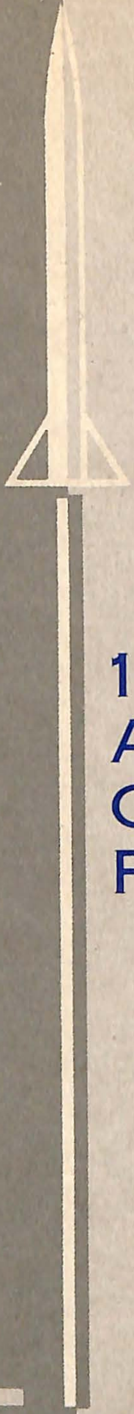

1960 AEROSPACE FORECAST OF TECHNICAL REQUIREMENTS

AIA

AEROSPACE INDUSTRIES ASSOCIATION

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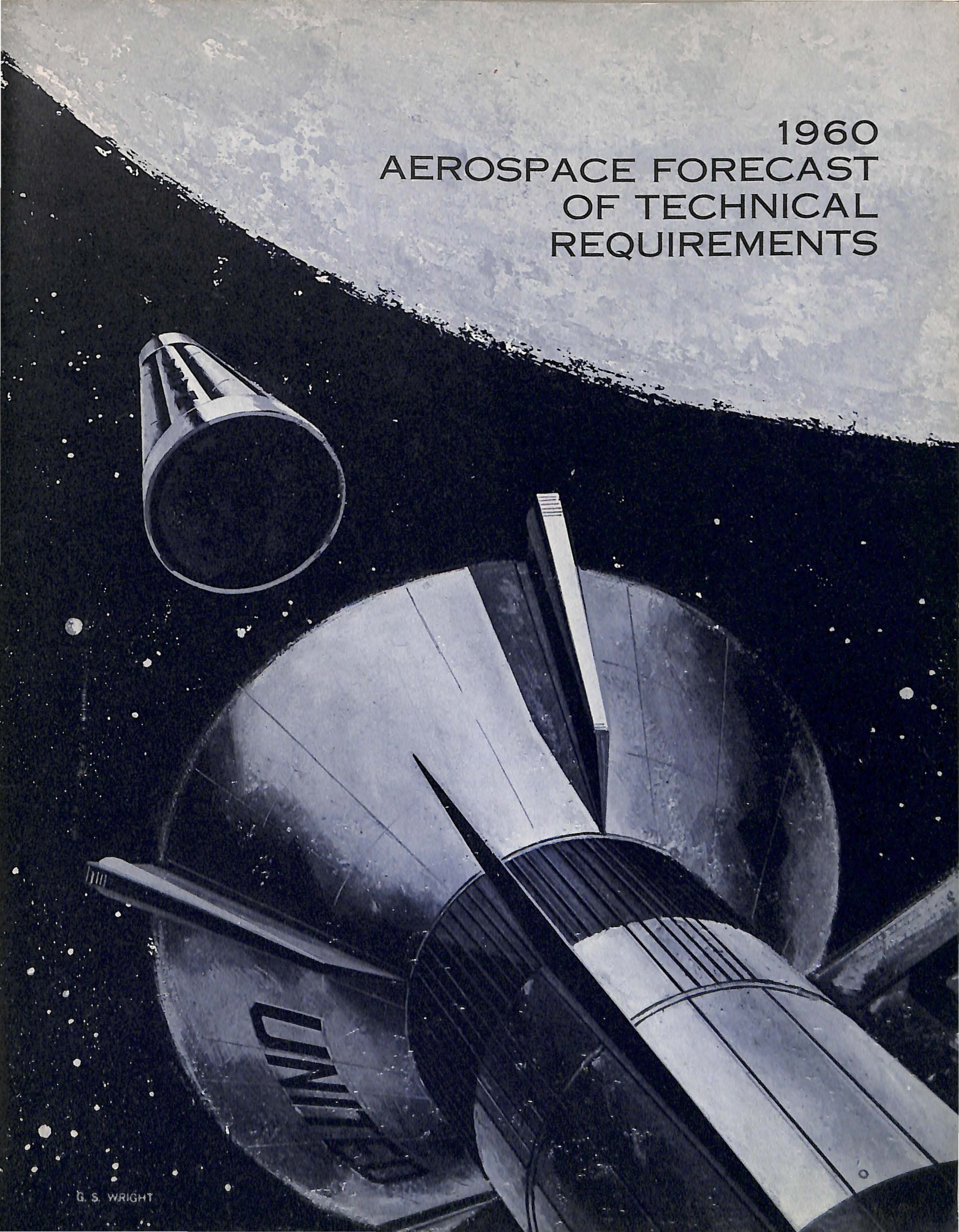
1960
AEROSPACE FORECAST OF TECHNICAL REQUIREMENTS



1960
AEROSPACE FORECAST
of
TECHNICAL REQUIREMENTS

FOREWORD

This report, the seventh AIA Forecast of Technical Requirements, continues the objectives of the earlier summaries. Its purpose is timely advice to the governmental and defense agencies, and to industries serving the aerospace manufacturer; its hope is to foster the research and development required to meet the anticipated technical needs of our national aerospace products. Information herein was supplied by the airframe, missile and electronic equipment manufacturing members of AIA. It represents the combined opinions of responsible experts in the technical fields considered.

The tolerances associated with ten-year technical forecasts are such that, except in cases of significant 'breakthroughs', major changes are unlikely to be reflected in annual reviews. For this reason, AIA plans to prepare this report on a biennial basis in the future. Supplements may be issued during intervening years to summarize critical changes and present data on subjects omitted from the preceding comprehensive publication.

CONTENTS

The decade 1960-1970 will see man's first personal entry into space. That this achievement postdates by only sixty years the birth of the American aviation industry is indicative of the rate at which technological capability is advancing. The rate of development of new scientific concepts now is such that plans for the accommodation of future needs must be determined at the earliest possible date.

This Forecast Report has been prepared by technical committees of the AIA as a guide to the direction of aerospace research and development to best serve the requisites of air transportation, space exploration and the nation's defense effort in the next ten years. Emphasis is placed on the engineering interpretation of future trends and requirements in the fields of materials, systems, equipment, manufacturing technology and testing.

It should be emphasized that the contents of this report are essentially long-term forecasts prepared in the light of contemporary knowledge and currently anticipated aerospace systems. As with any long range projection, the specific data must be a collection of the most competent available opinions and may not be presumed to represent irrefutable fact. The tolerances on the values shown are naturally quite broad. The important evidence is the trend of industry needs, the direction that requirements are taking.

The data presented herein are unclassified. Since the purpose is to advise the maximum technical audience, avoidance of the limitations of secured information is mandatory. Those organizations having access to recent classified data and planning documents may wish to modify the predictions of this report accordingly.

