CONSERVATION OF STRATEGIC METALS

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INTRODUCTION

NASA Lewis Research Center has undertaken a long-range program in support of the aerospace industry aimed at reducing the use of strategic materials in gas turbine engines (refs. 1 and 2). The program, which is called COSAM (Conservation of Strategic Aerospace Materials), has three general objectives:

(1) Contribute basic scientific understanding to the turbine engine "technology bank" so that our national security is not jeopardized if our strategic material supply lines are disrupted

(2) Help reduce the dependence of United States military and civilian gas turbine engines on worldwide supply/price fluctuations in regard to strategic materials

(3) Through research, contribute to the United States position of preeminence in the world gas turbine engine markets by minimizing the acquisition costs and optimizing the performance of gas turbine engines

NASA plans to accomplish these objectives of the COSAM Program by three major research thrusts: strategic element substitution; advanced processing concepts; and alternate material identification. Results from research and any required supporting technology will give industry the materials technology options it needs to make tradeoffs in material properties for critical components against the cost and availability impacts related to their strategic metal content. This paper presents an overview of the COSAM Program and briefly highlights the early progress that has been made.

VULNERABILITY OF U.S. AEROSPACE TO SUPPLY INSTABILITIES

The COSAM Program uses the following as a working definition of strategic metals: "those predominantly or wholly imported elements contained in the metallic alloys used in aerospace components which are essential to the strategic economic health of the U.S. aerospace industry." As a result of meetings with the ASME Gas Turbine Panel in 1979 and a survey of aerospace companies in 1980, the COSAM Program was focused primarily on the needs of the aircraft engine industry. Based on these findings and other discussions with several aircraft engine manufacturers, four elements emerged that were of particular concern. The alloys used to build the critical high-temperature components for aircraft propulsion systems require the use of the four metals - cobalt, tantalum, columbium, and chromium. Today we are almost totally dependent on foreign sources for these metals (fig. 1). In several of the countries listed in figure 1, political disturbances have led to supply interruptions. Therefore, the U.S. aircraft engine industry is very vulnerable to supply instabilities of the essential metals needed for engine manufacturing.

METAL	% IMPORTED	MAJOR FOREIGN SOURCES
COBALT	97	ZAIRE, ZAMBIA
COLUMBIUM	100	BRAZIL, CANADA
TANTALUM	97	THAILAND, MALAYSIA
CHROMIUM	91	SOUTH AFRICA, ZIMBABWE

Figure 1

STRATEGIC MATERIAL RESOURCES IN AFRICA

Currently, the African Third World nations of Zaire, Zambia, Zimbabwe, and South Africa play a major role in supplying strategic materials to the United States (fig. 2). Foreign cartels, political unrest, and production limitations have led to severe market availability/cost fluctuations. In fact, such problems could lead to a total interruption of flow of such strategic metals in times of world crisis. There are regions of instability (ref. 3) in Africa where some political groups might be able to wage "a long-term resource war against the U.S." (ref. 4).

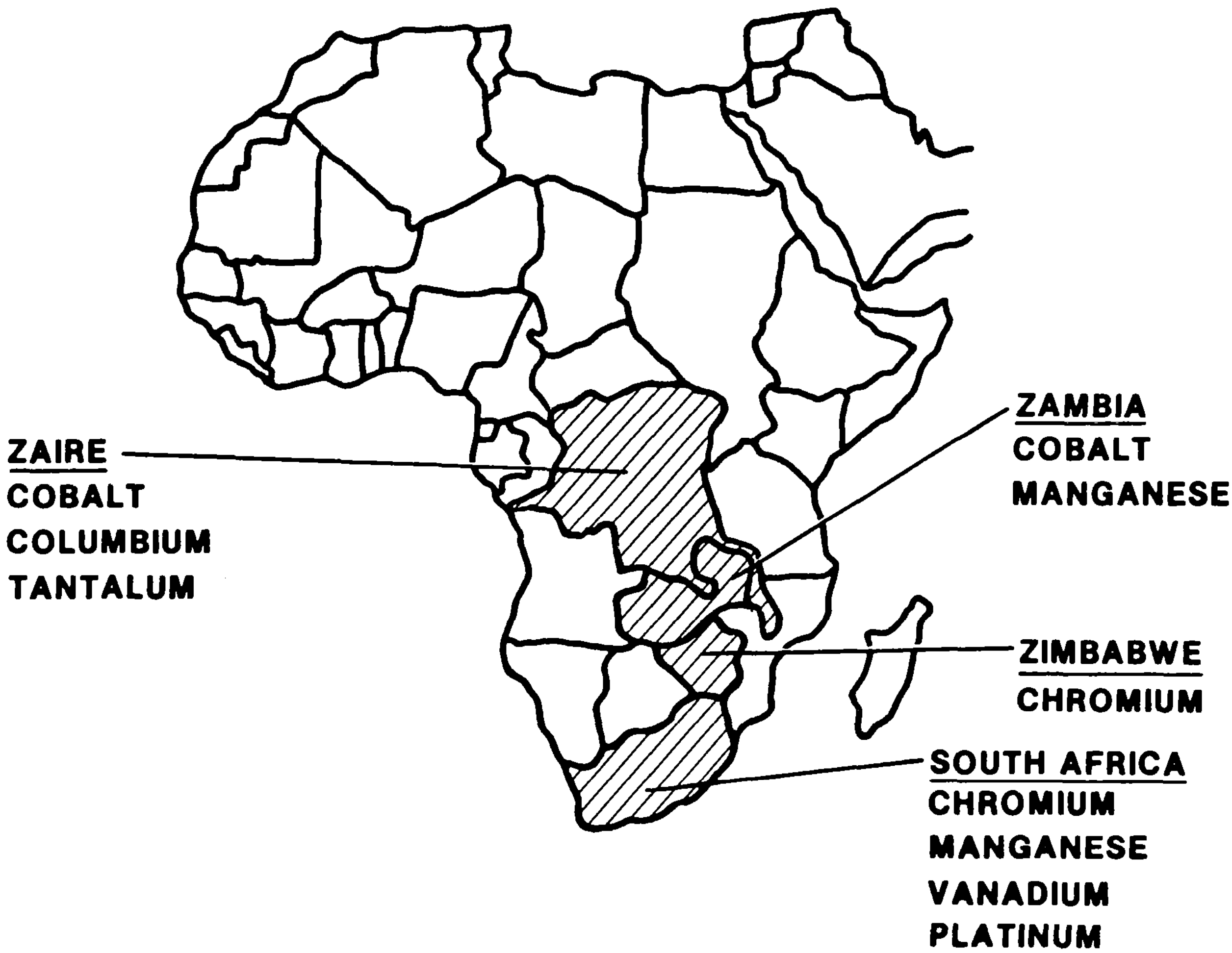
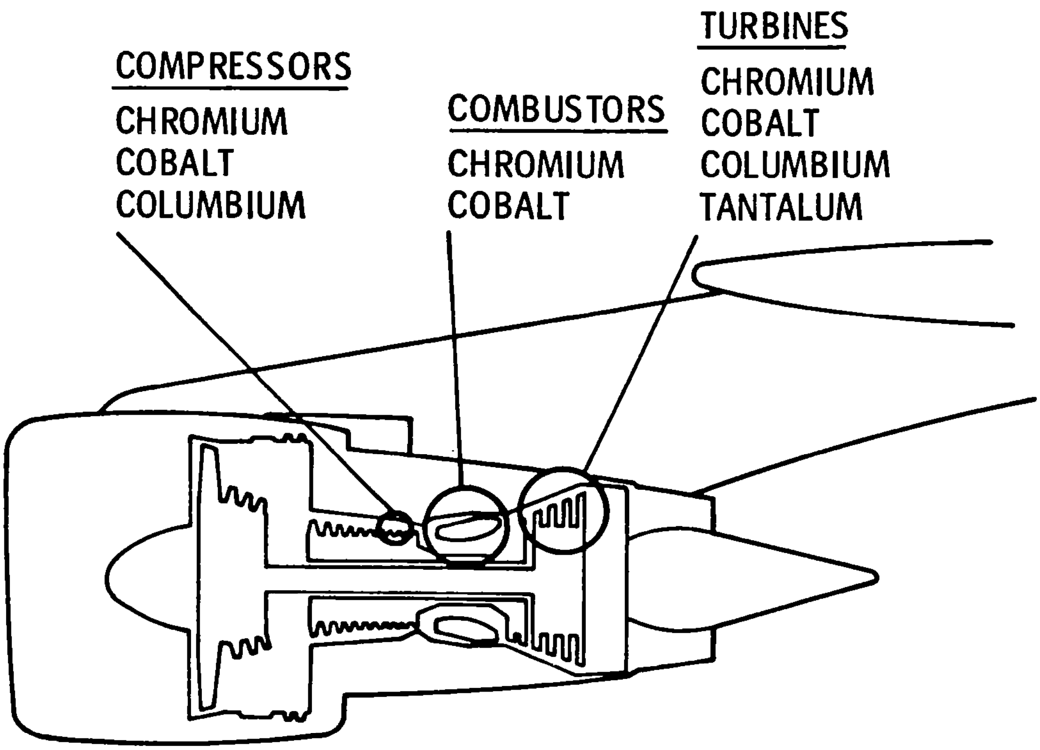


Figure 2

DEPENDENCE OF GAS TURBINE ENGINES ON STRATEGIC METALS

The strategic metals cobalt, tantalum, columbium, and chromium are contained in superalloys, steels, and stainless steels that are used in engine manufacturing. The locations of these metals in aircraft engine compressors, turbines, and combustors are shown in figure 3. The need for these metals has increased as the demands have grown for higher durability plus higher performance fuel efficient aircraft turbine engines. Based on the essential nature of these metals and in order for the U.S. aircraft industry to maintain its competitive position, supplies must be readily available at a reasonably stable cost.



