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NASA's Activities in the Conservation of Strategic Aerospace Materials

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NASA's ACTIVITIES IN THE CONSERVATION OF STRATEGIC AEROSPACE MATERIALS

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ABSTRACT

NASA has several activities underway directed at conserving strategic materials used in the aerospace industry. Research efforts involving universities and industry as well as in-house activities at the NASA-Lewis Research Center comprise the current program. These initial research efforts are preparatory to an anticipated much broader program focusing on the "Conservation of Strategic Aerospace Materials - COSAM." The primary objective of the COSAM Program is to help reduce the dependence of the United States aerospace industry on strategic metals, such as cobalt, columbium, tantalum, and chromium, by providing the materials technology needed to minimize the strategic metal content of critical aerospace components with prime emphasis on components for gas turbine engines. Thrusts in three technology areas are planned for the COSAM Program, including near-term activities in the area of strategic element substitution; intermediate-range activities in the area of materials processing; and long-term, high-risk activities in the area of "new classes" of high temperature metallic materials. This paper describes in some detail the projects currently underway and initial results generated to date. Initial emphasis has been placed in the area of strategic element substitution. Specifically, the role of cobalt in nickel-base and cobalt-base superalloys vital to the aerospace industry is being examined in great detail by means of cooperative university-industry-government research efforts. Investigations are also underway in the area of "new classes" of alloys. Specifically, a study has been undertaken to investigate the mechanical and physical properties of intermetallics that will contain a minimum of the strategic metals. Current plans for the much larger COSAM Program also are presented in this paper.

INTRODUCTION

The United States is heavily reliant upon foreign sources for the supply of most strategic metals required by our aerospace industry. With the exception of molybdenum, iron, magnesium, and the rare earths, the United States imports from 50 to 100 percent of such aerospace metals as Co, Cb, Ta, Cr, and Mn (ref. 1). However, the potential for foreign cartels, political unrest, and production limitation is great and is intensified by steadily declining known reserves. Thus, the United States can expect to be faced with supply shortages and price escalation for many strategic metals. Since these metals are vital to the welfare of the nation's economy, their continued availability at a reasonable cost is a national issue which requires cooperative action between the aerospace industry and appropriate government agencies.

The aerospace industry is currently a major factor in the positive inflow of funds from U.S. exports (ref. 2). This industry, and within it the aircraft engine industry in particular, relies heavily upon imports for several key strategic metals including cobalt, columbium, tantalum, and chromium. In order to offset or minimize future disruptions in supply, efforts to develop viable options must begin now, since a new material can take from 5 to 10 years of research and development efforts before qualifying for aerospace service.

NASA currently plans to take a leading role in addressing the aerospace industry's needs to minimize the use of strategic metals for advanced aerospace systems. The materials technology program now being planned by NASA is designated COSAM - Conservation of Strategic Aerospace Materials. The COSAM program has as its broad objective the reduction of the dependence of the U.S. aerospace industry on strategic metals. This objective will be accomplished by providing the materials technology options needed to allow individual companies to trade-off the material properties of critical components versus cost and availability of their strategic metal content. This paper will summarize NASA's current Pre-COSAM activities and broadly outlines the planned COSAM Program.

STRATEGIC METALS

As the basis for what are considered strategic metals, we will focus on the aircraft engine industry's needs. Based on 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, columbium, tantalum, and chromium. These metals are contained in steels, stainless steels, and superalloys that are used in engine manufacturing. The location of these metals in aircraft engine compressors, turbines, and combustors is illustrated in figure 1. The need for such 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 for the U.S. aircraft industry to maintain its competitive position, it is necessary that supplies be readily available at a reasonably stable cost. To achieve these requirements, domestic sources of key metals are desirable. However, the U.S. has never been self-sufficient in these metals. Today, we are almost totally dependent on foreign sources for these metals as shown in figure 2. In several of the countries listed in figure 2, recent political disturbances have led to supply interruptions. Therefore, the U.S. aircraft engine industry can be seen to be highly vulnerable to supply instabilities of the essential metals for engine manufacturing. Accompanying supply disruptions or increased demand is an accelerated price increase. Escalated prices during the recent few years are evident for tantalum, columbium, cobalt, and to a lesser degree for chromium, as shown in figure 3. These rapid price increases illustrate the vulnerability of the U.S. aircraft engine industry to cost fluctuations. The essential nature of cobalt, columbium, tantalum, and chromium along with their vulnerability to supply instabilities and cost fluctuations combine to cause these metals to be classified as strategic aerospace metals.

OVERVIEW OF THE COSAM PROGRAM

The COSAM Program has as its primary objective the reduction of the dependence of the U.S. aerospace industry on strategic metals. The COSAM Program will further provide the industry with options for making their own property versus availability/cost trade-offs when selecting aerospace alloys. These objectives will be achieved by providing the technology needed to minimize the strategic metal content of critical components in aerospace structures. Initial emphasis will be placed on the aircraft engine industry. The program will initially focus on conservation of the strategic metals cobalt, columbium, tantalum, and chromium. Strategic metals such as titanium, the precious metals, tungsten, and others may be brought into the COSAM Program as it progresses. A three-pronged approach is planned as shown in figure 4, and will consist of strategic element substitution, process technology, and alternate materials. Conservation, as well as reduced dependence on strategic metals, will be achieved in the area of strategic element substitution by systematically examining the effects of replacing cobalt, columbium, and tantalum with less strategic elements in current, high use engine alloys. This will help guide future material specifications if one or more of these metals becomes in short supply. Conservation through process technology will be achieved by advancements in those net-shape and tailored-structure processes that minimize strategic material input requirements. This will lower total usage. And in the longer term, development of alternate materials that replace most strategic metals with those highly available in the U.S. could lead to a substantial reduction in the U.S. dependence on foreign sources. Both of the later two technology areas will help conserve the four strategic metals Co, Cb, Ta and Cr.

PRE-COSAM ACTIVITIES

The COSAM Program has been proposed to begin in FY 1982, i.e., in October 1981. Thus, efforts on planning and organizing the program are currently underway. In addition to the planning activities, several small research activities have already been initiated. These research activities will dovetail in a logical fashion into the proposed COSAM Program. These research activities focus on two of the three major thrusts of the COSAM Program - strategic element substitution and development of alternate materials. Special emphasis of these initial efforts is on developing a fundamental understanding of the role of strategic elements in current aircraft engine alloys so that effective alloying element substitution can be conducted. Similarly, in the development of alternate materials, a basic understanding of materials properties and alloying concepts is being emphasized. Consequently, university grants play a major part in the Pre-COSAM projects. In addition, cooperative programs with industry augmented by in-house research at the NASA-Lewis Research Center comprise the approach used in these initial projects. This cooperative approach will be carried into the COSAM Program where industry, university, and government in-house research will each play a key role. The subsequent paragraphs will describe in some detail the Pre-COSAM research efforts.

