AEROSPACE INDUSTRIES ASSOCIATION
OF AMERICA INCORPORATED

1959
ANNUAL FORECAST OF TRENDS AND REQUIREMENTS

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AEROSPACE INDUSTRIES ASSOCIATION
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Los Angeles 36, California

F O R E W O R D

This is the Sixth Annual Forecast of Trends and Requirements prepared by the Aerospace Industries Association for distribution to the Department of Defense, other government agencies, and industries serving the aerospace complex. The report is based on information supplied by the various AIA member companies and was compiled by the Research and Testing Committee, and by the Manufacturing Equipment, Tooling, and Test Committees.

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INTRODUCTION

The advance of international scientific capability requires that the United States accelerate research and development in weapon and space system technology. The AIA technical committees, representing the aerospace industry, have assumed the responsibility of forecasting some of the technical requirements which must be met in the near future by materials, systems and methods.

The Annual Forecast Report compiles the best opinions of the available industry sources. These are presented to encourage the direction of research and development studies toward ends which will best serve the aerospace industry, our defense effort, and the community at large.

Previous issues of this report have consisted of written text briefly reviewing the five-year and ten-year forecasts of trends and requirements. The 1959 forecast incorporates changes in format and presents in graphical form the more important elements to be taken into consideration in the planning of future research and development programs. These changes were adopted to facilitate visualization of technical trends and the anticipated chronological variation in the attendant requirements.

The 1959 report is divided into two parts: Part One presents the engineering interpretation of future trends and requirements; Part Two presents the corresponding required developments in manufacturing technology.

The data herein are unclassified. Those organizations which have access to recent classified data and planning documents may wish to modify the predictions of this report accordingly. In some instances, it was not appropriate to reproduce herein the detailed background data which were accumulated on specific subjects. Such information is, however, being retained on file by the Los Angeles office of AIA and will be available for review by member companies and qualified government agencies.

It should be remembered that these are essentially long-term forecasts prepared in the light of current knowledge, and that the tolerances of values shown are quite broad. Judgement must be exercised in applying these data to the establishment of specific development programs or research objectives.

PART ONE

ENGINEERING FORECAST

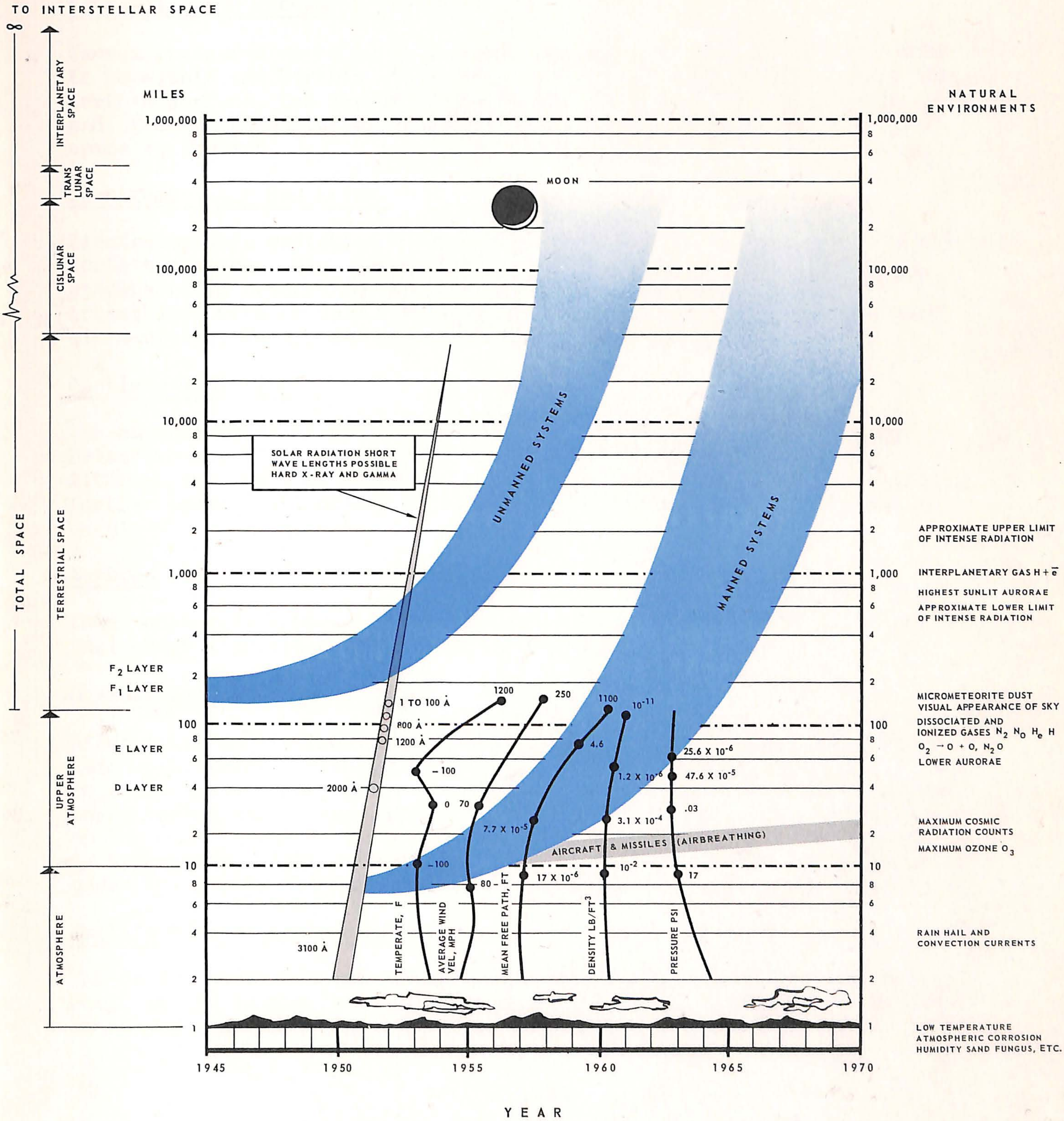
In the following pages are presented the engineering interpretation of future developments in our aerospace product, together with predictions of the effect of those developments on the material components of that product.

This portion of the report is divided into four sections:

Environmental Trends	These trends in both natural and induced environments show the conditions under which future air and space vehicles are expected to operate and, therefore, represent performance requirements for materials, systems, and components.
System Trends	This section presents a limited number of design trends which critically affect system components and materials requirements.
Materials and Process Requirements	These charts represent the future developments in materials and processing of materials that will be required to meet the performance conditions established by the environmental and systems trends.
Test Requirements	This information indicates the test capabilities that must be developed in order to assure proper evaluation of materials and systems under the anticipated operating conditions.

The reader will note that, in many instances, the required developments have been expressed in terms of temperature. Such temperature extremes arise from significant heat fluxes, the source and strength of which will vary from vehicle to vehicle. Use of temperature as a simplified criteria avoids the necessity of reference to particular vehicle systems and separates the material requirement from the surrounding design characteristics. Time of temperature duration, of course, is a factor in the development of specific requirements; however, the qualitative nature of these data is such that this refinement is not a primary consideration.

ENVIRONMENTAL TRENDS



NATURAL ENVIRONMENTS

Extremely High Vacuum

Vacuum pressures up to 10 miles above the Earth's surface are considered to be within the Earth's atmosphere. Between 10 and 120 miles above the Earth's surface, the vacuum pressures represent a partial space-equivalent and, from a standpoint of pressure, above 120 miles constitutes a total space equivalent.

Electromagnetic Radiation

Electromagnetic radiation becomes a significant factor 20 miles above the Earth's surface. High intensities of ultra-violet are absorbed by the atmosphere in generating ozone at approximately this distance. Progressively, with greater distances out from the Earth's surface, extreme ultra-violet, X-ray, and gamma radiations are encountered.

Particle Radiation

The natural belts of radiation surrounding the Earth (the "van Allen Belts") consist of particle-type radiations--electrons or protons. Although some data as to the extent of this radiation has been published, further investigations are required before quantitative information can be given.

Aurorae

These phenomena apparently result from corpuscular solar radiation and their most significant effect is the emission of X-rays.

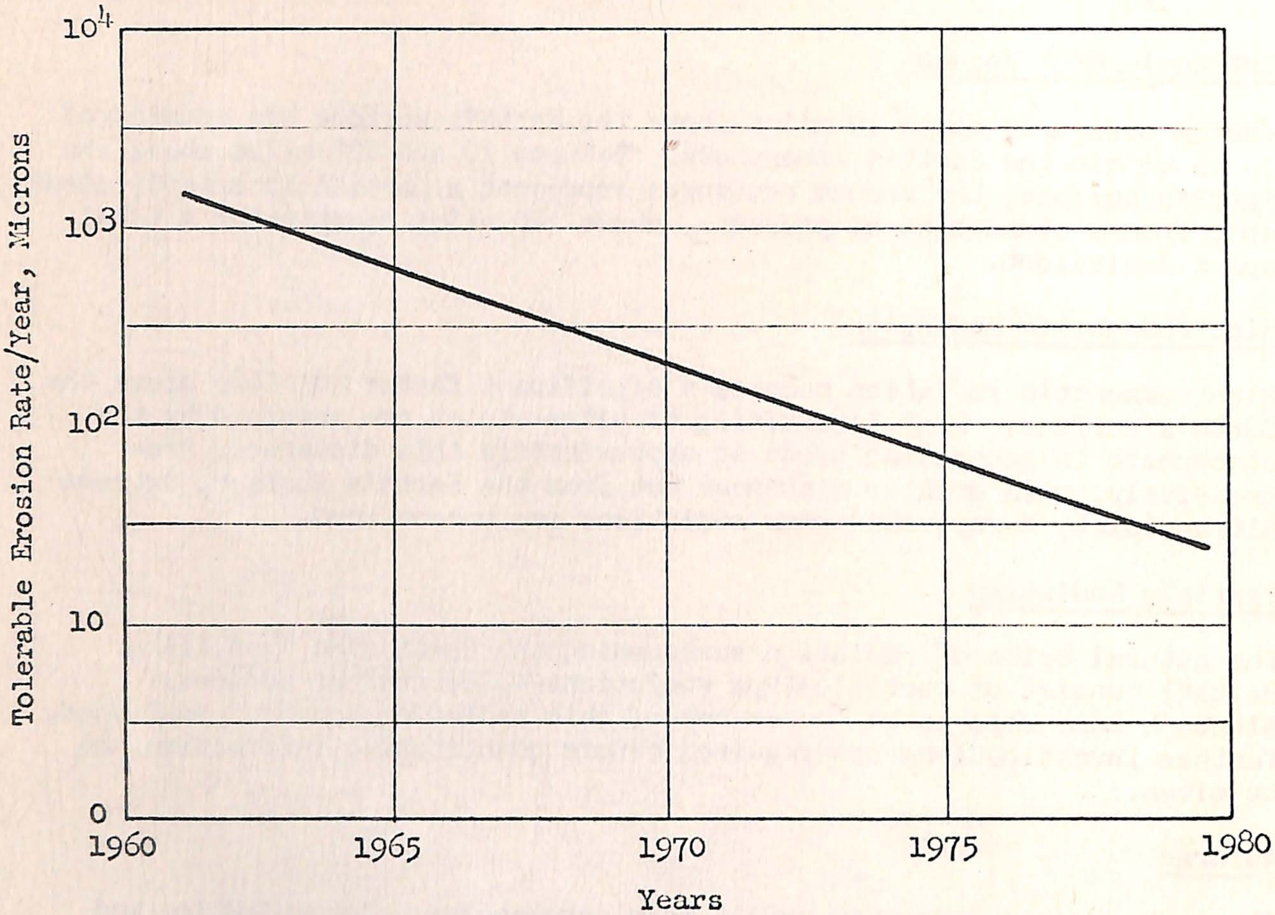
Dissociated and Ionized Gases

Dissociated and ionized gases are significant mainly due to their alteration of chemical activity from that commonly encountered with these gases in their normal state (e.g., change of oxidation rate). In addition to encountering such dissociations as $O_2 \rightarrow O + O$ and $N_2 \rightarrow N + N$, as indicated on the chart, Page 2, dissociation and ionization may also be encountered in hypersonic flight in Earth and planetary atmospheres, high temperature gases (plasmas), chemical rockets, plasma jets, nuclear rockets, etc.

Earth's Natural Environments

The environments such as rain, hail, sand, fungus, humidity, salt spray, etc., at and in the immediate locale of the Earth's surface, are described in many of the "MIL" Specifications and therefore are not discussed here.

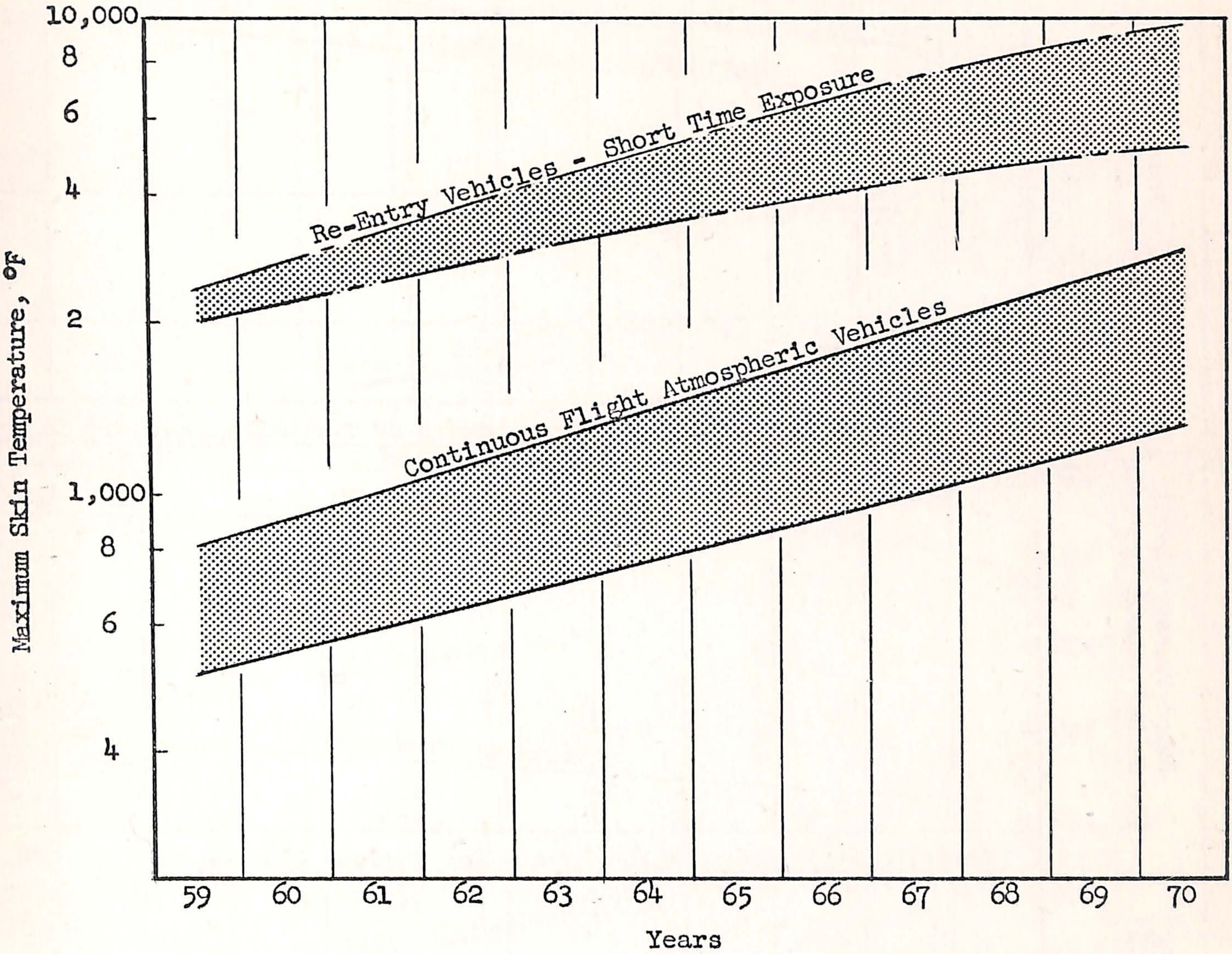
MICROMETEORITE DUST EROSION



Estimates of the magnitude of micrometeorite dust have not been sufficiently determined to establish a realistic trend or probability of encounter. However, estimates of protection requirements based on the best information available at this time are shown in the above chart.

These rates of surface degradation should be held, either by surface materials (including transparent windows) or coating stamina, or by protection mechanisms, renewal, or maintenance procedures. This should generally hold for either metallic or organic materials in space.

INDUCED TEMPERATURE ENVIRONMENTAL TRENDS

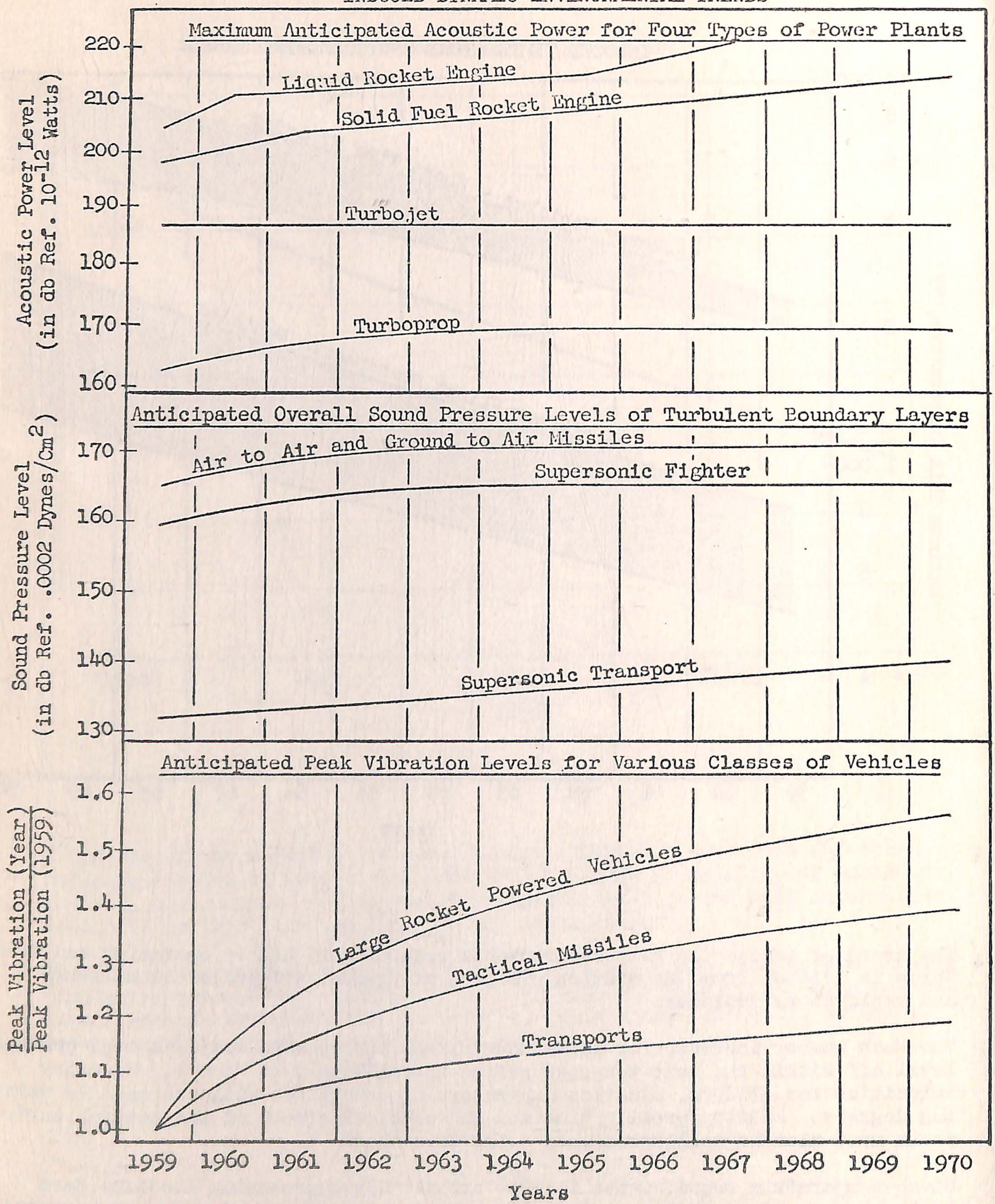


The trend of increasing heat environments resulting in higher operating temperatures is evident from the mission profiles of present and projected military and exploratory vehicles.

The Mach number increase for continuous flight atmospheric vehicles will probably level off within the next ten-year period approximately at Mach 4. Re-entry velocities for gliders, missiles and returning satellites will increase in varying degrees. Mission profile time and the combined effect of the natural environments must also be considered when using this chart.

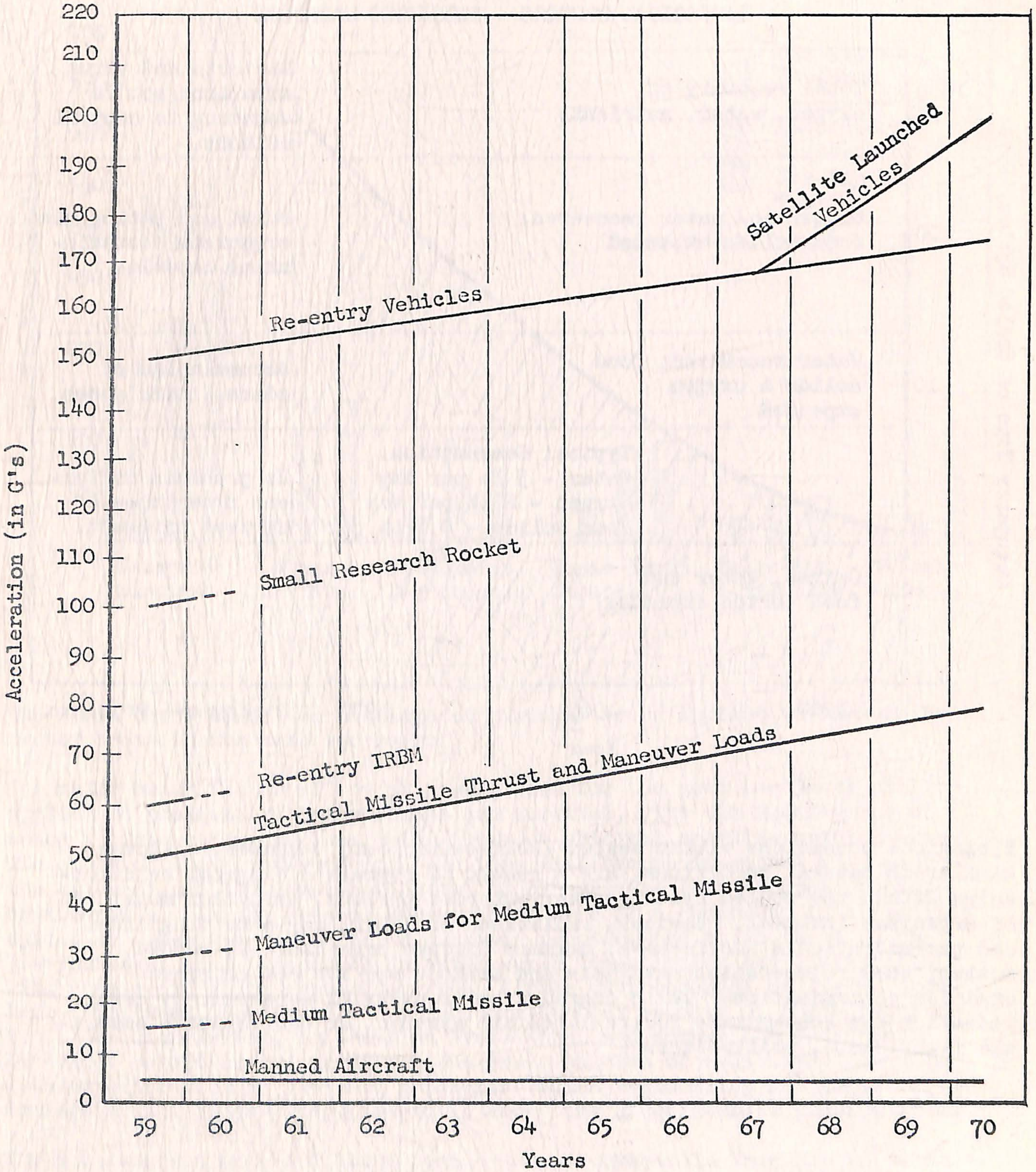
Since temperature requirements in 1959 are already approaching absolute zero (with the use of cryogenic fuels), the relative importance of the problem areas are a function of time rather than temperature as a function of time.