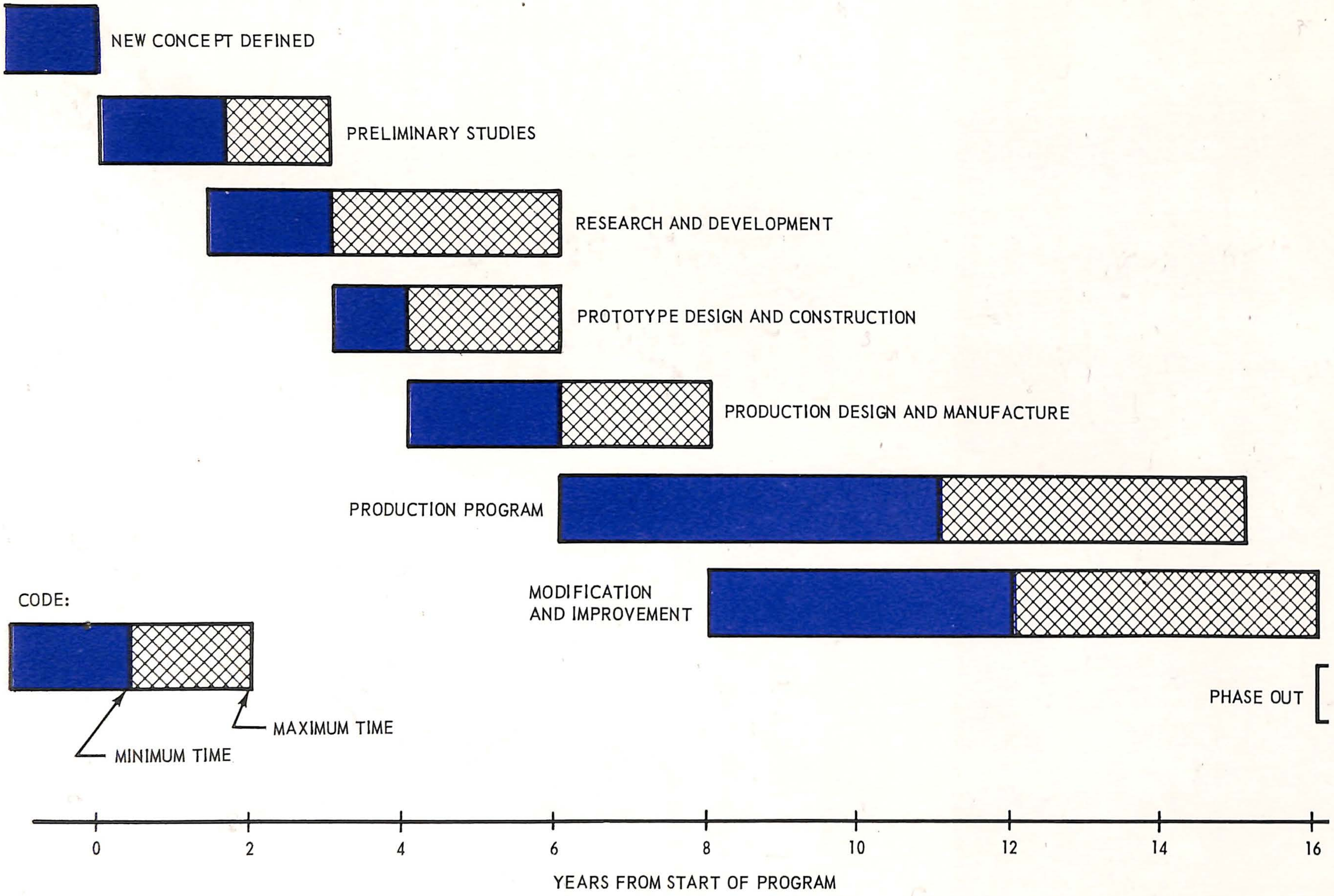
The approach taken to the presentation of component technical requirements has been to first report the anticipated trends in system conditions as a whole, in Sections 1 and 2. These lead to the specific demands on equipment, materials and processes, and in turn, to the necessary developments in manufacturing and testing capability, Sections 3 through 6.

As further useful background information, and as guidance in the application of this report, it is helpful to examine the complete life cycle of an aerospace vehicular system. In general, aerospace vehicles fall into one of four categories: (1) commercial and military transports, (2) manned fighters and bombers, (3) military missiles, (4) satellites and space probes. The cycle depicted on page 7 is intended to show, in a broad way, the relationship of the various phases of a production program and applies only to complete vehicular systems.

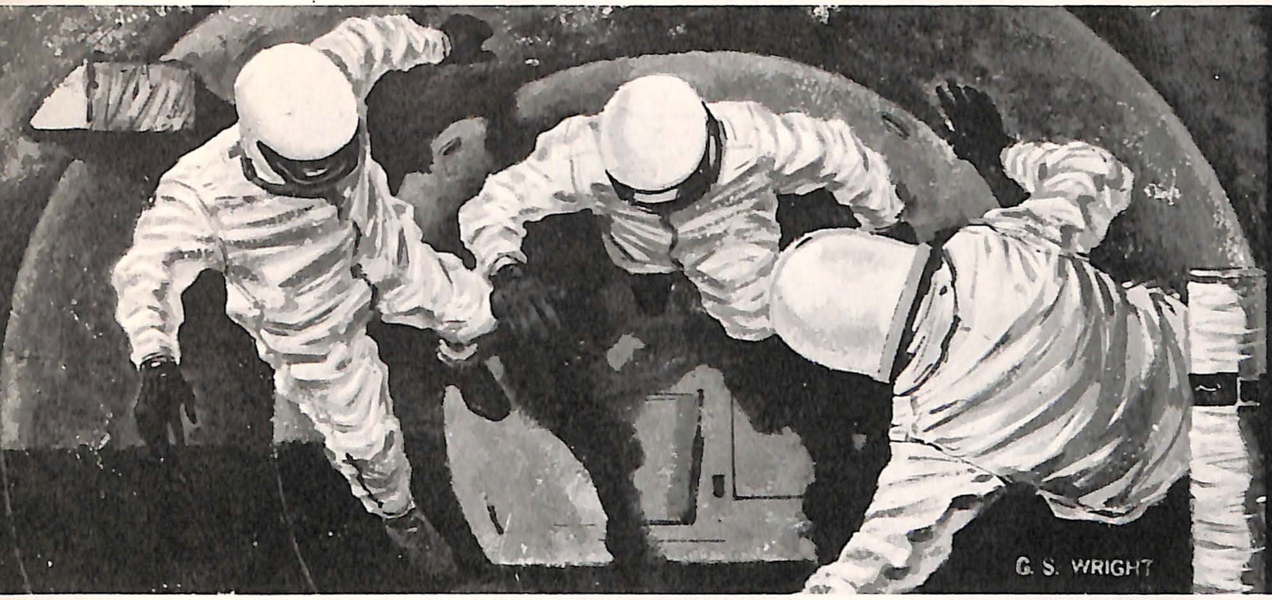
The chart is not intended to define the phasing for any particular system such as a commercial transport or a ballistic missile. The purpose is to explain the individual phases and how they relate to one another. It should be pointed out that in the research and development phase, the work on subsystems involves feasibility studies to determine which existing subsystem or concept may be suitable for the particular vehicle or could be made suitable by further development. Further, this research and development phase covers only the application of existing materials and methods to the particular vehicle. It now becomes apparent that even before an advanced vehicular system can be programed, the advanced materials and methods must be available, and in sufficient quantity to accommodate the proposed production program.

Basic research produces ideas, which through applied research, become the concepts later developed into hardware for our military needs as well as our civilian needs. At almost any point in the life cycle of an aerospace system, a new concept, derived from the research and development studies, may be recognized. That concept, when materialized and made the subject of a separate program, can follow a similar life cycle of its own.

In the next ten-year period, there seems to be developing a trend toward greater design emphasis on reliability and simplicity, with less concern for direct weight reduction. This is particularly true of the unmanned military systems, where present and near-future propulsion systems have adequate thrust for the short-time powered flights needed for data gathering in space exploration. In the air-supported types of vehicles, weight reduction continues to be critical, but greater emphasis will be placed on reliability and simplicity. It also appears that, in the forthcoming military systems, an increasingly longer operational life with more occasion for modifying and improving existing systems will be the trend. A considerable reduction in production volume, as compared with past programs, is to be expected for the majority of systems.



