THE ROLE OF MATERIALS AND STRUCTURES TECHNOLOGY IN DEFENSE-PART II

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In a recent report to Congress, the General Accounting Office (GAO) assessed Federal materials research and development and made three recommendations aimed at modernizing the materials policy formulation process and the management of Federal materials R&D activity:

1, Establish an institution to analyze materials issues and provide policy guidance,
2. Establish a comprehensive unclassified information system for materials R&D built on existing information in the Smithsonian Science Information Exchange, and
3. The Science Exchange should include in its information systems materials R&-D information developed outside the Federal Govern merit.'

In reviewing the Federal materials R&D the GAO study highlighted three aspects of past and present Federal materials R&D (table 1). First, program funding in constant dollars is actually decreasing. Second, Federal R&D effort is highly fragmented. Third, data are incomplete and have been poorly gathered over the last 15 years, and collection is sporadic and insufficient for policymaking.

TABLE 1. –Highlights of GAO Review of Federal Materials R&D

● Program funding in constant dollars
1962-1972 = $185 million to $331 million
(real growth only 6% in constant dollars)
● Federal R&D effort is highly fragmented.
1) No overall Federal materials R&D program.
2) Large number of specific mission-oriented R&D activities.
(Fy 1974–23 agencies–90 subdivisionals sponsoring materials R&D)

Source: “Federal Materials Research and Development” Modernizing Institutions and Management. ” GAO, DEC, 2. IW5

I Requested by Senators]ohn Tunney and William Brock to (1) analyze Federal Funding for Materials R&D and (2) evaluate the effectiveness of Federal Materials R&D. “Federal Materials Research and Development: Modernizing Institutions and Management,” GAO Dec. 2, 1975.

It would seem to me that these findings and recommendations could be deliberated this week by this assembly of experts and could help provide a mechanism to aid in formulating the means for establishing and implementing such a plan,

But specifically, I am here with Jerry Persh of Office of the Director of Defense Research and Engineering and Max Williams of the University of Pittsburgh to address the questions of the role of materials in defense (table 2), From the DOD point of view, could these recommendations of the GAO be sufficient to assess the DOD materials R&D and to determine weakness in the program and disseminate information more readily? What about the very large body of classified materials R&D and materials data that is an integral part of DOD weapons systems? Would a more complete DOD system be more relevant, or can the recommendations made by the GAO satisfy DOD's major needs?

TABLE 2.–Questions for the Role of Materials in Defense

1, Can R&D be made more productive in a world of declining real dollar funding?
2. Can the design team approach significantly increase cost effectiveness?
3, Would DOD funds allocated to basic science–not mission oriented–be more effective in furthering the long range, materials-associated needs of DOD rather than depending on NSF funding for basic research?
4. How can centers of excellence for areas such as casting, welding, etc., involving individuals from industry, academia and Government be more effective in advancing and disseminating technology?
5. Is the trend toward reductions in DOD's manpower and resources in its materials and structures divisions severely reducing its effectiveness?
6. What is the best way to expedite the development of materials and technologies that limit the development of new systems and weapons?
7. How can R&D programs of DOD be better coordinated to more effectively develop new materials and technology?

The policy questions posed by Jerry Persh (table 3), should also be examined in light of the GAO study.

DOD Materials and Structures Technology and Industry Support

For many years the DOD Materials and Structures Technology programs were the main support in the United States, underlying in the area of high performance materials the basic research and development effort underway.

TABLE 3. –Policy Questions

- Role of Federally supported industrial materials and structures R&D in the U.S. National Technology Base,
- Role of company sponsored R&D
- Should (or can) industry make a greater effort to coordinate itself (or depend on the Government to perform this role)
- How to assess U.S. National Technology Base in materials and structures (with consideration to U.S. competitive base in industry).
- What are weaknesses, or strengths. of the way the “system” operates?

With the advent of NASA, the growth in NSF and the recent formation of ERDA (absorbing the old AEC), the proportion of U.S. materials and structures R&D supported by the DOD has been in general decline since about 1968 in relation to other Federal programs. The potential military relevance (PMR) clause in Public Law 91-441 and in ASPR 15-205.3 and 15-203.35 helped accelerate this decline.

The needs of the DOD, and industry supporting the DOD in the area of materials and structures technology, have increased, as pointed out by Jerry Persh. The dilemma, then, is how to generate the necessary technology base to insure that it will be adequate to support our military hardware programs, not only with a declining DOD manpower and financial base, but with serious challenges being made to the Independent Research and Development (IR&D) programs of the defense industry in support of DOD objectives.

The subject of IR&D is debated yearly in the Congress. The major attitudes are to either eliminate it or excessively control it, and the new requirement for potential military relationships in Public Law 91-441 have exerted a constraint on industry's desire to continue to generate the technology base necessary to support DOD objectives for future weapons systems.

In the face of these constraints, the last decade in DOD weapons systems development has encompassed a more fundamental approach to structural response of complex materials systems for weapons systems which includes:

- "Design-to-a-cost" philosophy,
- New concepts in structural integrity, and
- Minimum life cycle costs consistent with enhanced safety and improved performance.