INDUCED DYNAMIC ENVIRONMENTAL TRENDS



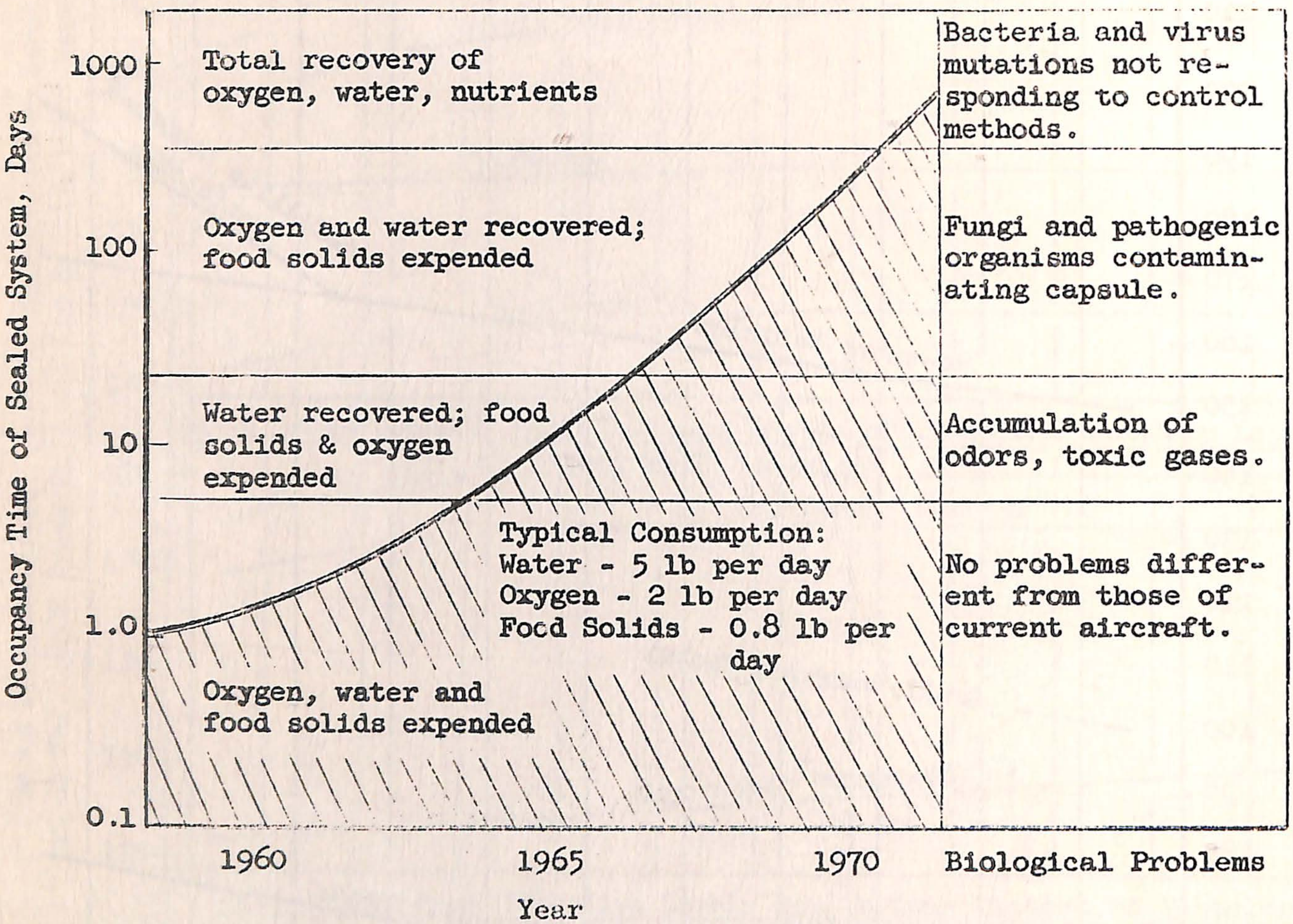
For jet and rocket engines, the acoustic power is approximately proportional to the mechanical power of the engine, thus the top curve is based on a prognostication of engine thrusts.

ANTICIPATED ACCELERATIONS FOR VARIOUS VEHICLES



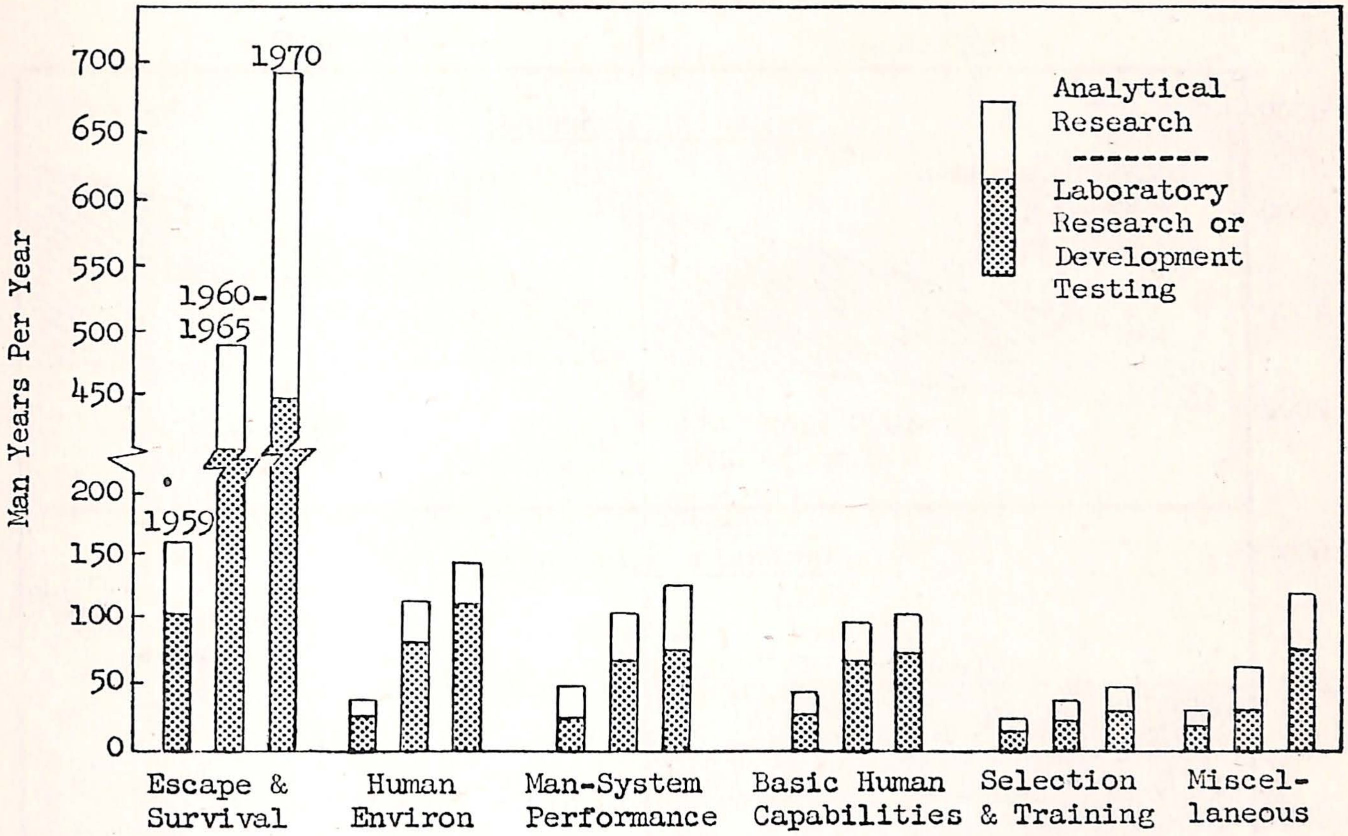
The maximum acceleration associated with a re-entry vehicle should not increase appreciably until perhaps the late 1960's when a re-entry vehicle might be launched from a satellite. Thrust and maneuver loads for tactical missiles will increase as designs and performances are improved.

BIOLOGICAL FACTORS - INHABITED CAPSULES



Biological conditions within sealed (self-sufficient) vehicles, although similar to natural conditions, are a result of overall ecological relationships within the sealed system. Over extended periods, unforseen mutations of organisms (natural, chemical, radiation, or other) may make fungicides and pharmaceuticals ineffective; dormant disease organisms may become active; food regeneration materials and methods are subject to microorganism contamination. Toxic degradation products of materials by cosmic radiation can contaminate recirculated air systems, as can volatile materials (lubricants, plasticizers).

HUMAN SYSTEMS

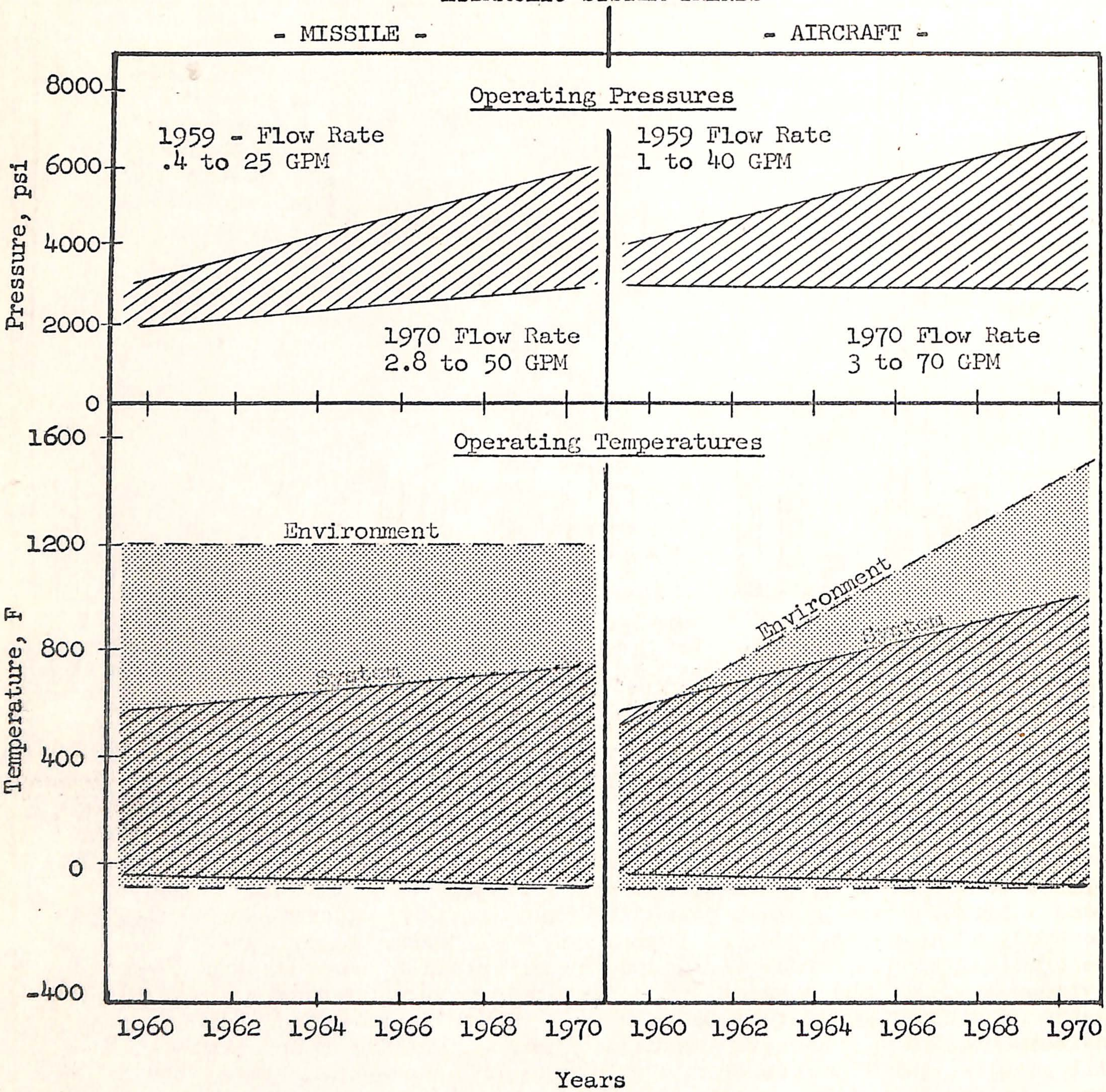


The chart above shows the anticipated manpower to be applied to various human factor areas in the next ten years.

The major human factor effort at present and for the next ten years will be applied to problems of human escape and survival, with the development of space vehicle escape systems being the most critical specific problem area. The study of human environmental problems will become important with most of the critical problem areas reflecting an orientation towards space vehicle environments. In the area of human performance as a component in a specific system or subsystem, anticipated manpower requirements match those in the environmental area. Research in basic human capabilities and limitations will require slightly less effort than either environmental or system problems. Critical problems involve the more complex aspects of human behavior, i.e., decision making, information processing, and search and detection. Personnel selection and training constitute an area of relatively low effort with concentration on training problems. Human reliability and pilot factor accidents will receive major emphasis among the miscellaneous problem areas.

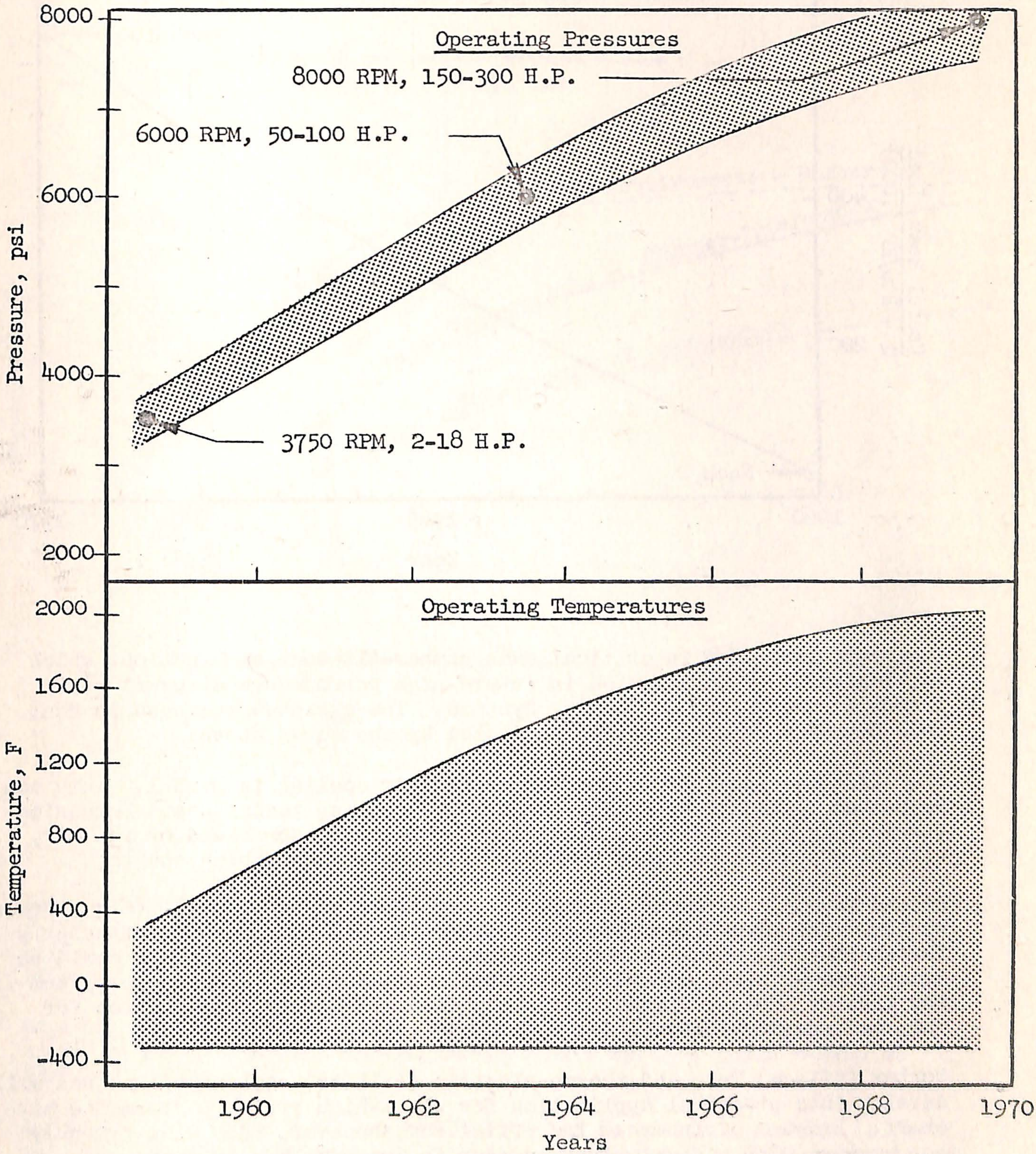
The manpower estimate indicates that a two or three-fold increase in human factor personnel will be required by 1970 to cope with the problems of human existence and performance in increasingly extreme environments and in ever more complex systems.

HYDRAULIC SYSTEM TRENDS



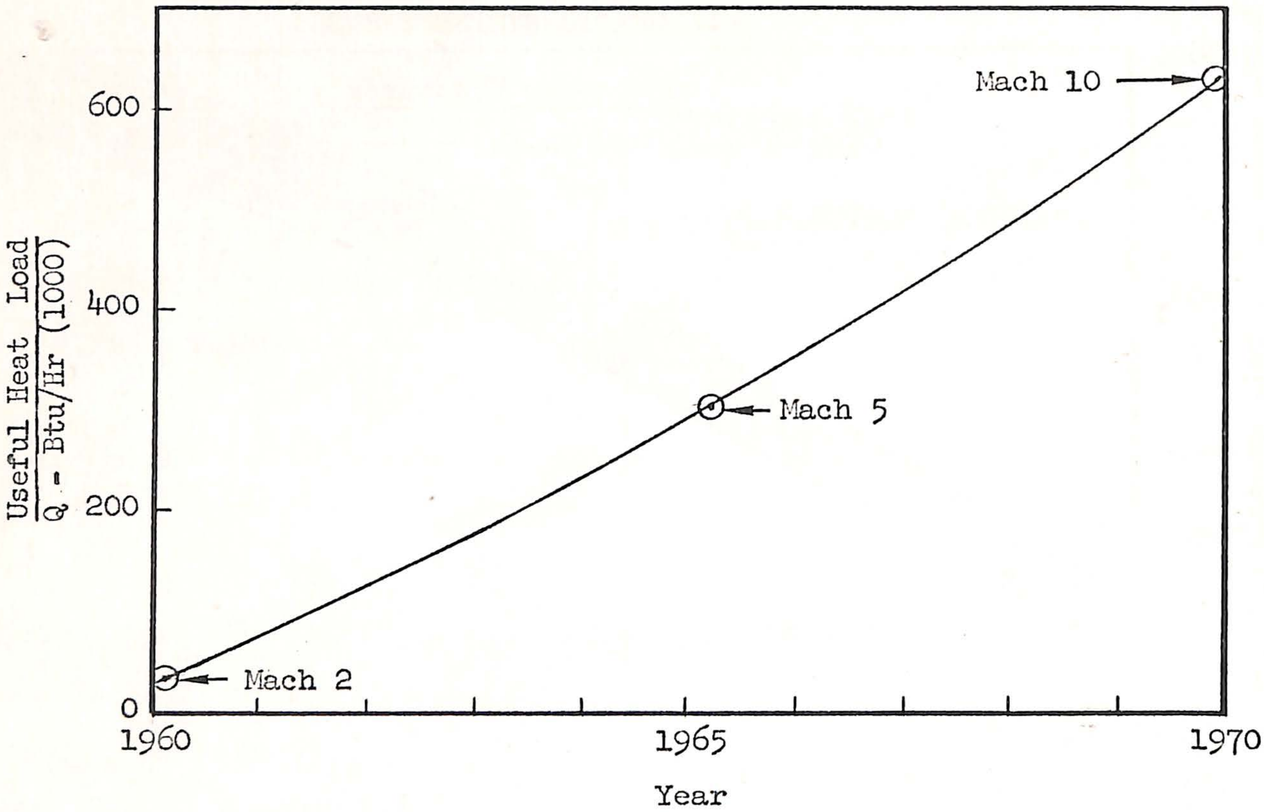
In addition to the above performance requirements, exposure to nuclear and high vacuum environments must also be considered.

PNEUMATIC SYSTEM TRENDS



The pneumatic system trends indicate higher power requirements, resulting in higher pressures and shaft speeds. Gas temperatures will be as high as 2000 F or as low as -300 F in the case of cryogenics.

