away places!...
- ✓ Can save lives!...
- ✓ They are smart!...
- ✓ They are cool!...
- ✓ They are like poetry...



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Cost of making engineering design changes



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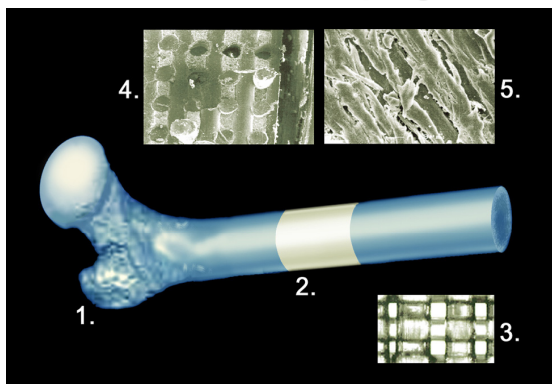
Rapid prototyping adds to student enthusiasm



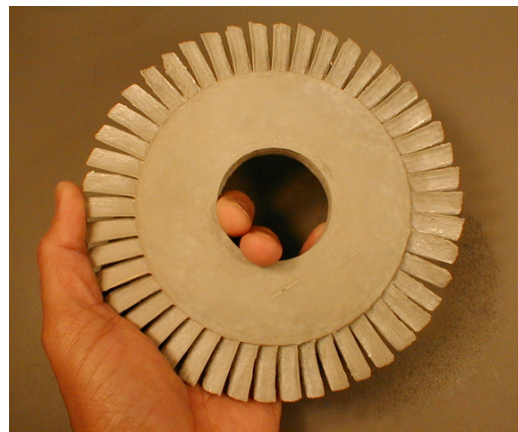
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The lectures also conveyed ACR's interests in developing new materials and processes



1. Human Femur 2. Porous Polymer Scaffold 3. Scaffold Section(25x)
4. Impregnated Detail (30x) 5. Bone Tissue Growth (+ 7 Days)



Rapid prototyped bio-implants



Rapid prototyped ceramic blisk



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Materials selection fundamentals

- To provide an understanding of how to select a material for a specific application, based on the design requirements of a given component.
- A component for space application
 - Weight savings matched against the component property requirements.
 - Compare the weight of a component made from tungsten and a ceramic material.
 - Calculate the cost of a space payload in terms of its weight.
 - Cost savings achievable by reducing the weight of the payload.



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Student activities

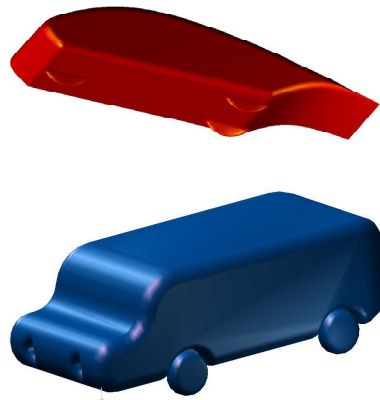
- A student team would decide their design concept (suggested model cars)
- Use Solid Works™ CAD for design and modeling
- Use Stratasys FDM™ 1600 to convert CAD to RP
- Test the models in a wind tunnel

“How does an idea become a reality?”

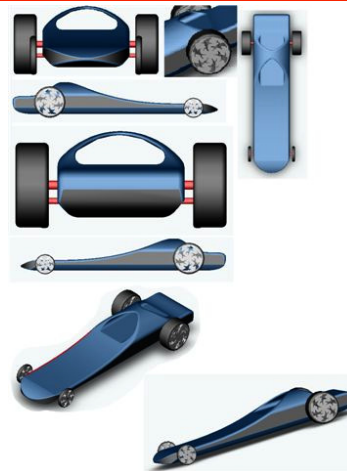


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1999-2002



2003

Prototype models created using Solid Works™ by student teams



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Rapid Prototyping

- After computer models were created, files were emailed to ACR for fabrication.
- Students toured ACR rapid prototyping facilities while models were being built.
- UA now has two RP machines for building models.
- Students encouraged that models they conceptualized and designed were being built before their eyes.



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Aerodynamics and wind tunnel testing

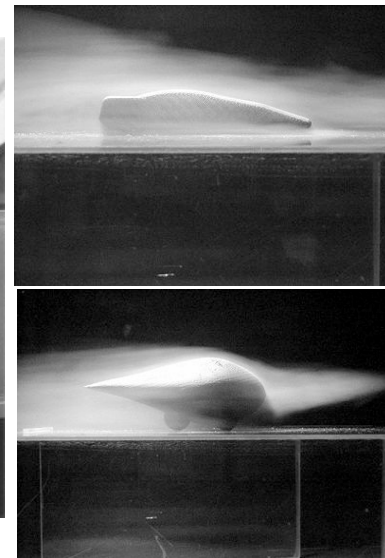
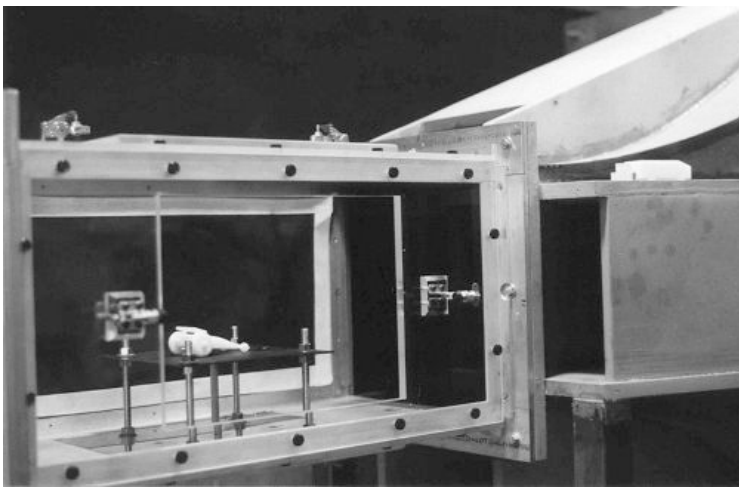
- Students learned basics of aerodynamics.
- Students received practical knowledge of aerodynamics by actually seeing their cars tested in the wind tunnel.
- Computer data analyzed and interpreted by the students gave them feedback as to how their cars would perform if built on a full scale.



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Models inside a specially constructed wind tunnel



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Some quotes

- “Much more interesting than hanging out”
- “I did not know this was engineering”
- “This is how they design good cars”
- “Computers have real uses”



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How do we know if SEA is working or not?

Sum of count		Ethnic origin			Grand total
Term	African - American	Hispanic	Native American	Others including women	
1997	4	39	9	24	76
1998	9	53	13	39	114
1999*	12	66	16	41	135
2000	15	68	15	41	139
2001	12	107	20	60	199
Grand total	52	333	73	205	663

University of Arizona College of Engineering and Mines Minority Enrollment 1997-2001

* SEA program started.



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Taking it to the next level

- Job shadow program with Hohokam middle school and Tucson Unified School District for middle school kids.
- Winter Engineering Academy for middle school girls
- First session in '02-'03 school year; transitioned to other middle schools in '03-'04
- ONR funded Autonomous Intelligent Networks & Systems (AINS) SME Education Center for ONR's Unmanned Aerial Vehicle (Silverfox™)
- Partnership between ACR, ONR, UCLA, Berkeley, MIT, Tohono O'odham Community College and Pima Community College



ACR's Silverfox™ UAV

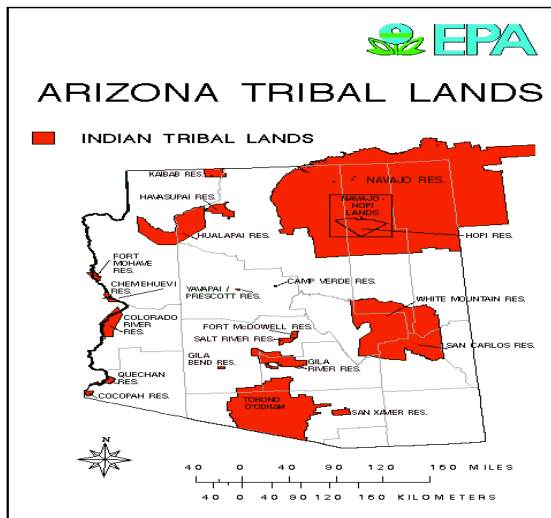


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Arizona's Native American population

General Demographics:

- 23 Tribes in the State
- They represent
 - 5% or 250,000 of the statewide population
 - 2.6% or 21,320 of the Pima County population
- They own 20 mil acres or 28% of the state lands
- Most land holdings are underdeveloped
- Primary development agriculture & casinos
- Job ratios – tribal lands 0.23 jobs/person, non-tribal lands 0.44 jobs/person
- Unemployment rates 4 times that of national average



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The Education Model

- **Foundational education SME curriculum**
 - Developmental education to enhance foundational SME learning
 - Structured tutorial program
 - Concurrent enrollment



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The Education Model

- Enhanced theory based SME curriculum
 - Classroom
 - AINS Researcher Lecture Series from University Professors
 - AINS Researcher Mentors from ACR and universities
 - Offsite
 - University summer SME exposure program
 - University summer SME study program



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The Education Model

- **Structured application based SME education**
 - **Application Classroom**
 - Internships with ACR and Raytheon, research assistantships with universities
 - Private Industry Technology Application Workshops
 - AINS Researcher Lecture Series
 - AINS Researcher Mentors



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The Education Model

- **Structured retention program**
 - AINS Research Institution student mentors
 - Offsite technology exposure program
 - Dedicated student advisor
 - Full scholarship



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AINS Program Objective Metrics

- Increase participation by Native Americans in SME
- Reach over 300 students over 5 years
- Have 10 students enrolled in a four year SME program 3 years from now



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Summary about SEA program

- SEA is the most successful outreach program at the University of Arizona (UA).
- Undergraduate students from other states want to participate as mentors.
- WEA is rapidly becoming a successful outreach program.
- Mentors with backgrounds similar to the students are preferable.
- Program experiences and methodologies easily transferable to other universities and states.
- ACR has hired interns who attended SEA.



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Summary about AINS program

- Good PR about the AINS program
- Good coordination between different universities, community colleges and ACR
- Congressional visits from senators and congressmen



University-Industry Initiatives to Enhance and Improve Enrollment of K-12 Students into Science and Engineering Programs

Contact Information

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- Ranji Vaidyanathan, Tel: 520-434-6392, email: rkv@acrtucson.com



**THE JUNIOR LABORATORY: A PLACE TO
INTRODUCE BASICS AS WELL AS NEW FINDINGS**

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and

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***THE JUNIOR LABORATORY: A PLACE TO
INTRODUCE BASICS AS WELL AS NEW
FINDINGS***



**Luz J. Martínez-Miranda, O. C. Wilson, Jr. and L. G.
Salamanca-Riba**

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Maryland**

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GOALS

TO FAMILIARIZE STUDENTS WITH THE BASIC TECHNIQUES OF MATERIALS SCIENCE WHILE GIVING THEM A TASTE OF WHAT WE DO IN THE RESEARCH OF MATERIALS.

-TO TEACH STUDENTS HOW TO COMMUNICATE THEIR RESULTS IN WRITING, AND ORALLY.

-TO TEACH STUDENTS HOW TO DESIGN AN EXPERIMENT.

CHALLENGES:

-HOW TO BE ABLE TO CHANGE SAMPLES, ADD TECHNIQUES, WITHOUT BURDENING THE STUDENTS

-HOW TO DO THE ABOVE AND STILL TEACH THEM WHAT THEY NEED TO LEARN.

-HOW TO KEEP THIS AS AN UNDERGRADUATE COURSE AND NOT A GRADUATE RESEARCH COURSE.

WHAT WE HAVE DONE...

- **WE HAVE CHANGED THE SAMPLES OR THE APPROACH TO TEACHING IN THREE OF THE ~14 EXPERIMENTS WE OFFER**
- **WE HAVE INTRODUCED AN ORAL PRESENTATION COMPONENT WHERE THE STUDENTS ARE ASKED TO RELATE A PARTICULAR EXPERIMENT WITH A RESEARCH RESULT AND HOW THEY WOULD GO USING THE TECHNIQUE TO STUDY IT.**
- **STUDENTS CAN SEE:**
 - THE IMPORTANCE OF THE TECHNIQUE IN THE PRESENT RESEARCH**
 - THE MATERIALS THAT ARE STUDIED NOWADAYS**
 - THE IMPORTANCE OF THE PROCESSING –
STRUCTURE – PROPERTIES WHICH WE EMPHASIZE**

TEM
Prof. L. G. Salamanca-Riba

Experiment Purpose:

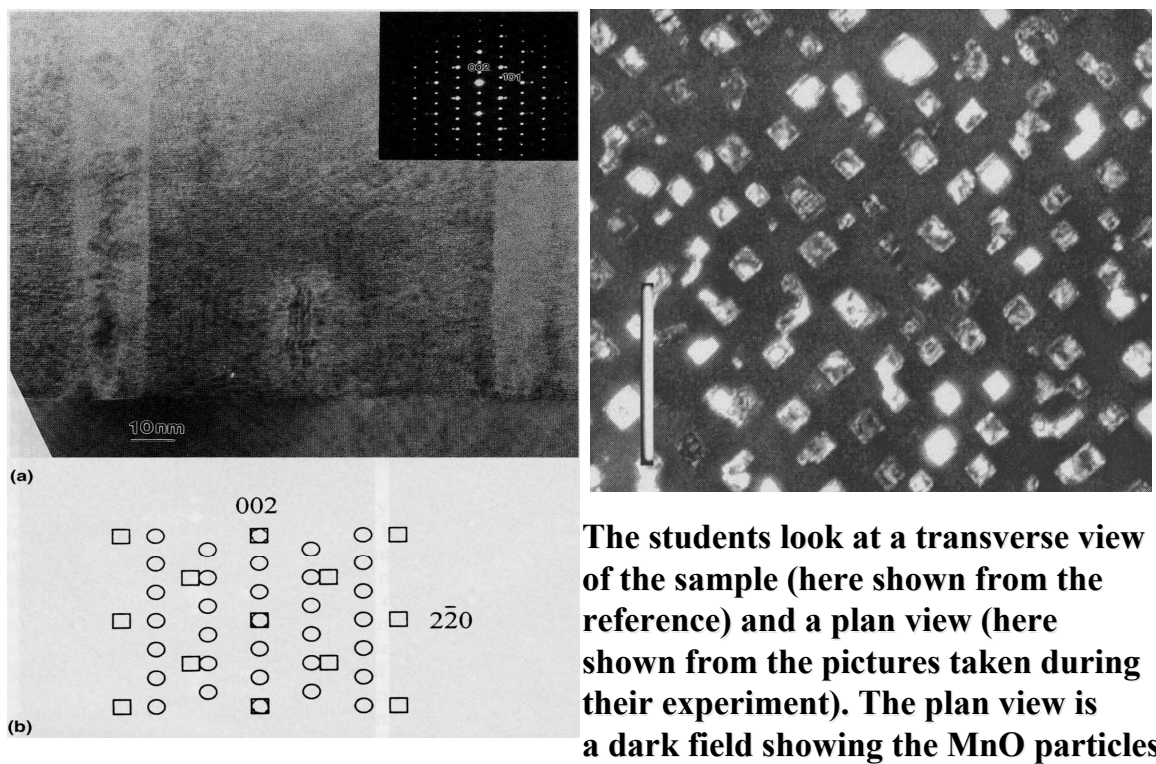
- a. The relation between the processing and the structure observed.
- b. A dark field vs. a bright field image
- c. They determine the lattice parameters of the film and the islands, and learn how to determine it from the pictures and the diffraction pattern
- d. What is the error in their measurement.
- e. Observe defects, grain boundaries

Before: Done with a semiconductor film

Now: Done with an $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$ (LSMO) film that under certain growth conditions develops MnO columns

Discussion: Effects on magnetic properties; observation of grain boundaries, defects

Ref: Y. Li, et al., JMR, 15, 1524 (2000)



Optical microscopy

Profs. Otto C. Wilson, Jr., R. Briber and L. J. Martinez-Miranda

Experiment purpose: To learn to use optical microscopy to study phase transitions in different materials; to use birefringence to determine the phase change or the structure of a sample; how to associate the birefringence with the difference in index of refraction, and how to determine how a sample is oriented with respect to the surface.

Before: Done with polymers and liquid crystals.

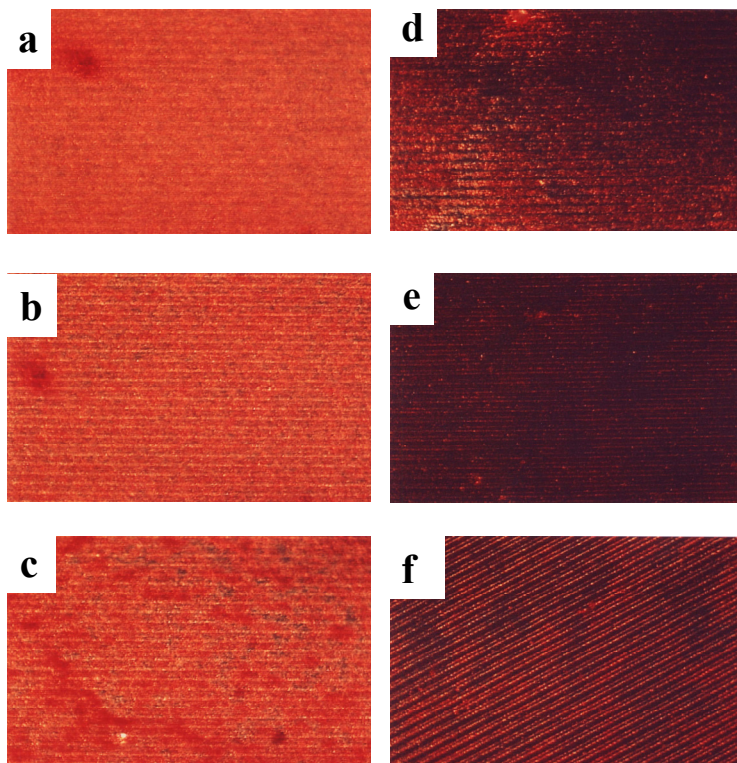
Now: The polymer part stays. We use an inorganic polymer, AlFeOOH , which acts as a liquid crystal and also like collagen.

Discussion: To begin to understand how the different alignments can lead to the different body parts.

Ref: L. J. Martínez-Miranda, A. J. Douglas and O. C. Wilson, Jr., accepted in *Molec. Cryst. Liq. Cryst.* (2002).

Students observe the phase change from the isotropic (a) to the homoetropic phase (c-d) to the striped domain structure.

They time the changes with the help of a video system.



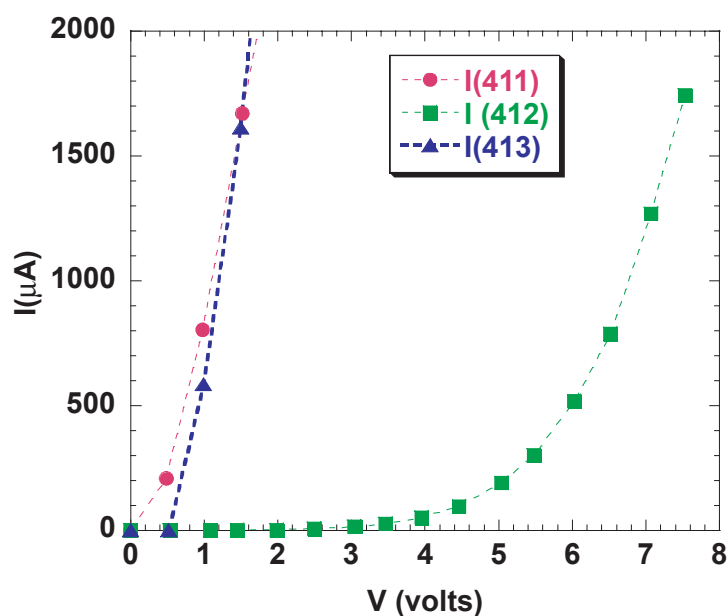
RECTIFYING COMPONENTS : A NEW TWIST TO AN OLD PROBLEM (L. J. Martínez-Miranda)

The students look at a p-n junction and at LED's to observe the turn-on voltage.

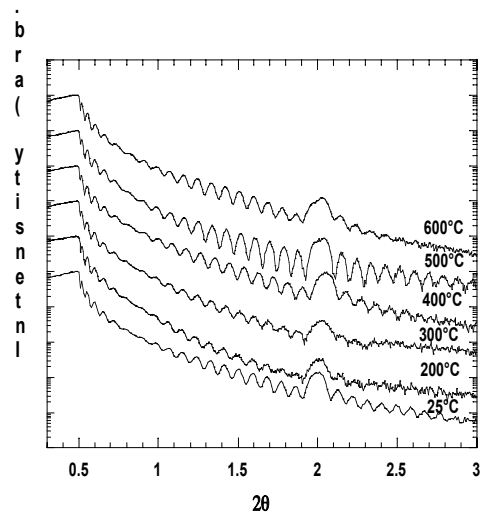
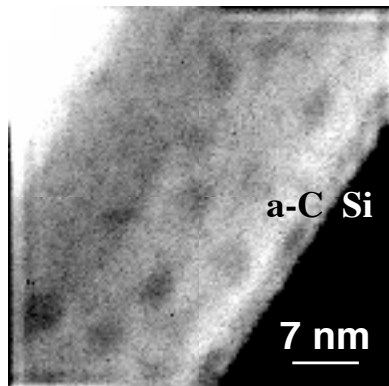
In addition, students study various rectifying components that have been prepared such that the density varies between 2.5 (samples 411 and 413) and 3.4 (sample 412).

They observe the effect of the density on the turn-on voltage.

Samples donated by
Dr. J. Sullivan and Dr.
M. P. Siegal, SNL



Rectifying components



We also show them that the properties of the C films are changed not by changing the entire film but by the creation of nano islands of higher density, even at room temperature.

Ref: M. P. Siegal, et al, Appl. Phys. Lett. 76, 2047 (2000); M. P. Siegal, et al. Appl Phys. Lett., 76, 3052 (2000); L. J. Martínez-Miranda, et al. Appl. Phys. Lett., 79, 542-544 (2001).

X-ray diffraction

L. J. Martínez-Miranda

Experiment Purpose: to become familiar with the structural analysis of powders, textured samples and single crystals

In the future: add crystals prepared using different chemical routes, some of them nanocrystalline. (This is done to a certain extent with the Cu samples, but we don't explore the nanorange.)

Discussion: See how the way it is processed affects the structure (including nanostructure), comparing the signal at low angle with the signal at high angle.

Samples donated: Dr. Lynn Kurihara, NRL

The students get together and discuss their results, comparing how their samples were prepared, and how that is reflected on the samples' structure or in its properties.

This gives them an opportunity to practice their oral skills with their colleagues.



Conclusions

We have shown, through the examples above, that we can change the material in various experiments without altering the basics we are teaching.

We make the students aware that these techniques are used in our research to look into the properties of the materials.

We have noticed that after the experiment the students ask us questions regarding the materials, or any other type of materials related to the experiments.

We hope that the fact that they will also retain part of the basic lessons we want to teach them.



- The TEM research was supported by the NSF-MRSEC grant No. DMR 00-80008
- The rectifying components research was supported by the US DOE under contract No. DE-ACO4-94AL85000
- The AlFeOOH microscope work was supported in part by an internal UMCP-GRB fund (for L. J. M. M.).
- We are very grateful to Dr. Lynn K. Kurihara, from NRL, Dr. Michael Siegal from SNL and Dr. J. P Sullivan from SNL for their interest and willingness to let us use some of their samples.

CARBON NANOTUBE REINFORCED POLYMERS FOR RADIATION SHIELDING APPLICATIONS

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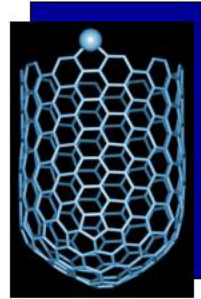
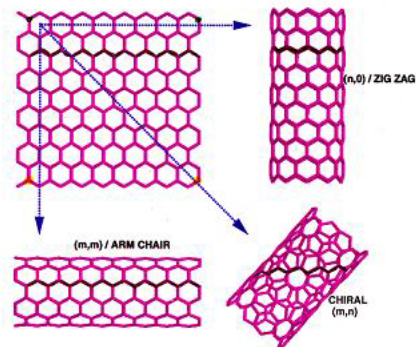
Dr. Ranji Vaidyanathan

Carbon Nanotube

CNT is a tubular form of carbon with diameter as small as 1 nm.
Length: few nm to microns.

CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube.

• STRIP OF A GRAPHENE SHEET ROLLED INTO A TUBE



CNT exhibits extraordinary mechanical properties: Young's modulus over 1 Tera Pascal, as stiff as diamond, and tensile strength ~ 200 GPa.

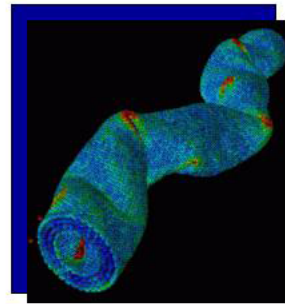
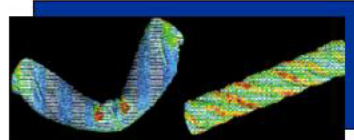
CNT can be metallic or semiconducting, depending on chirality.



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CNT Properties

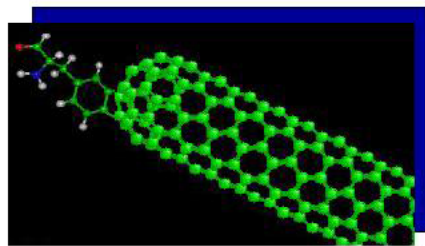
- The strongest and most flexible molecular material because of C-C covalent bonding and seamless hexagonal network architecture
- Young's modulus of over 1 TPa vs 70 GPa for Aluminum, 700 GPa for C-fiber
 - strength to weight ratio 500 times > for Al; similar improvements over steel and titanium; one order of magnitude improvement over graphite/epoxy
- Maximum strain ~10% much higher than any material
- Thermal conductivity ~ 3000 W/mK in the axial direction with small values in the radial direction



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CNT Properties (cont.)

- Electrical conductivity six orders of magnitude higher than copper
- Can be metallic or semiconducting depending on chirality
 - 'tunable' bandgap
 - electronic properties can be tailored through application of external magnetic field, application of mechanical deformation...
- Very high current carrying capacity
- Excellent field emitter; high aspect ratio and small tip radius of curvature are ideal for field emission
- Can be functionalized



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Background

- ❑ **Extended deep space exploration voyages**
 - Human beings and electronics need protection
- ❑ **Radiation environment**
 - Electrons, ions, and secondary neutrons due to particle interactions
- ❑ **Hydrogen rich materials**
 - Better flux shielding characteristics than Al, alloys



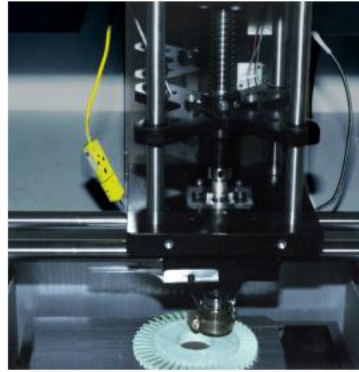
Background (cont'd)

- ❑ **Addition of carbon to shield materials**
 - Improved neutron reflective capabilities
- ❑ **Hydrocarbon-based polymers**
 - Polyethylene (PE) - low neutrons flux transmission
- ❑ **Extrusion freeform fabrication (EFF)**
 - Multiple layers, complex shapes and parts
 - Alignment of fibers - improved properties



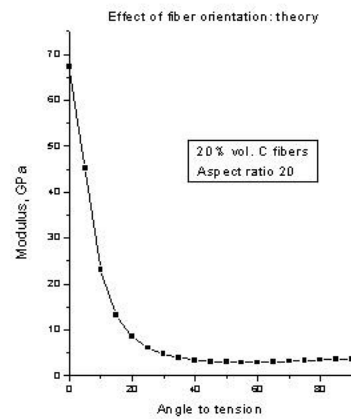
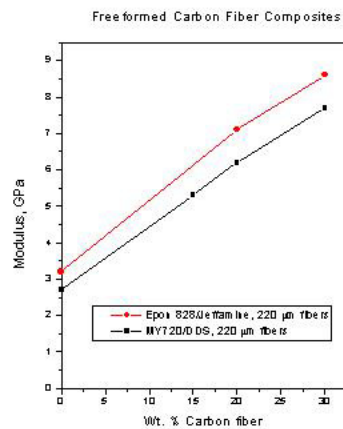
Extrusion Freeform Fabrication (EFF)

The Stratasys 3-D Modeler with retrofitted high-pressure extrusion head

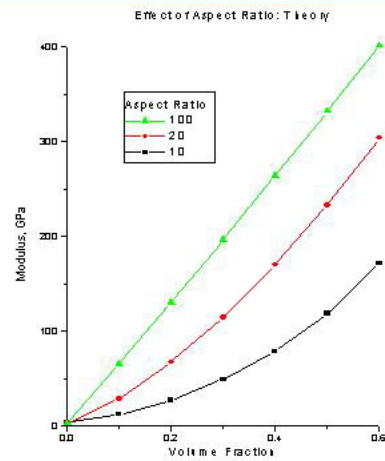


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Extrusion Freeform Fabrication (EFF)

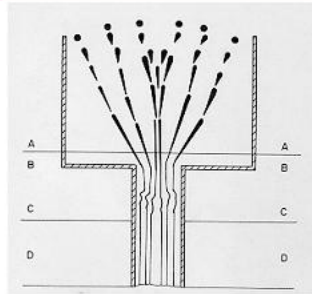


Extrusion Freeform Fabrication (EFF)

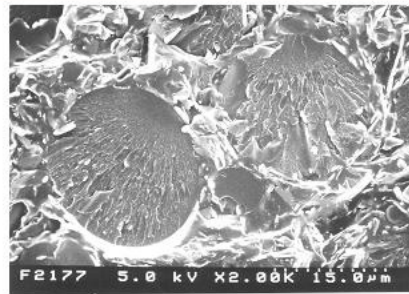


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Extrusion Freeform Fabrication (EFF)



**Schematic of fibrillation
through an orifice**

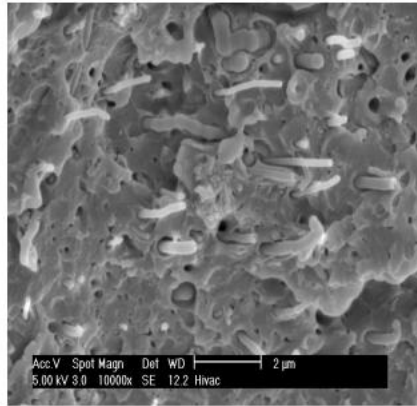


**SEM of PEOx/polystyrene
copolymer after EFF/Heat treatment**



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Extrusion Freeform Fabrication (EFF)



- Extrusion effect
 - Fracture surface
 - Vapor-grown carbon fiber reinforced composite
 - Shows alignment of the fibers



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Scope of Research

- Addition of carbon nanotubes to PE
 - Functionalization (SWNTs, f-SWNTs)
 - Dispersion and alignment in the polymer
 - methodology and optimization
 - Innovative EFF concept
 - As reinforcing agents
 - improved strength
 - enhanced reflective capability to certain wavelengths of neutron radiation
 - Multifunctionality



Materials and Experiments

- ❑ Single wall nanotubes (SWNTs) from CNI
 - Purified (p-SWNTs)
 - Functionalized via fluorination (f-SWNTs)
- ❑ PE (medium M_w)
- ❑ Dispersion of SWNTs
 - Incipient wetting
 - High shear mixing
- ❑ Composite processing
 - EFF, multiple extrusion for alignment improvement



PE/SWNT Nanocomposites



- Fabricated 2-in diameter samples for radiation testing
- Fabricated 1-in diameter for the MISSE experiment

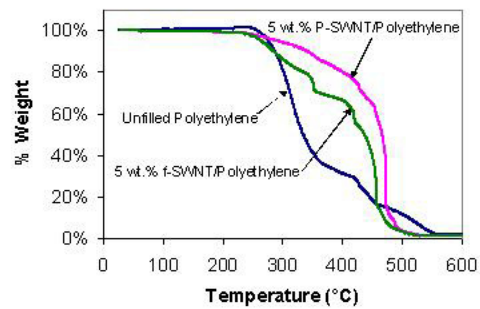


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TGA Analysis

□ TGA

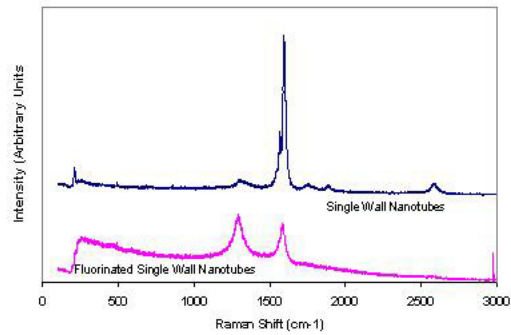
- Comparison between filled and unfilled PE
- Thermal stability increases with addition of SWNTs (reduced weight loss)
- Increased oxidation resistance



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Raman Spectroscopy

- Defines alignment of SWNTs in EFF processed nanocomposites
 - Parallel and perpendicular to the extrusion direction
 - Typical Raman spectra (figure)



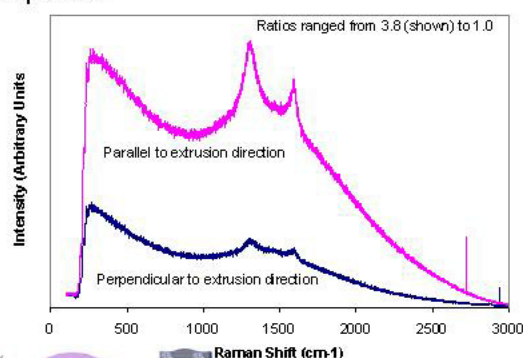
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Raman Spectroscopy (cont'd)

- Improvement in alignment for the f-SWNTs/PE compared to p-SWNTs/PE nanocomposites
 - Possibly due to better dispersion

Composite Blend	Ratio
1.5 wt% f-SWNT/PE	3.8
1.5 wt% p-SWNT/PE	1.29
5 wt% p-SWNT/PE	1.35

Raman intensity ratios for SWNT/PE composite blends



Radiation Exposure

□ Radiation testing

- Texas A&M University Cyclotron Institute
- Irradiated at 40 MeV,
 - Total fluence of 3×10^{10} protons/cm²
 - Flux of 1.5×10^7 protons/cm²/sec
- Sample sets in the beamline end station prior to irradiation



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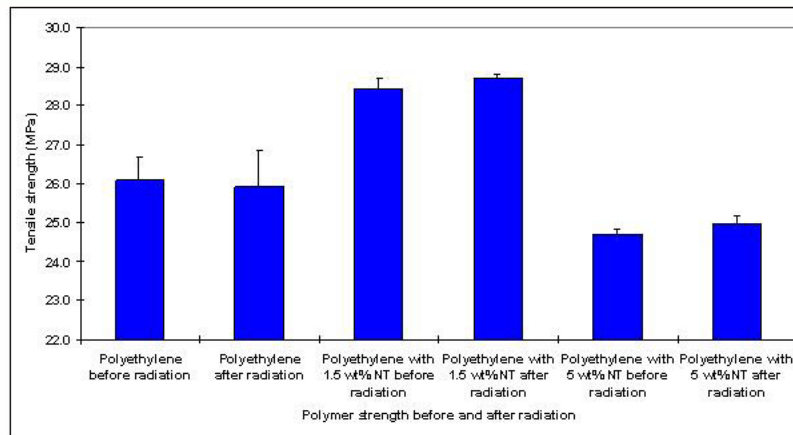
Mechanical Properties

□ Mechanical Testing

- Tensile tests ASTM D638
- Non-irradiated and post-irradiated control samples
- 1.5 wt% for f-SWNTs/PE nanocomposites
- 5 wt% only for p-SWNTs/PE nanocomposites
- Fluorination
 - Improved dispersion, improved alignment - improved mechanical properties

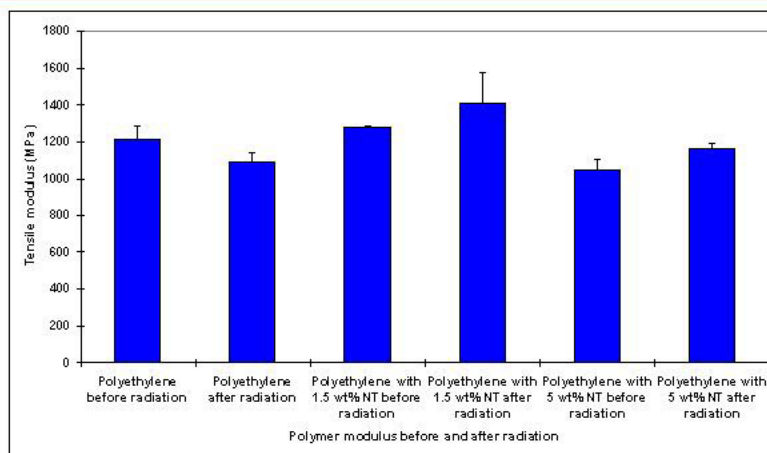


Mechanical Properties



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Mechanical Properties (cont'd)



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Summary

- ❑ SWNT addition
 - Improved thermal stability and atomic oxygen resistance for PE
- ❑ Preliminary results
 - Alignment of nanotubes improved due to EFF
 - Require improved alignment for better mechanical properties
- ❑ Fluorination
 - Improved dispersion, improved alignment - improved mechanical properties



Summary & Future Work

- Radiation exposure
 - Did not affect mechanical properties of the PE/SWNTs nanocomposites
- Future work focus:
 - Improve the mechanical testing parameters for statistical studies of the properties
 - Comparative study of the properties of PE filled with f-SWNTs and p-SWNTs using the same concentrations



Acknowledgments

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Program Manager: Dr. S. Thibeault

NASA Langley Research Center

Hampton, VA 23681



MATLAB EXERCISE: THE PERIODIC TABLE

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Maureen M. Julian

MATLAB Exercise: The Periodic Table

National Educators' Workshop
October 2003

Maureen M. Julian

Department of Materials Science and Engineering Virginia Tech, Blacksburg VA 24061

Keywords: computer based instruction, periodic table, entropy, thermodynamics, technetium, data analysis

Prerequisite Knowledge: some advanced computation language such as MATLAB or Mathematica, general chemistry, periodic table

Objective: To produce and analyze a three-dimensional graph of the standard molar entropies of the elements.

Equipment and Materials: MATLAB, web access.

Introduction:

Every week my thermodynamics students receive a MATLAB¹ problem as part of their homework assignment. Last year the most popular problem was the creation of a three-dimensional periodic table with the molar entropies, designed to explore the third law of thermodynamics. This exercise fits into a broader scheme of acquiring a working knowledge of an advanced interactive mathematical language and is part of a series of MATLAB exercises created for use in courses in thermodynamics and x-ray crystallography, and for a one-year introductory course in the Department of Materials Science and Engineering. MATLAB and other languages, for example, *Mathematica*,² have facilities that are useful and easy to use such as the three-dimensional bar graphs presented here. Although MATLAB is required for most of our students, these exercises have no MATLAB prerequisites. The emphasis is on the scientific content, not on previous MATLAB expertise. The success of this advanced software made practical a significant increase in the material taught during the semester. This increase was facilitated by an increase in the amount and depth of the analytical work done by the students. This paper describes the use of the computer software and presents an unexpectedly interesting example.

Each week new MATLAB techniques are added, so that the sophistication of the students' programming progresses along with their understanding of the course material. Good programming documentation is paramount. At the end of the course, each student collects the exercises in a loose-leaf book that becomes a personal reference. The students tell me that they are using the exercise books to aid in assignments for other courses.

For my own reference, I use *MATLAB Guide* (1) for an overall view, *MATLAB Programming for Engineers* (2) for documentation, and *Numerical Methods with MATLAB*,

¹ MATLAB is a registered trademark of The MathWorks, Inc.

² *Mathematica* is a registered trademark of Wolfram Research, Inc.

Implementation and Application (3) for numerical methods. There are many excellent web pages specializing in, for example, graphics (4).

In this paper, a three-dimensional bar graph illustrates the relationship between the standard molar entropy of each individual element to the position of that element in the periodic table. This exercise is made feasible by the combination of a simple MATLAB command that creates the bar graph and web pages, such as (5) which list physical properties of each element in the form illustrated for beryllium in Table 1. Properties such as density, boiling point, and atomic radius lend themselves to similar three-dimensional analysis. This exercise is also a stand-alone exercise or can be adapted to other mathematical languages.

Procedure:

Extensive documentation is required for all MATLAB exercises for my classes. The specific form is adapted from Chapman (6). An easy-to-read format is required. Spaces can force order into what otherwise would be chaotic data entry. Good formatting facilitates proof reading, which is critical when large amounts of data are entered, as in this case.

M-files, which are computer files containing the MATLAB program, are required. The students are encouraged to avoid working in the command window unless they are debugging or exploring various alternatives. The use of m-files allows work be saved, interrupted, shared, and reused.

Table 2 is an example of a “starter” m-file that was sent to the class by e-mail along with the rest of the homework assignment. The student exercise is to complete the first six rows of the periodic table, omitting the rare earth series.

Let us go over the program line by line. The % sign indicates a comment line. These comments are not an active part of the program, but give a place for storing relevant information. The comments can be on the same line as the active command, as shown in the first three lines of the code.

First notice the **clear**, **close all**, and **clc** commands. Beginning every script file with these commands avoids later confusion. The **clear** command clears all variables and functions in the program. The **close all** command closes all figure windows, preventing overdrawing of a figure. The **clc** command clears the command window so all the information in the command window is associated with the particular run at hand.

Next the name and location, including the complete path, of the script file, are given, so the file can be easily identified at a later time from a printed copy. The *purpose* line gives a complete sentence on the purpose of the file. The specific homework problem from the textbook may be included.

Next is the *record of revisions*. The parts of the code must be attributed to the person who wrote them. Good habits prevent honor code violations such as plagiarism. When the student changes the file, the next line will contain the date the student worked on the file, the name of the student, and finally what the student did. For example- 10/5/2003 Mary Jones Finish periodic table.

The *variables* are defined with their units. Other information such as a reference to the data may be appropriate, as in this example. Here the variable is S, the standard molar entropy of each element, and the units of S are $\text{J K}^{-1}\text{mol}^{-1}$. As variables are added to the active part of the program, they are inserted into this list. This insertion helps not only in debugging a program, but also in later expansion.

The next line presents the data. Notice the use of zeros and the alignment of the matrix to present clearly the format of the periodic table. The data, in this case the standard molar entropies of the elements, are put in positions to mimic the periodic table.

The line, `bar3(S)` takes the information in the matrix, `S`, and plots it as a three-dimensional bar graph with the height of the bars being the entropies of the elements. This elegant yet simple command is the work horse and heart of the program.

Every element is labeled with a `text` statement. The first three arguments give the `x`, `y`, `z` bar graph coordinates. The fourth argument is a string, which labels the element, and the last two arguments control the color of the string. Finally we add the title of the graph, and the labels for the `x`, `y`, and `z` axes.

When the student executes this 'starter' program, Figure (1) is produced. Clearly the beginnings of the periodic table emerge.

Figure (2) is the completed periodic table. The most prominent feature is the highest entropy value, which occurs for element number 43, technetium. A useful discussion ensued on this surprising value. Often the student is intimidated by published data. Here is an excellent example to build confidence in the student's ability to judge information. The question to be explored is to distinguish between an unexpected piece of data or an error in the reporting of the data. Scientists are daily faced with the conundrum. After all, some of the greatest theoretical advances come from explaining unexpected data. For example Einstein's formulation of relativity began with trying to explain the constancy of the speed of light in the Michelson-Morley experiment.

No one in the class knew anything about the element technetium. Technetium, atomic number 43, was predicted based on the absence of atomic number 43 in the periodic table (6). Many scientists began looking for it. In 1937, Carlo Perrier and Emilio Segre isolated technetium after receiving a sample of molybdenum, atomic number 42, that Ernest Lawrence had bombarded with deuterons in the Berkeley cyclotron. The name comes from the Greek word *τεχνητεος* meaning artificial, because technetium is the first artificial element discovered. At 298 K the standard state is a solid silvery gray metal that tarnishes easily. Surprisingly technetium has been found in the spectra of several classes of stars. Because technetium bonds to many biological molecules and because the ⁹⁹Tc isotope has a reasonable half-life of six hours, it is used in many medical radioisotope tests.

Table 3 lists the ten highest values for molar entropies in the first six periods of the periodic table (5). Entropy is a measure of disorder, so we would expect the gases to have the highest entropies. Except for the metal technetium, a solid in the standard state, all these elements are non-metals and gases in the standard state. Our suspicions were raised as to the validity of the technetium value.

Consider other physical properties of the elements near technetium in the periodic table. The elements surrounding technetium in the same period, that is the second transition series, are Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, and Cd. The elements in Group VIIb are Mn, Tc, and Re.

Figure (3) shows a three-dimensional mesh graph plotting the density with respect to the position of the element in the periodic table. Clearly there is not any great anomaly in the density function for Tc. Similar graphs were plotted for melting point, boiling point, ionization energy, atomic radius and electronegativity. None of these functions showed any special discontinuity for Tc.

Finally if we go to another web page (7), we find the information listed in Table 4. Here the molar entropy of technetium in the gaseous state is 181.0 J/mol-K. In the light of Table 3, this is

entirely reasonable for the entropy of a gas. The value of the entropy is omitted for the standard state. Thus we may reasonably conclude that an inappropriate piece of data was introduced into the information used to compile the original homework assignment.

A special feature I introduce with the MATLAB exercises is that an assignment can be resubmitted until a perfect grade is received. I do this because at the end of the term the student submits an exercise book with each of the weekly MATLABs. The page for the table of contents has the assignment title and the new MATLAB techniques learned. For example the techniques learned here might be three-dimensional bar graph, text labeling, and mesh graph. Each exercise has its complete documentation. Then the exercise book becomes a reference for the student, and I am told that the book is used to complete assignments for other classes.

Comments:

The use of advanced mathematical computational languages is an important teaching tool. Relatively large amounts of data can be not only easily handled but also qualitatively judged. In this exercise the students produced a three-dimensional graph of the standard molar entropies of the elements. A byproduct was an apparent anomaly for the element technetium. This prompted a study of this element in order to determine if the standard molar entropy of technetium is really unusually high or if perhaps the data were incorrectly reported. We concluded that the data had been misreported.

I wish to thank all my Materials Science and Engineering students who made the MATLAB journey in their courses especially Lisa Copely who allowed me to use some of her assignments. This material is a subset of the material presented at the Faculty Development Institute at Virginia Polytechnic Institute and State University (8).

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2. Chapman, S. J., MATLAB Programming for Engineers, Second Ed.; Brooks/Cole: Pacific Grove, CA, 2002.
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4. MATLAB graphics. <http://www.csc.fi/visualization/intensk99/matlab/> (accessed July 2003).
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4. Chapman pg. 63.
6. Periodic table, technetium. <http://pearl1.lanl.gov/periodic/elements/43.html> (accessed July 2003)
7. Periodic table, www.webelements.com (accessed July 2003).
8. Julian, M. Teaching with MATLAB, Faculty Development Institute, Virginia Polytechnic Institute and State University, Blacksburg, VA, Track G 2003, June 5, 2003.

Bibliography:

Dr. Maureen M. Julian of the Department of Materials Science and Engineering, Virginia Polytechnic and State University at Blacksburg, VA, is a crystallographer. She emphasizes the use of MATLAB in her courses. She teaches crystallography, thermodynamics, and the year introductory course in Materials Science and Engineering. Her research involves Research Interests are x-ray crystallography of body stones, absorption edges, epitaxial relationships, computer bases instruction, history of crystallography, women in crystallography, and teaching of crystallography.

Table 1. Physical Properties of Beryllium (5)

Element	Beryllium	Symbol	Be
Atomic Number	4	Molar Mass	9.01 gm mol ⁻¹
Electron Configuration	{He}2s ²	Normal State	Solid Metal
Density @STP	1.85 g cm ⁻³	Melting Point	1287°C
Boiling Point	2471°C	Stable Isotopes	⁹ Be
Atomic Radius	112 pm	Ionic Radius	27 (2+) pm
Electronegativity (Pauling)	1.57	Ionization Energy (1 st)	899 kJ mol ⁻¹
Ionization Energy (2 nd)	1757 kJ mol ⁻¹	Ionization Energy (3 rd)	14848 kJ mol ⁻¹
Molar Heat Capacity	16.4 J K ⁻¹ mol ⁻¹	Standard Molar Entropy	9.5 J K ⁻¹ mol ⁻¹
Enthalpy of Fusion	9.8 kJ mol ⁻¹	Enthalpy of Vaporization	308.8 kJ mol ⁻¹

Table 2. Starter m-file for periodic table exercise

```
Clear    %clears variable and functions
close    %closes all windows
clc      %clears command window
%
% Script file: MyDocuments\PeriodicTableEntropies.m
%
% Purpose:
%3D-Plot periodic table with entropies of elements
%
% Record of revisions:
% Date      Programmer   Description of Change
%7/1/03     Julian      Bar graph of 1st 9 elements
%
%Define variables:
% S= standard molar entropy of element J K-1mol-1
% reference: http://www.gordonengland.co.uk/elements
% enter data
S= [ 130  29  51  64
      0   9  32  42
      0   0   0  34
      0   0   0  30]
bar3(S)
% label the element hydrogen
text(1,1,130,'H','color','w')
title ('Standard Molar Entropies of the Elements.')
xlabel('Periods')
ylabel('Groups')
zlabel('Entropy, S, J/k-mol')
```


Table 3. Ten highest values of entropy in the first six rows of the periodic table (5)

Element	Symbol	Entropy J/mol-K
technetium	Tc	181.1
iodine	I	180.8
radon	Rn	176.2
bromine	Br	175.0
xenon	Xe	169.7
chlorine	Cl	165.2
krypton	Kr	164.1
oxygen	O	161.0
fluorine	F	158.8
argon	Ar	154.8

Table 4. Entropy, enthalpy and heat capacity of technetium (7)

State	$\Delta_f H^\circ$ /kJ mol ⁻¹	$\Delta_f G^\circ$ /kJ mol ⁻¹	S° /J K ⁻¹ mol ⁻¹	$C_p H$ /J K ⁻¹ mol ⁻¹	$H^\circ_{298.15} - H^\circ_0$ /kJ mol ⁻¹
Solid	0	0			
Gas	678		181.0	20.8	6.20

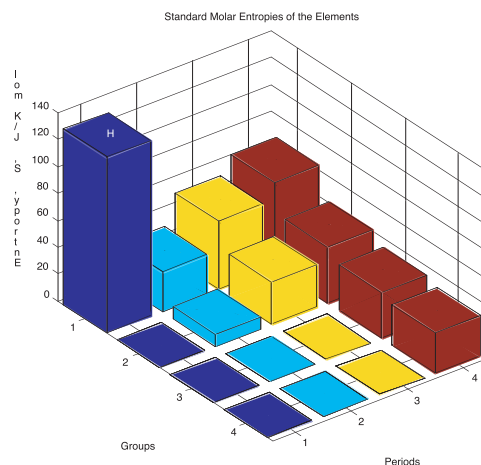


Figure 1. Execution of starter program from Table 1.

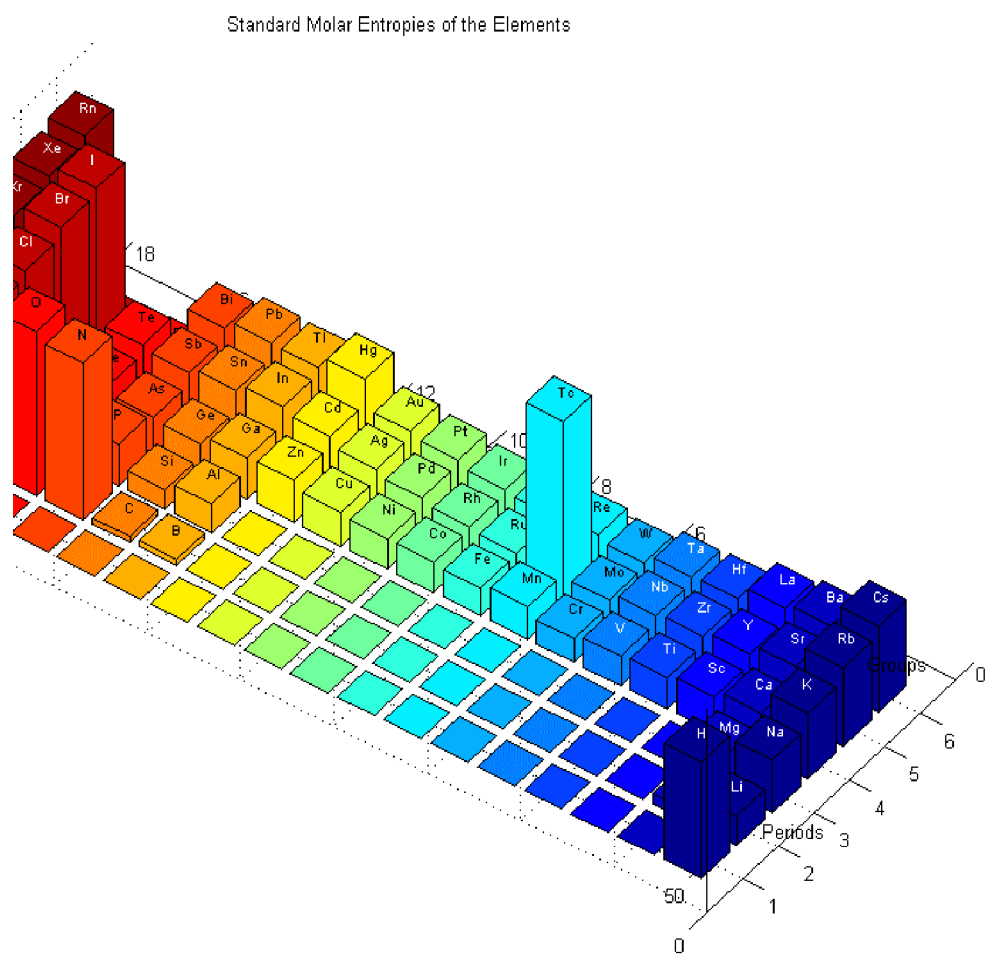


Figure 2. Periodic Table of Standard Molar Entropies (7). See text.