NEEDED FOR PERFORMANCE AND LONG LIFE

COBALT - HIGH TEMPERATURE STRENGTHENER
COLUMBIUM - INTERMEDIATE TEMPERATURE STRENGTHENER
TANTALUM - OXIDATION RESISTANCE
CHROMIUM - CORROSION RESISTANCE

Figure 3

VOLATILE AND UNPREDICTABLE PRICES OF STRATEGIC MATERIALS

Because of supply disruption or increased demand, it is not uncommon for price changes of several hundred percent to occur (fig. 4 and ref. 5). These rapid price increases illustrate the vulnerability of the U.S. aircraft engine industry to cost fluctuations. The essential nature of chromium, cobalt, columbium, and tantalum and their vulnerability to supply instabilities and cost fluctuations combine to cause these metals to be classified as strategic aerospace metals. The possibility of a total supply disruption during a time of worldwide crisis is, of course, readily recognizable.

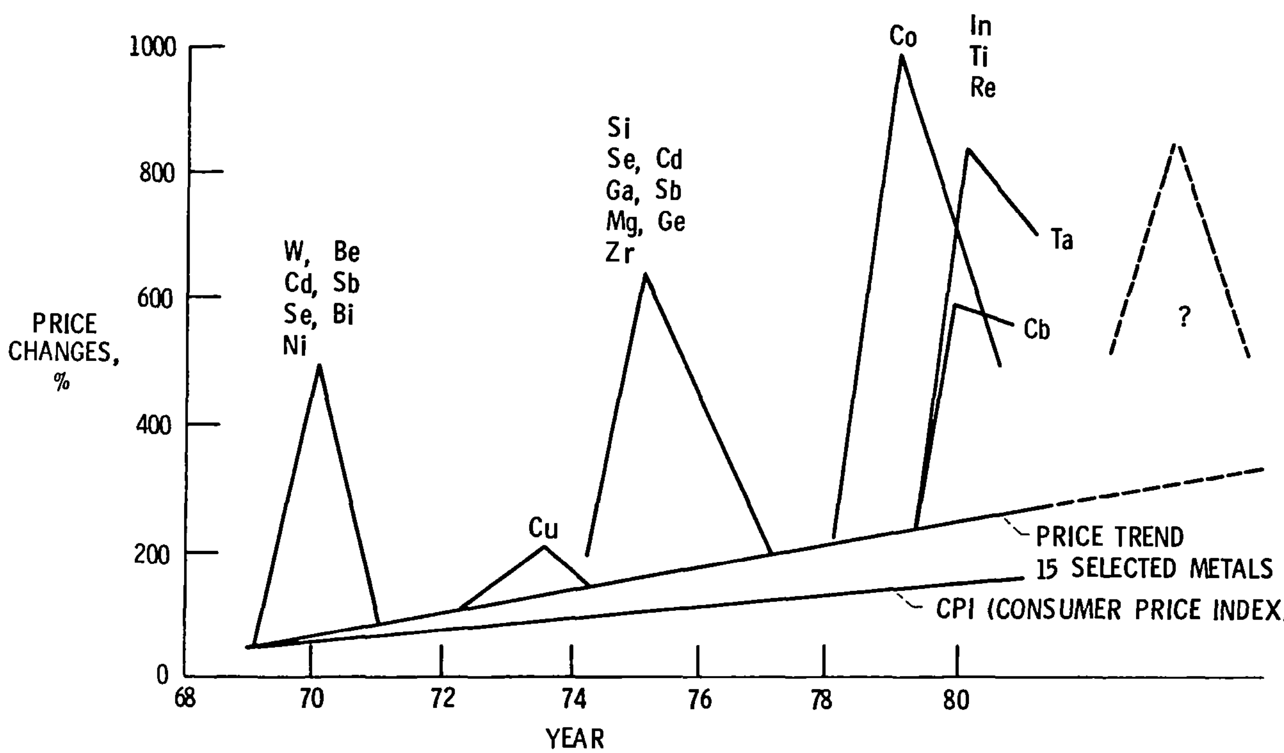


Figure 4

MAJOR THRUSTS OF COSAM PROGRAM

The three objectives of the COSAM Program given in the INTRODUCTION are being accomplished by a systematic basic research and technology effort aimed at reducing the need for strategic metals in advanced aerospace components. The COSAM Program is aimed at providing industry with options so that they can make their own property versus availability/cost tradeoffs when selecting aerospace alloys. The three-pronged approach to COSAM is shown in figure 5. It consists of research on strategic element substitution, advanced processing concepts, and development of alternate materials. Conservation, as well as reduced dependence on strategic metals, will be achieved in the area of strategic element substitution by examining systematically the effects of replacing cobalt, columbium, and tantalum with less strategic elements in current, high use engine alloys. Conservation through advanced processing concepts research will be approached by investigating the interface stability in a simulated dual alloy or tailored structure (use strategic metal containing alloys only where needed) component. In the longer term, developing (higher risk) alternate materials that are readily available in the U.S. to replace the most strategic metals could lead to a dramatic reduction in our dependence on foreign sources. These last two technology areas will also help conserve the strategic metals cobalt, tantalum, columbium, and chromium.

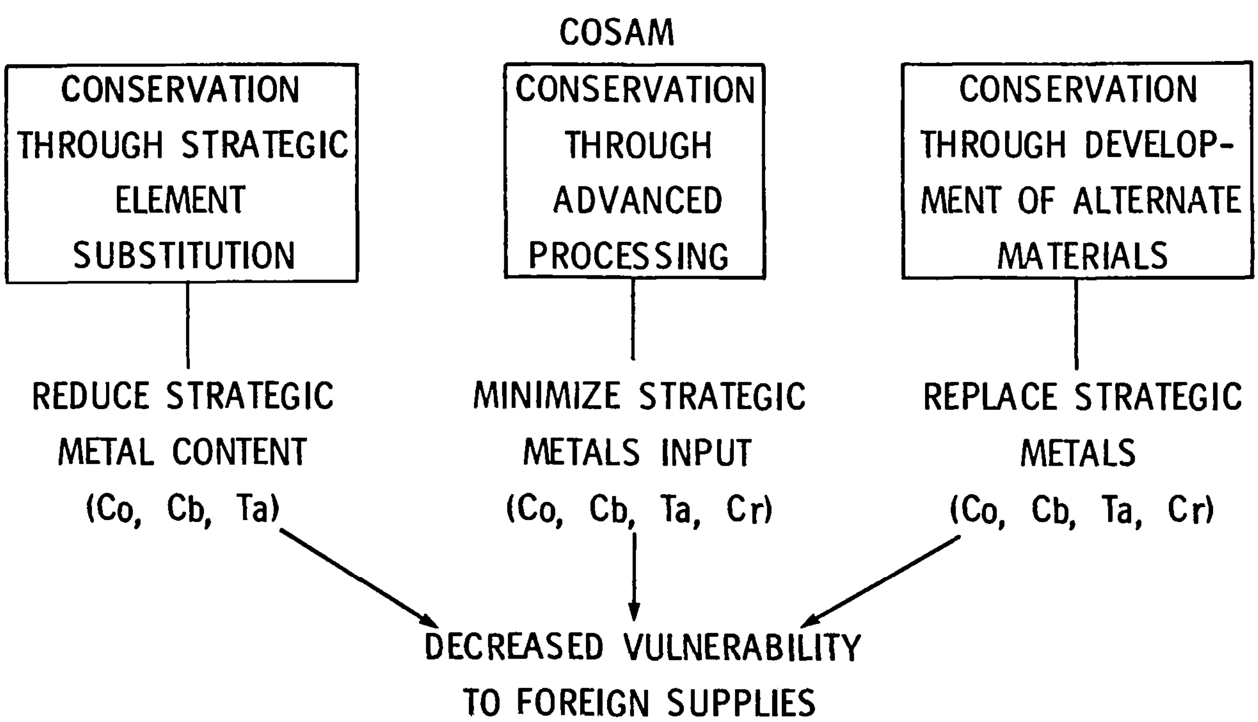


Figure 5

COOPERATIVE NASA-INDUSTRY-UNIVERSITY PROGRAMS

Various research efforts are being conducted under the overall programmatic management of the NASA Lewis Research Center. Some of this work is being conducted in-house at Lewis. There are also cooperative programs under way involving Lewis with both industry and universities to optimize the expertise at each organization and to seek synergistic results from the combined efforts. This research cooperation is presented graphically in figure 6. Typical roles for each organization are shown. These roles, of course, vary from program to program. For example, one project can involve an industry contract or a university grant for the bulk of the effort with a range of supporting contributions from the other partners. Another project may be conducted mainly in-house at Lewis with a range of support from industry or a university. The subsequent figures outline some of the current projects and present limited highlights of results obtained to date.

