Materials and The Aerospace Industry: Academic Perspective

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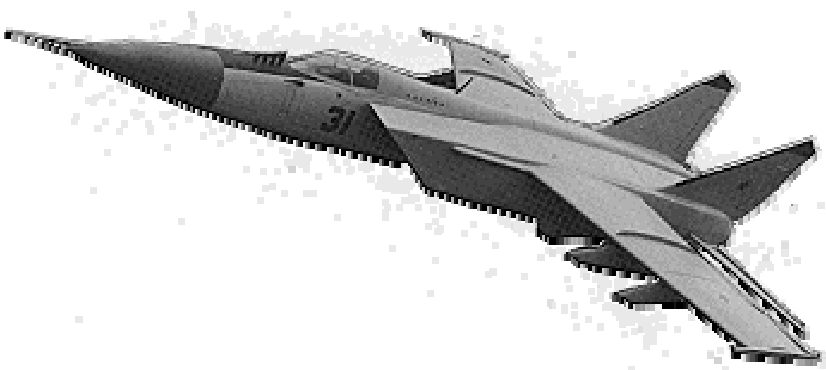
Background

- Materials have always been one of the drivers of technological change…
  - Alloys
  - Semiconductors
  - Polymers
  - …

Hard materials

Soft materials



Examples of Aerospace Materials Drivers in The Past 50-60 Years……

- Aeroengine efficiency and performance
  - Advances in materials have enabled significant changes in aeroengines in the past 50-60 years (largely empirical alloy design & microstructure design – from polycrystals to single crystals)
  - Thermal barrier coatings (up to 1100 C)
- Airframes and space vehicles
  - Lightweight and strong/stiff composites
  - Structural aluminum and titanium alloys and landing gear steels
  - Thermal protection systems and carbon-carbon composites for the space shuttle
- Avionics
  - The integration of electronics and optical telecommunications

However…….

- Many of the basic research labs that produced these discoveries have disappeared within the aerospace industry in the US
- Many of the basic research labs have closed
  - Boeing in the 1960's
  - McDonnell Douglas and Martin Marietta in the mid 1990's
  - Compared to areas such as nano and bio the aerospace materials arena has lost its luster as a frontier area of materials research
  - Very few of the remaining labs have a focus beyond incremental contributions to emerging systems
- The limited amount of ongoing basic materials research is driven primarily by military needs in an era of shrinking military research budgets
- NASA's materials research budget has also shrunk to very low levels over the past few decades
- Hence we cannot assume that the innovation from the DoD- and NASA-driven research will keep the US competitive in the commercial aerospace arena, as it has done in earlier times

Why Does This Matter?

- Well the aerospace industry is one of the major areas in which the US maintains a global leadership position that provides high quality American manufacturing jobs
- For example – the cost of a commercial jet aircraft of $100-200M provides key jobs to US workers
- These are jobs that cannot be easily replaced by those in the service industry
- Also the relatively high cost of the aerospace products helps to reduce the unfavorable trade imbalance with such as China and India that are likely to be the major consumers of aircraft in the next few decades
- Hence the potential loss of leadership in this area has important consequences

Who’s The Competition?

- In the case of big aircraft the immediate competition is Europe with Airbus being perhaps the fiercest competition
- However a country such as Brazil has emerged as a major competitor in the area of mid sized commercial aircraft (38% of the market)
- Canada also a player in the area of mid-sized aircraft
- Long term competition may also emerge from countries like China, Russia and Japan
- These are countries that have the potential in materials processing, engine technology and electronics to develop globally competitive aerospace industries within the next few decades…..

The Framework For Fundamental Materials Research in The Aerospace Industry

- Most major aircraft consist of three components
  - Airframe (about 1/3 of the cost)
  - Aeroengine (about 1/3 of the cost)
  - Avionics (about 1/3 of the cost)
- In each of these components materials play a major role driving technological change and innovation
- The industry is currently living on materials that were largely developed 20-40 years ago
- It also takes between 15 and 30 years to develop and apply new aerospace materials that would give the US a competitive edge
- So how do we develop and apply new materials that will enhance US competitiveness in the aerospace industry within this timeframe?

The Potential Approaches to Materials Research

- Short term/incremental research
  - Alloy and microstructure design
  - Optimization of emerging existing processes e.g. friction stir welding
- Medium term intermediate research
  - Extensions of ongoing research e.g. ceramic matrix composites and TBCs
  - MEMS and nanotechnology
- Long term transformative research
  - High temperature materials and structures beyond nickel
  - Light weight structural materials beyond Al and PMCs
  - Active materials, molecular electronics, optoelectronics, materials beyond Moore's law and bio-inspired design
  - Shrinking the world through flight – long term science-based approach

Short Term Approaches to Materials Research

- Most of the existing commercial aircraft consist of relatively few classes of materials
  - Aeroengines – PMC, Ti alloys, Ni- and Co-base alloys
  - Aiframe materials – Al alloys, Ti alloys, PMCs
  - Avionics
- The short term approach should be to stimulate fundamental research that could lead to innovation in materials and processing within interdisciplinary teams – e.g. friction stir welding
- Science-based reliability models could also enhance the utilization of existing materials and systems
  - Thermal barrier coatings and aircraft thrust/efficiency
  - Failure prediction and NDE models for aerospace materials

Medium Term Approaches……

- Significant advances beyond existing materials and processes
  - Airframes – Be alloys multifunctional structures, in-situ composites
  - Aeroengines – functionally graded TBCs or EBCs, intermetallics
  - Avionics – MEMS/nanotechnology
- Critical mass of long term support for extensions to current classes of materials from ongoing activities
- The goal should be to use a fundamental science approach to stimulate discovery that could lead to long term solutions in
  - High temperature oxidation e.g. TBCs/EBCs
  - Fracture resistance e.g. intermetallics
  - Manufacturing and processing e.g. Be and its alloys
  - Environmental/security issues e.g. MEMS/nanotechnology

Long Term Transformative Research…..