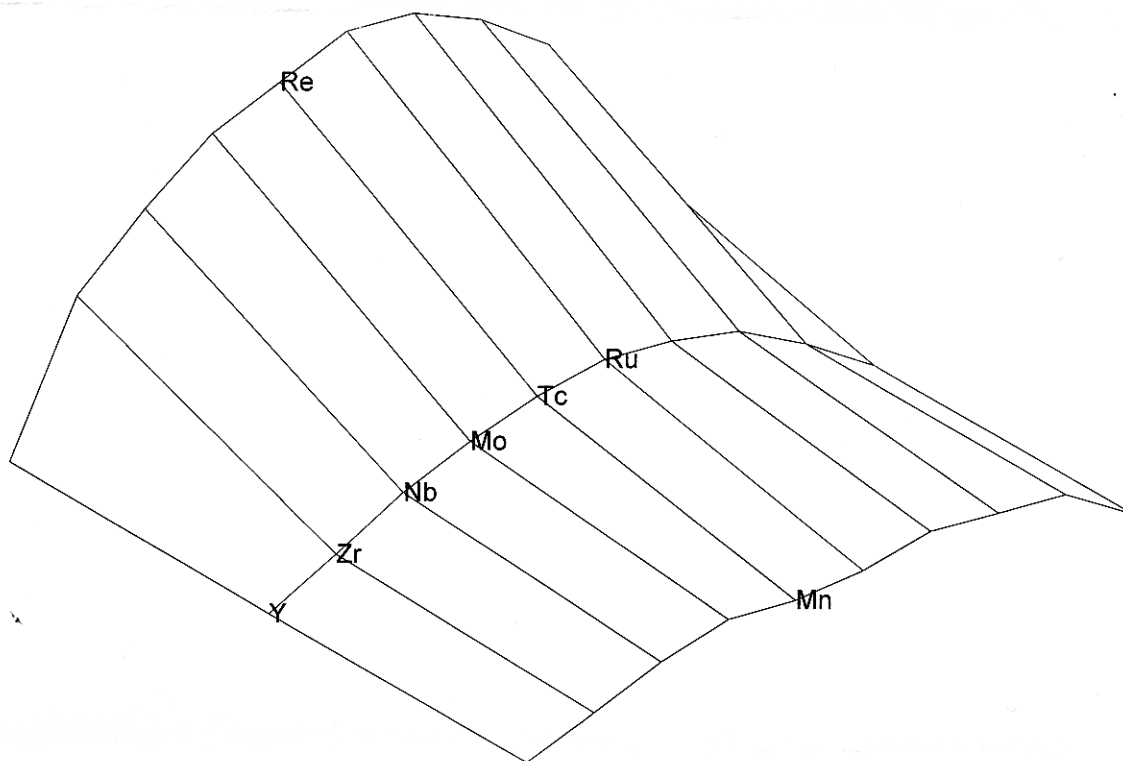


Figure 3. Three-dimensional surface graph of density.

AN APPARATUS FOR MONITORING THE HEALTH OF ELECTRICAL CABLES

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Paul Tatum⁽²⁾

Rachel Pace⁽²⁾

and

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On left – Devdas M. Pai

An Apparatus for Monitoring the Health of Electrical Cables

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Keywords

Smart material, piezoelectric, health monitoring, ultrasonic waves, electrical cables

Prerequisite Knowledge

Introductory Physics

Objective

To create piezoelectric sensors that will detect a sound wave passing through an insulated wire.

Equipment and Materials

The supplies listed below are separated into two categories; General Supplies that can be found in most physics and instrumentation labs and Special Supplies that will need to be purchased specially for this experiment.

General Supplies:

Acetone	8 oz.	Metal ruler		iron/solder		Wire, copper red insulated	
Aluminum foil	1 sheet	Multi-meter		Toothpicks		22 gauge	
Cellophane tape		pipe or rod	7ft.	Twine		Wood board	
Copper foil		Rubber cleaning gloves		Voltage amplifier		2in.x4in.x 12in	
Digital oscilloscope		Sand paper		Wire strippers		X-Acto knife	
Electrical tape		240 grit		Wire, copper 10 gauge single strand	48 ft.		
Function generator		Scissors		Wire, copper black insulated 22 gauge			
Mechanical pencil		Screws, wood – 1-in.	12				
		Soldering					

Special Supplies

	Supplier	Part#	Qty.	Cost
Piezoelectric Material 2in.x2in.	Piezo Systems Inc. 186 Massachusetts Ave. Cambridge, MA 02139 (617) 547-1777 www.piezo.com	T110-A4E-602	1	\$150.00
BNC Jack	Radio Shack	Ug-1094	2	\$4.00

Etching Solution	300 W. 3 rd St. Suite 1400 Fort Worth, Texas 76102 (817) 415-3200 www.radioshack.com			
Conductive Epoxy	ITW Chemtronics 8125 Cobb Center Drive Kennesaw, GA 30152-4386 1-800-645-5244 www.chemtronics.com	CW2400	1	\$20.00

* Optional materials and tools for mounting board

Board, pine 12in. x 12in. x 0.75in.	Board, pine 2in. x 4in. x 12in	Wood screws-1&3/4 in (12)	12in. Table saw
-------------------------------------	--------------------------------	---------------------------	-----------------

Introduction

As with most elements of infrastructure, electrical wiring is innocuous; usually hidden away and unnoticed until it fails. Failure of infrastructure, however, sometimes leads to serious health and safety hazards. Electrical wiring fails when the polymeric (usually rubber) insulation material that sheathes the conductor gets embrittled with age from exposure to pressure, temperature or radiation cycling or when the insulation gets removed by the chafing of wires against each other. Miles of such wiring can be found in typical aircraft, with significant lengths of the wiring immersed in aviation fuel – a recipe for an explosion if a spark were to occur. Diagnosing the health of wiring is thus an important aspect of monitoring the health of aging aircraft. Stress wave propagation through wiring affords a quick and non-invasive method for health monitoring. The extent to which a stress wave propagating through the cable core gets attenuated depends on the condition of the surrounding insulation. When the insulation is in good condition – supple and pliable, there is more damping or attenuation of the waveform. As the insulation gets embrittled and cracked, the attenuation is likely to reduce and the waveform of the propagating stress wave is likely to change. The monitoring of these changes provides a potential tool to evaluate wiring or cabling in service that is not accessible for visual inspection. This experiment has been designed for use in an introductory mechanical or materials engineering instrumentation lab. Initial setup (after procuring all the materials) should take the lab instructor about 4 hours. A single measurement can be initiated and saved to disk in less than 3 minutes, allowing for all the students in a typical lab section to take their own data rather than share a single set of data for the entire class.

Procedure

Mounting board (optional)

The 10 gauge wire can be mounted on a pipe and suspended using the wood blocks to support it. If this method is chosen skip to the section below ‘Creating the Sensors.’ An alternate method for a more compact apparatus is to mount the 10 gauge wire to a 12 in. square board.

Materials

- Board, pine – 1 pc. 12 in. x 12 in. x 0.75 in.
- Wire, copper 10 gauge 48 ft.
- Wood tiles (6) 2 in. x 2 in. x 0.25 in. (cut from the 2 in. x 4 in. board) (six one inch flat brackets may be substituted for the wood tiles)
- Wood screws (12) 1 in.

Manufacturing procedure

1. Set the height of the blade on the table saw to 1/4 in. above the table deck. Use the pencil to divide the 12 in. x 12 in. board into three equal sections along the grain by drawing a line from one end to the other.
2. Cut a 1/4 in. deep groove along each line with the table saw. Label the middle groove 10 ft. and the other grooves 2 ft. and 20 ft.
3. Measure the insulated wire and use a magic marker to mark it at 2 ft., 10 ft. and 20 ft. from one end.
4. Measure 9 in. from the 2 ft. mark and place this section in the end of the groove marked 2 ft.
5. Place a 2 in. x 2 in. wood tile over the wire and groove and screw into place with two wood screws, securing the wire in the groove.
6. Bend the wire up at 90 degrees from the board, measure four inches from the wood tile and bend the wire at 90 degrees so that the section with the 2 ft. mark is parallel to the board.
7. Bend two more 90 degree angles in the wire at the other end so that the remaining wire fits into the groove at the other end of the board with enough room to secure it with a wood tile and screws. You should now have one section of wire secured to the board and elevated about 4 in. above it. The 2 ft. mark will be where you place one sensor.
8. Repeat these steps with the other two sections of wire labeled 10 ft. and 20 ft. using their respective grooves.
9. Neatly coil all excess wire. There should be approximately 20 ft. of excess wire beyond the mounting board.

Creating the sensors

Materials

- Copper foil 1 in. x 1 in. 0.75 in. x 0.75 in. and 1/16 in x 1 in.
- Piezoelectric material 0.5 in. x 0.5 in. square

Cellophane tape 4 in. of 1 in. wide clear, cut into eight 1 in. x 0.5 in. strips.

- Etching solution
- Conductive epoxy

Manufacturing procedure

1. Remove the cap from the etching solution bottle and place a few drops of the solution in the cap.
2. Dip each edge of the PZT tile into the solution just enough to remove about a half millimeter of the PZT surface on each side, being careful not to remove more than half a millimeter. Blot the tile dry with a paper towel.
3. Place the 1 in. x 1 in. copper foil onto a sheet of white paper.
4. Center the PZT on the 1 in. x 1 in. copper foil and lightly trace the outline with a pencil.
5. Remove the PZT and paint a thin coat of epoxy into the outlined section of the copper foil, then place the PZT onto the epoxy and gently press into place. Clean up any epoxy that squeezes out from the edges using a tooth pick.
6. Place tape around the edges of the PZT being sure to cover the edges where the material was etched away but not cover the active section of the PZT. There should be enough excess tape to completely cover the foil and also secure it to the paper.
7. Using the X-Acto knife and a straight edge gently score the surface of the PZT vertically in half mm increments from one edge to the other.
8. Paint a thin coating of epoxy on the PZT being careful to leave a margin near the taped edges.
9. Press the 0.75 in. square of copper foil onto the PZT and tape the edges down.
10. Mark an arrow onto the exposed copper foil in the direction of the scored marks made on the PZT for future reference. The sensor should now be firmly taped to the sheet of paper.
11. Let the epoxy cure over night, then use the X-Acto knife to cut around the edges of the larger copper foil to remove the sensor from the paper.
12. Turn the sensor over and feel for the edge of the PZT tile and mark it with your finger nail on both edges of the PZT in the direction parallel with the arrow on the other side.
13. Use scissors to cut along these lines to trim off excess foil. These two edges of the sensor will be the two that meet when the sensor is wrapped around the wire. The arrow represents the direction of the wire.

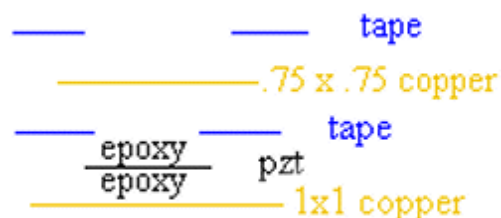
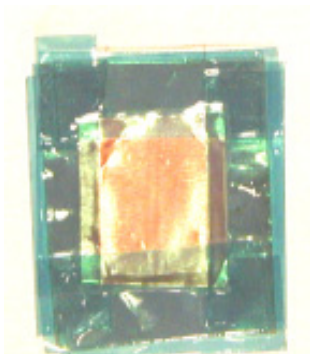


Figure 1. Completed sensor (left) and side view diagram (right)

Placing the sensors on the wire

If you have opted to hang the coil on a bar, measure the 10 gauge insulated wire and mark distances of 2 ft., 10 ft. and 20 ft. with a permanent marker. Coil the wire over the rod and hang in the wooden blocks so that the sections marked off are easily accessible. There will be a sensor placed at each mark so refer back to these directions for each sensor placement. Then continue with the following.

1. Straighten a segment of the wire near the mark so that the radius of the coil is taken out as much as possible for about 6 in.
2. Lightly sand the insulation at the marked sections just to scratch it a bit so that the epoxy will hold better.
3. Place a prepared sensor arrow side down on a hard surface.
4. Place the handle of the X-Acto knife along the same axis as the arrow and roll it from one side to the other using enough pressure to crack the PZT along the scored marks.
5. Paint a bead of epoxy along the center line of the sensor parallel with the arrow on the 1 in. x 1 in. copper side.
6. Place the sensor onto the marked section of the wire with the epoxy against the wire and pointing in the direction of the length of the wire and firmly bend the sensor around the wire so that the two meeting ends are clearly visible, making sure the sensor makes good contact all along the diameter of the wire. You should hear and feel the PZT material cracking as it is bent around the wire.
7. Remove any squeezed epoxy from the wire surface so as not to short out the ends of the sensor.
8. Insert the thin strip of copper foil 3 mm under the edge of the sensor so that it makes contact with the epoxy and copper on the bottom of the sensor and let the tag end stick out freely. This will be your ground contact for the bottom of the sensor.
9. Tape the sensor in place with electrical tape and let cure over night. Folder clips can be used to hold the sensor in place if desired.
10. To test the sensors connect them to oscilloscope (trigger set to single) and lightly tap the wire with a ruler. The oscilloscope should register a wave at each sensor.

Attaching the BNC jacks

Materials

- BNC jacks (3)
- Solder
- Wire, copper 22 gauge black and red
- Copper foil 1 in. x 0.25 in. (3)
- Electrical tape
- Aluminum foil

Manufacturing procedure

1. Cut 5 in. of black and red 22 gauge wire.
2. Strip the insulation from both ends of each wire.
3. Solder the red wire into the center post of the BNC jack and the black wire to the ground connection.
4. Cover both connections with electrical tape.
5. Solder the opposite ends of each wire to a separate 1 in. x 0.25 in. piece of copper foil.
6. Place the black wire connection onto the sensors ground connector (copper tag) and tape into place with electrical tape.
7. Place the red wire connection onto the exposed copper section of the top of the sensor and tape into place.
8. Secure all loose wires with electrical tape.
9. Attach the coaxial cable to the BNC jack and tape the cable to the 10 gauge wire for support.
10. Cover the entire sensor and all connections with aluminum foil to shield it from external noise.
11. Use a clip to insure that there is a solid connection between the aluminum foil shield and the BNC jack.
12. Use a multi meter to make sure there is no short circuit at the end of the coaxial cable between the pin and the ground.

The sensor is now ready. Repeat steps above for the other two sensors

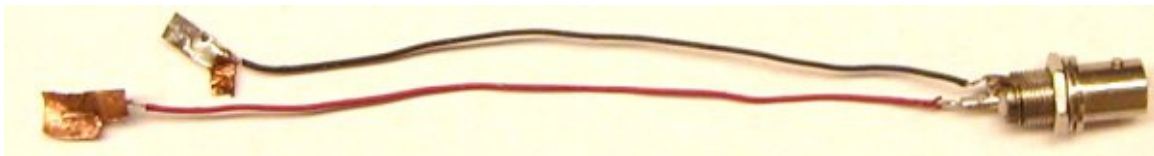


Figure 2. *An assembled BNC jack with leads*

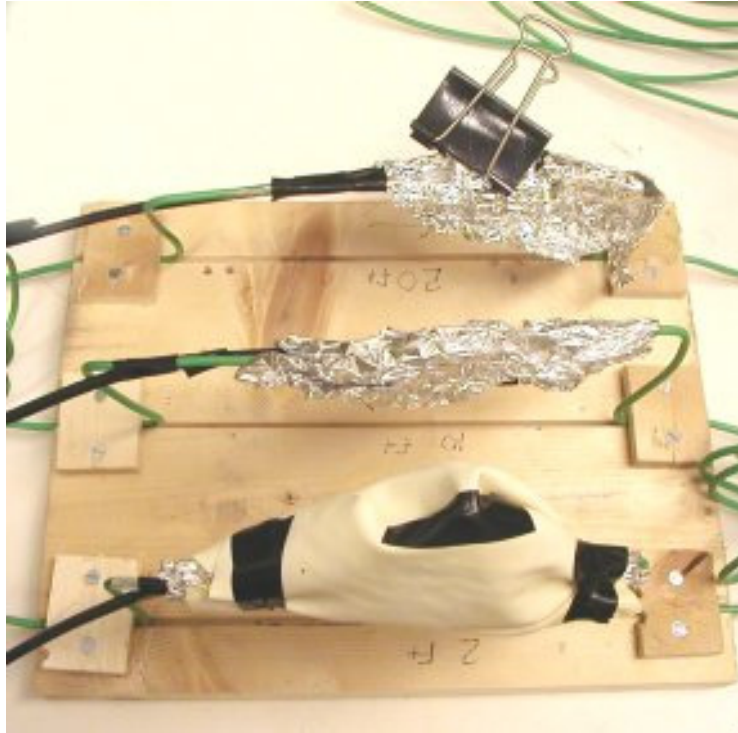


Figure 3. Completed setup with mounting board



Figure 4 Diagram of the completed apparatus with sensors at 2 ft., 10 ft. and 20 ft.

Connecting the function generator, amplifier and oscilloscope

Warning: Care should be taken when using the voltage amplifier. A direct connection between the output of the voltage amplifier and one of the sensors can cause serious damage to the oscilloscope.

1. Using coaxial cables (or appropriate connectors for your oscilloscope) connect the 10ft. sensor to channel 1 and the 20 ft. sensor to channel 2.
2. Connect the EXT. jack on the function generator to the EXT. jack on the oscilloscope and set the oscilloscope trigger to EXT.
3. Connect the function generator OUTPUT to the voltage amplifier INPUT.
4. Connect the voltage amplifier OUTPUT to the sensor located at the 2 ft. mark. This sensor will now be referred to as the actuator as it will be generating the wave from the inputted voltage. *IMPORTANT! Once the cable is connected to the actuator cover all metal on the actuator with rubber cut from the rubber cleaning glove (or other insulating material) and tape securely into place.* Should the metal of the actuator touch the aluminum foil of the sensor at the 10 ft. mark it could cause serious damage to the oscilloscope.

5. Set the oscilloscope to trace channel 1 to A and channel 2 to B.

You are now ready to begin testing the wire.

NOTE: to test that the sensors are functioning properly you can connect each sensors cable directly to the function generators OUTPUT, then using a constant sine wave set between 4 kHz and 15 kHz at 9 V_{p-p} listen for a tone. The sensors will create an audible tone when working properly.

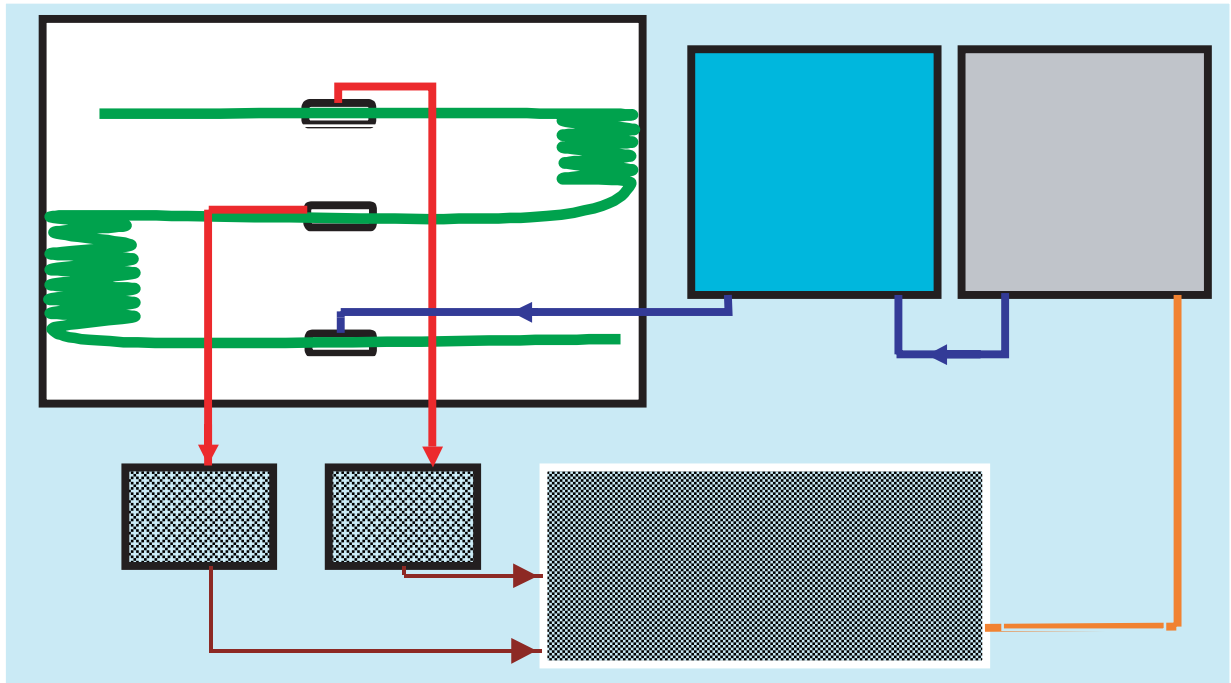


Figure 5. *Experimental setup*

Collecting Data

1. Set the function generator to burst mode to generate 5 pulses of 8 kHz frequency with an amplitude of 1 V_{p-p}.
2. Attach a coaxial cable connecting the EXT jacks on the function generator and the oscilloscope. Making sure the oscilloscope trigger is set to EXT and that channel 1 and 2 are set at 2 ms and 6 V.
3. Use the trigger on the function generator to send a five wave burst to the actuator.
4. Confirm that a signal is registering on both channels.
5. Adjust the voltage on the oscilloscope as needed and increase the voltage of the function generator as needed using increments of 1 kHz.
6. Fine tuning of the signal can be done by adjusting the frequency in small increments until the best signal is received from each sensor. The individual sensors may get peak signals at different frequencies. Once an adequate signal is registered set the trace channels A and B to collect 20 sweeps averaged to eliminate noise.

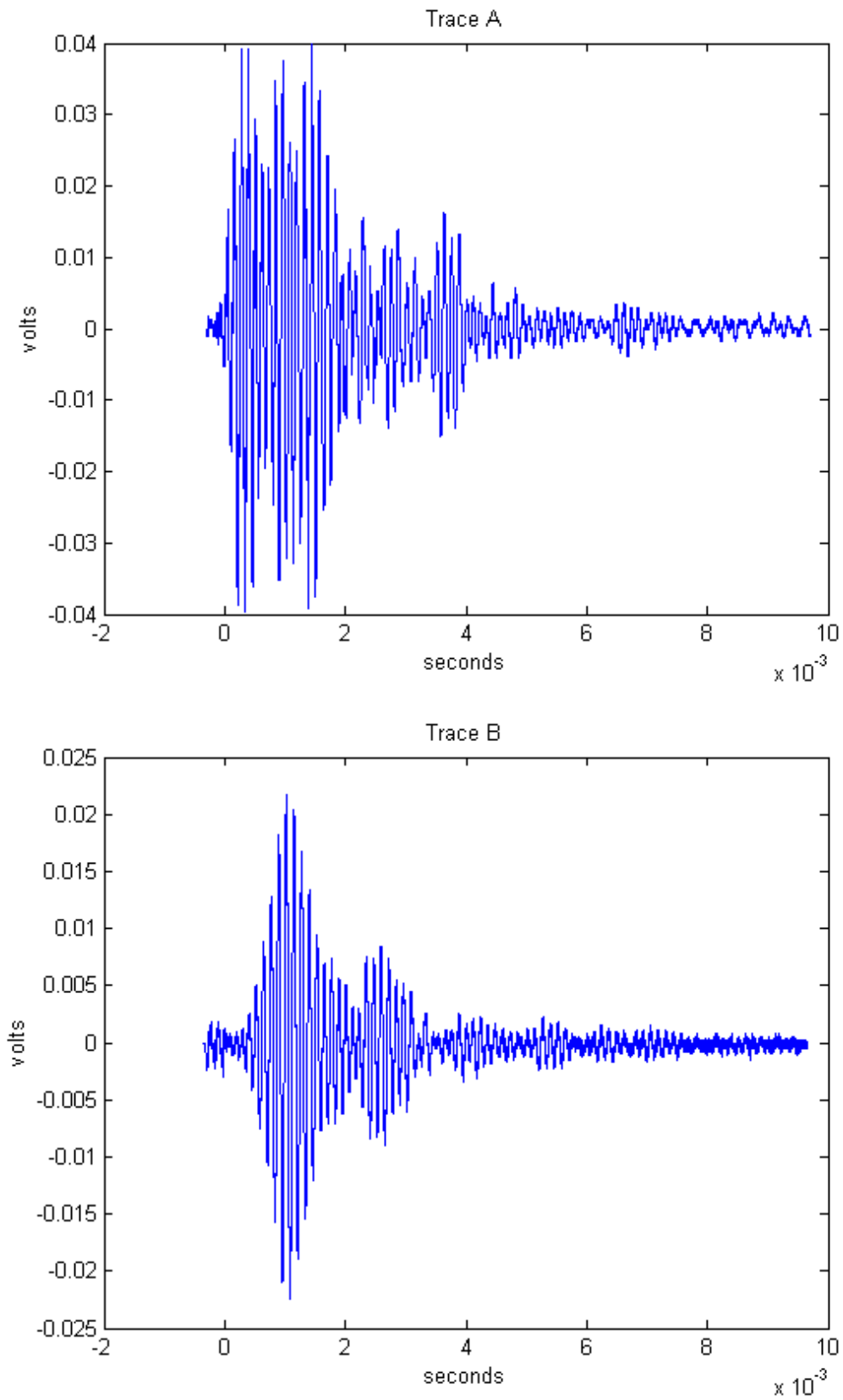


Figure 6. A typical signal from channel 1 (top) and channel 2 (bottom)

Comments

This paper demonstrates the manufacture and use of piezoelectric sensors attached to a common insulated electrical wire to monitor sound waves passing through the wire. It is a moderately inexpensive and compact apparatus that can be used to demonstrate how sound waves behave in an insulated wire.

Acknowledgement

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Pai, D. M., and Sundaresan, N. R., "The Use of Piezoelectric Materials in Smart Structures," Proceedings of the 2003 ASEE Annual Conference, (CD-ROM Paper #1740), Nashville, TN, June 2003.

**INTEGRATING MATERIAL SCIENCE INTO THE 6TH
GRADE CURRICULUM NORFOLK PUBLIC SCHOOL
SYSTEM/INTRODUCTION OF TECHNOLOGY**

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Integrating Material Science into the 6th Grade Curriculum Norfolk Public School System / Introduction of Technology

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Key Words: partial list: Vacuum, pressure, inertia, polymer, synthetic, static, vertical, horizontal, shear, gravity, impact, and shear.

Prerequisite Knowledge: Basic elementary Math, English, and Science

Objective: To relate MS into 6th Grade Introduction to Technology Education Curriculum including Virginia Sols and Standards of Learning

Equipment:

- 1. Vacuum Cannon:** Shop Vacuum, T-Valve, PCV Pipe, Pre-Made Cardboard Sealers, Ping Balls, Paper, Duct Tape, Pennies, Hot Glue.
- 2. Gak-Polymers:** Plastic Bags, Tape, 3-Oz Cups, Stirrers, Water, Glue, Borax, Measuring Cups.
- 3. Paper Bridges:** Paper, Scissors, Tape, 3/4 In Plywood, 3 Chairs

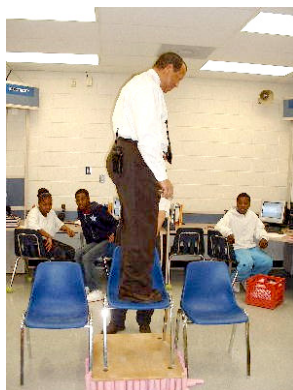
Introduction:

Mr. Goodman and I went to an all day workshop at Landstown High School in Virginia Beach concerning Materials Science used at the high school level. We were so impressed with the input, problem solving, and output of the seminar that we decided to try to integrate material science into the 6th grade level technology course. The output was so positive, we are now rewriting and instigating material science projects to cover the Sols taught at the middle school level technology curriculum. The curriculum is in progress and is now being written. In the curriculum, math and science Sols will be listed and correlated to state standards.

Middle school technology students are full of energy and need to be directed with hands on projects. They are visual learners. Material science projects fit in perfectly with deep problem solving procedures we want them to learn. By teaching material science projects and theories at the middle school level, they are more prepared for problem solving in the future. They will learn molecular structure, the periodic table, math theories, law of relativity plus almost all the Sols used in Math and Science at the middle school level.

Procedure:

1. Teacher construct canon, students cut projectile body template, attach projectile head (ping-pong ball) with duct tape, weight each projectile differently and mark on body, review launch procedures, launch projectiles and graph distance vs. weight, analyze data and look for bell graph.
2. Discus polymers and synthetic materials, review safety video on computer, measure water and glue, mix water and glue, prepare borax mixture, add to water/glue mix, stir, and do experiments to observe physical characteristics of gak, analyze data.
3. Discuss 3rd law of relativity, show theory use, cut out bridge structures, tape structures, construct bridge roadbed, apply road surface, test for critical mass, analyze structure failure and data.

Examples:**1 Vacuum Cannon****2 Gak (Silly Polymer):****3 Paper Bridges:**

Comments:

1. Students **must** follow safety and eye protection procedures during launch.
2. Students wear gloves and goggles during mixture. Students take home caution sheet about usage when taking home gak
3. Students discuss why implosion is important in building construction.

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Bibliography:

Tyrone Goodman has worked for Norfolk Public Schools since 1972. His first teaching position was woodworking at Willard Junior high School. Tyrone chaired the career and technical education department at Granby High School and taught Engineering, Electronics, and Principal of Technology (Applied Physics). In his position as Senior Coordinator of Engineering and Technical Careers, he supervises programs in agriculture, technology education, and trades and industrial. Tyrone earned a B.S. degree in Industrial Arts from Norfolk State University, a M.S degree from Virginia State University, and a C.A.G.S. degree from Virginia State University.

Mr. Abramson is a 25-year veteran teacher of Norfolk Public School System. He received Bachelors degree in Technology Education with a minor in Math from East Tennessee State University. He has taught High School Graphics and Metals. He taught 4 years in a transitional school for the disciplinary problem student. He took over and rebuilt the lab at Campostella Middle School. He was a leader in setting up and designing the physical network at Lafayette Winona Middle School. He is also a ten-year veteran on NPS Smart Team. He was involved with the original Creative Learning: Lab 2000 at Lafayette Winona Middle School. He was also used in the design and setup of his new Pitsco Synergistics Lab. He coordinated the rewriting the new 8th grade Technological Systems Curriculum for Norfolk Public School System. He is helping to coordinating the certifying of technology middle school teachers to teach the Dell TechKnow program at the middle school level. His program won Program Of The Year from the ITEA in 1998. He is a two-time winner of the NPS School Bell Award and twice a semifinalist for their Inspiration Award. His program was highlighted in the Norfolk Virginia Pilot Newspaper in February 24, 2003.

ELECTROSPINNING: A SIMPLE TECHNOLOGY WITH A BIG IMPACT

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Electrospinning: A Simple Technology with a Big Impact

National Educators' Workshop

October 19 - 22, 2003

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Key Words: Polymer micro- and nanofibers, electrospinning, ethylene-co-vinyl alcohol (EVOH), biomaterial

Prerequisite Knowledge: Basic electrical knowledge and safety, solution preparation skills, nanotechnology concepts

Objective: To demonstrate fabrication of very thin polymer fibers using electrospinning

Equipment and Materials:

1. Ethylene-co-vinyl alcohol (EVOH)
2. High-voltage (low current) supply
3. Small-bore syringe needle or glass pipette with wire
4. Ground electrode (foil, screen, drum)
5. Optical microscope

Introduction:

Current research in the authors' laboratories is focused on the processing of synthetic and biological polymers to create materials with tailored properties and functions for applications in medicine and nanotechnology. This motivation has rekindled interest in electrospinning, a fiber processing technique capable of generating fibers with diameters ranging from about 50 nanometers to 10 microns. These fibers can be used to fabricate ordered structures for various applications including tissue engineering scaffolds, clothing, drug delivery, and filtration. [1-8]

In electrospinning, polymer solutions or melts are deposited as continuous fibers that collect and form fibrous mats. A schematic of the electrospinning system is shown in Figure 1. The fibers are derived by charging a liquid versus a ground a short distance away. The charged liquid is attracted to the ground electrode of opposite polarity and, eventually, forms a fiber jet as the electric field strength exceeds the surface tension of the solution. The basic elements of a laboratory electrospinning system are simply a high voltage supply, ground electrode/fiber collector, source electrode, and a solution or melt to be spun. In the example described below, EVOH is electrospun from solution in isopropanol and water. EVOH has shown potential as a tissue engineering scaffold through cell culturing experiments with fibroblast and smooth muscle cells. [9]

Experimental Procedure:

Several samples of EVOH were obtained from Soarus LLC (Arlington Heights, IL) having compositions of 56 – 71 mol% vinyl alcohol repeat units. Isopropanol (2-propanol) was obtained from Aldrich, and 70/30% v/v alcohol/water solutions were made using distilled, deionized water. Solutions of EVOH and 2-propanol/water with compositions ranging from 2.5 – 20 w/v% were typically prepared by heating the appropriate amounts of polymer and solvent to 80°C until complete dissolution of polymer occurred (usually 2-3 hours). Dissolution was slower at lower temperatures, ranging from ca. 20 h at 65°C to about 10 h at 70°C. Solutions for electrospinning were cooled to room temperature (ca. 22-24°C). Precipitation of polymer always occurred, with the fraction precipitated being dependent upon the polymer concentration, but not until several hours after reaching room temperature. For example, a 50 ml solution of EVOH (62 mol% vinyl alcohol) in 2-propanol/water (10 w/v%) in a 100 mL round-bottom flask did not show signs of precipitation until after about 7 h at room temperature, and thus we were able to use room-temperature solutions for electrospinning within several hours of preparation. The precipitated mixture could be solubilized again by warming to about 50°C for 10 min, and subsequent precipitation and re-dissolution could be repeated many times.

The electrospinning set-up utilizes a Spellman CZE1000R high voltage supply (0-30 kV; Spellman High Voltage Electronics Corp.) with a low current output (limited to a few μ A). A syringe with a blunt-end needle can be used or, more simply, a glass pipette can be employed with a wire immersed in the solution. A positive voltage (15 kV) is applied to the polymer solution either by connection to the syringe needle or via the wire in the pipette, with the distance between the syringe or pipette tip and the target surface being ca. 20 cm. EVOH/2-propanol-water solutions prepared as described above should be electrospun within one hour after cooling to room temperature. Interestingly, dielectrics (e.g., a plastic petri dish) interposed between the electrospinning jet and grounded target can be easily coated, as can a human hand as is illustrated in Figure 2.

Comments:

It is known that a critical concentration of polymer in solution must be exceeded in order to observe electrospinning. Below this concentration, chain entanglements are insufficient to stabilize the jet, leading to spraying of droplets. For the 62 mol% vinyl alcohol copolymer in 70/30 v/v 2-propanol/water, spinning commences above about 5% w/v of polymer as indicated by the scanning electron micrographs in Figure 3. Below this concentration, droplets are formed which coalesce into ill-defined shapes on the grounded target. At 5% w/v, a hybrid structure of fibers and beaded fibers is seen. The micrographs also indicate that the average fiber diameter of the electrospun samples increases with increasing polymer concentration, which is common. Rather thick fibers are seen at 20% w/v, and, at 15% w/v, fibers appear to be fused at overlapping junctions, perhaps the result of incomplete solvent evaporation. The most uniform fibers derived with the experimental conditions outlined above were afforded at 10 % w/v.

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Biography:

Kristin Pawlowski is a graduate co-op student working toward a Ph.D. in Biomedical Engineering at NASA, Langley Research Center, and Virginia Commonwealth University. She is involved in electrospinning fabrication and subsequent characterization of electroactive polymers for aerospace and biomedical applications. Gary Wnek is Professor and Chair of Chemical Engineering at VCU, with research interests in polymers as biomaterials and as components of fuel cells and batteries. Gary Bowlin is an Associate Professor of Biomedical Engineering at VCU with research interests in tissue engineering and biomaterials, especially vascular grafts and cardiovascular system repair.

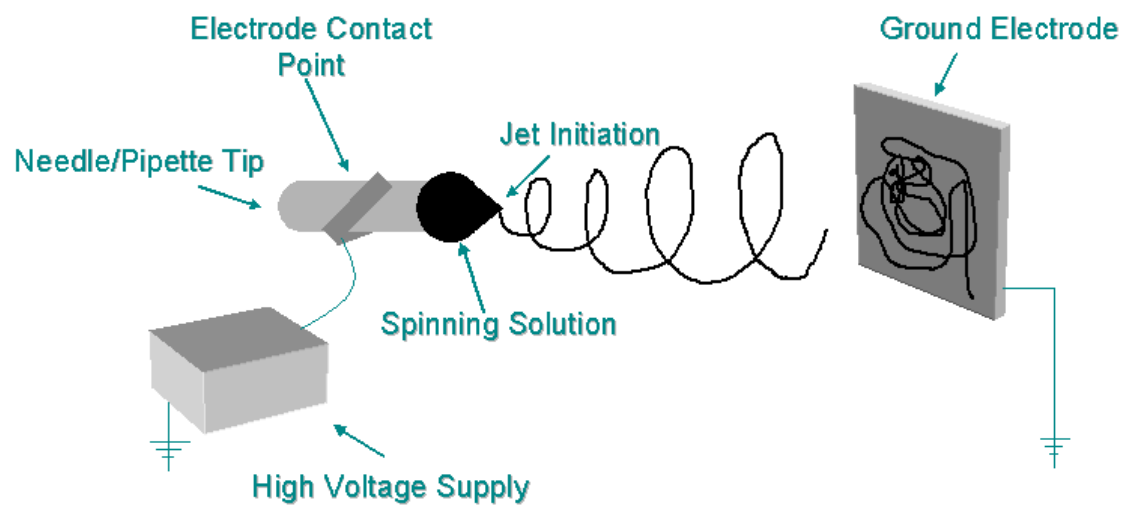
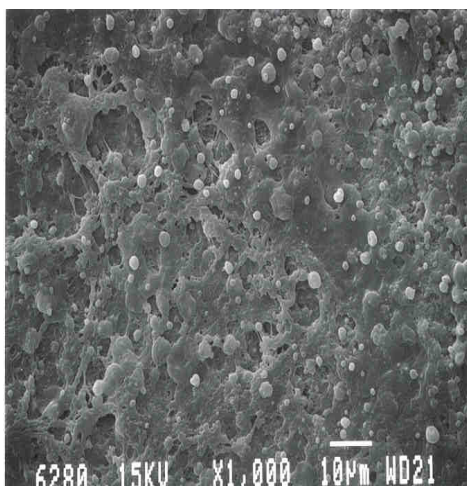


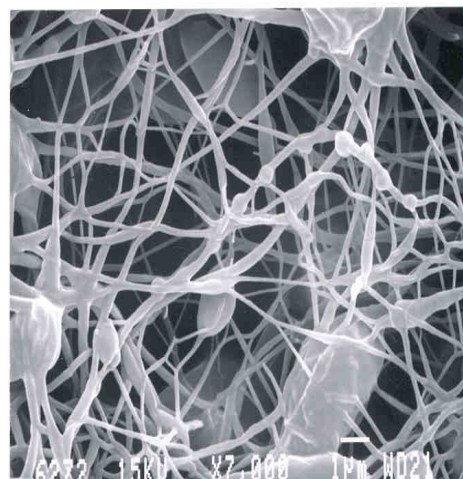
Figure 1. Schematic of experimental set-up.



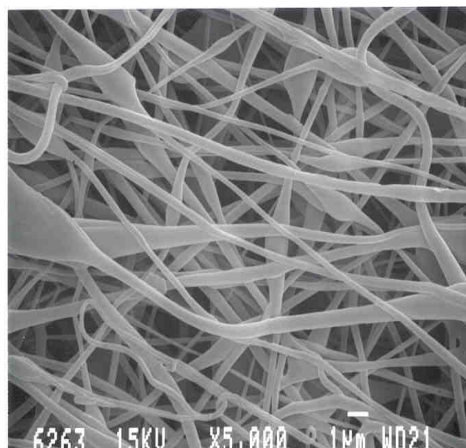
Figure 2. EVOH electrospun directly onto a human hand.



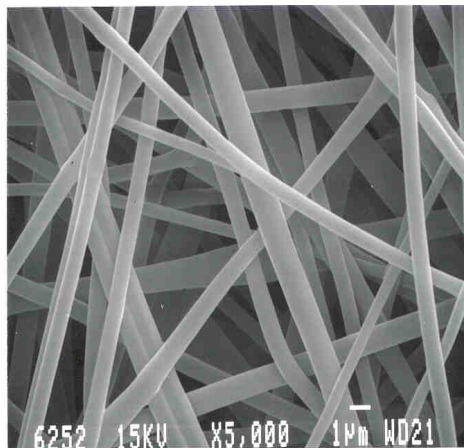
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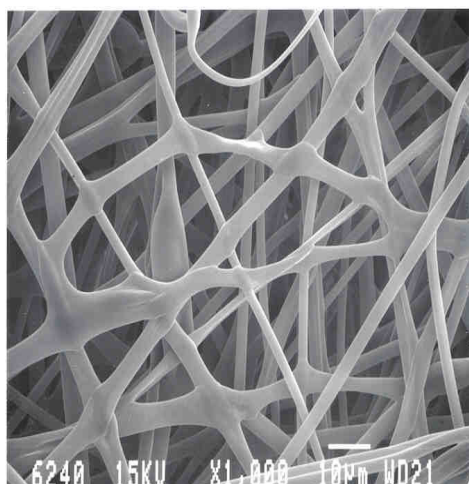
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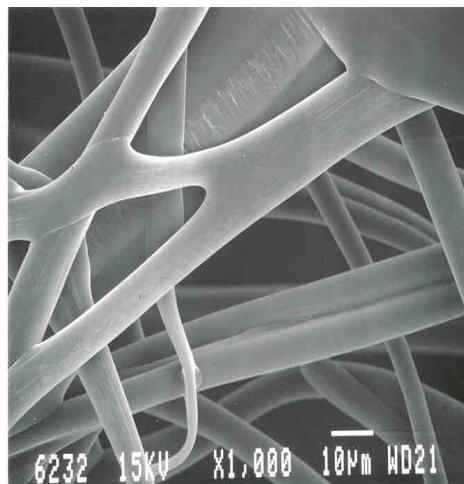
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15%



20%

Figure 3. Scanning electron micrographs of 62 mol% EVOH spun from 70/30 2-propanol/H₂O at various concentrations (g polymer/ml solvent).

**SIGNIFICANCE OF MICROWAVES IN THE
ENVIRONMENT
(AN EXTENDED STUDY)**
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Key Words

Microwaves, greenhouse effect, dielectric relaxation, thermal bath, carbon dioxide, polarization, chemical reactions

Abstract

This paper is an extension of the work that has been done in the microwave spectroscopy research labs at Southeast Missouri State University and the University of North Texas. Carbon dioxide molecule is a non-polar molecule and as such does not participate in any chemical reaction. The polarization of CO₂ is considered to be an extremely important problem for its use to initiate chemical reactions. Microwave technology was used in a previous study to polarize CO₂ using x-band radiation between 8.8 – 10.6 GHz. This experiment is extended to higher frequencies and polarization has been achieved for this molecule at other frequencies. In this paper the results for a couple of these microwave frequencies higher than 10.6 GHz are presented.

Introduction

The chemistry of carbon dioxide is one of the most interesting topics for the scientists in this modern age of technology. Science has made such a tremendous progress in several fields and the humanity is reaping the rewards of this important progress. But at the same time this progress in technology has a big price tag for the humanity to pay and this is in terms of the pollution that we as human beings have to face. The Green House Effect is one of the hottest topics of this modern technological era. A significant percentage of this problem is the presence of carbon dioxide in the atmosphere that is depleting the ozone layer. This is a very critical problem and the problem is based on the unavoidable production of carbon dioxide in this modern technological world. In this research experiment there is a possible solution to this problem in which one can make use of the CO_2 molecule and avoid its exposure to the atmosphere. More and more applications of microwave technology have been found in chemistry, pharmaceutical, plastic recycling etc. In this experiment microwave technology is used to activate carbon dioxide. Carbon dioxide is the byproduct of many chemical reactions. The amount of carbon dioxide has increased significantly in the last decade that causes the green house effect. More importantly, scientific research of carbon dioxide is being carried out in utilizing the gas as a carbon source in chemical industry. The bond energy of $\text{C}=\text{O}$ in $\text{O}=\text{C}=\text{O}$ is 799 KJ/mol. Researchers have studied several important properties of carbon dioxide { 1 }. A lot of research has been done on the activation of carbon dioxide photo chemically and electrochemically. But no reports have been seen on the research subject of activating carbon dioxide by using microwave technology. The main goal of this research experiment is to activate and utilize CO_2 molecule by using microwave technology.

We studied the polarization behavior of CO_2 using a resonant cavity in the TE_{011} mode in a microwave spectrometer. Such a spectrometer has been used in a number of experiments {2-7}. In these experiments we studied the microwave dielectric response of polar liquids, semiconductors, high temperature superconductors, ferroelectric materials, and liquid crystals. The polarization of CO_2 has been studied using this technique between 8.8 and 10.6 GHz {8}.

Theory, Procedure and Results

In this paper we have extended this study up to a frequency of 11.77 GHz. A very sensitive thermal bath is used to cool the CO_2 molecule and the thermal bath is connected to a computer that controls the temperature. It is a very sensitive technique to monitor the temperature and it keeps it constant for the desired time for polarization. The CO_2 (dry ice) is taken in a balloon and a capillary tube is attached at the end of the balloon. The capillary tube is then inserted inside the microwave resonant cavity. The microwave resonant cavity containing the CO_2 sample is cooled to the desired temperatures using the computer controlled thermal bath. The microwave field at the desired frequency is

applied to the resonant cavity and the absorption signals are monitored on to the oscilloscope. The perturbation of the electric field in the applied microwave signal is studied using the Slater's perturbation equations {2 - 4}. The microwave polarization behavior of carbon dioxide is studied between 10.7 – 11.9 GHz. A scan of frequency between this range indicated significant polarization close to 11.41 GHz and 11.77 GHz. The results for these frequencies are shown in Figures 1 and 2. It can be seen from these figures that the CO₂ molecule shows a polarization behavior at 11.41 GHz. On the other hand the polarization behavior gets stronger at a microwave frequency of 11.77 GHz. This experiment will be extended to much higher frequencies till an optimum value of polarization is achieved for CO₂. Once that happens, the polarized CO₂ will be introduced in a microwave reaction chamber in which a chemical reaction will be completed by the polarized CO₂ molecule. The microwave reaction chamber was bought from a research grant received from the Research Corporation.

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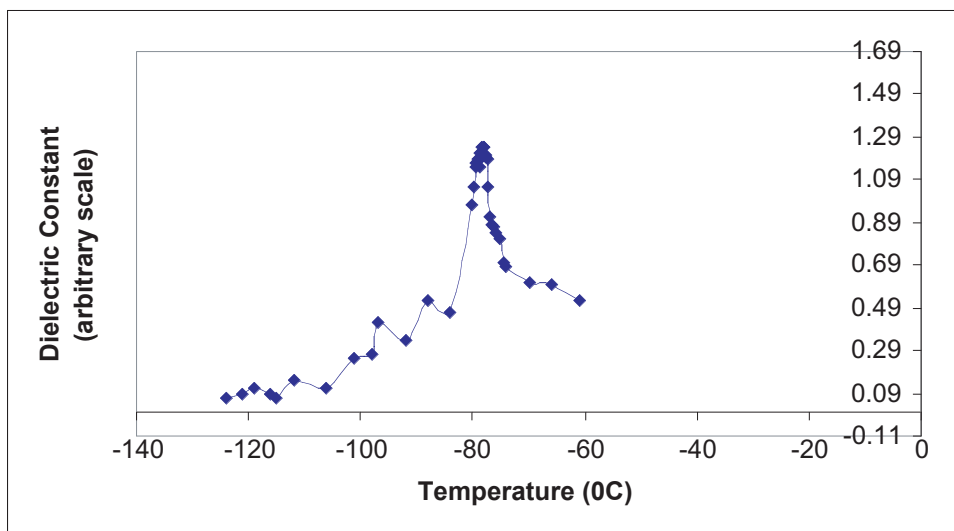


Figure 1. The polarization behavior of CO₂ at a microwave frequency of 11.41 GHz.

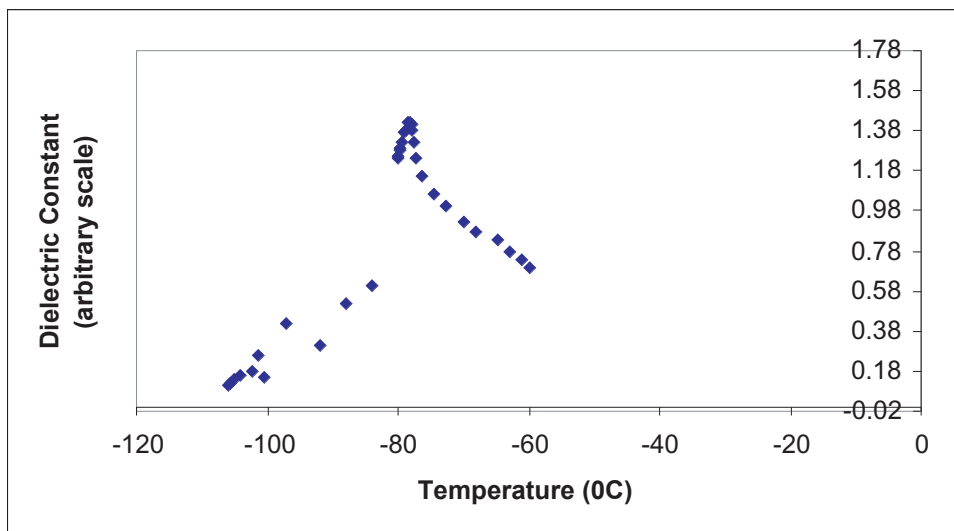


Figure 2. The polarization behavior of CO₂ at a microwave frequency of 11.77 GHz.

**THE CLASSROOM IS OUR LATTICE: A SERIES OF
“QUICK” VISUALIZATION EXERCISES FOR THE
INTRODUCTORY MATERIALS SCIENCE COURSE**
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"The Classroom is our Lattice": A Series of "Quick" Visualization Exercises for the Introductory Materials Science Course

18th Annual National Educators' Workshop

October 19-22, 2003

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Key Words: lattice, crystalline material, amorphous materials, lattice defects, vacancies, solid solution, grains and grain boundaries, diffusion, and visualization

Prerequisite Knowledge: none

Objective: To illustrate and promote learning the fundamental concepts in materials science through an activity utilizing an environment familiar to students, the traditional classroom.

Equipment and Materials: A classroom set up in columns and rows.

Introduction: This series of exercises has been developed to address the needs of students taking an introductory materials science course presented in a traditional lecture format. Students are taught visualization skills early in their engineering education but it is often not obvious to them how these skills can be applied to materials science, particularly in regard to crystallography and other phenomenon associated with atomic arrangements. Using this theme and our classroom environment, the new concepts can be presented throughout the semester that expand on activities done with the lattice and basic atomic arrangements in materials. Within each class, the learning styles of the students are diverse (often the majority are kinetic or hands-on learners)^[1] and the exercises presented actively involve students in creating the physical model. For the students, this 'quick' activity complements both the schematics in the text and computer animations presented in the course.

Experimental Procedure: In order to give the students a starting point for study and an 'easy-to-understand' physical model, "The Classroom is our Lattice" exercises are used throughout the semester. Some of the topics covered in the Western New England College course are listed in Table 1.

Table 1. Topics from course syllabus

(Reference - ME309 Materials Science- WNEC)

Atomic arrangement
Crystal structure (of metals)
Imperfections in solids – point defects, dislocations, grains
Diffusion – carburization and nitriding
Solid solutions – alloying and solid solution strengthening
Strengthening mechanisms – precipitation hardening

To begin the visualization exercises, our classroom desks, which are arranged in a regular, two dimensional, periodic array of points, become the lattice, and each student is an atom ‘residing’ at a lattice point. (Noting our classroom is set-up in the typical columns and rows manner and our desks are chairs with connected tablets.) Pointing out this arrangement to students and extending their thoughts to a three-dimensional model (by noting there are classrooms with students in the same arrangement a floor above and below them), provides students with an immediate visual ‘picture’ of the arrangement of atoms in a crystalline solid.

From the basic ‘lattice’ of desks in the classroom and the variety of students (differentiated by gender or clothing color), the following concepts are actively demonstrated.

Atomic Arrangement:

Lattice – Students notice the arrangement of desks in rows and columns that create an array of points in two-dimensions. The instructor highlights that this array can extend into three-dimensions and in the context of materials science, ‘this regular geometric arrangement of points in crystal space’^[2] is termed a lattice.

Crystalline material – Students reside at their individual desks in the classroom. In this exercise, it is pointed out that each student represents an atom on a lattice point, thus creating a regular arrangement of atoms in the space of the classroom, i.e. a crystalline material or typical metal. If the material is comprised of more than one atom per lattice point, the second atom (or another student) would be sitting on the tablet of the same desk in the classroom.

Lattice parameter- Students observe the distance between the desks and the locations of the desks with respect to on another and in the context of an orthogonal coordinate system. The instructor can use computer animations to illustrate the types of Bravais lattices and the common unit cells, i.e., SC, FCC, BCC and HCP.

Amorphous materials – Students move the desks to any position in the classroom, then note the randomness, or lack of a regular array. Alternatively, students can move around the room and then, ‘freeze’. The instructor points out that they are not associated with a lattice point and their arrangement no longer matches the regular arrangement of atoms in a crystalline material. Material processing methods to produce amorphous materials are discussed in this exercise. For example, an amorphous microstructure is produced when liquid metal is cooled rapidly or quenched to fabricate a braze alloy, or a metal is evaporated onto a cold (usually room temperature or below) to produce a thin film or coating. The instructor also discusses the variables of time and temperature and their influences on the structure of metals, i.e. amorphous versus crystalline.

Imperfections in Solids:

Point Defects – Students make observations about the classroom lattice, which is often not a perfect arrangement with students at every desk. Noting that the characteristics of materials are dependent on the imperfections in a the crystal structure, the instructor uses the arrangement of students and their gender or clothing color to illustrate various point defects in a crystalline material. Additionally, the instructor discusses the ‘benefit’ of imperfections and their influence on mechanical and physical properties. A common misconception is that students associate the

term ‘defect’ or ‘imperfection’ as only detrimental to material properties and thus, its use in bulk applications. Here, the students are reminded of the size scale in which these imperfections (nanometers) exist versus the materials use in a bulk application (millimeters to meters.)

Vacancies – Students observe the classroom is full of desks, but every seat is not taken. That is, there are vacancies available in the classroom, just as there are empty lattice points within a crystalline material. Here, the instructor is able to point out that the measured density of a material (or metal) is typically less than the theoretical density calculated based on the unit cell and atomic radius.

Interstitial Impurity – The classroom remains in the rows and columns arrangement and often a small portion of the classroom is sectioned off. Some students will sit at the desks and other students will be placed in the aisles. The instructor labels the students in the aisle, interstitial atoms or impurities. The instructor notes that they are residing within the material but not at regular lattice points. If all students represent the same element, then the material contains self-interstitial atoms. Students are differentiated by gender or color or their clothing and labeled carbon atoms, then, they are mixed with the students sitting in the desks, who are labeled iron. The instructor points out that the smaller carbon atoms easily fill the voids between the iron atoms, which reside on the lattice points. Students realize that this is the basic atomic arrangement in iron-carbon alloys, notably, steel. For alloys in which the interstitial atom is larger, the lattice may distort, or a strain is produced within the lattice. In the classroom lattice, students try to squeeze between the desks, to model the interstitial impurity.