Strategic element substitition. - Four metals were mentioned previously as being classified as strategic metals. Cobalt was selected from these four metals for the Pre-COSAM strategic element substitution research. The basis for selecting cobalt was twofold. First, the largest single use of cobalt in the U.S. is in superalloys for jet engine applications. Figure 5 illustrates that about 30% of cobalt goes into the production of superalloys (ref. 3). Many of the other applications indicated in figure 5 are also important to the nation's economy and security as well. Secondly, the specific roles that cobalt plays in nickel-base superalloy fabrication and performance has not been clearly established. Most superalloys currently in use were developed at a time when cobalt was plentiful and inexpensive. Literature results (ref. 4) are conflicting as to the role that cobalt plays in nickel-base superalloys in important areas such as phase stability, γ' partitioning, strength, fabricability, and oxidation and hot corrosion resistance. Because of these uncertainties, there exists a strong possibility that the strategic element cobalt can be substantially reduced or possibly eliminated from several superalloys without sacrifice of the key properties for which these alloys were selected for engine service.

Four nickel-base and one cobalt-base superalloys have been selected for the Pre-COSAM investigation. The five alloys are listed in figure 6 along with their typical applications in the aircraft engine industry, the forms in which the alloys are used, and remarks as to why they were selected for the Pre-COSAM activity. Applications include turbine disks, low pressure blades, turbine blades, and combustors. A variety of product forms are represented by the applications of the five alloys as noted in figure 6. The selection of the five alloys was based primarily upon the considerations given in this figure. Waspaloy* was selected because it represents the highest tonnage of cobalt in commercial aircraft engines. Selection of Udimet-700* was based on the fact that this alloy is used in the as-cast, as-wrought ingot, as-wrought powder, and as-HIP powder metallurgy fabricated conditions. The potential for determining the impact of cobalt on both conventionally-cast as well as on single crystal turbine blades was the reason for selecting MAR-M247*. Rene' 150* was chosen because it is one of the most advanced directionally solidified alloys. The wrought, sheet alloy HA-188* was selected because it represents one of the largest uses of a cobalt-base alloy in aircraft engines.

The primary purpose of the cobalt strategic element substitution research is to determine the fundamental role of cobalt in a wide variety of nickel-base superalloys and in a high-use cobalt base superalloy. A secondary purpose is to develop the methodology to explore the roles of other strategic elements in similarly chosen alloys so as to have maximum impact on a wide range of users.

Figure 7 shows the participants in the Pre-COSAM activities on cobalt strategic element substitution. These initial research efforts are planned for a three-year period and consist of cooperative programs involving universities, industry, and NASA-Lewis Research Center. Nominal compositions of the

*Trademarks

Waspaloy	United Technologies Corporation
Udimet	Special Metals Corporation
Mar-M	Martin Marietta Corporation
Rene'	General Electric Corporation
HA	Cabot Corporation

five alloys given in figure 7 indicate that cobalt content ranges from 10% in Mar-M247 to 39% in HA-188. In addition the γ' phase ranges from 20% in Waspaloy to 65% in Rene'-150. The first phase in each research effort will involve substituting the less strategic element, nickel, for cobalt in incremental steps to a zero cobalt content. The effects of this substitution on properties and phases present, such as γ', will make-up the major portion of the research effort in the first year of each program element. Efforts in subsequent years will be directed at identifying and optimizing alloying elements as substitutes for cobalt in the five alloys so as to maintain the key properties of these alloys.

The cooperative nature of the research being conducted on Waspaloy and Udimet-700 is illustrated in figure 8. The role of industry as represented by Special Metals Corporation is outlined. Their primary role is to characterize and optimize fabrication and heat treating procedures for the reduced cobalt Waspaloy and Udimet-700 alloys. The university role in this effort is also shown in figure 8. Columbia University will be involved with mechanical property characterization, structural stability, microstructural features, and theoretical formulations to identify future alloy modifications if required for the second phase of the project. Purdue University will be primarily responsible for microstructural and microchemistry characterization of the reduced cobalt content alloys. To round out the program, NASA-Lewis Research Center will be involved in further mechanical and physical metallurgy characterization of the alloys as shown in figure 8. The output of this cooperative effort is expected to be a clearer understanding of the role of cobalt in nickel-base superalloys.

Some preliminary results on the effects of reducing cobalt in Waspaloy, a 13% cobalt alloy, are shown in figure 9 (ref. 5). Tensile strength appears to be insensitive to the amount of cobalt in the alloy. However, rupture life decreased with decreasing amount of cobalt in Waspaloy. Further testing will be required to better characterize this apparent effect.

The research efforts on MAR M247 and Rene' 150 parallel the previously described efforts on Waspaloy and Udimet-700. It is anticipated that these projects will lead to an understanding of the fundamental role of cobalt in a variety of conventional and directional nickel-base superalloys. These results should provide an improved technical base to develop modified superalloys in the proposed COSAM Program.

Alternate Materials. - Research in this area must be considered to be high risk and long range, but it has the potential of a high payoff in terms of significantly reducing the nation's dependence on strategic materials. As an example of alternate materials, intermetallic compounds are currently being investigated for possible structural applications. Initial efforts are centered on nickel and iron aluminides. Successful development of this type of alternate material offers the possibility of partially or totally replacing all the strategic materials in components where intermetallic compounds can be utilized.

Intermetallic compounds are of interest because of their potential high temperature strength as shown in figure 10 (ref. 6). It can be seen in this figure that nickel aluminides have the strength capability of competing with current nickel-base alloys. However, a possible disadvantage of this type of material is that simple binary aluminide compounds have shown a lack of room temperature ductility (fig. 11). The factors which influence the high ductile-to-brittle transition temperature of nickel aluminide (~600+ °C) are currently being investigated as part of the Pre-COSAM activities. A NASA grant with Dartmouth University is aimed at understanding the fundamental deformation mechanisms in nickel aluminide. From these investigations, methods of improving the low temperature ductility of nickel aluminide may be suggested. An accompanying in-house research project at NASA-Lewis Research Center is focusing on the high temperature mechanical properties of aluminides. These Pre-COSAM studies will provide a fundamental basis for more extensive research to develop these nonstrategic, alternate materials in the COSAM Program.