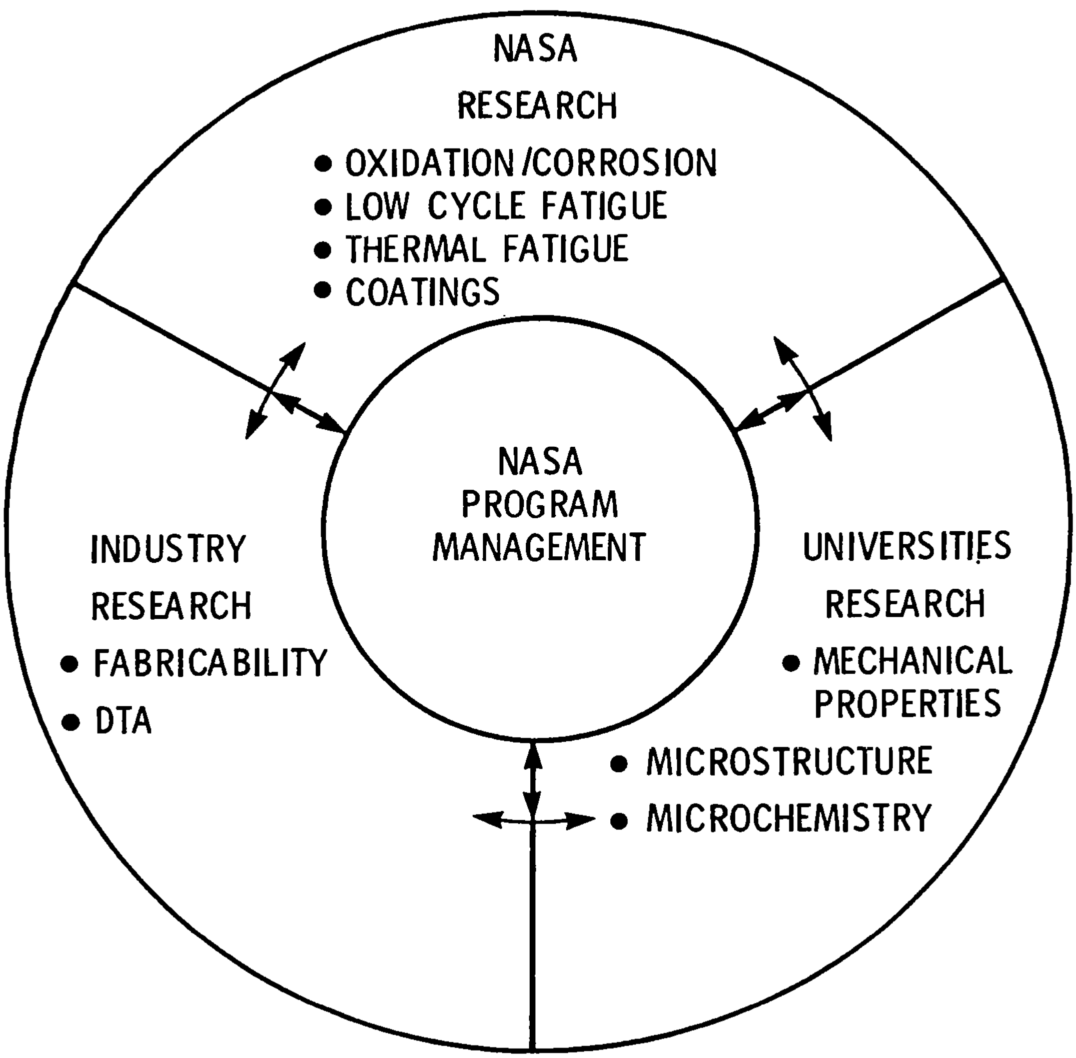


Figure 6

RECENT TRENDS IN UNITED STATES AND AEROSPACE COBALT USAGE

As a result of the high cost of cobalt in 1978 and 1979, the United States has experienced a decline in cobalt usage (ref. 6). Figure 7 shows that 20 million pounds of cobalt were consumed in 1978 but that by 1981 usage was down to an estimated 13.6 million pounds, a reduction of about 33 percent in only 3 years. During this same period, the use of cobalt to produce superalloys, primarily nickel-base alloys for aircraft engines, increased from 4 million pounds in 1978 to a peak of 7.2 million pounds in 1980 before it declined to an estimated 5.4 million pounds in 1981.

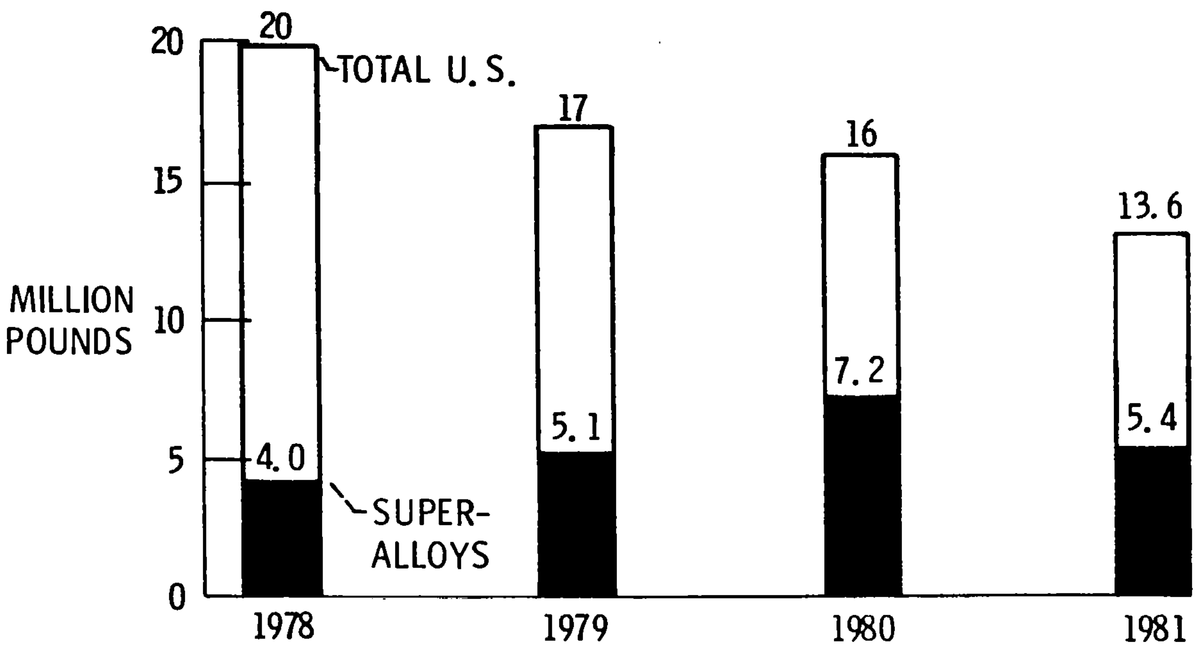


Figure 7

DISTRIBUTION OF 1981 UNITED STATES COBALT CONSUMPTION

The importance of cobalt to superalloy production is illustrated in figure 8. Of the 13.6 million pounds of cobalt consumed by the United States in 1981, 40 percent of it went for superalloy production. Because of the importance of cobalt to the aircraft engine industry and its high cost and lack of availability in 1979 and 1980, several programs were initiated to identify substitutes for it in a variety of nickel-base superalloys. Such programs could have long-term national benefits, and, in addition, the methodology developed in these programs could serve as a model for future efforts involving other strategic elements.