Substitutional Impurity – Each student is sitting at a desk in the classroom. The instructor uses a characteristic, such as gender or clothing color, to identify one large group (balance) and one small group (10% of class). The former are the host atoms and the latter are the impurity atoms. As students look around the classroom, they see the lattice remains the same but some of their neighbors may be in a different ‘group’ or the substitutional impurity. It is demonstrated by the small group of students that they are residing on the lattice points but are different from the rest of the ‘students’ or atoms. The concepts of solid solution and alloying are discussed in latter sections.

Edge Dislocations – First, the instructor sets aside a few extra desks. Students are seated in their regular classroom arrangement. The instructor inserts the extra desks into the middle of the classroom, creating a partial column, or the ‘extra half-plane of atoms’. This matches the schematic diagram depicting an edge dislocation. Also, when the extra desks are inserted into the regular ‘lattice of the classroom’, adjacent students have to move slightly from their original positions. There is strain imposed in the lattice by the dislocation is highlighted the instructor.

Grains and Grain Boundaries -The classroom, which is arranged in rows and columns, represents a single crystal with a ‘perfect lattice’. The instructor divides the classroom into three or four sections and orients each section differently with represent to one another while the perfect lattice is maintained within each section. The students are told to look around and to note that the lattice (or crystal structure) has not changed, but the individual crystals are oriented differently with respect to each other. The instructor points out that the lattice is still present within each grain and the grain boundary regions ‘glue’ the individual grains together. It is noted that the bulk material still retains the crystal structure such as FCC or BCC, and the grain boundaries are where ‘interesting things’ tend to happen, such as short circuit paths for diffusion or for corrosion and carbide formation. Also, it is important to point out that grains are part of the bulk material and grain size influences mechanical properties.

Other concepts:

Concept of Solid Solution and Alloying– The students, who are seated at the desks, are divided into two groups, either by gender or color of their clothing. The instructor points out that the mixture of students occupying random or, in some cases, particular desks in the classroom models a solid solution. Here, students are reminded that the material has a crystalline structure (noting the lattice) and there is no ‘liquid’ present. Often, students see the word, ‘solution’, they tend to put it in the context of a liquids, and this misconception becomes problematic when teaching phase diagrams. Also, *alloying* can be discussed by changing the percentage of students in each group and by noting the arrangement of the classroom. The concept of *phases* is explained by grouping ‘similarly clothed students’ in different area of the classroom with different spacing between the desks. A specific example, precipitation hardening is illustrated by placing several students in small ‘clusters’ (representing the precipitate) within the regular classroom arrangement (representing the matrix.)

Concept of Diffusion – Students remain seated at their desks and the instructor notes that they will tend to stay in their seats and not move very often, if at all, at room temperature. However, if the temperature is increased significantly or a ‘fire was lit under their desk’, they would move. The student’s choice of a new position might be to a vacant desk (i.e., lattice point) or by swapping desks with another student (i.e., exchange between lattice points). Also, students can model interstitial atoms that could easily move (or diffuse) throughout the lattice (classroom) as the temperature increased. The instructor is able to focus on the ease of interstitial diffusion versus substitutional diffusion and the order of magnitude of the diffusion coefficient in different materials. Computer animations complement this visualization exercise. Carburization is modeled by having several students stand in the front of the room and ‘act’ as carbon atoms trying to gain access (or ‘diffuse’) into the classroom lattice. The instructor highlights the ease with which the students (carbon atoms) fit in the spaces between the desks or in the interstitial positions of the lattice (iron).

Comments: These few ‘quick’ exercises in a lecture give students a very practical picture to which they can connect the illustrations in the text book and more complex crystal structures presented in computer animations. From the basic ‘lattice’ of desks in the classroom and the variety of students (differentiated by gender or clothing color), terms such as vacancies, interstitial and substitutional impurity point defects, edge dislocations, grains and grain boundaries and concepts such as solid solutions and diffusion, can be simply illustrated. The theme of these visualization exercises ties together the fundamental concepts usually taught in an introductory materials science course and complements the lecture.

Experiencing these visualization exercises from a qualitative point of view, students respond positively to this familiar model of the classroom and are able to build their knowledge base readily, as the concepts increase in complexity. Also, students find these models easy to remember as noted by responses to quiz questions, which frequently included descriptions of the ‘classroom lattice’. Using these visualization exercises, students can use their everyday, familiar environment to begin their study of materials science, and the instructor has an active learning tool to add to the course.

For future and more diverse applications, this idea may adapted to other concepts in materials science as a way to help students visually the structure of materials and events occurring on micro- or nano-scale? Additionally, K-12 activities may incorporate this visualization exercise to explain and illustrate the atomic arrangements in materials used for both the nanoscale and bulk engineering applications.

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Bibliography: MARY B. VOLLARO

Mary B. Vollaro is Assistant Professor in the Mechanical Engineering Department at Western New England College in Springfield, Massachusetts. Dr. Vollaro received her Ph.D. at the University of Connecticut, her M.S. at Rensselaer Polytechnic Institute, and her B.S.M.E. at Western New England College. Her research and interests are in materials science and manufacturing processes, engineering educations and K-12 engineering outreach programs. She has also held engineering positions in industry (in particular, the materials science area).

THERMAL CONDUCTIVITY: A SMALL APPARATUS TO INTRODUCE THE CONCEPT

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Thermal Conductivity: A Small Apparatus to Introduce the Concept

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Key Words: Thermal transport properties, thermal conductivity, thermal conductivity apparatus, errors in measurement, student design

Prerequisite Knowledge (Reviewed prior to starting the experiment):

What is thermal conductivity?

What is the meaning of each of the terms in the thermal conductivity equation?

How does it vary between materials? With what materials do you associate a high thermal conductivity (metals, semiconductors or insulators)?

How does heat travel across a sample?

What is the error in the measurements?

Equipment:

1. Home made thermal conductivity apparatus
2. Two thermistors
3. Two slides each of Aluminum, Copper and Glass.

Introduction:

Thermal conductivity is important in electronic applications, especially in the miniaturized devices in use today, because the material used to move heat away from the device, and avoids any damage or malfunction that would arise if the device is heated in excess of its operating temperature. Sometimes one does not want heat to travel to other part of the device, and uses a heat sink. Another important application is in the space industry, where one wants to keep the area where people are at room temperature while the outside of the ship is either at very cold temperatures (like in an airplane) or at very high temperatures (like in the shuttle).

In this experiment, the students will measure the thermal conductivity of three materials, aluminum, copper and glass. Using Al as reference, they will measure the power dissipated dQ/dt across the slab based on the rate of change of temperature as a function of position. The students then will estimate the heat transfer, dQ at specific time intervals, dt , for Al. Based on the number they obtain for Al, they will calculate the thermal conductivity and heat transfer for glass and Cu.

Procedure:

The purpose of the experiment is determine the thermal conductivity, which is given by the equation:

$$dQ/dt = -\kappa A dT/dx \quad (1)$$

The numbers that the students are able to obtain are: the area A of the sample they are going to examine; T at two different points separated by a distance dx , so the quantity dT/dx is known; the time intervals at which the measurements are taken; for aluminum, the thermal conductivity κ , which will serve to calculate the amount of heat given out by the heater. For the other samples, Cu and glass they have the dQ calculated with the aluminum sample and need to calculate the thermal conductivity κ .

The apparatus used to estimate the thermal conductivity of materials is very expensive (~\$10,000). In fact, it exceeds the budget for the entire laboratory. We have gone with a home designed apparatus, which has the advantage that students can look at it and suggest ways of improving the design. The apparatus with which the measurements are done is shown in Figure 1. It consists of: a. Two thermometers, equipped with long thermistor cables; b. Thermal conductivity apparatus, which has: 1. heater (sautering iron), that produces a constant heat flow; 2. holder for the slabs; 3. a ruler to measure the temperature at specific places. The figure shows the holder with an Al slab.



Figure 1. Equipment used in this experiment. The home-made thermal conductivity apparatus is shown in the front and the two thermistors in the back.

The procedure that the students get is shown in Figure 2. At the end of the experiment, they are asked to estimate the error by estimating the standard deviation of dT/dx . In practice they can also estimate the error in calculating the area A ; however the standard deviation in the rate of temperature as a function of distance gives the larger error. The results obtained by each of the Spring 2003 groups and the errors are shown in Table I. The only error that seems too large is the one from Monday group A, which is probably an error in the measurement of the dQ . We have ignored that the measurement for Al, to which all other measurements refer to, also has errors. The other errors, while large, are reasonable considering that the sample is open to air, is a very thin sample and suffers from heat dissipation. Other errors that cannot be directly measured are how accurately is the distance measurement from student to student and how much attention are they paying to have the thermistors at the marked distance.

Procedure:

- 1. Using a ruler or a calliper, measure the cross-sectional area A of the Al, the glass slide, and the Cu. Which A is the one we must measure.**
- 2. Turn on the heater and wait a few minutes while it stabilizes. If it is on, wait for a few minutes. Do not touch it: HOT HOT HOT.**
- 3. Place the Al in the sample holder. Note: you must mark on the piece of Al the location of the places where you will measure the temperature (Why?).**
- 4. Use the thermometer to record the temperature at these same two places. Take 4 measurements, waiting 1 minute in between them.**
- 5. Record the temperature, temperature gradient, and time of measurement.**
- 6. For Al, use the value for the thermal conductivity provided in table 7.19 in dePodesta's book¹, and determine the power dissipated at each reading**
- 7. Using the time intervals for your reading, determine the heat dissipated for the last three readings.**
- 8. Determine the error of your measurements, estimating the standard deviation for dT/dx .**

Figure 2. Procedure handed out to the students.

The students are asked to give their input on how to improve the design. The design as it stands now has integrated many of the suggestions over the years. This years suggestions include: covering the sample to avoid heat dissipation and getting a holder for the thermistor to avoid having them move from place to place. This is very similar to the suggestion from one of the attendees, who went further by suggesting that the sample be insulated with PVC filled with hardware store foam. The PVC would then be drilled at specific distances to have a fixed thermal interrogation probe.

Comments:

This laboratory helps the students to understand the concept of thermal conductivity, and to see the transfer of heat from one point to the other of a sample. In the words of one of the students: “We were made aware that heat moves from one point to the other”. Students applied their knowledge of errors in order to determine how close they were. Students were asked to suggest ways of improving the design.

Groups	κ_{Cu} (W/DegK-m)	error for κ_{Cu}
Real (Between 273.15K and 373.15K)	388 ¹	7
Monday A	280	1028*
Monday B	661	245
Wednesday A	239	99
Wednesday B	537	309

*too many oscillations in the Al measurement

Table I. Results obtained by the groups from the Spring 2003 semester.

References

1. dePodesta, Michael, Understanding the Properties of Matter, 2nd Ed, Taylor and Francis, 2002

Biography:

L. J. Martínez-Miranda is Associate Professor of Materials in the Dept. of Materials Science and Engineering (formerly Materials and Nuclear Eng) at the University of Maryland, College Park. She received her bachelor's and master's degree in Physics from the Universidad de Puerto Rico in Río Piedras, a bachelor's of Music degree from the Conservatorio de Music de Puerto Rico and her doctoral degree in Physics from the Massachusetts Institute of Technology. Her research interests are in X-rays scattering from liquid crystals, and related biomaterials and nanomaterials. In addition, at Maryland she has been responsible for designing the junior level laboratory course, which complements the laboratory course in mechanical properties. She has designed experiments that deal with the structural, electrical and thermal properties of materials, and has asked for help from her colleagues in designing some of the experiments. With the help of colleagues she has brought some of the most recent results in research to this lab, so the students will see it as something that is vibrant. In addition, she has taught the introduction to design course, the physics of materials course, the introductory course for materials science students and will soon teach a scattering course.

**THE MATERIALS SCIENCE AND ENGINEERING
COMMUNICATIONS PROGRAM AT VIRGINIA TECH**

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The MSE Communications Program at Virginia Tech



About being technically articulate and workplace-effective

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R. Kander, Professor and Head, ISAT, James Madison University

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Background - Acknowledgements



R.W. Hendricks and E.C. Pappas, "Advanced Engineering Communication: An Integrated Writing and Communication Program for Materials Engineers," *Journal of Engineering Education*, Vol. 85, October 1996, 343-352.

- *founding philosophies, student assessment before and after initiation of program*

E.C. Pappas, S.L. Kampe, R.W. Hendricks, R. Kander, "Assessment of a Decade of Experience with an Advanced Engineering Communications Program at Virginia Tech and its Role in ABET Accreditation," submitted to *Journal of Engineering Education*, 2003.

- *increasing program scope, alumni surveys, curriculum assessment, ABET 2000*

Outline



- Background - Communications at Virginia Tech
 - the default setting
 - MSE vision / model
- Current Program
- Assessment
 - method
 - results
- Comments and future
- Summary

Communications at Virginia Tech (and likely elsewhere)



By default

University: Core Curriculum - 7 defined and common philosophies underlying higher education at VT

- | | |
|---|--|
| 2. Ideas, Cultural Traditions, and Values | 5. Quantitative and Symbolic Reasoning |
| 3. Society and Human Behavior | 6. Creativity and Aesthetic Experience |
| 4. Scientific Reasoning and Discovery | 7. Critical Issues in a Global Context |

---> #1. *Writing and Discourse*

- 2 writing intensive courses required
- Writing intensive = 15 pages of written composition, with revision and response

College of Engineering: Department-driven approaches

- Technical Writing (3 credits, Sophomore or Junior Year)
- Another WI course, sometimes in major, sometimes not

Communications in MSE



Communications across-the-curriculum approach

Instruction in communication and professional conduct incorporated *within* 9 MSE courses

- Lectures, Labs, Communications Workshops
- Sophomore (3), Junior (3 courses), Senior (3 courses)

Communications Skills

- Writing (including drafts, revisions, final copies)
 - Term papers
 - Report writing
 - Publication writing
- Presentations
- Posters
- Progress reporting
- Interviewing
- e-mail

Professional Conduct and Development

- resumes
- workplace issues
- diversity issues
- team projects
- brainstorming
- creativity

MSE Communications Program: Philosophy



Incremental instruction of skills over time is more effective than intensive, short-time-constant training

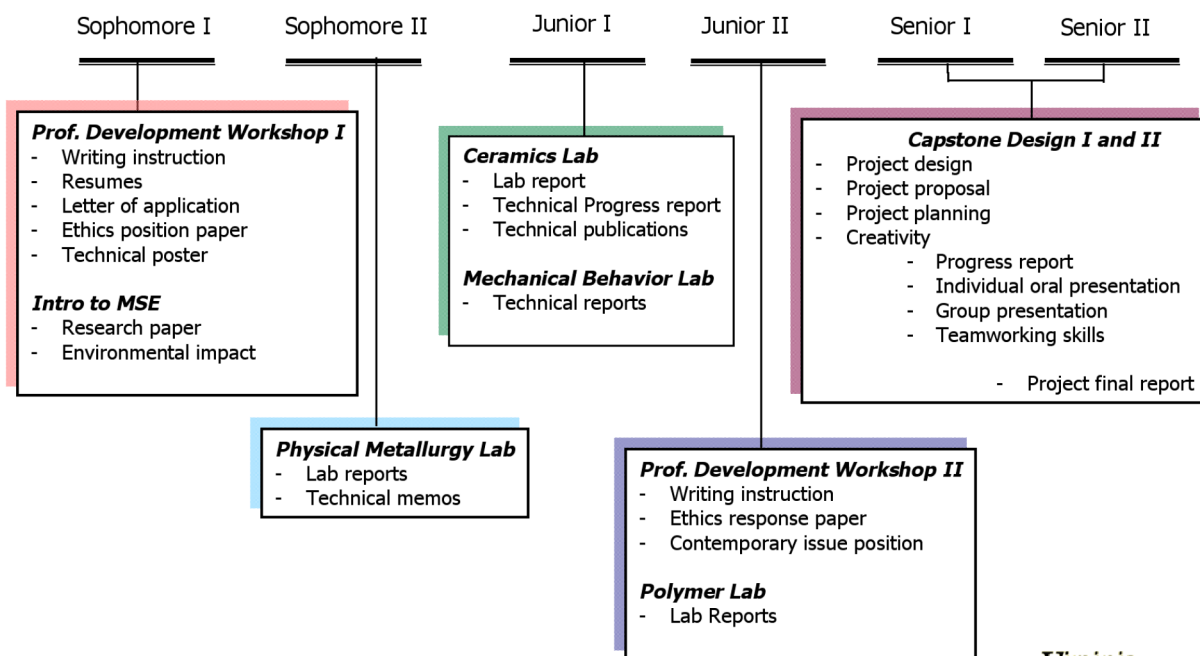
- Skills become additive and routine over time
- Skills are taught concurrent with the technical topics within the curriculum
- Articulate communication supports technical understanding
- A consistent message and emphasis is maintained throughout the curriculum
- A consistency of delivery and quality of instruction is maintained throughout the curriculum
- Communications skills provide additive-value to the MSE degree

Particularly Unique Features of MSE Communications Program



- *Administered by a Humanities-educated full-and-equal colleague on MSE faculty*
 - Dr. Eric Pappas, Ed.D. English; Director 1995 - August 2003
 - Dr. Marie Paretti, B.S. ChE, Ph.D English; Director September 2003 -
- Team-teaching
 - "Regular" and "Out-of-discipline" faculty
- *Portfolios as a record of achievements*
 - an assemblage of the students' best works (17 items total)

Examples



Assessment of the Program



General procedure

1. Decide upon the basis for assessment
 - questions to be asked, and how they will be asked
2. Request input from alumni (survey)
 - those working in industry
 - those who have attended graduate school
3. Devise a method to quantify how information is currently presented within the curriculum
4. Act on results

Assessment



Basis: Accreditation Board for Engineering and Technology (ABET) Program Criteria

The ABET General Program Criteria are:

- a. an ability to apply knowledge of mathematics, science, and engineering
- b. an ability to design and conduct experiments, as well as to analyze and interpret data
- c. an ability to design a system, component, or process to meet desired needs
- d. an ability to function on multi-disciplinary teams
- e. an ability to identify, formulate, and solve engineering problems**
- f. an understanding of professional and ethical responsibility**
- g. an ability to communicate effectively**
- h. the broad education necessary to understand the impact of engineering solutions in a global and societal context**
- i. a recognition of the need for, and an ability to engage in life-long learning
- j. a knowledge of contemporary issues**
- k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

The ABET MSE-Specific Criteria are:

- l. ability to apply advanced science (such as chemistry and physics) and engineering principles to materials systems
- m. integrated understanding of the scientific and engineering principles underlying the above four major elements of the field, viz., structure, properties, processing, and performance related to material systems appropriate to the field
- n. ability to apply and integrate knowledge from each of the above four elements of the field to solve materials selection and design problems
- o. ability to utilize experimental, statistical, and computational methods consistent with the goals of the program

MATERIALS SCIENCE AND ENGINEERING

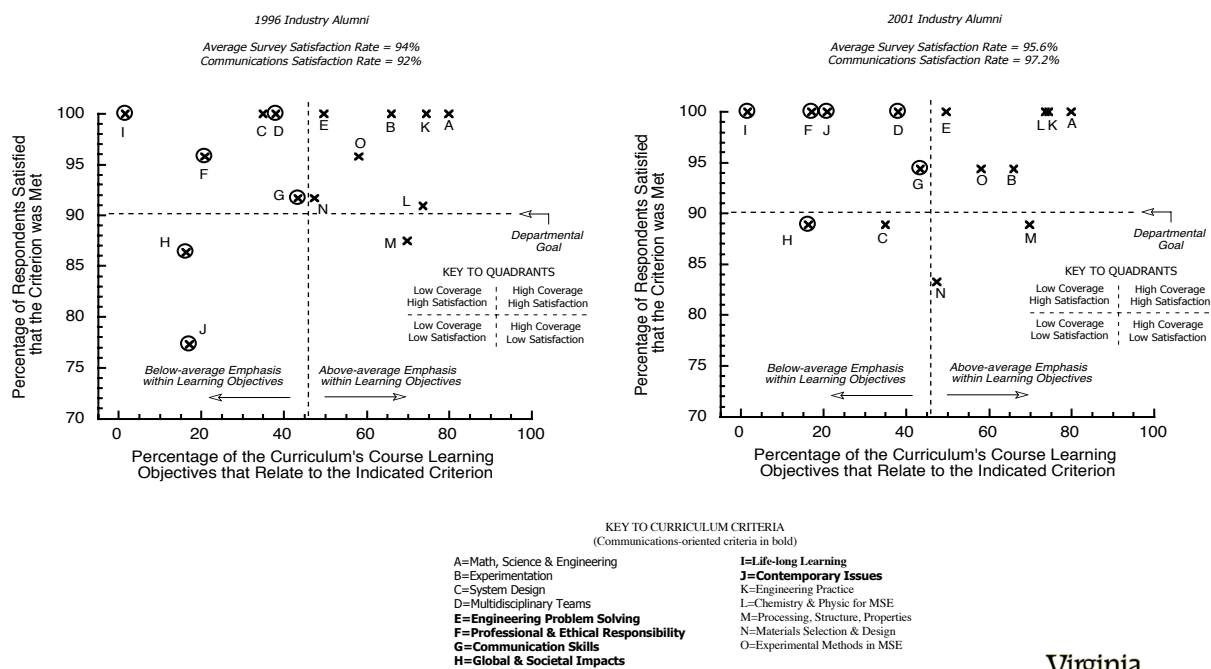
18th Annual National Educators Workshop
20 - 22 October 2003



Assessment, continued



Survey of Alumni working in Industry: 1996 vs. 2001



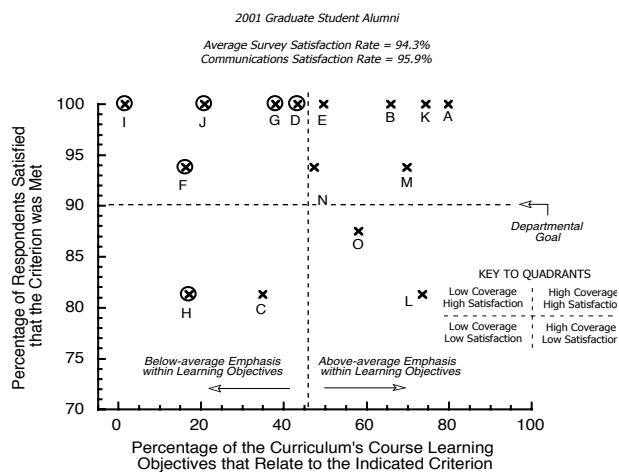
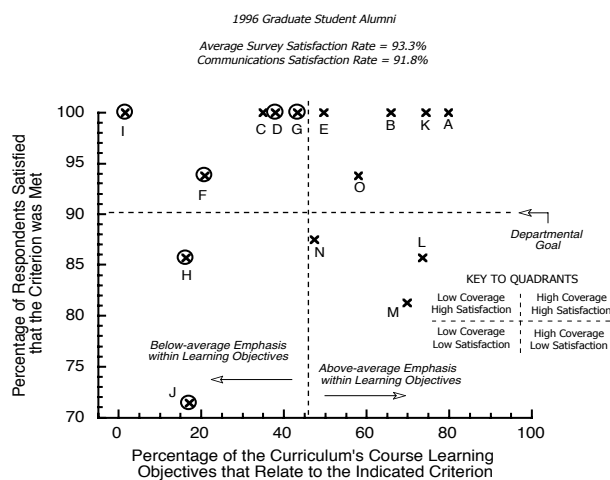
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Assessment, continued



Survey of Alumni who attended Graduate School: 1996 vs. 2001



KEY TO CURRICULUM CRITERIA (Communications-oriented criteria in bold)

- | | |
|--|-------------------------------------|
| A=Math, Science & Engineering | I=Life-long Learning |
| B=Experimentation | J=Contemporary Issues |
| C=System Design | K=Engineering Practice |
| D=Multidisciplinary Teams | L=Chemistry & Physics for MSE |
| E=Engineering Problem Solving | M=Processing, Structure, Properties |
| F=Professional & Ethical Responsibility | N=Materials Selection & Design |
| G=Communication Skills | O=Experimental Methods in MSE |
| H=Global & Societal Impacts | |

MATERIALS SCIENCE AND ENGINEERING

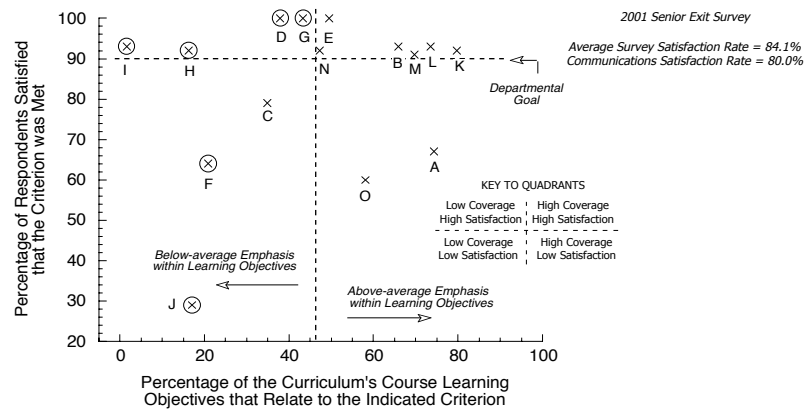
18th Annual National Educators Workshop
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Assessment, continued



Survey of Exiting Seniors: 2001



KEY TO CURRICULUM CRITERIA (Communications-oriented criteria in bold)

- | | |
|--|-------------------------------------|
| A=Math, Science & Engineering | I=Life-long Learning |
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MATERIALS SCIENCE AND ENGINEERING

18th Annual National Educators Workshop
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Comments and Future



- Requires broad acceptance and cooperation from faculty
 - Occupation of a faculty slot by an “out-of-discipline” colleague
 - Across-the-curriculum cooperation needed
 - Credibility, acceptance by students
- New director, as of September 2003
 - Dr. Marie Paretti, B.S. ChE, Ph.D., English
 - Internal program assessment
 - External program assessment (surveys)
- COE to expand program to other departments

Summary



- MSE at Virginia Tech has developed a comprehensive communications program that runs concurrently with the traditional, technical curriculum
- Students are taught / practice all conceivable workplace communication skills
- Students are provided the opportunity to consider and discuss a wide variety of workplace and societal issues
- A long-running assessment program indicates extremely high regard for the communications program by former students
- 2nd generation of program administration has begun

Acknowledgements



- Office of the Dean of Engineering at VT
 - Dr. Wayne Clough (currently President, Georgia Tech)
 - Dr. William F. Stephenson (retired)
 - Dr. Hassan Aref, Dean of COE at VT
- Departments of MSE and ESM
 - Dr. Ronald S. Gordon, former MSE Head
 - Dr. Edmund Henneke, former ESM Head
 - Dr. David E. Clark, MSE Head
 - Dr. Norman E. Dowling, Interim ESM Head

FISHING FOR THE BEST LINE: EVALUATING POLYMERS USED FOR SPORT FISHING

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Fishing for the Best Line: Evaluating Polymers used for Sport Fishing

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Key words: polymer, monofilament, co-polymer, fluoropolymer, modulus of elasticity, tensile strength

Prerequisite knowledge: Students should understand the basic concepts of; stress, strain, modulus of elasticity, and ultimate tensile strength.

Objectives: Students gain hands-on experience measuring mechanical properties of polymer materials. Properties are considered as they relate to performance of the material in application.

Equipment and Materials:

Samples of fishing line – available from most discount or sporting goods stores	6” scale
Micrometer	Permanent markers
Calipers	scissors
Spring gauges	

Procedure: Samples of fishing line are provided to the students, along with product descriptions from the manufacturers, and background and application information. The advertising claims, imaginative product names (IronSilk™, SpiderWire™, Sufix® TriTanium™ Plus) and range of product prices readily lead to questions about material properties the students can explore. The descriptive information is organized into a table and used to create sample groups for tabulation of results. Table 1 shows descriptions for three sample groups, all of which have the same advertised rating of six pounds “test”. The first two sample groups are nylon, and the third group is a fluoropolymer alloy, described by the manufacturer as a fluorocarbon. The materials are available in spools of 100 yards in length or more.

Table 1 – Sample Group Descriptions

Sample Group	Manufacturer	Type	Material	Lbs. Test	Cost (\$/yard)
1	Eagle Claw	Ambassador Eagle, Premium	Nylon monofilament	6	0.0022
2	Stren ¹	Original, clear blue	Nylon monofilament	6	0.0339
3	Yo-Zuri ²	Hybrid, camo green	Fluorocarbon polymer alloy	6	0.0290

Six samples of each type of line are cut, with each piece approximately 12 inches in length. The diameter of each type of line is recorded, and the students calculate the cross-sectional area for each group.

Using a permanent marker and a scale, 2-inch gage lengths are marked on each sample. For identification it is helpful to use a different color marker for each sample group. Drafting tape or PostIt™ notes can be used to hold the lines straight for marking. A smooth washer, small wire rings or other hardware should be tied to at least one end each end of each sample, and preferably to both. This hardware is helpful in preventing damage to the samples during testing. The polymer samples are very sensitive to nicks, kinks, scratches or other damage. The measured properties of the polymers are also sensitive to the style of knot used to affix the hardware. Data are shown in this paper for samples tested with hardware on one end, using simple overhand knots, and for samples prepared with hardware on both ends, tied with “Palomar” knots. Care must be taken to knot the line to form a loop, without damaging the line or leaving the knot so loose that the line slips through the knot when tension is applied. Three samples from each group are submerged in room temperature tap water for analysis after a one-hour soak.

Using a spring gage, data are collected for the elongation at rated strength and ultimate tensile strength for each sample. For measurements on samples with hardware on one end only, the sample should be held parallel to a table or other flat surface, on which a scale has been placed above a light-colored background. Students should work in teams of two or more, to apply tension to the sample and monitor the elongation between the gage marks. The loop on one end of the sample should be attached to the hook on the spring gage. The free end of the sample should be grasped with a pair of pliers or other mechanical gripper. Students should **not** attempt to perform the test by pulling on the line with their bare fingers.

When samples have been prepared with hardware on both ends, a vise or clamp can be used to hold one end of the sample, and a spring gage used to apply force. This technique is illustrated in Photo 1. Table 2 lists the raw data for the three sample groups, for dry and soaked samples, prepared with overhand knots. Using the formula for direct tensile stress, $\sigma = F/A$, students calculate the tensile strength for each sample group and test condition. Average values for Ultimate Tensile Strength are presented in Table 3, along with the material type for each group. It is important to note that many of the samples failed at loads near or below their strength. The experiment was repeated using a Palomar knot recommended by one of the manufacturers³. Table 4 lists data collected from samples prepared with Palomar knots, with hardware (polymer washers) at both ends. A summary of the measured and calculated values for the second trial is shown in Table 5.

Photo 1 - Testing with spring gage, washers on both ends of sample.



Comments: The choice of knotting technique had a significant impact on the measured strength of all three materials. The data for these tests using the overhand knot indicate that the lowest cost material, the .012 inch diameter nylon monofilament appeared to have the highest load strength, but that may be a consequence of the larger diameter creating less knot sensitivity, not the inherent tensile strength of the material. The 0.010 diameter nylon had a higher tensile strength dry, but after a one-hour soak in tap water, the material failed at the knot used to create the loop for the spring gage. The fluorocarbon material was least affected by the soak, losing only approximately 28,000 psi of tensile strength. It was not possible with any of the materials to make significant measurements of the elongation at their rated load using the overhand knot, since they had an average breaking strength below the rated load. It is not clear why this was the case for the dry samples, because the failures were not associated with the knots or grips used to apply the load. The number of failures at the knot locations for the soaked samples indicate that the combination of knotting and soaking caused a significant increase in local stress, leading to failure.

Table 2 – Raw Data from Tensile Tests, Overhand Knot, Single-end Hardware

Sample Group (three samples for each group for each test condition)	Condition	Length at Rated Load of 6 Pounds (inches)	Ultimate Tensile Load (pounds)	Break Note
1	Dry	2.38	6.0	
1	Dry	broke < rated load	4.0	
1	Dry	2.5	6.5	
1	Soaked	2.5	6.0	
1	Soaked	broke < rated load	4.5	
1	Soaked	broke < rated load	4.5	
2	Dry	broke < rated load	4.25	
2	Dry	broke < rated load	4.5	
2	Dry	broke < rated load	5.25	
2	Soaked	broke < rated load	2.0	near knot
2	Soaked	broke < rated load	3.0	near knot
2	Soaked	broke < rated load	2.5	near knot
3	Dry	broke < rated load	4.25	
3	Dry	broke < rated load	4.0	
3	Dry	2.38	6.25	
3	Soaked	broke < rated load	4.0	near knot
3	Soaked	broke < rated load	2.5	near grips
3	Soaked	broke < rated load	5.0	

Table 3 – Summary of Results, Overhand Knot, Single-end Hardware

Sample Group Average	Material Type	Diameter (inches)	Average Breaking Load, Dry (pounds)	Ultimate Tensile Strength, Dry (psi)	Average Breaking Load, Soaked (pounds)	Ultimate Tensile Strength, Soaked (psi)
1	Nylon	0.012	5.5	109,000	5	99,000
2	Nylon	0.010	4.7	134,000	2.5	72,000
3	Fluorocarbon	0.010	4.8	138,000	3.8	110,000

Table 4 – Raw Data from Tensile Tests, Palomar Knot, Double-end Hardware

Sample Group (no soaked samples for test group 2)	Condition	Length at Load of 5 Pounds (inches)	Ultimate Tensile Load (pounds)
1	Dry	2.38	6.5
1	Dry	2.38	6.25
1	Dry	2.38	6.25
1	Soaked		5.25
1	Soaked		6.25
1	Soaked		6.0
2	Dry	2.31	6.0
2	Dry	broke < 5 pounds	3.75
2	Dry	2.44	6.0
3	Dry	2.38	5.75
3	Dry	2.31	8.5
3	Dry	2.31	7.5
3	Soaked		5.25
3	Soaked		5.5
3	Soaked		6.25

Table 5 – Summary of Results, Palomar Knot, Double-end Hardware

Sample Group Average	Material Type	Diameter (inches)	Elongation (%)	Average Breaking Load, Dry (pounds)	Ultimate Tensile Strength, Dry (psi)	Average Breaking Load, Soaked (pounds)	Ultimate Tensile Strength, Soaked (psi)
1	Nylon	0.012	19	6.3	126,000	5.8	116,000
2	Nylon	0.010	19	5.3	150,400		
3	Fluorocarbon	0.010	17	7.3	207,700	5.7	162,000

When samples were tested with the Palomar knot, the fluorocarbon material had the highest measured tensile strength, but was more significantly affected by the soak than the nylon monofilament. This is an important observation in this experiment, since use of a line for sport fishing typically requires both knotting and soaking. The Eagle Claw brand monofilament had a higher measured breaking strength dry than the Stren monofilament, but this was apparently a consequence of the larger diameter of the Eagle Claw material, not its inherent tensile strength. Students enjoyed comparing their measurements with manufacturer's specifications and comparing the relative costs of the materials tested.

Significant work has been done in the area of testing fishing line. References 4 and 5 below by Wayne L. Elban are very good sources for information about fracture behavior and structuring a lab experience around knot selection. The other references below are general resources for fishing line material or information.

References:

1. Stren, P.O. Box 700, Dept. BSN, Madison, NC 27025; 1-800-243-9700; www.stren.com
 2. Yo-Zuri, 513 N.W. Enterprise Dr., Dept. BSN, Port St. Lucie, FL 34986; 1-888-336-9775; www.yo-zuri.com
 3. "A Guide to Knots and Lines: Angler's Reference," Form No. L000587, Stren Fishing Lines, Remington Arms Company, Inc., 870 Remington Drive, Madison, North Carolina, 27025
 4. Elban, W.L.: Fracture Behavior of Nylon Monofilament Fishing Line, in National Educators' Workshop: Update 2000, NASA/CP-2001-211029, 2001, pp. 81-112.
 5. Elban, W.L., and Frantz, D.L.: Fishing Line Knot Tying Contest: A Freshmen Experience, in National Educators' Workshop: Update 2001, NASA/CP-2002-211735, 2002, pp. 149-170.
- "Choose the Right Fishing Line", Bassin', pp. 38-41 on www.ebassin.com
- Berkley, 1900 18th St., Dept. BSN, Sprit Lake, IA 51360; 1-877-777-3850; www.purefishing.com
- Cajun Line, 3801 Westmore Dr., Dept. BSN, Columbia, SC 29223; 1-800-347-3759; www.cajunline.com
- Seaguar, 513 N.W. Enterprise Dr., Dept. BSN, Port St. Lucie, FL 34986; 1-888-336-9775; www.seaguar.com
- Silver Thread, 3601 Jenny Lind Road, Dept. BSN, Fort Smith, AR 72901; 1-800-531-1201; www.lurenet.com
- Triple Fish, 1240 Commons Ct., Dept. BSN, Clermont, FL 34711; (352) 243-0873; www.TripleFish.net

Kenneth G. and Michael K. Budinski, Engineering Materials: Properties and Selection, Seventh Edition, Prentice Hall, Upper Saddle River, New Jersey, 2002

Robert L. Mott, Applied Strength of Materials, Fourth Edition, Prentice Hall, Upper Saddle River, New Jersey, 2002

Biography: Sarah Leach, P.E., is an assistant professor of Mechanical Engineering Technology at Purdue University Elkhart/South Bend. Her primary teaching responsibilities are in materials and applied mechanics. She remains an active member of ASME and ASEE, and serves as the faculty advisor for the local student chapter of the American Society of Mechanical Engineers.

**ACOUSTICAL MEASUREMENTS OF DAMAGE
ACCUMULATION IN BRICK PAVERS**

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and

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Acoustical Measurements of Damage Accumulation in Brick Pavers

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Eric Roades
Karen Dalton
Chenn Zhou

Key Words:

Fatigue, Fatigue Damage, Non-destructive testing, Acoustics.

Prerequisite Knowledge:

Basic understanding of fatigue principles and damage accumulation.
General knowledge of digital oscilloscopes, load frames, and treatment of the test results.

Objective(s):

Detection of damage in brick due to loading using acoustic methods: spectrum analysis and Q factor calculation.

Equipment and Materials:

1. Brick pavers.
2. Load Frame - to apply and hold static loads on bricks to induce damage.
3. Digital Oscilloscope with FFT capabilities.
4. Piezoceramic Sensors (Disc, var. sizes).
5. Hammer and Impact Instrumentation.
6. Assorted cables for connection of sensors to oscilloscope.
7. Grease or other viscous substance for temporary adhesion of sensors to specimen.

Introduction:

Purdue University Calumet is conducting funded research on the application of an advanced computational fluid dynamics (CFD) model to evaluate erosion patterns in the brick lining of a blast furnace in the steel industry. The purpose of this evaluation is to maximize the campaign life of the furnace. To develop the CFD modeling, it is necessary to determine different parametric effects of performance of the furnace, including actual erosion of the brick wall. Therefore, as a first step, Purdue University Calumet conducted preliminary laboratory experiments on brick pavers using acoustical methods which are described in this paper. The laboratory investigations were conducted

with the active participation of Purdue students and we intend to incorporate some experiments into the laboratory session of the regular courses.

Procedure:

Loading of the bricks was done using the MTS TestStar IIs at Purdue University Calumet. The bricks were loaded according to the schedule in Table 1.

Table 1. Loading Schedule

Loading #	Load (psi)	Duration (hrs)
1	326	113
2	474	4
3	563	42
4	607	45.5

Prior to the initial loading, testing was performed on the brick for the purpose of establishing a baseline with which to compare subsequent test results. Experimental setup is shown in Figure 1.

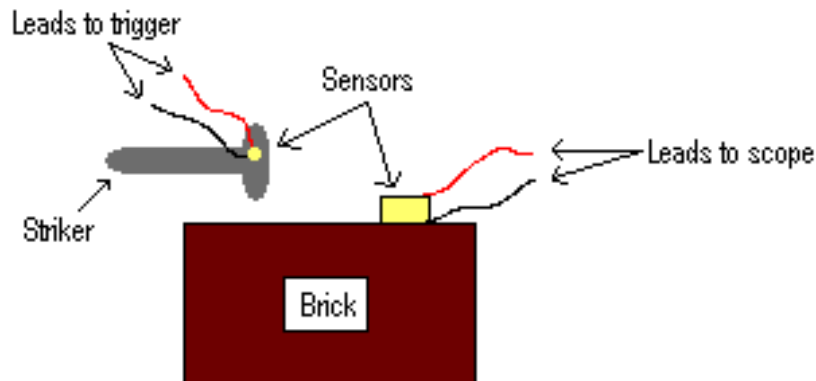


Figure 1. Schematic of experimental setup

The testing procedure was similar to that used earlier for steel pins and described in [1]. The impact was provided by hammer and with a striker of special instrumentation developed by the senior design student team [2]. The oscilloscope was set to capture upon impact of the striker, giving the time response of the brick. This time response was processed for spectrum and quality factor (Q factor). The spectrum was found using a Fast Fourier Transform (FFT) of the time response. The Q factor was calculated with the following equation.

$$Q_i = f_i * \pi / \alpha_i$$

In the equation above, f represents the frequency and α is the amplitude of the signal in question.

Quality factor is the ratio of the center frequency to the bandwidth in a given sample range of the time response. In this application, a drop in the quality factor is an indication of damage.

Seven tests were performed for the baseline and after each subsequent loading. These tests were then averaged to reduce the effects of electrical noise and other random variations.

Results:

The resonant frequency and quality factor (Q) were registered at the end of each loading step and corresponding records and plots are given in figures 2, 3, and 4. It can be concluded from the plots in figures 2 and 3 that the resonant frequency and quality factor are decreased with the progression of testing and accumulation of damage. It is important to emphasize that the damage was detected without visible cracks or wear on the surfaces of the brick and, therefore, we probably were able to detect early phase, or the initiation of damage.

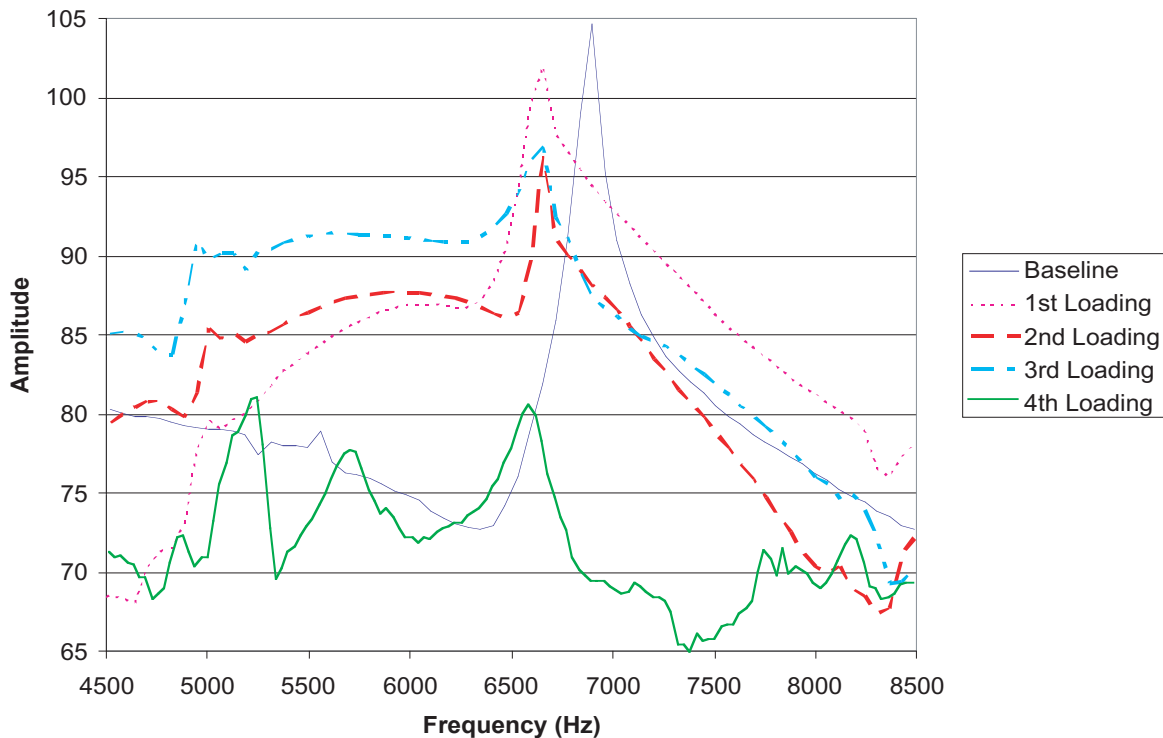


Figure 2. Acoustical response in the brick after progressive loading

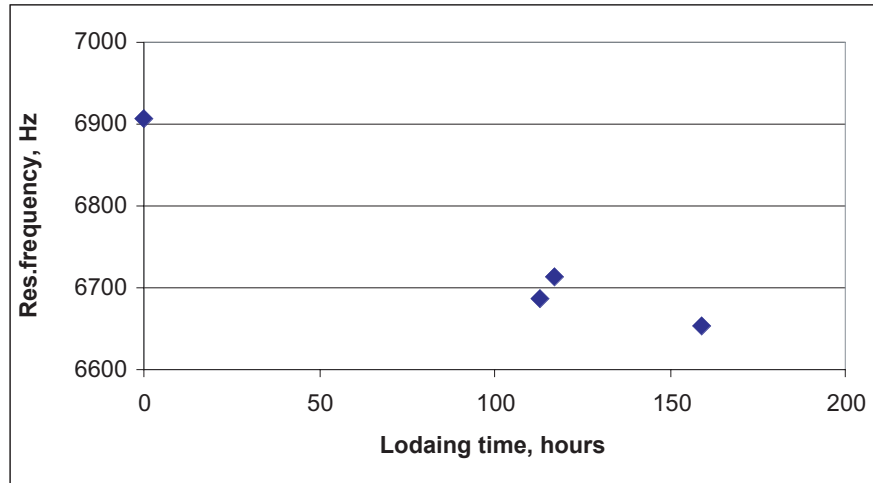


Figure 3. First resonance frequency of brick versus loading time

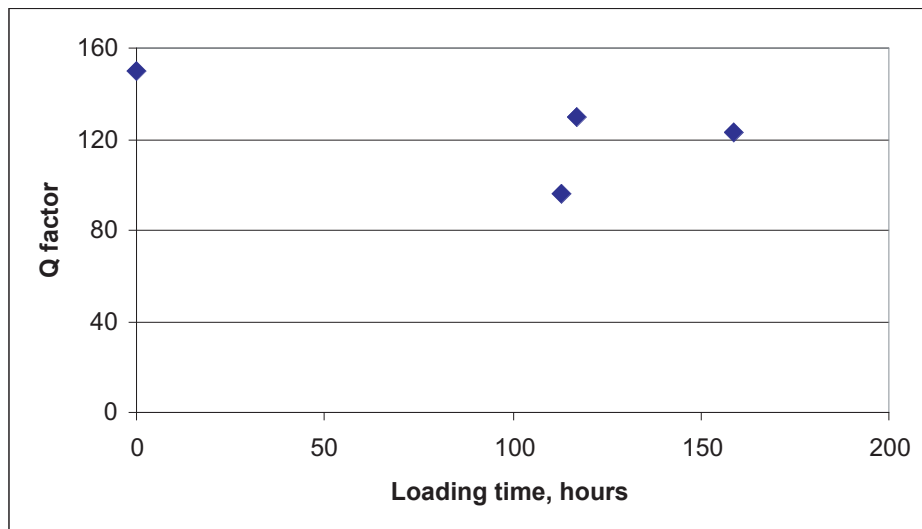


Figure 4. Q factor for the first resonance frequency versus loading time.

Conclusions:

1. Acoustical methods used in the described experiments permit the observance of damage accumulation in the tested brick pavers.
2. Better results are obtained by using a striker that is capable of producing repeatable impacts versus the use of a hammer or other device that is susceptible to variations induced by the user.

References:

1. Y. Kin, A. Sutin, and A. Chudnovsky, "Nonlinear Acoustic Technology for the Investigation of Structure Damage". Society of Experimental Mechanics Annual Conference Proceedings, Portland, Oregon, June 2001.
2. Yulian Kin, Alexander Sutin, Eric Roades, Karen Dalton, Kimberly Bateman, "Non-Linear Acoustic System for Damage Assessment", Proceedings of the National Educator's Workshop, Update 2001. Standard Experiments in Engineering Materials, Science, and Technology.

NOVEL METHODS OF INCREASING STUDENT INTEREST IN FLUID MECHANICS

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Novel Methods of Increasing Student Interest in Fluid Mechanics

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Key Words: Fluid Momentum-Force, Bernoulli Equation, Reynolds Number, Atmospheric Pressure

Prerequisite Knowledge: Integral and Differential Calculus

Objective: To excite students about Fluid Mechanics and aid in the understanding of fundamental concepts.

Equipment and Materials:

1. Large Water Gun ("Supersoaker")
2. Toy Dump Truck
3. Portable Vacuum with Exhaust Feature
4. Duct Tape
5. Funnel
6. Ping-Pong Ball
7. Plastic Drinking Cups
8. Plastic Straws
9. Stop Watch
10. Large Newsprint
11. Flat Wooden Sticks

Introduction:

Introductory fluid mechanics can be one of the most intimidating and challenging classes that engineering students take. Because fluid phenomena are so prevalent in everyday life, however, there are numerous opportunities to demonstrate the concepts and equations of fluid mechanics with insightful, and often fun and exciting, classroom demonstrations. In this workshop, we present a number of novel in-class demonstrations that connect the equations of fluid mechanics to everyday phenomena, while making the subject matter more enjoyable for engineering students. Demonstrations include "The Super Soaker-dump truck" experiment for fluid momentum-force, the "Bernoulli Vacuum" where the exhaust from a vacuum cleaner is used hold a ping-pong ball firmly in place for the Bernoulli pressure-velocity relationship, "Drinking Games", a race to see who can achieve the highest Reynolds number in a straw and "Fluid Mechanics Judo" where the atmospheric pressure on a sheet of newsprint acts as a counter force allowing

he instructor to break a large stick. An experimental procedure and comment section is provided for each of the four experiments.

Experimental Procedures:

The Super Soaker-Dump Truck: All demonstration materials are initially hidden from the class. Note: if you have the Super Soaker already out, nobody will volunteer to come to the front of the class! An excessively large Super Soaker is removed from a duffle bag and the professor asks the class if he should begin to pump it to a higher pressure. (At this point the class is completely in suspense about what is going to happen next.) Rather than the student getting soaked down, however, he is handed the Super Soaker. The professor then pulls a toy dump truck out of another duffle bag and instructs the student to line up his shot and shoot the back end of the dump truck. The toy moves forward due to the force created by the change in horizontal momentum of the Super Soaker fluid jet.



Figure 1. Toy dump truck and Super Soaker “momentum source”

The Bernoulli Vacuum: The hose from a portable living room vacuum is connected to the exhaust port so that air blows out of the hose. A funnel is then *duct-taped* to the end of hose, providing a good seal. The vacuum is turned on and a ping-pong ball is placed above the mouth of the funnel. The air from the vacuum will blow the ball away. Next,

however, the ball is placed down in the funnel against the hole. As long as the vacuum is running, the end of the hose can be shaken vigorously and the ball will now stay in place. This provides a dramatic demonstration of the Bernoulli effect.



Figure 2. The Bernoulli vacuum. The vacuum blows out rather than sucks in and the special attachment has a funnel duct-taped to one end. The ping-pong balls remain trapped in the funnel due to the Bernoulli effect.

Drinking Games: In this contest, students are challenged to create the highest Reynolds number in a straw. Two volunteers are solicited. Each is given standard drinking straws and a cup containing 200 mL (6.75 oz) of water. A stopwatch is used to time how long it takes to drink the 200 mL. They are told to drink the water through their straws as quickly as possible. Based on the volumetric flow rate, the diameter of the straw and the viscosity of water, the average Reynolds numbers are calculated to determine whether the flow in the tube is laminar or turbulent. Where appropriate, the volunteers can be segregated by age with those over 21 being given a simulated adult beverage (apple juice) and those under 21 being given a child's "sippy" cup filled with just water.



Figure 3. The measuring cup and stop watch are used to estimate the volume flow rate and hence the Reynolds number in this race to see who can achieve the highest Reynolds number in a straw.

Fluid Mechanics Judo: A twelve-inch (12") long, thin, flat wooden stick is placed on the edge of a table with two to three inches (2"-3") hanging over the edge. In order to show that the stick is solid, the instructor strikes down sharply on the end of the stick, causing it to fly through the air. The stick is placed back on the table. A sheet of standard sized newsprint is now spread over the stick. When the end of the stick is pushed down slowly and gently, the newsprint lifts up. The newsprint is then spread smoothly and evenly over the stick to help prevent air from leaking underneath. The stick is once again struck sharply. When done properly, the end of the stick will be broken off. This simple demonstration illustrates the potentially large force provided by atmospheric pressure.



Fisher Scientific Website (Breaking Board Paradox)
 URL: <https://www1.fishersci.com/Coupon?gid=2376799&cid=134>

Figure 4. The newsprint is used to snap a board in this demonstration of the force exerted by atmospheric pressure.

Comments:

The Super Soaker-Dump Truck: This demonstration provides an illustration of a problem typically solved using Momentum-Force equations. For a steady flow situation, the problem can be described by:

$$\int u \rho \mathbf{v} \cdot \mathbf{n} = \Sigma \mathbf{F}_{cv} \quad (1.)$$

where u is the velocity in the x direction, ρ is the density of the fluid, $\mathbf{v}$ is the overall velocity vector, $\mathbf{n}$ is a unit vector in the direction of interest and $\mathbf{F}_{cv}$ is the resulting force on the control volume. The problem is typically sketched as follows:

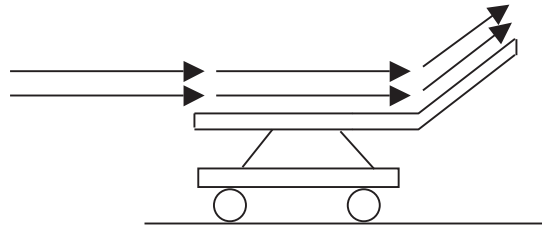


Figure 5. Typical introductory fluid mechanics problem of a force created on an object due to a deflected fluid jet.