COSAM PROGRAM

The proposed COSAM Program is intended to build on the fundamental understanding from the early research for cobalt substitution, as shown in figure 12. Major efforts will be devoted to developing, and if warranted, to scaling-up low or no-cobalt nickel base superalloys for fabrication into various components, and with demonstration of continued promise, to verification in engine tests. Similar efforts will also be conducted for other strategic metals such as columbium and tantalum.

In the area of alternate materials, much more work will be required to develop materials such as intermetallic compounds. As shown in figure 13, initial efforts will focus on fundamental studies aimed at improving low temperature ductility and high temperature strength of FeAl and NiAl intermetallics. Complete property characterization will follow on more promising compositions. Reiterations of these basic steps will be required to further optimize the alternate materials and make them viable candidates as structural materials for aircraft engines. Scale-up and rig testing of promising compositions for blades and vanes will follow. The development of alternate materials will help conserve the strategic metals Co, Cb, Ta, and Cr.

The third area of the proposed COSAM Program involves conservation through improved materials processing technology. Although none of these activities are now underway in the Pre-COSAM effort, they will play a major part in the COSAM Program. Contemplated areas of research are shown in figure 14. Conservation of strategic materials will be achieved from initial melting practices, through component fabrication, and recycling of serviced components. An example of one method of processing technology is tailored fabrication which utilizes strategic metal containing alloys only where required. Figure 15 illustrates the critical placement of strategic metals where conservation of these strategic metals is achieved by using low strategic metal alloys in less critical areas. Technology development requirements will include near-net-shape castings, high temperature joining methods, and repair welding methods. Following component fabrication development and characterization, engine verification will be undertaken. Similar programs are anticipated for other materials processing programs. For example, early efforts on near-net-shape fabrication of a turbine disk (ref. 7) have been shown to be able to reduce input material weight compared to conventional casting/forging practice and further gains appear possible. Processing technology will help conserve the strategic metals Co, Cb, Ta, and Cr.

SUMMARY

This paper has presented NASA's planned COSAM Program and described some of the Pre-COSAM activities that are currently underway. The primary points made about this program are summarized below:

1. Advancements in materials technologies are needed to provide the aerospace industry with alternative materials options in the event of future strategic metal shortages or excessive price increases.

2. The primary role of NASA through its proposed COSAM Program will be to address strategic material problems within the aerospace industry, but the COSAM Program should make contributions to a national data base that will benefit many other domestic industries.

3. The COSAM Program is constructed so as to involve cooperative research efforts in industry from alloy producers, component fabricators, and engine manufacturers along with universities and government research facilities (primarily the Lewis Research Center).

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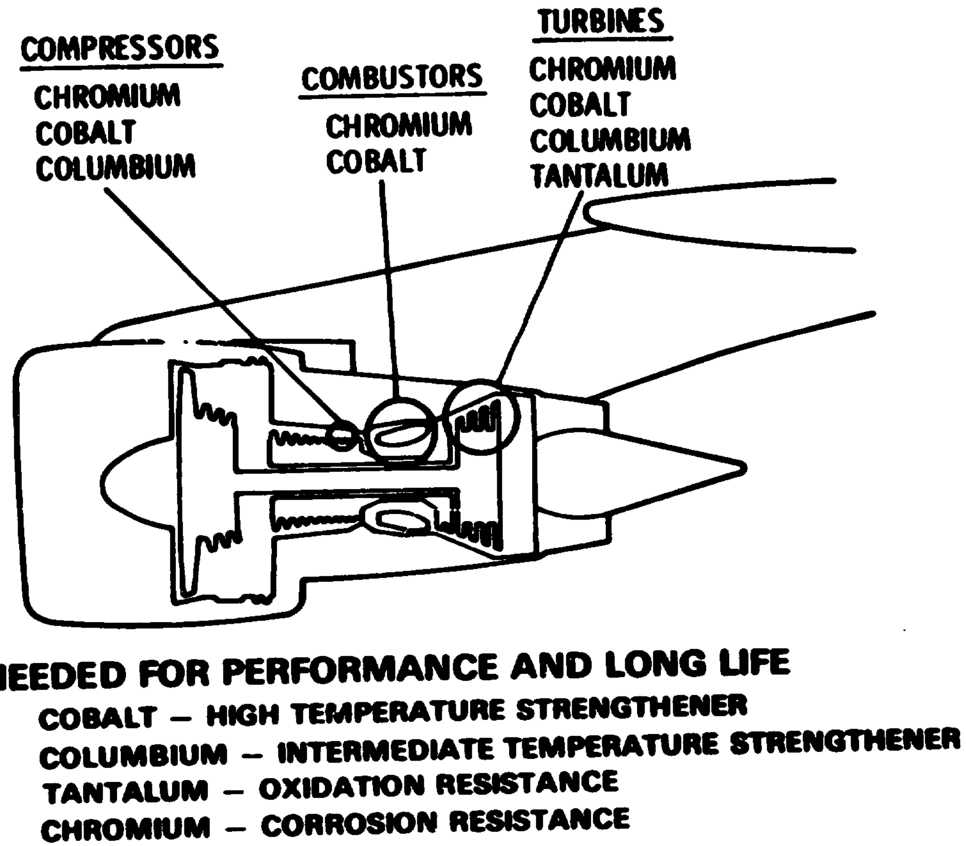

Figure 1. - Current gas turbine engines depend on strategic metals for several major components.

METAL	% IMPORTED	MAJOR FOREIGN SOURCE
COBALT	97	ZAIRE
COLUMBIUM	100	BRAZIL
TANTALUM	97	THAILAND
CHROMIUM	91	SOUTH AFRICA, ZIMBABWE

Figure 2. - Import dependence and major sources of selected strategic metals.