COOLING SYSTEMS



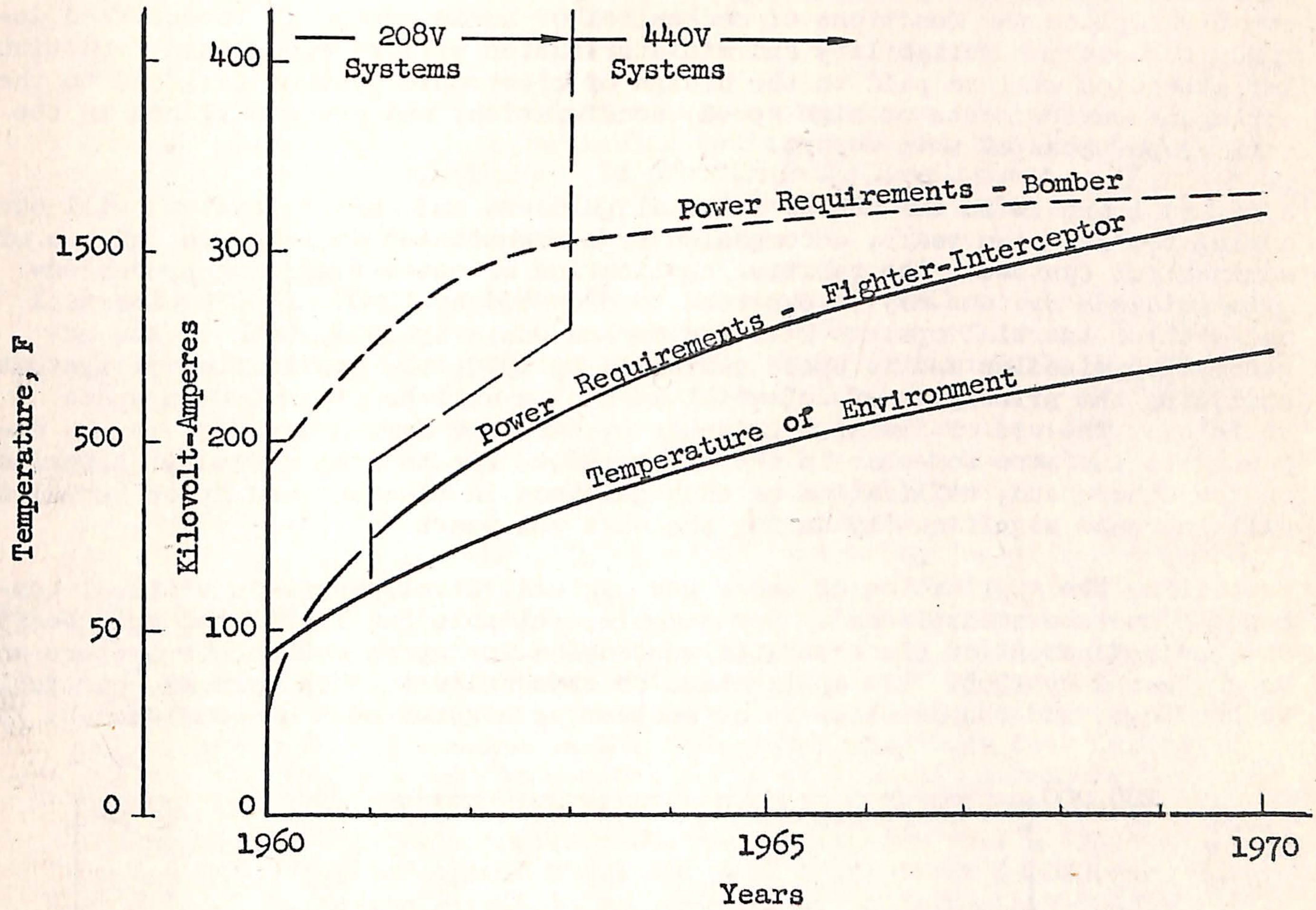
The rapid increases in critical Mach number-Altitude combinations which may logically be anticipated in future high performance aircraft will intensify the burden on Cooling Systems. The expected increase in Heat Load Capacity requirements is indicated by the curve above.

The effective speed limit for direct ram air cooling is Mach 1. This can be pushed to Mach 2 or 3 with evaporative cooling techniques. Expansion-turbine Air Cycle systems, utilizing turbo-compressor bleed or ram air, will be effective at least to Mach 5 with multiple turbine staging.

Beyond Mach 5, the weight penalty of Air Cycle or Vapor Cycle (e.g., Freon) systems will favor liquified gas boilers (liquid nitrogen), particularly for short-term, high heat load regimes. Reasonable temperature could be maintained within a manned space vehicle utilizing a vapor-cycle system for free or orbital flight, with liquified gas boiler augmentation for exit and re-entry heat loads.

Vortex (Hilsca) Tube and thermo-electric (Peltier) cooling techniques will develop into practical application for ultra-high cruise performance aircraft. Because of inherent low efficiency, however, they will probably not compete with higher weight systems in the next 5 - 10 years.

ELECTRICAL SYSTEMS TRENDS



Alternator speed will vary from the present 6,000 RPM for fighter craft and 8,000 for bombers to 12,000 RPM continuous duty and 24,000 RPM intermittent duty by 1965. (These maximums are not to be anticipated in maximum machine sizes, as armature peripheral speeds would be extreme.)

One contributor indicated that system frequency may be expected to use to 3200 cps during this decade, while others felt it would remain at 400 cps.

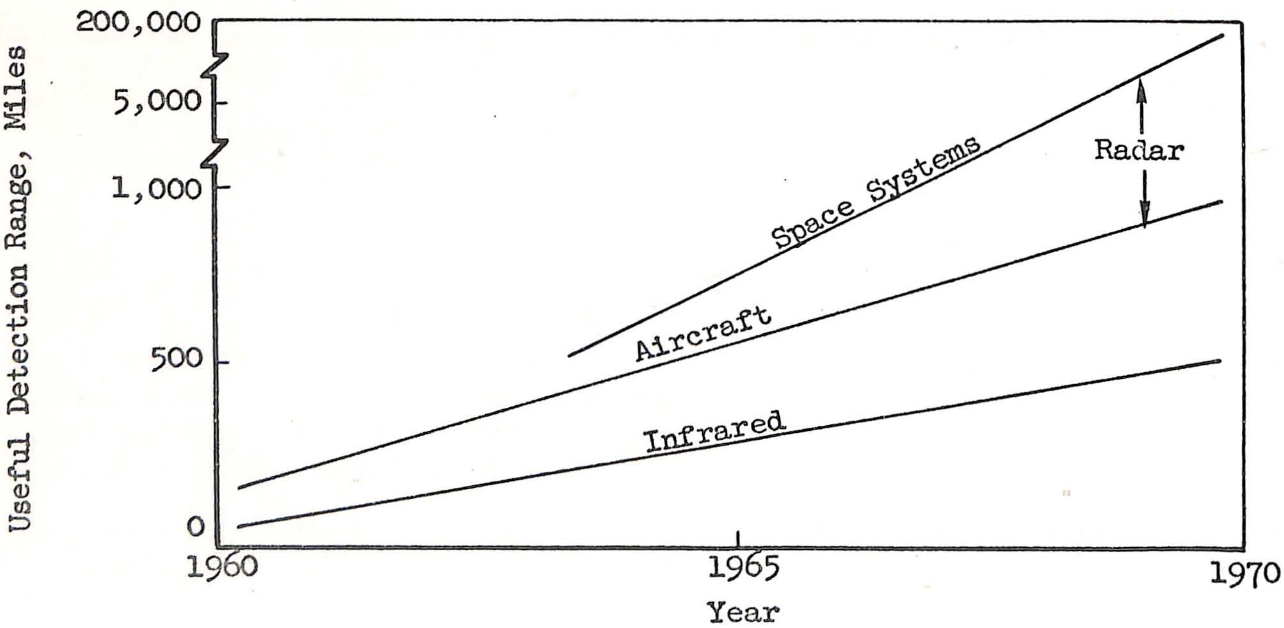
Ballistic and space vehicles are too varied in size and mission to chart, but the indicated criteria are believed to encompass the requirements of such vehicles.

ELECTRONIC AND GUIDANCE SYSTEMS

Unquestionably, during the next ten years there will be an increasing usage of electronic equipment, particularly in those areas where such components may capably replace the functions of mechanical or human systems. Intensified demands for extreme reliability and miniaturization will be recognized. Particular attention will be paid to the design of electronic systems tailored to the stringent environments of high speed, acceleration, and space outlined in the earlier portions of this report.

A marked increase in the use of inertial guidance and control systems will occur during the next ten years, accompanied by a significant decrease in the use of noninertial systems. The relative application of space-fixed and precessed-gyro guidance systems may be expected to drop 50% by 1970. Doppler-inertial and stellar-inertial systems will see marked usage by 1965, both in second-generation missiles and in space vehicles; by 1970, the application of systems utilizing the principles of celestial mechanics will be extensive in space vehicles. The use of infrared guidance systems for manned aircraft may be expected to increase somewhat in the early 1960s, but to drop markedly thereafter; on the other hand, utilization of such guidance in missiles and space vehicles will increase significantly during the next ten years.

Supporting the application of these new systems, developments in critical components must be accomplished. For example, reliable gas-lubricated spin bearings and the refinement of electrostatic suspension for gyros and accelerometers must be perfected by 1965. The application of cryogenics to such systems, particularly to bearings, and the development of nuclear spin gyros must be completed by 1970.



The useful-range requirements for airborne detection systems will be substantially increased during the next ten years. The effects of rare and ionized gases, aurorae, and cosmic interferences, as suggested earlier in this report, will require consideration; concurrently, emphasis will be placed on high reliability and reduction of volume and weight.

PROPULSION

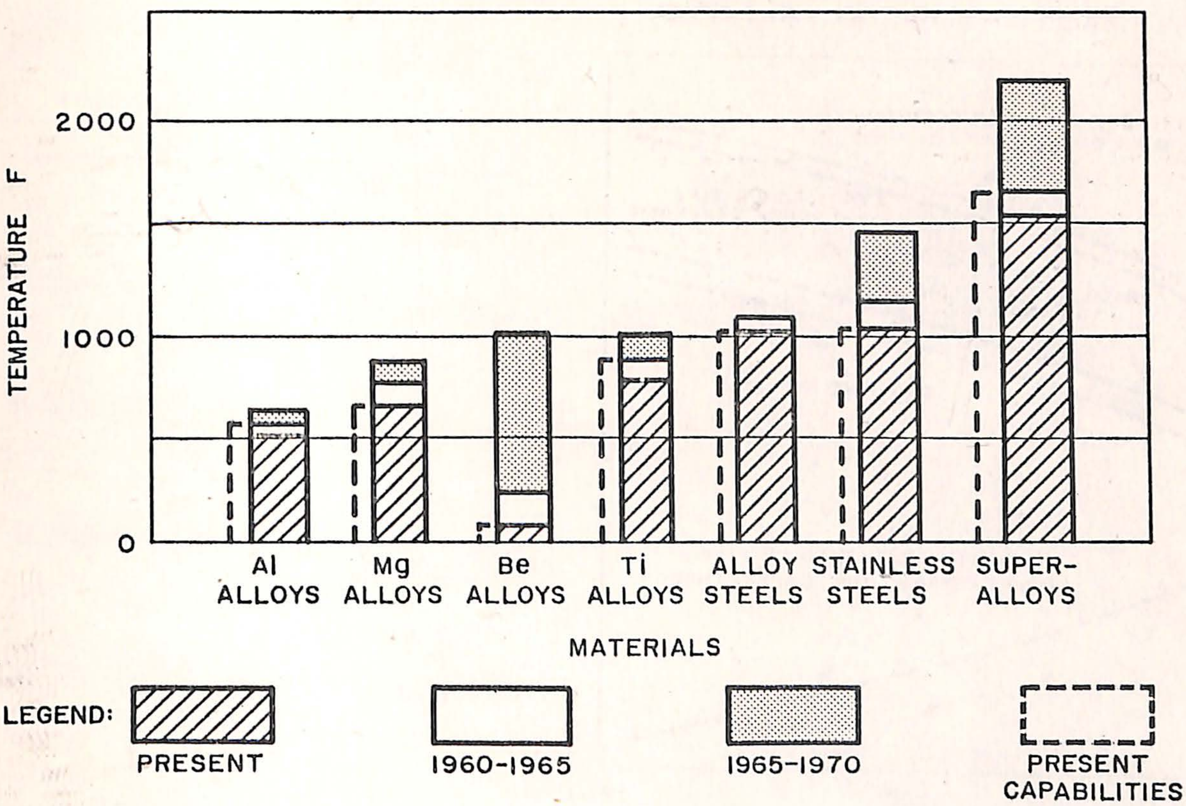
In theory, it may be possible to select a propulsion system having the desired performance for a particular vehicle once the vehicle characteristics have been established. In practice, the development status of propulsion systems have generally separated into two major categories, air breathing systems and rocket systems.

The air breathing systems, by their very nature, will be limited to vehicles for the movement of large cargoes from one point on the earth's surface to another. Improvements in propulsion systems will depend not only upon the availability of high energy fuels (see chart, page 31), but also on the development of accessories and lubricants suitable for the more severe operating environments which will be encountered when the potentialities of the new power plants are utilized.

Rocket systems possess the capability for providing "super performance" within the earth's atmosphere or for operation outside the earth's atmosphere. The rocket engine is still in the formative stages of development. A clear superiority for the application of solid or liquid propellant rockets for selected categories of vehicles has not yet been established. Thrust control for manned vehicles requires further development. Basic design parameters for combustion chambers, fuel injectors, and accessories have not been established at a level comparable to similar items in the air breathing systems. It is apparent that, for the foreseeable future, improvements in operational rocket systems will be dependent upon efficient utilization of high energy fuels (see page 31). Such development can result in an increase of approximately 50% in specific impulse in the next ten years. Theoretical studies, however, indicate that a 4-fold increase in specific impulse is possible with free radical and nuclear power plants. Continued development of these systems should result in their replacing the chemical reaction power plant as the chief source of power for high performance vehicles after 1970.

Ion rockets and photon engines have been studied as possible power plants for use in outer space where low thrust, high specific impulse engines can be used effectively. Development of these systems will be accelerated when space flight by chemical and nuclear powered vehicles becomes more frequent.

METALS AND ALLOYS

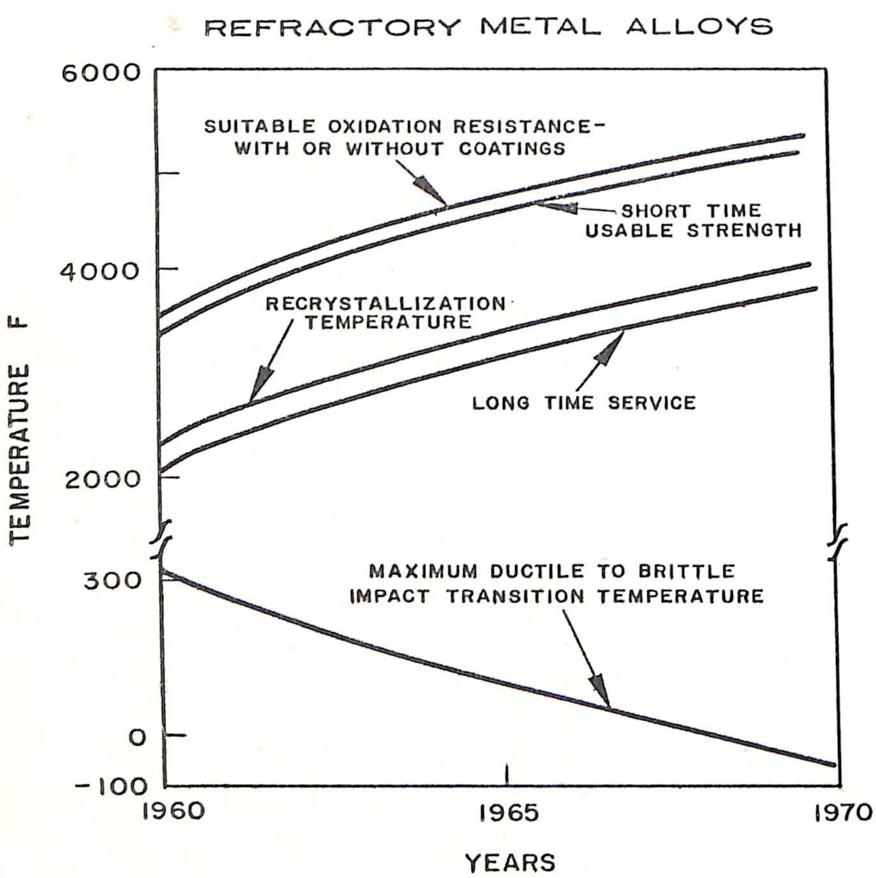


The trend in structures is toward higher temperature which is frequently accompanied by usage of high density metals. To avoid excessive weight penalties in future structures, the paramount needs are:

1. Increased load-carrying capability throughout the entire service temperature range, i.e., alloys that do not go through a brittle range prior to reaching the maximum service temperature.
2. Improved fabrication characteristics, i.e., greater ductility, better weldability, and improvement in other properties that affect the manufacturing operations.
3. Increased availability to close tolerances in desired mill forms, i.e., sheet, bar, extrusions, forgings, and castings.

From the above chart it is apparent that beryllium falls far short of 1970 anticipated requirements. In addition to the broad needs listed above, specific current shortcomings of beryllium are poor weldability and lack of ductility.

Aluminum alloys have a higher potential thermal limitation than shown on the chart in view of developments in sintered aluminum powders.



The above trend and forecast curves are intended to show improvements that could be realized if the proper emphasis is placed on the development and application of refractory metal alloys. The differentiation between the materials considered here and the super-alloys shown on the preceding chart is that the evaluation on the above chart is based on columbium, molybdenum, tantalum, tungsten, and their alloys. The above chart does not reflect the combination of properties possible with all of these materials. Rather, it shows that with tungsten alloys in the present state of development which have the highest usable strength also have the highest impact transition temperature. Columbium and tantalum have lower impact transition temperatures, but also lower usable service temperatures. The trend indicated in the chart is that alloys should be developed having both usable strength at high temperatures and a ductile to brittle transition temperature of -65°F or lower.

The needs (increased load carrying ability, improved fabrication, and increased availability) cited on the previous page are also important factors for refractory metals.

APPLICATION FORMS
CHART 1

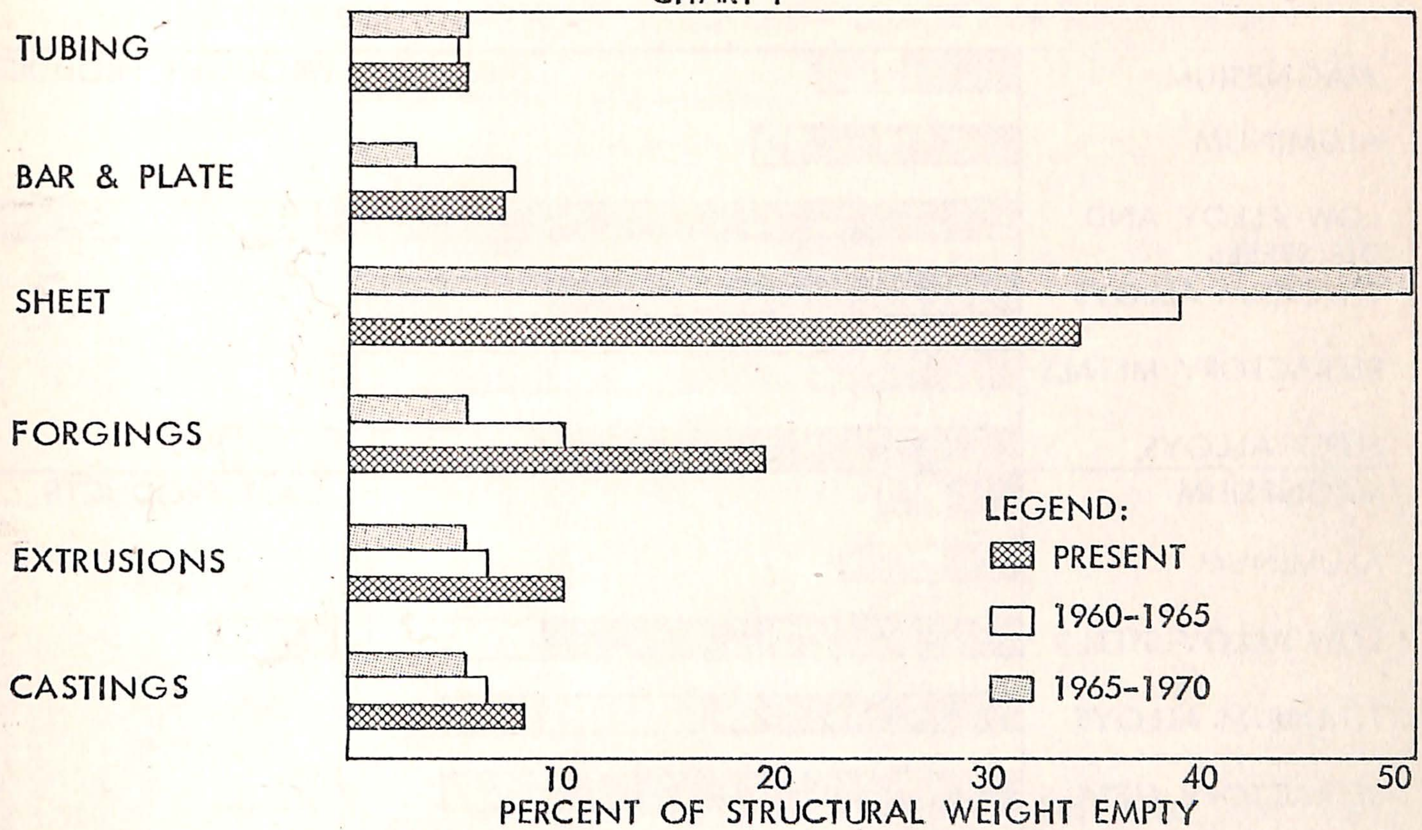


Chart 1 above shows the usage of the wrought and cast products as a percentage of the vehicle structural weight empty. This chart also shows that high strength, high temperature airframe missile and spacecraft will employ a greater proportion of built-up structure and a reduced amount of integral structure. This trend is reflected by the increase in the usage of sheet material and the reduction in requirements for the other cast and wrought forms of materials. This basic change in design trends is due principally to the fact that the high mechanical properties of the future sheet materials can be most efficiently utilized by built-up structure design. To achieve equivalent efficiency in an integral structure, complete machining would be required.

The trends and applications for castings, forgings, extrusions, sheet and tubing indicate the need for closer dimensional tolerances and control, improved surface finishes and improved reliability and integrity for the 5- and 10-year period.

The use of castings will reduce, and in many applications weldments will be used in place of castings.

Relatively small precision forgings will be assembled into larger complex built-up fittings to replace large conventional forgings.

Aluminum and magnesium alloys will continue to be used for some of the internal structure. Landing gears and supporting structure will utilize these materials because of the temperature environment established by use of rubber tires, seals and gaskets.