The Bernoulli Vacuum: This demonstration provides an illustration of how to use concepts from the Bernoulli equation to explain fluids phenomena. One of the most important topics in introductory fluid mechanics is the relationship between velocity and pressure as given by the Bernoulli equation,

$$p_1 + \frac{1}{2} \rho U_1^2 = p_2 + \frac{1}{2} \rho U_2^2. \quad (2.)$$

One of the physical insights obtained from this equation is “when the velocity goes up, the pressure goes down”. The Bernoulli equation can be used to explain a number of interesting fluid mechanics phenomena, such as how an airplane wing works. In the case of the Bernoulli vacuum, there is a paradoxical phenomenon that the vacuum is blowing out, yet the ping pong ball is held firmly in place. When air strikes the ball in the funnel it produces a stagnation pressure at the bottom of the ball and begins to push it out. A small air gap opens up between the ball and the funnel wall, allowing the air to escape. In order to conserve mass, the air speeds up in the small gap, producing a very low pressure on a ring of the ping pong ball. The force due to atmospheric pressure on the top of the ball is greater than the force due to stagnation pressure and the gap pressure, firmly holding the ball in place.

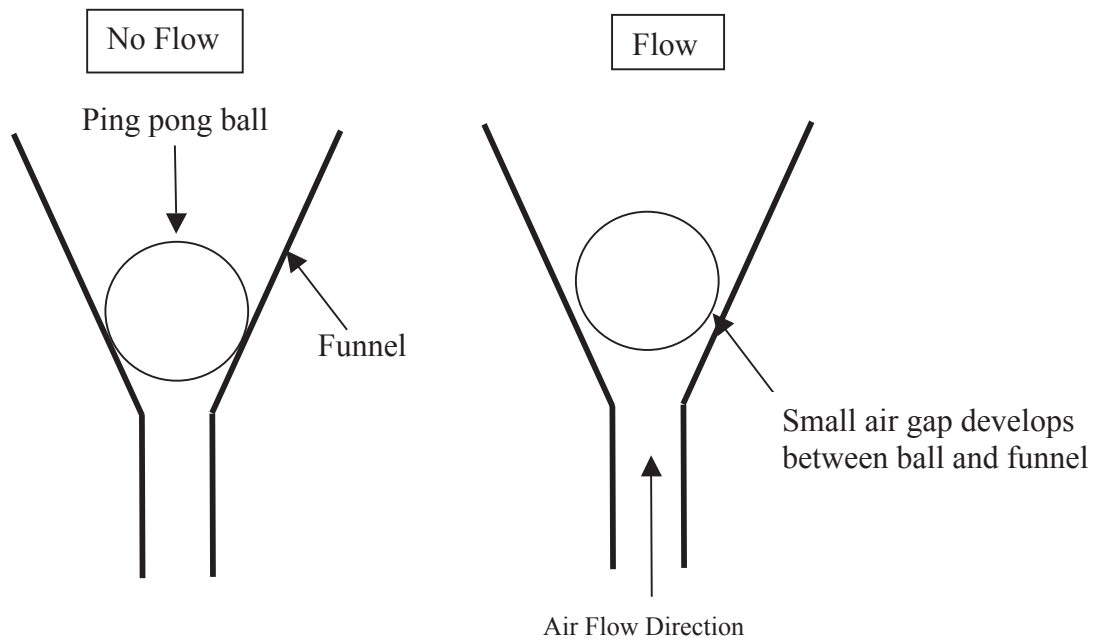


Figure 6. How the Bernoulli vacuum works. When the vacuum is turned on, the ball lifts off the surface of the funnel to create a thin gap. From conservation of mass, the fluid must speed up through the gap, creating an extremely low pressure on the lower side of the ball and thus the ball is held firmly in place.

Drinking Games: This demonstration helps to motivate students with the importance of the calculation of Reynolds numbers (Re) for internal flow situations. It also demonstrates to students that most internal flows of engineering interest are turbulent. The transition to from laminar to turbulent flow in a circular pipe occurs for $2100 < Re < 4000$.

$$Re = UD/\nu \quad (3.)$$

where U is the average velocity, D is the pipe diameter and ν is the viscosity of the fluid.

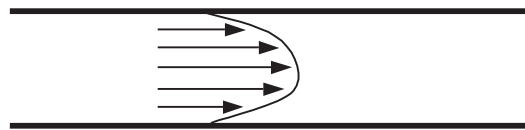


Figure 7. Flow in a circular pipe. The Reynolds number of the flow is used to determine if the flow is laminar or turbulent.

Fluid Mechanics Judo: This demonstration dramatizes the force due to atmospheric pressure. The change in pressure with depth in an incompressible fluid is given by the equation:

$$\Delta P = \rho gh \quad (4.)$$

where ρ is the fluid density, g is the acceleration due to gravity, and h is the depth of the fluid. At sea level the pressure of 14.7 psi is due to the weight of the entire atmosphere above. The force exerted by this pressure scales with the area over which it acts and therefore the large area newspaper exerts a tremendous force on the stick, causing it to break.

References:

Munson, B. R., Young, D. F. and Okiishi, T. H. Fundamentals of Fluid Mechanics, 4th ed. 2002, John Wiley & Sons.

Biography:

Dr. James T. McLeskey, Jr. is an Assistant Professor of Mechanical Engineering at Virginia Commonwealth University (VCU). Dr. McLeskey's research interests are in the field of Energy Conversion Systems with a particular emphasis on the optical characterization of photovoltaic materials. Prior to joining the faculty at VCU, he worked for six years in the power industry as a generator design engineer and four years teaching high school level physics and chemistry. Dr. Donald A. Jordan is an Assistant Professor of Mechanical and Aerospace Engineering at the University of Virginia (UVA). His current research interests are continuous wavelet transforms, the turbulent energy cascade and atrial fibrillation. Dr. Jordan has been twice awarded Mechanical Engineering Teacher of the Year and was honored in April 2003 with an All-University Teaching Award for his work in teaching Fluid Mechanics.

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PHOTOS AT LANGLEY RESEARCH CENTER







Merrill Rudd
Material Science Technology-Energy Concepts, Inc.

SPACE FLIGHT: A HUMAN PERSPECTIVE

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Kathryn Thornton

A photograph of a space shuttle in orbit above Earth. The shuttle is positioned in the upper right corner, with its solar panel array extended. The Earth's horizon is visible in the center, showing a blue sky and a yellowish-white glow from the sun. The sun is a bright, multi-pointed star in the upper left. The text "Space Flight: A Human Perspective" is overlaid in the upper center.

Space Flight: A Human Perspective

Kathryn Thornton

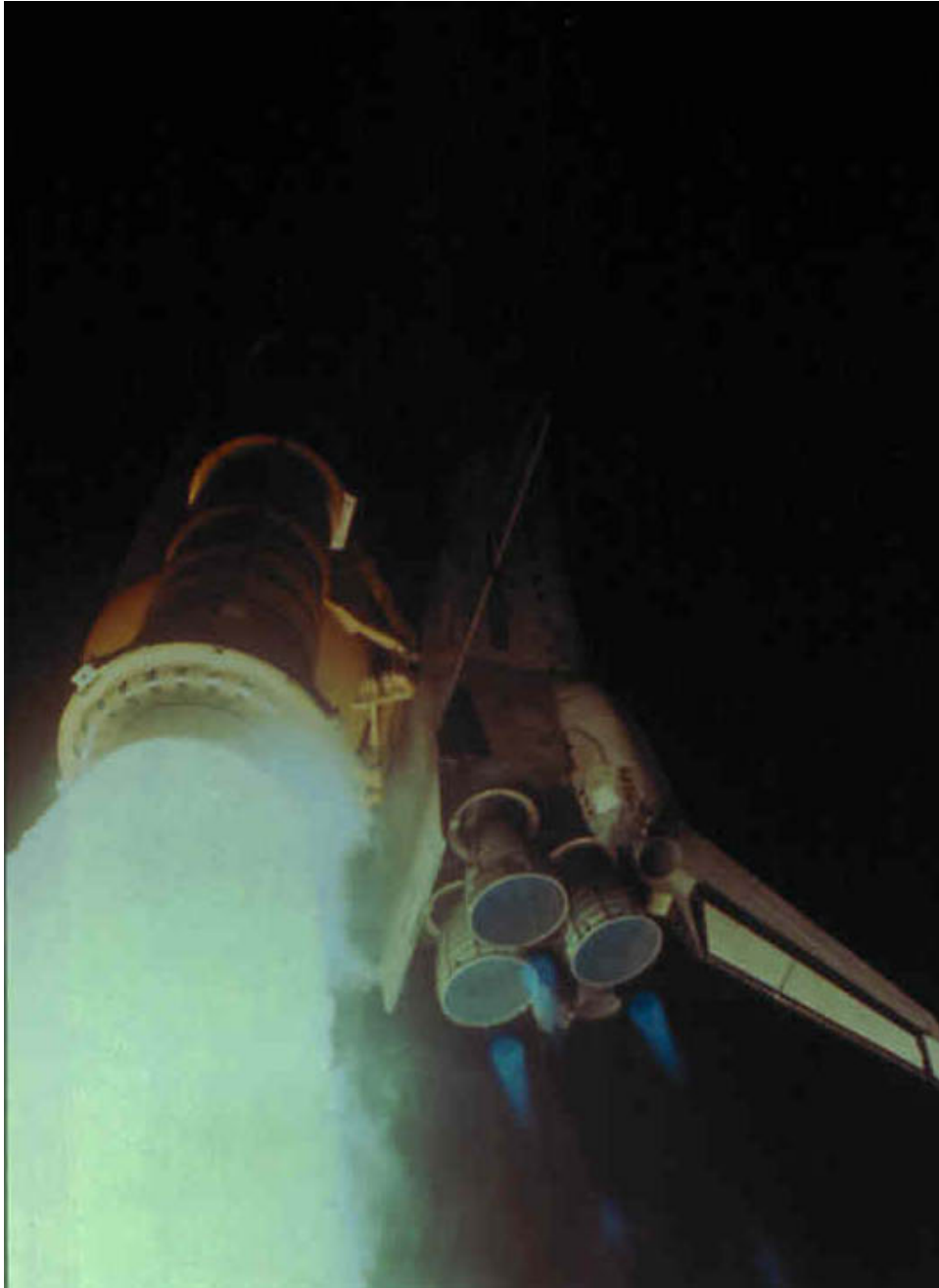
University of Virginia





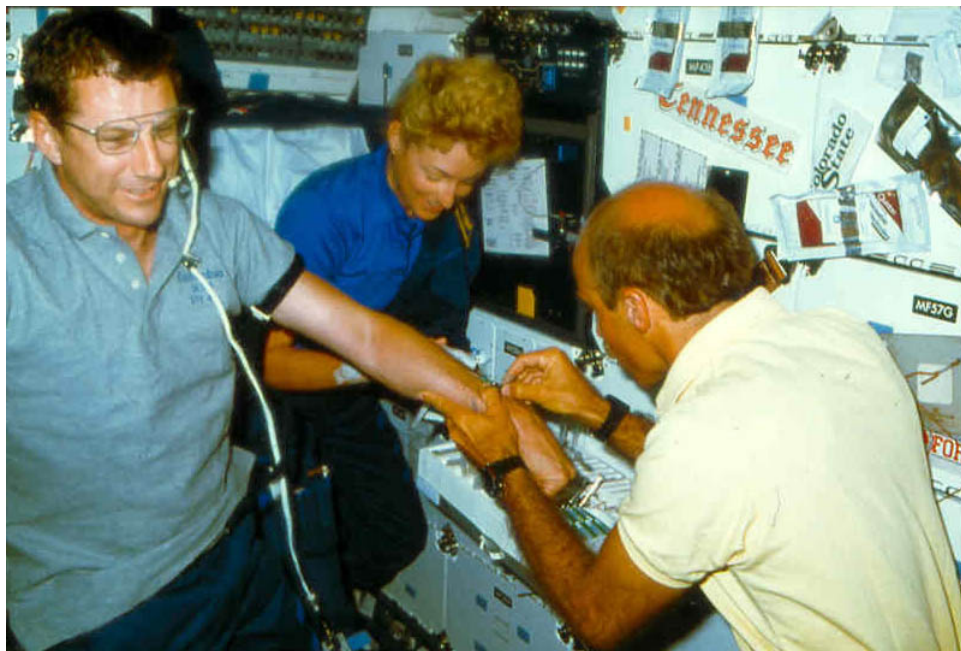


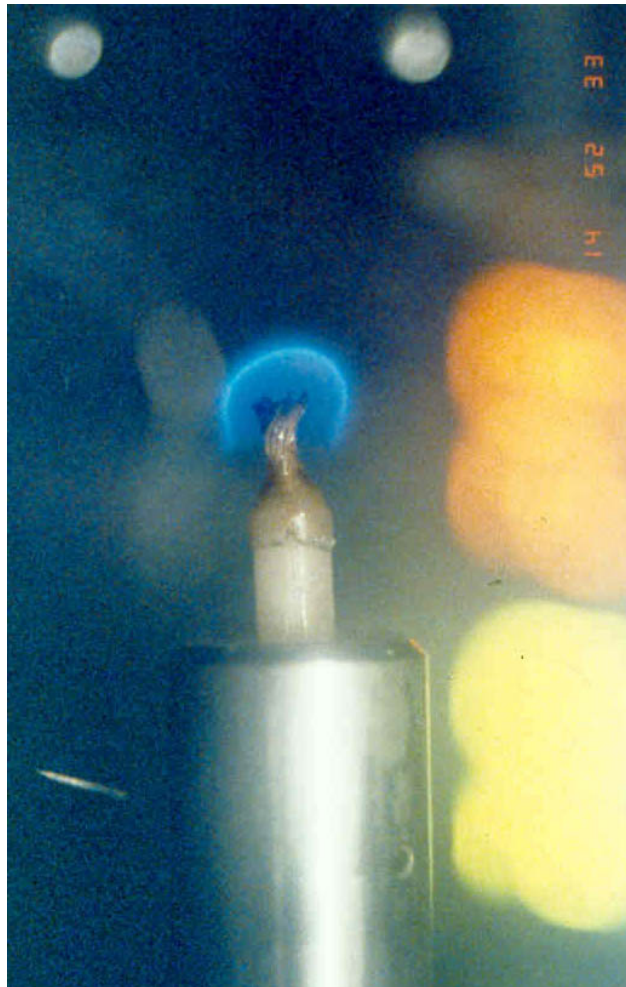
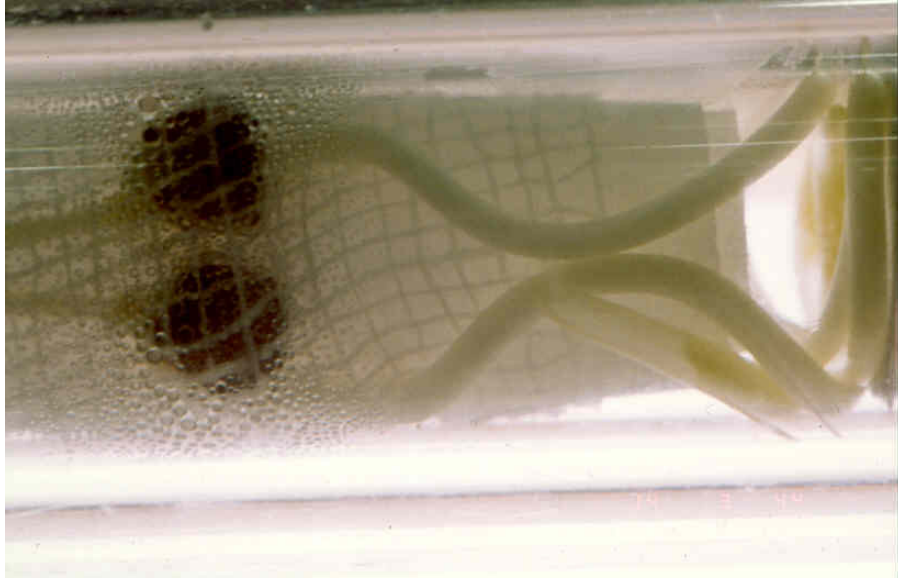




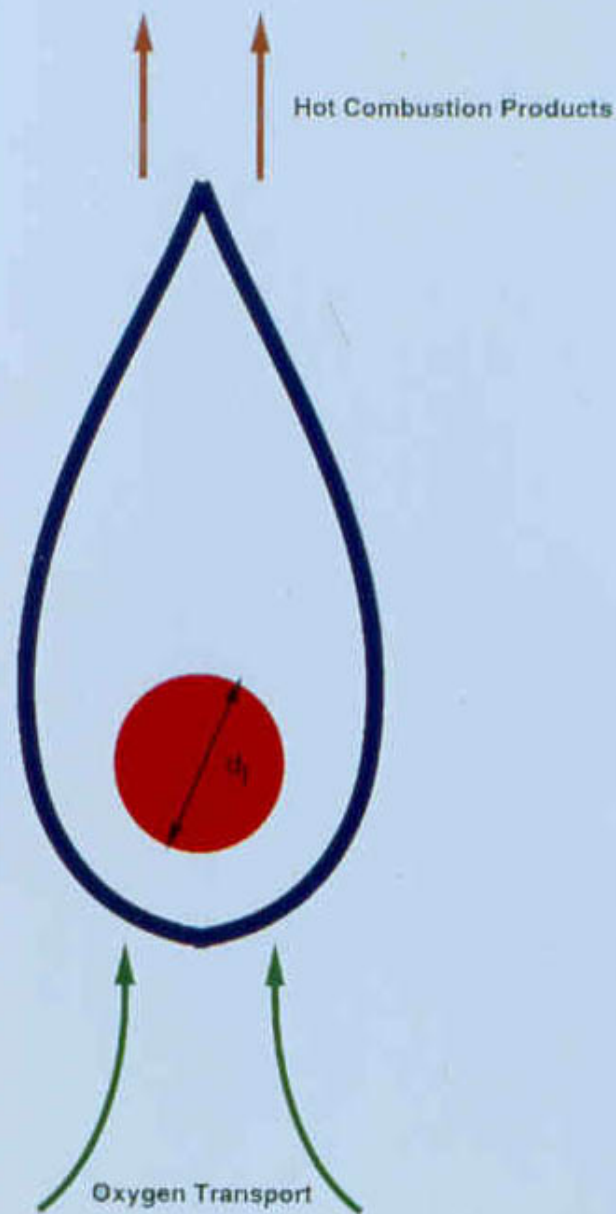




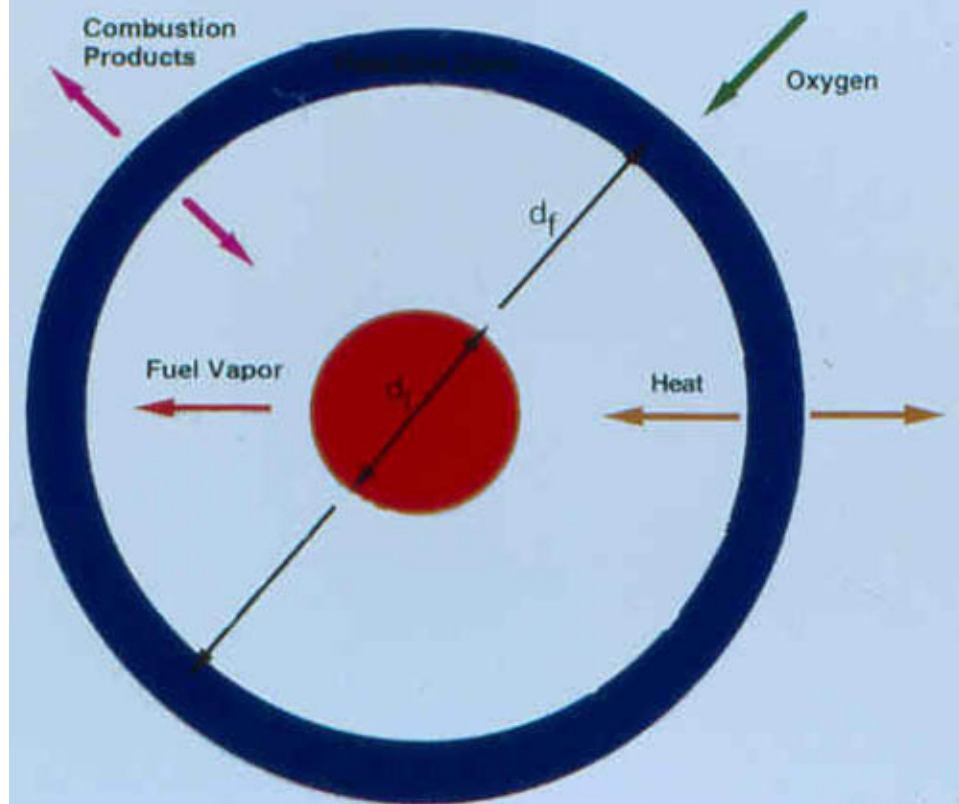


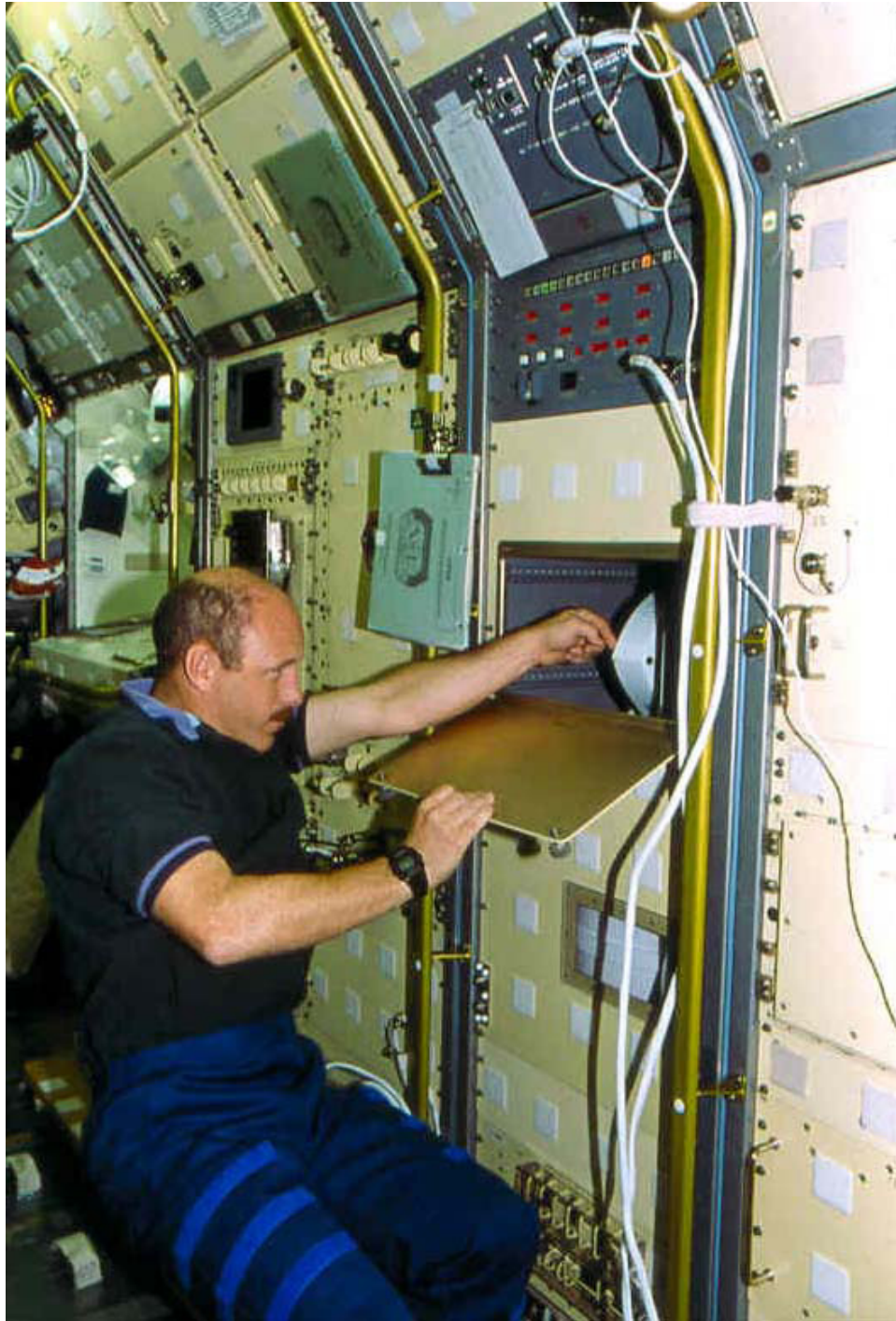


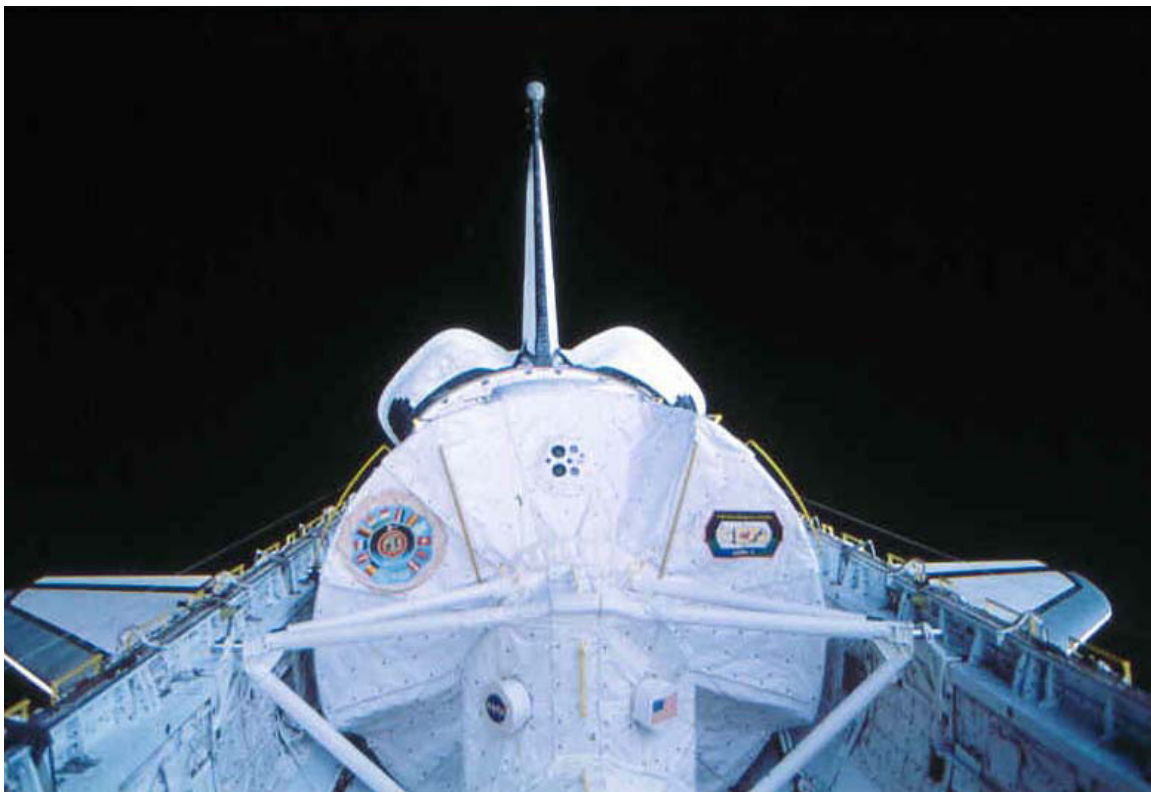
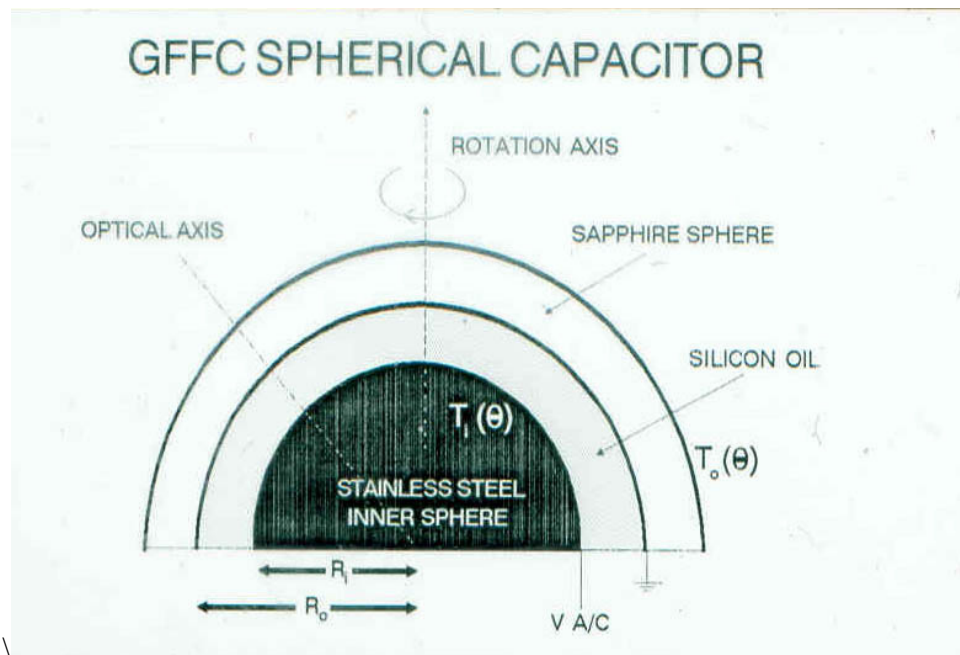
Normal Gravity

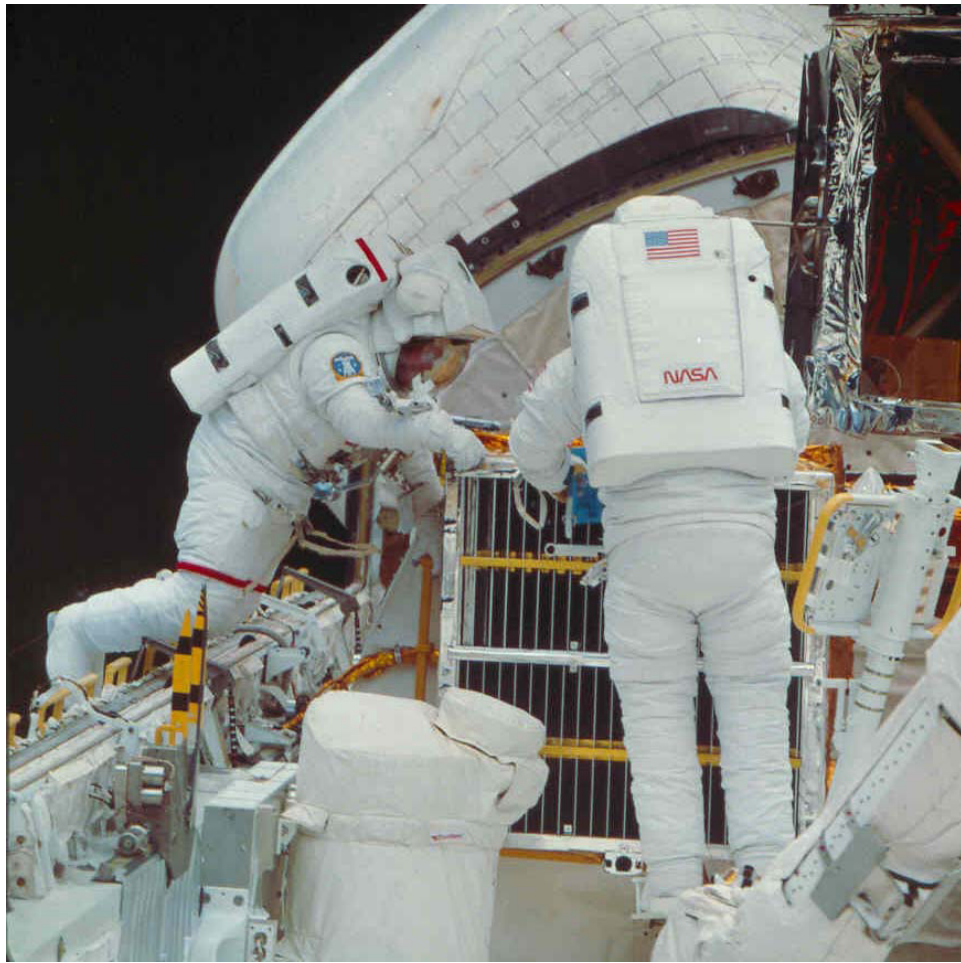


Microgravity













HUBBLE TELESCOPE TAKES PHOTO OF HEAVEN

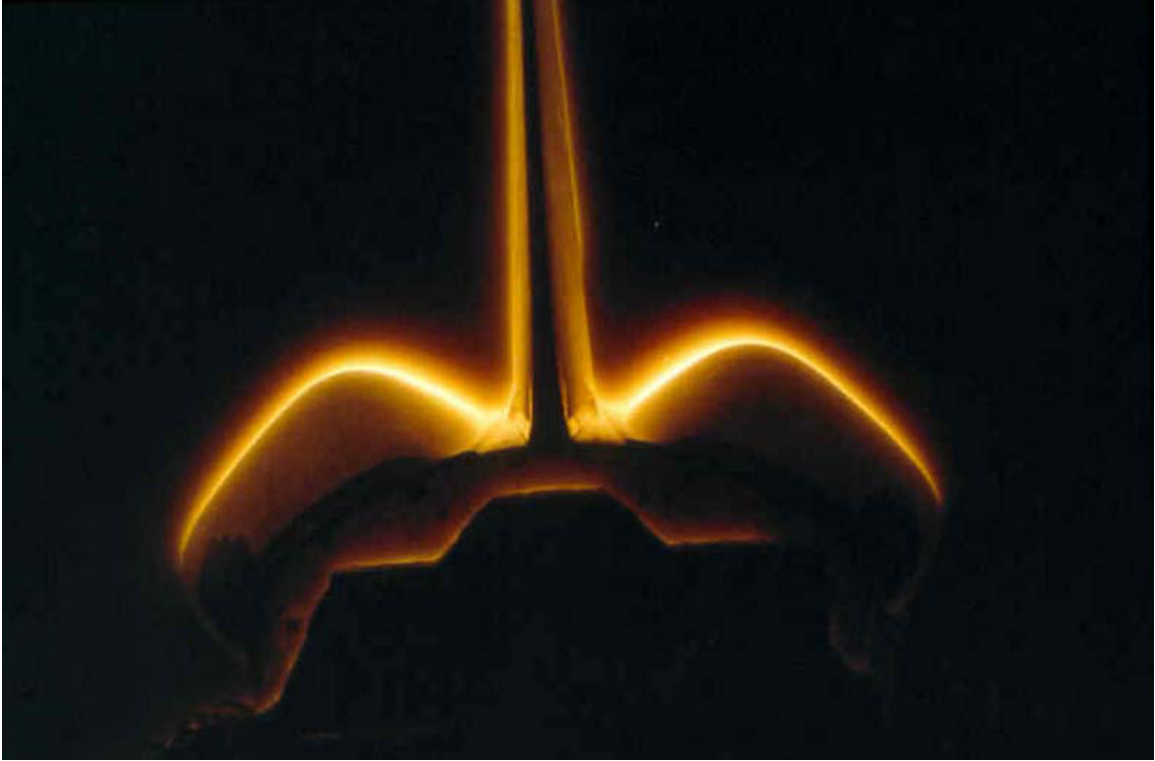
HUBBLE Space
Telescope can
focus on objects
billions of light
years away.



POPE JOHN PAUL II
has requested copies
of the Hubble Tele-
scope photographs.

***Incredible image beamed
to NASA on December 26!***

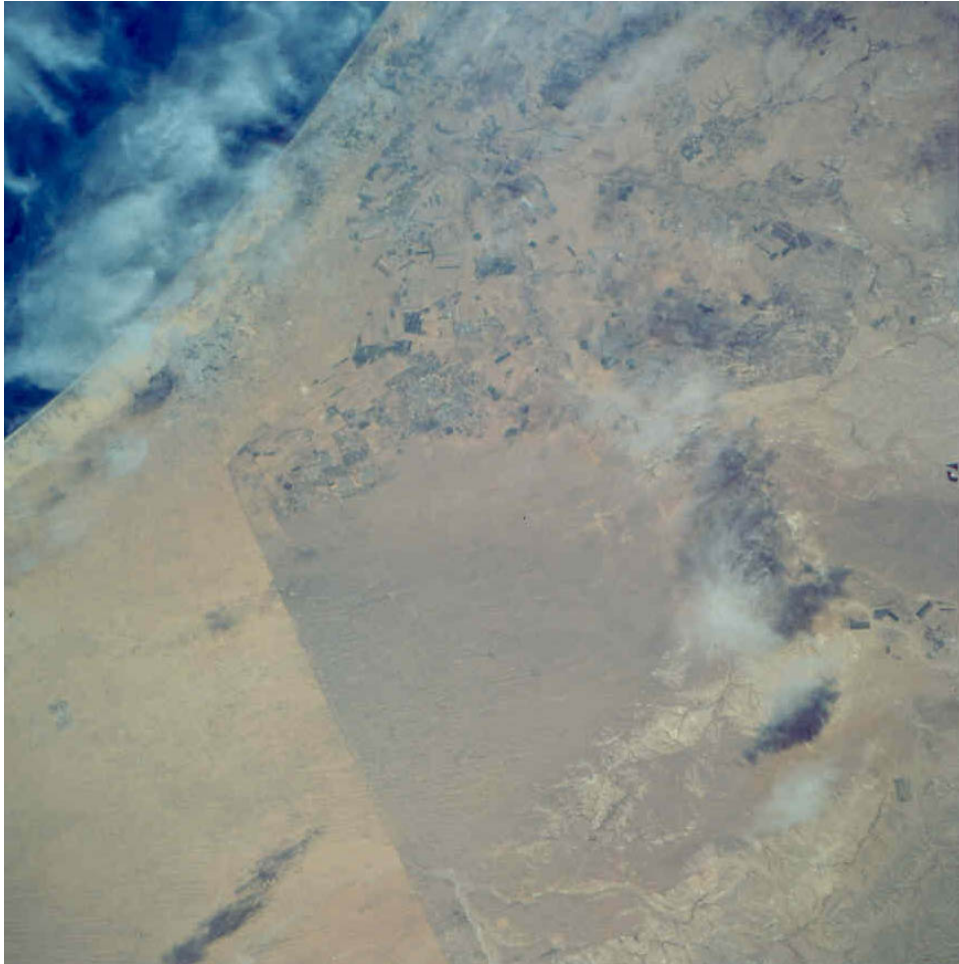




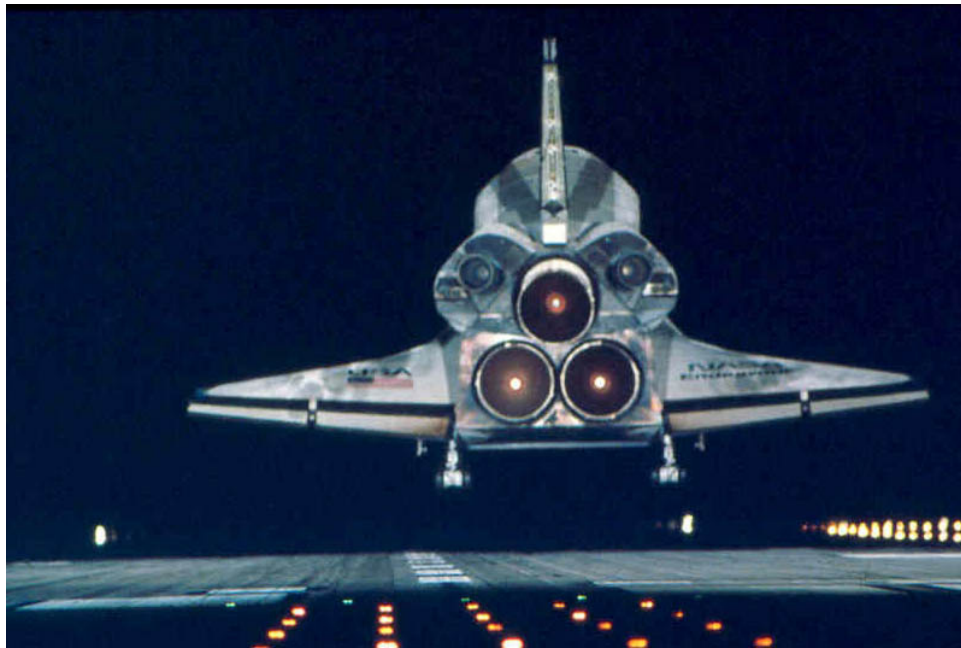
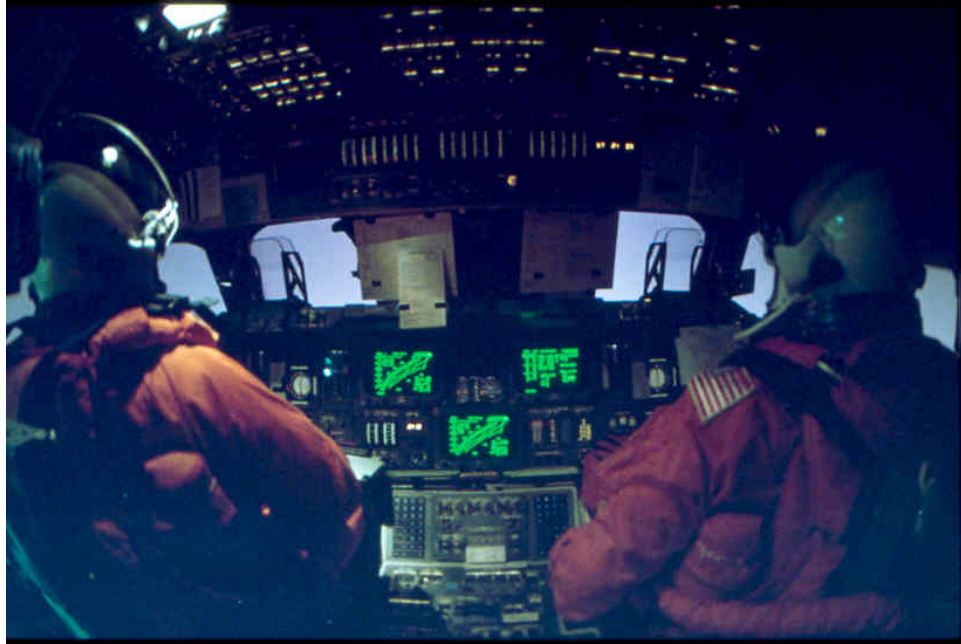


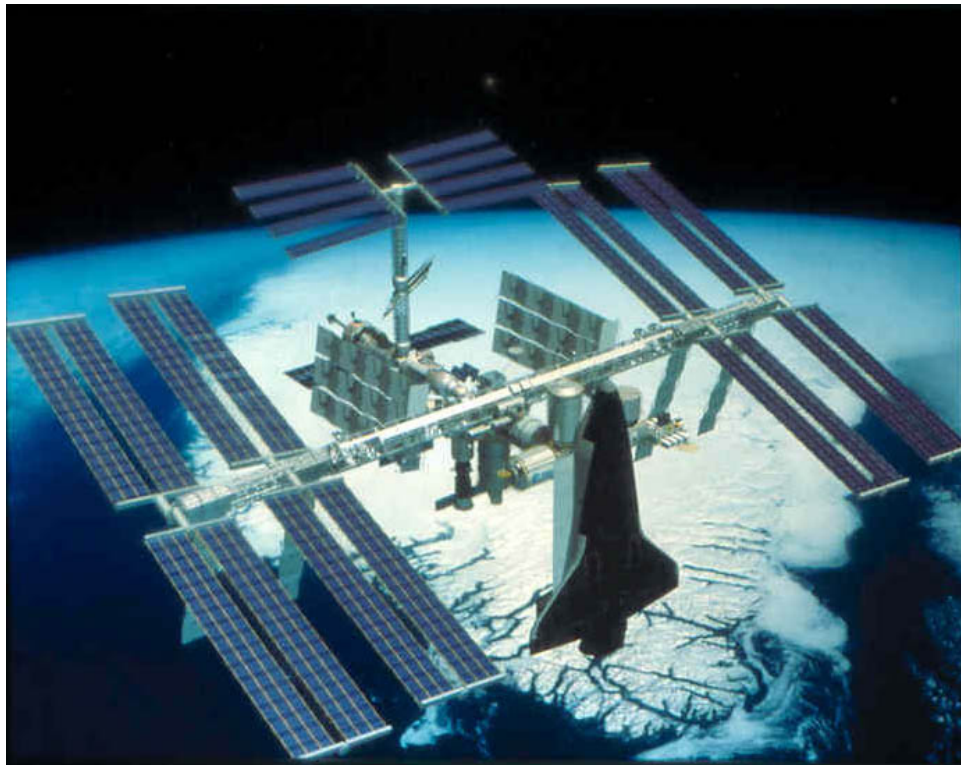


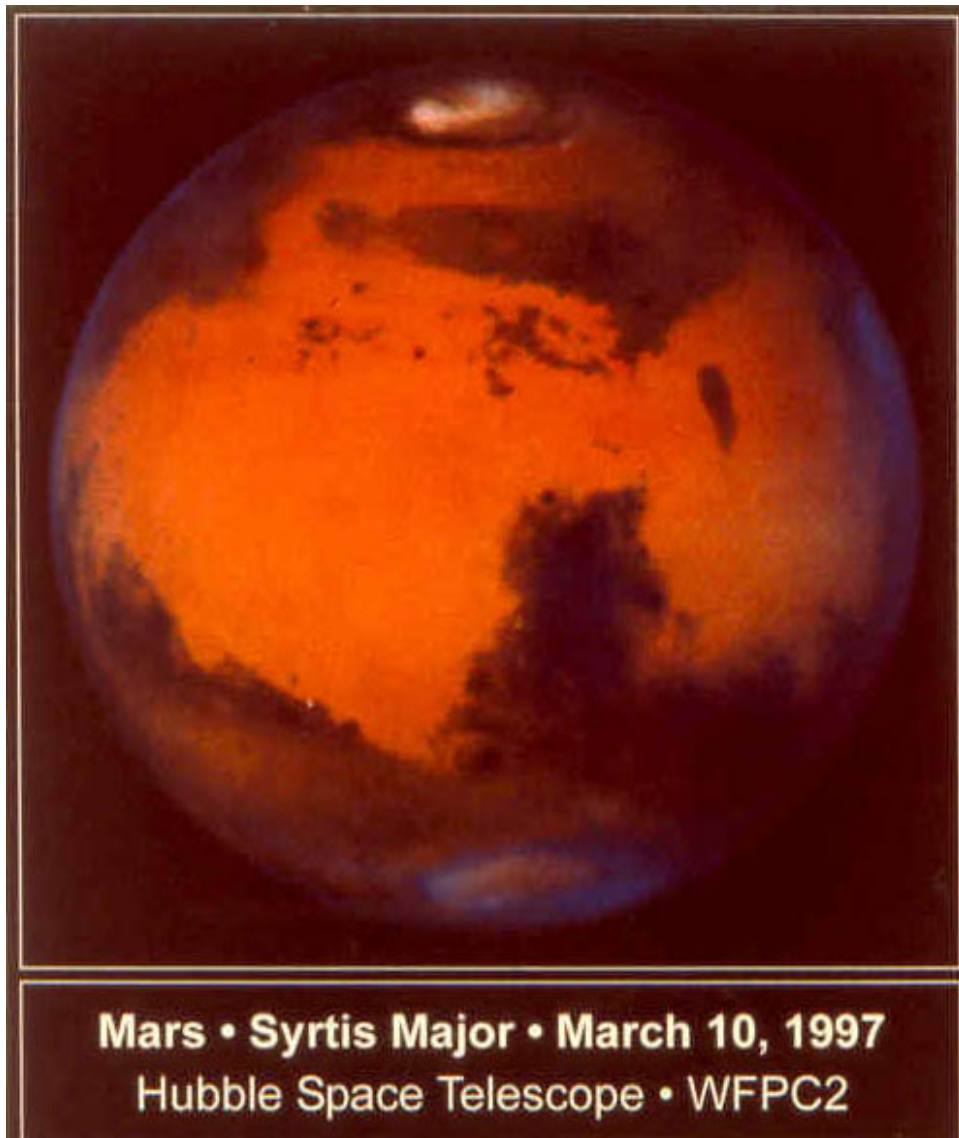












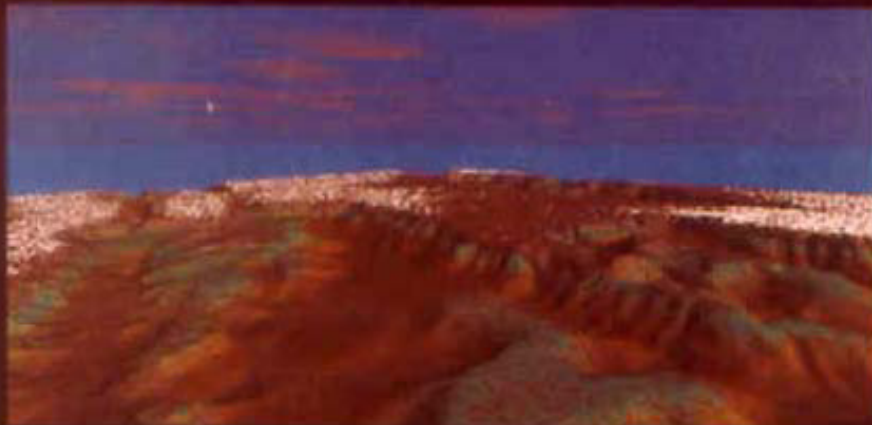
Mars • Syrtis Major • March 10, 1997
Hubble Space Telescope • WFPC2

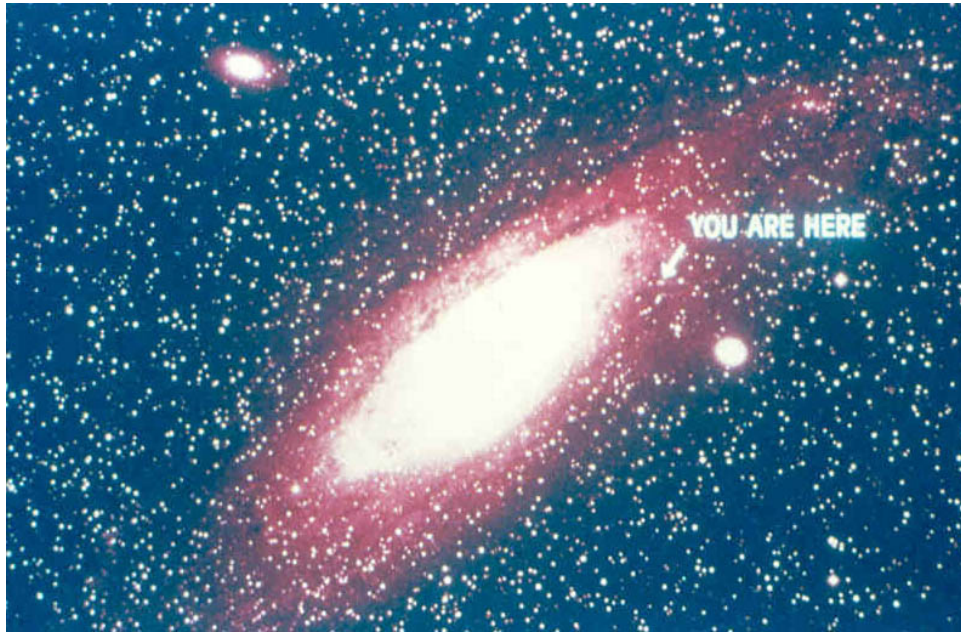






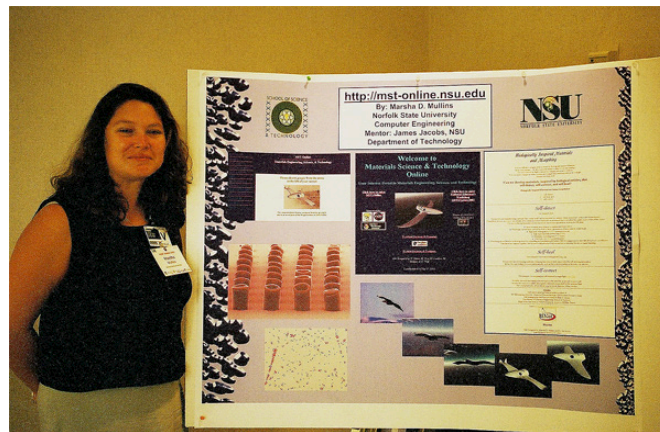
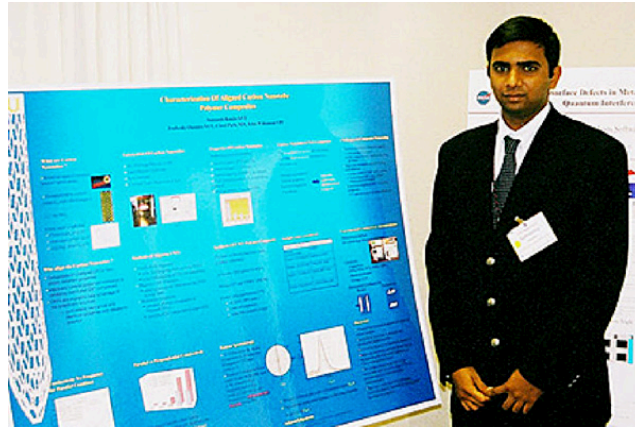
Terraforming Mars

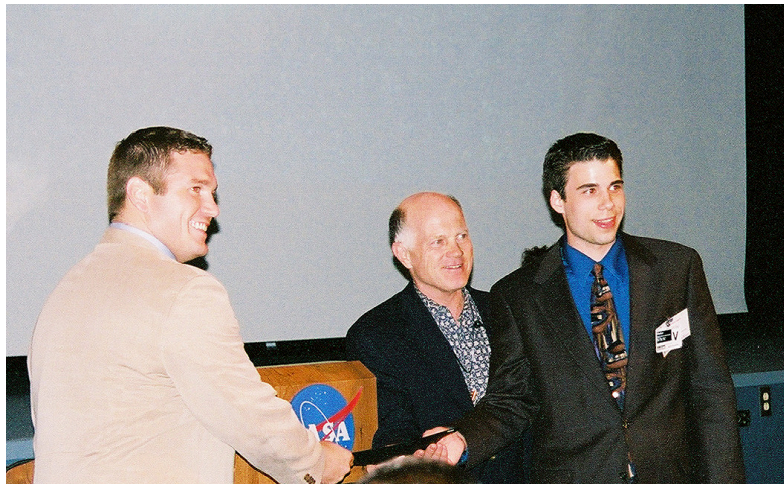




POSTER CONTEST AND WINNERS







**WELCOME TO JEFFERSON LABORATORY &
APPLIED RESEARCH CENTER**

Michelle Shinn

Jefferson Laboratory

Dr. Maria McDemmond

Norfolk State University



Michelle Shinn
Jefferson Laboratory



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SCIENCE EDUCATION PRESENTATION

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MEASUREMENTS USING THE LIGHTEST TOUCH: LIGHT

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Amin Dharamsi

Measurements using the lightest **touch:** light

A hundred years of flight (for human kind)
during 12 billion years of light from nature

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October 21 2003

National Educators Workshop

NSU/Jefferson Lab/NASA

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Synopsis



- **Quantitative** Measurements (in Science and Technology)
- Measurements should be:
 - Precise and sensitive
 - Non-intrusive
 - fast, “real-time”
- **Optical Measurements** are suitable
- **Dilemma.** To measure characteristic (eg density, temperature, etc) of an object we must “touch” it
 - Touch *will* disturb system
 - Measurement not useful if perturbation severe
 - Need **Lightest Touch**
 - Light does the trick!
- However
 - must understand interaction of light with matter (to understand any perturbation to the system)
 - must discuss the sensitivity and precision of any such measurement
- We attempt to discuss these issues now

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Light - that ephemeral stuff



- Humans have always wondered about “light”
- All societies have held this luminous stuff in awe and recognized their debt to it
- ALL civilizations have had “deities” associated with light
 - Sun god Ra of Egyptians
 - Sun god Shams of Persians
 - Sun god Baal of Babylonians
 - Sun goddess Malina of the Eskimos
 - Sun goddess Helios of Greeks
 - And then, of course, the Abrahamic god also said *“Let there be Light!”*



Baal,
the
Mesopotamian
Sun god

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Some of the mystery has been
shed



- From “corpuscular” to “wave” and back
– *and Forth* - *and Both!*
TO
- This still *strange* business of Quantum
Electrodynamics (QED) with its funny
“probability amplitudes” and interferences
of such amplitudes

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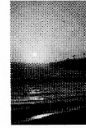
In **awe** of light



- Light is good!
- Light is fast! (“Mississippi one and two and three” gets you to the moon and back)
- Light is **useful!**
- “Light” is the ***full electromagnetic spectrum***
 - From gamma rays to long, long, long wavelength waves
 - NO ENDS TO INTERVAL as far as is known today

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We Need to USE Light



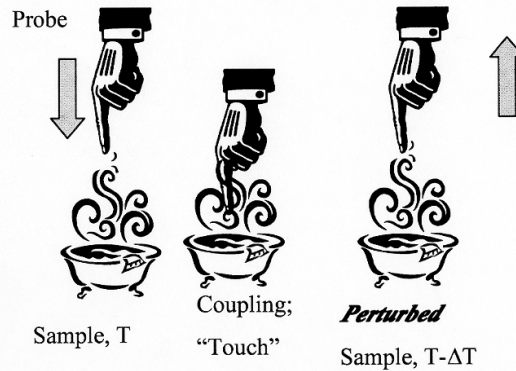
- One use is “Measurement”
 - Of what?
- Of many many important quantities.
- Only *quantitative* measurements allow us to enhance science and develop technology
- But any GOOD MEASUREMENT MUST BE “NON INTRUSIVE”
 - What good is it to say I measured that quantity just “a second” ago but I do not know what it is now because I was clumsy and I disturbed the system and have probably left it in a *different* state

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A disclaimer first!