For example, in the last 5 years new concepts in fracture mechanics have been introduced into the characterization of materials and into the structural integrity program of aircraft and missiles for determining operating stress levels and prediction of the life of structures, and very importantly, for determining proper inspection intervals of aircraft.

This technology has found widespread use in aerospace applications and now has created a high level of interest for surface ship needs in both the Navy and Coast Guard where high-strength, heat-treatable steels are being used to achieve higher performance. Here, older technology of determining structural integrity is suddenly no longer adequate. For example, in the case of the application of high-strength, low-alloy, heat-treatable steels applied to ship construction, recent attention to notch toughness as a material parameter for ship construction has focused attention on the inability of producing welds that satisfy current charpy V-notch (CVN) energy requirements and the multiplicity of required test specimens and notch locations for different plate thicknesses required for low-temperature (less than +32°F) applications. Metallurgical studies are needed to determine whether a solution to this problem is economically feasible in view of the severe restrictions placed on production weld fabrication in the shipyard to satisfy present requirements for critical low-temperature weld joints with present-day steels.

Finally, there is no doubt that high-performance Naval and Coast Guard surface ships of the future probably will employ materials with intermediate to high, strength-to-weight ratios. Because some of these materials are susceptible to rapid fracture resulting from small flaws, sub-critical crack growth aspects of material behavior, such as stress corrosion cracking and fatigue, would he incorporated in the design process (as in aircraft) preferably as part of an overall fracture control plan to insure safety, reliability, and economics. This fracture control plan is a methodology for avoiding failure by fracture over the design life and includes considerations of the elements identified in table 4, At the heart of this plan would be the application of fracture mechanics considerations that assumes an initial flow which can

TABLE 4.– Elements of Fracture Control Plan

- Load and Environmental Definitions
- Structural Design
- Material Properties Selection and Quality Control
- Fabrication Processes
- Inspection and Maintenance

Source: Ref. NMAB-327.

propagate and lead to fracture and the necessary fracture control steps that will prevent this from happening.

This need and the problems described focus on the requirement for new processes, new non-destructive inspection (NDI) procedures, and the need for the generation and the maintenance of a materials properties data base that is much more detailed and sophisticated than is available at present. I would like to use this point as one example where policy is needed and where this assembly may be able to generate some meaningful recommendations to the DOD in one aspect of materials policy.

Materials Standards and a Properties Data Base

Jerry Persh has alluded to the problem of declining manpower and resources in the DOD in the past few years which has steadily contributed to an erosion of the DOD materials and structures technology base. This is especially true in the area of materials and process specifications which serves as the backbone of hardware procurement for the DOD, where over a 50 percent decline has taken place in the last 10 years.

The DOD has been fortunate in having more than 4,000 materials and process specifications available and maintained to ensure that the standardization effort in the DOD is consistent with the procurement of military hardware which meets the performance, reliability, and Iife expectancy of the using services. However, because of the declining manpower and financial resources being allocated to the generation and maintenance of these specifications and standards, and with the increasing sophistication of the newer weapon systems, the ability of the services to fill the needs of standardization in this area is declining. With this growing sophistication in weapon systems and the need for greater performance has been an increasing demand for enhanced structural integrity, minimum acquisitions cost and low life cycle costs.

A second problem is the data base of meaningful properties on which to base specifications and accomplish engineering design. There is a need for:

1. A better means of generating materials property data,
2. A proper format to display data being generated on major DOD programs so all meaningful data are available. and
3. A long-term program of R&D to develop property data on new materials and composites to enhance the transition of materials and process technology to the newer weapon systems.

The newer requirements place severe demands on materials of construction and require more extensive materials characteriza-

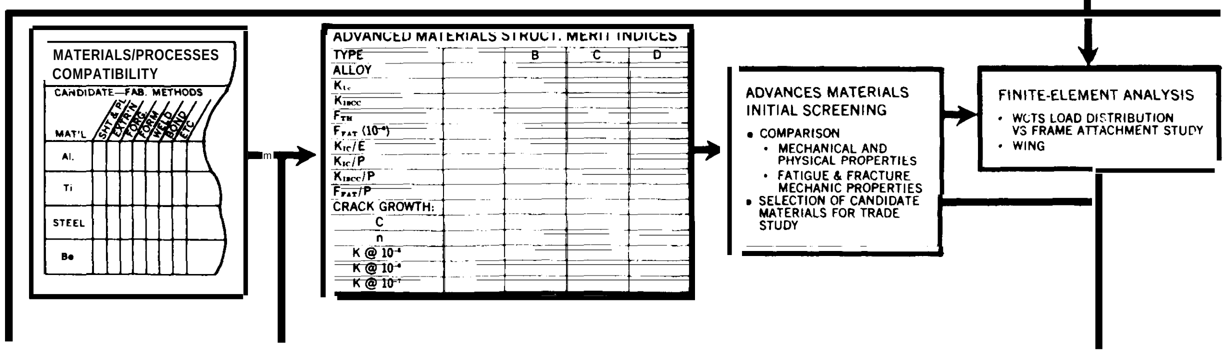
TABLE 5.