APPLICATION FORMS
CHART 2

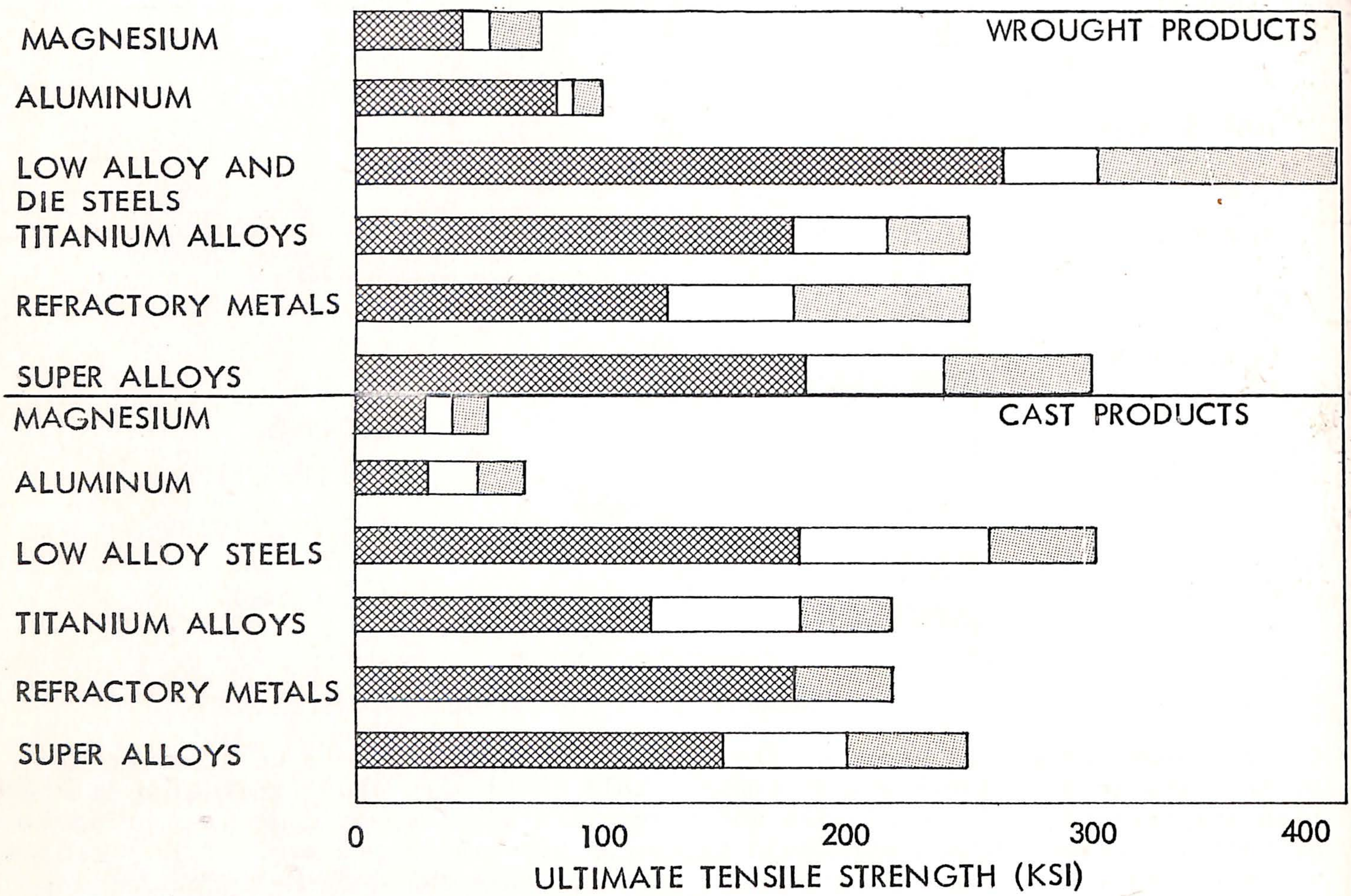
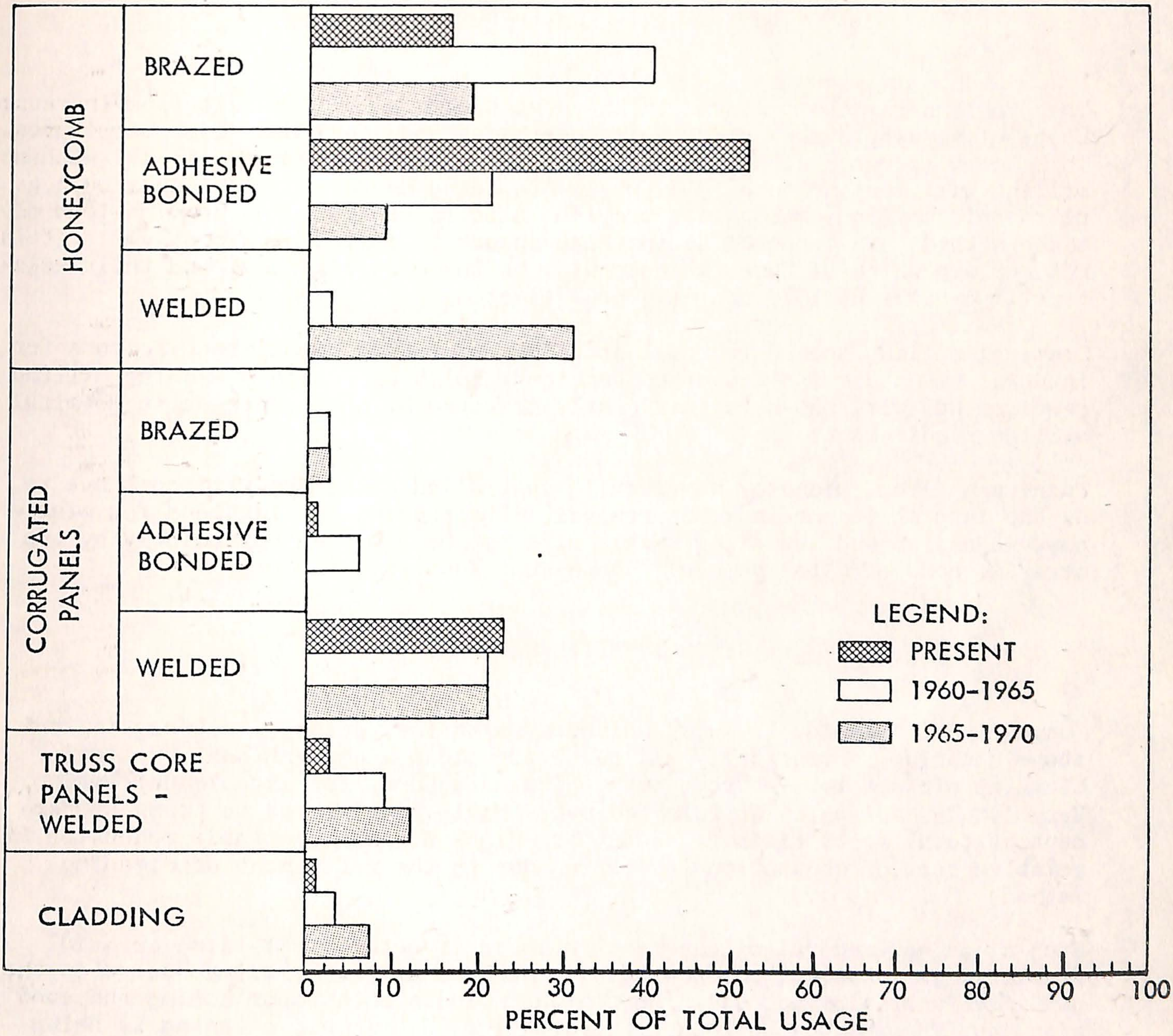


Chart 2 indicates the increase in mechanical properties of the cast and wrought alloys that is anticipated during the next 5- to 10-year period.

APPLICATION FORMS
CHART 3

TOTAL COMPOSITE MATERIAL STRUCTURE - USAGE FOR AIR VEHICLES



In composite structure, the object is to combine similar and/or dissimilar materials in a manner so as to take advantage of the specific properties of each, and attain the desired structural integrity of the whole assembly. This is an important factor when the high performance of current and future aircraft is considered. Where the lower limit of high speed aircraft is now assumed to be Mach .9, in the 1960 to 1965 period Mach 3 aircraft will be in volume production.

TRENDS IN METAL REMOVAL METHODS

The problems in metal removal in the next ten years will result from increased usage of very hard metals, ceramics, carbides and steel honeycomb structures. This trend in material usage means that metal removal by conventional machine milling will decline about 30%, while broaching and newer techniques such as ultrasonic milling, mechanical erosion, electro erosion, and combinations of these methods are expected to increase in use to solve these problems. It is not certain which of these methods will be the most efficient and their relative importance by 1970 can only be estimated.

Chemical milling should increase steadily due to additional requirements for integral structure in lieu of conventional built up design. Machine milling requirements will not be significantly affected by this increase in chemical milling requirements.

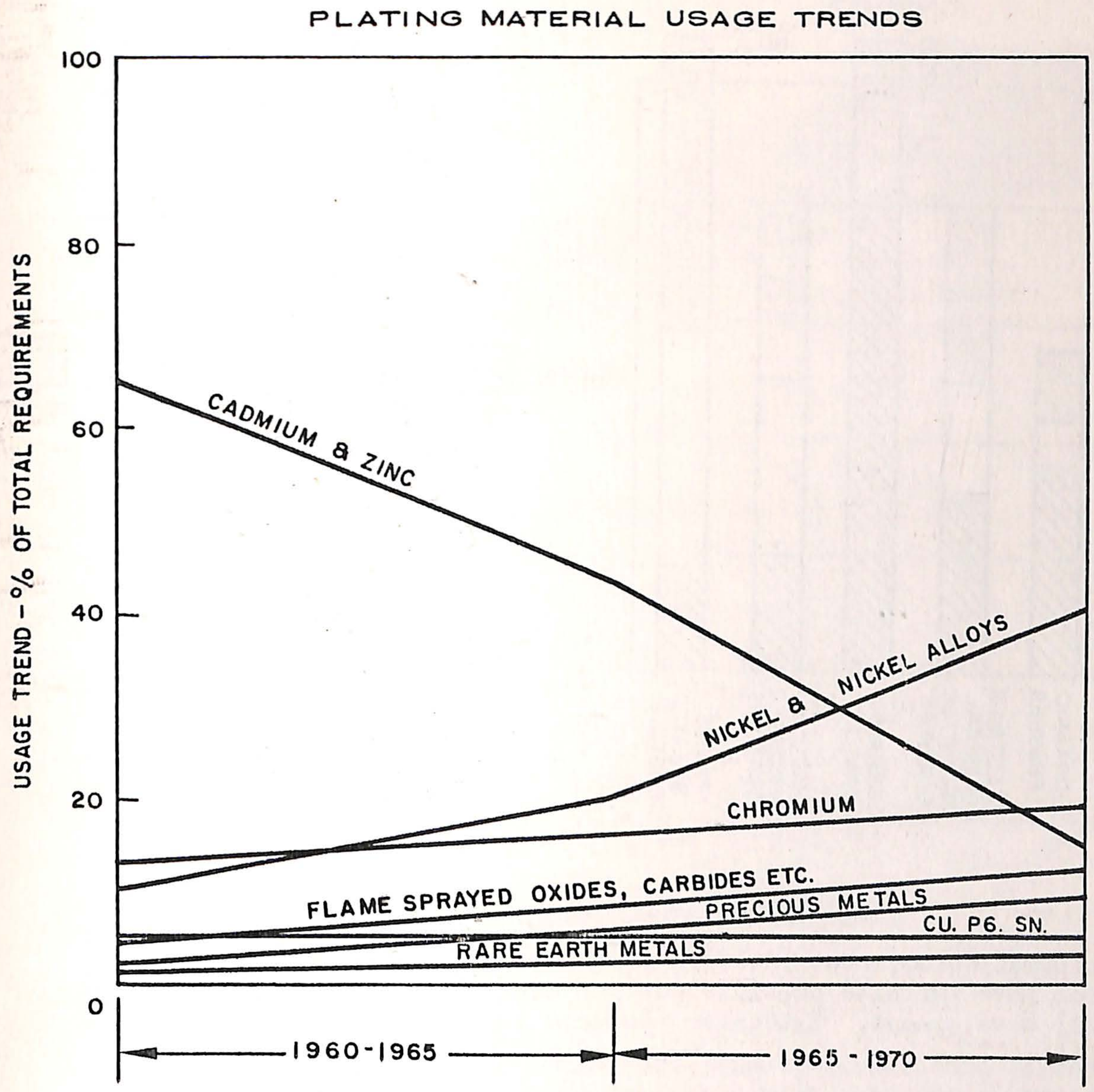
Machine milling, aided by numerically controlled machines, will continue to be the largest factor in metal removal. Its present applications for aluminum, magnesium and low alloy steels will not be replaced appreciably by the newer methods of metal removal due to cost factors.

TRENDS IN METAL CLEANING

Conventional cleaning includes solvents, alkaline, acids, electrolytic, and steam cleaning. Practically all parts are given a conventional chemical cleaning of some type at some stage of manufacture, for example degreasing. Very little decline is anticipated over the 10-year period in terms of percent of total parts cleaned. But there might be an appreciable reduction in relative cost of conventional cleaning due to the refinement of cleaning methods.

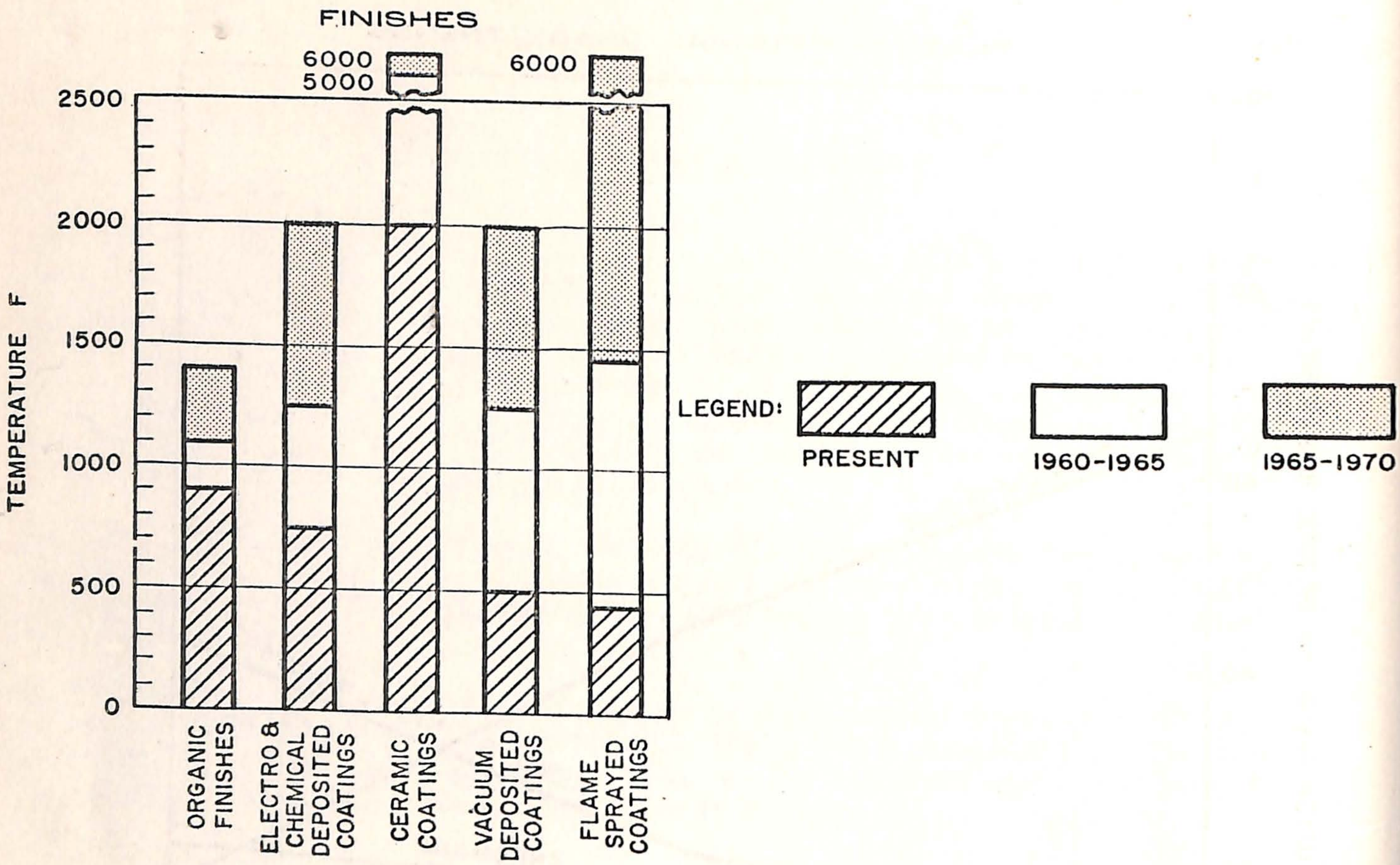
Etch cleaning, removal of a very thin layer of metal by alkaline or acid etchants, is comparatively new and is expected to reach maximum usage in the next five years. Blast cleaning, which includes both vapor honing and sand blasting, is expected to increase gradually. Ultrasonic cleaning is being rapidly explored. High temperature salt cleaning is expected to remain in low usage due to high initial cost. The potential for electro-erosion is not well defined at present.

Trends in metal removal methods and trends in metal cleaning are further discussed in Part Two of this report.



The usage trend for the next ten year period will show increases for materials with improved high temperature properties. The materials will also be required to have additional properties such as wear resistance, impact strength, stable conductivity, radiation resistance, emissivity properties, and impermeability for protecting oxidizable materials.

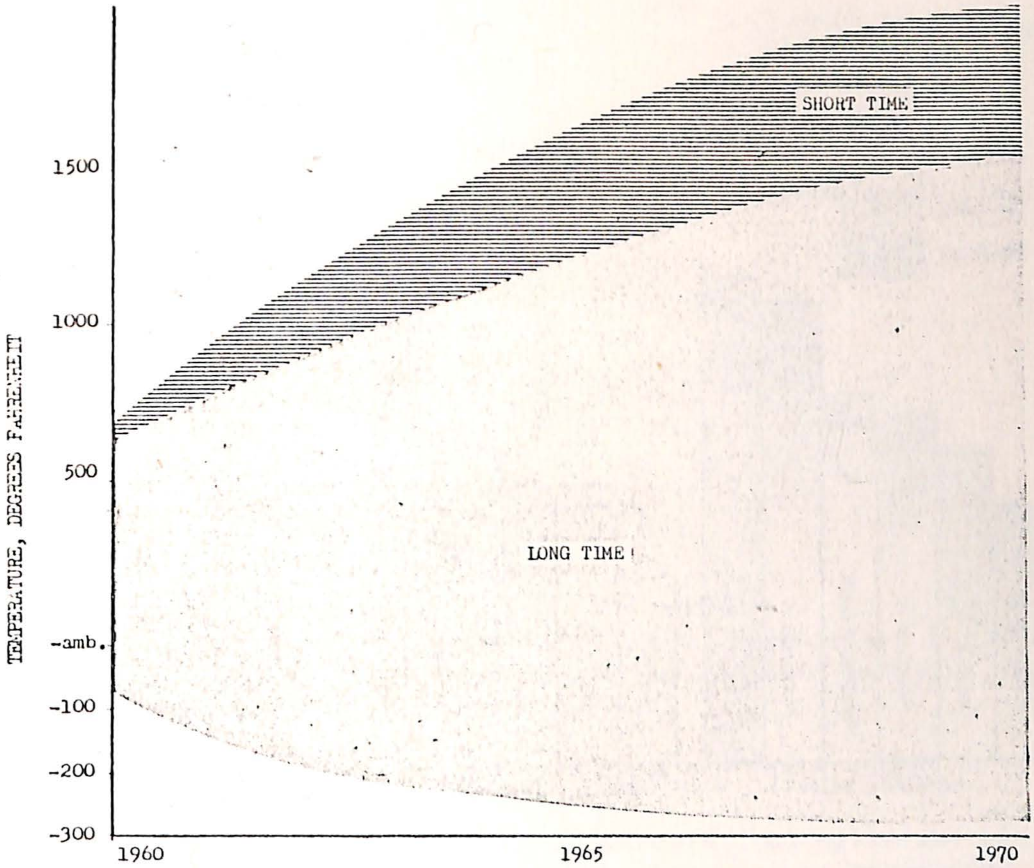
These requirements will be accompanied by decreasing usage of metals having lower temperature limitations. Electroless plated deposits heat treated to produce excellent hardness and wear resistance will find increasing usage in the 1000° to 2000°F temperature range. More use of precious metals is indicated as temperature and reliability requirements increase. Rare earth metals for electronics and nuclear reactor systems are expected to find increased usage as their supply is increased.



The above information does not include (1) multilayer electrodeposited coatings which have infinite possible combinations or (2) plasma jet coatings under development. Extensive research is required in the latter area.

Aluminized silicone paint is included under "Organic Finishes". Except for "Organic Finishes", coatings which exceed the present temperature requirements in all categories are available in experimental or pilot stage.