- A completely non-intrusive measurements NOT possible
- active probes *must couple* to (i.e. “touch”) target - coupling disturbs target



- Generally active probes preferred because we want control over the measurement and its precision
- **“Lightest touch”** is a (weak) **light** probe!
- But, ultimately, even *one* photon disturbs system

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But how does light “touch” anything?



- Answer---antennas, antennas, antennas
 - *Everything*, yes, *Everything*, can and does act as an antenna
- Transmitting Antennas
- Receiving Antennas

That is it!

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You do not believe me, Right?



- But it is true.
- Light can only be absorbed, emitted or scattered by an atom, molecule or collection of these (liquids and solids) if the constituent electrons (and protons) **shake**
- ***All shaking charges emit light***
 - ***Transmitting antenna***
 - ***Analogous to radio and TV station antennas***
- ***Light shakes charges***
 - ***Receiving antenna***
 - ***Analogous to radio and TV receivers***

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Light GRABS Atom and Molecules By FORCING them to act as ANTENNAS (whenever it can)



Electric Dipole Transition $1s \rightarrow 2p^0$

Magnetic Dipole Transition $3p^0 \rightarrow 2p^1$

Electric Quadrupole Transition $1s \rightarrow 3d^0$

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Key Aspect



- All atoms, molecules like to be “tickled” in ways that are specific to them
 - When a charge shakes it does so at frequencies dependent on the atom or molecular states it inhabits
 - Conversely if light is to shake charges in atoms or molecules it would have to humor them by attempting to shake them at their characteristic frequencies

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And, Finally, **The** Principle of using the lightest touch!



- Make light interact with matter
- Find out what happened
 - How much light was absorbed?
 - What frequencies/wavelengths (colors) were absorbed?
 - Were there any additional wavelengths generated?
 - Which direction did the light come out (need to go) in?
 - What is the “polarization” of the light
 - EtcEtc.....Etc....
- This identifies precisely the “target”
 - AND WE HAVE ACCOMPLISHED OUR TASK OF A NON-INTRUSIVE MEASUREMENT

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We know (reasonably well) “CROSS SECTIONS”



- “Crosssections” of
 - Absorption
 - Emission
 - Scattering
 - Collisions
- And, from these, we find out how many atoms/molecules of what did the absorption, emission, scattering etc
- Grand Result: We have a nonintrusive (lightest touch) measurement!!

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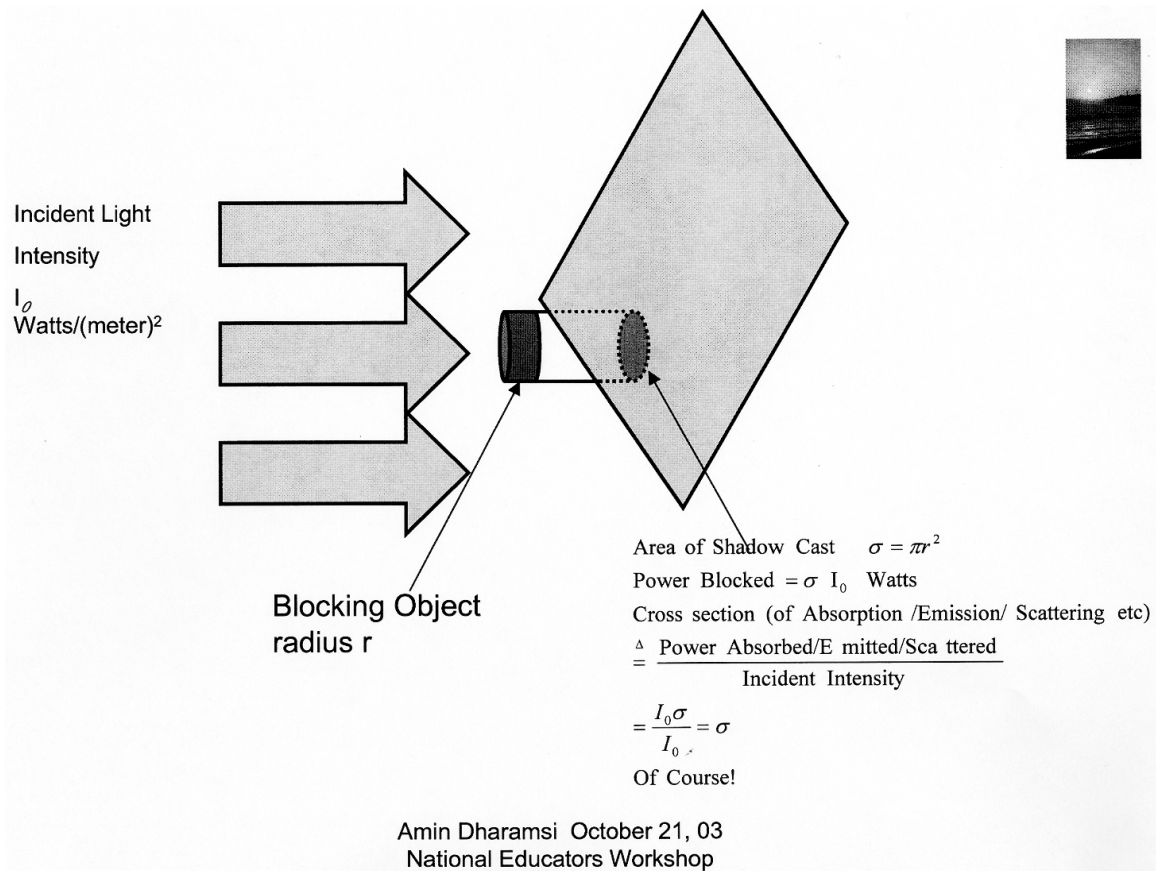
But What is a “Cross-section” ?



- Of course it is an area- but what area?
- It is the area of the “shadow cast”



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The Shadow Cast by a Typical Atom/Molecule



- I sound more learned (I hope!) when I say, instead, “*The Absorption **Cross-section** of a typical Radiative Transition*”
- Shadow is a spot about 0.000000000000000001 cm² in area - And this is a DARK shadow (1 Angstrom squared)
- Today we often need to deal with crosssections that are 100,000 to 1,000,000 times *smaller*

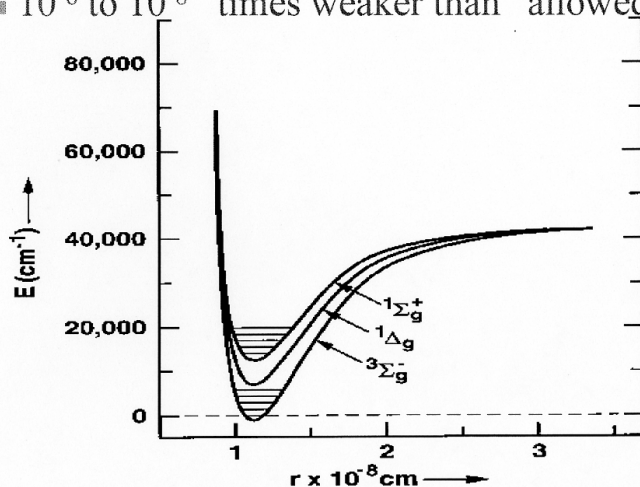
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Example of an “Uncooperative” Molecule

-the (very important!) Oxygen A-Band



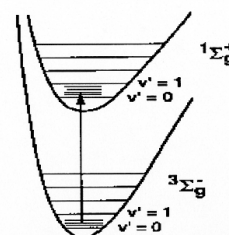
- Electric Dipole Forbidden, “Spin Forbidden in Near IR
- Magnetic Dipole Coupled
- 10^{-6} to 10^{-8} times weaker than “allowed” transitions



LOWER ELECTRONIC STATES OF O₂

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O₂ A BAND TRANSITIONS



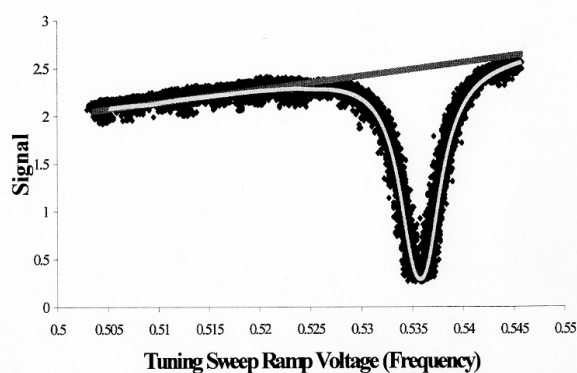
Conventional Absorption Spectroscopy: Experimental Result



Four lines ($\sigma_1 \sim 10^{-24} \text{ cm}^2 \text{ cm}^{-1} \text{ mol}^{-1}$; σ_{2-4} between 10^{-25} to $10^{-27} \text{ cm}^2 \text{ cm}^{-1} \text{ mol}^{-1}$).

		σ ($\text{cm}^2 \text{ cm}^{-1}$ molecule $^{-1}$)
Line 1	RR (13, 13)	4.75×10^{-24}
Line 2	RR (13,13)*	9.62×10^{-27}
Line 3	RR (43,43)	1.04×10^{-27}
Line 4	RQ (12,13)	1.18×10^{-26}

Conventional Absorption Measurement
($N=0$)



Magnetic Dipole Driven Spin-Forbidden

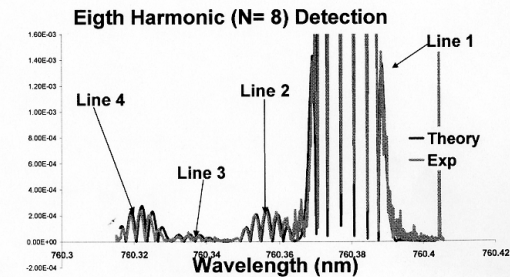
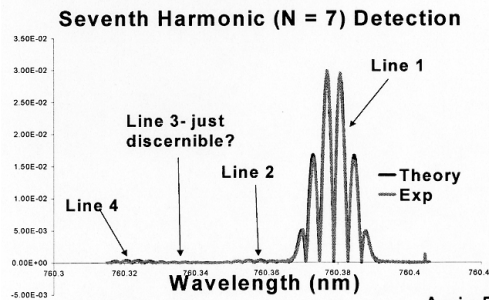
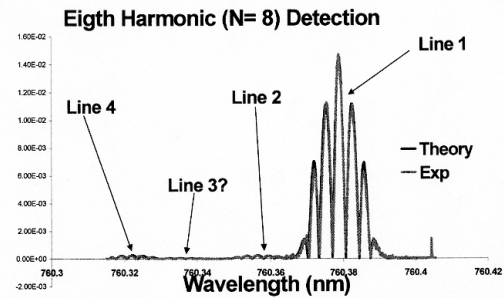
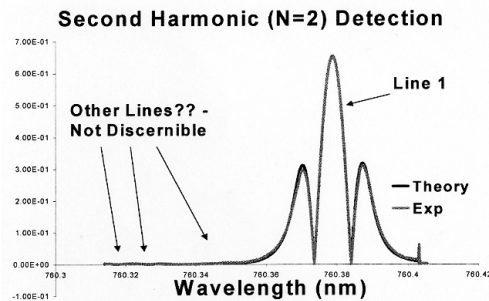
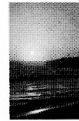
Radiative cross sections

$< 0.00000000000000000001 \text{ cm}^2 (=10^{-21} \text{ cm}^2)$

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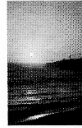
Resolution of Overlapping Lines with Disparate Absorption Cross-sections

Absorption path length: 107 meters in air



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Summary



- Each material has a set of “fingerprints”- a spectrum
- What patterns the fingerprints exhibit tell us **what** we have
- How “dark” the fingerprints show up- after “development” tell us **the concentration, and/or temperature and/or velocity etc etc**
- We do it precisely and non intrusively and with the **lightest** touch

Thank you

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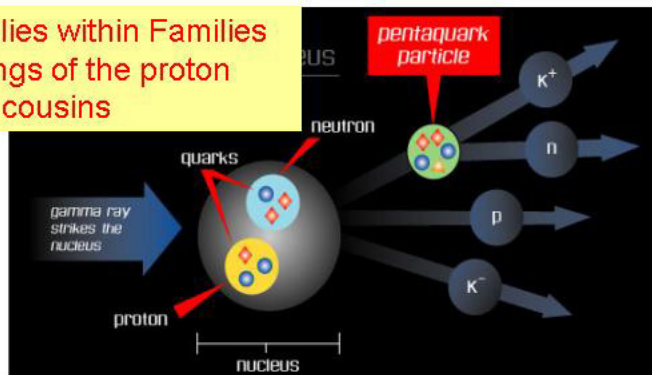


Elton Smith

Pentaquarks: Discovering new particles

Elton S. Smith, Jefferson Lab

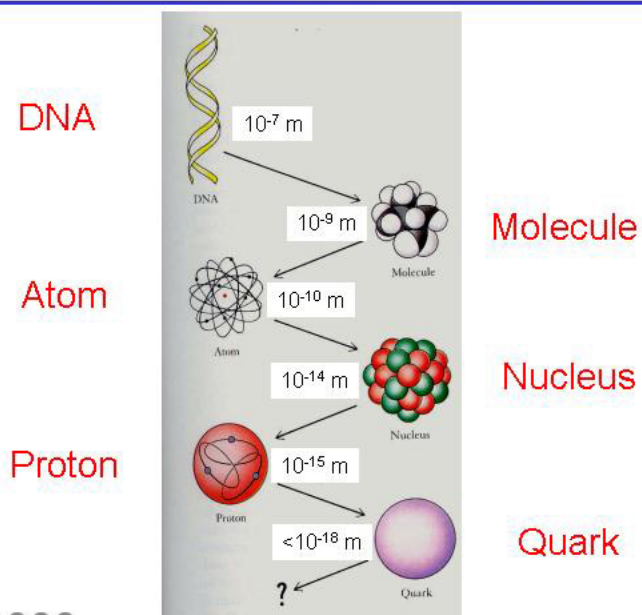
- Families within Families
- Siblings of the proton
- New cousins



Elton S. Smith

3

Families within families



Elton S. Smith 18th Annual National Educator's Workshop Oct 21, 2003

4

Families of atoms



PERIODIC SYSTEM OF THE ELEMENTS IN GROUPS AND SERIES.

GROUPS OF ELEMENTS

Series	0	I	II	III	IV	V	VI	VII	VIII
1		Hydrogen H 1.008							
2	Helium He 4.0	Lithium Li 7.0	Beryllium Be 9.1	Boron B 11.0	Carbon C 12.0	Nitrogen N 14.04	Oxygen O 16.00	Fluorine F 19.0	
3	Sodium Na 23.0	Magnesium Mg 24.3	Aluminum Al 27.0	Silicon Si 28.1	Phosphorus P 31.0	Sulfur S 32.06	Chlorine Cl 35.45		
4	Argon Ar 39.9	Potassium K 39.1	Calcium Ca 40.1	Scandium Sc 44.1	Titanium Ti 48.1	Vanadium V 51.4	Chromium Cr 52.0	Manganese Mn 55.0	Iron Fe 55.85
									Cobalt Co 58.93
									Nickel Ni 58.71
									Copper Cu 63.55
									Zinc Zn 65.38
									Gallium Ga 69.72
									Germanium Ge 72.64
									Arsenic As 74.92
									Selenium Se 78.96
									Bromine Br 79.90
									Krypton Kr 83.80
									Rubidium Rb 85.47
									Silver Ag 107.88
									Cadmium Cd 112.41
									Indium In 114.82
									Thallium Tl 204.38
									Lead Pb 207.2
									Bismuth Bi 208.98
									Poisonous Po 209
									Astatine At 210
									Radium Ra 226
									Actinium Ac 227
									Thorium Th 232
									Uranium U 238
									Neptunium Np 237
									Plutonium Pu 244

HIGHER BASIC OXIDES
R | R₂O | RO | R₂O₃ | RO₂ | R₂O₃ | RO₂ | R₂O₃ | RO₂

HIGHER ACIDIC HYDROGEN COMPOUNDS
RH₄ | RH₃ | RH₂ | RH

Gaps in table lead to predictions for the properties of undiscovered atoms



Mendeleev and Meyer (1869)



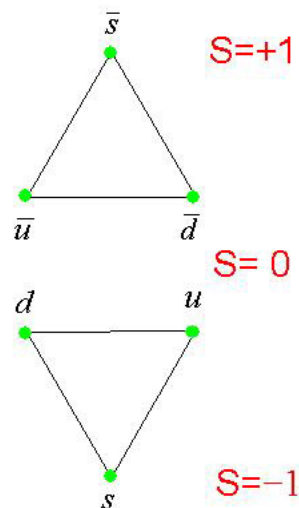
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Properties of quarks

Quark Flavor	Charge (Q)	Strangeness (S)
u	+2/3	0
d	-1/3	0
s	-1/3	-1
$\bar{u}$	-2/3	0
$\bar{d}$	+1/3	0
$\bar{s}$	+1/3	+1



Protons are made of (uud)
Neutrons are made of (ddu)

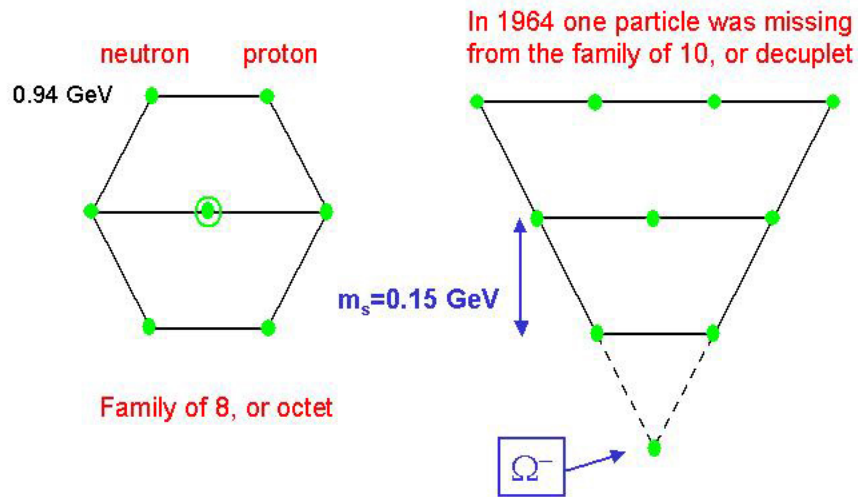


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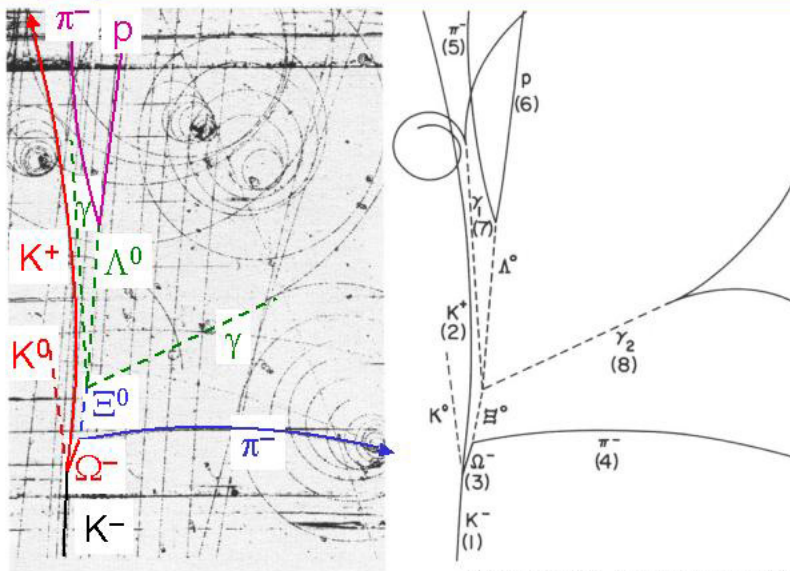
Families of protons and neutrons



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Production and decay of $\Omega^- \rightarrow \Xi^0 \pi^-$



V.E. Barnes et. al., Phys. Rev. Lett. 8, 204 (1964)

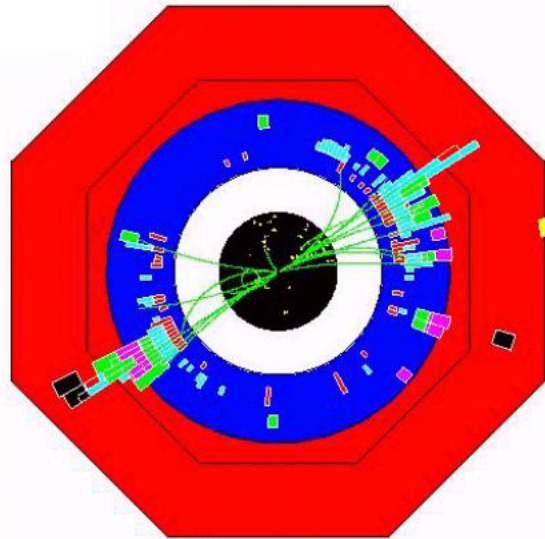
FIG. 2. Photograph and line diagram of event showing decay of Ω^- .



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Interactions understood in terms of quarks



Very high energy

$$e^+ e^- \rightarrow Z^0 \rightarrow q \bar{q}$$

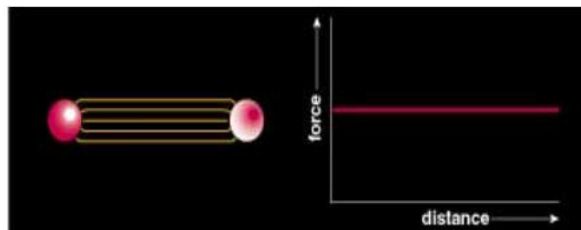
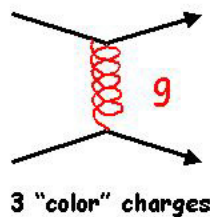
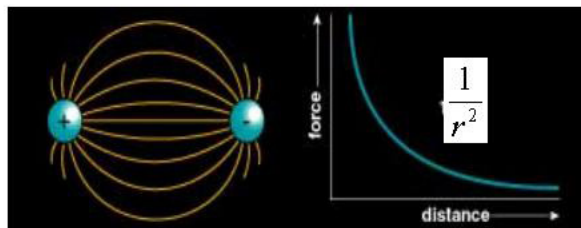
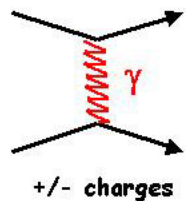
"free" quarks not found, only particles that contain quarks



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Electromagnetic and color forces



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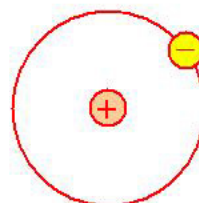
10

Particles are color neutral

Quarks are not free,
but rather confined
within
colorless particles



Atoms are charge neutral
binding positive nuclei to
negative electrons



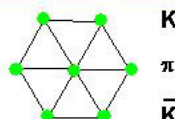
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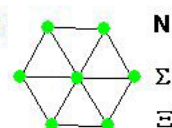
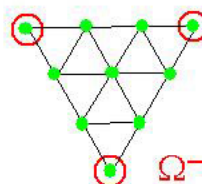
Possible combinations of color neutral multiplets

Particles from $q\bar{q}$



K
 π
 $\bar{K}$

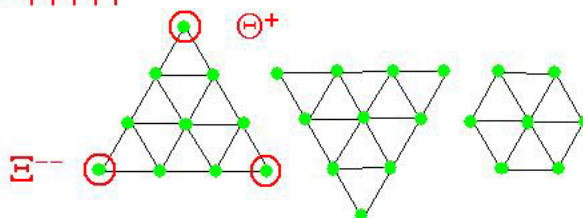
Particles from qqq



N
 Σ
 Ξ

Ω^-

Particles from $qqqq\bar{q}$



Θ^+

Ξ^{--}



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What are pentaquarks?

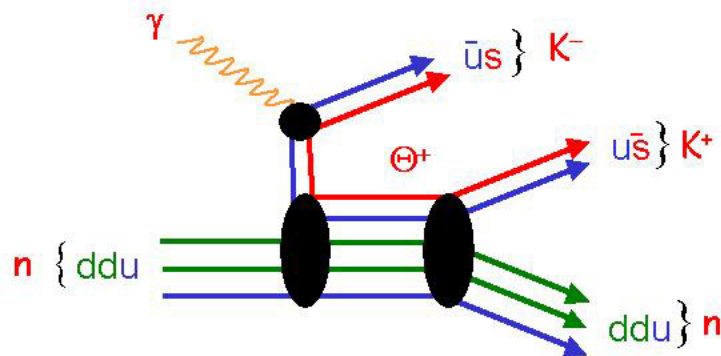
- Particles with minimum quark content is 5-quarks.
- General idea of a five-quark states has been around since late 60's.
- However, no 5-quark states were found.
- Experimental searches were revived by the specific prediction in 1997 by three Russian physicists that the Θ^+ should have a mass of 1.53 GeV.



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How do we look for the Θ^+ ?



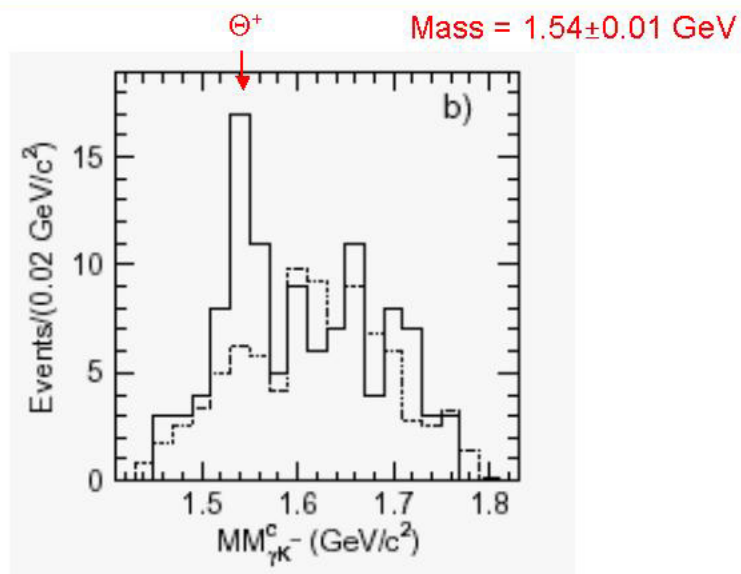
Θ^+ is composed of (uudd $\bar{s}$) quarks



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Japanese group reports first observation



Spring-8 Collaboration, hep-ex/0301020



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Search for pentaquark at JLab



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CEBAF Large Acceptance Spectrometer

Torus magnet
6 superconducting coils

Liquid D₂ (H₂) target +
γ start counter; e minitorus

Drift chambers
argon/CO₂ gas, 35,000 cells

Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers

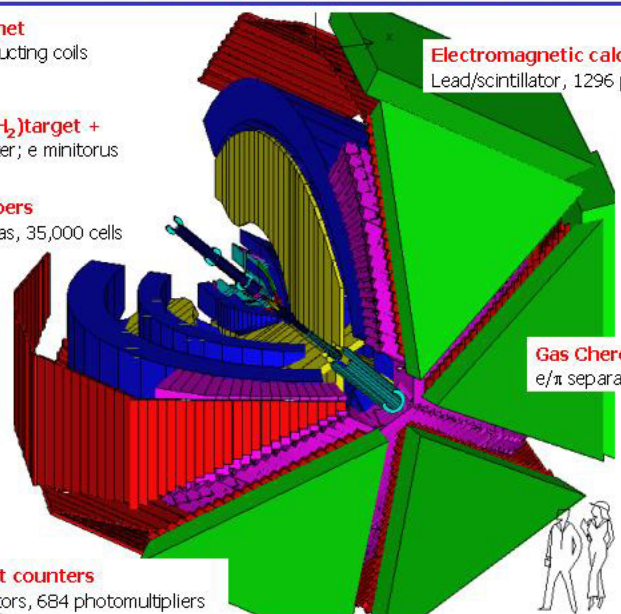
Gas Cherenkov counters
e/π separation, 256 PMTs

Time-of-flight counters
plastic scintillators, 684 photomultipliers

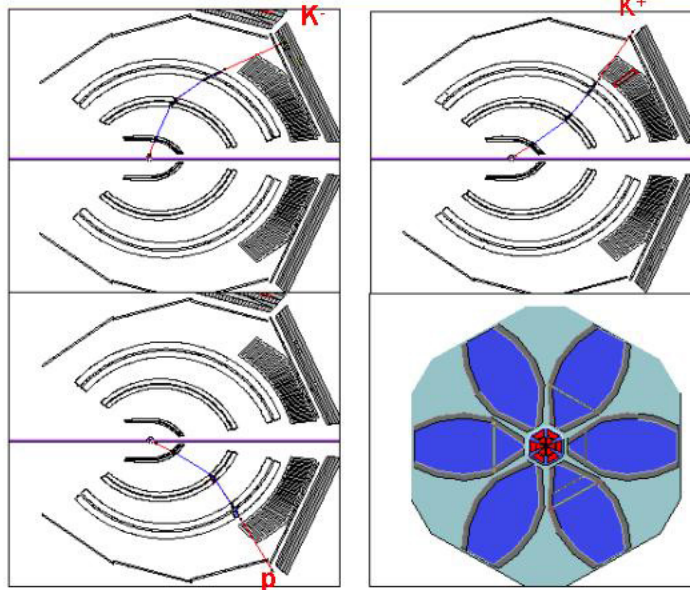


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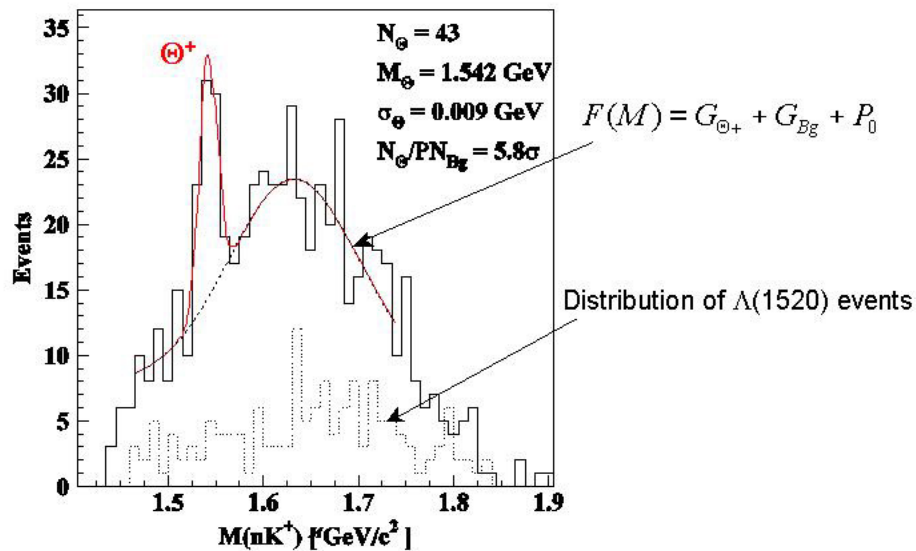
$\gamma d \rightarrow p K^+ K^- (n)$ in CLAS



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CLAS: nK^+ invariant mass distribution



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Θ^+ : experimental status

- Experimental evidence for the Θ^+ has been reported at six laboratories.
- Most properties of this particle still need to be measured.
- This topic of intense interest both theoretical and experimental.

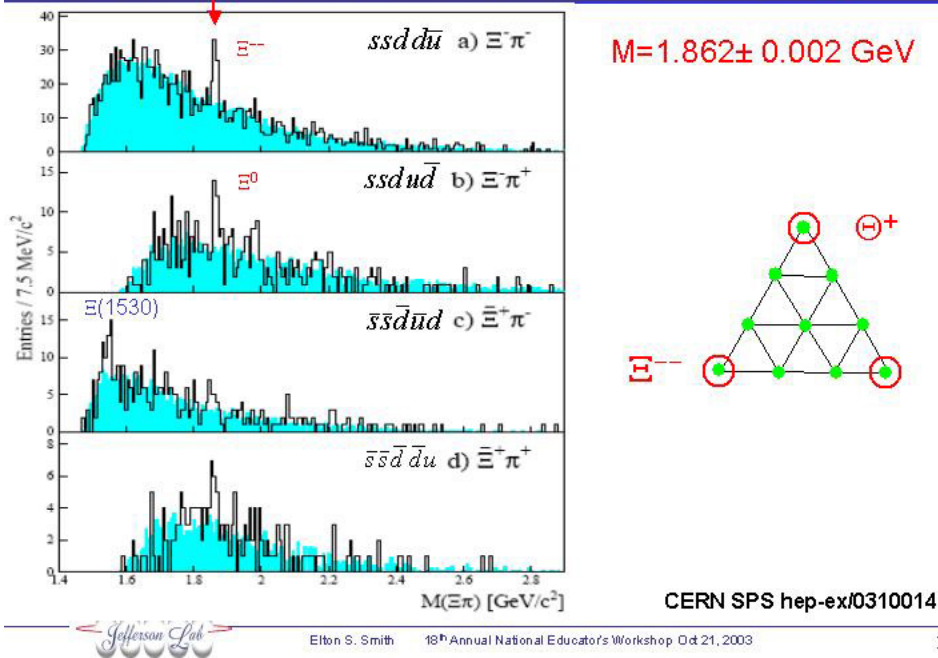
Two weeks ago
this would have been the end of the talk...



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A new cousin: observation of exotic Ξ^{--}



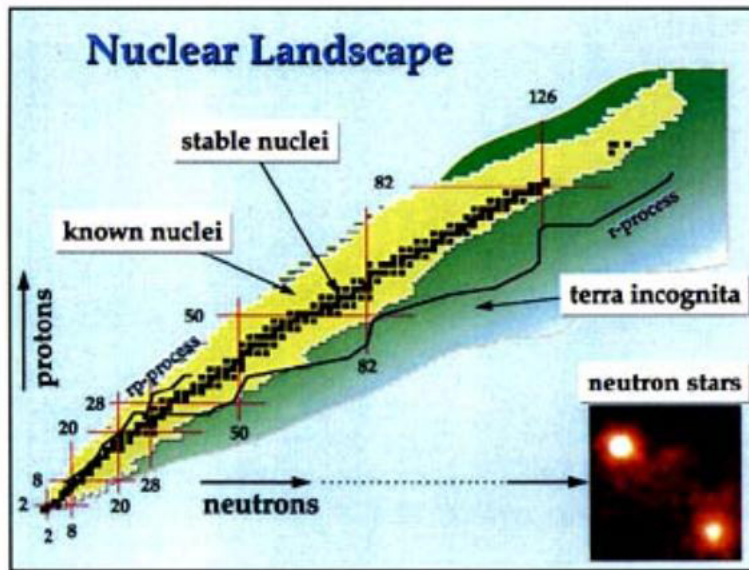
Summary

- Protons and neutrons are part of a family of elementary particles composed of 3 quarks which have been known for forty years.
- Just when we thought we understood the nature of “color neutral” particles, we find
- Striking evidence for “exotic” cousins composed of 4 quarks and 1 anti-quark which have been found at several laboratories around the world, including JLab.
- The existence of these particles was predicted based on a new proposed family of particles.

Index of popular articles on the Pentaquark <http://www.jlab.org/news/articles/>

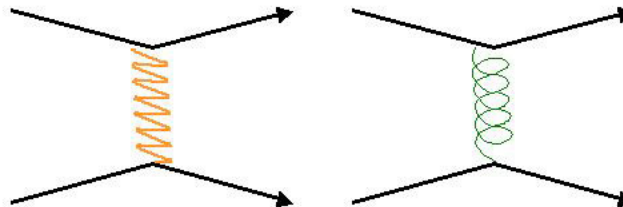


Families of nuclei



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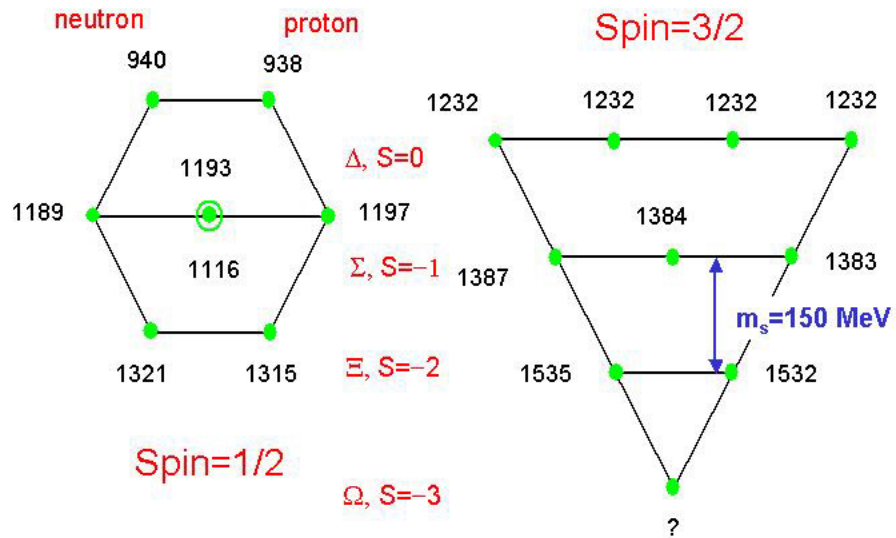
23



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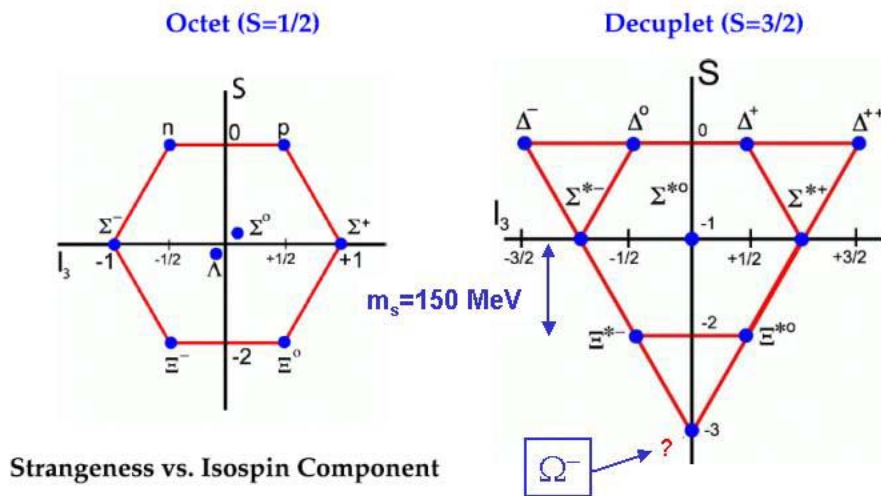
Families of protons and neutrons



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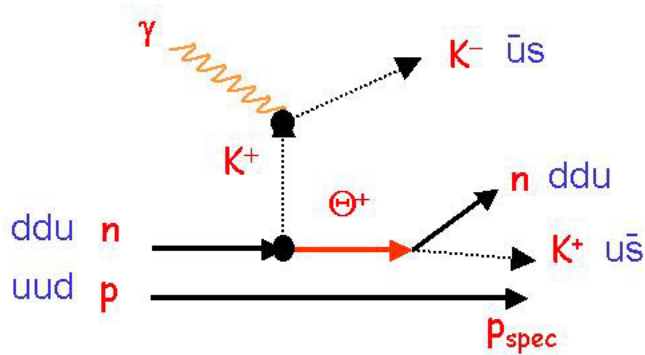
Families of protons and neutrons



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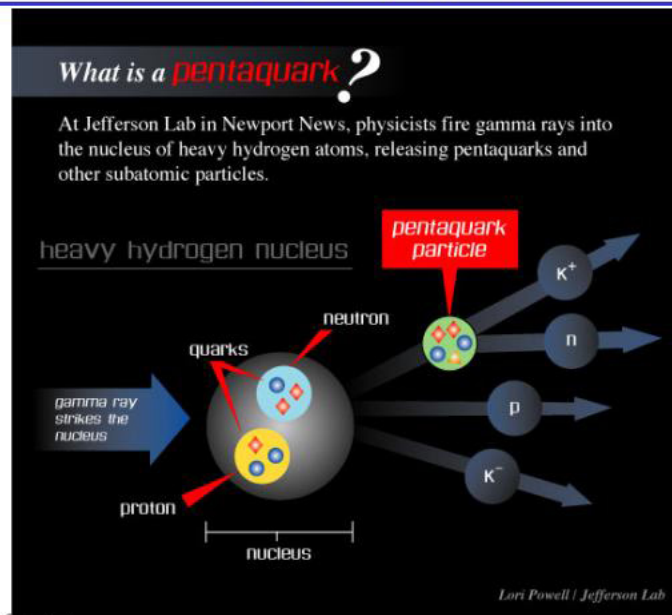
How do we look for the Θ^+ ?



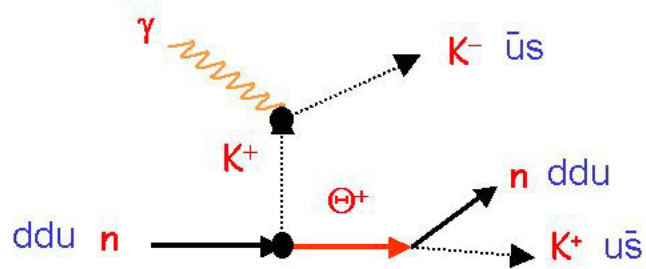
Θ^+ is composed of $(uudd\bar{s})$ quarks



Search for pentaquark at JLab



How do we look for the Θ^+ ?



Θ^+ is composed of $(uudd\bar{s})$ quarks

EXPERIMENTAL EXCURSIONS IN DIELECTRIC AND MAGNETIC MATERIALS: P-E, C-V, B-H, L-I

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James V. Masi

Experimental Excursions in Dielectric and Magnetic Materials

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Key Words: Dielectric spectroscopy, Magnetic Materials, Measurements, Materials analysis.

Prerequisite Knowledge: Basic knowledge of electronics, electromagnetic wave propagation, materials science.

Objectives: To demonstrate by experiment the electric and magnetic properties of both dielectric and magnetic materials as they relate to the fundamental properties of these materials.

Equipment and Materials:

1. HP LCR bridge;
2. HP Impedance bridge;
3. Miscellaneous capacitors, inductors, dielectric materials, ferroelectric materials, ferromagnetic materials, and common circuit components;
4. A liquid crystal display (watch or other);
5. Epoxies, miscellaneous polymers, etc.; and
6. HP Materials analyzer (optional)

Experiment 1: Dielectric Phenomena

Introduction:

There is a great deal of interest in the fundamental and applied aspects of dielectric spectroscopy (DS) of polymeric materials. Fundamental investigations of the dielectric response yield a wealth of information about different molecular motions and relaxation processes in non-polar dielectrics, ferroelectrics, and polymers, as well as the cure processes and quality control of thermosets and thermoplastics. DS is performed over a wide frequency range, from 10^{-5} Hz to 10^{11} Hz, where polymers, dielectrics, and ferroelectrics respond to an applied electric field. This enables the researcher to relate the observed dielectric response to low frequency and/or high frequency phenomena. Industrial interest in dielectric and electrical properties of polymers, dielectrics, and ferroelectrics has increased due in large part to the increased use of these materials in electronic devices, optoelectronic switches, printed circuitry, microwave circuits, batteries, power devices, fuel cells, and many other applications.

Details of the basic aspects of dielectric behavior of polymeric materials and ferroelectrics can be found in several books and key reviews [1 (old) and 2 (newer)],

most of which pertains to the systems that are time invariant. Time and frequency-dependent characteristics have recently become of great interest in property and process control. The use of dielectric spectroscopy in time varying systems has been described by Williams [3]. Examples include systems that undergo a chemical and/or physical change as a result of chemical reaction, crystallization, vitrification, phase separation, polymerization, Curie temperature changes, etc. In this experiment we will use dielectric measurements to investigate cure, i.e. the conversion of (usually) liquid prepolymers into a thermoset polymer network, ferroelectric P-E curves, and standard capacitors with defects.

Theory

Without going into detail, one can describe a simple dielectric systems [4] in terms of the following: complex dielectric constant, response to the electric field, and the capacitance of the material.

- The **complex dielectric constant** (sometimes called the relative permittivity), (F/m), $\epsilon^* = \epsilon_0(\epsilon_r' - j\epsilon_r'')$, where ϵ_r' is the real part of the complex dielectric constant and ϵ_r'' is the imaginary part (loss constant). [NOTE: $\epsilon_r''/\epsilon_r' = \tan \delta$, the loss tangent or dissipation factor]. The permittivity of free space, $\epsilon_0 = (1/36\pi) \times 10^{-9}$ F/m. All of these “constants” can be factors of frequency, temperature, time, etc.
- The **Electric Field**, E (V/m), the **Displacement Vector**, $\mathbf{D} = \epsilon_0\epsilon_r'\mathbf{E}$, (Coulomb/m²), and the **Polarization Vector**, $\mathbf{P} = \epsilon_0(\epsilon_r' - 1)\mathbf{E}$, (Coulomb/m²). The susceptibility, $\chi = (\epsilon_r' - 1)$ is sometimes substituted in the definition of Polarization or polarizability per unit volume. The **P-E curve** at various frequencies (also called the dielectric hysteresis curve) gives information on the dielectric constant and the frequency dependence of the dielectric. Electronic, ionic, dipolar, and orientation polarizability/polarization are the four dominant polarizations in solids. The regions of the frequency spectrum where these mechanisms are most prominent are shown in Figure 1 below. A table of some representative materials and their low frequency dielectric constants are also shown below in Appendix 1.

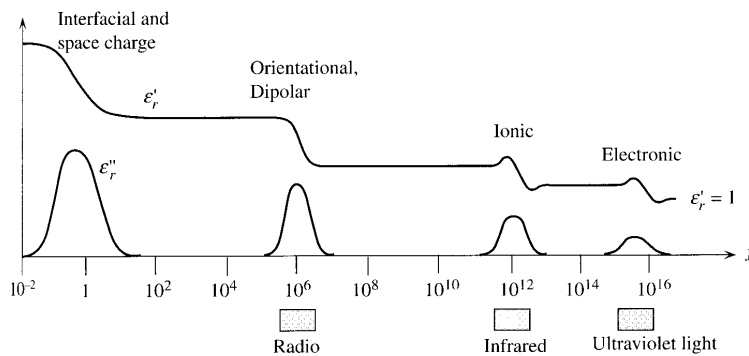


Figure 1. The frequency dependence of real and imaginary parts of the dielectric constant in the presence of an alternating electric field over the frequency range where interfacial, orientational, ionic, and electronic polarization mechanisms are operative.[4]

P-E responses are shown for four devices in Figure 2. NOTE: In reality, the shapes of these curves are very sensitive to frequency and temperature.

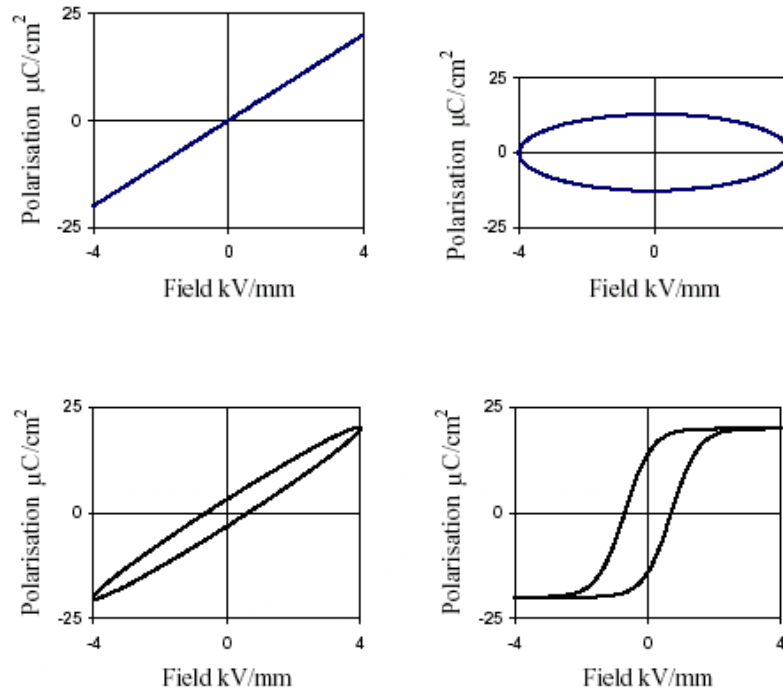


Figure 2: Polarization vs. electric field responses for: (a) Ideal linear capacitor; (b) Ideal resistor; (c) Lossy capacitor; and (d) Non-linear ferroelectric. [5]

IEEE standard 180 defines several reference points on the curve that allow comparisons of materials. Figure 3 shows these: E_c , the Coercive field, P_r remnant polarization, and P_s saturation polarization. For a better understanding of these terms a more complete description of ferroelectric terminology is necessary.[6]

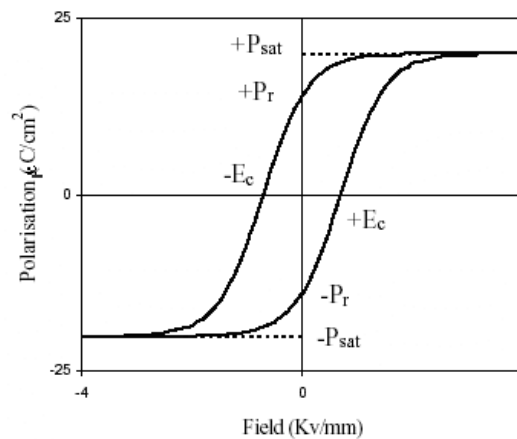


Figure 3. P-E hysteresis loop parameters for a ferroelectric material

- The **Capacitance**, $C = \epsilon_0 \epsilon_r A/d$, (F), (for a parallel plate capacitor with plate area A and plate separation d). The **C-V curve** gives information on the voltage dependence of the capacitance (very useful for semiconductor p-n junctions).

- The **characteristic equation** for a capacitor is defined as $dq/dt = i = C dV/dt$, where i is the instantaneous current (rate of change of charge with respect to time) equal to the capacitance times the time rate of change of the voltage across the capacitor. With time dependence of the capacitance (permittivity), this is more properly written $i = C dV/dt + V dC/dt$.

Experimental Procedure:

Figures 4 (a) and (b) are photographs of a typical Hewlett Packard LCR scanned frequency bridge* and a materials analyzer.

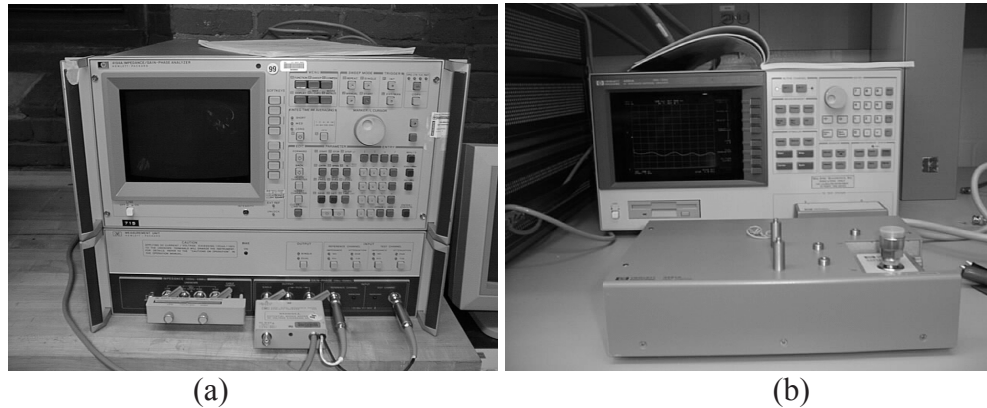


Figure 4. Typical HP LCR frequency scanning bridge (a) and Materials analyzer (b)

The LCR scanned frequency bridge is the primary data-gathering instrument for this set of dielectric experiments. The materials analyzer is sensitive up to 1.8 GHz (It is also extremely expensive).