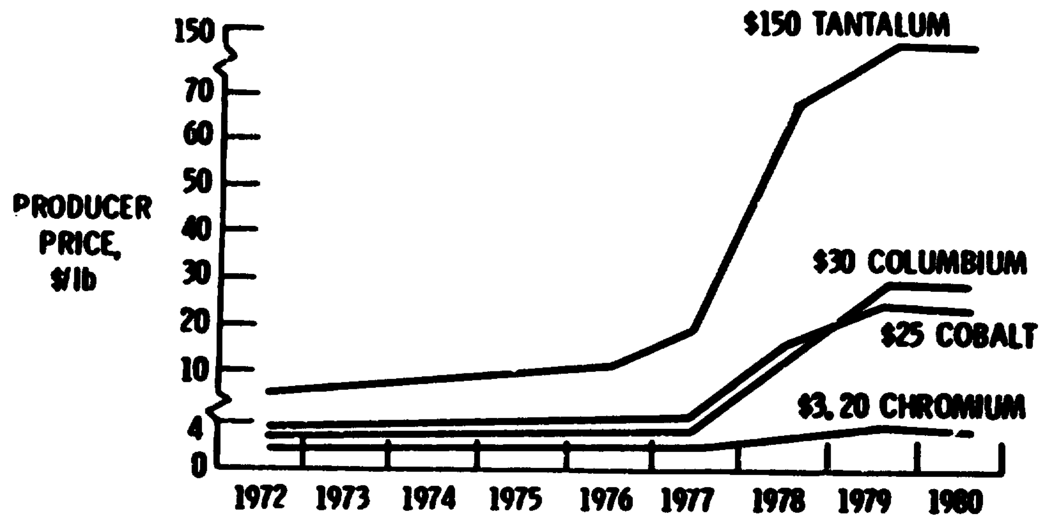

Figure 3. - Cost increase of selected strategic metals over past nine years.

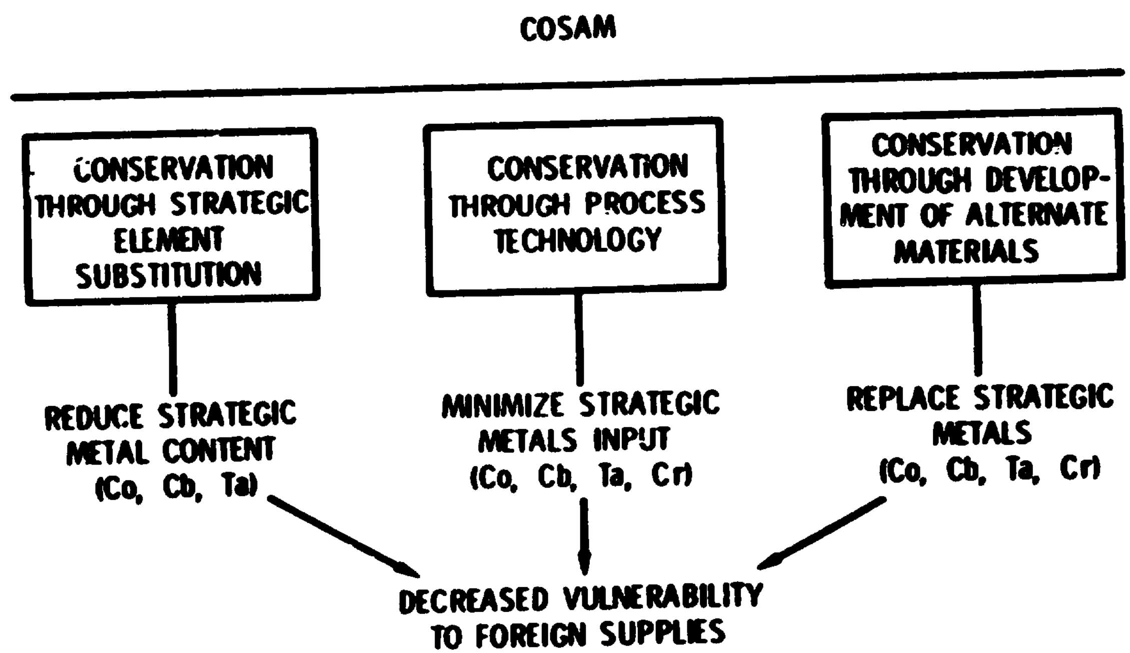

Figure 4. - Conservation of strategic aerospace materials through three major thrust areas.

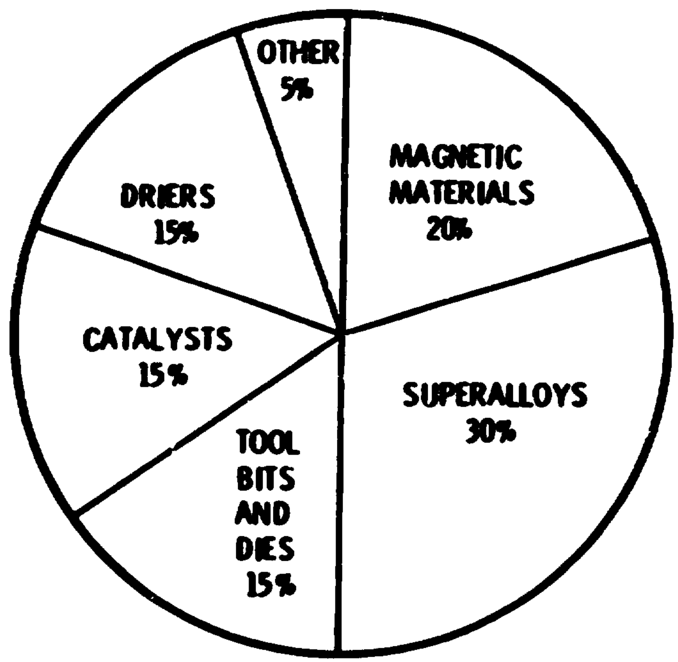

Figure 5. - Distribution of United States 1979 consumption of cobalt (20.3 million pounds total consumption).

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) ASTROLY	TURBINE DISK	AS-HIP-POWDER	
(RENÉ 77)	LP BLADES	CAST	
MAR-M247	TURBINE BLADES	CAST	CONVENTIONALLY-CAST AND SINGLE CRYSTAL
RENÉ 150	TURBINE BLADES	DS-CAST	HIGHLY COMPLEX DIRECTIONALLY-CAST ALLOY
HA-188	COMBUSTORS	WROUGHT	HIGH USE COBALT-BASE SHEET ALLOY

Figure 6. - Superalloys selected for pre-COSAM activities.