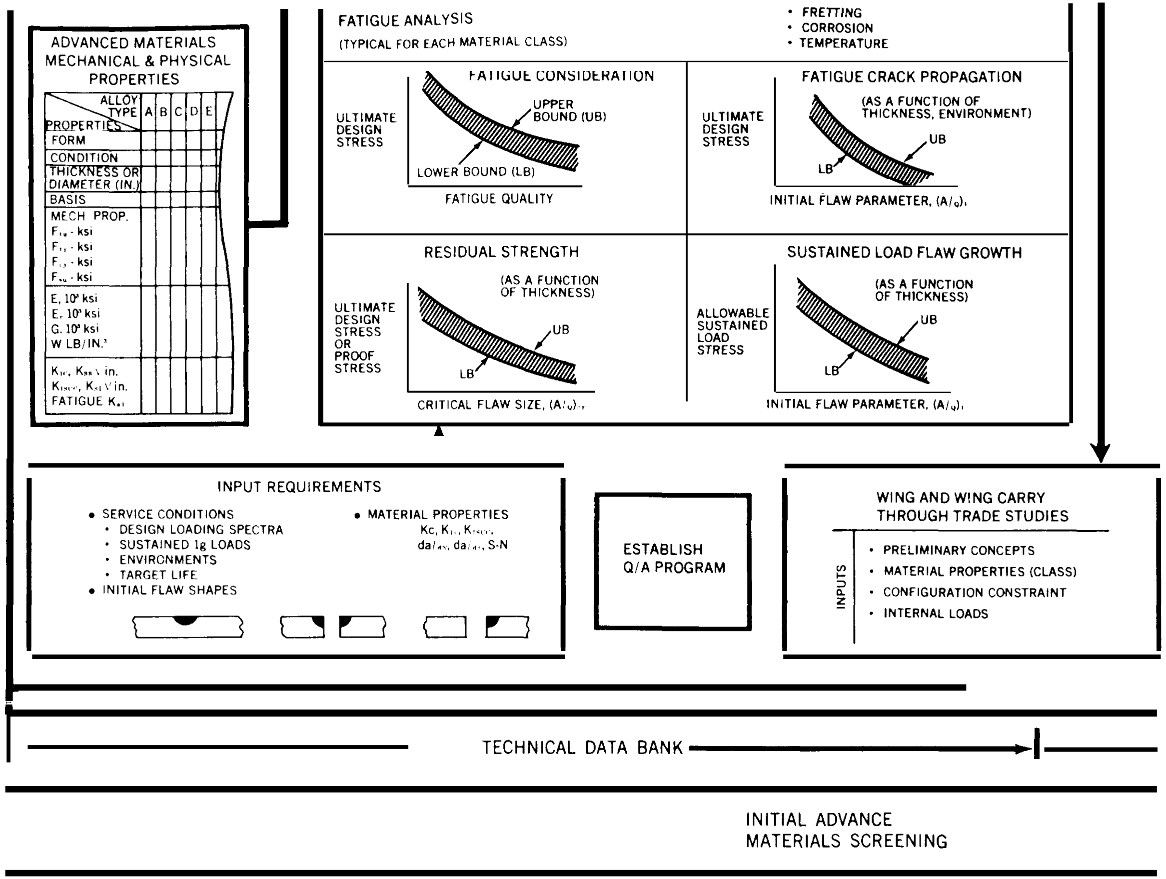
MATERIAL TESTING

DETERMINE:
- CANDIDATE MATERIALS
- AMOUNT OF TEST MATERIAL REQUIRED
- AREAS WHERE INSUFFICIENT DATA EXISTS
- CRITICAL PROCESS STEPS

DEFINE:
- SPECIFIC TEST VARIABLES FOR CANDIDATE MATERIALS
- DATA REQUIREMENTS FOR DESIGN
- TYPES OF ENVIRONMENTS
- PROPOSED TEST PLAN