Advantages and disadvantages of non-bridge type systems include:

- **LCR meters:** (e.g. HP4284, Wayne-Kerr B4625): quick, convenient, $\tan\delta$ measurements are accurate to within 0.001 or less (with very careful measurement techniques); reasonably large frequency range (20 Hz to 40 MHz, but not very good above 500 kHz), limited to low voltages in stand alone form (< 10 V).
- **Hysteresis measurements:** This is the only method by which one can actually record and observe the voltage and current signals and the nature of the P-E relationship. Non-linear effects can be readily identified and quantified. Very wide voltage and frequency ranges can be covered once the basic system is set up (limited by the specifications of instruments making up the system). This is also the only method in which one can easily depart from sine wave drive and still expect to get useful results. Determination of the loss tangent becomes unreliable below 0.01 (this could be improved somewhat by using accurate current measurement methods and noise suppression).

* Manual scanning LCR bridges will work as well, albeit a slower data gathering rate.

Dielectric Cure Monitoring

Dielectric Cure Monitoring [11] provides an easy approach to monitor the cure characteristics of polymers and advanced polymer composites. The technique measures the dielectric properties (C , $\tan\delta$) via rotation of a polar resin molecule, providing real-time information on viscosity and percent cure. Operating in the kHz-MHz frequency range, dielectric cure monitoring provides an alternative between high-frequency fiber-optic methods and low-frequency dielectric methods, using simple bridge techniques and miniaturization with electrode-based simplicity and robustness.

The method provides a signal from small, embedded electrode sensors. The location of significant cure events is identified, such as viscosity minimum, gel point, and end of cure. The information is used in designing process control and optimization for active thermal control. The system is straightforward to implement and provides a high level of performance compared to conventional mechanical methods.

Dipole Rotation Approach

Dielectric Cure Monitoring follows cure by monitoring the movement of charge. A thermosetting polymer contains two types of mobile charge (a) rotating polar molecules and (b) free drifting (mobile) ions, as seen in Figure 5. Each can be used to monitor the cure process since each becomes increasingly hindered as the polymer network forms.

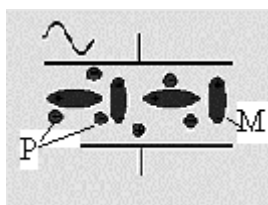


Figure 5. Depiction of mobile (M) and polar (P) molecules

Cure monitoring relies mostly on rotating polar molecules called dipoles. Properties of rotating dipoles are a better indicator of absolute cure, since their chemistry and concentration are well-known. The dipole spectrum provides a unique signature, detailing viscosity, percent cure, and degree of sensor contact. Rotating dipoles thus provide molecular-level information that can be used to deduce individual cure parameters.

Frequency-Domain Cure Monitoring

In Frequency-Domain Cure Monitoring, the frequency domain is displayed as a dipole relaxation spectrum of dielectric constant or loss tangent vs. frequency. Results are displayed as a complex dielectric constant and loss tangent vs temperature, viscosity and/or frequency, similar to mechanical rheological measurement. The specific frequency-viscosity relationship is initially calibrated using simultaneous DS and rheometry measurement and this calibration is used to predict viscosity based on loss peak frequency. Typical results for Hexcel 8552 composite are shown below in Figure 6. [13, 14]

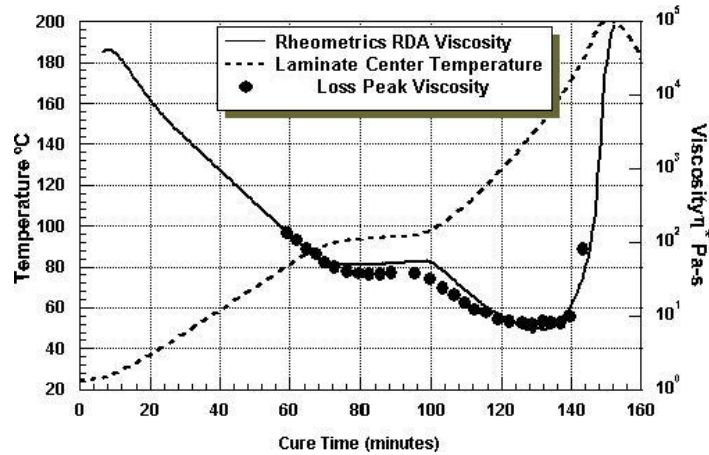


Figure 6. DS viscosity and temperature vs cure time [13]

A simple frequency domain cure monitoring experiment involves the use of standard 5-Minute Epoxy®, a set of electrodes, and a capacitance/dissipation factor bridge. The setup for the experiment is shown in Figure 7. The basic structure is really nothing more than a sectioned HDPE film container, aluminum electrodes, and leads to the bridge. The first electrode is placed in the bottom of the container, the epoxy is mixed and quickly placed over the bottom electrode, and the top electrode is pressed on top of the epoxy.

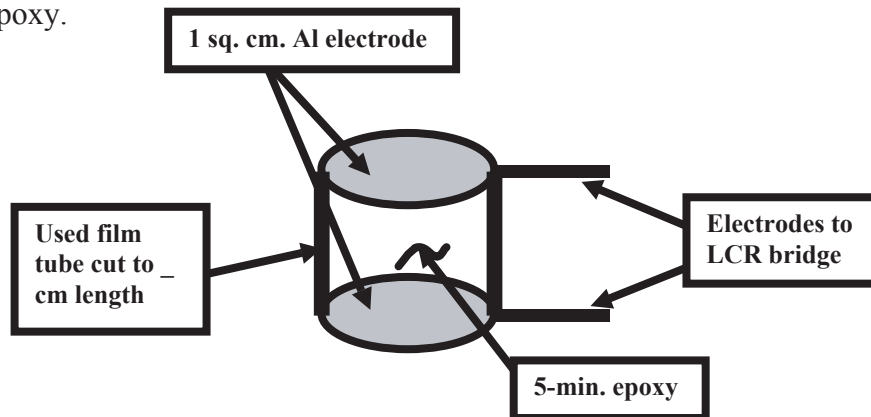


Figure 7. Simple epoxy cure monitoring

Data are taken for C , dissipation factor, and time, (starting at room temperature) as the cure progresses. Changes occurring in loss tangent for 5 Minute Epoxy during 22°C isothermal cure are seen in the Figure 8 below. These experiments indicate that it is possible to monitor the cure profile of thermosets using dielectric measurements.

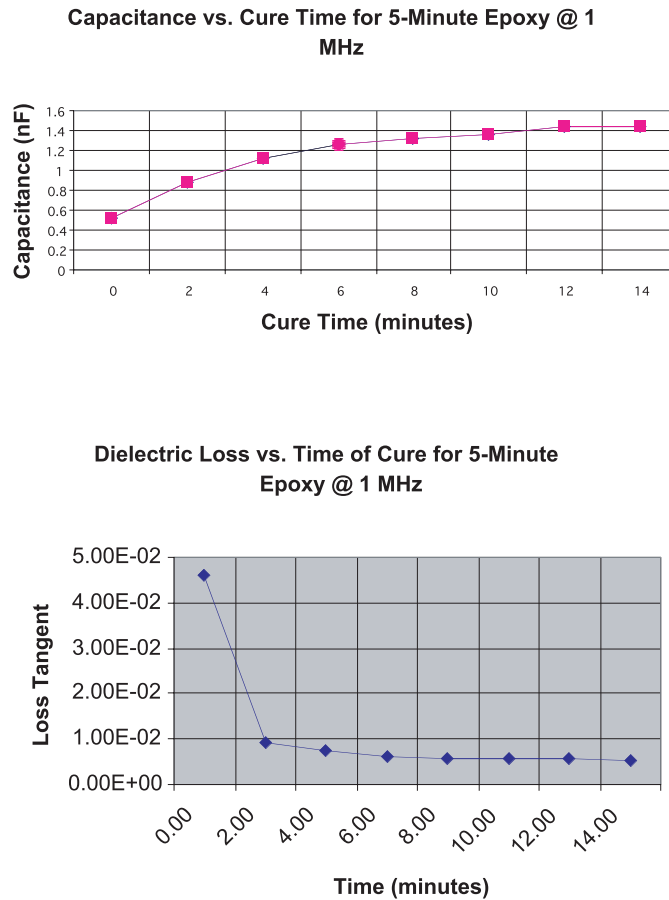


Figure 8. Capacitance and loss tangent vs. cure time for 5-Minute Epoxy @ 1MHz, 30C

Ferroelectric P-E and C-T Measurements

Ferroelectric measurements can be made on poled and unpoled ferroelectric samples, among which are: small volume, high capacitance capacitors; ferroelectric poled “beepers, such as those used on smoke alarms; and ferroelectric liquid crystal devices. The schematic for these measurements is shown in Figure 9.

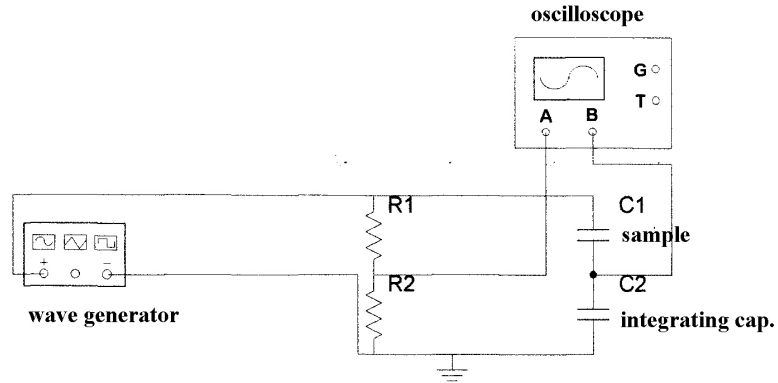


Figure 9. Schematic of a circuit for P-E loop measurements

A typical “stacked” perovskite capacitor and its P-E curve are shown below in Figure 10.

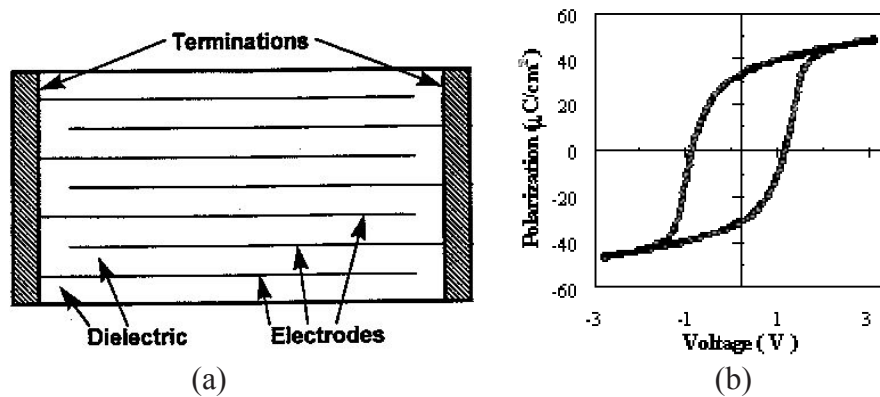


Figure 10. Schematic of typical BaTiO_3 capacitor (courtesy of Panasonic) and P-E curve for one of these capacitors

This can be used as a quality control or process-monitoring tool for defects or variations.

By measuring the C-T curve for these materials, variations in crystallite size can also be determined as shown in Figure 11.

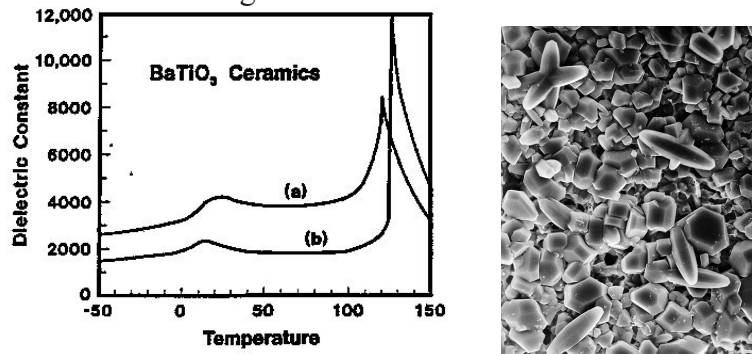


Figure 11. The variation of the relative permittivity (ϵ_r) with temperature for BaTiO_3 ceramics with (a) 1 mm grain size and (b) 5 mm grain size and a typical sample of a mixed perovskite. [12]

Experiment 2: Magnetic Phenomena

Introduction:[7]

When the early civilizations made the discovery that iron was indeed attracted to lodestone, the era of magnetism and its devices and effects was launched. After that time, the earliest device recorded was the compass, an invention of the Chinese. Since then, ferromagnetic (Fe, Ni, Co, etc.), ferrimagnetic (eg. F_3O_4), and paramagnetic materials have been used in technology applications such as magnets, magnetic tapes and disks, magnetic resonance imaging contrast enhancers, and magneto-optic memories, to name a few. Organic/molecular based materials, with p or d orbitals aiding the magnetic properties, have been a source of scientific curiosity for a number of years [9,10], but only recently have such materials become a reality.

Because the pattern of the magnetic field generated by a current loop is similar to that exhibited by a permanent magnet, the loop is regarded as a magnetic dipole with a north pole and a south pole. The magnetic moment m of a loop of area A has a magnitude $m = IA$, and the direction of m is normal to the plane of the loop in accordance with the right-hand rule. Magnetization in a material substance is associated with atomic current loops generated by two principal mechanisms: (1) **orbital motions** of the electrons around the nucleus and similar motions of the protons around each other in the nucleus and (2) **electron spin**. The magnetic moment of an electron is due to the combination of its orbital motion and its spinning motion about its own axis. The magnetic moment of the nucleus is much smaller than that of an electron, and therefore the total magnetic moment of an atom is dominated by the sum of the magnetic moments of its electrons. The magnetic behavior of a material is governed by the interaction of the magnetic dipole moments of its atoms with an external magnetic field. This behavior, which depends on the crystalline structure of the material, is used as a basis for classifying materials as **diamagnetic, paramagnetic, or ferromagnetic**. The atoms of a diamagnetic material have no permanent magnetic dipole moments. In contrast, both paramagnetic and ferromagnetic materials have atoms with permanent magnetic dipole moments, but the atoms of materials belonging to these two classes have very different organizational structures. It is the classification of these materials, the variations with processes, temperature dependence, and packaging anomalies which can be determined by studying the flux density vs. the magnetic field intensity, the inductance vs. the applied current, the inductance vs. frequency, and the relation of these to structural and chemical variations in these systems.

Theory

Without going into detail, one can describe a simple magnetic systems [8] in terms of the following: complex permeability, magnetic susceptibility, reluctance, inductance, magnetic field intensity, and magnetic flux density.

- The **complex permeability** (given as the product of the permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ H/m and μ_r = a **number** dependent upon the material used [$\mu_{\text{vac}} = 1$]). $\mu^* = \mu_0 (\mu_r' + j\mu_r'')$ (H/m), where μ_r' is the real part of the permeability and μ_r'' is the imaginary or loss constant of the permeability. [NOTE: $\mu_r''/\mu_r' = \tan$

δ_{mag} , the loss tangent or magnetic loss factor]. The **magnetic susceptibility** is defined as $\chi_m = \mu_r - 1$.

- The **Magnetic Field Intensity** or **Magnetic Field**, H (A/m), the **Magnetic Flux Density**, $B = \mu_0 \mu_r H$, (Tesla or Weber/m²). [NOTE: These are complex vector quantities as are their dielectric counterparts E and D]. The **magnetization vector** is defined as $M = \chi_m H$. [ALSO NOTE: The values of B are often given in terms of **GAUSS** (10⁻⁴ T) and H in terms of **OERSTEDS** (79.55 A/m).....**old units die hard**]. The **B-H curve** (see Figure 12) at various frequencies (also called the magnetic hysteresis curve) gives information on the incremental permeability (see experimental section) and the frequency dependence of the properties of the magnetic material.

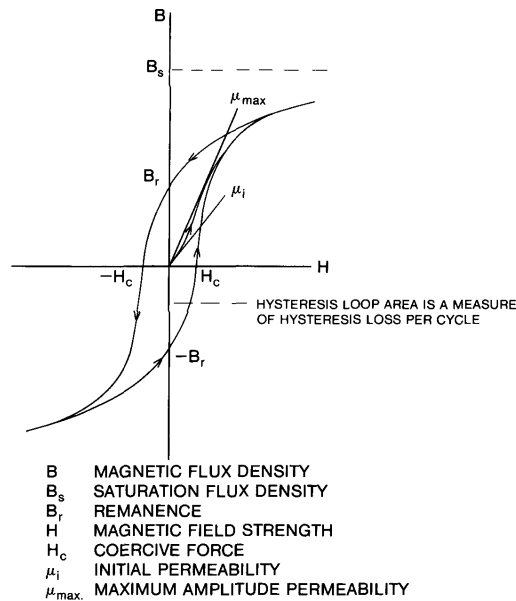


Figure 12. B-H hysteresis curve of a soft magnetic material (enclosed portion is the **hysteresis loss**).[8]

Shown below in Figure 13 is a depiction (by degree of H_c) of so-called “soft” and “hard” magnetic materials (e.g. a Mn-Zn ferrite is a magnetically soft material while ALNICO magnetic material is magnetically hard. Also shown are some actual ferromagnetic materials (note **old units!**)

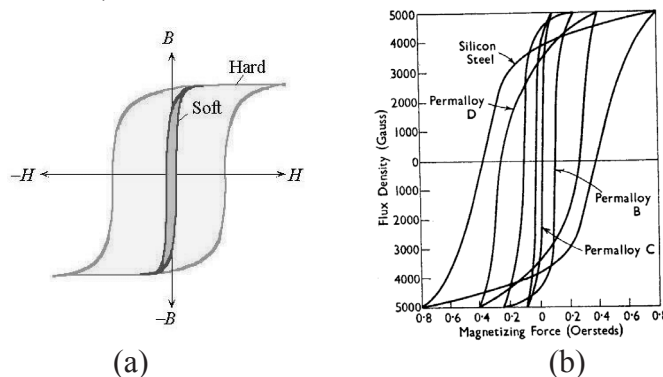


Figure 13 . (a) Magnetically soft and hard material depiction on B-H curve [4] and (b) some actual ferromagnetic materials [8]

- The **Reluctance**, $R = l/(\mu_o \mu_r A)$, where l is the magnetic path length in a material (or air) in meters, A is the cross sectional area in meters².
- The **flux**, $\Phi = Ni/(R_c + R_g)$, the subscripts c and g refer to the core and gap (air) reluctances respectively, N is the number of turns, and i is the current in the coil. Also, $\Phi = \int \mathbf{B} \cdot d\mathbf{A}$, by definition.
- The **Inductance**, $L = N^2/(R_c + R_g)$, (H), (for a single material inductor with cross sectional area A and magnetic path length l_c in the magnetic material and l_g in the air gap. The ***L-I curve*** gives information on the current dependence of the inductance (very useful for power supply design and circuit design).
- The **characteristic equation** for an inductor is defined as $V = L di/dt$, where V is the voltage across the inductor, i is the instantaneous current (rate of change of charge with respect to time) equal to the inductance times the time rate of change of the current through the inductor. With time dependence of the inductance (permeability), this is more properly written $V = L di/dt + i dL/dt$.

Some examples of types of magnetic materials are given in Appendix 2.

Experimental Procedure:

Initial Permeability, Losses & Inductance Factor

Three properties can be measured, using only an inductance meter to measure an equivalent series inductance and resistance. From these values, and a knowledge of the inductor sample, three parameters may be derived. These are:

Inductance Factor, A_L , given by

$$A_L[nH/t^2] = L[nH]/N^2$$

where L is the inductance in nH, and N is the number of turns,

Initial Permeability (the real part only), μ_i , given by

$$\mu_i = L/L_o$$

where L is the measured inductance, and L_o is the air core inductance.

Losses, described by $\tan\delta/\mu_i$, given by

$$\tan\delta/\mu_i = L_o R_s / \omega L^2$$

where μ_i is the initial permeability, $\tan\delta/\mu_i$ is the lossy component of the total reactance, ω is $2\pi f$, and other terms are as defined above.

Equipment:

Precision LCR meter.

Test Conditions: Flux Density < 10 Gauss

Frequency: as specified.

Core: 3C8 Mn-Zn Ferrite toroid (Curie temperature is relatively low for easier measurements), solid and gapped (1 mm).

The core is stabilized at room temperature (22° C) and wound with the correct number of Turns (in this case 100). Since most LCR meters have a resistor, usually 100 Ω , in series between the oscillator and the unknown to be measured, the number of turns should be chosen such that the reactance of the core is at least 10 Ω . This condition ensures that a minimum of 10% of the test signal is applied to the core. A typical core with a gap is shown in Figure 14 below.

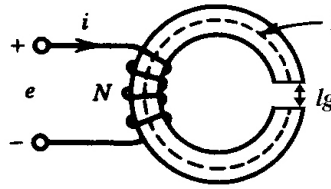


Figure 14 . Toroid with gap

With the frequency set and voltage adjusted for test conditions, the LCR meter will measure R_s and L_s . Caution: When measuring very small value reactances, be sure to test the accuracy of the measurement instrument. Perform the tests for three frequencies (1kHz, 10kHz, and 100kHz, for example). Note the differences in the inductance. Be sure to keep the voltage level the same for each frequency. The values of the inductances measured will be dependent on the gap, as indicated in the above equations. Now take the solid toroid and tap it about ten times with a small tack hammer. Measure the inductance again and note the difference. The disturbance of the grain boundaries and other nano-fracture effects are at least a part of the cause for the change. See photomicrograph in Figure 15 below. NOTE: Potting the core in thermally cured epoxy has a similar effect. Why?

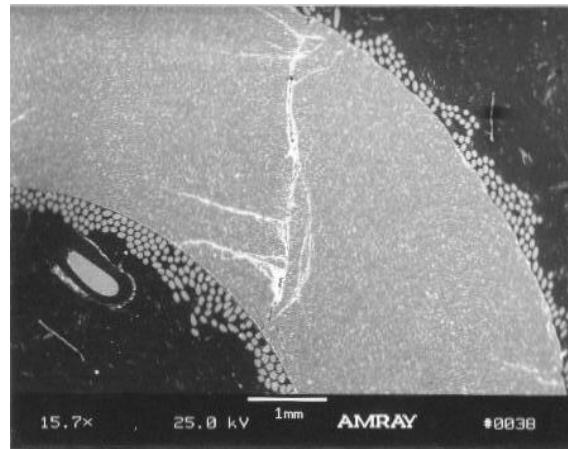


Figure 15 . SEM of cracked toroid. ΔL was $-(L_o - L)/L_o$ for defected core

Changes in Inductance versus Temperature & Curie Temperature [8]

These two tests may be performed using an inductance meter and a temperature-controlled oven. The inductance meter will measure R_s and L_s .

Equipment:

Precision LCR meter

Temperature Controlled Chamber for DUT

Test Conditions:

Flux Density <10 Gauss

Temperature as specified

Frequency: 10 to 100 kHz.

The cores to be tested are placed in the temperature chamber and subjected to two stabilizing temperature cycles, with approximately two hours at each temperature. The first inductance measurement, L_1 is made at the lowest temperature, θ_1 , after a ten-minute soak at that temperature. This procedure is repeated up to the highest specified temperature, θ_2 . A measurement made in the 20°C to 25°C range is considered the reference inductance, L_{ref} , at the reference temperature, θ_{ref} .

After measuring the highest temperature, a final measurement should be made again at the reference temperature. Both measurements of the reference inductance should be the same within the bridge accuracy. If these two readings are significantly dissimilar, more temperature stabilizing cycles may be needed to eliminate irreversible inductance changes in the samples. From the inductance reading at various temperatures, the temperature coefficient of inductance may be calculated from

$$T.C. = \frac{L_{\theta 2} - L_{ref}}{L_{ref}(\theta_2 - \theta_{ref})} = \frac{L_{\theta 2} - L_{\theta 1}}{L_{ref}(\theta_2 - \theta_1)}$$

where all terms are as defined above.

For Curie Temperature measurement, temperature is slowly increased while inductance is monitored. The temperature at which core inductance decreases to 10% of the room temperature value is the Curie Temperature.

Flux Density, Residual Flux Density, Coercive Force, & Amplitude Permeability

There are four intrinsic material parameters that can be determined from the B-H loop measurement. The core under test is used as a transformer and the relationship between winding current (H) and secondary winding integrated voltage (B) is measured. This relationship is displayed using the “X versus Y” display mode on an oscilloscope. Magnetic terms are readily expressed in electrical terms to calibrate the display in units of A/m versus Tesla (T, or Webers/m²). Once this calibration is achieved, salient points on the B-H curve may be easily obtained.

Equipment:

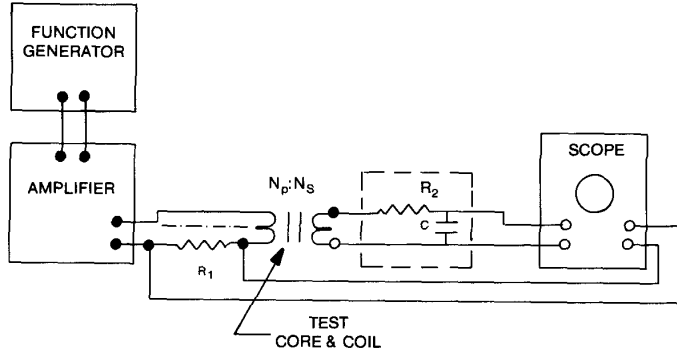
Function Generator

Amplifier

RC Network

Dual Channel Oscilloscope

The test circuit is as shown in Figure 16.



Typical Values : $R_1 = 1.0\Omega \pm 1\%$ (10 watts), $R_2 = 10.0k\Omega \pm 1\%$ (2 watts), $C = 1.0\mu f \pm 1\%$

Figure 16. B-H test setup [8] and Walker Scientific AH 400 hysteresis plotting equipment

Resistor R_1 is kept small in comparison with the inductive reactance of the wound sample. Cores must be properly installed and wound with primary and secondary winding. Field strength, H , is set by varying the current which is read as voltage across resistor R_1 . A commercial (very well designed) hysteresis plotting instrumentation from Walker Scientific is shown in Figure 16. A typical variation in B-H for Fe-Si 3 wt% at various frequencies is shown in Figure 17 below.

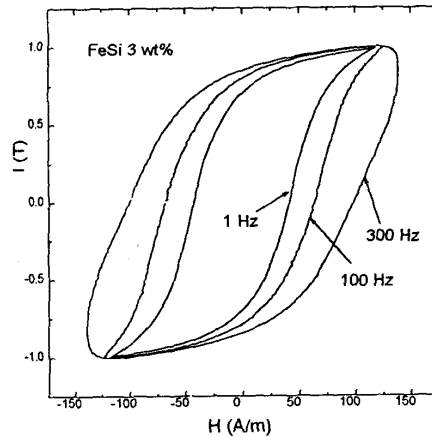


Figure 17. Hysteresis loop shape frequency in a non-oriented Fe-Si lamination.

$$H_{[Oe]} = \frac{0.4\pi nI}{l_{e[cm]}} = \frac{0.4\pi n_p V_p}{l_{e[cm]} R_1} \quad (\times 79.55 \text{ for A/m})$$

Flux density of the cores is determined by integrating the secondary voltage using the RC circuit. (NOTE: these equations are in Gauss and Oersted, with the area in cm^2 .)

$$B_{[G]} = \frac{R_2 C V_p 10^8}{n_s A_{e[cm^2]}} \quad (\times 10^{-4} \text{ for Tesla})$$

where R_2 is the integrating resistance, and C is the integrating capacitor. From the displayed hysteresis loop saturation flux density, B_s , values for coercive force, H_c , and residual flux density, B_r , may be determined once the oscilloscope is calibrated. Finally, amplitude permeability, μ_a , is given by

$$\mu_a = \frac{\hat{B}}{H}$$

where B represents peak flux density between 10 Gauss and saturation, an H is the corresponding field strength.

Power Loss

Power loss is readily measured using a Volt-Amp-Watt (VAW) meter.

Equipment:

Signal Generator

Power Amplifier

Clark Hess 256 VAW Meter

Temperature Chamber

The equipment is connected as shown in Figure 18 below.

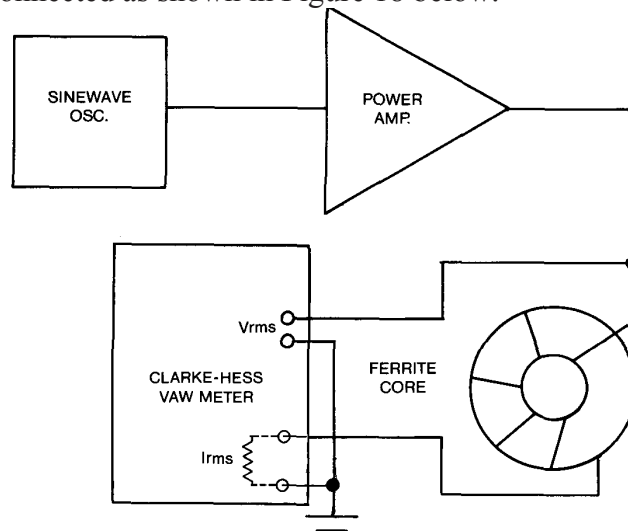


Figure 18. Power Loss test [8]

Frequency is set and voltage is adjusted to the desired flux density level, given by the relation

$$E_{[V_{rms}]} = 4.44 f n B_{[G]} A_{[cm^2]} 10^{-8} \quad (\times 10^{-8} \text{ using T and m}^2)$$

Power losses are indicated by the VAW meter in watts. Measurements are made as rapidly as possible to avoid temperature rise in the samples. Material power loss density is determined by dividing the measured power loss by the effective volume of the ferrite core. A VAW meter may also be used to measure magnetizing current, I_m . This value can be used to calculate the winding loss ($I_m^2 R_{ac}$), a part of the total power loss.

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Biography:

Dr. James V. Masi received his B.S. in Physics from Fairfield University, the M.S. in Physics from Long Island U., and the Ph.D. in Materials Science from the University of Delaware. He has over 43 years experience in industry and academia and has worked and researched in solid-state devices, liquid crystals, corrosion, semiconductors, luminescence, energy devices, electromagnetics, dental materials, and other areas of materials science. He joined Western New England College in 1980 and is presently professor emeritus of Electrical Engineering and Bioengineering. He was Executive Director of The National Center for Telecommunications Technologies (NSF Center of Excellence) from 1997-2001. He holds over 60 patents, has authored over 140 articles and papers, and has authored 3 books and 3 videotapes.

Appendix 1

Examples of polarization mechanisms, dielectric constants for solids, liquids, and gases

Example	Polarization	Static ϵ_r ' (low freq)	Comment
Ar gas	Electronic	1.0005	Small N in gases: $\epsilon_r' \approx 1$
Ar liquid (T=87.3 K)	Electronic	1.53	Van der Waals bonding
Si (crystalline)	Electronic (due to valence electrons)	11.9	Covalent solid, bond polarization
Ge (crystalline)	Electronic (due to valence electrons)	16	Covalent solid, bond polarization
Ice (crystalline)	Electronic and dipolar	2.4	Covalent oriented
NaCl (crystalline)	Ionic	5.9	Ionic solid
CsCl (crystalline)	Ionic	7.2	Ionic solid
Water (liquid)	Orientational, dipolar	80	Dipolar liquid
Nitromethane (27 C)	Orientational	32	Dipolar liquid
PVC (polyvinyl chloride)	Orientational	7	Hindered dipolar in polymer
Barium Titanate	Orientational	2600	Crystalline asymmetry

Appendix 2

Soft magnetic alloys and their basic parameters. μ_{max} $\equiv$ maximum relative permeability; H_c $\equiv$ coercive field; B_s $\equiv$ saturation magnetization.

	Composition (wt%)	μ_{max}	H_c (A/m)	B_s (T)
Fe	Fe100	3 - 50 $\cdot 10^3$	10 - 100	2.16
Fe-Si non-oriented	Fe99-96Si1-4	5 - 15 $\cdot 10^3$	30 - 80	1.98 - 2.12
Fe-Si grain-oriented	Fe97Si3	30 - 100 $\cdot 10^3$	4 - 15	2.02
Sintered powders	Fe99.5P0.5	0.2 - 2 $\cdot 10^3$	50 - 500	1.65 - 1.95
Supermalloy	Fe16Ni79Mo5	8 $\cdot 10^5$	0.5	0.80
Mumetal	Fe16Ni77Cu5Cr2	10 5	5	0.65
Permendur	Fe50Co50	5 $\cdot 10^3$	150	2.45
Ferrites	(Mn,Zn)O $\cdot$ Fe2O3	3 $\cdot 10^3$	40	0.50
Sendust	Fe85Si9.5Al5.5	1.5 $\cdot 10^3$	5	1.70
Fe-based amorphous	Fe78B13Si9 (at %)	0.5 - 2 $\cdot 10^5$	2 - 5	1.56
Co-based amorphous	Co71Fe4B10Si15 (at %)	8 $\cdot 10^5$	0.5	0.85
Nanocrystalline	Fe73.5Cu1Nb3 Si13.5B9 (at %)	10 5	1	1.2

ROBOTIC CONTROL

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Robotic Control

National Educator's Workshop

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Key Words: CIM, Computer Vision, Robotic Arm, IMAQ vision builder

Prerequisite Knowledge: Computer Integrated Manufacturing (CIM), Programming language constructs, LabVIEW

Objective: Integration of a Computer Vision System with a Robotic Arm to separate a defective object from a normal on the assembly line using pattern matching technique.

Equipment and Materials:

1. **Rhino Robot(with Robotalk Software) with Conveyor System**
2. **PC (Pentium IV) with IMAQ vision and LabVIEW**
3. **Vision Board installed in PC.**
4. **Data Acquisition Card installed in PC.**
5. **Sony XC-ST50CE monochrome camera**

ABSTRACT

In this project, we have integrated the Vision System (camera) controlled by Labview (LV), along with the Rhino Robot controlled by RoboTalk (RT), in order to control the movement of the conveyor belt to simulate a Computer Integrated Manufacturing environment. RT is a programming language, used here to control the motors of the Rhino Robot, as well as the conveyor belt. LV is a graphical software system for developing software for scientific and engineering applications. The software applications are developed using LV, RT, and the IMAQ Browser 6.0. The IMAQ vision builder is a tool for prototyping and testing image processing applications. The objective of this project is to show how to interface various software applications, to scan, determine, and discharge an object from a conveyor belt. We have demonstrated how Labview can be used to detect the presence of the object and determine if an object is acceptable, which will move the object along the conveyor belt into a waiting bucket. Alternatively, if the object is found defective the computer will send an output signal to the Mark III Controller and the robotic arm will remove the object from the conveyor belt. In this context, we are using RT, LV, and the IMAQ Browser 6.0 to integrate certain operations.

Introduction

Computer Integrated Manufacturing, also known as CIM, is a process through which several operations in a manufacturing process are systematically coordinated and integrated. Due to its many advantages, CIM is the approach that many companies are using to get to the automated factory of the future. One advantage of Computer Integrated Manufacturing is that it creates more productive and efficient manufacturing operations based on accurate, real-time monitoring and analysis of process control data. The purpose of CIM is to transform product designs and materials into saleable goods at a minimum cost in the shortest possible period of time. CIM begins with the design of a product and ends with the manufacture of that product. With CIM, the customary split between the design and manufacturing functions is (supposed to be) eliminated. This can lead to fast accurate and flexible manufacturing systems with numerous improvement possibilities and technology advancements. .

Background

In this project, we have integrated the Vision System (camera) controlled by Labview with the Rhino Robot controlled by Robotalk, to control the movement of the conveyor belt to separate a defective object from an acceptable object. LV is a graphical software system for developing software for scientific and engineering applications. RoboTalk is a programming language that will control motors of the Rhino Robot, as well as the conveyor belt. The IMAQ vision builder is a tool for prototyping and testing image processing application. The RT program will be activated once it receives 5 volts from LV, it will also have a wait command in the program that will wait to receive the logical 1 (5 volts) output to the Mark III controller from LV. Also, since RT is what allows LV to communicate with the robot, this was a main factor that led us to work with LV. We will be using the LV application in order to create our interface, which will determine if a particular object is accepted or rejected by the standards in which we have set throughout this project.

The IMAQ vision builder drives the computer vision system, along with LV. IMAQ vision builder is a tool for prototyping and testing image processing applications. To prototype our image processing application, we have built a customized program with the IMAQ Vision Builder scripting feature. The scripting feature records every step of our processing algorithm. Some of the features of the IMAQ vision builder are the image browser and acquisition windows.

The Scara Robot is controlled by a Mark III Controller, is driven by a microprocessor and operates based on the binary bit stream sent by the PC through the RS-232C (serial) communication port. The program written in RoboTalk is responsible in sending the bit stream through the serial port.

Problem Definition

In this project, have integrated the Vision System (camera) controlled by Labview with the Rhino Robot controlled by RoboTalk, in order to control the movement of the conveyor belt, which simulates a CIM environment. Our goal is to use a robotic arm to remove a damaged or defective object from a moving conveyor belt and then dispose the damaged object onto another waiting conveyor belt.

Implementation Scheme:

- Develop a virtual instrument capable of sensing the presence of an object on the conveyor belt.

- Intimate the Mark III Controller to either move the conveyor belt or not.
- Interface the output of the decision of the vision system through the digital output ports of DAQ Card fed into the controller.
- Develop a program in RoboTalk to carry out different functions involved in picking up the object, and placing the object on the conveyor belt, based on the decision provided by a Labview program. These particular details are provided in the block diagrams on the following page.

Hardware

Mark III Controller – a Microprocessor based system, which sends commands to different

motors
based on
the bit
streams
received
by it on
the serial

Labview

- On/off switch sets the arm and belt to home positions.
- Scans and determines if the items is good/bad.
- Sends an output signal to the Scara machine to control the robotic arm.
- Acceptable/reject light will light up
- Counts the acceptable/reject items
- Emergency buttons will shut down the robotic arm/belt.

communication ports.

RoboTalk	Robotic Arm/ Conveyor Belt
-Function to position the arm/belt to hard home. -Function to control the conveyor belt in a two-directional movement. -Function to control the movement of the robotic arm to grab and drop an object on the conveyor belt. -Function to receive a five-volt input from Labview.	-Receives 5 volts from Labview -Sets or returns to hard home positions -Sets conveyor belt to home positions -Controls robotic arm to retrieve and deliver objects to be discharged from the conveyor belt. -Repositions both, the arm and conveyor belt to hard home.

Camera – used to capture the images of the object and is interfaced with the PC through a vision card.

Conveyor Belt – used to move in an increment of 5 seconds or until the Mark III controller tells it to wait for a longer period of time.

IMAQ Vision Board – used to acquire the images from the camera into LabVIEW.

Software

Labview — used to display the images and send out a logical one signal to the Mark III controller.

IMAQ Vision Builder — software that works with LabVIEW to receive and compare the images in a database.

RoboTalk — a low level programming language that is being used to control the Rhino robot and to receive a logical one signal from one of the 8 pins on the Mark III controller.

Methodology

The objective of this project is to show how to interact with various software applications to scan, determine, and discharge an object from a conveyor belt. We have demonstrated how LV detects the presence of the object and determines if an object is acceptable or not, having the conveyor belt move an object into a waiting bucket if it is not acceptable. If the object is not acceptable, the computer will send an output signal to the Scara robot to inform the robotic arm that it needs to remove the object from the conveyor belt.

We have accomplished this task by using LV as an interface to interact with RT, which controls the robotic arm. LV will be displayed on the computer screen. As LV is being displayed, the Mark III controller will be controlling the conveyor belt. The conveyor belt will be running in 5-second increments. The conveyor belt will stop so that each object is seen directly under the camera view. As the camera, which is connected to the image board views the object; LV displays the images on the computer screen. LV will match this image against other objects that have been being stored in its database, and determine if the object is acceptable or not. If acceptable, the movement of the object will be continued along the assembly line until it falls into a bucket. If the object is not acceptable, LV will then send a logical one signal to RT. In RT, we have developed code that will allow RT to wait for a logical one signal from LV. The logical one signal will be passed to the Mark III controller on one of its 8 input pins. RT will be waiting for that signal from the Mark III controller. Once RT receives the logical one signal, it will execute the program. The code in RT is written in a low-level programming language. The program will have a loop so when the program finishes its execution, it will go back to the beginning of the loop, and the robot will start from the home position. It will then move from its home position to the point over the conveyor belt to remove the waiting damaged or rejected object off of the belt. Once over the object, it will lower its arm and open its grip to grab the object. Once the object is in its grip, the arm will rise and the robot will swing in the opposite direction from the moving conveyor belt. It will swing to a rolling conveyor belt. Once the arm is over the rolling belt, it will lower its arm and open its grip, allowing the rejected object to slide down the rolling belt into another bucket. At that time, the robot will then return back to its starting position. As the robot goes through moving the objects, RT will wait until the program has executed before going back the top of the loop. The Mark III controller will

give the robot 10 seconds to complete the executions and then it will move the conveyor belt again in 5-second increments. It will continue to do this until the hardware is shut off.

Results of our Investigations

We have successfully constructed a system that is capable of photographing an object and storing it in the database in the form of a template and use it as a frame of reference to compare future objects as to whether they conform to given dimensions or not. Further if the test object does not compare with the template favorably then a series of code is activated to lift the object from the conveyor belt and sent to a waiting bucket named "**Rejected**". Alternatively if the test object satisfies the requirements it is allowed to pass over the conveyor to the "**Accepted**" bucket.

The steps involved in the operation are as follows.

- Step1:** The template object is first photographed and the statistics (image processing) of this stored. A region of interest (ROI) is marked for this object, which is later, searched for in the test object.
- Step2:** The test object starts moving on the conveyor and stops below the camera. This is accomplished by the signal sent by LV to Robot controller to move the object from its initial position to under the camera. This is accomplished by the first part of the Robotalk program shown in Figure1. The camera photographs the object and searches for the ROI in the image and compares it with the template object characteristics. Figure 2 shows the front panel of the VI, which compares the test object with that of the template. Figure 3 represents the block diagram of Figure2.
- Step3:** Based on the result of the comparison a digital one is generated at the appropriate out port of the DAQ card. What this means is if a Boolean "**Yes**" is generated, a digital one is fed to a certain port of the controller. Alternatively if a Boolean "**No**" is generated a digital one is fed different input port of the controller.
- Step4:** Depending on which port of the controller is energized that particular segment of the Robotalk program is executed. One segment of the program activates the belt to move further if a test object is "**Accepted**". Alternatively if the object is "**Rejected**" another segment of the code is activated, which activates the robotic arm to lift the defective

Conclusions

During the process of our Robotic Control project, we have demonstrated how the Scara robot can be controlled with LabView to simulate certain functions of the human i.e.

- Utilizing the robotic arm to grab and release objects.
- Transporting objects to a separate location.
- Utilizing a vision system to identify and separate an acceptable object from a defective object.

By acquiring the images of objects as they move along the conveyor belt, the image acquisition sees which objects are wanted and unwanted. Knowing which objects belongs and which don't, the image acquisition system acts as a sense of sight for the Scara robot. This project has given us an insight into how to integrate hardware and software to simulate a CIM type of environment.

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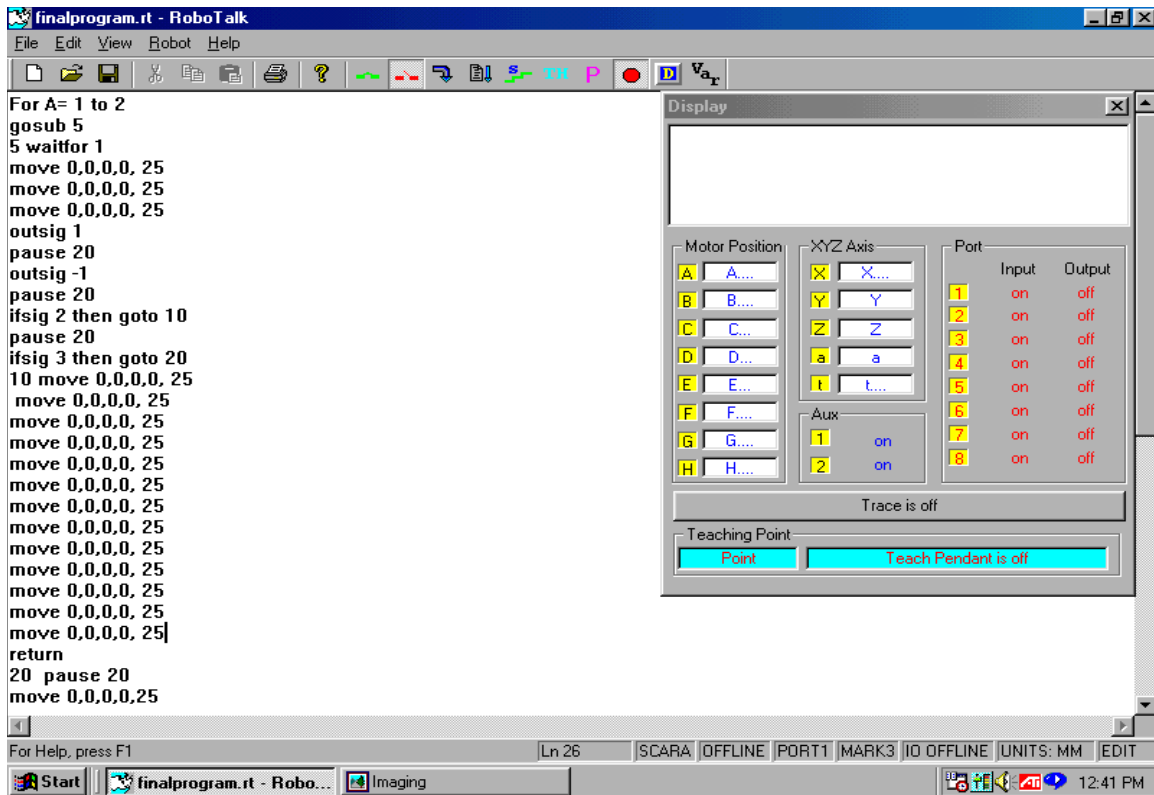


Figure 1: Psuedocode of the Robotalk program, which controls Robotic arm.

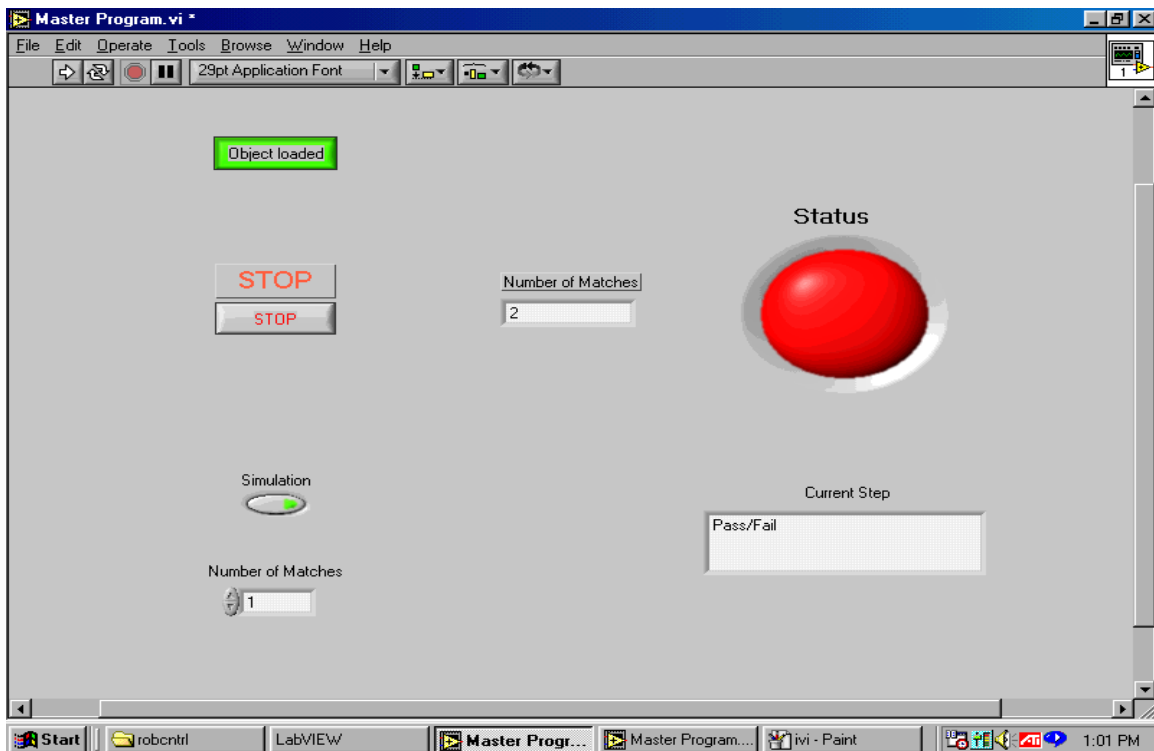


Figure 2: Front panel of the virtual instrument for image processing and robot control

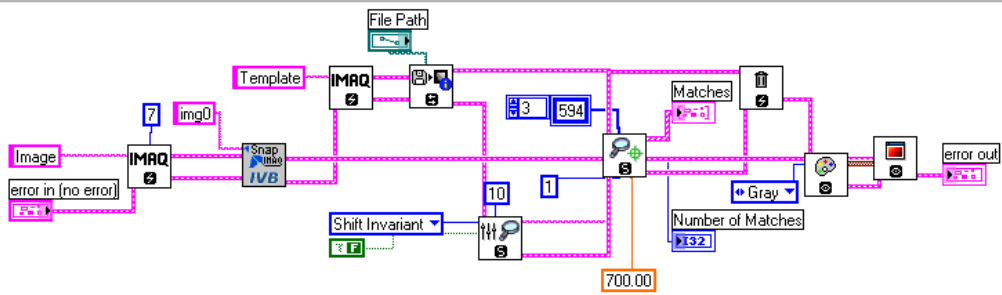
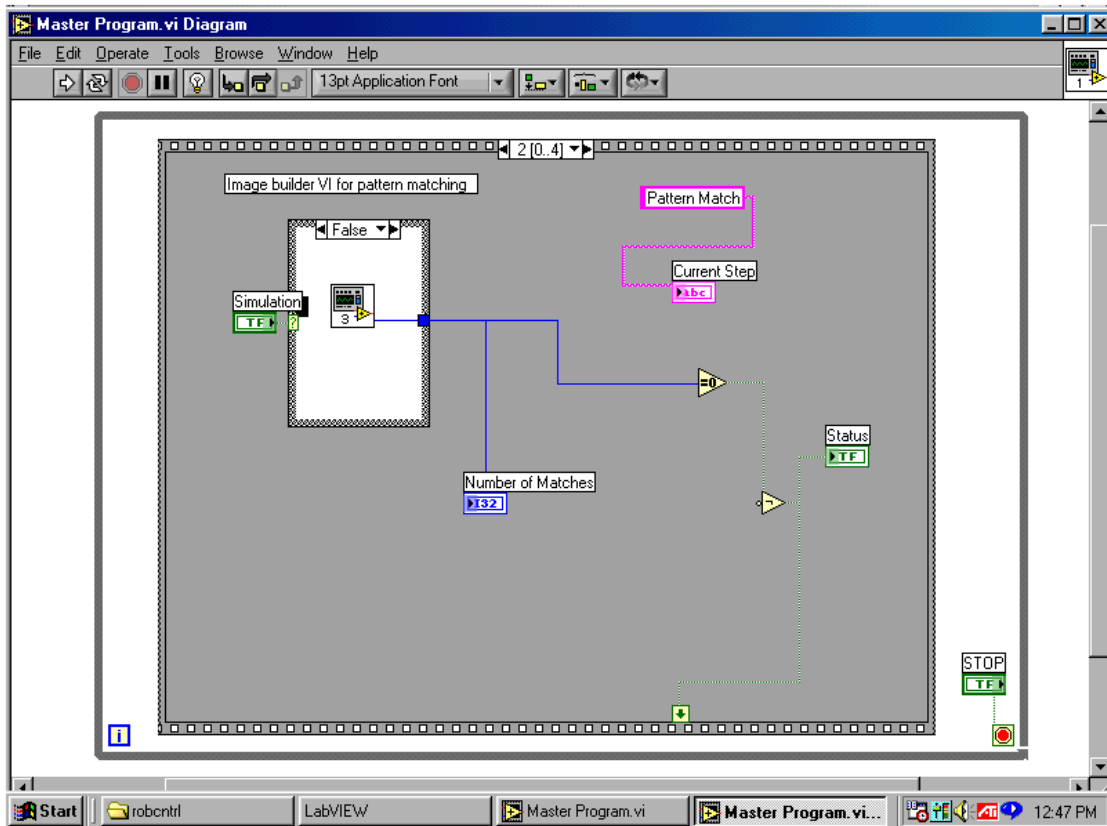


Figure 3: Block diagram of the VI for image processing and Robot control.

DETERMINATION OF PARAMETERS IN EXTRUSION PROCESS USING HOME-MADE DEVICE

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Determination of Parameters in Extrusion Process Using Home-Made Device

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Key Words: Plastic deformation, extrusion, ideal work, redundant work, frictional work, optimum die angle, visio-plasticity

Prerequisite Knowledge: Basic knowledge of material forming processes, stresses, strains, power and work in deformation processes.

Objective: Visualization of the material flow in extrusion process and influence of the die angle on the required force and power of deformation. Measuring forces in extrusion. Measuring strains using experimental method known as visio-plasticity.

Equipment:

Homemade extrusion set up (pictured below). Set-up Costs:

- a) Material app. \$50.00 (aluminum block).
 - b) Machining time for milling of surfaces, app. 50 hours (cost undetermined).
 - c) Steel compression springs for measurement of the force, app.\$26.
 - d) Linear actuator, manufacturer Grainger, Palatine, IL, cost app. \$288.
- Cost of the extrusion material: Play-Doh, different colors, cost app. \$40.

INTRODUCTION

a) Brief Description of Extrusion Process

In extrusion process round material billet is forced through a die opening by the ram. The die may be round or various other shapes. The friction between the billet and die causes the retardation of the material close to the die and surface of the cylinder, causing non-uniform material flow pattern. That pattern is highly influenced by the die angle, friction coefficient between die and material extruded and temperature of the material. There are four basic types of extrusion: direct, indirect, hydrostatic and impact [1] *.

b) Work of Deformation in Direct Extrusion

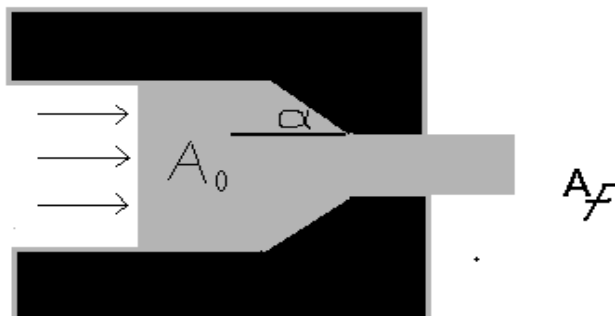


Fig.1. Direct Extrusion

Direct extrusion is the most commonly used extrusion process. It is a similar process to forcing the paste through the opening of the toothpaste tube. The basic geometry of direct extrusion process is shown in Fig. 1.