AEROSPACE SYSTEM LIFE CYCLE PROGRAM PHASING



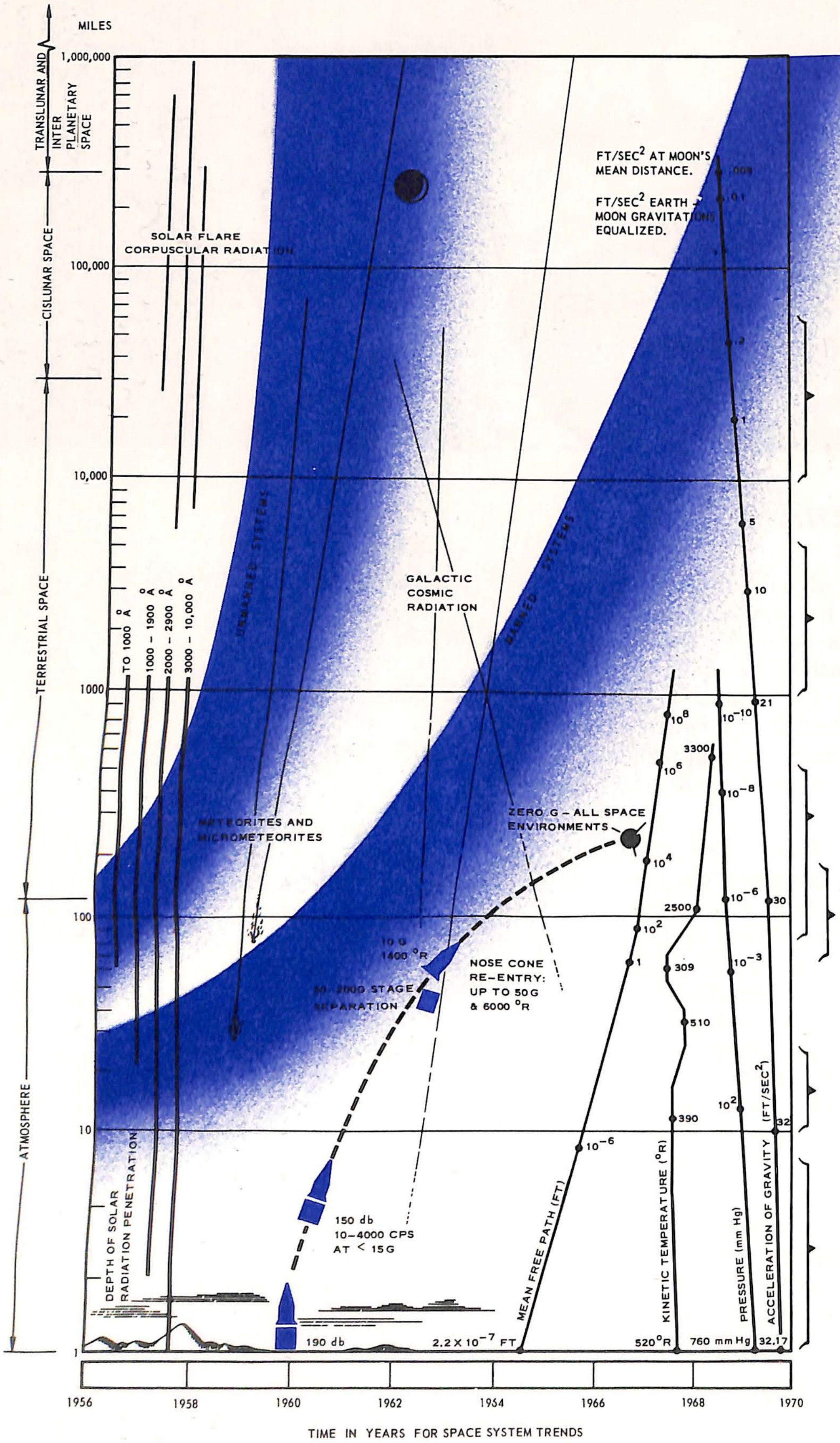
SECTION 1

Environmental Trends

The characteristics of an aerospace system are defined by its environments. As man and his machines enter the Space Age, they encounter an entire new realm of environmental circumstances. Such considerations as cosmic radiation, meteoritic impact, high levels of acoustic energy and the hazards of closed ecological systems have become paramount.

Environments, as a concept, fall into two categories: Natural Environments are those conditions which obtain at a given point in space and time. In relation to natural circumstances, the term 'trend' does not imply changes in the environments, but the expectation of exposure to those conditions. Induced Environments, on the other hand, are in effect man-made, created by the aerospace system, its components and its mission. Both categories dictate design criteria and establish capability limits.

It should be emphasized that the information presented in the following pages is intended to serve as background for the requirements cited in later sections. These are not design data, but rather are general descriptions of the anticipated environmental conditions.



ENVIRONMENTAL DESCRIPTION

SPACE GAS: $H^+ + e^-$
10 TO 2×10^4 PARTICLES/$IN.^3$

SOLAR FLARE CORPUSCULAR RADIATION: 0.1 TO 1 BEV AT 10^{-5} TO 10^{-7} PRIMARY PROTONS/$IN.^3$

GALACTIC COSMIC RADIATION: $1-10^9$ BEV/NUCLEON; 85% PROTONS, 14% α PARTICLES. INTERACTS WITH ATMOSPHERE TO FORM MANY NEW PARTICLES PLUS PHOTONS.

SOLAR WIND
50 ev TO 20 KEV AT $\sim 10^4$ TO $10^6/IN.^3$

OUTER VAN ALLEN BELT
ELECTRONS – $6 \times 10^6/IN.^2$ – SEC FOR > 40 KEV;
6×10^6 TO $6 \times 10^8/IN.^2$ – SEC FOR > 200 KEV;
$\sim 10^6/IN.^2$ – SEC FOR > 2.5 MEV
PROTONS – $5 \times 10^6/IN.^2$ – SEC FOR > 10 MEV; $6/IN.^2$ – SEC FOR > 60 MEV.
TOTAL SOLAR FLUX: 130 WATTS/FT^2
RADIATION SINK OF SPACE ≈ 7° R.

INNER VAN ALLEN RADIATION BELT
PROTONS – $6 \times 10^7/IN.^2$ – SEC FOR > 10 MEV, $1.3 \times 10^5/IN.^2$ – SEC FOR > 40 MEV.
ELECTRONS – $10^{10}/IN.^2$ – SEC – STERADIAN FOR > 20 KEV, $6 \times 10^7/IN.^2$ – SEC STERADIAN FOR > 600 KEV

HYDROGEN (H_2, H, H^+) APPARENTLY PREDOMINANT CONSTITUENT OF ATMOSPHERE.

ATMOSPHERIC IONIZATION
$\sim 10^2$ TO 6×10^7 PARTICLES/$IN.^3$

FREE MOLECULAR MOTION.
THERMODYNAMIC, RAM AIR, ACOUSTIC PROPAGATION, AND AERODYNAMIC EFFECTS BECOME NEGLIGIBLE.

METEORITES REACT WITH ATMOSPHERE BETWEEN $\sim$ 80 TO 30 MILES

OZONE LAYER (O_3)
UP TO $\sim$ 12 ppm

TROPOSPHERE ENVIRONMENTS
HIGH AND LOW TEMPERATURE
DYNAMIC PRESSURE
HUMIDITY, SAND, DUST
SHOCK, VIBRATION, ACOUSTICS, ACCELERATION.

ENVIRONMENTS AND SPACE SYSTEM TRENDS

NATURAL ENVIRONMENTS

Extremely High 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 pressures represent a partial space equivalent; and for most considerations, above 120 miles the pressures encountered constitute a total space equivalent. At altitudes above 120 miles extreme low pressures range from 1.5 x 10^{-6} mm Hg down to an estimated value of 10^{-11} or 10^{-12} mm Hg for solar system space and 10^{-15} to 10^{-20} mm Hg for intergalactic space.

Electromagnetic Radiation

Electromagnetic solar radiation is a continuum over virtually the complete range of wavelengths with a spectrum and energy output closely approximating that of a 6000 °K black body. From 2000 A° down to 200 A° (vacuum ultraviolet) line spectra predominate. Ultraviolet radiation below 2000 A° represents a small part of the total solar radiant energy, but the higher quantum energies of this radiation can activate chemical reactions not encountered with the longer wavelength radiation. By far the major portion of the sun's energy is radiated between 2000 A° to 32,000 A° with the peak occurring around 4550 A° (blue). Radio frequency radiation is primarily of spatial origin, and its spectrum and intensity vary considerably with solar and stellar activity. The high quantum energy X-ray and gamma radiation of varying intensities emanate primarily from the attenuation and decay of high energy particles.

High Energy Particle Radiation

High energy particle radiation encountered in helicocentric space consists primarily of solar protons and electrons, and galactic cosmic rays. This radiation is absorbed by the earth's atmosphere, but secondary radiation from cosmic rays is detectable on the earth's surface. Two or more bands of magnetically trapped protons and electrons have been detected beyond the earth's atmosphere. The outer band has mostly low energy particles, probably coming from the sun. A portion of the inner band has high energy particles which may result from decay products of cosmic ray collisions with atmospheric gas molecules. Cosmic rays consist of protons, alpha particles and heavier nuclei. These particles, originating from outer space, have low intensities, but extremely high energies. Their interaction with the atmosphere or other matter produces secondary particles and electromagnetic radiation. A similar reaction is believed to cause the auroral displays, when radiation particles collide with the upper atmosphere in the polar regions.