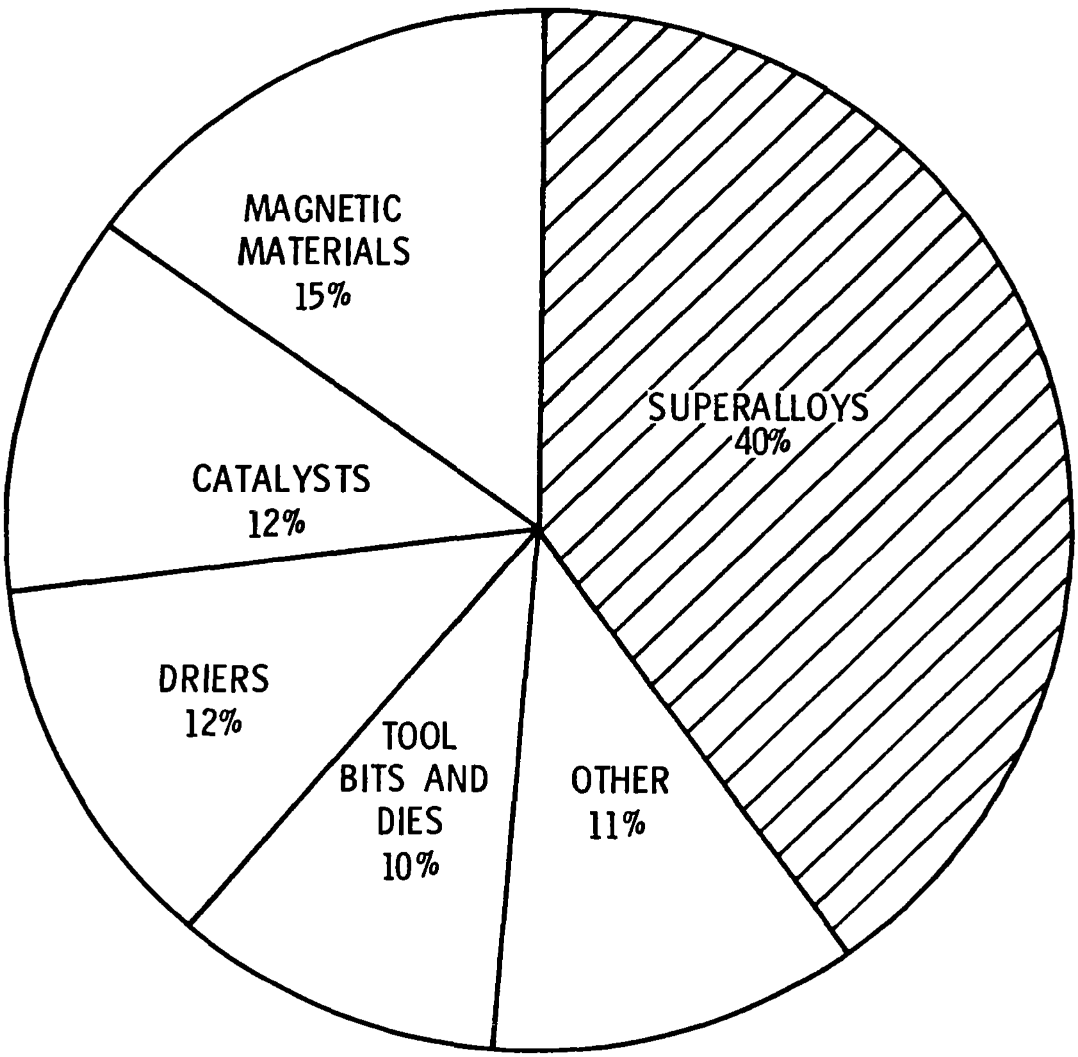


Figure 8

SUPERALLOYS SELECTED FOR COBALT SUBSTITUTION

Four nickel-base superalloys were selected for the COSAM investigation on cobalt. The four alloys are listed in figure 9 with their typical applications in the aircraft engine industry, the forms in which they are used and remarks as to why they were selected for the COSAM activity. Applications include turbine disks as well as low- and high-pressure turbine blades. A variety of product forms are represented by the applications of the four alloys as noted in the figure. The selection of the four alloys was based primarily on the considerations given in this figure. Waspaloy was selected because it represented the highest tonnage of cobalt in commercial aircraft engines. Udimet-700 was selected because it has a composition similar to many of the cobalt-containing nickel-base superalloys, and it is used in the as-cast, as-wrought ingot, as-wrought powder, and as-HIP powder metallurgy fabricated conditions. Thus, the composition versus processing study opportunities were great. The potential for determining the impact of cobalt on both conventionally cast and D.S. polycrystalline and single crystal turbine blades was the reason for selecting MAR-M247. René 150 was chosen because it is an advanced directionally solidified alloy.

ALLOY	TYPICAL ENGINE APPLICATION	FORM	REMARKS
WASPALOY	TURBINE DISK	FORGED	HIGHEST USE WROUGHT ALLOY IN CURRENT ENGINES
UDIMET-700	TURBINE DISK	FORGED	SIMILAR ALLOYS USED IN VARIOUS FORMS AND APPLICATIONS
(LC) ASTROLOY	TURBINE DISK	AS-HIP-POWDER	
(RENÉ 77)	TURBINE BLADES	CAST	
MAR-M247	TURBINE BLADES & WHEELS	CAST	CONVENTIONALLY-CAST, D.S. AND SINGLE CRYSTAL
RENÉ 150	TURBINE BLADES	DS-CAST	HIGHLY COMPLEX DIRECTIONALLY-CAST ALLOY

Figure 9

PARTICIPANTS' ROLES IN COOPERATIVE PROGRAM ON WASPALOY AND UDIMET-700

The cooperative nature of the research being conducted on Waspaloy and Udimet-700 is illustrated in figure 10. The role of industry, as represented by Special Metals Corporation, is to characterize and optimize fabrication and heat-treating procedures for the reduced cobalt Waspaloy and Udimet-700 alloys. The roles of Columbia University and Purdue University are also shown in the figure. Columbia University is conducting mechanical property characterization, structural stability, microstructural feature evaluation, and theoretical formulations to identify future alloy modifications, if required, for the second portion of the project. Purdue University is responsible primarily for microstructural and microchemistry characterization of the reduced cobalt content alloys. NASA Lewis is involved in special mechanical and physical metallurgy characterization of the alloys. The result of this cooperative effort is expected to be a clearer understanding of the role of cobalt in nickel-base superalloys.

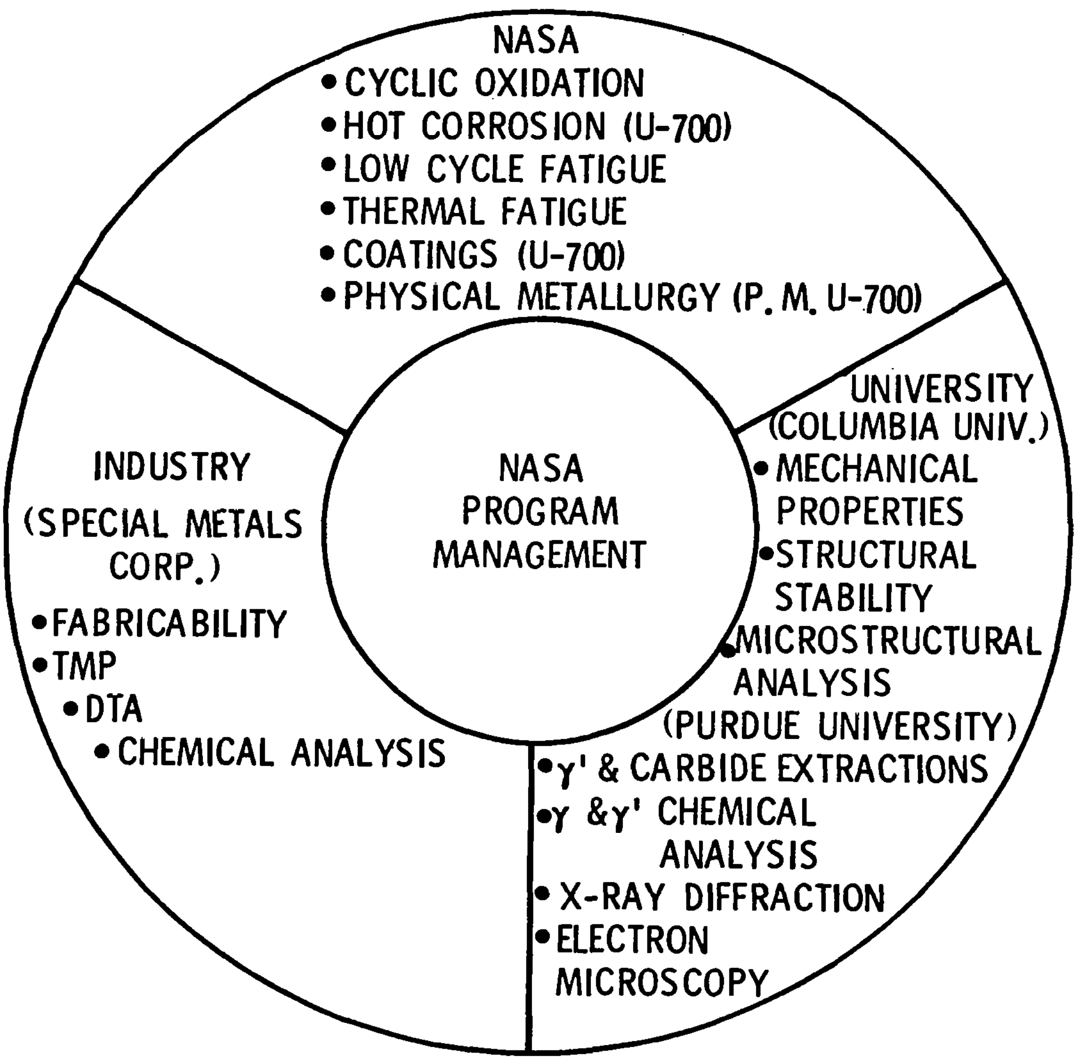


Figure 10

EFFECT OF COBALT CONTENT IN WASPALOY ON RUPTURE LIFE AND TENSILE STRENGTH

Some preliminary results on the effects of reducing cobalt in Waspaloy (13-percent cobalt alloy) were reported by Maurer et al. (ref. 7) of Special Metals Corporation. Highlights of that study are shown in figure 11. Tensile strength decreases only slightly as the amount of cobalt in the alloy decreases. However, rupture life decreased substantially with decreasing amounts of cobalt in Waspaloy.

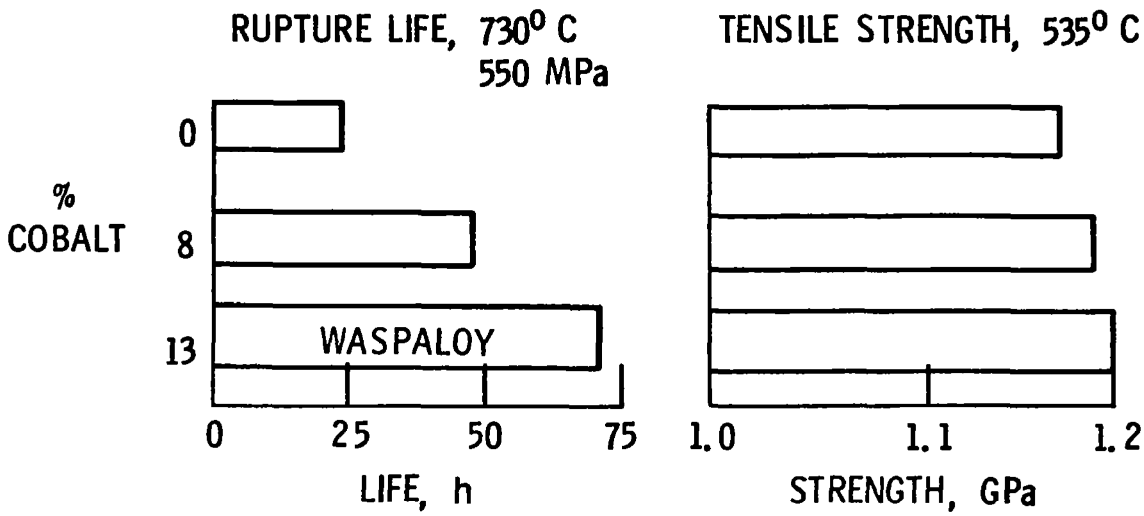


Figure 11

EFFECT OF COBALT ON CYCLIC OXIDATION RESISTANCE OF UDIMET-700

Research at NASA Lewis has focused on the cyclic oxidation resistance of the low/no cobalt Udimet-700 alloys. Initial results of this study are shown in figure 12. At 1100° C, removing cobalt from Udimet-700 improved the cyclic oxidation resistance based on specific weight change data; however, confirmatory metallographic analyses of the depths of attack have yet to be conducted. Tests at 1000° and 1150° C revealed a similar behavior. Hot corrosion resistance of the low/no cobalt Udimet-700 alloys is also under investigation at NASA Lewis. Initial qualitative results from tests using NaCl-doped flames in a Mach 0.3 burner rig indicate that corrosion resistance also increases with decreasing cobalt content.