* Numbers in [] represent references at the end of the article.

In contrast to squeezing the toothpaste, the extrusion of metal requires large forces and powerful equipment.

The total work U_t required to extrude the part in direct extrusion from original area A_0 to final area A_f (or from the original length L_0 to final length L_f), is considered to be the sum of ideal work U_i (work that is needed to change a shape of material if no friction or distortion is present), U_f (work needed to overcome friction between cylinder, die and billet) and redundant work U_r , (energy spent in distortion of the billet).

That is,

$$U_t = U_i + U_f + U_r \quad (1)$$

Ideal work per unit volume u_i is computed from the properties of material (yield strength in case of perfectly plastic material) and true strain ϵ as:

$$u = Y \epsilon \quad (2)$$

True strain ϵ can be expressed as:

$$\epsilon = \ln (A_0/A_f) = \ln (L_f/L_0) = \ln R \quad (3)$$

where R is known as an extrusion ratio.

The ideal work U_i done to deform the billet is

$$U_i = u A_0 L_0 \quad (4)$$

This work is supplied by the ram force F that travels a distance L_0 .

$$\text{Work} = F L_0 = p A_0 L_0 \quad (5)$$

Where p is the extrusion pressure at the ram. Equating the work of plastic deformation (Eq. 2) to the external work done (Eq. 5), we find that

$$u = p = Y \ln (A_0 / A_f) = Y (\ln R) \quad (6)$$

c) Redundant and Frictional Work

The equation (6) pertains to ideal process without any friction and inhomogeneous deformation. Actual work is spent during the process on overcoming friction and redundant work due to the internal distortion in excess of that needed to produce the desired shape [2]. In addition to “wasting” the energy, this inhomogeneous deformation can cause internal defects and non-homogeneous properties of the final product. Naturally, it is desirable to design the dies to minimize friction and redundant work. However, determination of friction and redundant work analytically is a very difficult job.

It could be shown [2] that based on the slab method analysis, the extrusion pressure p for the small die angle α and coefficient of friction μ can be expressed as:

$$p = Y [1 + (\tan \alpha) / \mu] [(R)^{\mu \cot \alpha} - 1] \quad (7)$$

An estimate of pressure can be obtained from the total power P provided by the piston moving with the velocity V_0 and exerting pressure p on the material billet as:

$$P = pV_0 (\pi D_0^2 / 4) \quad (8)$$

In equation (7) the redundant work due to the inhomogeneous deformation is not included. Several attempts to better estimate the force and work of extrusion are made using “upper bound” approach and “slip line theory” but these are too advanced for undergraduate students [2]. These approaches are developed only for specific geometries.

Experimental investigation of the extrusion process has shown that that extrusion force is the function of the die angle. While ideal work of extrusion is independent of the die angle, force required to overcome friction decreases with increase in die angle due to shorter contact area between billet and extrusion cylinder. The amount of redundant work increases with the increase of the die angle as shown schematically in the **Figure 2**. There is an optimum angle for which the total work is minimum and the aim of the engineer is to determine that angle and design the dies with that angle. That angle can be determined only experimentally.

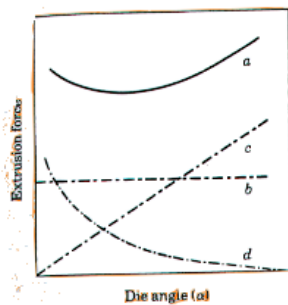


Fig. 2. Work in the Extrusion as a Function of Die Angle
a) total work; b) ideal work; c) work spent on redundant deformation; d) work required to overcome friction

EXPERIMENTAL DEMONSTRATION OF EXTRUSION PROCESS

a) Experimental set-up

While work spent on ideal deformation and on overcoming friction is easier to comprehend, for most students the redundant work is an abstract phenomenon. The best way for students to understand the mechanics of the extrusion process including material flow and the concept of redundant work is to visualize flow pattern of the material in the process. The common practice for visualizing the flow pattern is to halve the round billet lengthwise and mark one face with the grid pattern. The two halves are then placed together in the container and then extruded. They are taken apart and inspected. We have modified this approach by designing the extrusion set-up as seen in **Fig. 3**.

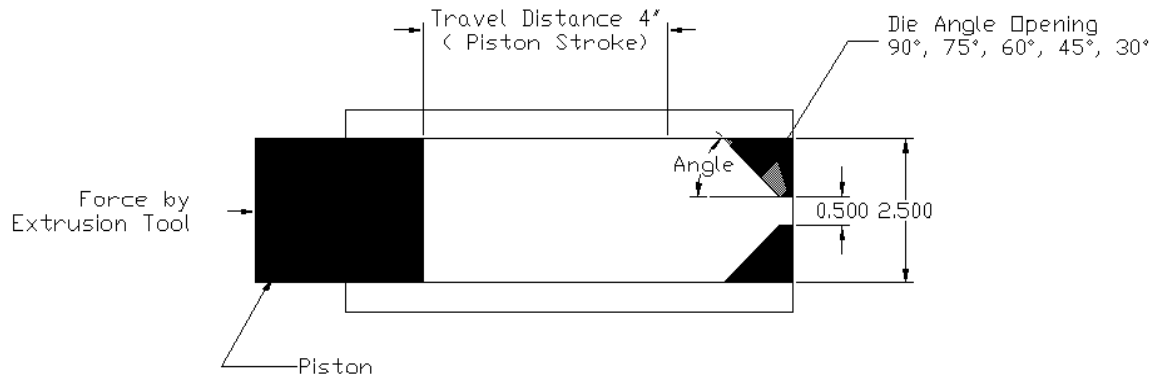


Fig.3 The Experimental Set-up

Physical dimension and the mechanical specification of the set-up are given below:

Piston:	2.5" x 1.5" (Cross Sectional Area of the Cylinder)
Die Opening:	0.5" x 1.5" (Cross Sectional Area at the Die Exit)
Cavity:	8.0 x 1.5" x 2.5"
Angle of the Die:	90°, 75°, 60°, 45°, 30°
Stroke of the Piston	4" Maximum
Maximum Force by Piston:	600 lb
Spring Constant:	58 lb/in (Located at the end of piston)
Motor:	120V, AC, 1PH, 1.4 Amps, (Maximum)
Piston Constant Velocity:	7 in/min

The force exerted on the specimen is measured by measuring the deflection of the spring. Spring constant was experimentally determined. The angle of extrusion can be changed using exchangeable dies. The cylinder was covered with the transparent acrylic plate so that the process can be observed. For the work piece material we have used "Play Doh" whose yield strength was estimated to be 0.75 lb/in². We tried several types of clay but only Play Doh was soft enough to be readily extruded using our set-up.

b) Experimental Procedure

We are conducting two sets of different experiments. In the first experiments we have tried to estimate the influence of extrusion angle on the force in extrusion. For that purpose we have used the following procedure:

- 1) The extrusion machine cavity was completely filled with the Play Doh
- 2) Different die angle openings were inserted in the following order: 90°, 75°, 60°, 45°, and 30°.
- 3) Spring deflections were recorded for each run.

c) Experimental Results

From these measurements the following results were obtained.

Die Angle Opening, Degrees	Deflection of Spring, In K = 58lb/in (Spring Constant)	Force, lb	Pressure, Psi
90	1	58	15.5
75	0.95	55.1	14.7
60	0.9	52.2	13.9
45	0.8	46.4	12.4
30	0.75	43.5	11.6

As can be seen from these results, that the force decreases with decreasing of angle of the die. We did not have enough small increments to be able to obtain increase in force for very small die angles.

Using equations (3) and (4) and measured yield strength we have estimated the ideal work necessary to change cross-section from the original to final. Comparison between the actual and ideal work give us the estimate of the friction and redundant work combined. Results are tabulated below.

Die Angle Opening Degrees	Force, lb Actual	Pressure Actual lb/in ²	Ideal Work Deformation lb*in/min	Total work lb*in/min	Efficiency Ideal vs Actual
90	58	15.5	118	406	29
75	55.1	14.7	118	386	31
60	52.2	13.9	118	365	32
45	46.4	12.4	118	325	36
30	43.5	11.6	118	304	39

The tabulations show that the total work is almost in all cases more than three time larger than the ideal work and the efficiency of extrusion process is about 30%.

In a second set of experiments, we used colored Play Doh to make specimens consisting of squares of different colors. The extrusion was done in several steps. After each step the shape and size of the deformed were observed and the diagonals of the square measured. The change in the length of the diagonals is used to compute the strain of the element. This method is called visio-plasticity. The difference between the deformations of elements in different positions is indication of the non-homogeneity of the deformation. Different angles of the extrusion dies produce different amount of redundant work. We are now in the process of developing procedure for the reporting of the results of this experiment.

CONCLUSIONS

We are developing undergraduate laboratory experiments in direct extrusion that will be used in Material Laboratory as well as demonstrated in the Manufacturing Processes class. The above described set-up is a relatively inexpensive device that can be used to introduce students to the process itself as well as measurement of force and work. The

inhomogeneity of the process and the sticking friction can be easily observed. The influence of the die angle on the total work can be estimated. Also, students will be introduced into visio-plasticity, which is a useful and relatively simple method of observation and analysis of plastic deformation.

Vision plasticity is a very successful method in explaining the concept of redundant work in extrusion and concept of redundant work in general. This powerful method is often neglected in material and manufacturing education. Experiment is similar to flow visualization methods used in fluid mechanics with possibilities for even more practical applications.

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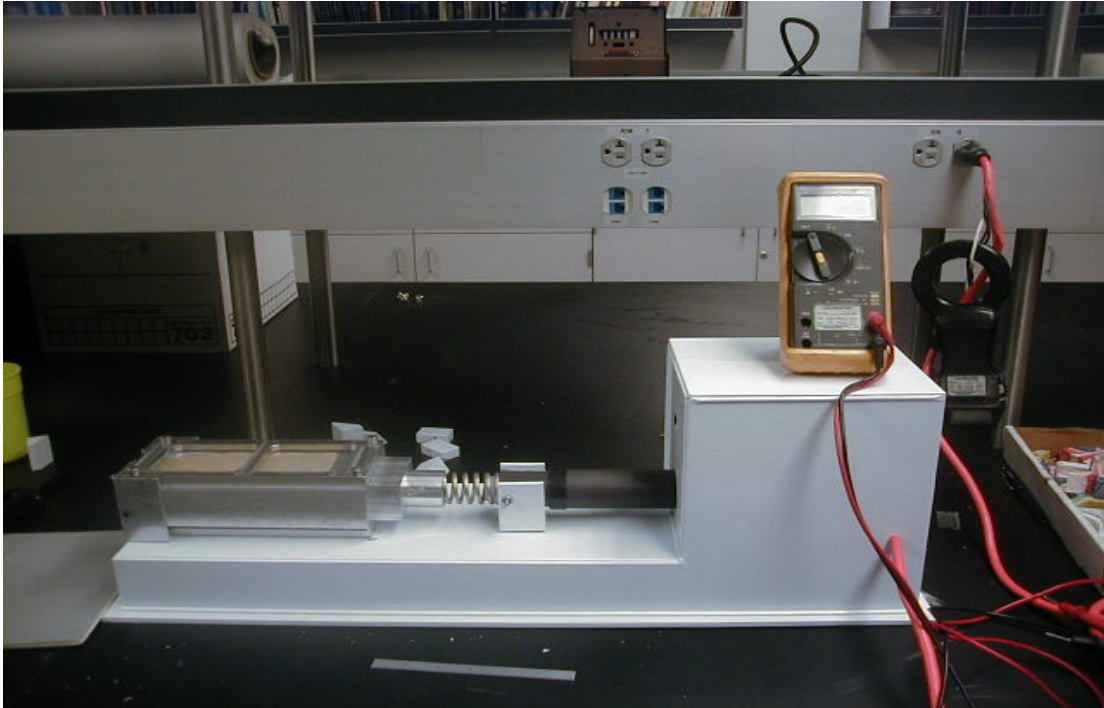
ACKNOWLEDGEMENTS

The author of this paper wishes to acknowledge the following three California State University Los Angeles students who worked on the development and manufactured this set-up: Namir Hadosmanovic, Oliver Gamage and Jose Tlaksa. Oliver worked as volunteer and Namir and Jose received one unit credit for this project.

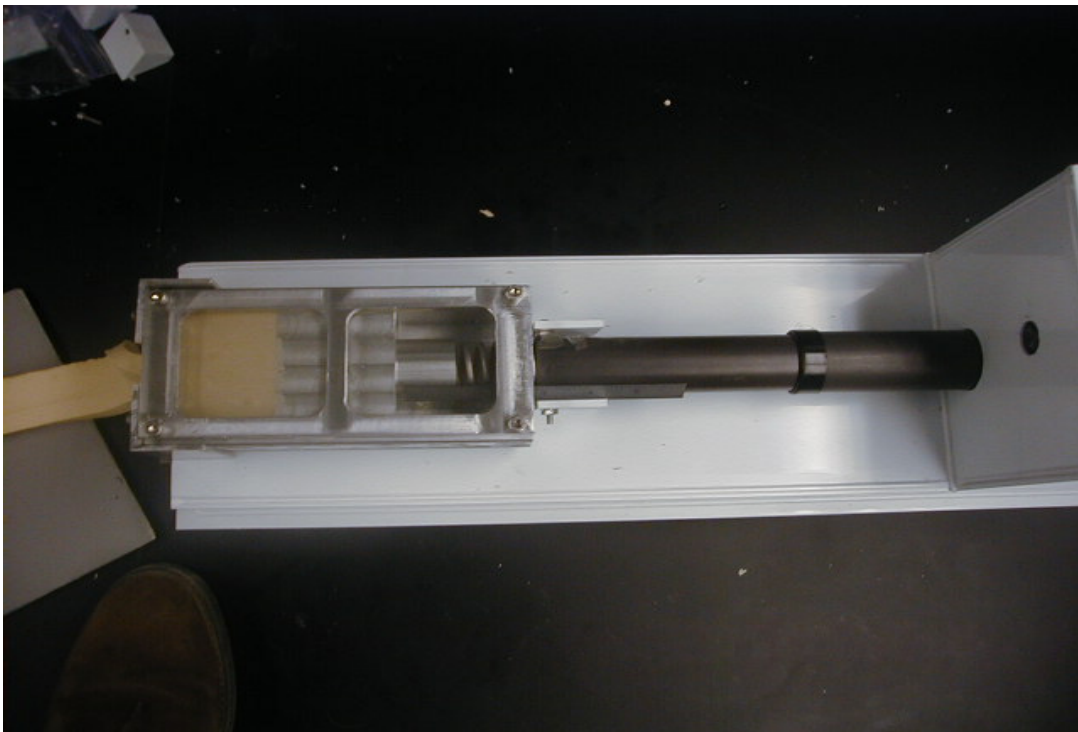
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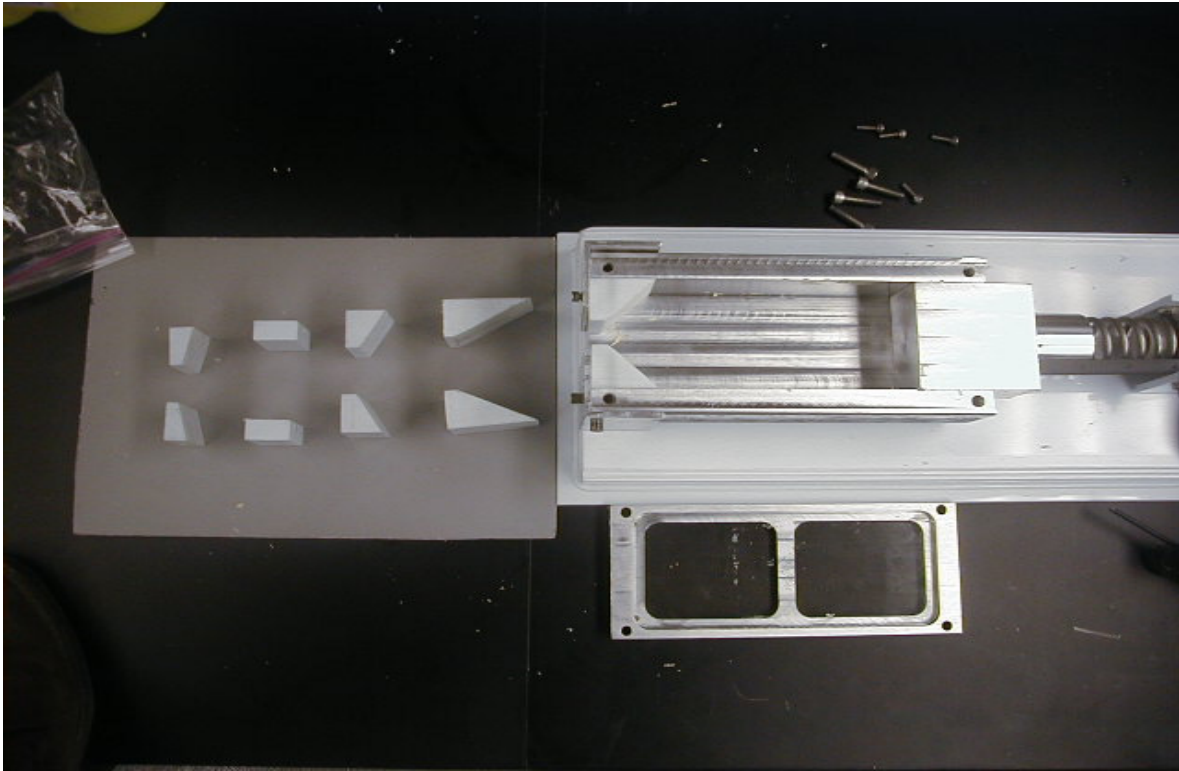
Neda S. Fabris has taught at California State University, LA since 1979. She teaches classes in manufacturing, materials, mechanics and design. She holds a Master of Engineering degree from the University of Sarajevo, Bosnia, and a M. S. and Ph.D. from Illinois Institute of Technology Chicago, and was a postgraduate researcher at *Technische Hochschule* in Aachen, Germany. Her recent awards include the Society of Manufacturing Engineers "Distinguished Manufacturing Educator" award of Region 12 (Southwest U.S.) in 1998 and the Society of Women Engineers "Engineering Educator of the Year in 2001". She has contributed several times to this conference.

APPENDIX

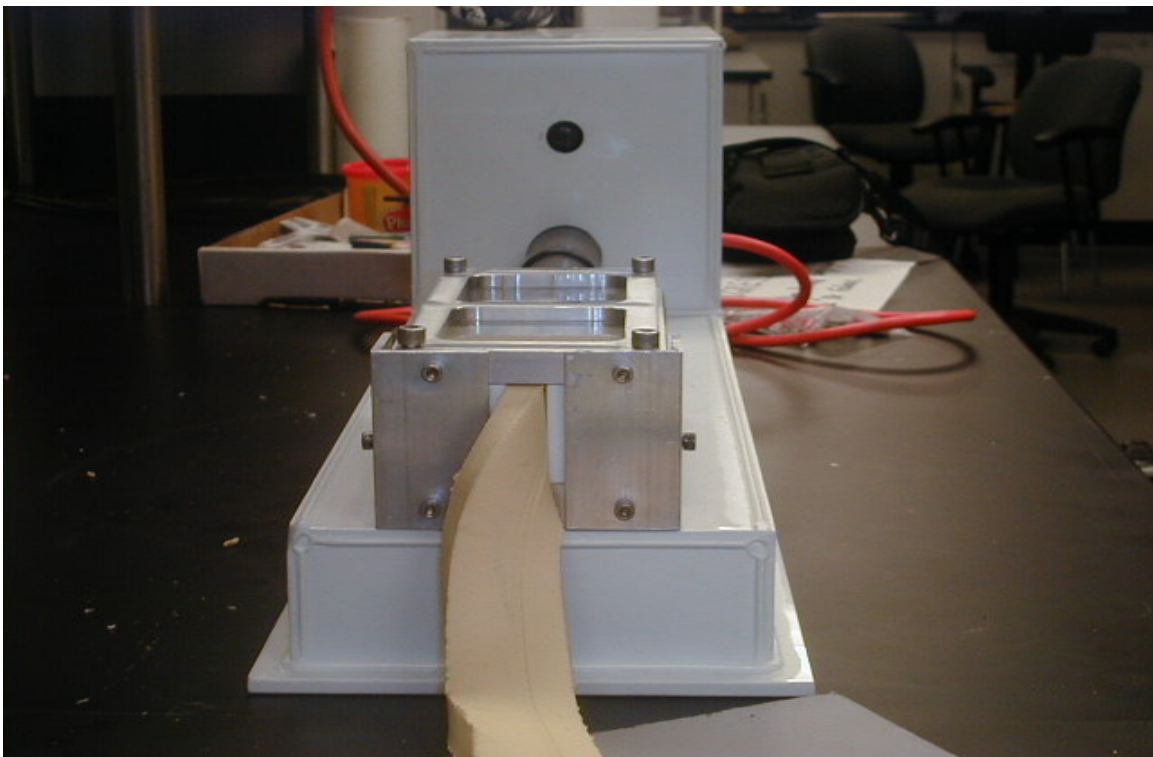


Above: Extrusion Machine with Ply-Doh in place ready to be extruded
Below: Material already extruded at the end of the stroke





Above: Extrusion tool machine with different die openings.
Below: Play-Doh being extruded by the machine.



NETWORKED ARRAY CIRCUITRY FOR POWER ALLOCATION AND DISTRIBUTION (PAD)

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Networked Array Circuitry for Power Allocation and Distribution (PAD)

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Key Words: Piezoelectric, Smart Materials, MOSFET and Actuators

Prerequisite Knowledge: Basic knowledge of electronics, electromagnetic wave propagation, smart materials, rectenna operations

Objective: To demonstrate the real circuit implementation of a power allocation and distribution network.

Procedure:

PAD Circuitry - The first element in the design of a PAD circuit is to construct a power lattice or grid similar to a screen. The power distribution grid will have vertical lines ③ referred to as columns and horizontal lines ④ referred to as rows. These lines are constructed of electrically conducting material. An actuator ⑤ is placed at the node or intersection ⑥ of each vertical and horizontal line as shown in Figs. 1 and 2.

Power to each actuator is fed from four directions. Such a system insures power being delivered to a given node if some (max. three) of the cross-links should break or be destroyed. If at least one line remains, power will continue to flow to the actuator. Even if all four break, power would still feed and control all other nodes or actuators in the membrane.

The simplest possible component for power distribution would be a variable resistor. An electronic device that can function as a simple variable resistor is a MOSFET ②. Enhancement mode power MOSFET's are classified as voltage controlled devices since the drain current I_D is controlled by the magnitude of the gate to source voltage, V_{GS} . When V_{GS} is high typically 10 volts, the drain-to-source resistance falls to a very low value (typically less than 1 ohm). I_D is also limited by the impedance of the load and the magnitude of the drain supply voltage. Applying a low voltage across the gate-to-source, simply 0 volts, causes the drain-to-source resistance to increase (typically several megaohms) and turns the MOSFET ② off. Thus one MOSFET can function as the control element to one piezoelectric displacement actuator.

Control/Address of MOSFET - The control logic used to refresh DRAM in a personal computer can be used. The memory logic voltage, 0 or 5 volts, is stored in a capacitor inside the memory. This capacitor will be discharged if not refreshed periodically. Rows and columns are energized systematically in a swept fashion to recharge the memory

capacitors. In a similar fashion, individual nodes in the power distribution grid can be addressed if the corresponding row and column are driven high. This solution implies that we have a MOSFET ② with two identical gate inputs capable of turning off the MOSFET independently. In a true **AND** gate fashion, the MOSFET will only conduct when both gate inputs (row ③ and column ④) are high. Most discrete MOSFET's used today have one gate drive. In earlier days, dual gate MOSFET's were used in RF mixers and automatic gain controlled IF (intermediary frequency) stage electronics. With the fabrication of ever increasing complex integrated circuits, the low demand for dual gate FET's has forced many manufacturers to stop making them. We were only able to obtain discontinued Motorola dual-gate depletion mode MOSFET's, the MFE201 ②. The depletion mode operation forced the control circuitry to use negative gate drive voltages in order to turn the MOSFET off.

Demo Model: A 4x4 PAD Circuit Fabrication - A 4 X 4 grid of MOSFET's was constructed by connecting all the number two gates (G2) of four MOSFET's together in every row ③. Refer to Fig. 2 for construction details. A row activation pulse will be applied to all of the G2 gates in the first row (row 0) in order to activate the first row. In addition, all of the number one gates (G1) of the first MOSFET in each row are tied together to form column 0④. A different voltage will be applied to each column to drive each actuator in the row to a desired on condition. Thus, two electrically independent layers are formed. The first layer has all of the G2 gates tied together in four rows ③. Connecting all of the G1 gates together in four columns ④ forms the second layer. It takes four row wires ③ and four column wire ④ to control sixteen MOSFET's and the corresponding actuators. This scheme can be extended to 10,000 actuators ⑤ by 100 row connections ③ and 100 column connections ④. The required number of row or column wires is given by the square root of the number of actuators ⑤.

Finally, in the design, a digital to analog converter board in a standard computer is used to turn on rows and columns wires in a round-robin fashion. A separate analog channel is used for each row or column. A Visual Basic program (Version 6.0) is used to control the digital to analog output board.

Visual Basic Control Program - First channel 8 of the DAC is changed from -5 volts (off condition) to 0 volts (on condition). Since it is tied to all of the G2 gates ③ in the first row of actuators, the row zero becomes active. Next, each channel 0 to channel 3 of the DAC is set to the voltage that the operator wants to apply to actuators 0 to 3. Each voltage level can be independently controlled because each channel 0 to 3 is tied to a separate G1 gate in row zero. Next channels 0 to 3 are sequenced off and finally channel 8 is turned off. The actuators in row 0 (the first row) are now charged to the appropriate voltage level.

Next channel 9 of the DAC (digital to analog output board) is changed from -5 volts (off condition) to 0 volts (on condition). Since it is tied to all of the G2 gates in the second row ③ of actuators, the row 1 becomes active. Next each channel 0 to channel 3 of the DAC is set to the voltage that the operator wants to apply to actuators 4 to 7. Each voltage level can be independently controlled because each channel 0 to 3 is tied to a separate G1 gate in row 2 ③. Next channels 0 to 3 are sequenced off and finally channel

9 is turned off. The actuators in row 1 (the second row ③) are now charged to the appropriate voltage level.

This sequencing continues with channels 10 and 11. When all sixteen actuators are charged, the basic program returns to channel 8 and row 0.

PAD APPLICATIONS:

Example 1: Actuator Equivalency - Piezoelectric actuators ⑤ have a wide range of voltage requirements from 10 volts to 200 volts and generally low current requirements. In general, they are voltage-controlled devices with an equivalent circuit of capacitors in series with resistors. The equivalent circuit is dominated by the capacitance value.

Our PAD design takes advantage of the capacitance of the actuators ⑤ by pulse charging them during a short on cycle. If the actuator has a low level of leakage (a very good capacitor), it will maintain that voltage until it is recharged by the next on pulse. However, an ideal capacitor is a dual edged sword. If the actuator does not have sufficient leakage, then it can not drain the charge when the voltage across it needs to be reduced. In that case, a parallel resistor would have to be placed across the actuator.

To simulate the actuators for our test, we selected a 1.5 μF epoxy dipped solid tantalum capacitor. It was a standard value closest to a typical value of 1.8 μF used by others. The capacitors used in the laboratory typically had one to two microamps leakage at 10 volts. This equates to an internal shunt resistance of 5 to 10 megaohms across the capacitor. One time constant (RC) is approximately 7.5 seconds. Therefore, it can take 45 or more seconds to discharge the capacitor from 10 volts to near several hundred millivolts.

TEST RESULTS OF PAD CIRCUIT:

Because only depletion-mode dual gate MOSFETs ② were available, negative voltages had to be applied to control the MOSFETs and actuators ⑤. The analog output board was capable of supplying negative as well as positive voltages. With -5 volts on G1 and -5 volts on G2 the MOSFET should be turned off. With the MOSFET turned off 15 millivolts was measured across the capacitor when the power grid was set to 10 volts. This voltage is developed by the leakage current flowing through the capacitor in series with the MOSFET leakage. The addition of a voltmeter or oscilloscope to measure the voltage across the capacitor would allow it to further discharge to a lower value. After a minute or two the voltage across the same capacitor (originally 15 millivolts) falls to 6 or 7 millivolts. In any real world deployment of a PAD system, designers will have to factor in some residual voltage remaining across the smart material due to leakage current. A better MOSFET may reduce that to an acceptable level, but it will always exist.

This design of a Power Allocation and Distribution (PAD) system can have a wide variety of practical applications. It consists of six layers that are electrically isolated from each other. Its power handling applications are only limited by the size of the power MOSFET's that can be incorporated in the construction of layer 2 as described below. It is possible to parallel several MOSFET's to increase the power rating of each cell. It can

be used as an input sensing system or an output distribution system. It is capable of greatly simplifying the complexity of wiring many actuators or sensors. The schematic shows an n-channel dual gate enhanced mode MOSFET as the main component; however, the system can be inverted by using p- channel MOSFET's for other applications.

The system consists of six layers with the following significant features:

- ① Layer 1 Common or ground layer. An electrically conductive common layer that can be ridged or flexible. It is shown with a ground symbol in the diagrams.
- ② Layer 2 Dual gate MOSFET layer. This special device is available in an enhanced mode or depletion mode if the application would allow positive and negative control voltages. The device selected would have to have appropriate voltage and current ratings for the application.
- ③ Layer 3 Row grid layer. This layer is electrically separate from all other layers. Each row element is separated from all other row elements but electrically connected to gate 2 of the MOSFET's in the row.
- ④ Layer 4 Column grid layer. This layer is electrically separate from all other layers. Each column element is separated from all other column elements but electrically connected to gate 1 of the MOSFET's in the column.
- ⑤ Layer 5 Device layer. This layer can be fabricated with piezoelectric actuators or sensors, magnetostrictive actuators or sensors; as well as, other devices. This layer contains the device you are controlling as an output or read as an input.
- ⑥ Layer 6 Interconnected surface grid. This final layer is electrically conductive and flexible. It is the input/output surface being controlled or read. This surface will contain individual cells of unlimited small or large size that can be addressed and individually controlled or read.

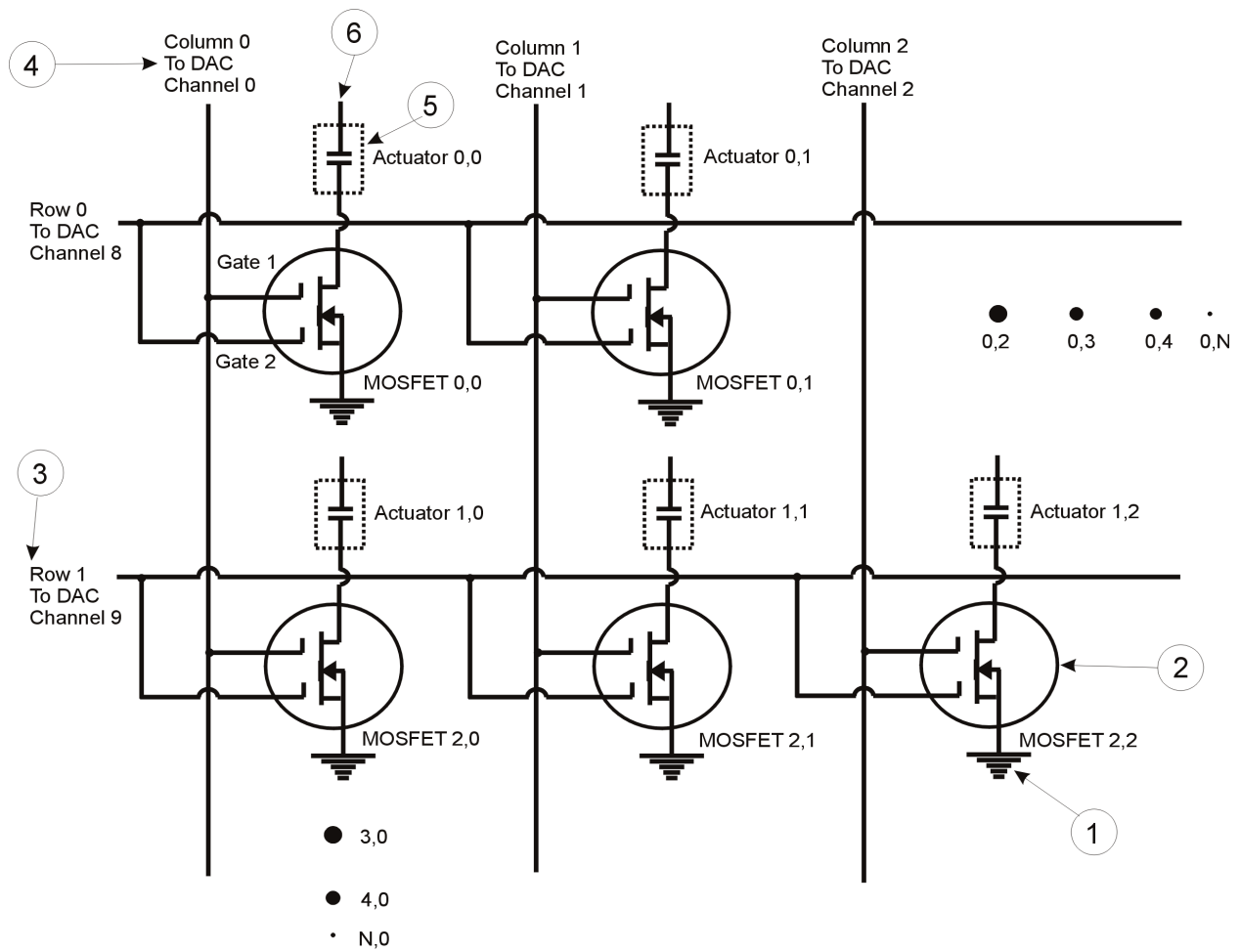


Fig. 1 Schematic of Power Allocation and Distribution (PAD) Circuit

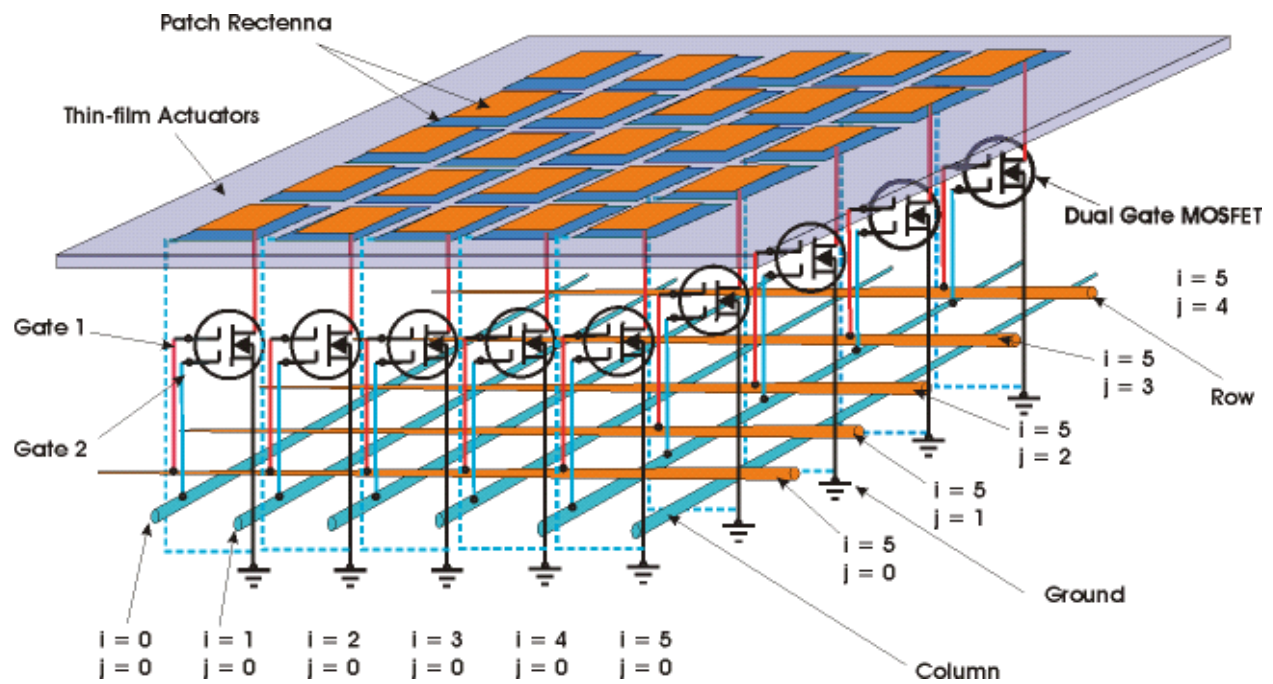


Fig. 2 Three Dimensional Layout of PAD circuit

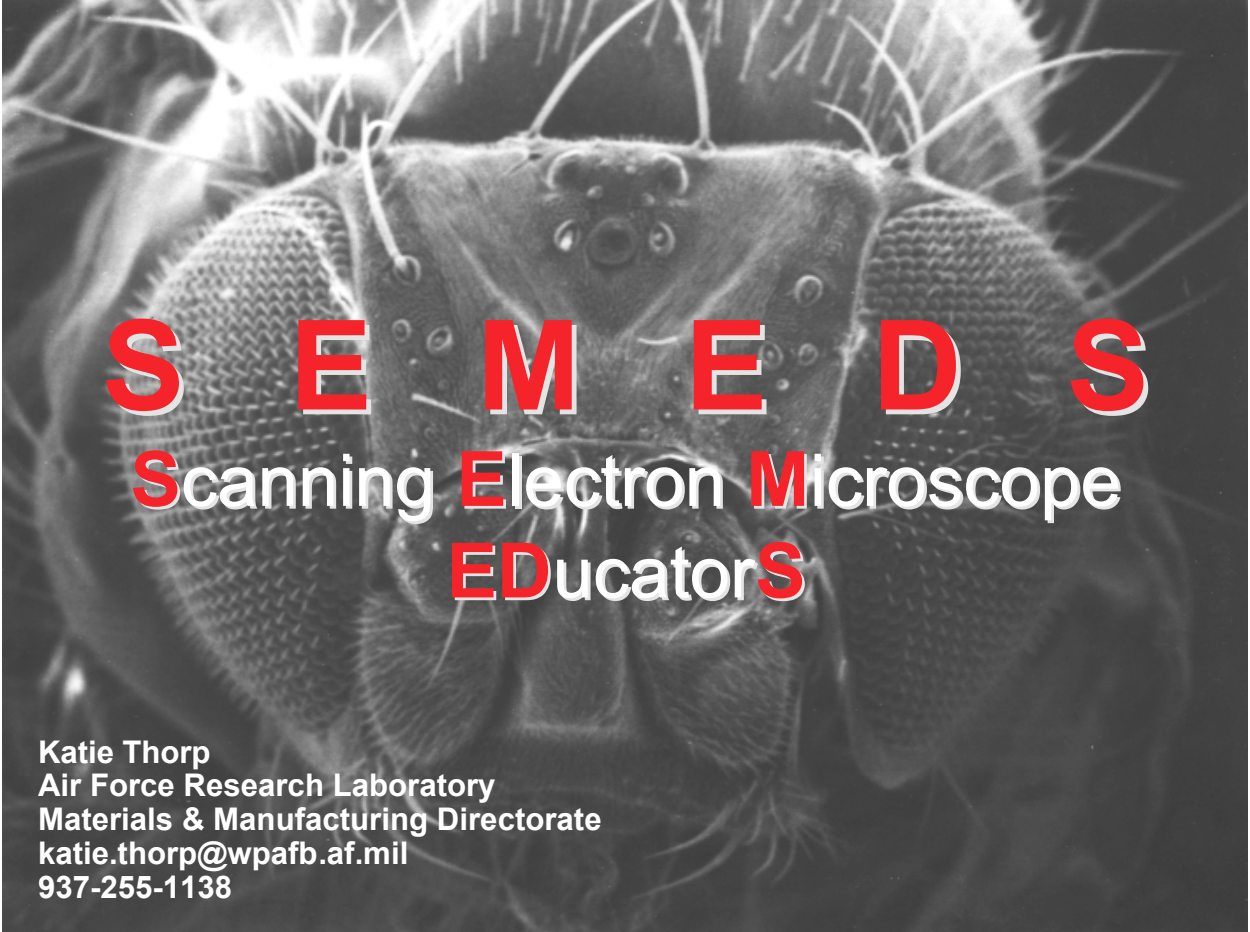
**SEMEDS: SCANNING ELECTRON MICROSCOPE
EDUCATORS
A MOTIVATIONAL SCIENCE PROGRAM
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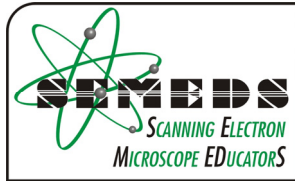
Katie Thorp

A high-magnification scanning electron micrograph (SEM) of a fly head, showing the intricate details of its compound eyes, antennae, and facial structure. The image is in grayscale, with the fly's head centered and slightly tilted. The text "SEMEDS" is overlaid in large, bold, red letters with a white outline, and "Scanning Electron Microscope Educators" is overlaid in smaller, bold, red letters with a white outline.

SEMEDS

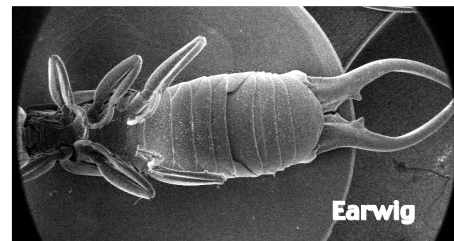
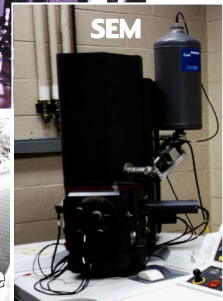
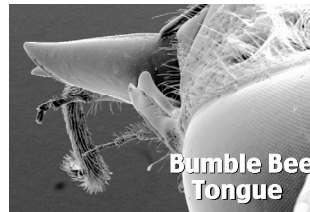
Scanning Electron Microscope Educators

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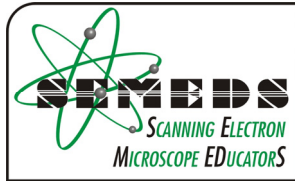


Program Definition

- Motivational science program
- Established in 1991
- Air Force Research Laboratory Materials & Manufacturing Directorate
- Junior and senior high school students and their teachers
- Learn about and use latest technology in scanning electron microscopes



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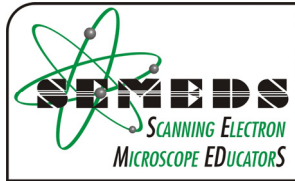


SEMEDS Goals

- Demonstrate that science is fun
- Show that scientists and engineers are real people
- Identify career opportunities in science and engineering
- Provide teachers with resources in electron microscopy
- Demonstrate how science is used in a working environment
- Establish a connection between the classroom and the real world



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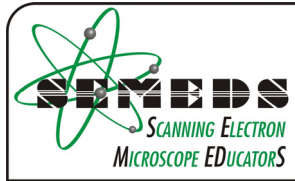


Program Description

- Rare opportunity for students and teachers
- Hands-on experience with the latest high tech equipment
- Fun and informative
- Students meet and work with scientists and engineers
- Run by volunteers
- Conducted at the end of the work day

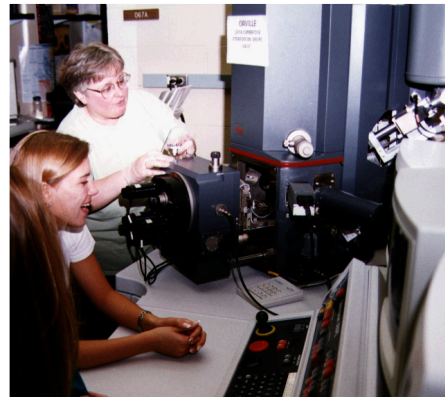


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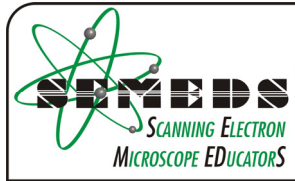


Program Organization

- Informational meeting for teachers at start of school year
- Teachers meet the volunteers
- Program organization discussed
- Teachers sign up for sessions
- Teachers taken through a typical session
- SEMEDS representative contacts teacher several weeks prior to scheduled session to confirm



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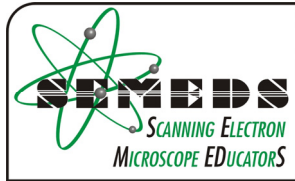
Where We've Been

- A Challenger Center survey revealed teachers desired working with SEMs above any other scientific instrument
- Challenger Center contacted the Materials & Manufacturing Directorate
- Meetings were conducted and a formal program was implemented
- Students responded positively to hands-on work *only*
- Program has averaged 22 sessions (approximately 400 students) a year since inception in 1991



Ladybug underside

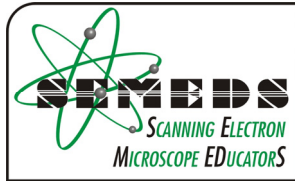
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Where We're Going...

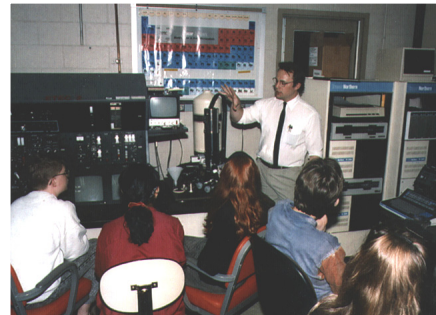
- Tech Trek - SEMEDS on wheels
- Established in 1999 to increase exposure and impact of SEMEDS
- Staffed by full-time educator from AFRL-funded WPAFB Educational Outreach Office
- Program has impacted over 12,000 students since inception in 1999



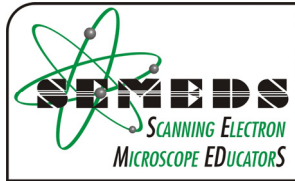


Session Description

- Teachers arrive with students and are greeted by SEMEDS Volunteers
- Volunteers talk briefly about their educational background and respective jobs
- Group is given a 15 minute talk on what makes the microscopes work and what they are used for



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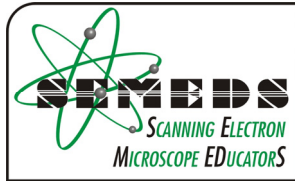


Session Description

- Group goes to lab (4-6 students per SEM)
- Volunteers explain how to operate the microscopes
- Volunteers stand back and let the students drive
- Typical session lasts about 1-2 hours
- Students are encouraged to explore
- Specimens are provided



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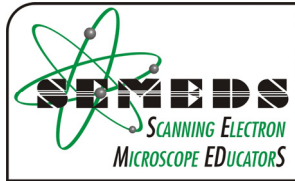


Program Results

- Excites teachers, parents, and STUDENTS
- Motivates students to consider science as a career
- Increases exposure of AFRL to local region
- Increases volunteerism

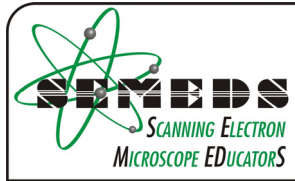


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Welcome to SEMEDS Scanning Electron Microscope EDucatorS

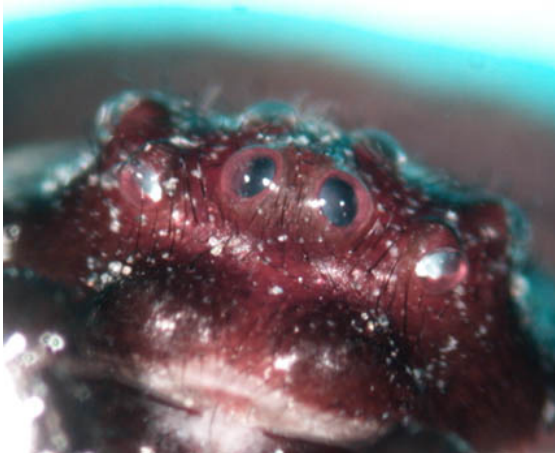
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Light Microscope

- 5-1000x
- Two dimensional - limited depth of focus

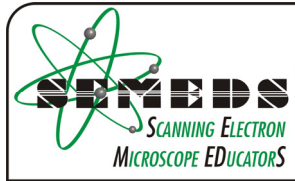
Black Widow Spider Eyes



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Cost
\$10 – \$20,000



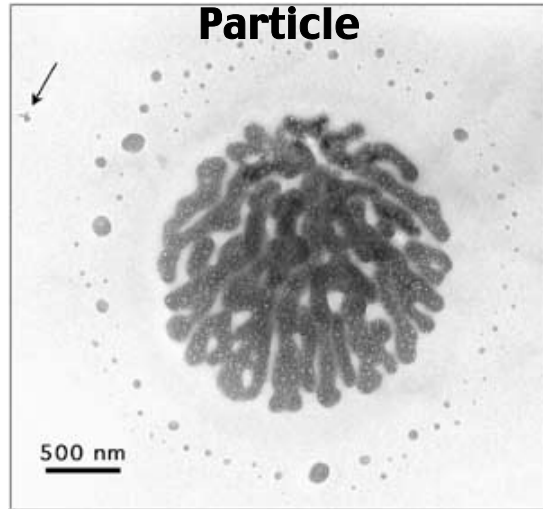
Transmission Electron Microscope (TEM)

- 250-500,000+
- Look through very thin samples

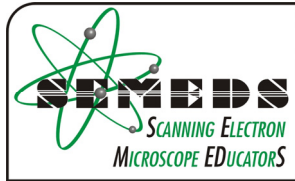


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Ammonium Sulfate Particle

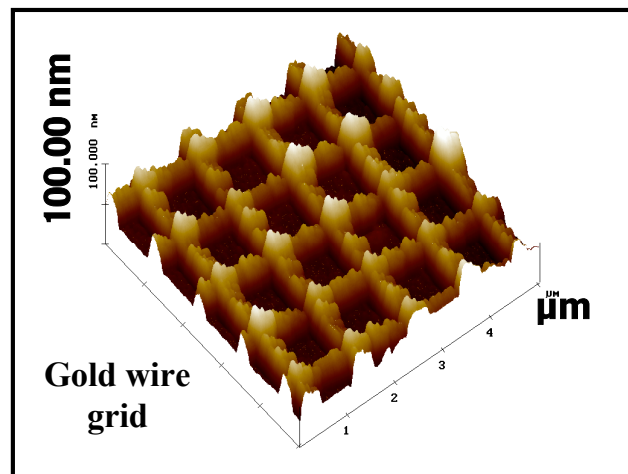


Cost
\$750,000–2,000,000



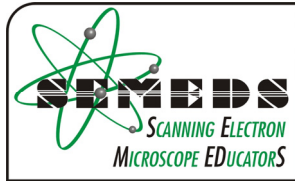
Atomic Force Microscope (AFM)

- 20,000-500,000+
- Fine surface contours

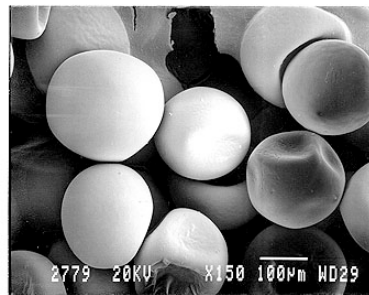


Cost
\$50,000 – \$250,000

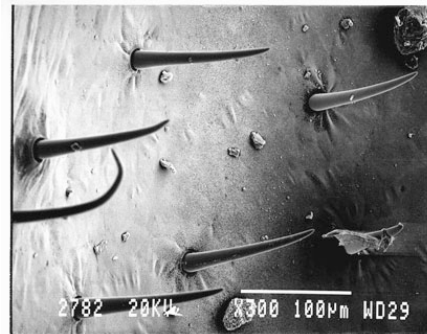
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Scanning Electron Microscope (SEM)



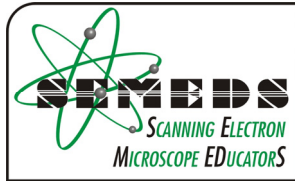
Shrimp Eggs



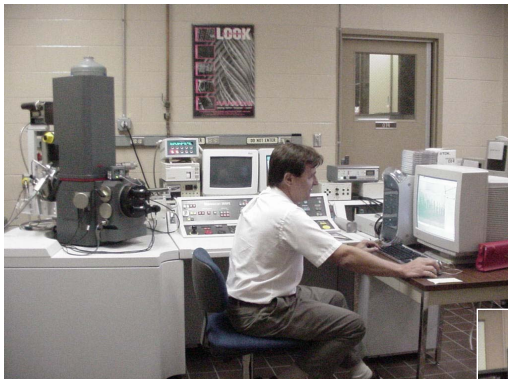
Bug Wing

Cost
\$75,000 – \$1,000,000

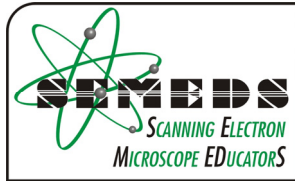
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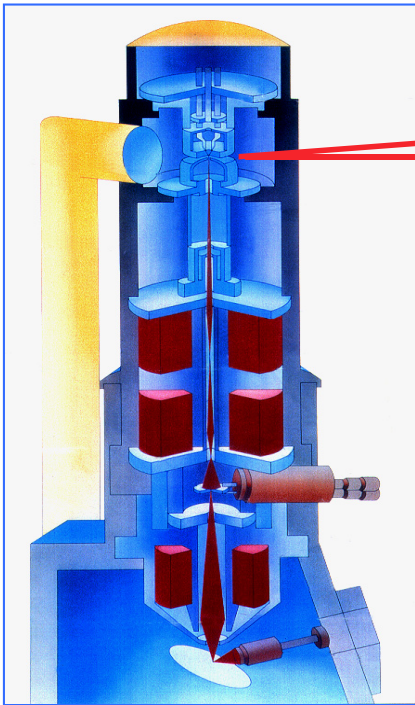
Scanning Electron Microscopes



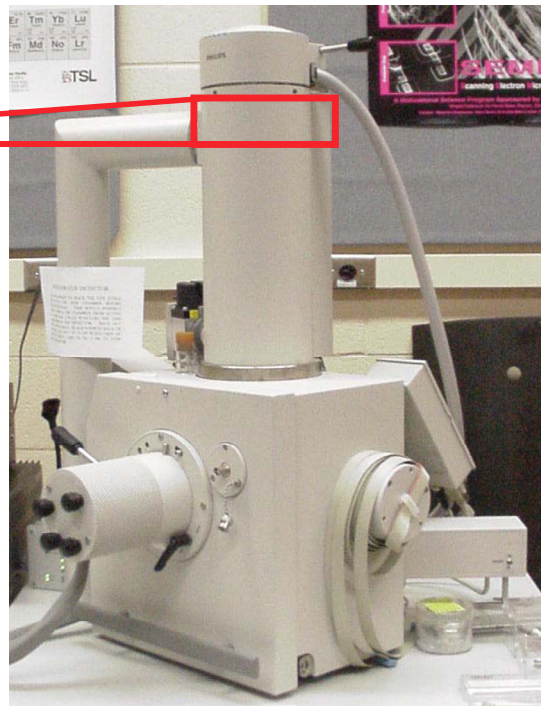
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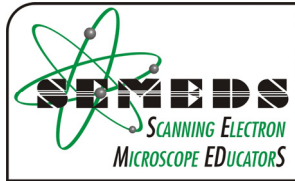