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), and their interference with radio transmission. Such excited state reactions can occur thermally, electrically, or by the direct absorption of photons. There is a concentrated band of ozone in the atmosphere between 50,000 and 100,000 feet with maximum concentration between 70,000 and 80,000 feet. This component can present a serious material and personnel hazard in high altitude supersonic flight.

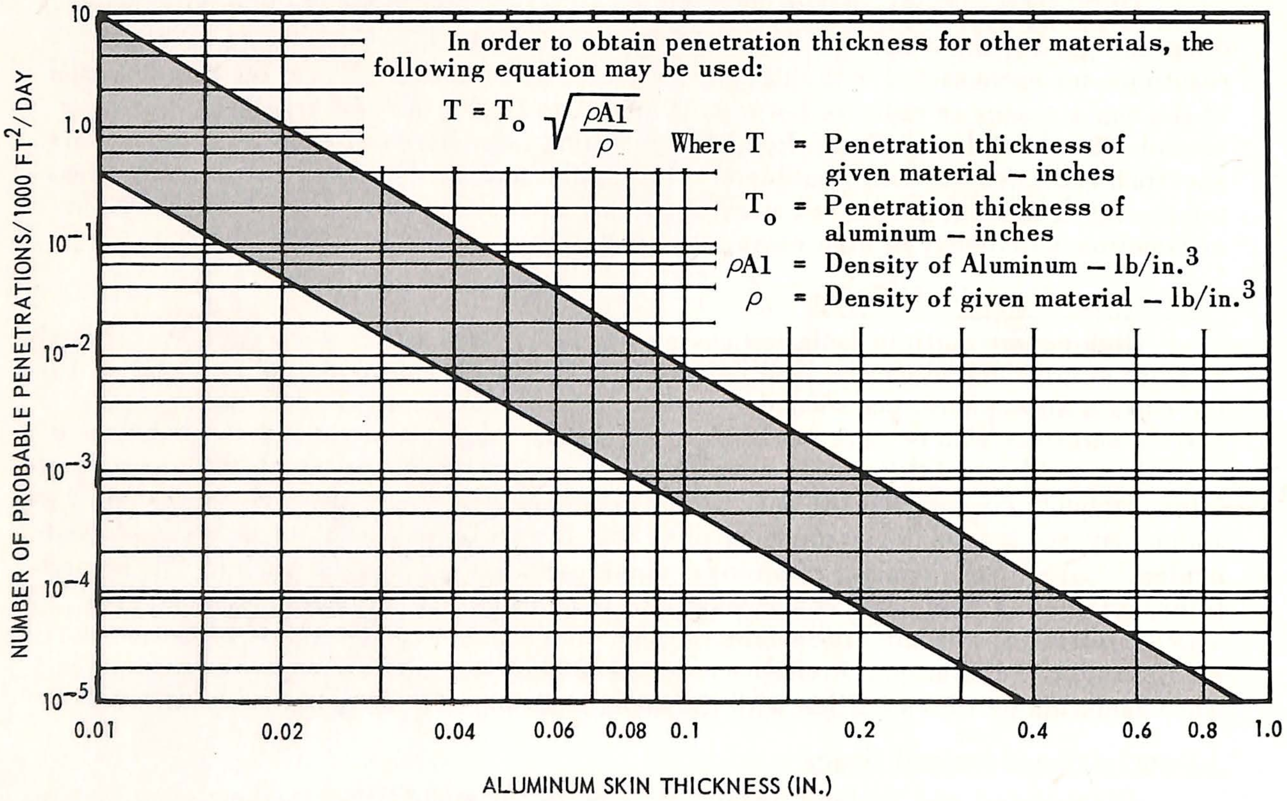
Meteorites

Characteristics of extraneous solid matter in geocentric space vary over a wide range of size, mass, density and velocity. Information to date on the meteoritic environment is rather meager. Publiched data are primarily the result of mathematical extrapolation based on several assumptions. It is known that the greater number of particles possess small mass and size, reaching a lower limit of approximately 10^{-11} grams and 10^{-4} cm diameter. Three classes of meteoritic composition are generally accepted: iron-nickel, stoney, and pithball (dust and frozen gases), with respective densities of 8, 3.4 and 0.05 to 0.3 grams/cc. The overall meteoritic velocities in the vicinity of the earth range from 7 to 45 miles/second.

The significant effects of this spatial debris to space vehicles are penetration and erosion. The spatial density of this material is relatively low, reducing the risk of penetration to reasonable limits. The following figure gives current estimates of such risk for nominal aluminum skin thicknesses.

Earth's Natural Environments

The variables of temperature, pressure, and contaminants such as rain, hail, sand, fungus, humidity, salt spray, etc., in the lower atmosphere of the earth are adequately described in many of the "MIL" specifications and, therefore, are not discussed here.



In order to obtain penetration thickness for other materials, the following equation may be used:

$$T = T_o \sqrt{\frac{\rho Al}{\rho}}$$

Where T = Penetration thickness of given material – inches

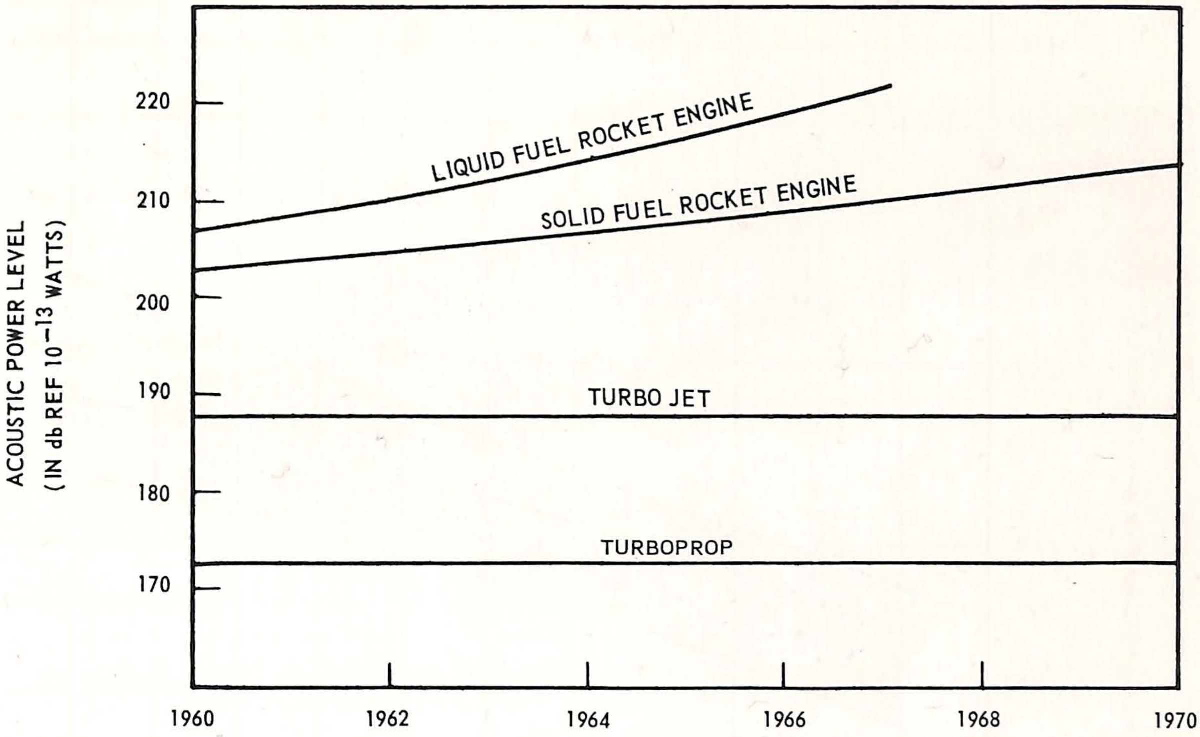
T_o = Penetration thickness of aluminum – inches