PRELIMINARY DESIGN




ADVANCED MATERIALS MECHANICAL & PHYSICAL PROPERTIES
ALLOY TYPE
A
B
C
D
E
PROPERTIES
FORM
CONDITION
THICKNESS OR DIAMETER (IN.)
BASIS
MECH PROP.
E, 10³ ksi
G, 10³ ksi
W LB/IN.³
FATIGUE
FATIGUE ANALYSIS
(TYPICAL FOR EACH MATERIAL CLASS)
• FRETTING
• CORROSION
• TEMPERATURE
FATIGUE CONSIDERATION
ULTIMATE DESIGN STRESS
UPPER BOUND (UB)
LOWER BOUND (LB)
FATIGUE QUALITY
FATIGUE CRACK PROPAGATION
(AS A FUNCTION OF THICKNESS, ENVIRONMENT)
UB
LB
INITIAL FLAW PARAMETER
RESIDUAL STRENGTH
(AS A FUNCTION OF THICKNESS)
ULTIMATE DESIGN STRESS OR PROOF STRESS
CRITICAL FLAW SIZE
SUSTAINED LOAD FLAW GROWTH
(AS A FUNCTION OF THICKNESS)
ALLOWABLE SUSTAINED LOAD STRESS
INPUT REQUIREMENTS
• SERVICE CONDITIONS
· DESIGN LOADING SPECTRA
· SUSTAINED 1g LOADS
· ENVIRONMENTS
· TARGET LIFE
• INITIAL FLAW SHAPES
• MATERIAL PROPERTIES
S-N
ESTABLISH Q/A PROGRAM
WING AND WING CARRY THROUGH TRADE STUDIES
INPUTS
· PRELIMINARY CONCEPTS
· MATERIAL PROPERTIES (CLASS)
· CONFIGURATION CONSTRAINT
· INTERNAL LOADS
TECHNICAL DATA BANK
INITIAL ADVANCE MATERIALS SCREENING

tion and a deeper understanding of structural response for prevention of failure.

Perhaps an insight into the use of the materials and process specifications and the materials properties data base in modern preliminary design in the preliminary design of a lighter aircraft, as shown in the chart of table 5, can indicate the importance of the specifications and materials properties data base.

The materials-testing requirements shown at the top of the chart would be accomplished on the candidate materials of interest in the forms necessary to generate the data needed, shown in the tables under "preliminary design, " In many cases if the data are not available, this test program for materials characterization could cost several millions of dollars for only a selected few mill forms of one material. The materials/process capability (specifications) would be evaluated, and if needed new specifications would be written or old ones modified or revised. The mechanical properties needed are illustrated in the tables given, as well as the method used in rating the materials.

The inputs required to ensure structural integrity for fracture mechanics and fatigue analysis under the proposed conditions are also detailed. The advanced screening and analysis then is made consistent with the requirements imposed by stress analysis, and mode studies are then accomplished against the initial conceptual design. All of these data make up the initial technical data bank. From this discussion it is evident that new approaches to these problems are needed. The questions that need answering are:

1. How can the DOD best use the resources of the voluntary standards organization, i.e., SAE, ASTM, AWS, AS ME, etc., to help update and prepare specifications in the materials and process field so that they are available and timely for new weapon systems production?
2. How do other agencies of the Federal Government prepare and update their specifications? Did the DOD and other agencies, i.e. NASA, ERDA, etc., coordinate their act iv i ties ?
3, Should there be a national standards system supported by the Federal Government of which the DOD would be a part ?
4. What effect will proposed legislation such as the Voluntary Standards and Certification Act of 1976, which among those proposed is the development of a uniform national standardization process, have if passed?

As to the materials properties data base problem, industry and the military spend large amounts of resources to characterize materials properties, Too often the data are scattered throughout development contract reports without organization, and there is no uniform method or requirement as to how these data should be analyzed, collected, and disseminated. There is a major need for Government and industry to get together to do this to save manpower and resources and to determine what data are really lacking so that the declining DOD resources in this area can be made more effective. The major policy question is then how best to' accomplish this.

Problems Limiting Development of New Systems and Weapons

There is no doubt that one of the most promising materials concepts for efficient structures in the newer weapon systems will be the use of high-stiffness, high-strength filamentary composites. I would like to use this structural concept as my second example to highlight the question of what is the best way to expedite the development of materials and technologies that limit the development of new systems and weapons, and to point out the problems of the transfer of this technology from R&D to production.

An example of some lessons learned in a major application of composites to a new strategic missile program can perhaps highlight the problem, may help this group in formulating some new ideas on how to do it better and more efficiently, and may even help detail ideas on how the DOD can better coordinate its R&D programs to insure more rapid application to weapon systems.

The Technology Transfer Problem With Composites

During the past 15 years, military aerospace interest in applying composites has been motivated by the desire for "more efficient" aerospace structures that can be lighter, stiffer, and stronger, together with the hope that they will be more durable and cost less. These have been the evaluation and selection criteria for the development and acceptance of composites. *

Certain benefits have accrued to the application of composite materials in the last 15 years (shown in table 6). Although significant progress has been made, problems remain which affect the further development and use of composite materials in military aircraft (table 7).

Perhaps as much as $500 million or more has been spent in this development, If the commercial aircraft applications are considered, perhaps another $100 million has been spent, and the

" Summary of "The Influence on Advanced Composites–An Assessment of the Future", june 11-12,]975.