- The real opportunity is to define a long term framework for transformative research and education
- Engage a critical mass of students and researchers in efforts to develop the materials beyond those that we have
- Explore high temperature materials beyond nickel e.g. Mo, Nb, Ru
- Use fundamental concepts in materials science to engineer changes in high temperature oxidation resistance and fracture resistance
- Explore new ways of processing and joining materials
- Develop avionics using electronics beyond Moore’s law
- Integrate controls, optics, fluids, heat exchange and chemical processes with selected programs
- Develop science around sustainability and related energy issues

Accelerating The Pace of Discovery

- Engage new approaches to promote rapid material discovery and innovation in materials design in the aerospace industry
  - Combinatorial materials science and informatics
  - Computational materials science
  - Neural networks, statistical methods
  - Materials design and topology optimization
- Funding of ACI Centers of Excellence in Aerospace Materials (Beyond MRSECS and ERCs)
- Promoting closer interactions and exchange between universities, industry and national labs
  - Harnessing the full potential of US and international infrastructure
  - Shared Technology Exchange Programs and Visiting Fellowships

Stimulating Innovation Beyond Discovery….

- Often the mechanisms of stimulating innovation beyond discovery are very fragile
- SBIR funds provide limited support - between 6 months and 3 years
- Venture capital funds and Angel investors also tend to concentrate on sexy emerging new areas
- Consequently small start-up companies that are filling the gaps are subjected to enormous strains
- Support within established companies support may evaporate depending on overall company performance
- Need more robust funding of start-ups and ideas over 8-10 year period
  - Public/private partnerships to fund emerging companies
  - Innovation hubs to assist with transitions from ideas to markets

Where Will The Innovators Come From?

- They will come from all over the world in a globalized economy – and we must connect to them wherever they are
  - Making the US an attractive place for foreign and local scientists and engineers in the face of increasingly stiff international competition
  - Joint research programs with scientists in India, China, Russia
  - International Science and Engineering Institutes e.g IMIs such as USAMI
- However we must also develop all of the available talent within the context of the changing population and demographics of the United States
  - Tapping into the youth and stimulating them to become innovators
  - Stimulating innovation in undergraduate and graduate education
  - Broadening participation to include significant contributions from under-represented groups

The Key Role of Education and Outreach

- Using Grand Challenge Problems to attract students and researchers and innovators to aerospace materials
  - Shrinking/flattening the world through flight
- Strengthening the base through education at all levels
  - Using popular media to communicate eg cartoons, music, TV programs
  - Greater rigor in high school science and math e.g. solid state, advanced calculus
  - Parallel effort in hands on technological education in high schools and community colleges (strengthen the base and the frontiers)
  - Stimulating innovation in undergraduate & graduate students e.g. innovation funds and awards
  - Interdisciplinary post-docs/fellowships to connect people to different fields
  - Introduce new courses in entrepreneurship, globalization, leadership and sustainability into science & engineering undergraduate/grad programs

Flexible Approaches to Graduate Education

- Many US students are discouraged by the long time that it takes to get a PhD – more flexible approaches are needed
- Also most people do not learn about materials science and engineering at the undergraduate level
- Hence there is a need for flexible programs that allow students to work while receiving a graduate education or continuous education
- Should also combine with programs on entrepreneurship, business and finance, globalization, sustainability and ethics
- Potential models include
  - Virtual programs
  - Evening programs
  - Collaborative R&D programs (university/academia)
  - Need structured incentives and programs to ensure impact

A Model of a Potential Program in Aerospace Materials Education

- Content - Materials fundamentals, materials design, modeling and simulations, aerospace materials science and engineering, mathematics, globalization, entrepreneurship, business and finance, ethics and leadership
- Potential Students
  - Full time (From 2 years MSE to Practitioners Degree and PhD)
  - Part time (3 years MSE to Practitioners Degree and PhD)
- Potential Instructors/Institutions
  - Princeton University
  - Cambridge University
  - Birmingham University
  - Ohio State University
  - Indian Institute of Science

  Washington University
  University of Washington in Seattle
  Wichita State University
  University of Connecticut
  University of Michigan

Broadening Participation

- Stronger efforts are needed to engage women and minorities in the US
- For example the National Societies and Minority Science and Engineering Societies should be engaged as partners in developing strategic plans ad networks for engaging their communities in strategic science and engineering education and innovation
- Possible models include
  - Minority Science and Engineering Institutes that network clusters on minority and non minority scientists into a critical mass of activity that broaden participation while making an impact on innovation for industry
  - Committed long term mentoring networks
  - Strengthening of the base in science and math
  - Research and industrial experience for high school and undergraduate students
  - Hands on activities in aerospace materials research and innovation
  - Using popular media to reach the different communities

Summary and Concluding Remarks

- Materials research & innovation are needed to maintain the lead that the US enjoys in the aerospace industry – in the face of emerging international competition
- Three approaches are proposed for aerospace materials innovation within the context of the ACI– incremental, intermediate and long term (all are important)
- However the pace of discovery and materials innovation could be accelerated by the integrated use of new computational and materials design tools
- New ways are needed to attract, educate and nurture talent in the aerospace materials community
- Possible education models were discussed within the context of the ACI
- Possible models were suggested for the broadening of participation of women and minorities e.g. Minority Science and Engineering Institutes, Societies, IMIs etc

THANK YOU!