ρAl = Density of Aluminum – lb/in.^{3}

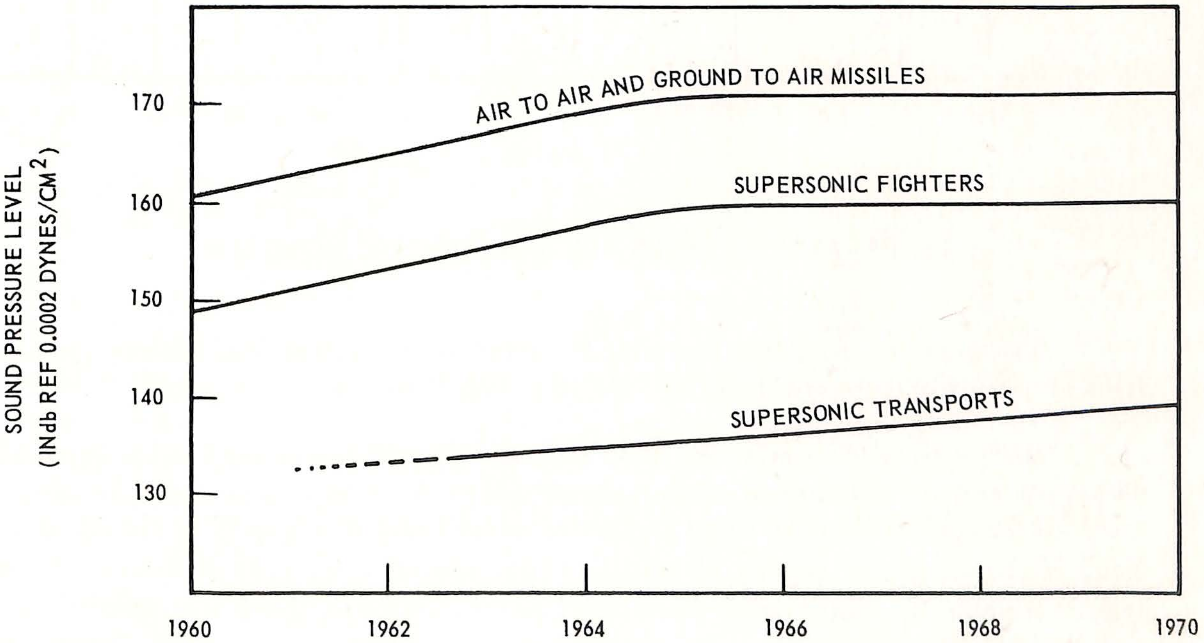
ρ = Density of given material – lb/in.^{3}

METEORITIC PENETRATION RISK FOR SPACE VEHICLES

This curve gives the current range of estimates for meteoritic penetration risk for a space vehicle. Limited data from satellites are consistent with these estimates. The relatively wide range of estimates emanates primarily from the fact that it is not known what the impact phenomenon of hypervelocity particles will be. The upper limit of the curve is based upon a penetration reaction that assumes a direct conversion of the solid particle kinetic energy into heat energy upon impact with the target material. This approach is estimated to be conservative by a factor of three or four. The lower limit is based upon a numerical approximation of the equations of motion at impact, and appears to yield more reasonable data. However, there is very little substantiating test data.