PARTICIPANTS	ALLOY	NOMINAL COMPOSITION										γ' CONTENT
		Ni	Cr	Co	Mo	W	Ta	Re	Al	Ti	Hf	
COLUMBIA UNIV. PURDUE UNIV. SPECIAL METALS NASA-LEWIS	WASPALOY	58	20	13	4	--	-	-	1.3	3	---	20%
COLUMBIA UNIV. PURDUE UNIV. SPECIAL METALS NASA-LEWIS	UDIMET-700	53	15	19	5	--	-	-	4.3	3.5	---	40%
CASE WESTERN RESERVE UNIV. TELEDYNE NASA-LEWIS	MAR-M 247	60	8	10	.6	10	3	-	5.5	1	1.4	55%
NASA-LEWIS	RENE' 150	59	5	12	1	5	6	3	5.5	---	1.5	65%
(TBD)*	HA-188	22	22	39	---	14	-	-	---	---		---

Figure 7. - Elements of pre-COSAM activities.

*TO BE DETERMINED.

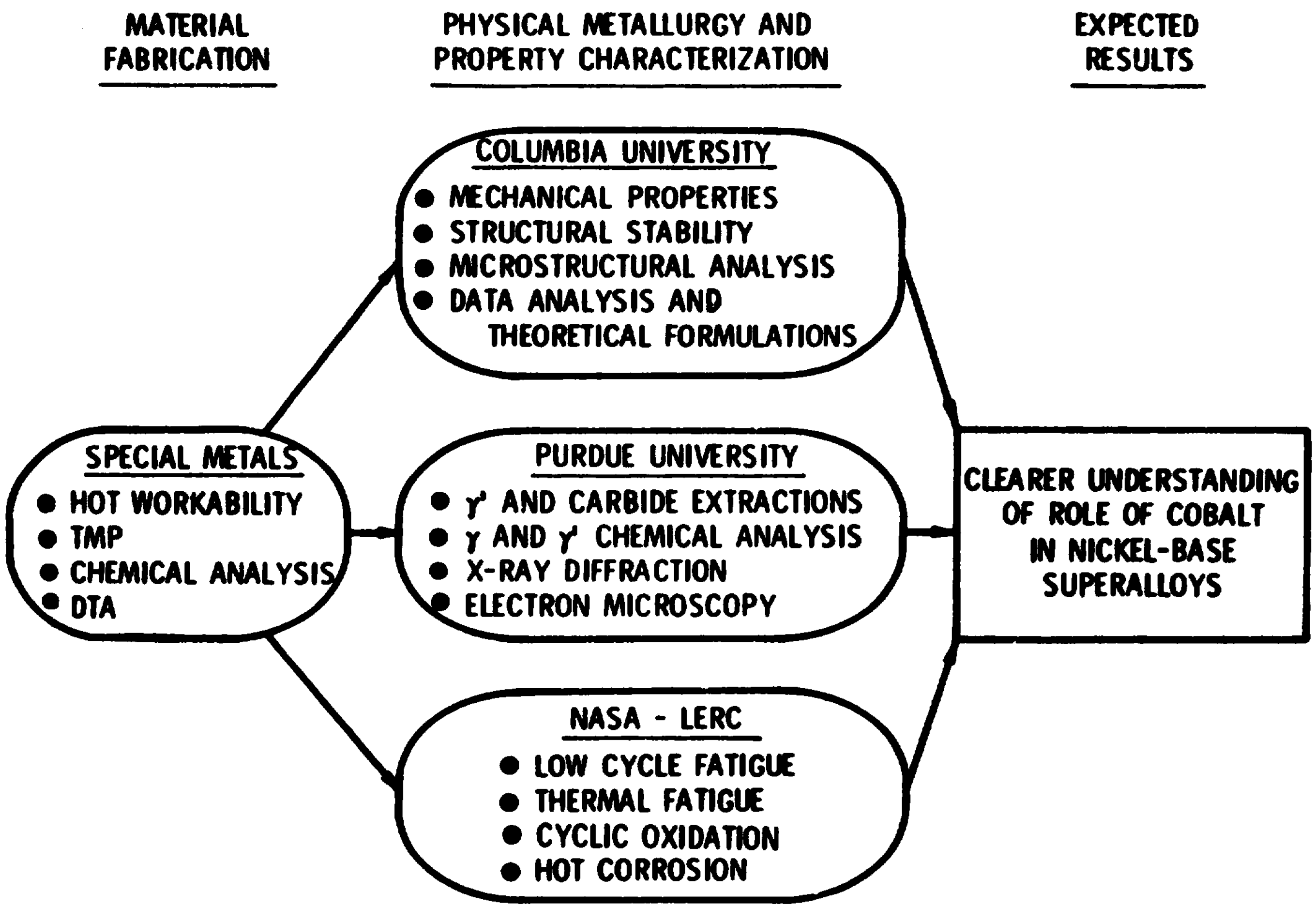

Figure 8. - Cooperative program to determine fundamental role of cobalt in WASPALOY and UDIMET-700.

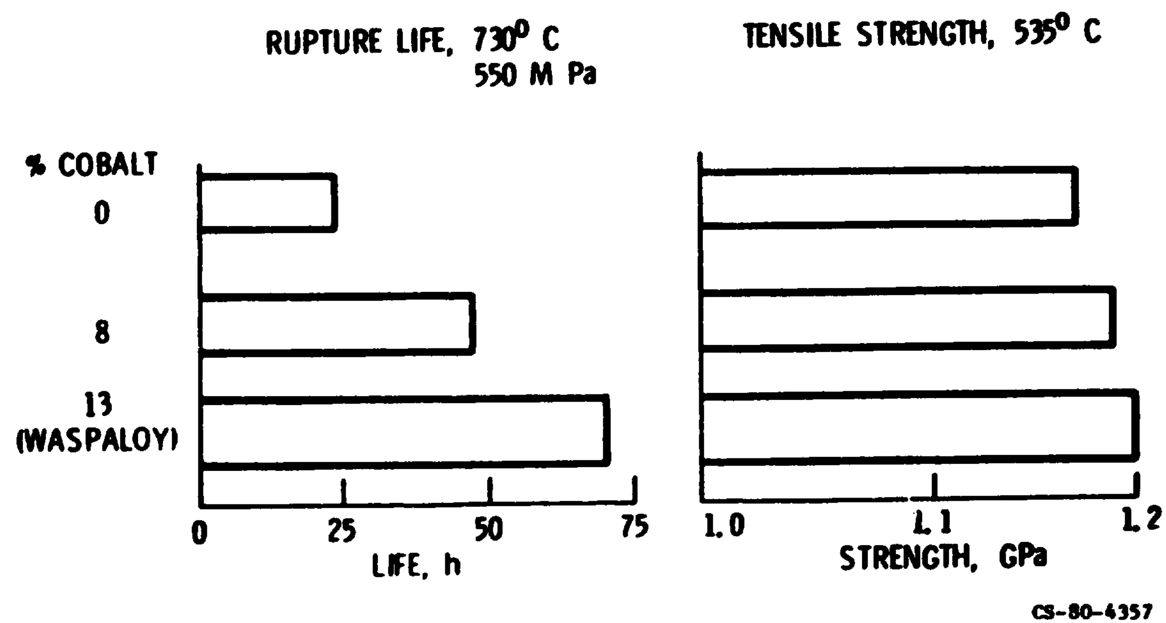

Figure 9. - Effect of cobalt content in WASPALOY on rupture life and tensile strength.