PLASTIC MATERIALS

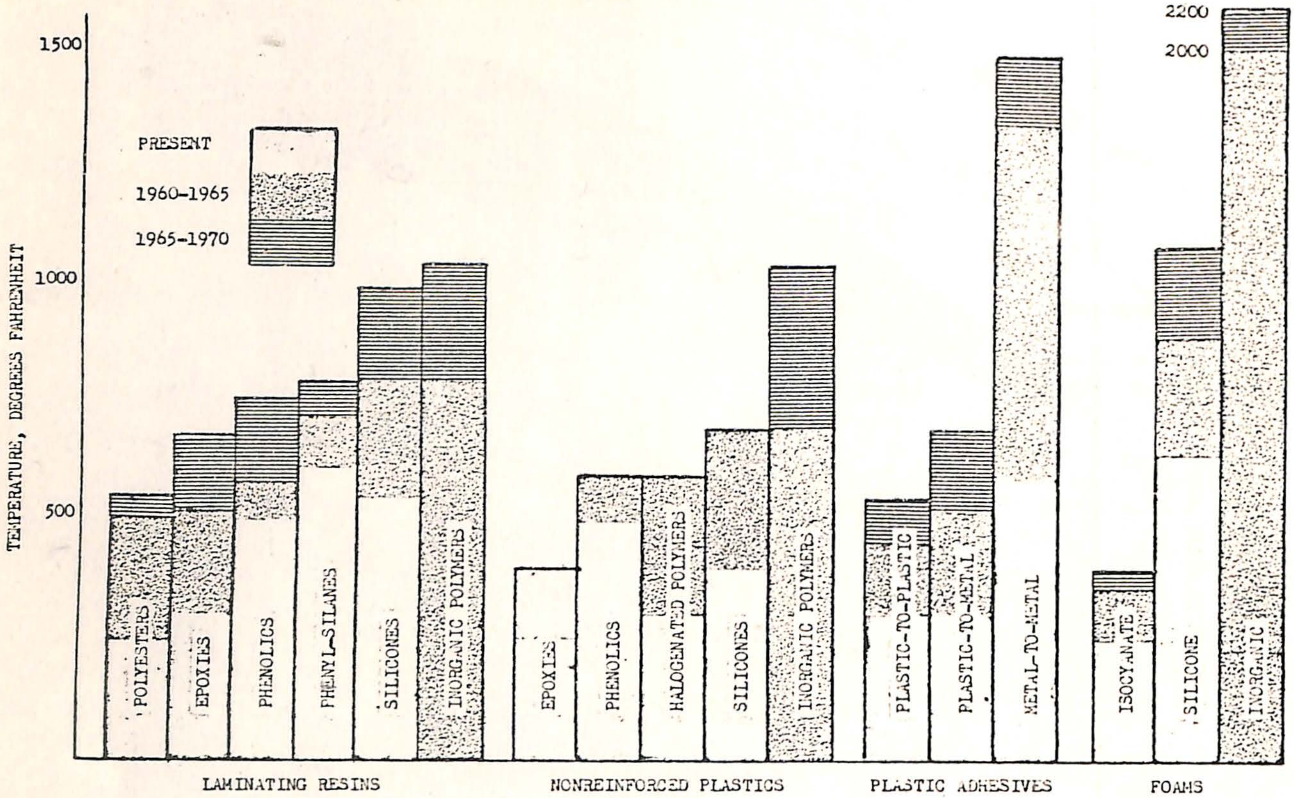


Time-Temperature Requirements

The three primary factors contibuting to temperature stresses on plastics are aerodynamic heating, high altitude subsonic cooling, and special environments such as liquid oxygen.

The above chart presents typical short and long time temperature requirements for all categories of plastics. The short time considered is approximately 0.1 hour, and the long time considered is 200 hours. Inasmuch as this is a generalized chart, these data should be considered in conjunction with the data presented on Page 25 which deals with more specific plastic categories under 200-hours service.

PLASTIC MATERIALS

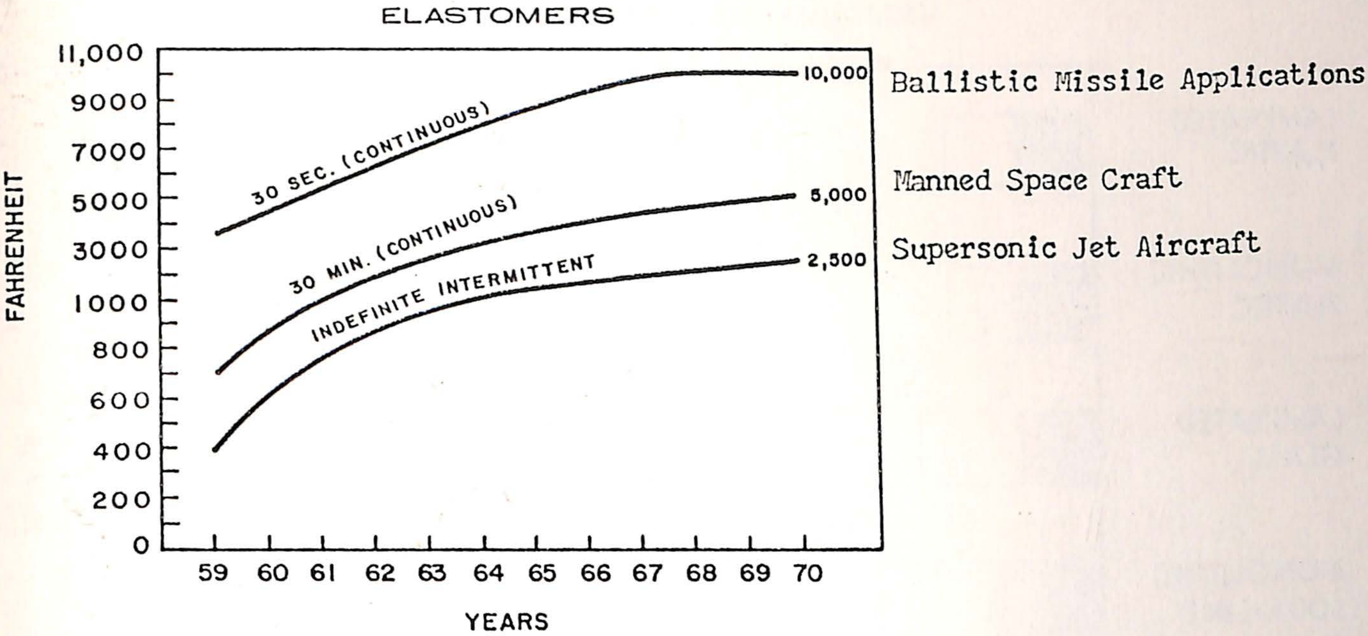


As with metals, the trend in plastics requirements is toward higher service temperatures. This trend is moderated by the instance of non-reinforced plastics which are used primarily in vehicle interiors. However, there will be instances of high-temperature requirements even for these materials, as, for example, in exterior and vehicle wall elements.

The above chart presents estimated requirements for 200 hour service. Laminating resins technology is lagging behind reinforcing fiber technology and will require special attention. The data given on non-reinforced plastics do not include the low temperature materials such as polyethylene, vinyl, and polysulfide compounds, for obvious reasons.

Forecast data on structural adhesives comprehend organic, semi-organic, and inorganic systems. It assumes that minimum design lap-shear strengths of the order of 1500 psi are maintained during exposure. The implication of this forecast is that fundamental research and development work needs to be accelerated to yield adhesive formulations when needed. The cost factor emphasizes this need, for the cost of structures fabricated by adhesive systems is expected to be substantially lower than for structures fabricated by welding or brazing.

Foam materials are used to stabilize the skins of sandwich structures and for radome core materials. Although factors other than temperature limitations are important in these applications, the primary limiting factor is performance at high temperature.



The trend is to shorter exposures and higher temperatures. As temperature requirements move higher the low temperature flexure temperature will also advance, thus elastomers for these temperature environments may have physical attributes of rigid thermoplastics at ambient.

<u>Elastomer Consumption Trend With Increasing Temperatures</u>

The use of natural rubber (unmodified) will decrease, but will find use in applications requiring radiation resistance and fair temperature resistance.

Neoprene consumption will decrease, but will find use in applications requiring radiation resistance, flame retardance, and moderate temperature resistance.

Buna N base polymer for hydraulic packings and hoses will partially be replaced by higher temperature and ozone resistant polymers.

Polysulfide rubbers will gradually fade away as a sealant and propellant base material. RTV fuel resistant silicones and urethanes will become more important as sealant base polymers.

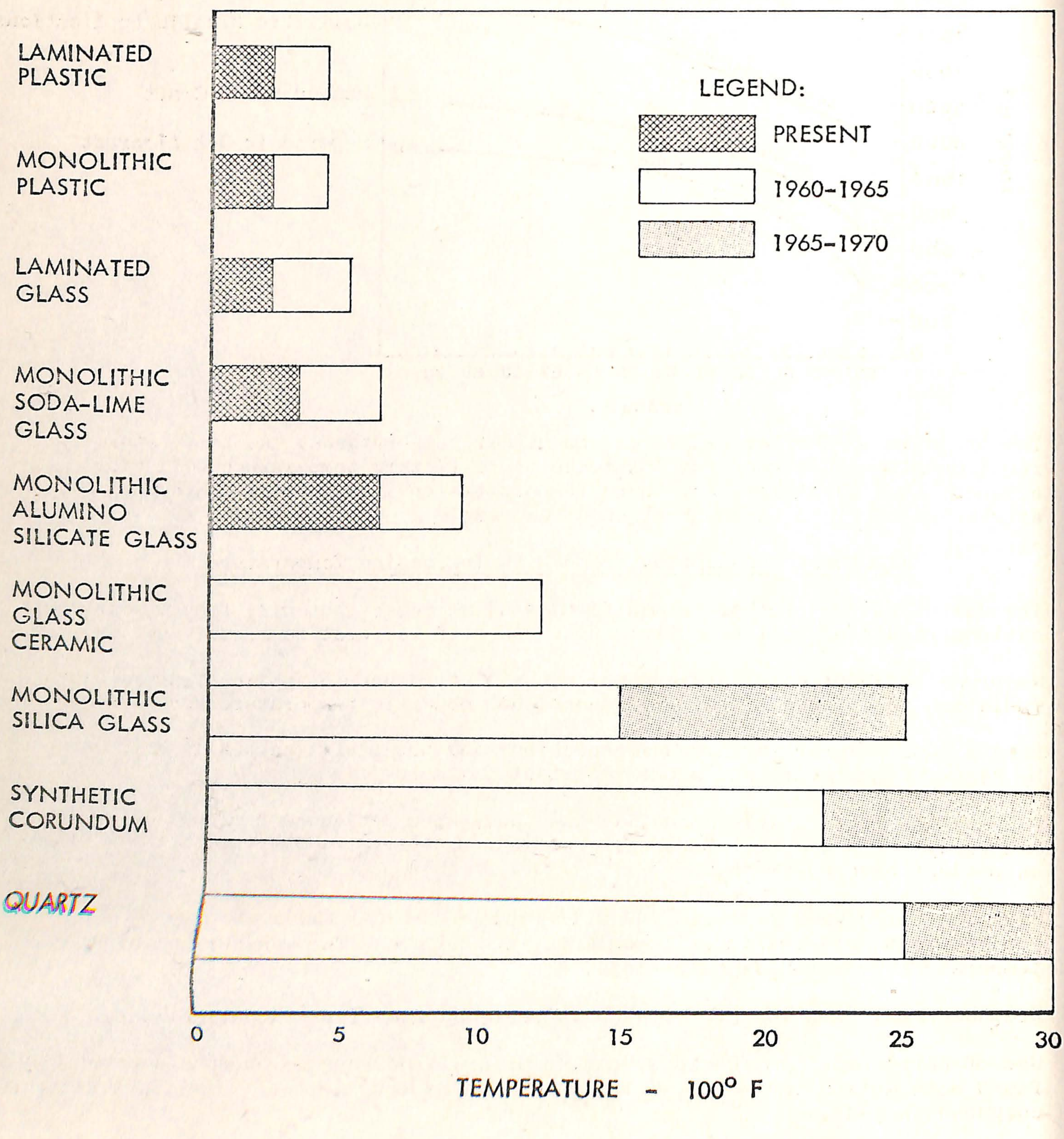
Silicone usage will increase and will replace natural rubber in some tire applications, polysulfides in sealants, and neoprene for weather and high temperature resistant applications.

Urethanes will continue to move up as heat and fuel resistance improves.

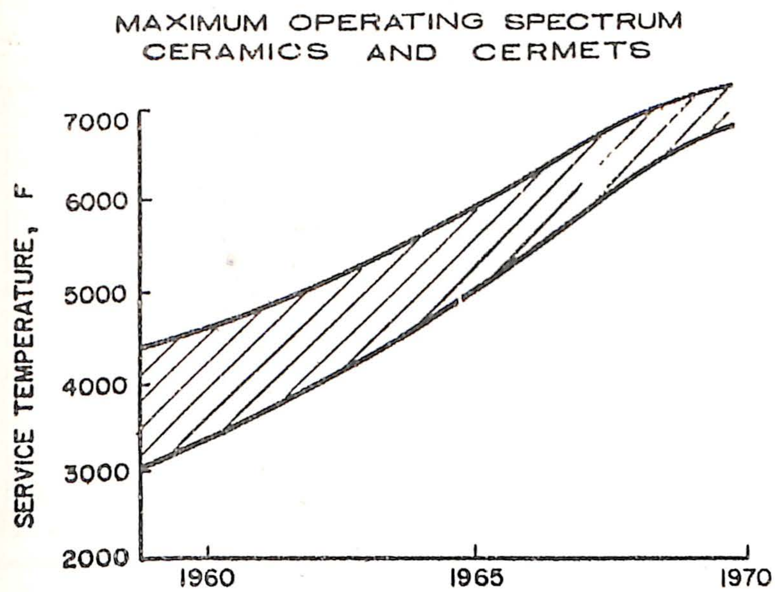
Use of butyl packings, O-rings, and hoses will increase as phosphate ester hydraulic fluid consumption increases, but may decline as tougher, heat resistant silicone compounds appear.

Fluorocarbons offer the best immediate answer for high temperature, high physical property, and fuel resistance. However, fluoro silicones and nitrile silicones will provide stiff competition because of lower density where the better physical properties of the fluorocarbon rubbers are not needed.

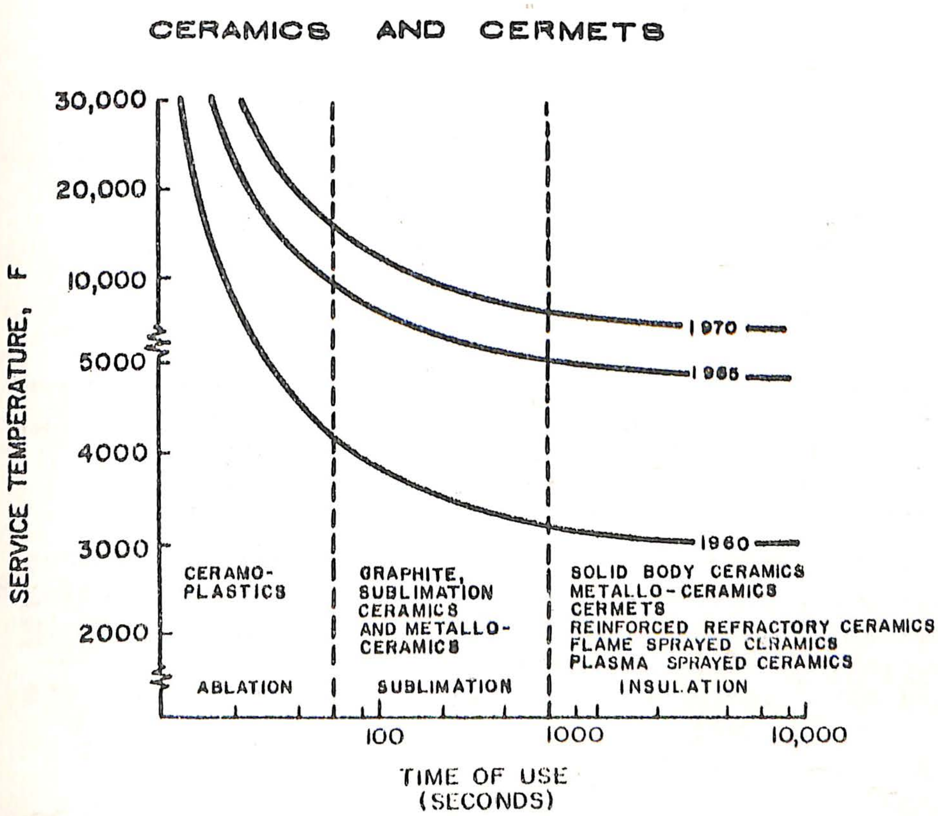
TRANSPARENT MATERIALS

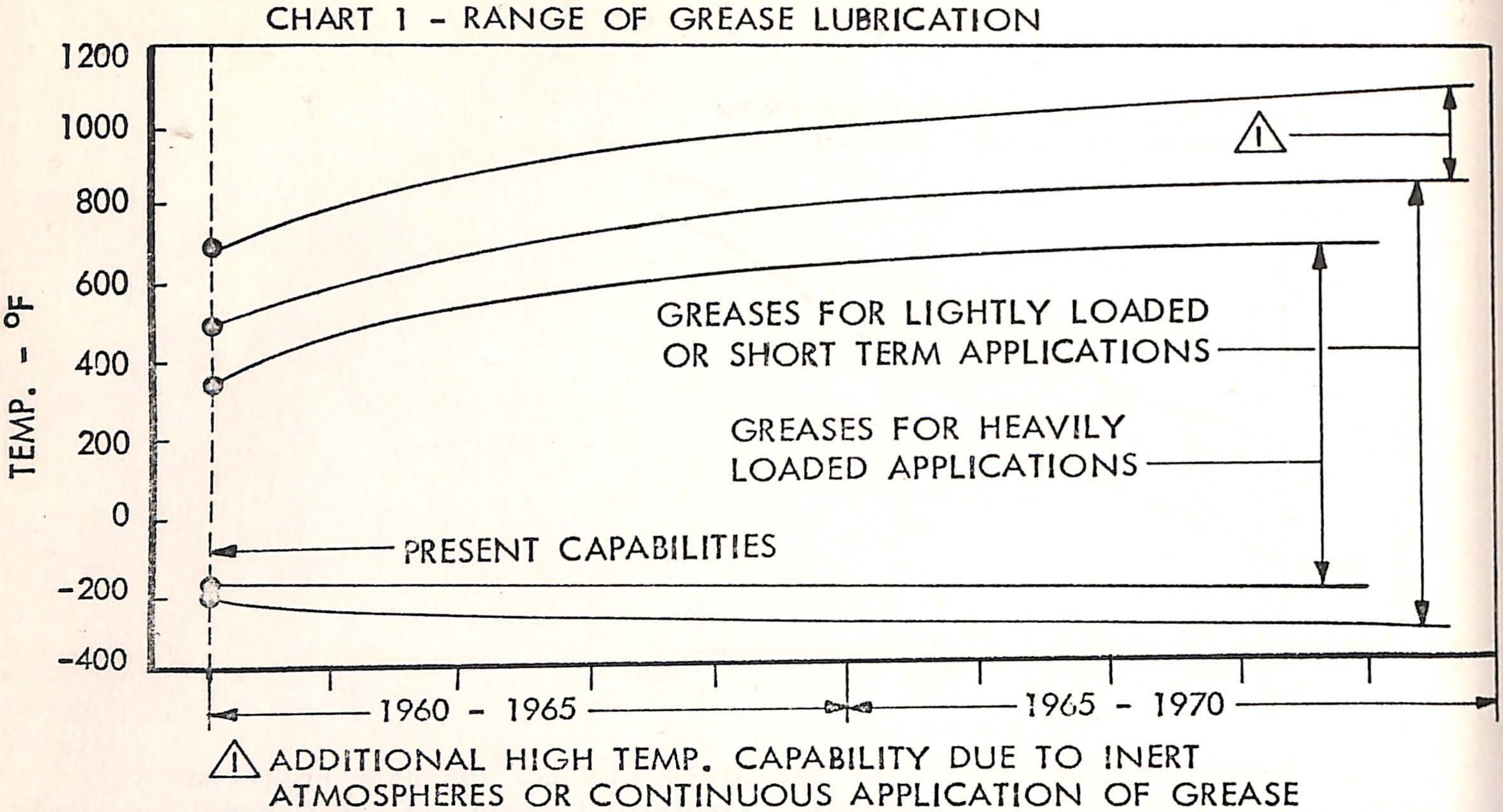


The above bar chart is very general in nature, and the intent is to show the types of material which may be used for temperatures expected. With the present state of development, it is clear that organic plastic materials cannot be used for the temperatures expected in advanced manned aircraft. Therefore, inorganic glass of some type must be used. The compound types shown on the chart indicate the temperature properties required, although improved compounds may be developed.



The development and application of ceramic materials as shown on these charts is intended to show reasonable development based on the current state of the art and the progress that has been realized over recent years. The above chart is based on the melting point of ceramic materials intended for insulation and/or resistance to temperature. The chart below also includes ablation and sublimation applications and considers the time at temperature.





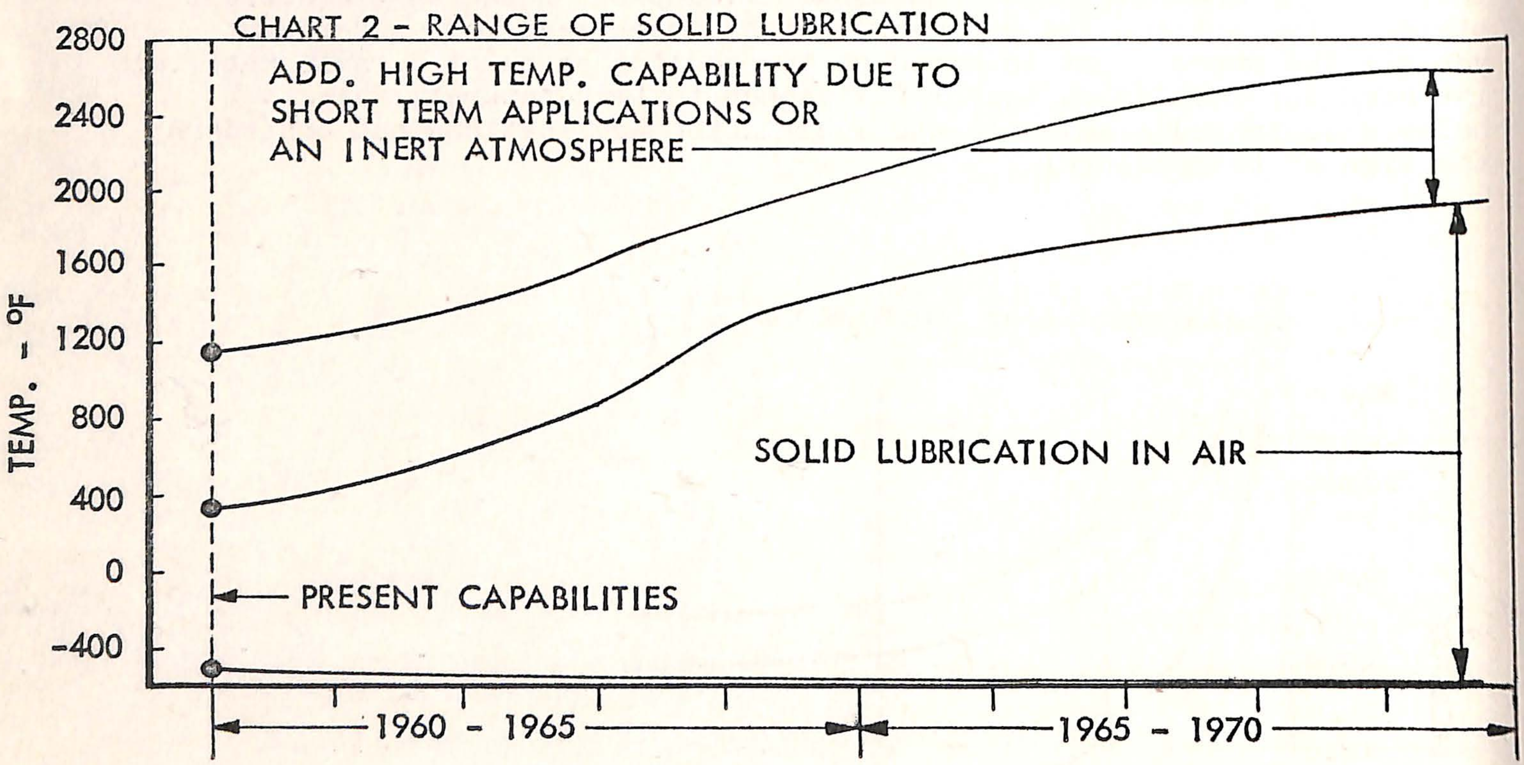


Chart I is a forecast of the trends and capabilities of grease lubrication for the next ten years. Temperature ranges given at a specific date refer to the general capabilities of grease lubrication at that date and not to the temperature range of a single grease. Greases are generally used for the lubrication of plain and antifriction bearings but may be employed for the lubrication of gears.