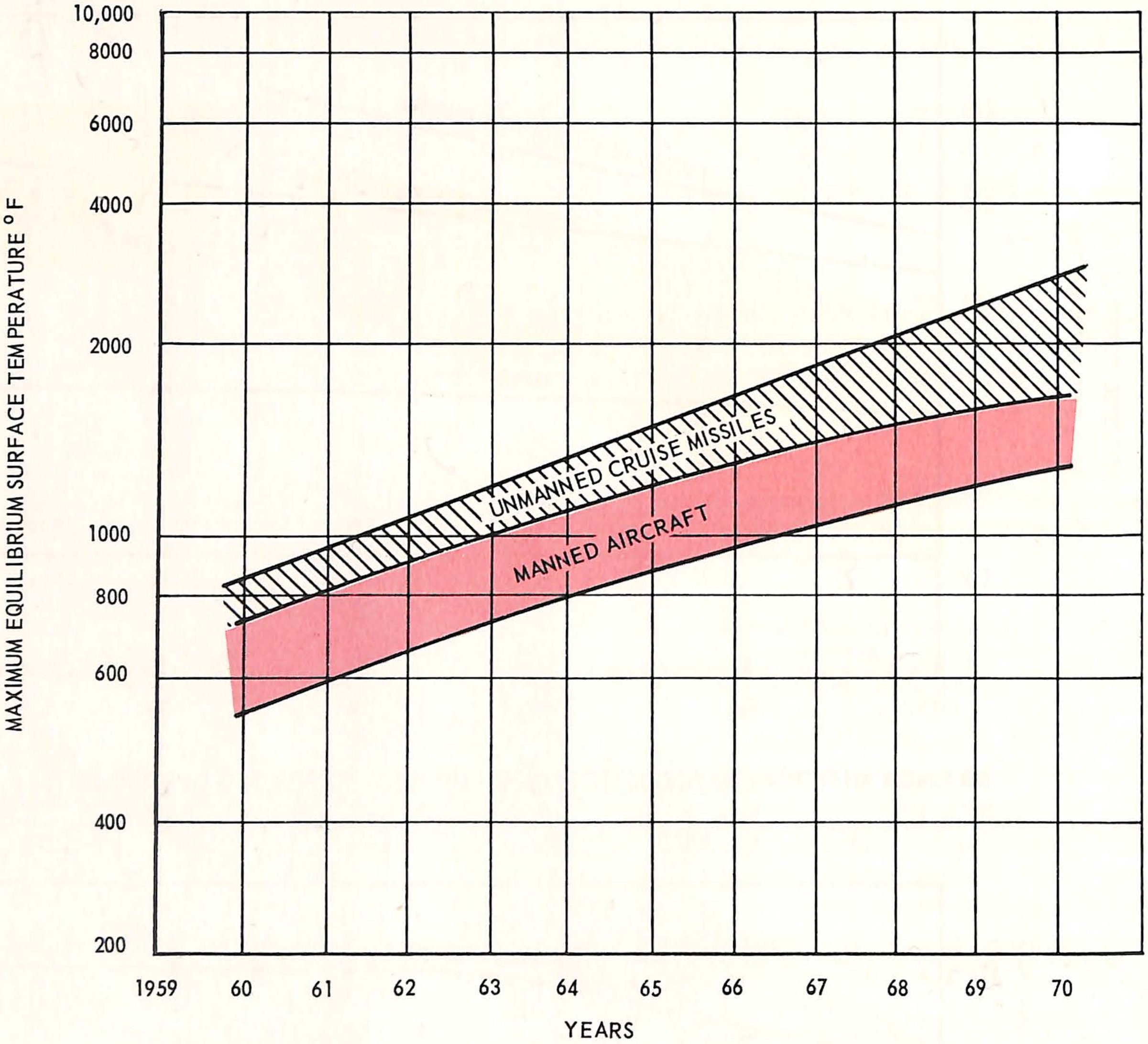


MAXIMUM ANTICIPATED ACOUSTIC POWER FOR FOUR TYPES OF POWER PLANTS



ANTICIPATED OVERALL SOUND PRESSURE LEVELS OF TURBULENT BOUNDARY LAYERS

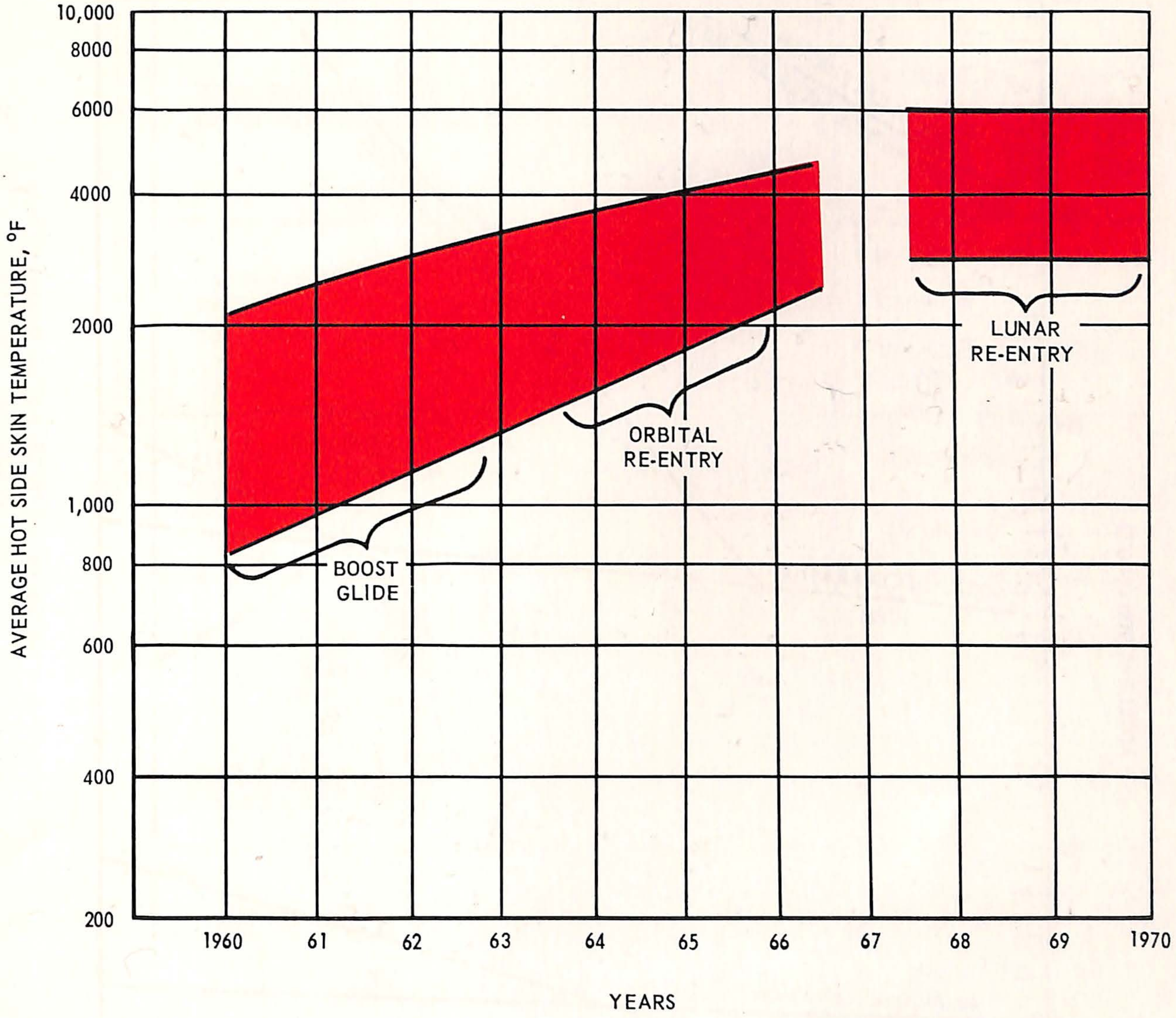
INDUCED DYNAMIC ENVIRONMENTS



TEMPERATURE TRENDS FOR ATMOSPHERIC VEHICLES

The trend toward higher operating temperatures is evident from the mission profiles of present and projected military and exploratory vehicles.

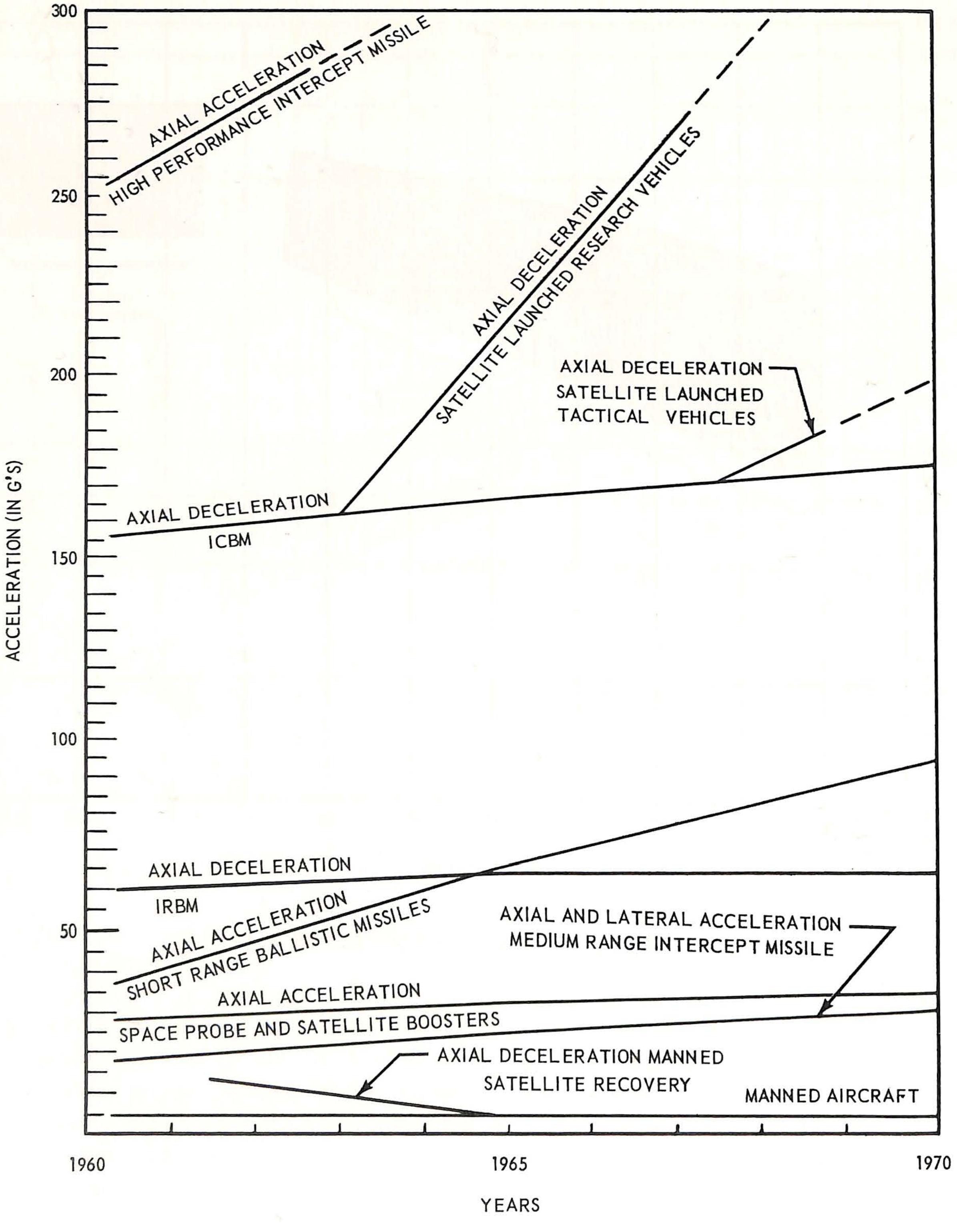
Mach number for continuous flight atmospheric vehicles is expected to level off within the next ten year period at approximately Mach 4. This presumes that weight trade-off for cooling systems would present an undue penalty at speeds in excess of Mach 4. A less severe penalty for cooling is anticipated in the case of unmanned systems, consequently higher temperatures are foreseen for these. Peak temperatures in certain locations on the vehicle under transient conditions will exceed those shown on the curve for equilibrium conditions.