TABLE 6. – Benefits Accrued and Progress Made Composites Structures Development *

1. Simultaneous development of materials, design, and manufacturing technologies rather than a sequential approach.
2. Early achievement of production applications, such as F-14 and F-15 empennage components,
3. Development of basic technologies at user facilities rather than exclusively at universities and Government laboratories.
4. Clear demonstration of an initial goal of potential weight savings on a substitute basis.
5. Development of competitive material sources on a commercial basis,

‘Conference on Advanced Composites–June 11-12.1975

TABLE 7. –Problems Remaining in Composites Materials Affecting Further Development and Use in Military Aircraft

1. Overselling composites through 100% usage for structural components.
2. Cost of material (e.g. tape) does not reduce as rapidly as projected,
3, The nonuniformity of materials is a normal occurrence.
4. Some programs experience “start’ ’-’’false start” and ‘*stop’- ’’go” syndromes.
5. Program delays due to Government inter-laboratory conflicts on responsibilities and goals.
6. Conflicts within a company between experienced metal designers and new composite design specialists.
7. Lack of confidence in small statistical samples of components.
8. Marginal cost tradeoffs and unclear cost-benefits.
9, No realistic definition of a successful “Goal” has been established.
10. New vehicle totally dependent on composites for its success is not like! y.
11. Misconception that all aerospace companies progress uniformly and share equally on developments.

Source: Conference on Advanced Composites-]une 11-12. 1975,

programs of both DOD and NASA indicate another $2OO million may be spent in the next 5 years. With this major expenditure over this length of time (2o years before major commitments to production), we might ask why so long a time and so much money, or, more importantly, have our resources been properly spent in pursuit of these deserving objectives?

Perhaps the qualification of composites for full scale application poses problems that from a cost and time point of view make the application of composites on an ongoing program difficult to accomplish. When this is coupled with the need to develop not only structural concept verification but also NDI acceptance criteria with a minimum data base, the confidence level for application then is not too high.

In order to assure structural integrity, the qualification testing (hot and wet fatigue testing as one example) does much to inhibit their use. One might ask what sort of a policy should best be pursued to stimulate more rapid applications? Should the DOD impose all of the requirements that seem much more difficult to satisfy than with metallic structures? Or should the DOD adopt the posture of the FAA in application to commercial aircraft where industry and the agency (FAA) together determine the optimum procedures for certificating end use based on the best judgment of the producers of the structure and a consensus of all interested industry members before "rule making" is applied?

In the field of composite application, systems performance can sometimes be the major driving force for commitment to development and production, It also can require a coordinated design team approach from the time of preliminary design to first lot production to insure cost-effective commitment to production and use. An example of this is the present application of graphite/epoxy composites in the Trident C-4 missile structure.

In reviewing the various means of fabricating missile structures to reduce weight and increase the range, graphite/epoxy materials provided a high, strength-to-weight ratio material that could be utilized in current production. The equipment segment of the C-4 Trident was chosen as the optimum structure to be designed from graphite/epoxy material since a weight reduction in this segment provides the greatest increase in the mission performance. Since the development phases of the C-4 program were followed very closely by the production program, it was essential to select a material satisfactory for design and producing components with high reliability and at a reasonable cost. For these reasons, the graphite/epoxy was selected as the advanced composite material that would provide the best opportunity for meeting these objectives.

In the initial materials evaluation, the graphite/epoxy tape produced satisfactory components; however, the manhours required to layup the complex shapes using the tape was excessive. and the orientation of the tape, gaps, voids and other discrepancies was difficult to control. A combination engineering/manufacturing development program with graphite/epoxy fabric showed that the fabric could meet all of the engineering requirements and result in an overall reduction in fabrication cost. Therefore, the graphite/epoxy fabric was adopted as the prime candidate for the graphite components.

Working closely with design, structures and materials, and process engineering, manufacturing concepts were established that would produce reliable, repetitive components at minimum cost. For many components, the autoclave cure method was found to be the optimum process, while other components were found to be produced more efficiently using matched dies on the silicone rubber mold technique for obtaining pressure. A close working relationship between engineering and manufacturing permitted the design, process, and acceptance criteria to be reviewed for each part; and changes were made, when possible, to permit ease of manufacturing. To ensure a repetitive high quality structural component, each initial production part is process verified to measure mechanical properties, to confirm process and document control, arid to substantiate adequacy of the tooling, Then, after successful completion of process verification, no changes are made in processes, controls, tooling, or other variables that could effect the integrity of the composite component.

The use of graphite fabric, cut-out templates, matched dies, establishment and control of the cure cycle, tooling aids to assist layup, and no modification of the manufacturing and process cycles after the fabrication of the initial production parts were some of the factors that greatly assisted in maintaining a low manufacturing cost for the composite parts. Although the initial development cost of the composite parts was higher than initially predicted, the learning curve drops rapidly as the production process is established. The close initial coordination between engineering and manufacturing in designing and manufacturing toward one composite concept pays off rapidly in the lower repetitive cost of the production parts.

In the course of this development, a number of key lessons were learned in the application of composites structures that indicate the unforeseen problems that can arise in the course of the introduction of a new structural materials concept to production, These include:

1. Composites pay off when everything works;
2. Serial production development does not work;
3. The use of woven cloth pays off big in certain applications:
4. There is a tendency for engineering to over-design for conservative reasons when the data base is not complete;
5. Structural analysis techniques are quite good for composites;

6. Tooling developments are tougher than expected:
7. Metal tolerances do not apply;
8. Training requirements can be grossly underestimated:
9. The QA accept/reject criteria can be a quagmire; and
10. The selection of the proper manufacturing manager can be quite critical.