CHART 3 - RANGE OF LUBRICATION WITH LIQUIDS, GASES AND MISTS

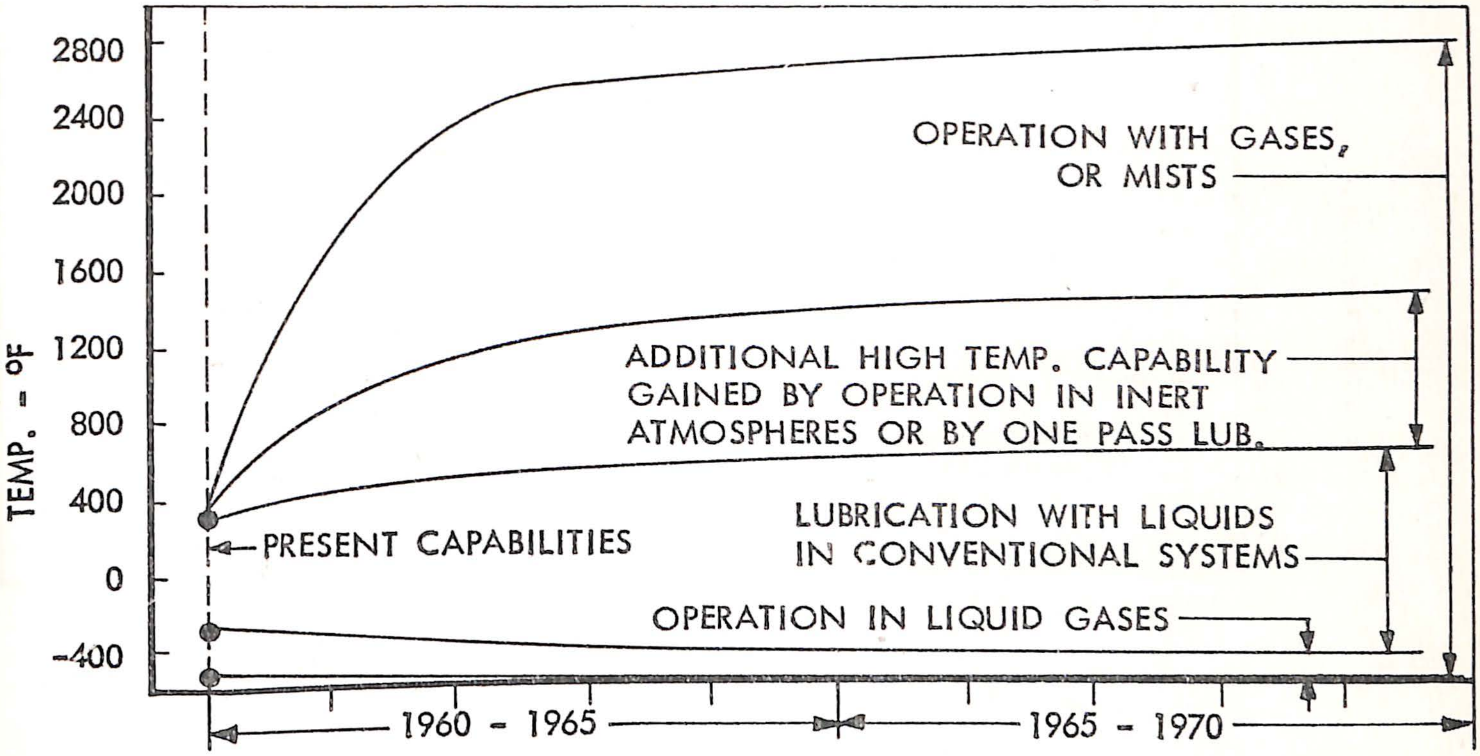


Chart 2 refers to lubrication with bonded solid films, lubricating coatings formed by reactions with the base metal and lubrication with powdered solids such as graphite and lead oxide. Temperature ranges given at a specific date refer to the general capabilities of solid lubrication and do not imply that a single lubricant is capable of operation over the entire temperature range.

Progress in the field of solid lubrication is dependent to a great degree on progress in the field of high temperature alloys. Non oxidizing base metals with high strengths and hardness at elevated temperatures are a necessity.

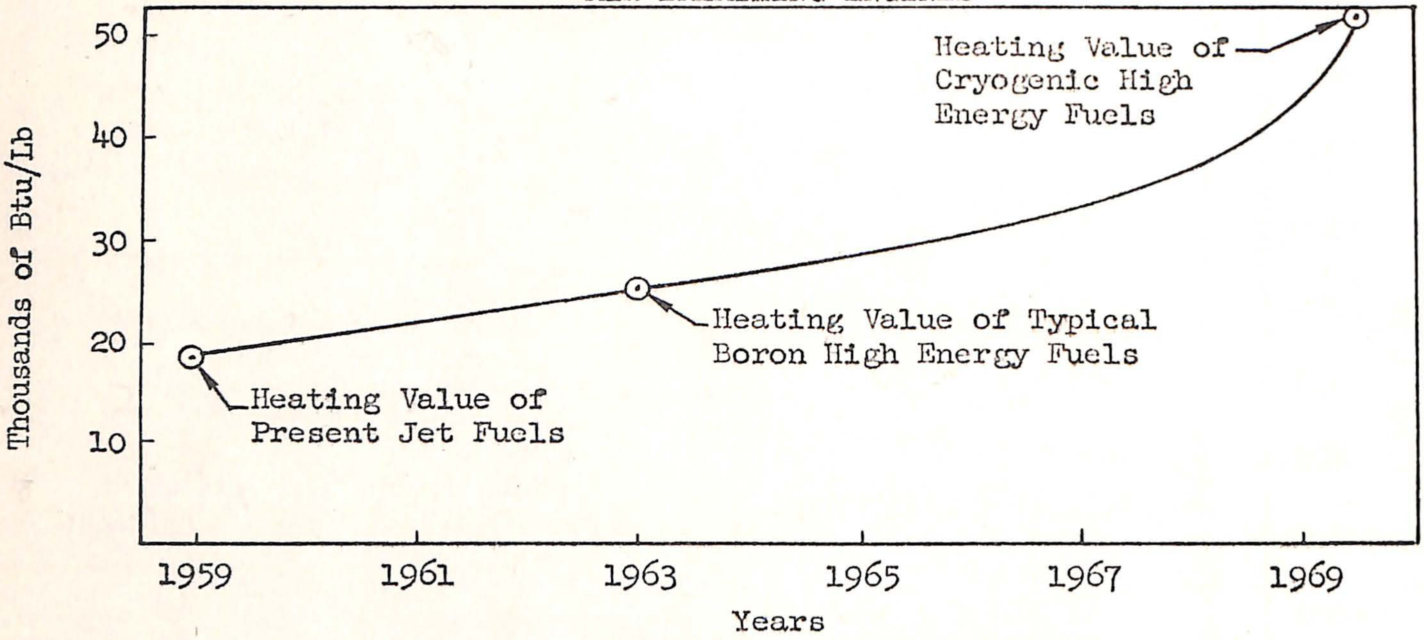
Solid lubricants are generally employed for the lubrication of slow moving, heavily loaded parts but powdered solids may be applied to rotating bearings and gears.

In Chart 3 temperature ranges given at a specific date refer to the general capabilities of the method of lubrication and do not imply that one specific lubricant is capable of operation over the entire temperature range.

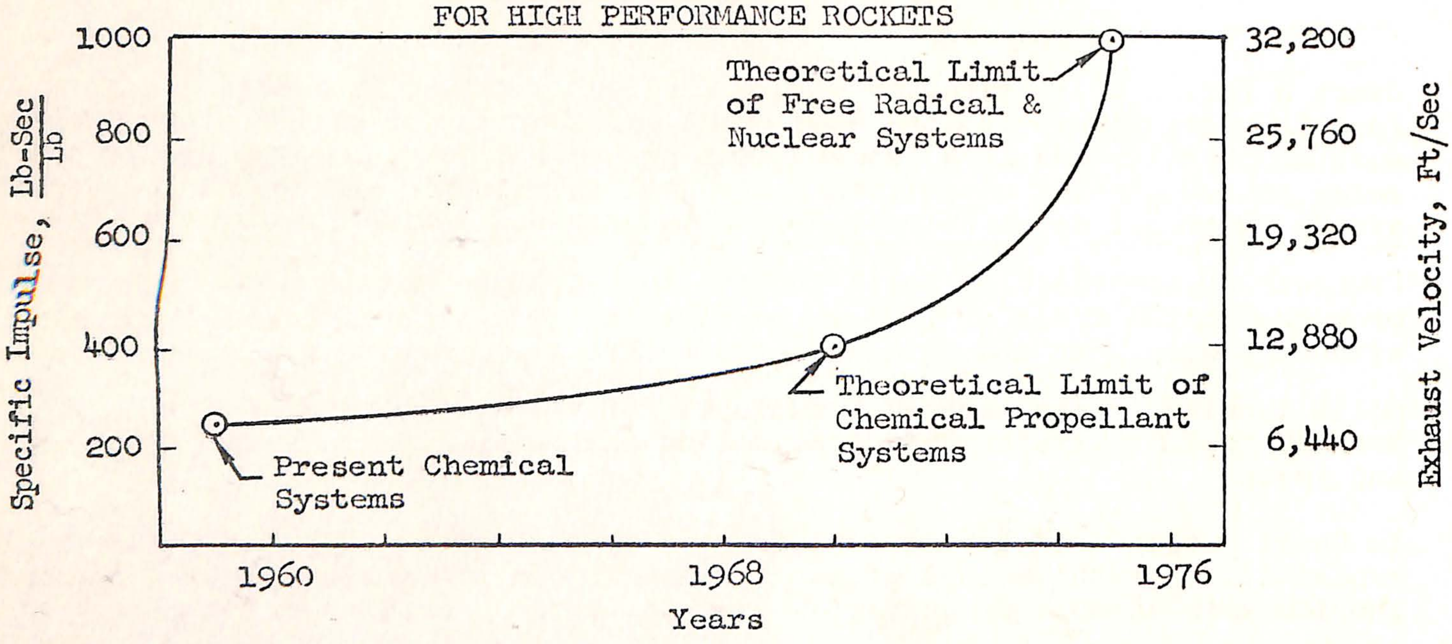
Lubrication with liquids in conventional systems refers to the use of organic liquids used in air by the conventional type of recirculating system. Additional capability due to operating in an inert atmosphere or by using high temperature organic fluids for one pass through the lubricated mechanism is indicated.

Operation with gases refers to either the use of reactive gases such as Freon which decompose and continuously form a lubricating film on the bearing metal or to the use of gas lubricated bearings which employ a gas film under pressure to support the load. Mists of organic liquids are used to protect bearings from oxidative attack at high temperatures and to supply lubricating agents to metal surfaces. Operations at low temperatures can be provided by gas supported bearings or by the operation of rolling element bearings in liquified gases.

TREND OF FUTURE FUEL REQUIREMENTS FOR HIGH PERFORMANCE AIR BREATHING ENGINES

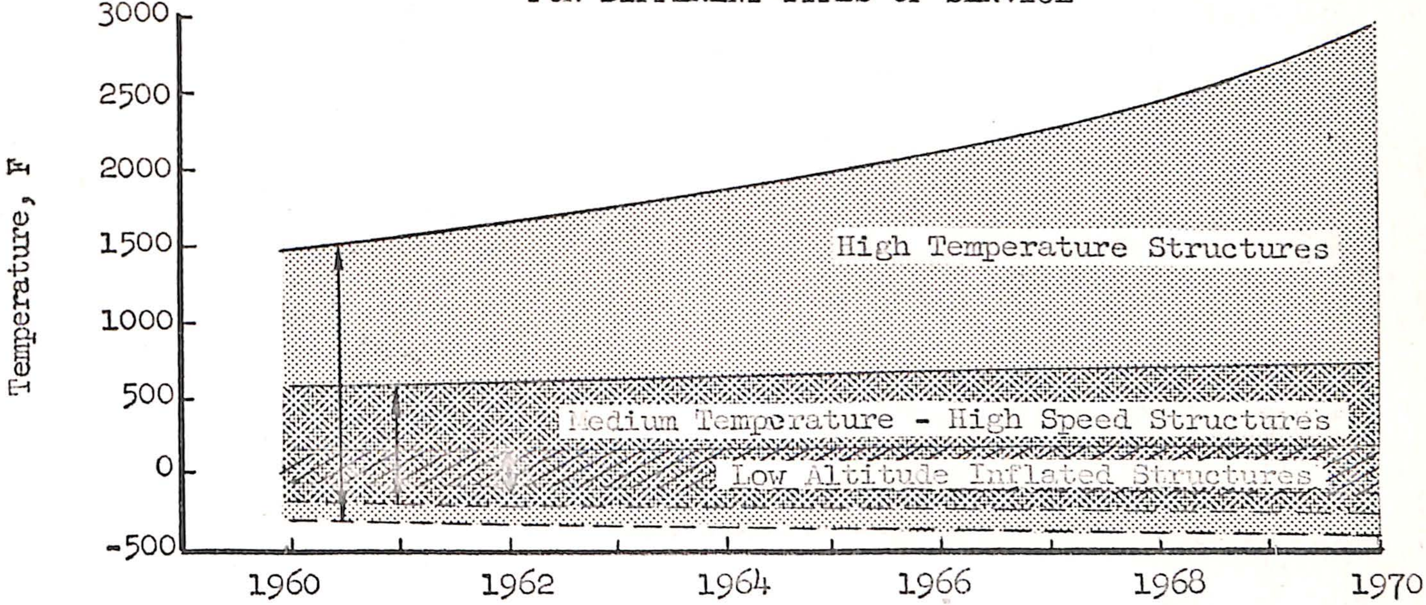


TREND OF FUTURE PROPELLANT REQUIREMENTS FOR HIGH PERFORMANCE ROCKETS



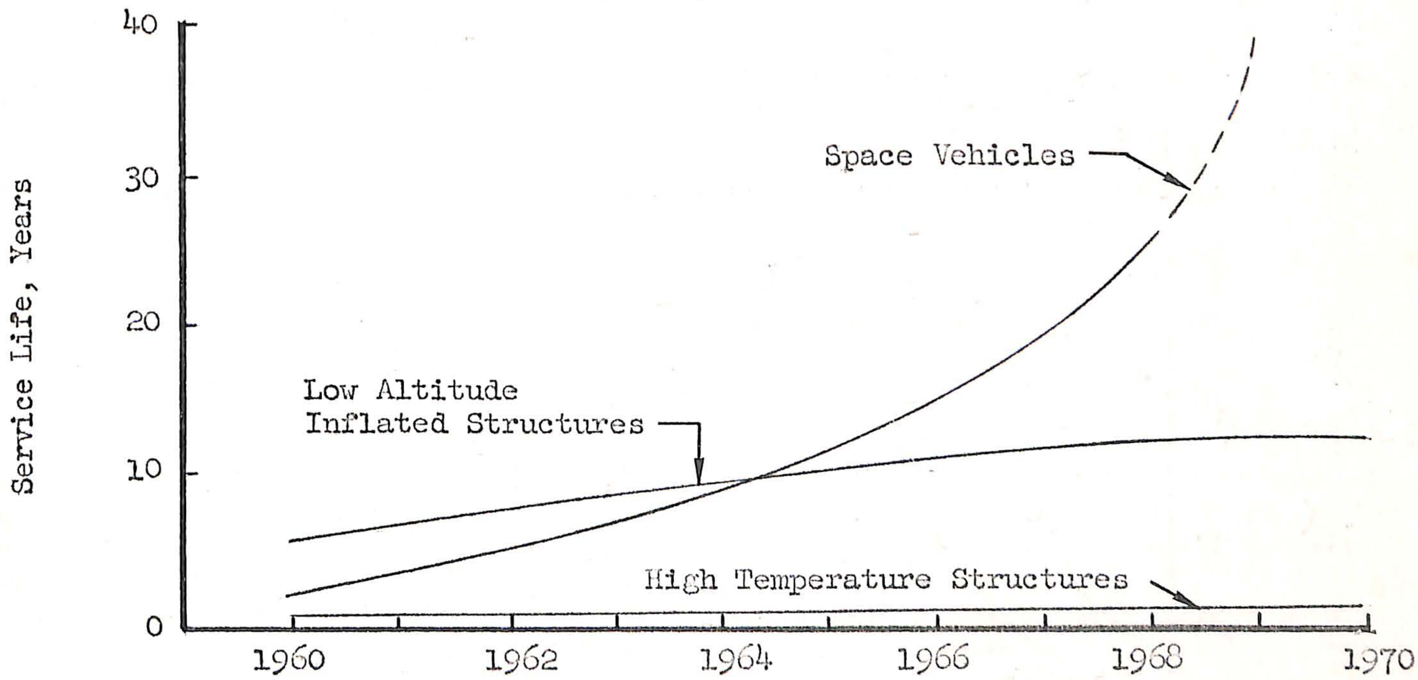
Utilization of high energy, high specific impulse chemical fuels will continue as the main development factor for the next ten years. The problems associated with the handling and storage of high energy boron fuels are being studied and solved. When sufficient quantities of these fuels are available, they will replace the JP- fuels for high performance vehicles. Cryogenic fuels for both air-breathing and rocket propulsion systems promise sufficient performance increases to make development of propulsion systems using these fuels extremely worthwhile. The advent of nuclear rocket propulsion will probably increase rather than diminish the use of cryogenic fuels. The development of the necessary equipment for ground storage and handling is well advanced. The development of vehicle-installed tanks, pumping equipment and flow regulating equipment will be accelerated.

SERVICE-TEMPERATURE RANGE FOR COATED FABRICS FOR DIFFERENT TYPES OF SERVICE



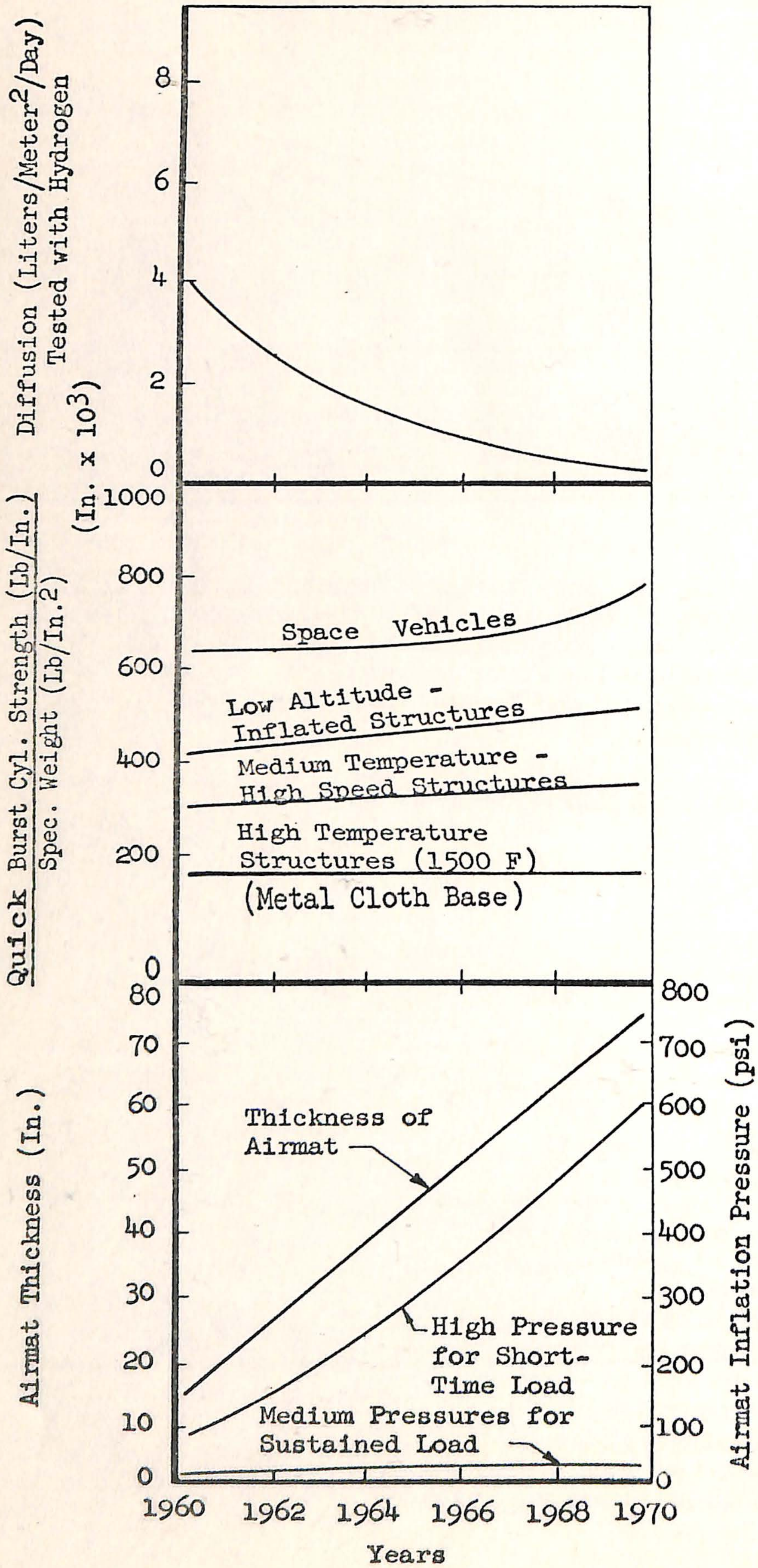
The requirements above assume that the low-altitude inflated structures are operated in tropical heat and arctic cold; the medium-temperature high-speed inflated structures are subjected to aerodynamic heating at times, but at other times may be at very high altitudes where temperatures are reduced by radiating into outer space; the highest and lowest temperatures occur with extreme types of space vehicles.

SERVICE LIFE OF INFLATED STRUCTURES USING COATED FABRICS



The assumptions are that the low-altitude structures are ordinary airships and airplanes, that the high-temperature structures are heated aerodynamically for short times only, and that the true space vehicles should be suitable for long trips to distant planets.

TEXTILES



DIFFUSION OF GASSES THROUGH COATED FABRICS USED FOR INFLATED STRUCTURES

It is assumed that the pre-1960 fabrics are for airships which use lifting gas. The 1970 fabrics are for space vehicles with air-breathing passengers, as well as for airships of that period.