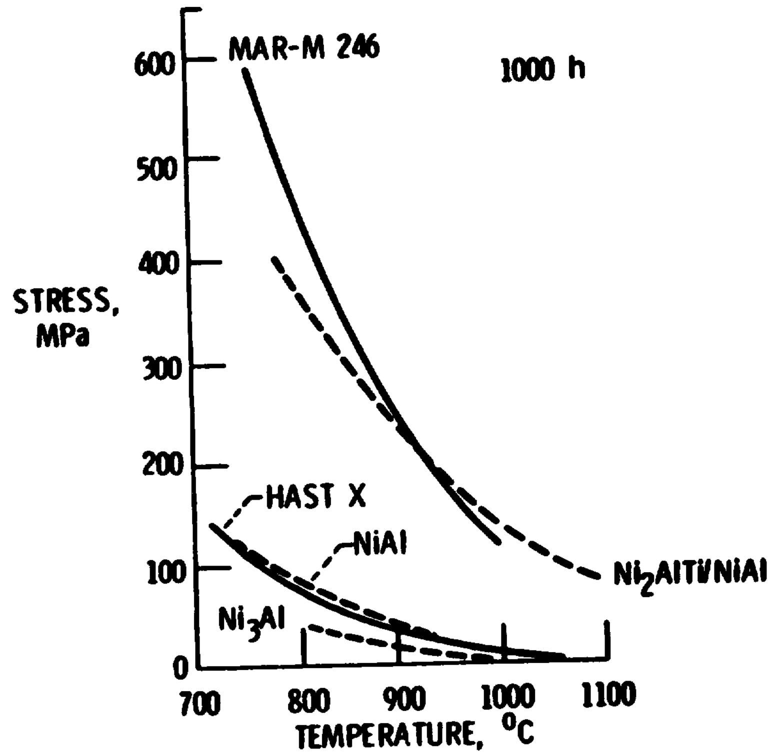

Figure 10. - Comparison of typical 1000-hour rupture strengths of aluminides and superalloys.

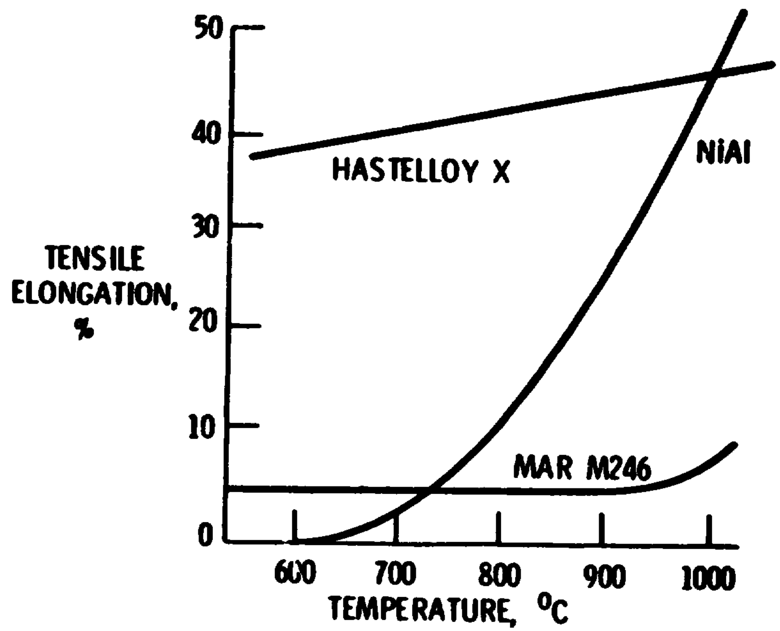

Figure 11. - Effect of test temperature on ductility of aluminides and superalloys.