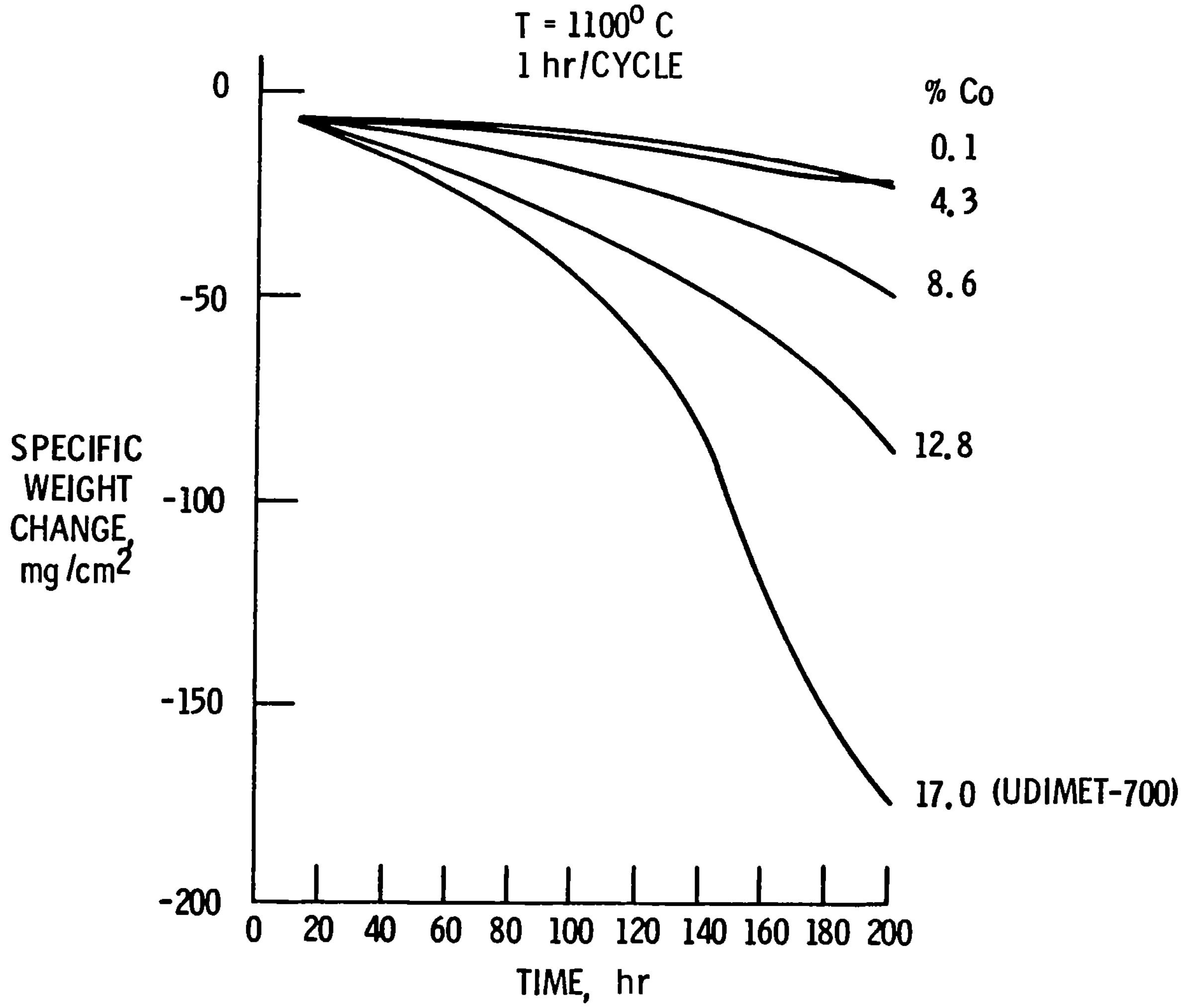


Figure 12

PARTICIPANT ROLES IN COOPERATIVE PROGRAM ON COLUMBIUM IN INCONEL 718

Columbium is considered to be a strategic aerospace metal because the United States imports 100 percent of it and because this metal is becoming increasingly important as an alloying element in nickel-base superalloys. The response of the aerospace industry to the cobalt shortage in 1978-79 was, in some instances, to switch to columbium-containing alloys as substitutes for cobalt-bearing alloys - for example, Inconel 718 (5-percent Cb - 0-percent Co) for Waspaloy (0-percent Cb - 13-percent Co). In 1980, 29 percent of the United States consumption of columbium went into the production of superalloys - the largest single use of columbium in the United States. Within the aerospace industry, Inconel 718 is probably the largest consumer of columbium. Inconel 718 is used as a turbine disk material. Disks are large, heavy components that contain the bulk of the columbium used. The increased demand for columbium in the aerospace industry has focused attention on identifying potential substitutes for it in nickel-base superalloys. A program has recently been initiated to identify potential substitutes for columbium in Inconel 718. This program is being conducted primarily under a grant with Case Western Reserve University. Special Metals Corporation has prepared the modified composition alloys and NASA Lewis is involved in evaluating alloy properties. The program organization is illustrated in figure 13.

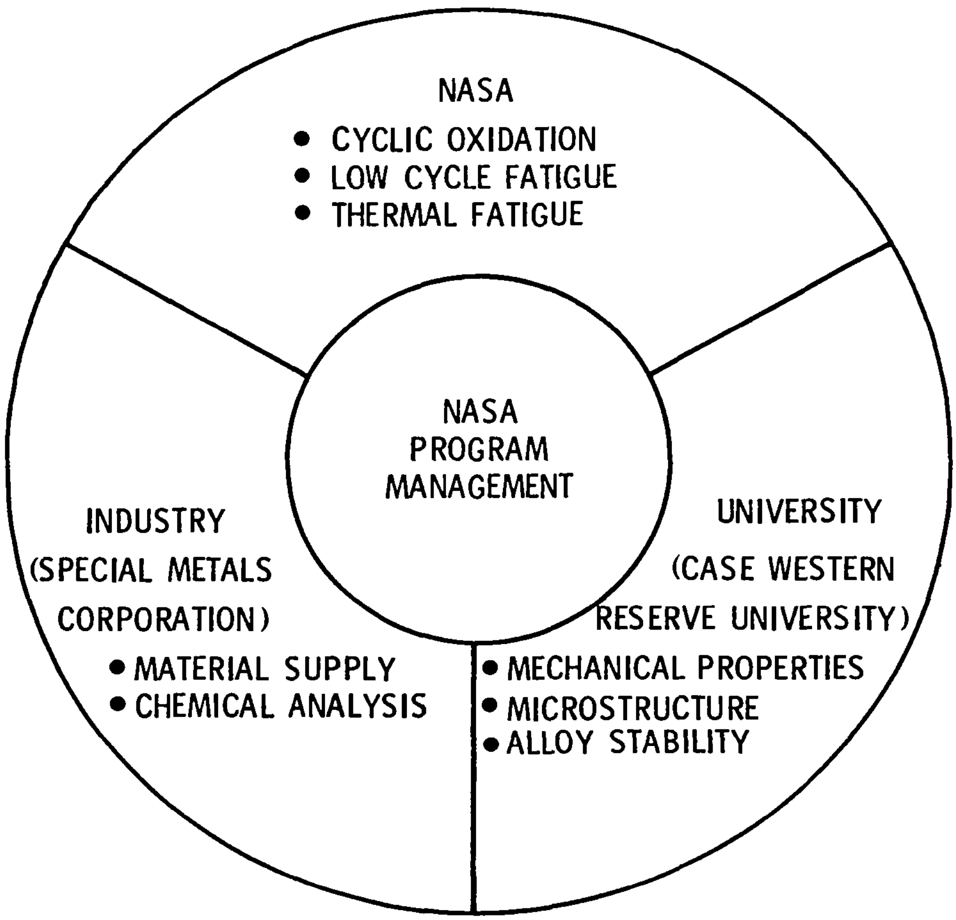


Figure 13

PARTICIPANT ROLES IN COOPERATIVE PROGRAM ON TANTALUM IN SUPERALLOYS

Tantalum is being used in advanced nickel-base superalloys primarily to improve oxidation resistance and to increase strength. Because of the increased use of tantalum in the aerospace industry and because the United States imports over 97 percent of it, this element is strategic and is of concern for the long term. Its major usage is for capacitors, another high national priority application, while the total use of tantalum in superalloys constitutes only about 6 percent of total United States consumption. However, tantalum is critical to advanced nickel-base superalloys. A joint Michigan Technological University/ General Electric/NASA Lewis program is just beginning to determine the role of tantalum in nickel-base superalloys. The program organization is shown in figure 14. Primary initial emphasis is on exploring the effects of reducing tantalum in conventionally cast, D.S. polycrystalline and single-crystal MAR-M247, an alloy that contains 4 percent tantalum. In addition, some limited studies will be conducted on B-1900+Hf, an alloy which contains 4.3 percent tantalum. Material for this part of the program is being supplied by TRW. Case Western Reserve University is exploring the effects of substituting tungsten for tantalum in single-crystal MAR-M247 alloys.