STRENGTH-WEIGHT RATIO OF COATED FABRICS DEVELOPED FOR DIFFERENT TYPES OF SERVICE

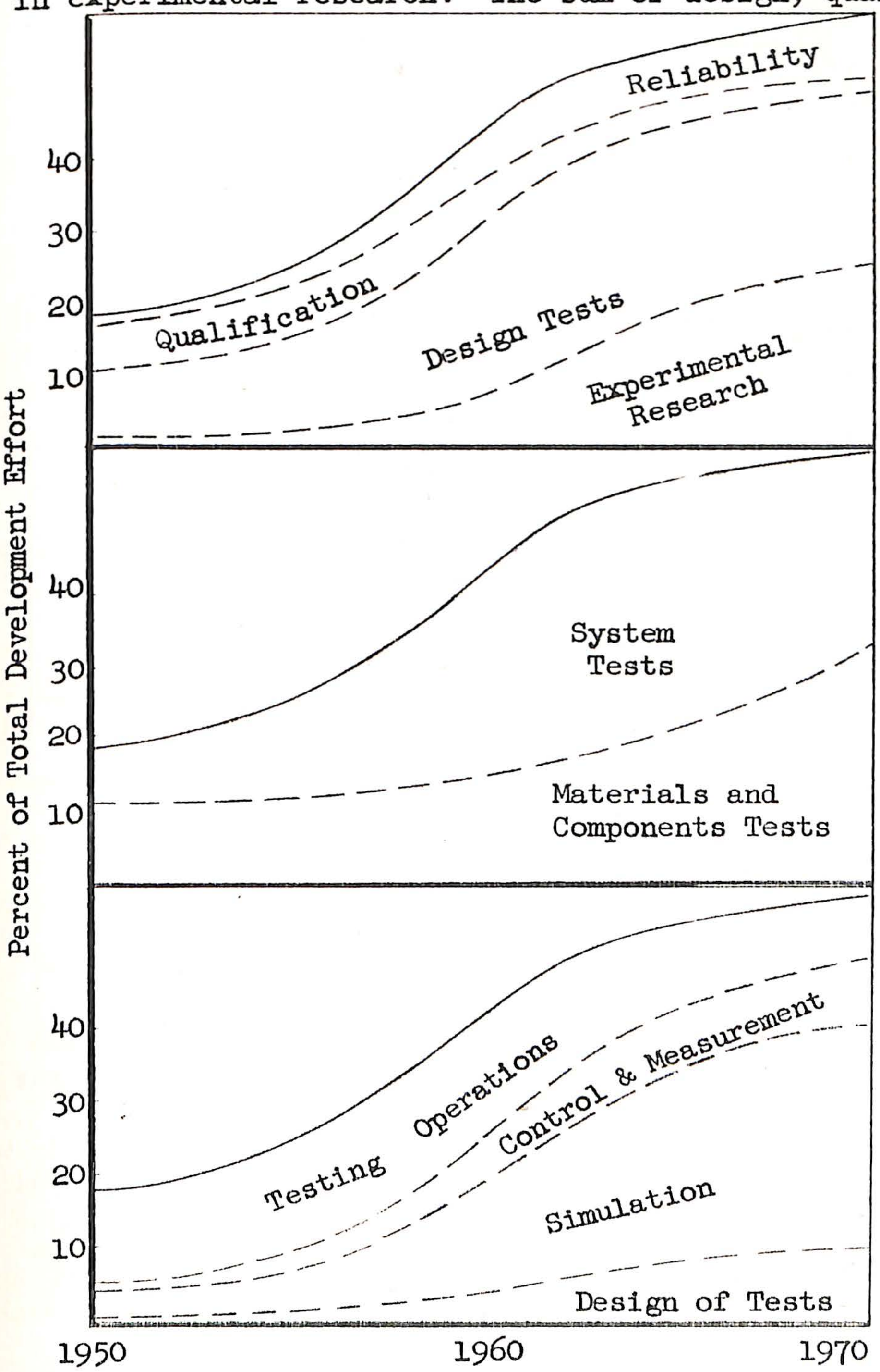
The space vehicles are assumed to use high-tenacity polymers of advanced types with gas-tight coatings. The low altitude structures include present day airships and the Inflatoplane. Medium- and high-temperature structures would be made of fiberglass or metal wires with special coatings.

THICKNESS AND PRESSURE OF INFLATED AIRMAT STRUCTURES

It is assumed that airmat structures with internal yarns to give inflated shapes other than cylindrical will benefit from improvements in materials and in processes of manufacture so that much larger structures can be built than at present.

LABORATORY TESTING TRENDS

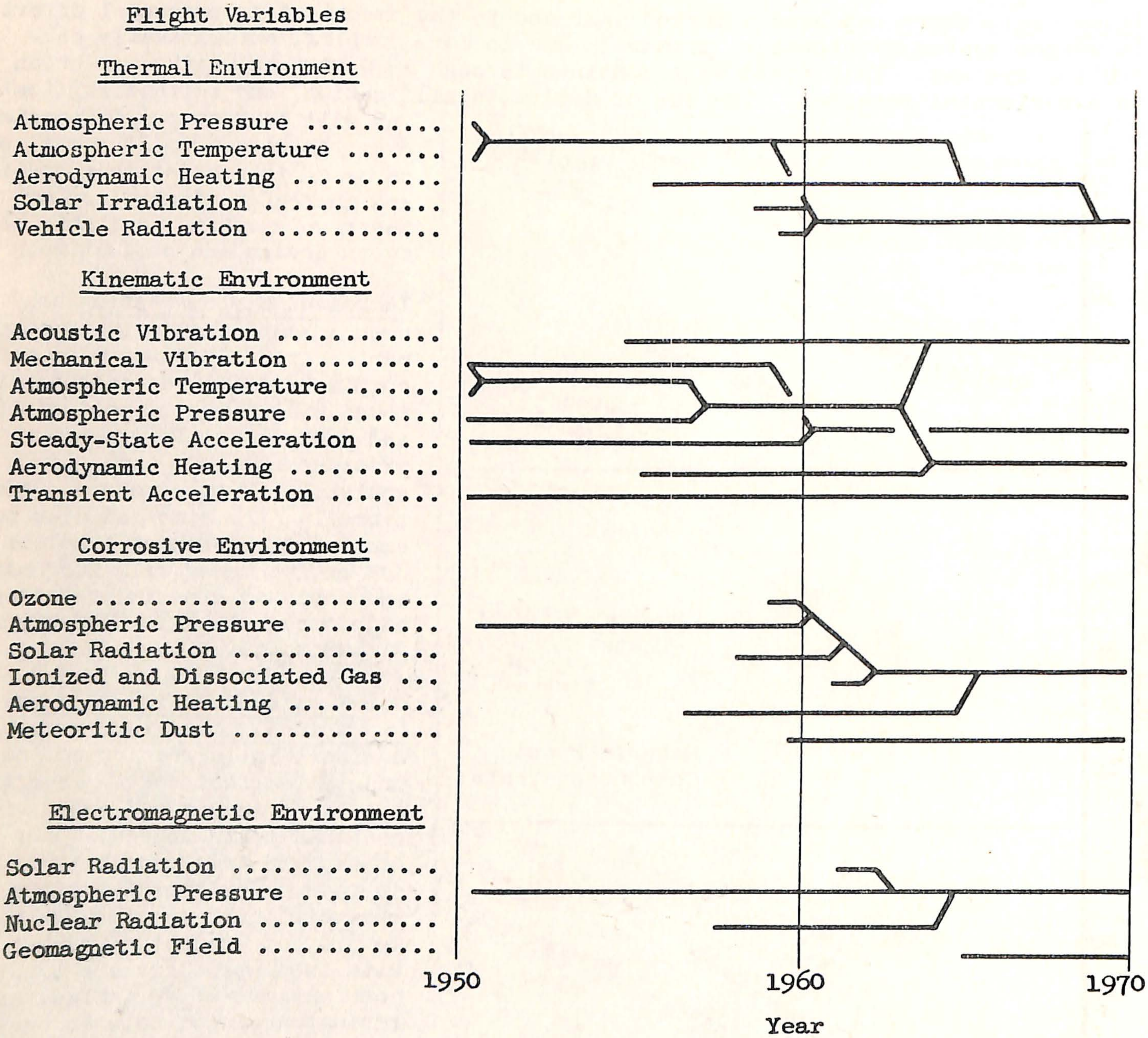
In General, there has been a marked increase in the amount of experimental effort in weapon system development, primarily due to more complex, automatically controlled systems. This trend will continue through 1970 with extensive expansion in experimental research. The sum of design, qualification, and reliability testing will tend to remain constant over the next 5 to 10 years, because of increasing test costs, and increased time to conduct tests versus time available between design and production.



Increased System Testing has been a major factor in the experimental trend, because with more complex and interdependent systems, evaluation of components and subsystems alone seldom provides reliable data for analytical system models. Additionally, the time and cost to construct experimental models and environments will increase the need for experimental research and component evaluation prior to system tests.

Simulation of Environment and Operational Conditions is predominant in increasing component and system test costs. Energy levels of inputs and loads will continue to increase. Outer-atmosphere and space flight introduce environments often more difficult to simulate than to protect against. Coupled with these problems are complex combinations of variables, and rapid transition between environmental regimes. New techniques for generation, measurement, and control of variables will be developed and applied in the next 5 to 10 year period. For example, simulation of high altitude thermal environment involves low pressure that can only be attained with diffusion or cryogenic pumps. High-energy solar irradiation must be simulated, and refrigeration systems must provide a radiation "sink" approaching absolute zero.

PROJECTED COMBINED ENVIRONMENT SIMULATION



This graphical presentation shows the past and future trends toward combining environmental variables. Additionally, during the next 5 - 10 years, considerable study and facility development will be directed toward simulating rapid transition between environmental regimes (e.g., transition between missile ground and outer atmosphere environments).

PART TWO

MANUFACTURING FORECAST

The accelerating pace of civilian and military developments in the Aerospace Industry has resulted in an ever-increasing demand for a higher level of manufacturing capability. New technologies and process complexities will require greater educational and technical specialization to produce the advanced weapons concepts that the industry foresees in the next ten years.

The time cycle from conception to series production is becoming shorter. Simultaneously, methods and equipment are becoming more complex and require extensive development to keep pace with advanced design concepts. These trends are graphically portrayed in Figure 1, indicating that increasingly complex tools, methods and equipment must be developed in shorter time spans in order to be ready for the production phase.

The materials used during the next ten years will present a variety of problems to manufacturers. Some (e.g., Beryllium) will be extremely difficult to form. Others will require the use of new chemical or electrical discharge machining methods. Many of these materials will require very high fabricating temperatures; thus, they will need protective coatings and/or atmospheric control to prevent contamination. Within five years, top service temperatures will be as high as 3000F for brief exposures. Within ten years, they will rise to 5000F. Low temperature properties will also be important for both structural and fabrication applications.

The use of new materials will also point up the need for new facilities. New and more complex processes will require better and more expensive equipment. In some cases, automation and numerical control must be adopted on a wide scale. Present handling and testing equipment will not be sensitive enough for future needs. There will also be a need for new standards of quality control and data evaluation.

These and other problems facing tooling and manufacturing during the next ten years are outlined in detail on the following pages.

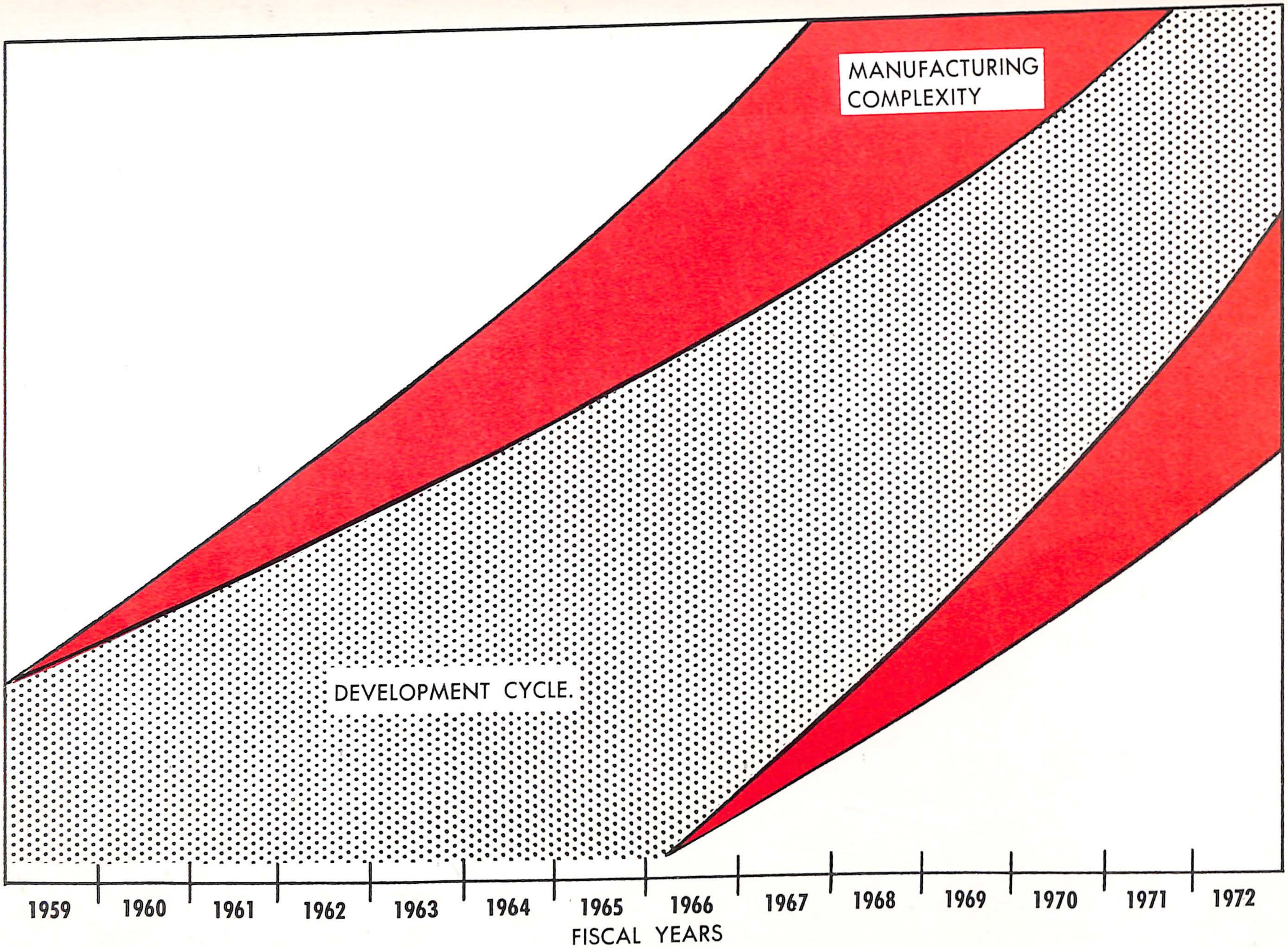


FIG. 1 DEVELOPMENT CYCLE
VS
MANUFACTURING COMPLEXITY

I Assembly and Joining

Fabrication and assembly trends are toward steel brazed and welded airframes and indicate particular need for equipment development in this area. Combined processes are apparently going to be necessary. More combined machines will be evident. For instance: Welding and machining in a welding positioner.

Two chief manufacturing and tooling problems will be (1) the necessity for achieving very close tolerances; and (2) brazing, welding, and heat treating in a carefully controlled atmosphere. Precision sub-assembly tooling will be required to locate details through brazing and heat treating processes and produce a stress-free, dimensionally-accurate unit. A minimum of drilling, dimpling, and trimming operations can be performed on detail parts which have been hardened prior to assembly. Assembly tooling and manufacturing will be required to join large sub-assemblies already in the hardened condition. Portable equipment and techniques will have to be developed for welding and localized heat treating during final assembly. Tooling will have to be precise and capable of providing a maximum of dimensional stability without contaminating the work piece.

A Welding

Welding requirements will include (1) close control of manufacturing variables; (2) clamping and positioning devices; and (3) economical means of welding under controlled atmospheric conditions.

1 Mechanized equipment must be developed to insure precision and consistent weld quality, especially in such applications as the assembly of tapered sheets in dimensions of 10' x 20' tapering from 0.005 to 0.500 inches. There must also be more accurate machine control of weld variables (arc volts, weld amps, weld travel, wire feed). There will be a need for joint followers that are unaffected by contamination factors (brazing, alloy, flux, etc.) for joining brazed sections. Equipment with travel rates of 2 to 300 ipm will have to be developed for welding molybdenum and titanium alloy sheets.

Resistance welding requirements will include a need for monitoring systems which accurately determine proper pre-weld requirements in addition to compensating for those variables in order to assure weld quality. Development and evaluation of high frequency resistance welding is needed as well as an electronic device to control all variables in a spot weld machine.

2 Clamping fixtures and positioners must be developed to enable positive holding and stabilizing of comparatively delicate parts. They will also be required for more uniform speed and better part alignment, particularly of thin sheet in thicknesses from 0.005 to 0.020 inch. Ultra-sonic welding equipment must first be developed that will produce resistant weld quality and have sufficient capacity to join materials for instance, titanium, PH steel, etc., in thicknesses from .005 to .125. Light-weight holding devices must be developed for ultrasonic welding; and semi-portable inert-gas equipment and techniques must be developed for joining major components during final assembly stages. Portable equipment will also be needed for weld-edge preparation. For weld fixtures used in sheet butt-welding, new fixture material must be developed for chilling, clamping, and locating. Improved ceramic materials may be adaptable for welding fixtures.

3 Controlled atmospheric conditions may be achieved through further development of weld-zone purification processes, such as tungsten inert gas welding. Heliarc welding--or some other inert gas shielded process--might be further developed. Molecular bombardment or electron general welding might be a possibility. Pressure welding and plasma jet might also offer promise. Electron gun welding in a vacuum on materials which combine readily with oxygen and nitrogen might yield highest quality welds. Improved ultrasonic welding techniques are also needed. For joining honeycomb panels, ultrasonic welding might be adapted with the welding medium being powdered or granular and attracted to the weld joints magnetically to allow welding at a low temperature. Large weldments, both restrained and unrestrained and welded before and after heat treatments should be investigated along with localized heat treating during final assembly.

B Brazing

Brazing requirements will include (1) means of controlling atmospheric contamination; (2) improved facilities for brazing new materials and larger units; (3) close control of manufacturing variables.

1 Improvements are necessary in controlling optimum atmosphere prior to and during the brazing cycle. Further developments will be needed in evaluating "stabilizers" to control node flow and defusion. Early efforts must also be directed towards developing alloys having low initial melt and high remelt points. Braze alloy development will continue to minimize solubility erosion. An investigation should be made of the feasibility of a jointly sponsored "space room" capable of providing a total inert-gas environment meeting the brazing requirements of the participating manufacturers.

2 Brazing fixtures for large-area parts and for panels capable of continued operation through 2750F must be developed. Tool materials for these fixtures and new types of brazing furnaces will be required. The new-type furnaces will be necessary to braze ceramics, cermets, glass, and refractory metals. Facilities development must progress toward heating only the assembly to brazing temperature with minimum tooling and furnace brick heat. This will enable development of techniques for quick heating of assemblies while minimizing contamination and solubility erosion. Fixtures incorporating rigid support, close tolerances, uniform heating and minimal deformation during heating cycles are needed.

3 Techniques and control must also be developed to permit "localized" brazing of large final-assembly panels. Development of portable brazing units will be required for this purpose. Improved techniques in preparing detail parts for fit-up are required to reduce the amount of filler alloy required. Non-metallic adhesives may be replaced by metallic materials.

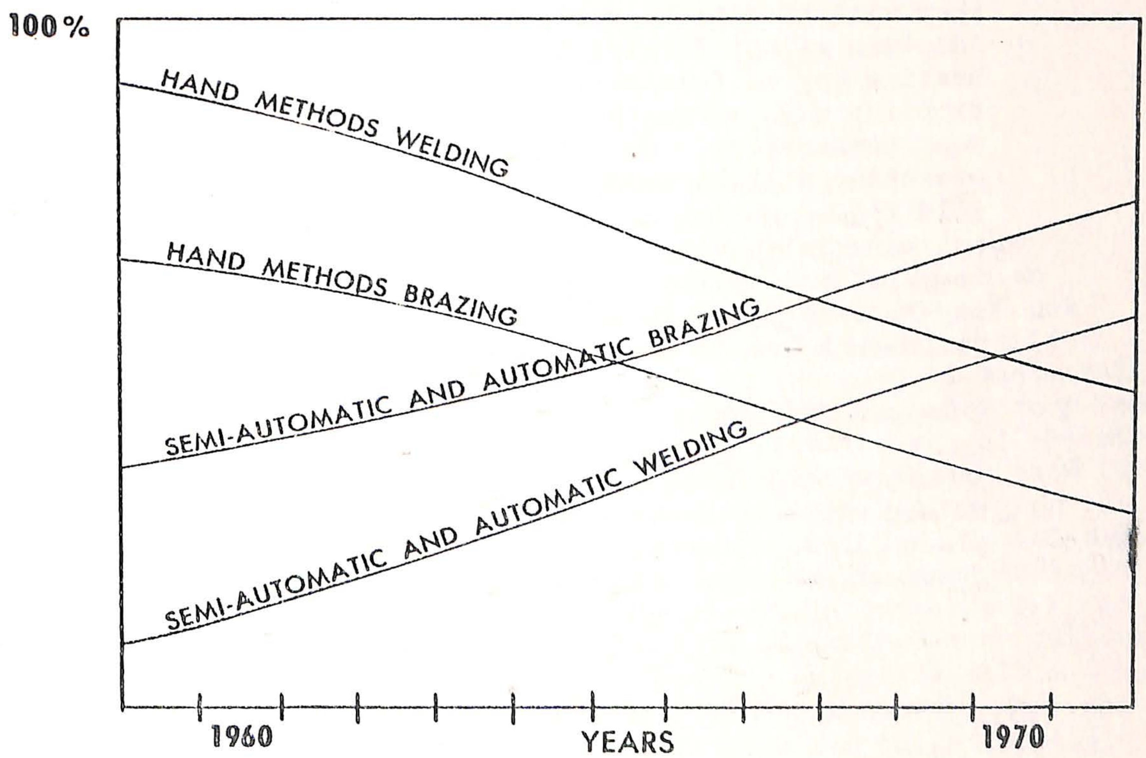


FIG. 2 BRAZING AND WELDING TRENDS

C Bonding

Bonding requirements will include development of new tooling concepts to cope with new materials and new designs. Emphasis will be on the use of ceramic adhesives and bonding extremely large contoured parts--perhaps even entire assemblies--such as wings or fins. Bonding of steels will become commonplace. Bonded structures capable of withstanding temperatures of 600F and above also will become commonplace, with ceramic adhesives replacing organic-metallics for service above 600F. Specially-designed individual tools will be needed for specific parts and sections with multipurpose tooling, such as autoclaves, being used progressively less as the trend to more complex assemblies of greater size increases. There will be increasing demand for light-weight curing fixtures having thermal properties similar to those of the material being bonded. There will have to be more mechanization of bonding processes. Numerical control concepts may be applied to yield economical and reliable bonded structures.