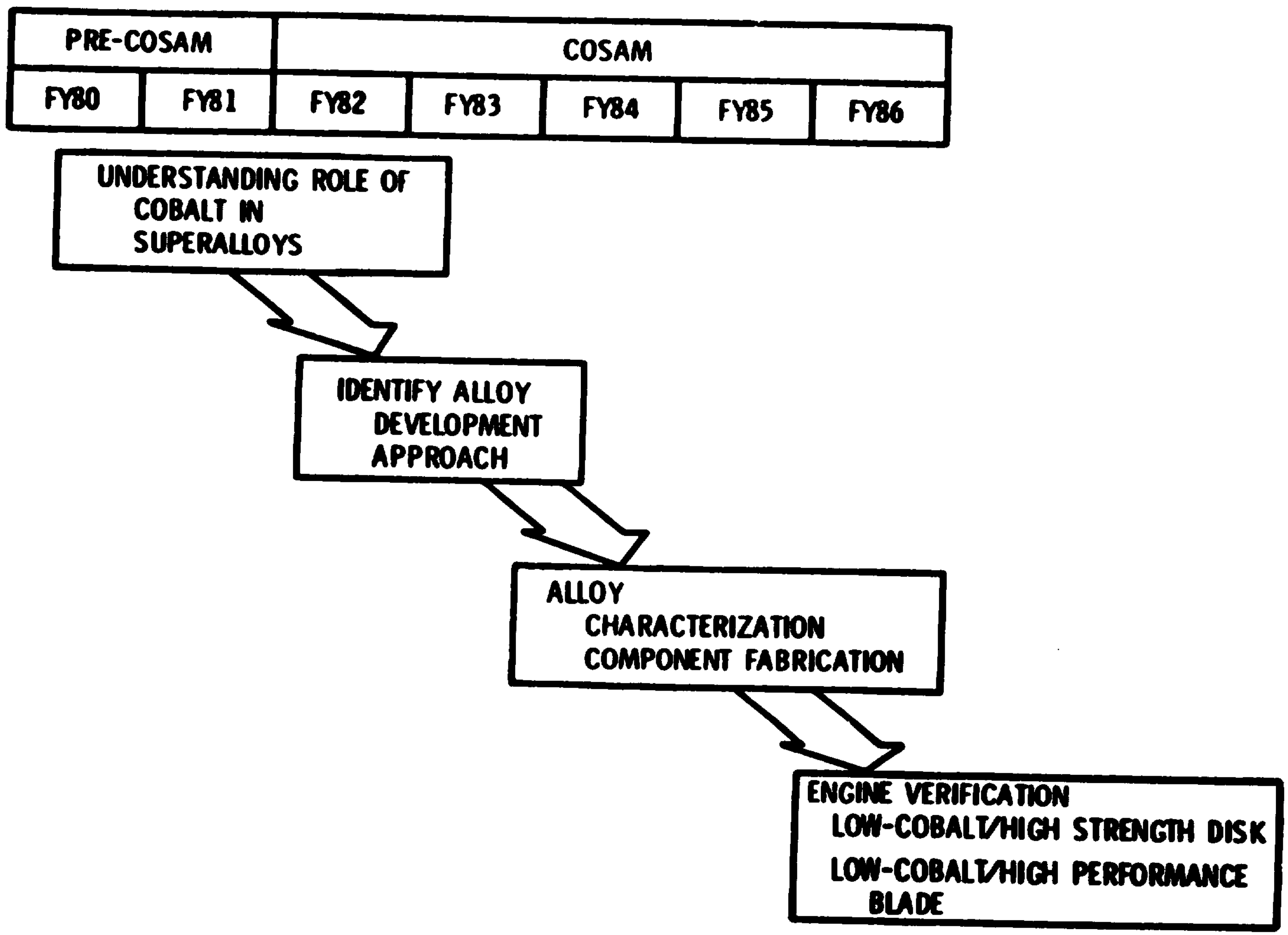

Figure 12. - Relation of pre-COSAM and COSAM programs. Cobalt conservation by strategic element substitution.

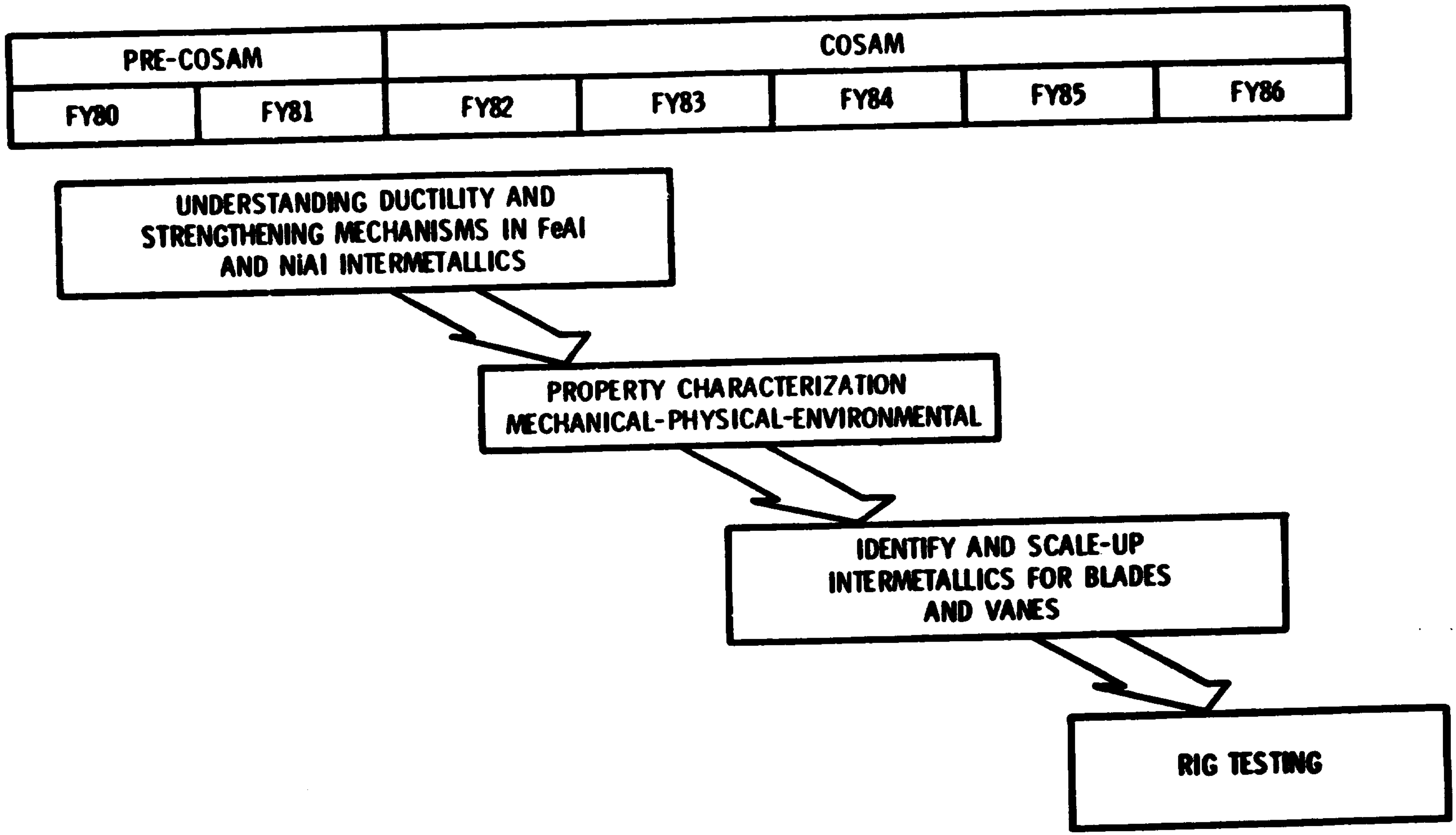

Figure 13. - Strategic metal conservation through development of alternate materials.