TEMPERATURE TRENDS FOR MANNED RE-ENTRY VEHICLES

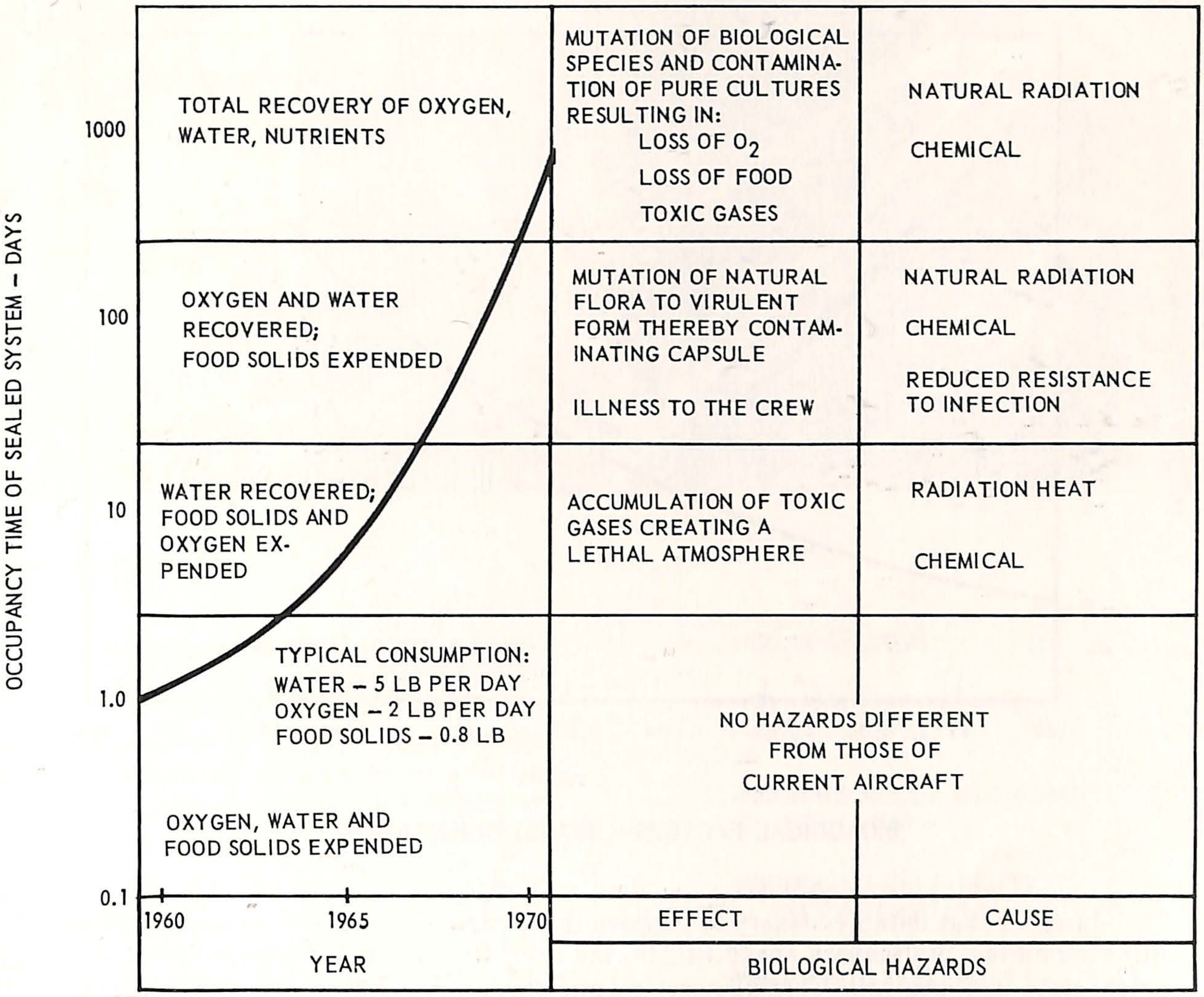
Operating temperatures will increase at a more drastic pace as the industry's products develop from boost glide to orbital re-entry to lunar re-entry systems. Predictions are less certain for these vehicles, however, since operating temperatures are so strongly dependent on configuration, re-entry corridors, and exploitation of technological advances. As rapidly as higher temperature materials become available, vehicles will be designed to use them.

Unmanned systems exist today which sustain temperatures higher than those shown above. Operating temperatures for ballistic re-entries are keyed to choice of ablation materials, and vary over a considerable range to as high as approximately 5000 °F.



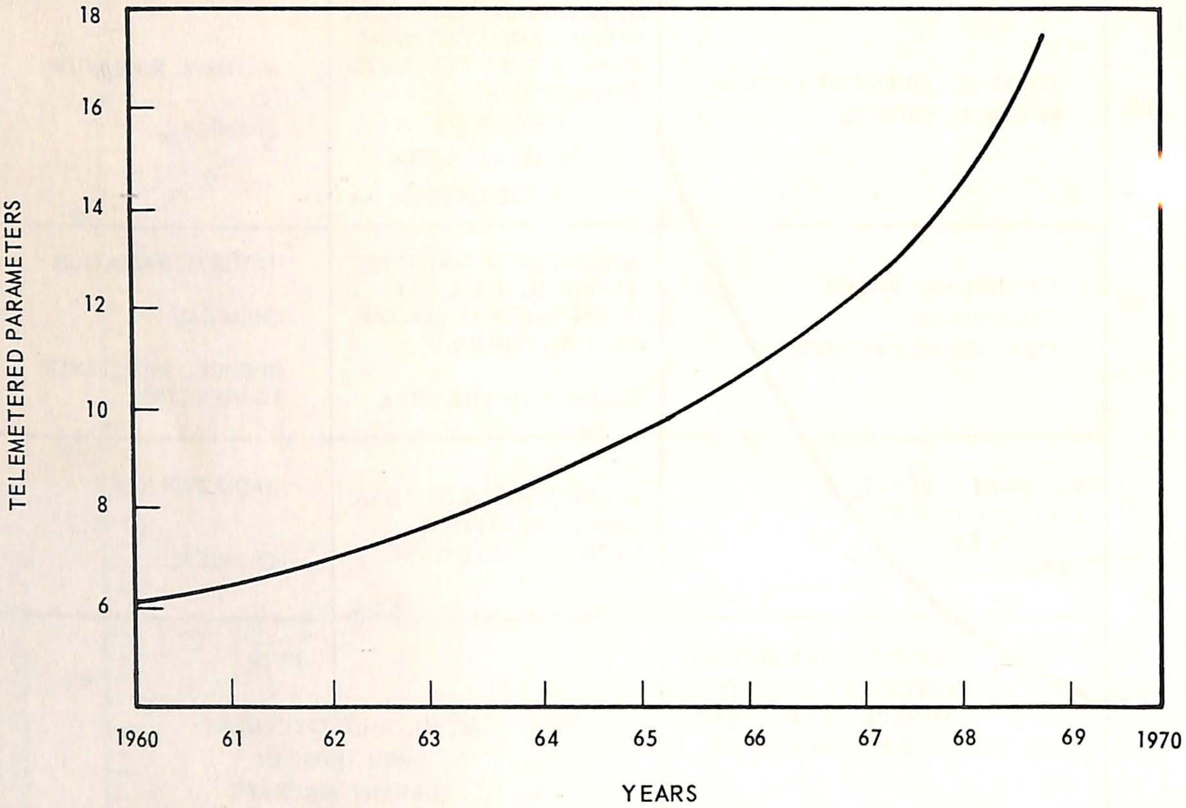
ANTICIPATED MAXIMUM ACCELERATIONS

Manned Ballistic and Orbital return vehicles, starting with Project Mercury, will be subject to short time accelerations ranging from 10 to 20 G's. Later in the decade, research space probe vehicles may be designed to withstand greater than 250 G's. Until that time, the highest load factors will appear in high performance intercept missiles.



BIOLOGICAL FACTORS – INHABITED CAPSULES

As the period of occupancy of a closed ecological environment is extended, the probability of induced fluctuation increases. Unlike terrestrial environment fluctuations, which return unnoticed to equilibrium as a result of natural forces, the artificial environment of manned space vehicle must be influenced by the occupant in a manner which will produce an immediate balancing response. Over extended periods, unforeseen mutations of organisms (natural, chemical, radiation, or others) may make fungicides and pharmaceuticals ineffective, dormant pathogens may become active, food regeneration materials and methods are subject to microorganism contamination. Toxic degradation products of materials by cosmic radiation can contaminate recirculating air systems as can volatile materials (lubricants, plasticizers). Although the astronaut will have several tools to apply in maintaining his life-sustaining balance, there always may be these possible biological variations with which he must cope.