My last example has to do with materials research and materials needs, particularly long range needs of the DOD and the policy as to who does it, and the way the R&D programs can best be coordinated for the developments of new materials and technology, It is not only in filamentary composites that we look for enhanced structural efficiency and durability, Future aircraft, for example, are still expected to use aluminum alloys as the principal material of construction, even though there may be increased use of composites in competition with aluminum and continued use of steels and titanium for special design applications.

Aluminum Alloys

The principal trend in aluminum alloy development for airframes has aimed at improved corrosion and stress corrosion resistance and increased fracture toughness. Improvements in these characteristics have generally been accompanied by a reduction in strength properties. This trend is clearly illustrated in figure 1 which indicates that the 7178-T6 composition remains the highest strength aluminum alloy available today. It was first used extensively 25 years ago; however, unfavorable stress corrosion and exfoliation experiences have limited its application during the past 10 years. Therefore, a high-priority need exists for a replacement material for 7178 which provides strength properties equal to or greater than 7178, with greatly improved toughness and corrosion-resistance characteristics. Such a product could be used to provide the following benefits in typical applications on a transport aircraft as well as high performance fighter aircraft.

Aluminum alloys with improved fatigue and stiffness are also of great interest and would obviously translate into similar weight reductions when used in airframe applications designed to fatigue and stiffness criteria. Ongoing research and developments in aluminum alloys that hold great interest for potential applications in airframe design include A1-Mg-Li alloys, powder metallurgy processing, controlled solidification process, and retrogressive aging (table 8).

FIGURE I.—Aluminum Alloy Developments

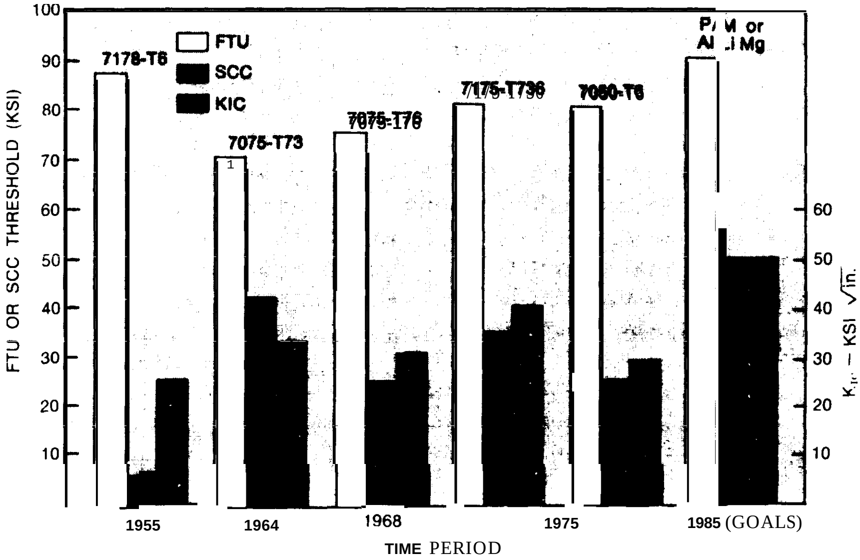


TABLE 8.—Potential Weight Reduction in Cargo Aircraft With Advanced Aluminum Alloys

Product and Application	Material Now Used	Potential Weight Reduction with an Advanced Alloy	Approx. (Ibs.) Reduction in Annual Fuel Consumption*
Misc. Forgings (2000 lbs.)	7075-T73	300	42,000
Extrusions (5000 lbs.j Horizontal Stabilizer & Beam Caps	7075-T76	400	56,000
Fuselage Floor Supports (3000 lbs.)	7075-T76	150	21,000
Fuselage Skin (900 lbs,)	7075-T76	80	11,000
Upper Wing Skin (6000 lbs.)	7075-T76	540	70,000

* Per aircraft, 3000 hours utilization per year.

Another perspective of alloy needs can be gained by a review of service problems with materials used in current aircraft construction. Failures experienced with current aluminum, titanium, and steel materials most often result from residual stress, stress corrosion, cracking in mechanical fastened joints, misprocessing, poor surface condition, corrosion or poor detail design which introduces stress concentrations such as sharp corners, abrupt stiffness changes, etc. Obviously, most of these problem sources cannot be directly remedied by providing the aircraft designer with an improved alloy which has optimized only for metallurgical features concerning micro-constituents, morphology, atomic bonds, aging kinetics, and defect densities.