Electron Gun

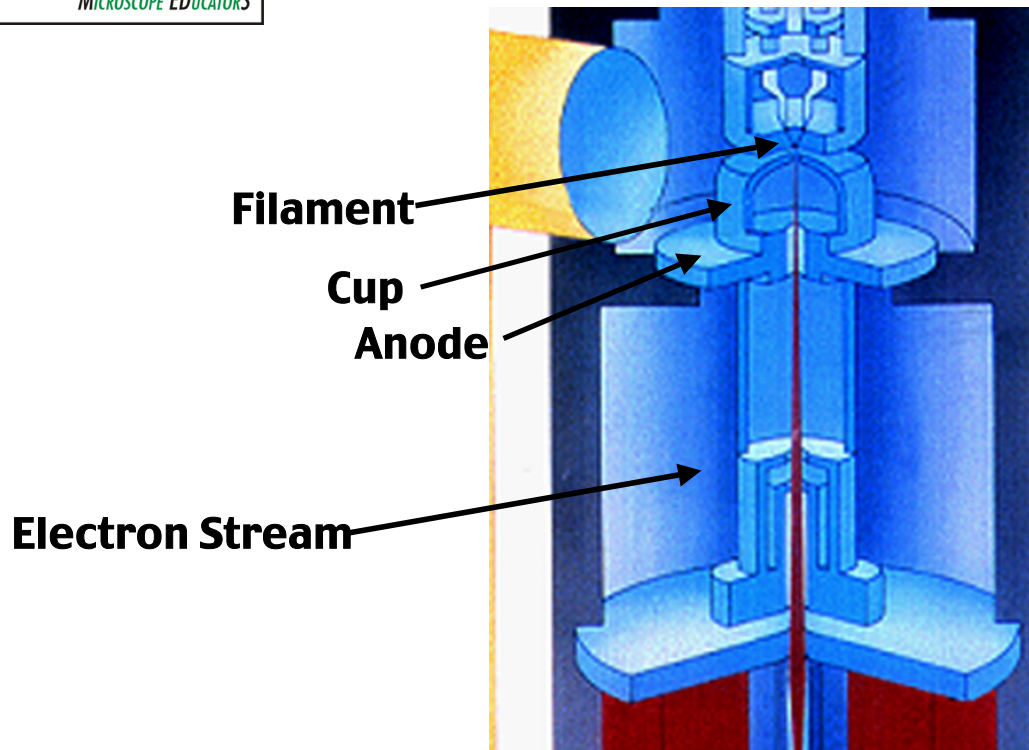


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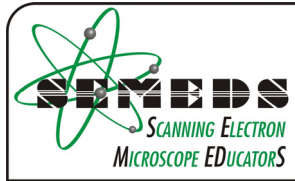




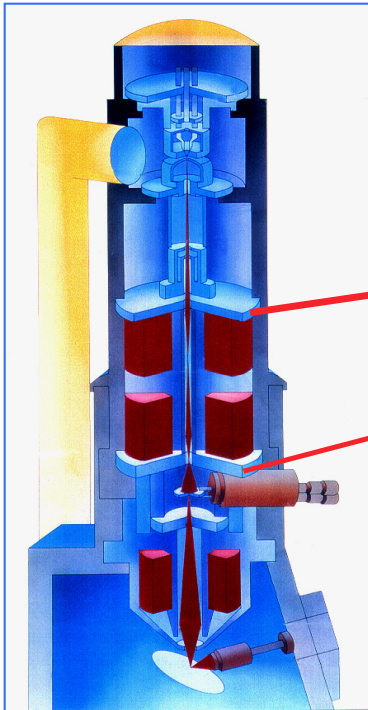
Electron Gun or Filament



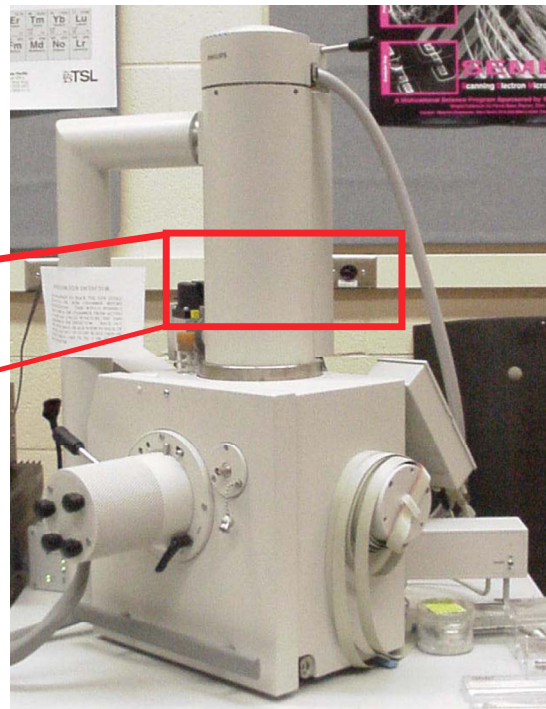
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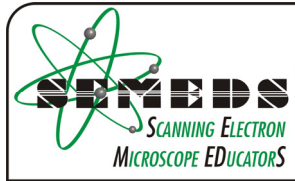


Electromagnetic Lenses

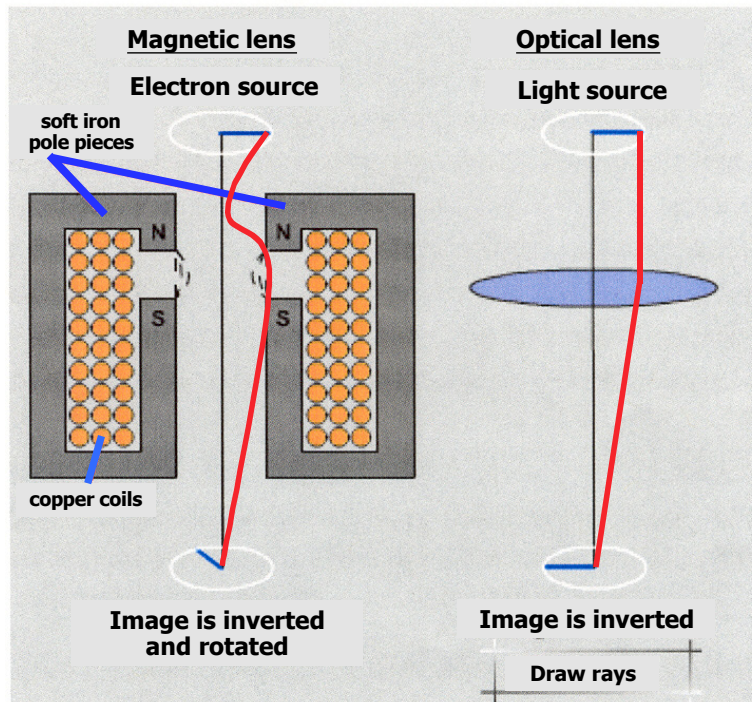


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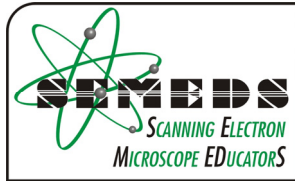




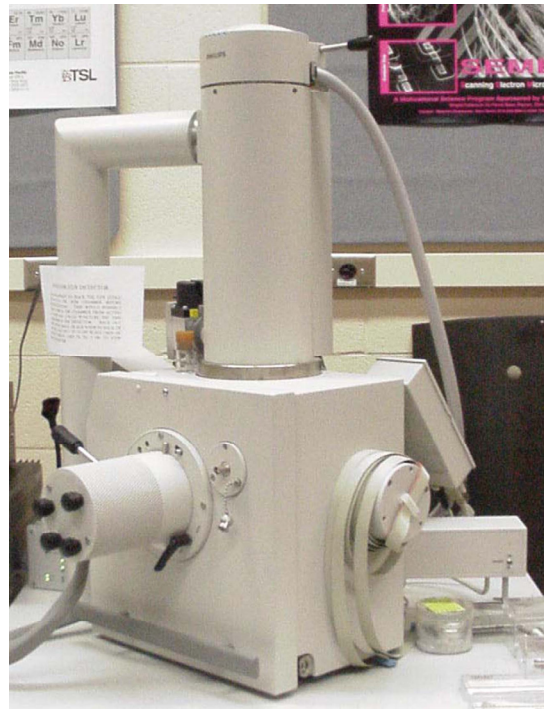
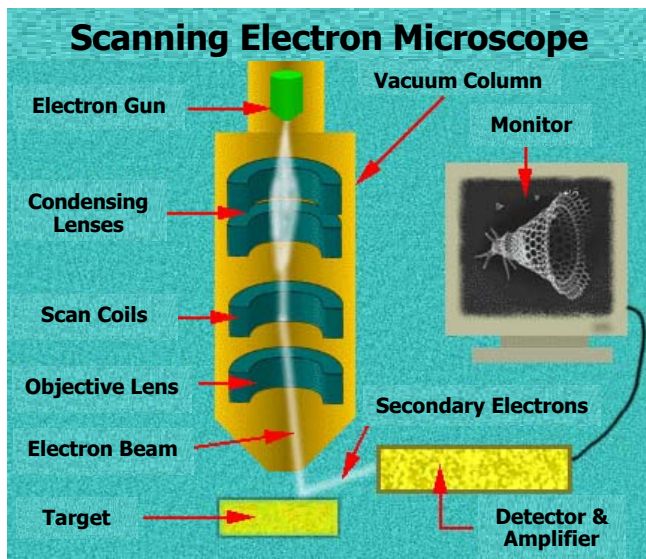
Electromagnetic Lenses



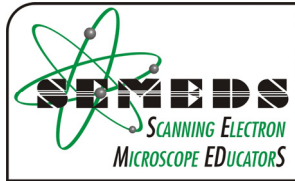
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SEM Construction

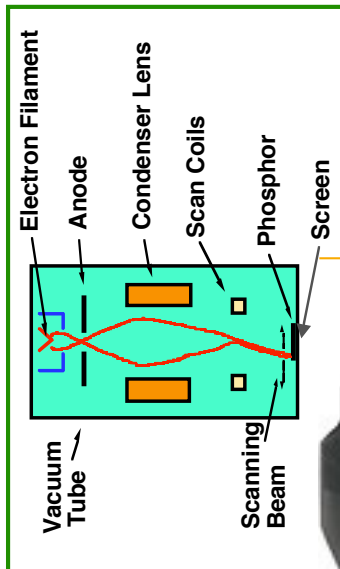


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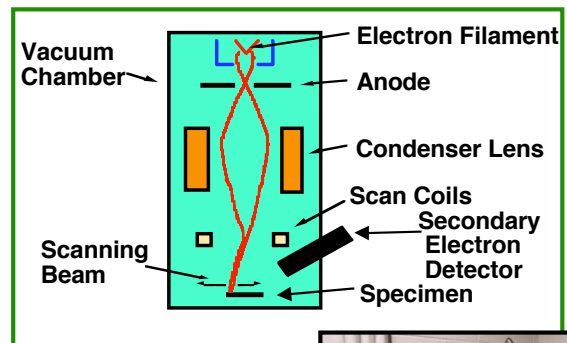


Television vs. SEM

Television

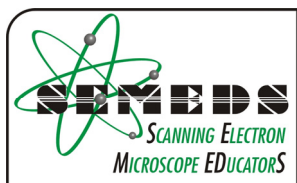


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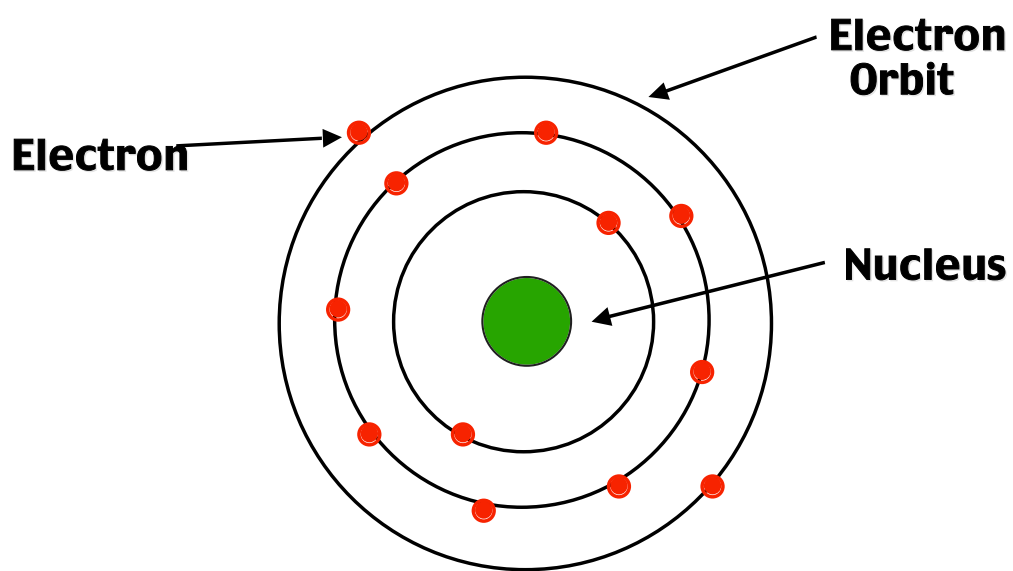


SEM

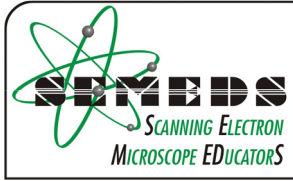




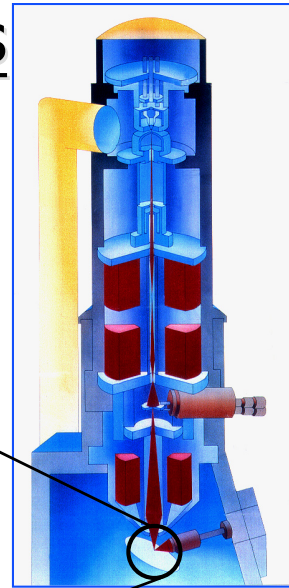
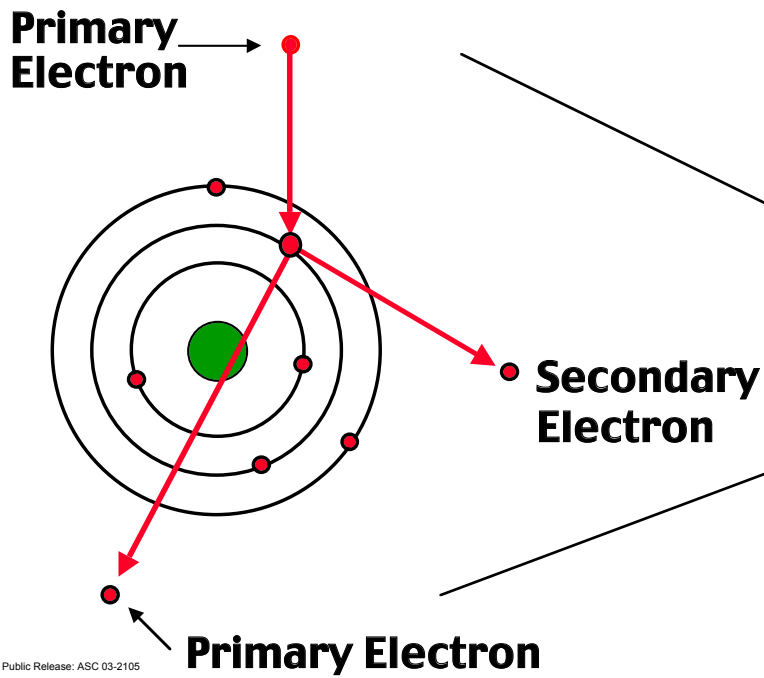
Bohr's Atom



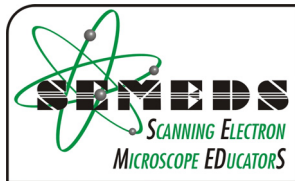
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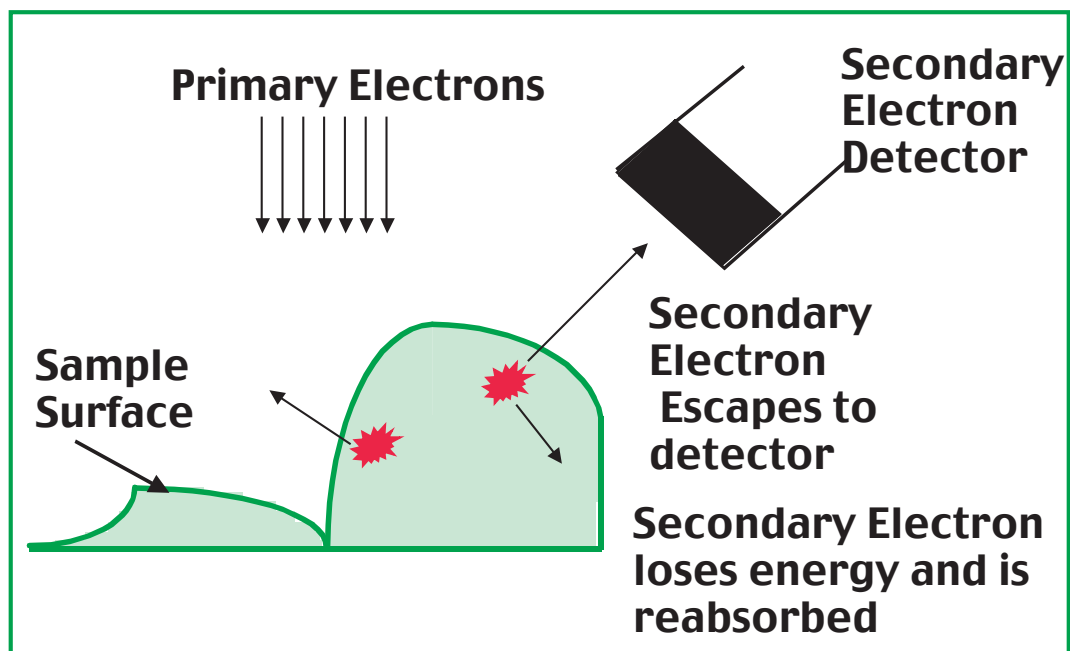
Secondary Electrons



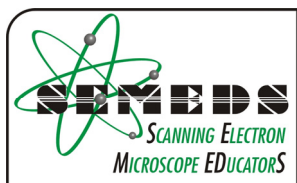
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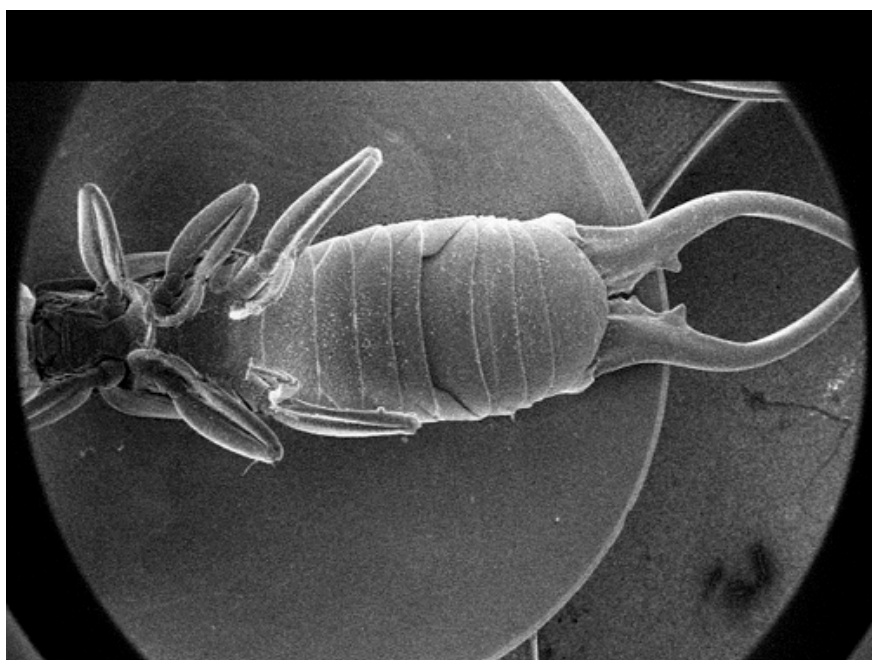
Secondary Electron Detection



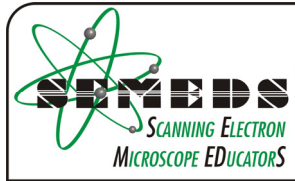
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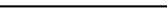


2.00 mm —————



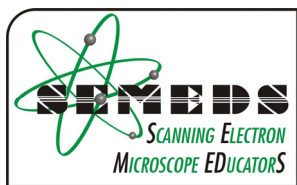
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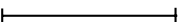


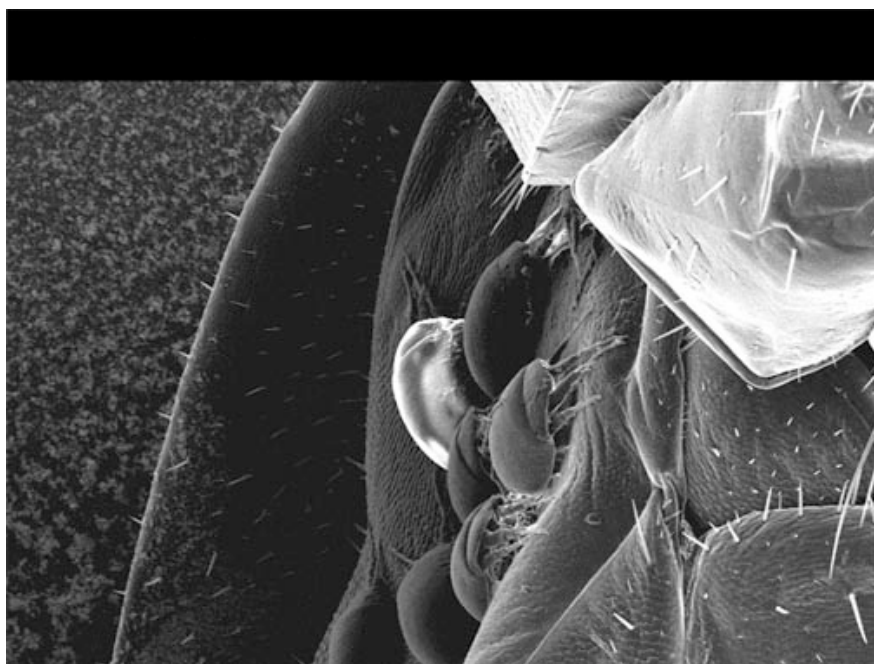
1.00 mm 



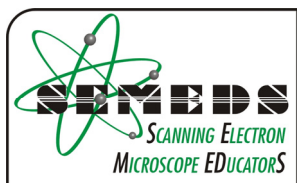
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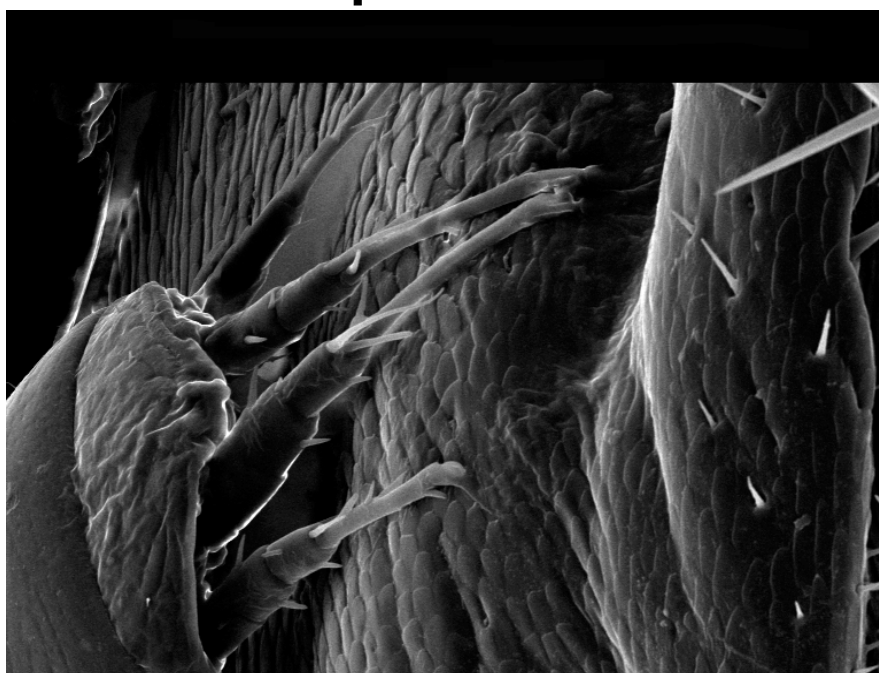
200 μm 



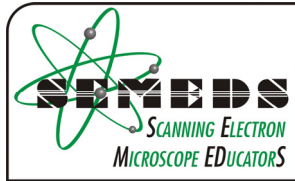
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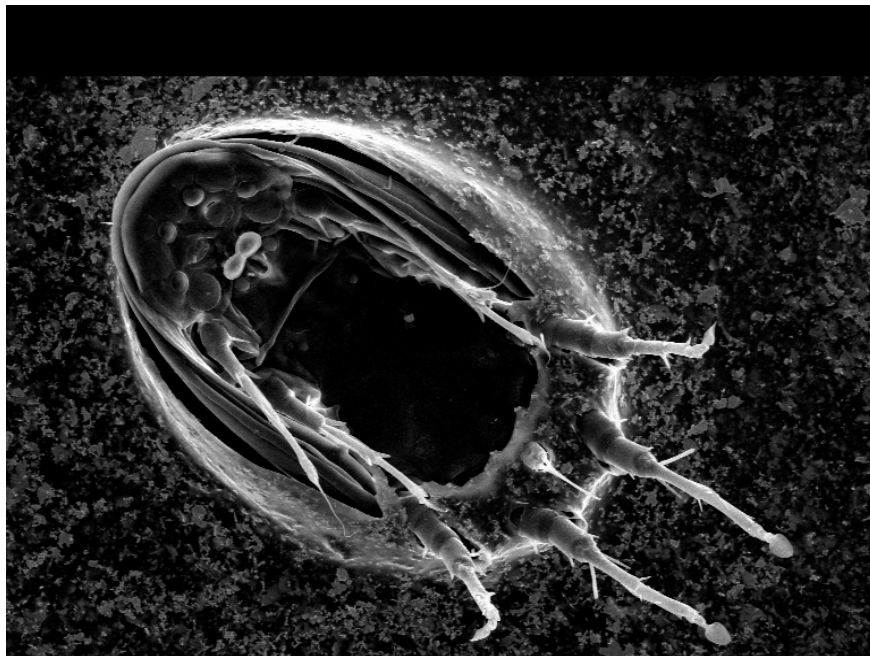
50.0 μm



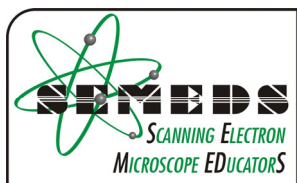
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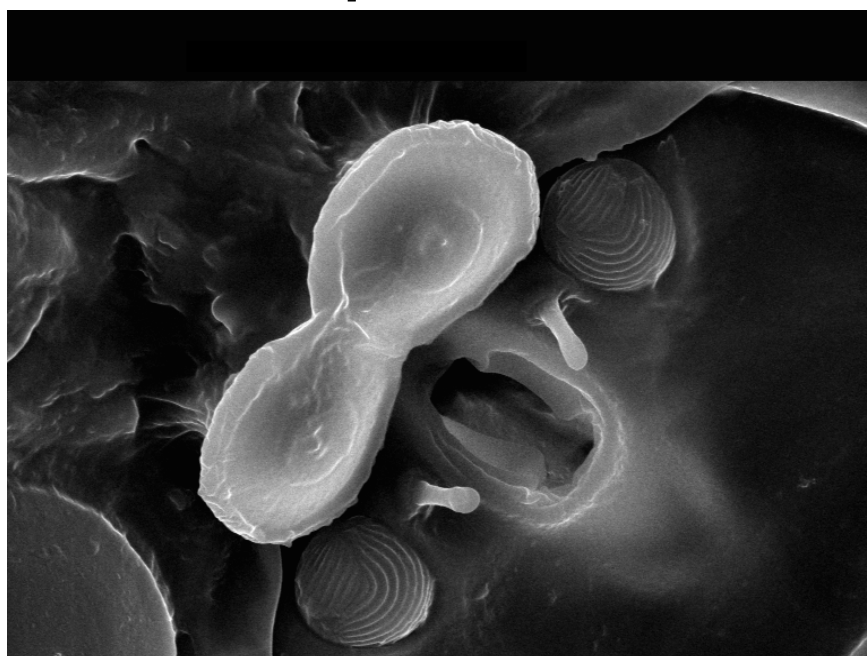
100 μm 



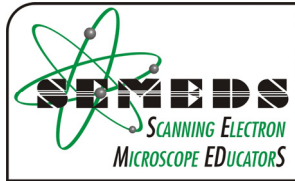
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10.0 μm —————

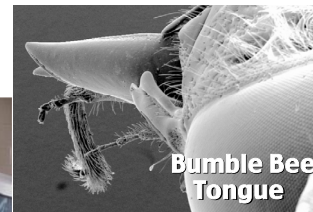


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Program Results

- Excites teachers, parents, and STUDENTS
- Motivates students to consider science as a career
- Increases exposure of AFRL to local region
- Increases volunteerism



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AUTOMATIC TEMPERATURE CONTROL USING LABVIEW TO MAINTAIN COMFORT ZONES

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AUTOMATIC TEMPERATURE CONTROL USING LABVIEW TO MAINTAIN COMFORT ZONES

National Educator's Workshop
October 19-22, 2003

Annette C. Booker, Samuel White, Malachi Hargrove, Kyron Copeland, Michael Williams and Prathap Basappa, School of Science and Technology, Norfolk State University, Norfolk, VA 23504

Key Words: LabVIEW, OpAMP, Thermistor, DAQ, A/D conversion

Prerequisite Knowledge: Programming, Basic Analog & Digital Electronics, A/D conversion, Graphical Programming Language, Basic Physics and mathematics

Objective: To design and develop a functional computer controlled precise temperature controller.

Equipment and Materials:

1. PC (Pentium IV)
2. National Instrument's DAQ card
3. Indigenously designed PCB
4. LabVIEW software
5. Relays

ABSTRACT

Temperature control is one of the key factors in maintaining comfort levels in work or residential environments. It is also crucial in several biochemical, metallurgical, and industrial processes. Although there are traditional methods of maintaining control, such as thermostats that use thermocouples to gather information, they are limited because of their crude design and lack of operational accuracy. In this work, we use the concept of a feedback control system to achieve accurate temperature control.

The system, essentially, consists of a hardware and software integration approach to maintain a desired temperature. The hardware operates as a constant current source driving a feedback operational amplifier circuit whose amplification varies with the value of a thermistor. The output voltage of this system is converted to a digital value by an analog/digital converter card. The software, created in LabVIEW, converts the voltage into a corresponding temperature and is compared with a preset value, which generates a Boolean value. The Boolean value triggers a set of relays which either turns on a heater or a fan, depending on whether the ambient temperature is less than or greater than the preset temperature. This paper will document all results of the testing, observations, challenges, and methods of accomplishing the tasks discussed before.

INTRODUCTION

In the work place it has been concluded that comfort yields the best results when it comes to work production and one of the main factors of comfort is the room temperature. Currently, the most common way of controlling temperature is by using a thermostat. Unfortunately, thermostats do not keep a steady temperature within a room

without constantly adjusting the settings [National Renewable Energy Laboratory]. With this idea in mind, our team decided to create and build a system that would allow any user to maintain a certain preset temperature without having to constantly adjust the temperature controls.

BACKGROUND

Maintaining constant temperature involves measuring current temperature and taking corrective measures to either switch on a heating unit or cooling unit, if necessary. After researching many different methods of collecting and controlling temperature, the team decided to use a thermistor to sense the temperature due to its precise variation with temperature and ease of implementation. Once data is collected from the complete circuit, it is processed and corrective action is taken. In our project, the analog signal is converted to a digital signal and a corresponding temperature.

LabVIEW

The basic underlying principle of operation, here, is to sense a certain magnitude of voltage proportional to the temperature. It is then arithmetically reconverted back to temperature and compared against a preset temperature leading to Boolean operations, which operate the heater or cooler relays based on whether the room temperature is greater or lower than the preset temperature. LabVIEW is selected based on its blending capability with the hardware in comparison to other text-based languages. We selected this language simply because of its user-friendly, GUI-based, format that is built upon a foundation of C++. LabVIEW is also a language that is frequently used in applications requiring measurement and automation such as electrical and computer engineering, physics, and chemical engineering.

DATA ACQUISITION

Our data acquisition and analysis were done using National Instruments LabView and Data Acquisition (DAQ) cards. Also a product of National Instruments, the DAQ card consists of multiple analog input and output and digital input and output ports necessary for both input and output streams of data to and from the source.

The data acquisition used in our project has two different stages: signal conditioning and acquisition of data. In the signal-conditioning phase, the desired signal to be measured is separated from the background noise through proper attenuation, amplification, and termination, on a case-by-case basis. In the second phase, namely the Data Acquisition (DAQ) stage, the incoming signal is acquired through a DAQ card, which is, essentially, an analog-to-digital conversion card. The digital information is then fed into the LabVIEW program where the signal is converted to a corresponding temperature and displayed on the front panel. In addition, this temperature is used for comparison with the preset temperature value.

Our system gathers a voltage from the circuit, and sends the information into LabVIEW. The LabVIEW program is then responsible for the analysis of this voltage and interpretation of it into a temperature. In our particular laboratory experiment we will also be utilizing the digital triggers that are present in the SCXI system [“Breakout Pin Translations”]. The digital ‘1’ or ‘0’ are generated by digital output terminals of the DAQ card based on a Boolean comparison between the preset temperature and the ambient temperature.

HARDWARE

The circuit diagram of the hardware designed and developed is given in Figure 3. The electronic circuit outputs a voltage proportional to the ambient temperature. The voltage is converted back into temperature through proper formulae. A thermistor is a

temperature sensor that utilizes a semiconductor's resistance change with temperature. The change in the resistance is related to the change in temperature in a nonlinear manner. On the average, the range of the thermistor goes from -100°C to 300°C [Potter]. Another factor that affects the temperature range is the melting point of the encapsulation material. If the encapsulation material melts the semiconductor will be exposed to the harsh environmental hazards. So in order to protect the semiconductor the encapsulation material is usually some inert material such as plastic, epoxy or Teflon. The encapsulation material can also affect the response time of the thermistor. When the encapsulation material is a material that has a good thermal contact the response time can be as low as a half a second. However, if the material has a poor thermal contact the response time can be higher than ten seconds [Potter].

The value of the thermistor's resistance varies in proportion to its temperature while the output voltage of the operational amplifier is proportional to the thermistor resistance connected in the feedback loop. The DAQ card recognizes the output of the operational amplifier and, once this occurs, the DAQ card gives the data to the program. While in the program, the voltage is converted into a temperature reading, via an equivalence equation. If this temperature is contained in the range of the preset range, the system is activated and a suitable action can take place.

Operational Amplifiers

Operational amplifiers are devices that measure the difference between the voltages applied to the two input "legs" (the positive minus the negative), multiplies this difference by a gain determined by the ratio of the feedback resistor (in our case thermistor) and the input resistor [Martin].

Relays

Relays are used as control switches. For our project, we decided to use our relay to act as a switch for our temperature control peripherals. In this context, based on the digital signal received by the DAQ card, the relay switches on power to the heating or cooling unit. The relay will maintain its operation until it receives a signal to change the peripheral or cease action all together.

Zener Diode

Zener diodes are used to maintain a constant voltage across over a circuit to ensure that if a voltage is inputted and exceeds the range of the system, the diode acts as a short circuit to stop increasing the voltage beyond a certain value and does not affect the rest of the system. Our desired range of operation for our complete circuit was zero to ten volts (this is also the range that the DAQ card can accept as input) and so we chose a Zener diode that fits these specifications. The Zener diode used in our project is also used as a component of the constant current source system.

Transistor

A PNP switching transistor was used in the construction of our circuit to assist the Zener diode in maintaining a constant current that flows through the circuit. It is also used to amplify the voltage that the Zener diode gives off [Philips Semiconductors].

PROBLEM STATEMENT

In this project, we have designed a system that is capable of controlling the temperature of a room by maintaining a preset limit. This task was accomplished through the development of hardware and software. In order to control the hardware side of the system for temperature control, a computer program developed in LabVIEW was utilized. The program consists of four basic sections/operations: 1.) Receive an analog

voltage from the hardware circuit; 2.) Convert the voltage received into a temperature reading; 3.) Compare the temperature to a user defined temperature range; and 4.) Send out a signal to a temperature control peripheral via a relay.

PHASE ONE

The first part of the program receives a voltage from the circuit through the use of the DAQ card; an analog input symbol was used to carry out this operation. Analog input symbols function by inputting the device number of the DAQ card and the receiving port as constants. The DAQ card has its limitations in that it can only accommodate a voltage from -10 V to $+10\text{ V}$; if the output of the circuit falls outside of this range then an attenuator is needed to decrease the voltage into the range of the DAQ card. To accomplish this, the team decided to use the Zener diode to limit the input voltage to DAQ card.

PHASE TWO

The second phase of the program, as previously stated, was to convert the voltage received from the analog input symbol into Celsius degrees. The temperature is determined using a function node, a pre-defined tool in LabVIEW that takes a number of variables and applies them to a mathematical function defined by the programmer. Once the function has been applied to the input variables it then outputs another variable to the program. The formula node uses the voltage received from the input port and applies it to an equation in order to convert the reading into degrees Celsius (refer to Fig. 2/Appendix A). Once the conversion of the voltage has been completed the program then proceeds into its third phase.

PHASE THREE

The third phase of the program was to compare the temperature from the function node to the comfort range constraints set by the user; this part of the program is handled by the comparison symbols and range icon used in LabVIEW. The input temperature is compared to a range set within a degree of the preset temperature; if the temperature falls within the range, neither peripheral is activated. However, if the temperature is outside of the preset range, a signal is sent into a nested case structure that activates a line that triggers the relay for one of the peripherals; this is the foundation of the fourth phase.

PHASE FOUR

The final phase of the program was to send out a signal to the correct temperature control peripheral. A nested case structure is used to determine if and which temperature control peripheral will be needed. Case structures are defined in LabVIEW and, depending on the input, perform a set action [LabVIEW]. The input into the case cell will be the output from the comparison symbols. If the temperature from the thermistor is less than the user's lower temperature limit then a digital signal will be sent to the relay from the DAQ card instructing it to turn on the heater. If the temperature is higher than the user's highest temperature setting then a signal will be sent to the relay from the DAQ card instructing it to turn off the heater. Our relays, as stated previously, work as a control device. The digital signal is sent out using a digital input/output symbol. The digital input/output symbol is a LabVIEW symbol that takes the device number of the DAQ card, the port number that the signal is outputted to, and the logical state that is outputted from the DAQ card. All of these parts are contained in a "while loop" structure, which is controlled by an off button that is set by user. The loop will iterate and take a temperature reading every half-minute and compare it to the user defined temperature range. Once the off button is triggered the program will stop taking readings and cease execution.

METHODOLOGY

In the above paragraphs, the implementation procedure using LabVIEW was discussed. Over the period of several months, we began by using a Data Acquisition node that would receive the analog input from the DAQ Card. This node runs into a Waveform Chart that outputs the given information into a chart that can be read by the user on the Front Panel of the Virtual Instrument [LabVIEW]. The formula node transforms the analog input voltage into a temperature value. This temperature value was then connected to a comparison function that would compare the signal versus a predetermined value.

On the front panel of the VI, there is an adjustable digital control, which determines the desired temperature value. The front panel of the VI is shown in Figure 1. For example, if the user would like to maintain a temperature of 70° F, then they could adjust it to that value. The input analog signal is converted to a temperature value using the equation:

$$T = B / \ln (V / V_0 + B / T_0)$$

Where B was the thermistor constant 4085, T_0 was the temperature 301 K, and V_0 was .576, the voltage taken from the thermistor to calibrate it. The temperature is then compared to the user's pre-set temperature range and the result of this comparison is sent to a nested case structure. If the temperature is within a one-degree range then a digital false (or 0) will be sent to both of the output channels. If the temperature is more than one degree higher or lower than 70° F, a false will be sent to the first case structure. Inside this case structure another case structure is present which will take the actual room temperature and determine if it is either higher or lower than the preset range. If the temperature is higher than the range then a digital true (or 1) will be sent through one of the two output channels; this trigger is connected to our fan in the circuit layout. If the temperature is lower than the range then a digital true (or 1) will be transmitted through our second output channel, which is connected to a light bulb. If the inputted signal comes out to a value less than 70°F, the comparison node gives off a True (T) signal. This true signal ultimately sends a digital true (or 1) through our second output channel, which is connected to a light bulb. The detailed implementation of this procedure is shown in Figure 2 which is the block diagram of the virtual instrument VI. With the interaction of these two instruments, the fan and the light bulb, the temperature read by the thermistor will vary with change while the temperature pre-determined by the user will be maintained. We have also implemented several other characteristics that will make the interactive program even more user-friendly and pleasing to the eye such as a temperature gauge and flashing icons that indicate whether the light bulb or the fan is active.

RESULTS AND OBSERVATIONS

We have thoroughly tested each individual part and have some basic results that deal with each system. In addition, our team was able to gather some data on the entire system, which is recorded in this documentation. The team found that the initial values of some of our components (i.e. the bulb) were not suitable for our experiment and demonstration so changes were made and tested once more. In addition, the team implemented our hardware circuit on a smaller breadboard, allowing for less space used in our environment. We also created an environment conducive to our needs; we want a compact, portable unit that housed all the needed hardware and other components with enough space to circulate the airflow. Moreover, our team has also included some possible additions that may be applied to the system to create a better atmosphere conducive to comfort and safety.

SOFTWARE

To test the program a power supply was attached to the inputs of the DAQ card. (This power supply allowed for the control of the voltage inputted into the program.) This voltage was compared to a user-defined voltage and, if the voltage was higher than the user defined voltage, a digital one was outputted to another voltage meter. This test proved that the program can compare the input voltage with a user-defined value.

Once the equation was determined, the program's user interface could be improved. One of the possible improvements was to add a temperature gauge to simulate a thermometer. This thermometer will be accompanied by a digital output symbol so that the user will know the exact degree they are setting the ambient temperature. Another improvement was to display the current temperature on the front panel as well as adding a thermometer display to coincide with the digital reading. Once these minor adjustments were completed, the program was ready for connection to the circuit for further testing. The front and back panels of the VI are shown in figures 1 and 2 respectively.

HARDWARE

We have successfully designed, developed and tested the system. With the addition of the Zener diode and transistor as well as removing the circuit from the faulty breadboard, the circuit gives a correct reading well within the range of the DAQ card. The thermistor was also tested and the proper ratio was obtained. In addition, the completed system was tested, the circuit and the program and the results were satisfactory. A sanity check on the performance of the system was conducted using different preset temperatures and the operation of the system was monitored. A table projecting our results is shown below.

Input Temperature	Preset Temperature	Range:		A/C On	Heater On	Nothing Operating
		Low	High			
81.72	84.50	83.50	85.50		X	
83.77	84.50	83.50	85.50			X
84.12	84.50	83.50	85.50			X
85.95	88.20	87.20	89.20		X	
87.09	88.20	87.20	89.20		X	
87.87	88.20	87.20	89.20			X
88.27	82.30	81.30	83.30	X		
85.57	82.30	81.30	81.30	X		
84.48	85.00	84.00	86.00			X
85.21	85.00	84.00	86.00			X

Table 1. Chart of data collection during testing. Observations of current temperature ("Inputted Temp.") and respective changes in temperature in the system when using 200-watt bulb. The original environment temperature was 81.85°F. All temperatures were taken in degrees Fahrenheit.

Input Temperature	Preset Temperature	Range:		A/C On	Heater On	Nothing Operating
		Low	High			
78.85	80.00	79.00	81.00		X	
79.78	80.00	79.00	81.00			X
79.16	80.00	79.00	81.00			X
79.78	78.00	77.00	79.00	X		
79.47	78.00	77.00	79.00	X		
78.55	78.00	77.00	79.00			X
77.36	75.70	74.70	76.70	X		
76.78	75.70	74.70	76.70	X		
77.36	85.12	84.12	86.12		X	
78.55	85.12	84.12	86.12		X	

Table 2. Observations for 100-watt bulb used as heating device. Original temperature in the environment was 78.85°F. All temperatures were taken in degrees Fahrenheit.

SIMULATION ENVIRONMENT

After the system was completed, the team constructed a simulation/demonstration environment. We used a light bulb and a small fan as our heating and cooling systems. Both of these components were placed in an aquarium and wired to their respective relays. However, while testing the system we discovered that when using the 200-watt bulb, the interior environment would get heated fast but when it needed to cool down in the same manner, the fan was not able to create the atmosphere. With this in mind, the team tried using small blocks to lift the roof of the environment about two inches from the top; the purpose was to allow the circulation of air from the exterior so that cooling down the atmosphere would quickly occur. Unfortunately, when we tested the system once more, though the temperature fell somewhat quickly, it still did not happen fast enough. This time, the team decided to use a lower wattage bulb (100-watt) and record the results (refer to Table 2). As is recorded, the lower wattage allowed the environment to slowly heat up as well as allowed the fan to cool off the environment at a faster pace.

Now that we had the entire system working we were able to place the components in the environment and affix them. The entire circuit, including the thermistor, was placed on a box in the center of the aquarium to allow for easy adjustment later; basically, we wanted to create a controlled environment with minimal exterior interferences. In addition, this environment is portable and easy to assemble for testing and demonstration. To ensure these factors, our team positioned and affixed each of the components (i.e. the light bulb, fan, relays, and circuit) to the aquarium floor and ceiling. The ceiling is actually a piece of shelving board that can be elevated, using blocks, to allow for airflow in and out of the aquarium

CONCLUSIONS

The climate control system that the team created is just a base model for any future work in the area and the implementation of the system on larger-scaled systems. We have, however, created a system that accurately collects the temperature of a room, converts that voltage reading into a temperature reading, compares the reading to a preset range of temperatures, and outputs a signal to a device to maintain temperature control.

Not only does the system operate as expected, it is also working at optimal level. The only possible additions that can be added to increase optimization is the use of a third LED to notify the user that no device is being activated when the temperature falls within the range and/or extending the project to other parameters as discussed before. In addition, other temperature sensors can be used to gather data and compare that accuracy to that of our system. The goals of our project were accomplished in a timely manner and accurate and predictable data was collected from a reliable and dependable system.

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APPENDIX A

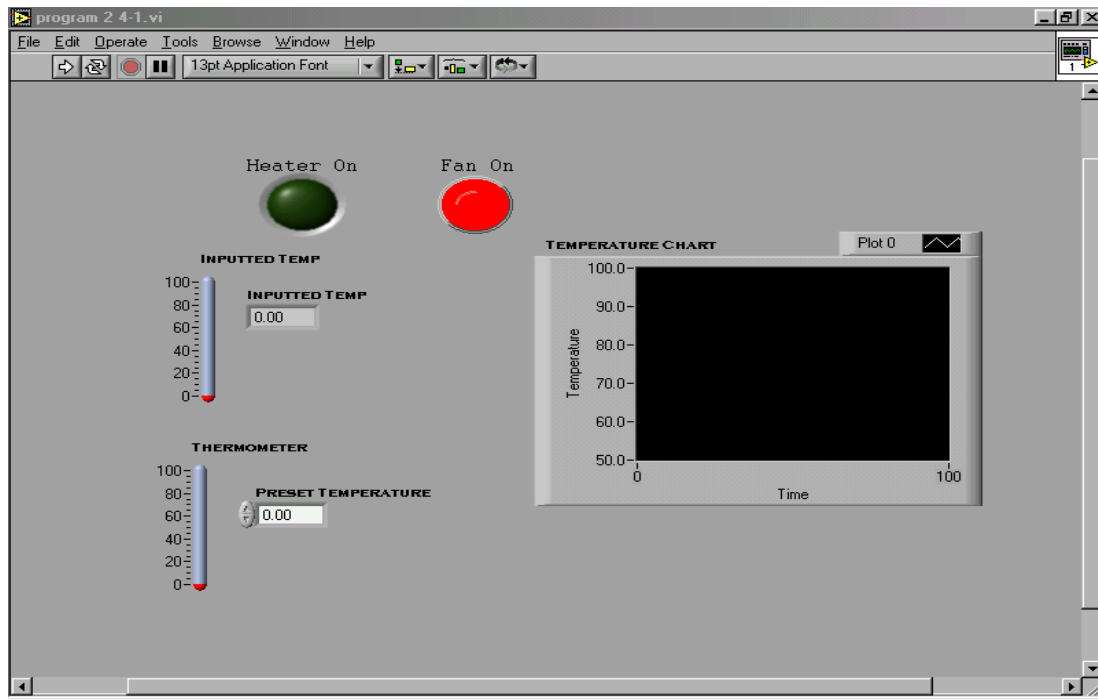


Figure 1. Display of the front panel of the LabVIEW program.

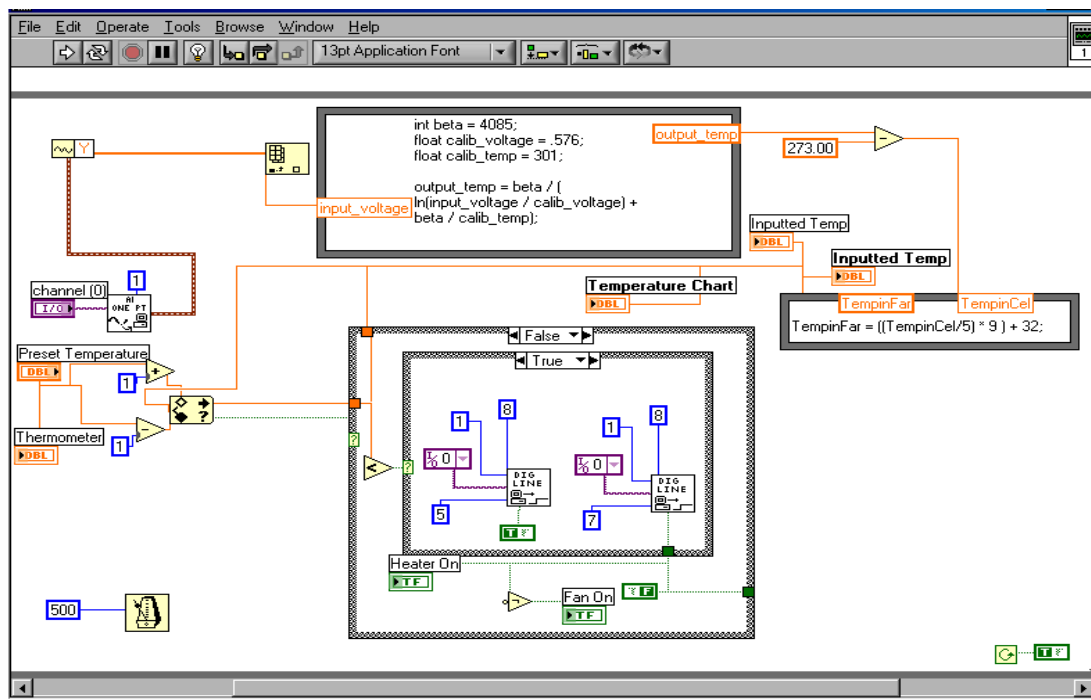


Figure 2. Segment of LabVIEW code that receives the data from the DAQ card, sends data through a series of formulas before triggering appropriate peripheral.

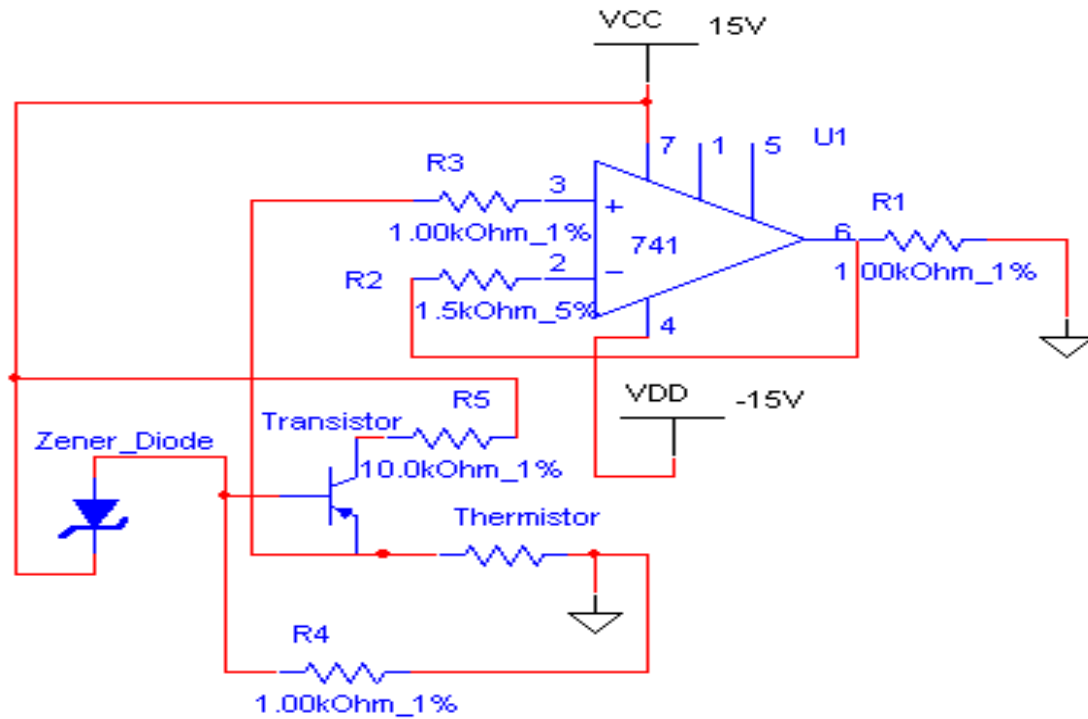


Figure 3. Schematic drawing of circuit. Displays the op amp (741CN), thermistor, transistor, Zener diode, power supply, and numerous resistors.

AUTOMATIC TEMPERATURE CONTROL USING LABVIEW TO MAINTAIN COMFORT ZONES

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