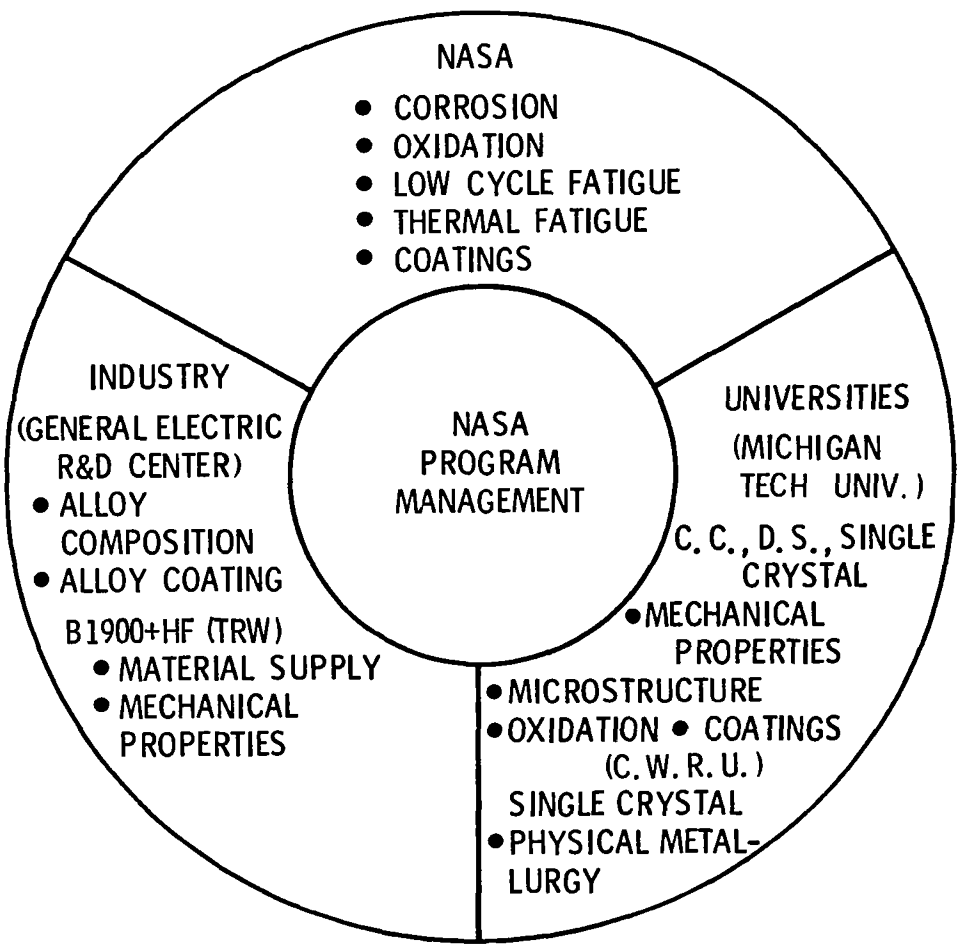


Figure 14

DUAL ALLOY INTERFACE STABILITY

The second major COSAM Program thrust is that of advanced processing. Turbine disks constitute a major portion of the weight of superalloys (and thus strategic materials) used in gas turbine engines. These components typically operate at higher temperatures in the rim and at lower temperatures in the hub area. In addition, creep is the primary deformation mechanism in the rim while fatigue resistance is required in the hub. Monolithic disks currently used are fabricated and heat treated to compromise the creep resistance that can be achieved with a large grain size material and fatigue resistance of a fine grain size material. An alternate approach would be to fabricate dual property disks (different heat treatments at the bore and rim) or dual alloy disks to optimize the required properties at the rim and hub. The concept of joining two P.M. nickel-base superalloys to achieve this goal was investigated by Kortovich (ref. 8) in a NASA Lewis sponsored program. The COSAM Program will carry this technique further by studying the feasibility of HIP joining a nickel-base alloy rim material and an iron-base alloy (low strategic metal content) hub material. The dual alloy joining concept is shown schematically in figure 15 along with the planned extension of this process to conserve strategic materials. Emphasis will be placed on HIP joint integrity, microstructural stability, and mechanical properties as compared to the base alloys. This program will be conducted on laboratory size test specimens and will not involve prototype or component fabrication.

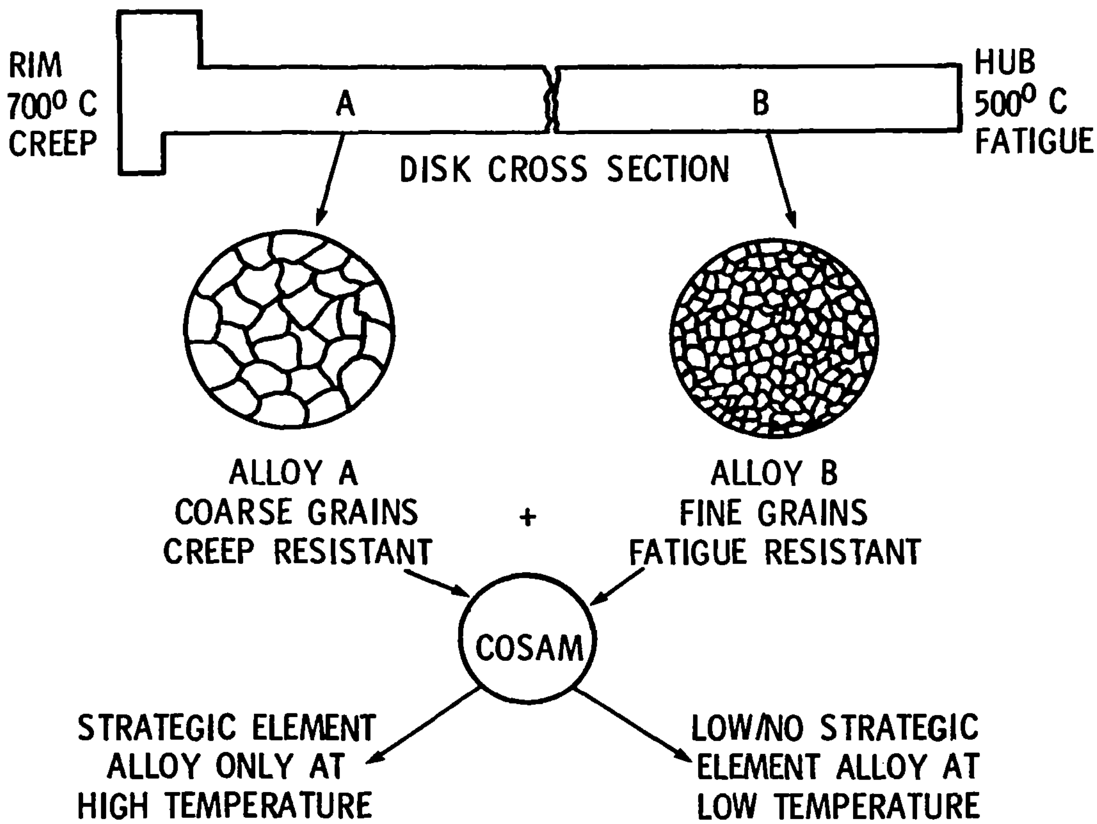


Figure 15

PARTICIPANTS' ROLES IN COOPERATIVE INTERMETALLIC COMPOUND PROGRAM

The third major COSAM Program thrust, alternate materials, has the potential of eliminating most or all of the cobalt, tantalum, and columbium containing alloys and also of replacing some of the strategic element chromium that is now used in gas turbine engines. One aspect of this thrust of the COSAM Program is focusing on the equiatomic iron and nickel aluminides (i.e., FeAl and NiAl) as potential alternatives to nickel-base superalloys. This program emphasizes a basic research approach toward understanding the deformation mechanisms that control high-temperature creep as well as those that control the lack of room temperature ductility. By necessity, the program is a long-term, high-risk effort, but it offers the potential of a substantial payoff if materials evolve which permit conserving all four currently identified strategic metals -- cobalt, tantalum, columbium, and chromium. These binary aluminides have several advantages:

(1) They exist over a wide range of compositions and have a large solubility for substitutional third element additions.

(2) They have a cubic crystal structure.

(3) They have very high melting points (except for FeAl which has a somewhat lower melting point).

(4) They contain inexpensive, readily available elements.

(5) They possess potential for self protection in oxidizing environments.

Their chief disadvantage is that they lack room temperature ductility. Figure 16 illustrates the organizational structure of the current intermetallic compound program.