The state of the art in high-strength steels is a case in point. Virtually all large aircraft for the past 20 years have used, and will continue to use, high-heat treat (260 KSI rein), low-alloy steels, primarily of the 4340 or 300M grades. The reasons are these steels offer the best combination of structural-strength and fatigue-strength efficiency at moderate costs. Successful use of these steels is achieved through precise design practices and controls, and very careful attention to all stages of processing and fabrication. Experience with thousands of HHT steel parts has evolved empirically-derived limits on sustained stress levels to avoid stress corrosion cracking (SCC). As shown in figure 2, sustained stresses in short transverse grain may typically be limited to only 25 percent of yield strength to avoid SCC. Clearly, steels capable of much higher thresholds would be very welcome to the aircraft designer, Similarly, fracture toughness related properties of KI_c and KI_{scc} of commonly used low alloy-steels show considerable room for improvement. (figure 3). This latter figure also indicates the trends in alloy development which certainly are in the proper direction.

The past 20 years have seen numerous unsuccessful attempts at "alloy design" to obtain new improved high-strength steels to replace the currently used low-alloy steels. One reason for this lack of success has been the failure to adequately consider the importance of the "engineering end of the classification scale" wherein 300 M- and 4340-type materials provide capability for readily attaining consistent, high integrity in large parts through highly developed melting, forging, heat treatment, and other practices. Too often laboratory alloy developments have been prematurely touted for their "significant breakthroughs" in SCC and/or KI_c properties, only to find this improvement has been attained at the expense of such a drastic sacrifice in processing and producibility that it precludes the alloy ever reaching pro-

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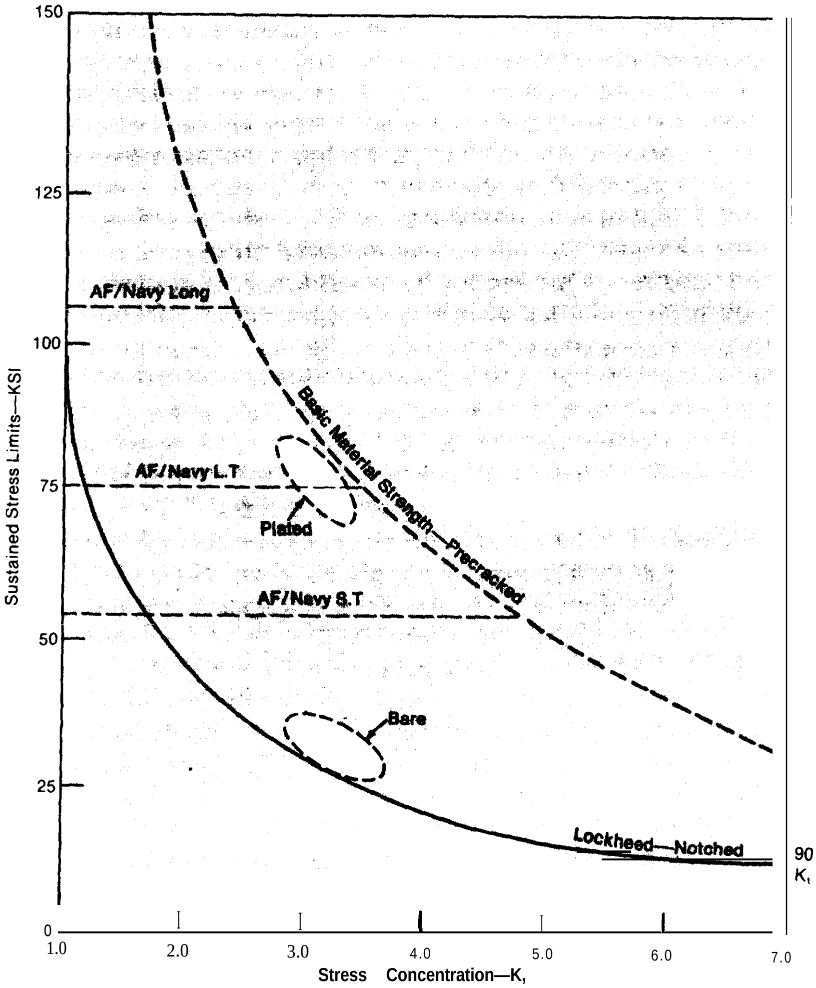
FIGURE 2.

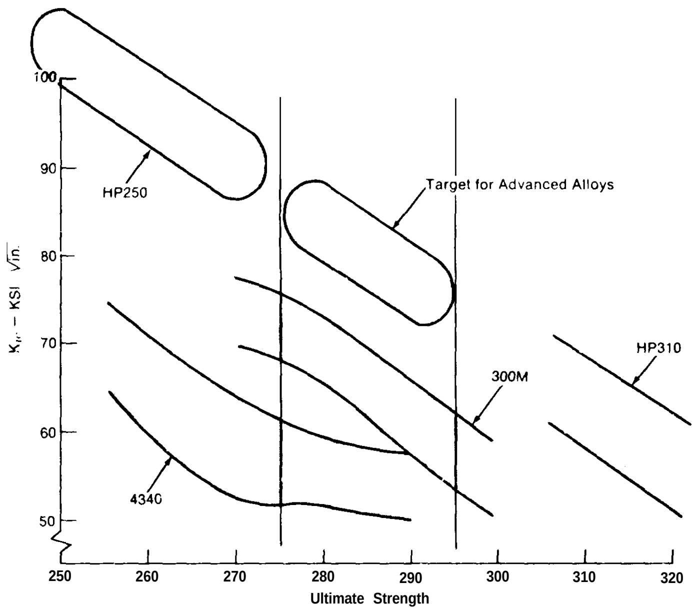


duction status, The aircraft industry is extremely interested in alIoy development of improved damage tolerance and more stress corrosion-resistant, high-strength steels; therefore, we urge those engaged in such alloy development to include producibility criteria in their development parameters so that processability of new materials at least approaches that of current alloys, as indi~ cated in figure 3.