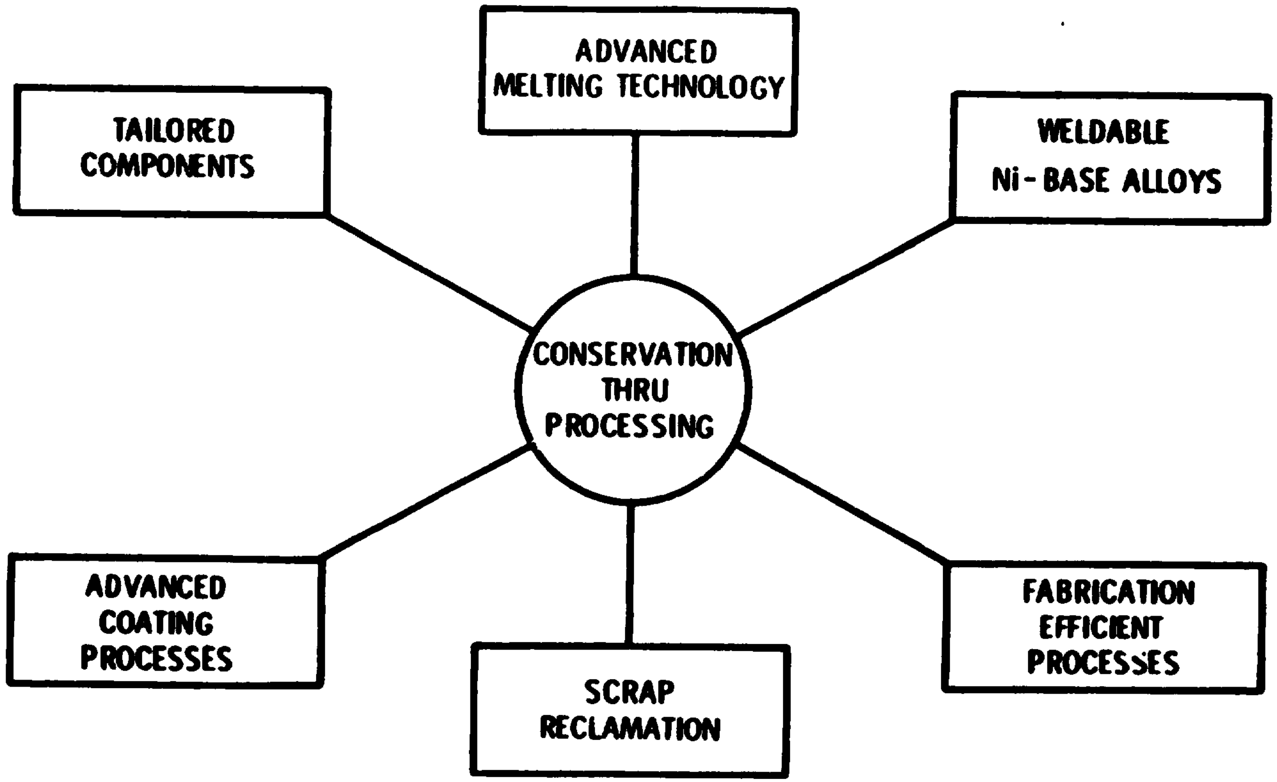

Figure 14. - Conservation of strategic materials through process technology.

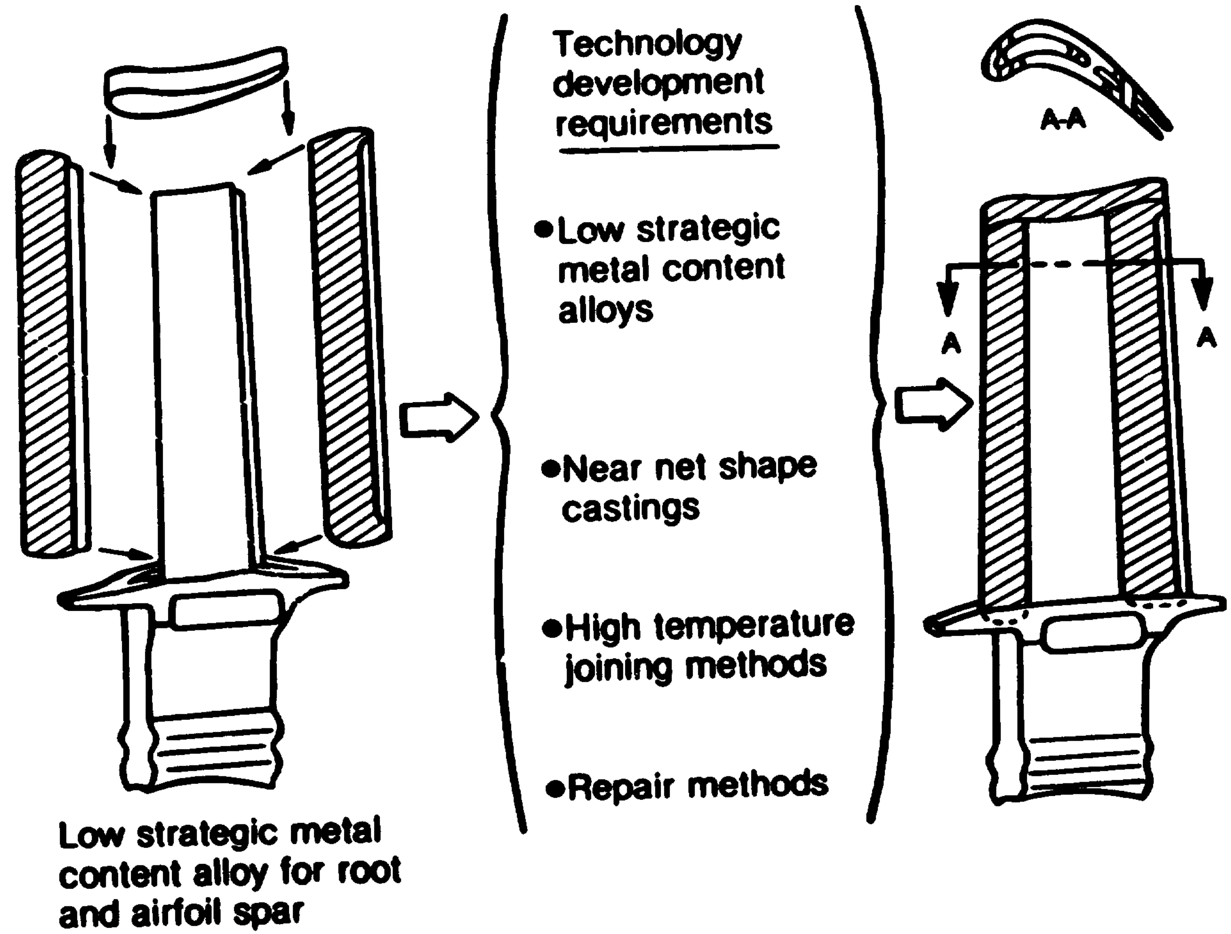

Figure 15. - Tailored fabrication as a process method to conserve strategic materials.