D Fasteners

High-strength, corrosion-resistant fasteners must be developed for extremely low temperatures and upset riveting of 320,000 psi materials. If rivets and sheet stock are made of materials up to 320,000 psi, it will be necessary to develop squeezers and dimplers capable of applying a force much higher than is now available. Furthermore, they will have to be designed to develop much higher heats. Adaption of hot forging techniques making use of resistance heating may be feasible. Methods will be needed for dimpling high strength materials having low ductility at room temperature. Hot dimpling equipment capable of 1300F operation will be needed. Continued work is necessary on cold flow dimpling to permit the working of 280 - 300,000 psi material having 4 to 10 percent elongation at room temperature. Tools to upset rivets by ultrasonic energy may be required. In some materials, it may be necessary to punch holes in conjunction with a controlled heat cycle.

E Chemical Joining

A method of joining metals without heat will be needed. A method might be developed which uses metallic compounds placed in the joints, with fastening accomplished by a chemical reaction triggered by gas.

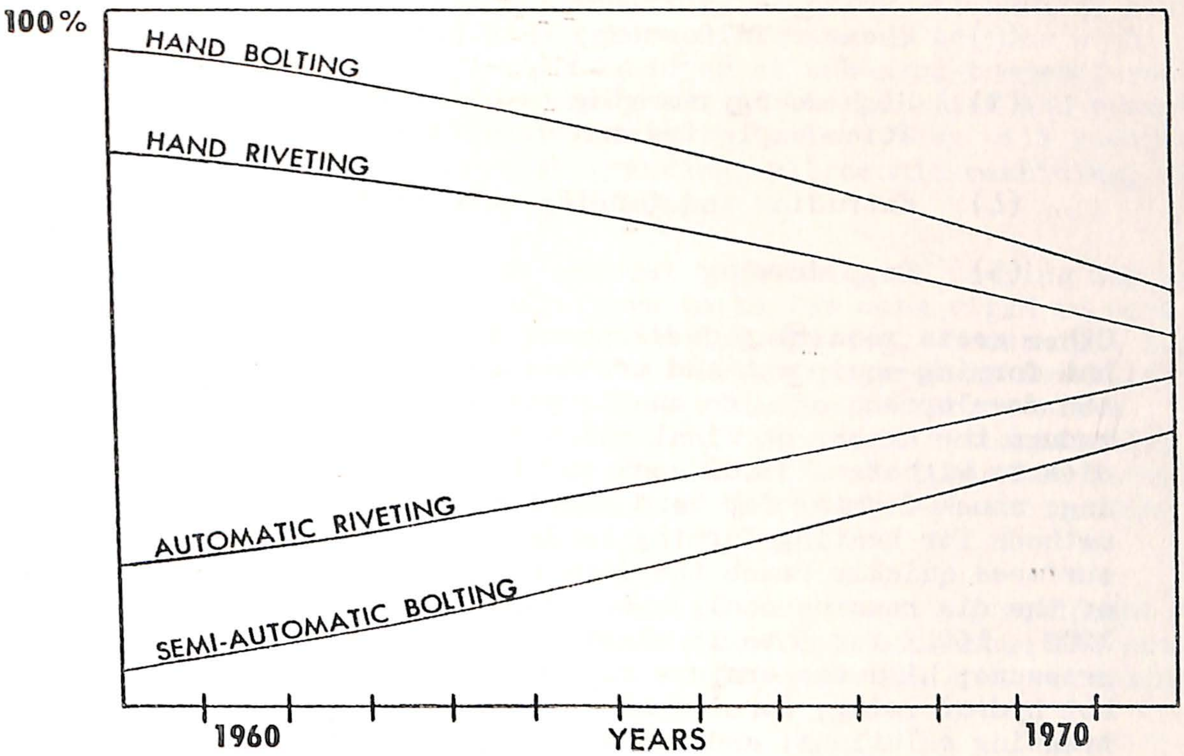


FIG. 3 BOLTING AND RIVETING TRENDS

II Metal Shaping

During the next ten years, as more emphasis is placed on developing high-strength steels with yields of 300,000 psi and titanium alloys with yields of 200,000 psi, fabrication techniques and equipment will be needed which place the metal as close as possible to its final configuration. The room temperature properties of these materials dictate the use of elevated forming temperatures and essentially eliminate finish hand forming. The rigidity of high-strength materials will eliminate springing into place at the time of assembly, yet gap tolerances and aerodynamic smoothness requirements will be more stringent. The physical properties of tooling materials suitable for use at these elevated temperatures must be determined and exploited to obtain the needed precision. Shaping materials cold and hot is trending toward higher accuracy, semi-automated equipment with precise control elements. Explosive and bulge forming are indicated for further development.

Parts will be shaped by:

(1) Precision casting

(2) Shear spin forming, both hot and cold

(3) High energy forming by shock wave and a combination explosive and draw forming

(4) Extruding and forging to close tolerances

(5) Deep drawing

Other areas requiring development include: Development of hot forming equipment and techniques to take advantage of the development of wide sheet material which can be used to reduce the number of final assembly joints in a structure; dies to withstand 35,000 psi and higher during Guerin forming; shock forming for hard sheet alloys; equipment and methods for heating forming tools to 2000F; dies, whose surfaces quickly reach the forming temperature while the bulk of the die remains cool; creep form equipment to operate at 1200 - 1500F for 5 to 15 minute cycles; application of fluid pressure; high temperature rubber and cast form blocks for hot hydroforming; forming of materials immersed in heat-treating solutions; and vacuum forming of sheet material at high temperature, similar to present-day vacuum forming of plastics.

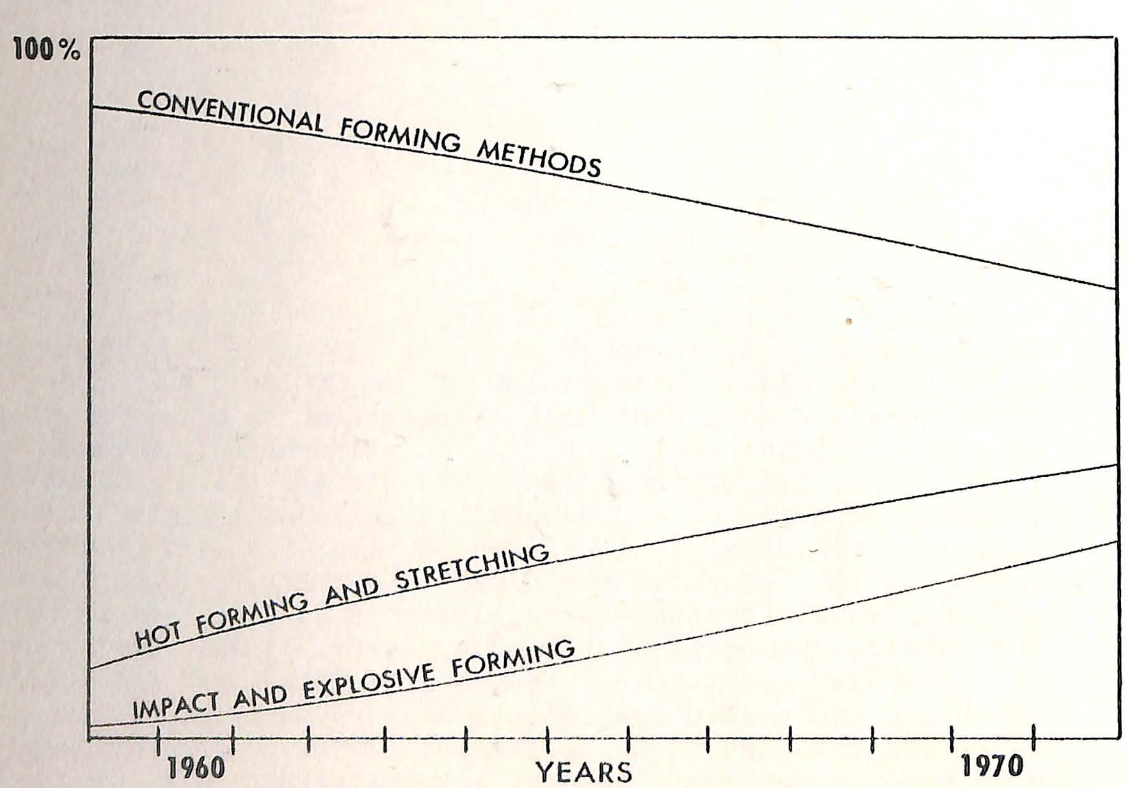


FIG. 4 MATERIALS SHAPING TRENDS

III Materials Removal

Some operations (e.g., shearing, blanking, machining) now performed at room temperature will have to be done with materials and/or tools heated or at sub-zero temperatures. Some metals and practically all of the ceramics and cermets cannot be machined with ordinary tools. They will require ceramic tools, abrasive grinding, ultrasonic machining, or electrical discharge machining.

Required also will be general tightening of tooling accuracy. Furthermore, tools will have to be far more rigid to work the high strength materials predicted for use. Mechanical tool docks will be needed for rapidly and accurately establishing points in a basic, mutually-perpendicular, three-plane coordinate system. Complete reliance on a mathematically established envelope (as opposed to the hand-lofted curve) will make tape-controlled, two or three-dimension cutting machines a basic need.

Generally speaking, the trend of manufacturing equipment is toward more specialized semi-automatic, automatic and numerically controlled machine tools, assembly and processing equipment.

Use of numerical control must be expanded to both machines and processes (chemical, electric discharge, ultrasonic, sub-zero). Tracer-proximity device control will have to be extended to control critical operations not suitable for programmed numerical control. Research will be necessary in areas such as automated profiling. Short tool life results from programming the path of the cutter's center rather than the path of the cutting edge. This requires development of new types of cutters or holder designs or some means of compensation in the machine itself.

Removing materials by electronic and chemical means, hot machining and increased applications of numerical control are areas which require development in the five and ten year period.

Numerical control should be developed to minimize the amount of tooling required; programming techniques should be simplified to allow low cost operation when numerical control equipment is used for prototype or limited quantity production.

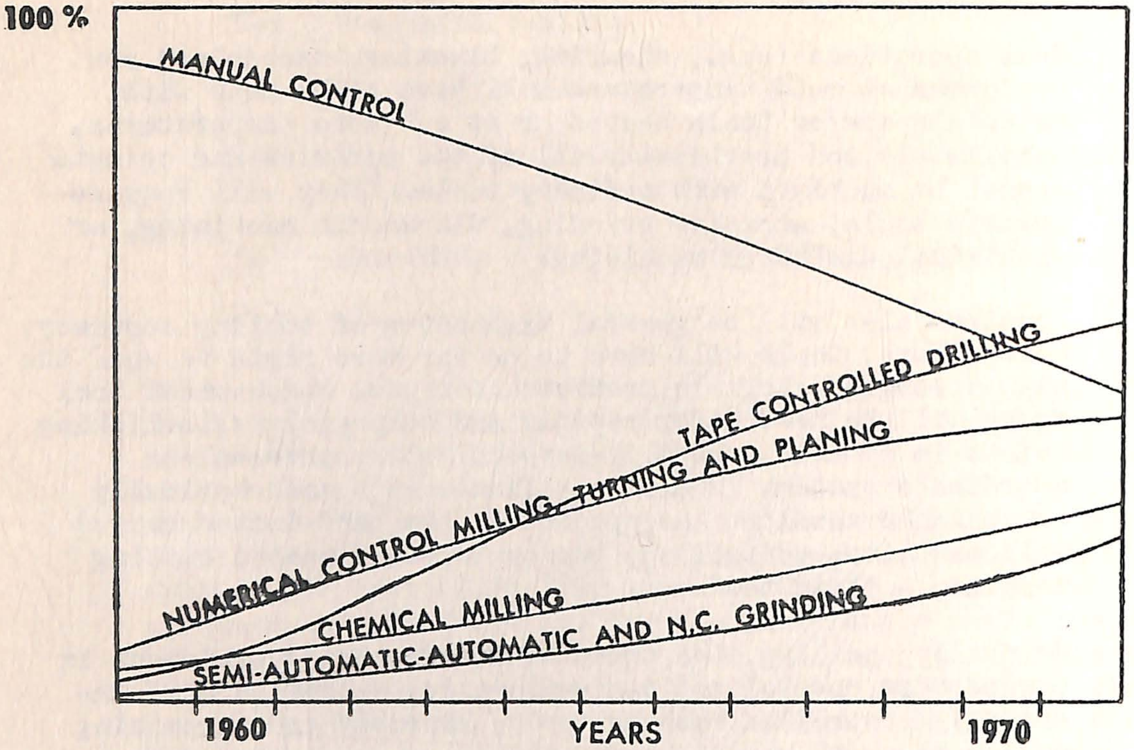


FIG. 5 MATERIALS REMOVAL TRENDS

Other areas requiring emphasis will include:

(1) Chemical milling of high-strength materials to close tolerances and with high surface finishes

(2) Grinding for high metal removal rates

(3) Ultra-high speed machining and drilling

(4) Special applications of ultrasonic machining, electrical discharge machining and grinding

(5) Sub-zero machining or other techniques utilizing improved cutting lubricants and coolants

(6) Cut-off saws of synthetic industrial diamonds

(7) Special applications of torch cutting to trim parts

(8) Close-tolerance machining techniques for stainless steel, titanium and other honeycomb material.

IV Plating and Cladding

Trends indicate considerable development is required in plating, coating and cladding and in the development of automatic systems to control the processes. Nondetrimental plating or cladding processes should be developed to withstand 1200F. These should include vapor plating, alloy cladding, electrolytic and electroless plating. Plating and/or cladding operations should be combined with joining processes for secondary structures where temperature capabilities are compatible with those of the parent materials. Temporary protective coatings must be developed for materials that cannot be given permanent coatings until fabrication is complete (e.g., Molybdenum).

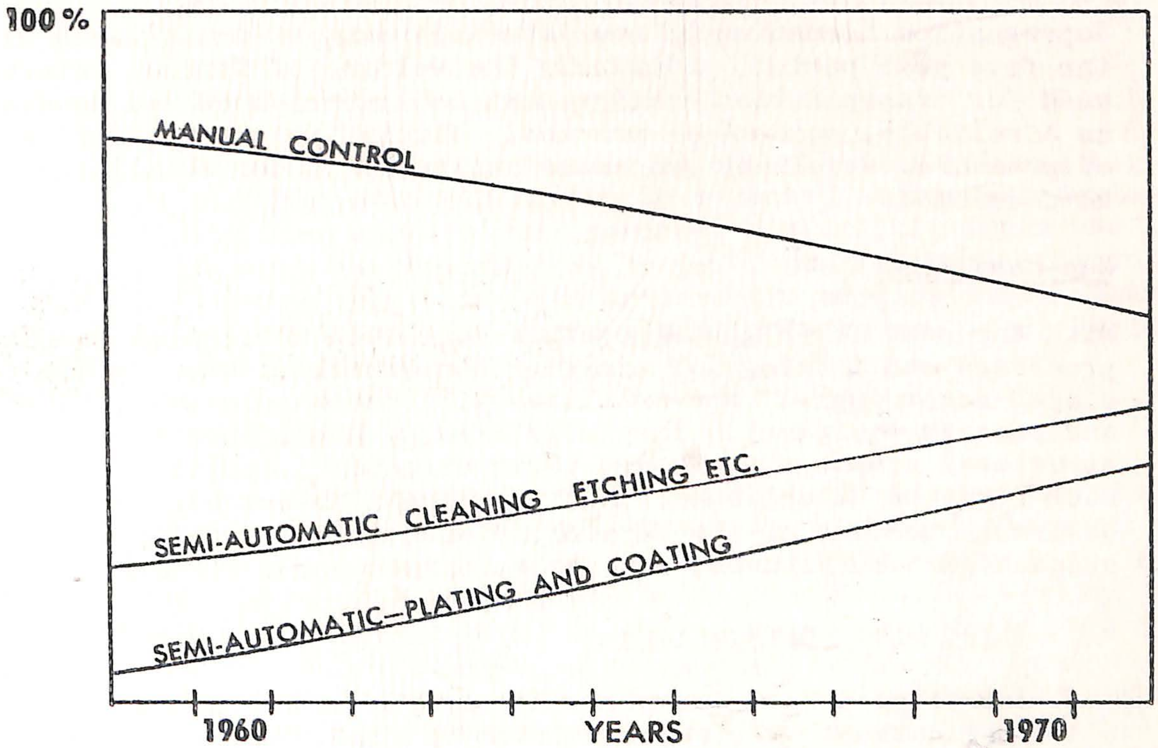


FIG. 6 CHEMICAL TREATMENT TRENDS

V Heat Treatment

Materials will be needed for tempering and heat treating fixtures (preferably of minimum mass) to control parts at heat treating temperatures. Also required will be equipment for annealing or heat treating large components above 2000F in closely controlled atmospheres. Other new types of furnaces, which may have to accommodate entire airframe sections, will be required to apply or cure organic sealants. Heat sources using radiant heating or induction coils may be needed to heat treat "localized" portions of assemblies too large for furnace treatment. Resistance heating might also provide the solution here. Autoclaves (approximately 200 psi pressure and 400F temperature) may be required to cure organically bonded components.

Within the next five years, heat treat procedures for high alloy materials (e.g., peerless, 1-1570, incoloy 90) and methods for simultaneously heat treating, forming, tempering, and stress relieving must be developed. Investigations of cryogenic effects in restoring ductility to weldments should be expanded. Improved cleaners and processes for removing scales resulting from thermal cycles will have to be developed. Within ten years specialized automatic heat sources for preheat, stress relieving, and heat treatment in welding fixtures must be developed to become part of the welding procedure. High vacuum and high temperature furnaces must be developed for heat treating high melting-point materials.

VI Powder Metallurgy and Fibrous Materials

Impregnation hardening of new materials must be established within the five year period. Similarly the welding of fibrous materials used for transpiration cooling must be investigated and developed as a reliable, economical process. Within ten years, fabrication of pressure vessels by processes utilizing powder metallurgy must be developed.

VII Non-Metallics

With the need for high-temperature materials developing rapidly, processes and tooling for applying non-metallics must be developed accordingly. Non-metallics will become common in tools and process equipment. They will also be fabricated into structural components, though their structural applications must first be established. Such applications are highly desirable because of the capability of the materials to withstand high temperatures, radiation, erosion, and corrosion.

A Structural Applications

Increased use of ceramics and cermets in structural applications will require tools to shape these materials within the tolerances desired. Means of casting, forming and machining them must be developed. These applications will probably require ceramic, ceramic-faced, or diamond-faced tools. Cermet may also replace present magnetic core materials, while ceramics may be used for encapsulating electronic components; either application will require high-temperature fabrication processes. Equipment must also be developed for attaching ceramic and cermet components to metal structures.

Ceramics and cermets should be evaluated as high-temperature sealants. They must also be investigated for radiation and temperature resistance, strength, and compatibility with exotic fuels.

Exotic methods of processing not discernable at this time are being studied on a test tube basis and require development to mature them into effective production equipment.

The increased use of plastics, ceramics and other high temperature materials indicates a trend to specialized equipment for filament winding, wrapping and curing.

The increased use of reinforced plastics for structural applications will require high temperature lay-up tools to form these materials to be complex shapes that will be required.

Casting and forming equipment must be developed for fabricating such materials as Vycor glass and other transparent materials to close tolerances.

B Non-Structural Applications

Ceramics and cermets must be evaluated as cutting tools for high-strength materials expected to be used during the five and ten year periods. Ceramic fixtures and protective coating must be developed for heat treating, welding and other high temperature applications. Means must be developed for applying ceramic coatings, sealants, and lubricants.

VIII Materials Handling

Techniques and equipment will have to be developed for special handling of many materials. Materials formed at elevated temperatures must be protected from atmospheric corrosion. Wide, extremely-thin sheet material must be transported without deformation. Exhaust and filtering systems will be widely needed to reduce health hazards in processing toxic materials, such as Beryllium. Any use of radioactive materials will require special automatic or remote-control machines; controls for chips and coolants; insulating materials; measuring methods or gages; and waste disposal equipment and techniques.

IX Electrical

Developments in this area within the five-year period will include a gradual transition to numerically controlled equipment. Within five years development also must include equipment for fabricating wiring required for service at 1200F. This could involve special equipment for bending high-strength insulating materials or metallic-sheathed, high temperature insulated conductors. Wire termination equipment also must be considered--either mechanical crimp or spot-weld crimp combinations.

X Electronic

Over the five-year period, machine soldering processes must be developed to include improvements in icicle control, positive definition of joint quality, and inspection methods. Generally, equipment will have to be more automatic. Both processes and equipment for solder termination will have to be developed to improve present types of circuit cards for operating temperatures in the 700F range.

In the ten year period there must be further development of flexible and/or multiple-layer circuit cards and associated processes and equipment for operating temperatures in the 1000F range. This will involve new insulating sheet material, new adhesives, and new processes and equipment for component lead termination. Mechanical or welding tools or a combination of them will probably have to be developed for lead termination for the 1000F range.

XI Testing

The trend toward miniturization and integrated system packages in the end product will require functional test equipment with increased accuracy and higher reliability. Such equipment will be internally complex but must be externally simple in order to reduce operator skill requirements.

Standards and facilities must be developed for testing in controlled environments in order to evaluate the effects of atmospheric substances, radiation damage, behavior under radiation, thermal conductivity, thermal expansion and strength at temperature.

Hydraulic and pneumatic testing will be done at higher temperatures and pressures. It is anticipated that pneumatic control systems will require pressures as high as 100,000 psi, thereby creating a need for new types of pressure monitors and increased safety provisions during tests. High altitude flight will also create a need for testing at very low pressures.

Entire test sequences will be recorded on tape for automatic testing. The trend is toward memory drums and storage devices that will be able to compare and make decisions with regard to the accumulated test data.

The need for precise mechanical measurements will create an increased trend toward the use of optics in test equipment. The increased use of transistors will require new and improved testing techniqes.

As the utilization of exotic and expensive materials increases, non-destructive testing will become more and more important. Continued effort must be placed on getting a maximum of data from a small quantity of material.

A break-through in the use of gravity or anti-gravity for propulsion will create a need for entirely new testing methods and techniques.

XII Inspection

Improved inspection techniques and equipment in all areas will develop as new materials become more familiar. Particularly needed, however, is extensive study to incorporate non-destructive, assembly inspection devices into assembly tools. Also needed in the near future is a fast and accurate, non-destructive inspection method for honeycomb panels.