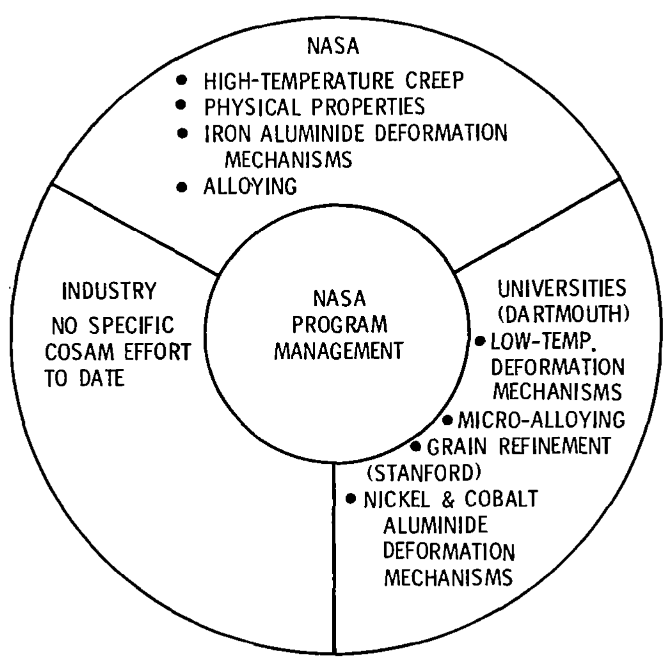


Figure 16

CREEP BEHAVIOR OF ALUMINIDES AT 1125° C

The in-house program is focused on understanding the slow plastic deformation behavior of extruded powder metallurgy polycrystalline aluminides in terms of existing deformation models and structural parameters. Some initial results of compressive creep testing of the three aluminides are shown in figure 17 along with data for two commercial superalloys for comparative purposes. In addition to creep testing, thermal expansion and lattice parameter measurements are also being evaluated. A transmission electron microscopy evaluation of dislocation interactions in deformed specimens is being conducted in-house on the iron aluminides. In support of these high-temperature deformation studies, Stanford University has a grant to explore similar dislocation interactions in the nickel aluminide.

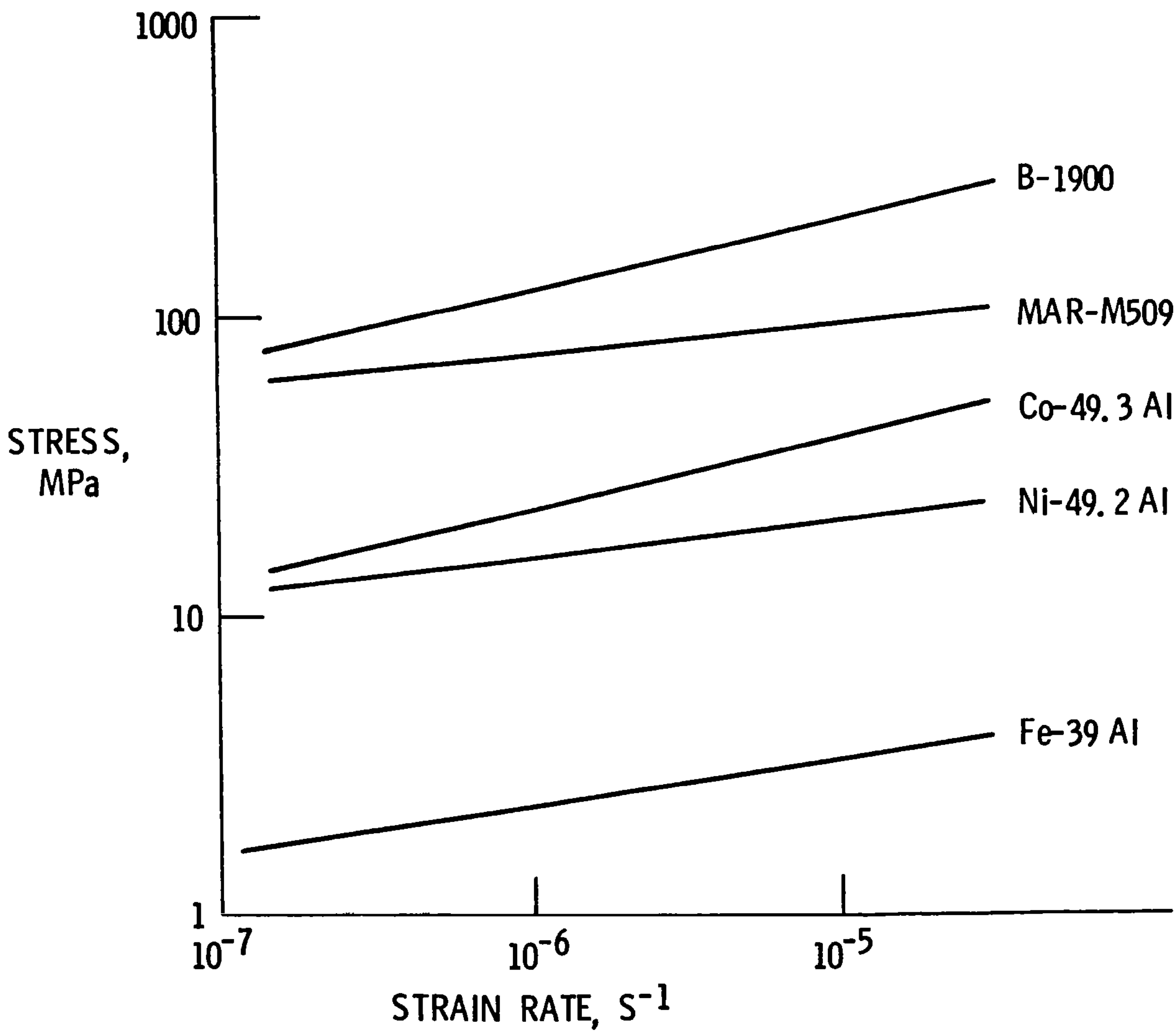


Figure 17

GRAIN SIZE EFFECTS ON DUCTILITY OF NICKEL ALUMINIDE AT 295° C

A COSAM investigation is being conducted at Dartmouth College on the low-temperature deformation mechanisms of nickel aluminide. Emphasis centers on grain size effects and microalloying to improve low-temperature ductility. The effect of decreasing grain size on tensile elongation at 295° C is shown in figure 18. Results indicate that below a grain size of about 10 micrometer diameter tensile ductility at 295° C can be achieved in nickel aluminide. Various microalloyed materials have been prepared and they are being tested.

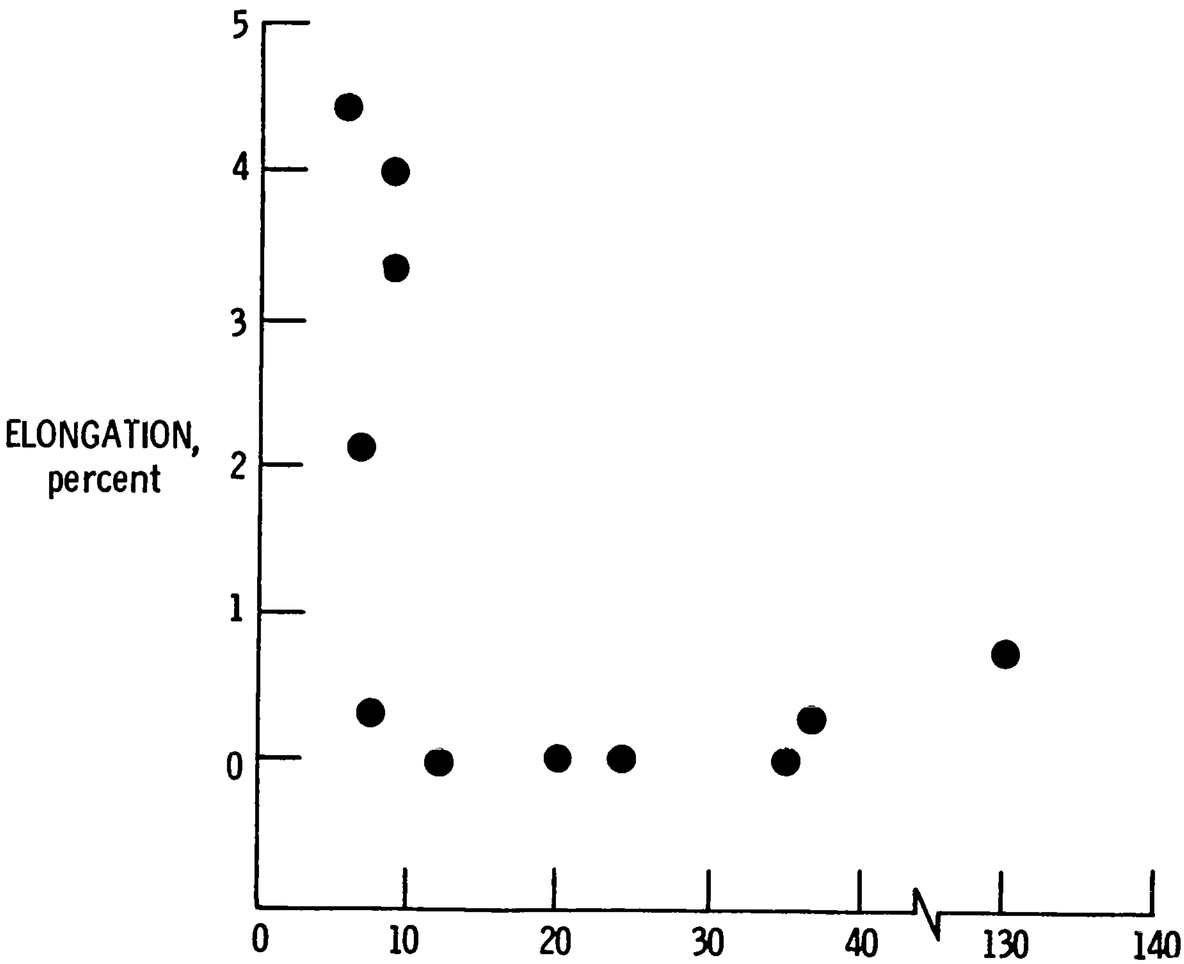


Figure 18

PARTICIPANTS' ROLES IN COOPERATIVE IRON-BASE PROGRAM

With the successful development of high-strength nickel-base superalloys (and to some extent cobalt-base superalloys) over the last 30 years, there has been little recent interest in developing iron-base alloys for the higher temperature gas turbine engine components. However, with the threat of strategic material supply disruptions or interruptions, iron-base alloys with low strategic metal contents are attractive as alternative materials for United States industrial consideration. A program has been initiated within the alternate materials thrust to investigate iron-base superalloys with aligned carbides for further strengthening as potential alternatives to current high strategic element content nickel- and cobalt-base superalloys. This is a joint program involving the University of Connecticut, United Technologies Research Center (UTRC), and NASA Lewis. Roles of the participants are illustrated in figure 19.