Current R&D Trends and Airframe Titanium Alloy Needs

Improvement in present alloys is being sought through using cleaner master alloys and improved melting procedures. Higher

FIGURE 3.–Fracture Toughness Versus Strength for Steel Alloys

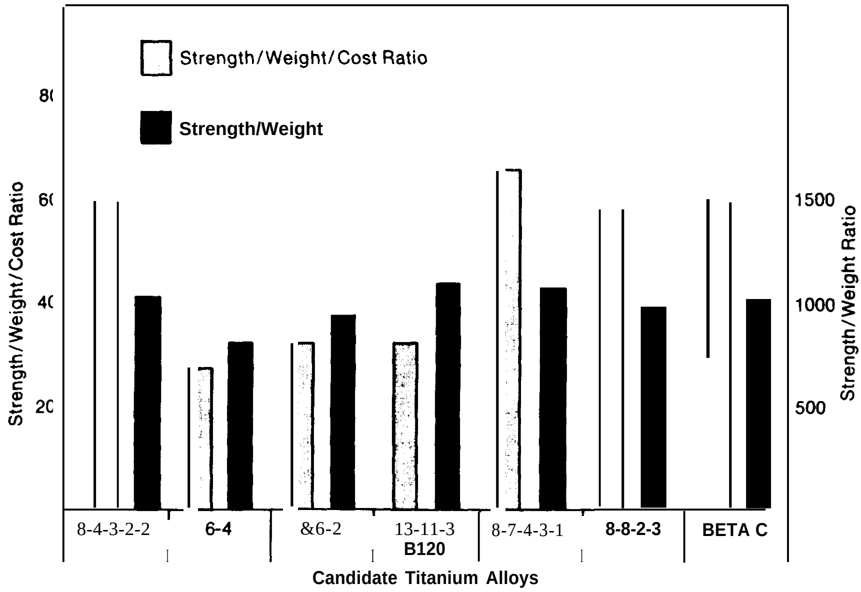


strength alloys are being investigated through interstitial hardening of beta and alpha-beta alloys and by developing alloys with modulated microstructure,

The raw material cost of an aluminum fighter is 2 percent of the fly-away cost; for 100 percent titanium, the raw material cost is 5 percent of the fly-away cost. If titanium raw material costs were halved, the fly-away cost of an all-titanium fighter aircraft would change by only 3 percent. It is apparent that raw material cost of titanium is not of major importance, and that the cost of fabrication is the significant factor. Improved cold-formable and age-hardenable beta alloys have made their appearance. Further improved performance is expected from alloys now in development. These new developments are expected to expand the use of titanium through Iowering fabrication costs and increasing the utilization ratio, as depicted in figure 4.

It is not only in supersonic aircraft that titanium can be used to advantage in airframes. The use of titanium will increase with the trend to larger cargo aircraft. The longer sections and spars of the larger aircraft have rigidity requirements beyond the capacity of aluminum alloys. Titanium alloys with elastic modulus values from 50 to 80 percent higher than aluminum alloys. and possessing increased strength and corrosion resistance represent optimum materials for airframe construction.

Figure 4.



The strength of conventionally heat-treated, alpha-beta alloys and beta alloys is being substantially increased to the 250-ksi level by texture hardening and thermo-mechanical treatments, and by producing modulated microstructure in current commercial alloys. Finally, deep-hardenable, alpha-beta alloys are being explored as replacements for high-strength steels in landing gears.

All of these potentials with advanced metallic materials of construction for high-performance structures require considerable amounts of R&D for the understanding and control of microstructural features, heat treatments, alloy composition, etc., to achieve these improvements. Besides improvement in alloy chemistry and microstructure, we are in dire need of better test methods to develop economical test methods for evaluating crack growth-resistance behavior of materials.

The policy question, then, with these examples is how best to marshall our national resources to achieve these aims. Are our present methods of utilizing university, industry, and Government facilities too fragmented and too remote to be able to work to the solutions of these problems effectively? How can industry, which is prevented from joint or cooperative efforts, somehow optimize its nonproprietary R&D in materials more expeditiously? How can information generated on the many R&D programs be assembled, analyzed, and presented as a materials data base for use by designers in a more efficient and economical manner? Can the DOD lead in marshaling this R&D? If not the DOD, then who in the Federal Government can? The analyses and solutions to these problems with some pragmatic recommendations by this fourth Henniker Conference will do much in assuring its success.