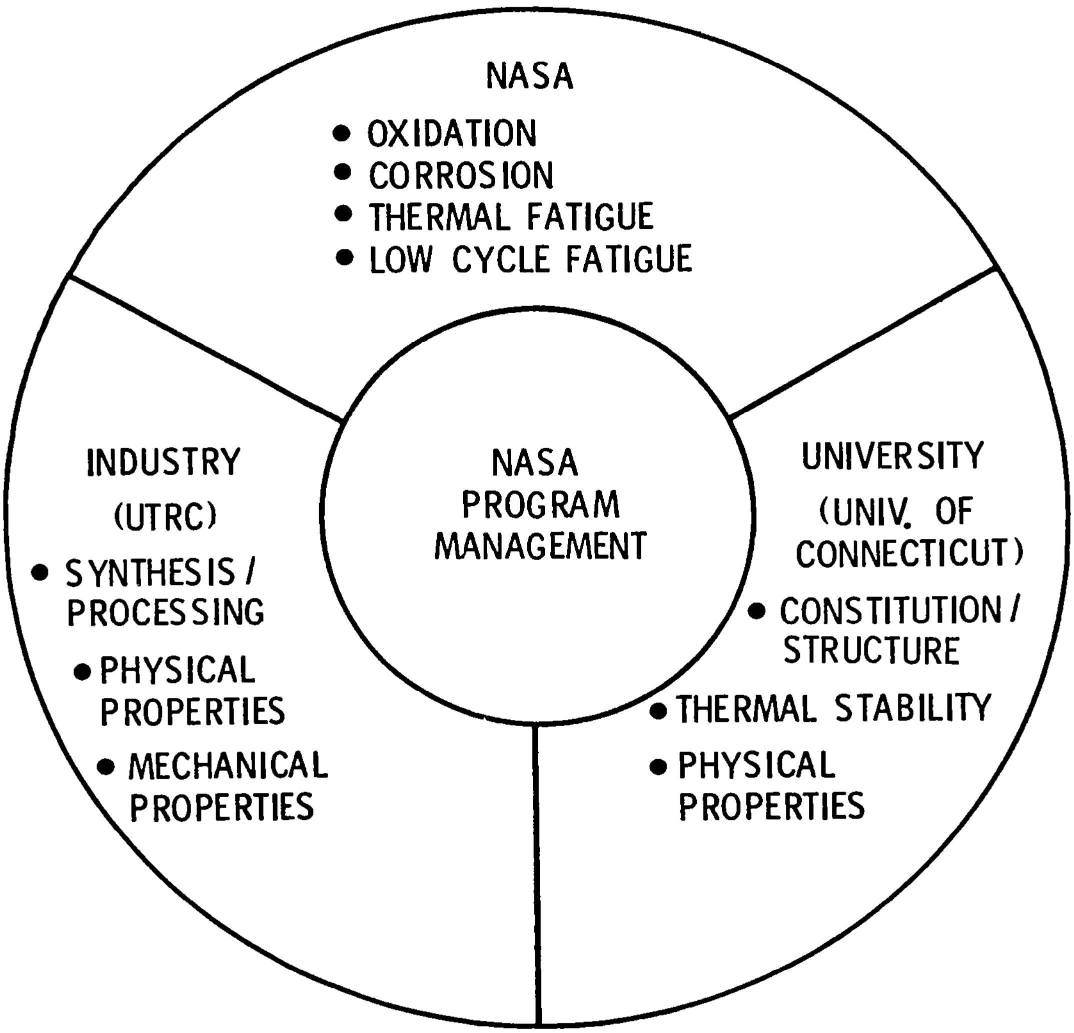


Figure 19

STRESS-RUPTURE POTENTIAL OF Fe - 20-Cr - 10-Mn - 3.2-C ALLOY

The rupture lives (determined by United Technologies Research Center) of iron-chromium-manganese-aluminum-carbon-type alloys are compared in figure 20 with the rupture lives of other iron-, nickel-, and cobalt-base alloys. Results indicate that the experimental iron-base alloy offers a strength advantage over the commercial cobalt-base alloy MAR-M509.

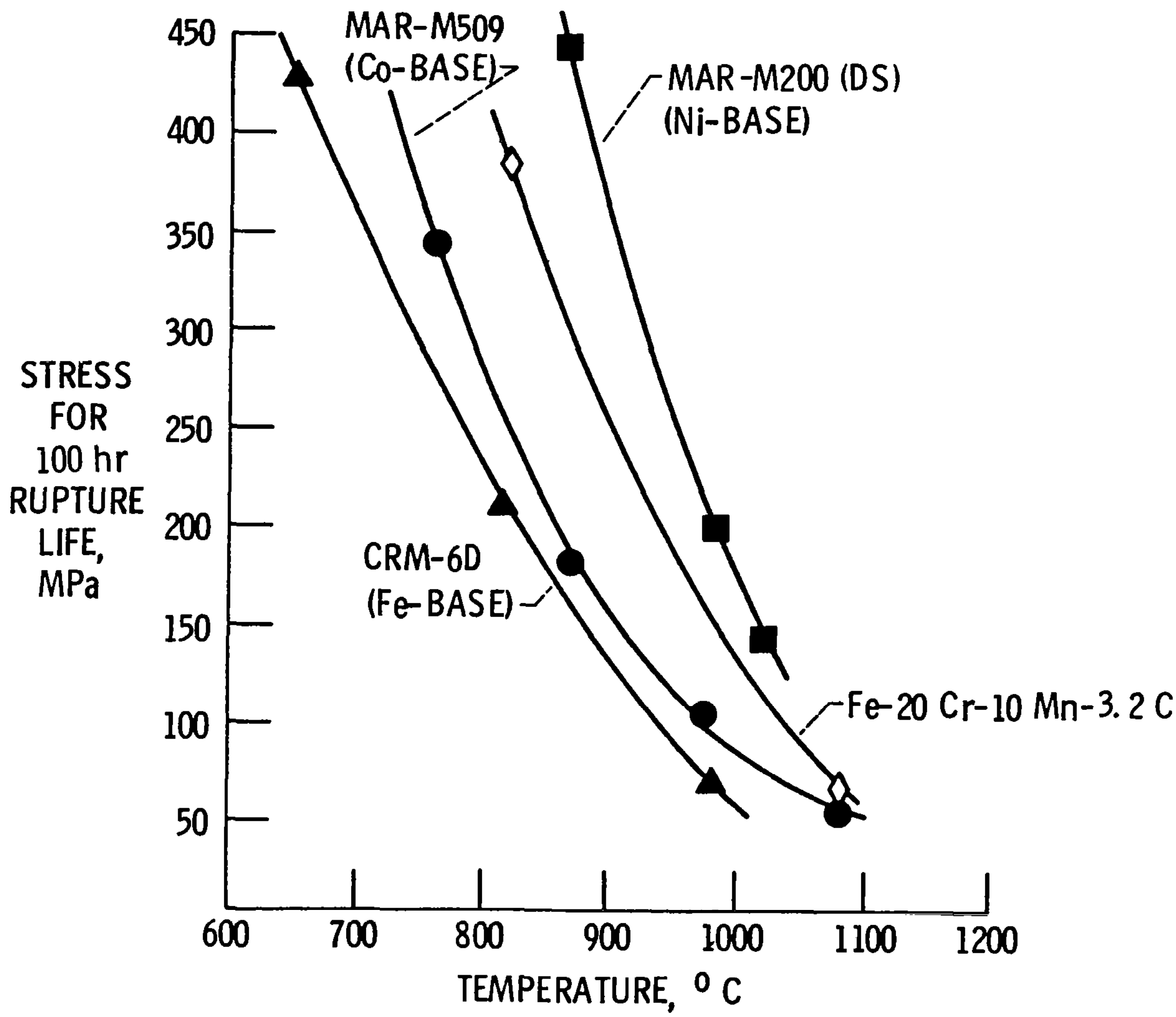


Figure 20

CONCLUDING REMARKS

NASA Lewis Research Center has undertaken a long-range program called COSAM (Conservation of Strategic Aerospace Materials):

(1) Program is in support of the aerospace industry and is aimed at reducing the use of strategic materials in gas turbine engines.

(2) Three-pronged approach to COSAM consists of research on strategic element substitutions, advanced processing concepts, and alternate materials.

(3) Program emphasizes cooperative research efforts with industry, universities, and Lewis Research Center.

(4) Program will help provide a technology base to serve as a guide for future gas turbine engine material development.

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