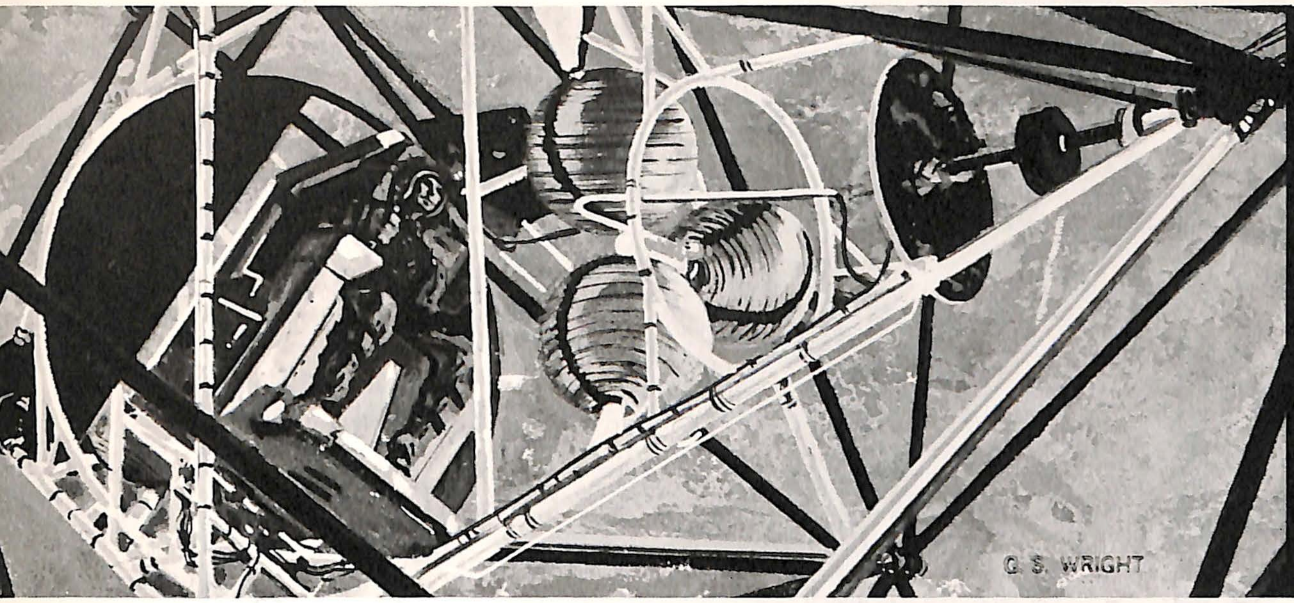
BIOLOGICAL FACTORS – BIOINSTRUMENTATION

In order that data necessary to improve the design of ecological systems may be collected during preliminary space flights, the need for reliable telemetered physiological data is essential. Careful monitoring of physiological data during early flights is also necessary to increase the probability of the safe return of the crews participating. The collection of such data has thus far been limited in the United States space effort to that obtained from the two monkeys, Able and Baker. Data collected on these primates were limited to four parameters, electrocardiogram, respiratory rate, chest sounds, and body temperature.

For extended space flight, instrumentation that permits the astronaut to know at all times what is happening to his atmosphere will be very important. This data must be telemetered to the scientists on earth. Environmental factors which require constant monitoring include, but are not limited to, barometric pressure, the partial pressure of oxygen and carbon dioxide, noxious gases, temperatures, radiation, humidity and air movement.

Instrumentation of the astronaut himself to measure physiological functions will be required. The welfare of the individual could be determined by constant monitoring of oxygen and carbon dioxide in expired air, heart rate, body temperature, blood pH, respiratory rate and volume, blood pressure, galvanic skin response, electroencephalogram, and electrocardiogram. The major problem at this time is the design of transducers which are acceptable to the crew member and do not restrict his natural movement or response.

The number of parameters which can be measured and telemetered depends upon the adaptation, miniaturization and integration of existing equipment and the required development of new instrumentation and techniques.



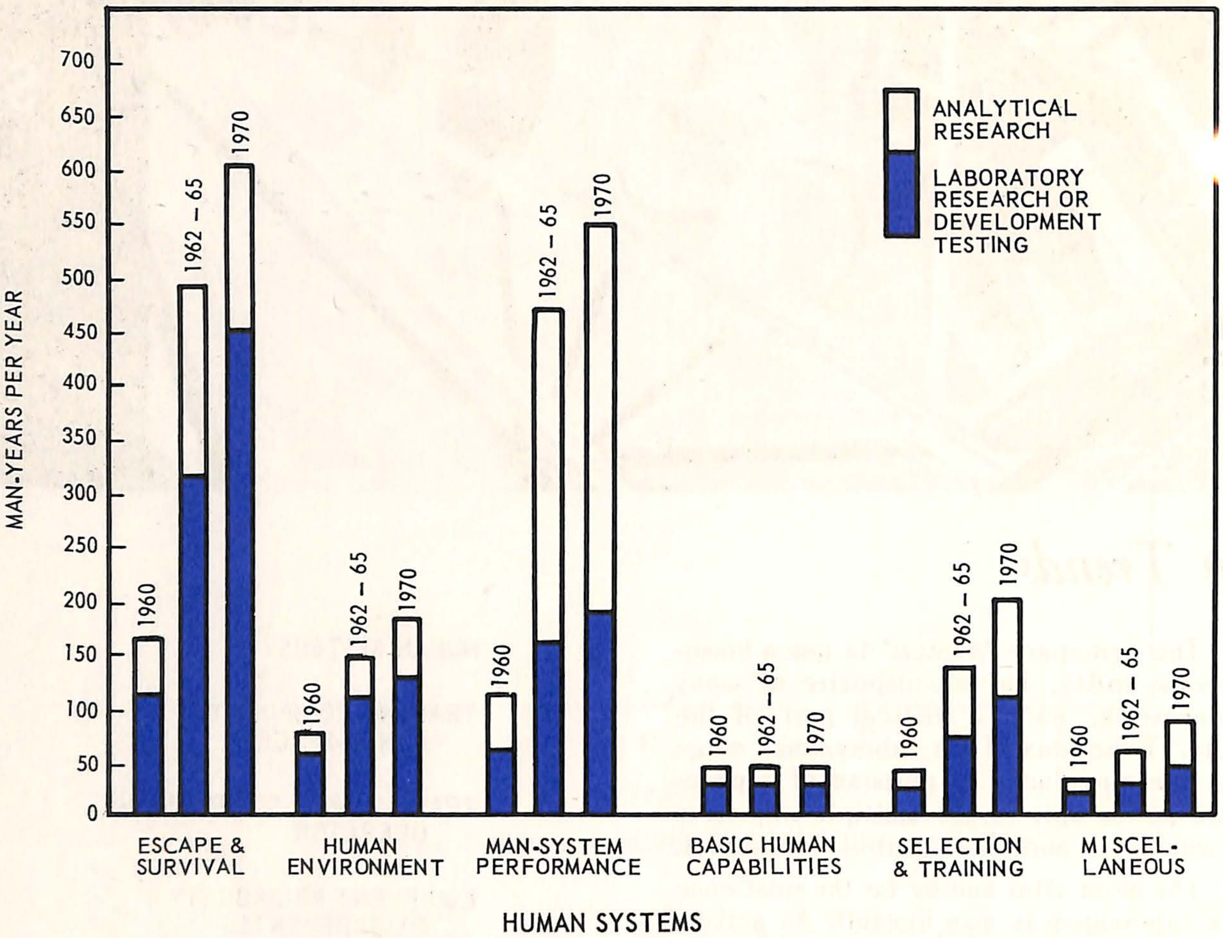
SECTION 2

System Trends

The aerospace 'system' is not a homogeneous entity, but a composite of many sub-systems, each a critical part of the whole. Functions of the sub-systems range from the singularity of purpose of a pneumatic power unit to the multiple objective of guidance and fire control equipment.

The most vital and by far the most complex sub-system is man himself. An active, essential partner in manned aircraft, man's initial role in space will be a passive one. But, as with every other sub-system, he will encounter new and stringent environments during the next decade. Human factors research and specialized training will be required to fit man into situations of unusual stress.

Unlike man, whose innate characteristics must be modified or accommodated, mechanical and electronic systems will be designed to the flight conditions. That design problem, however, will entail new sciences and radical improvements in present technologies.

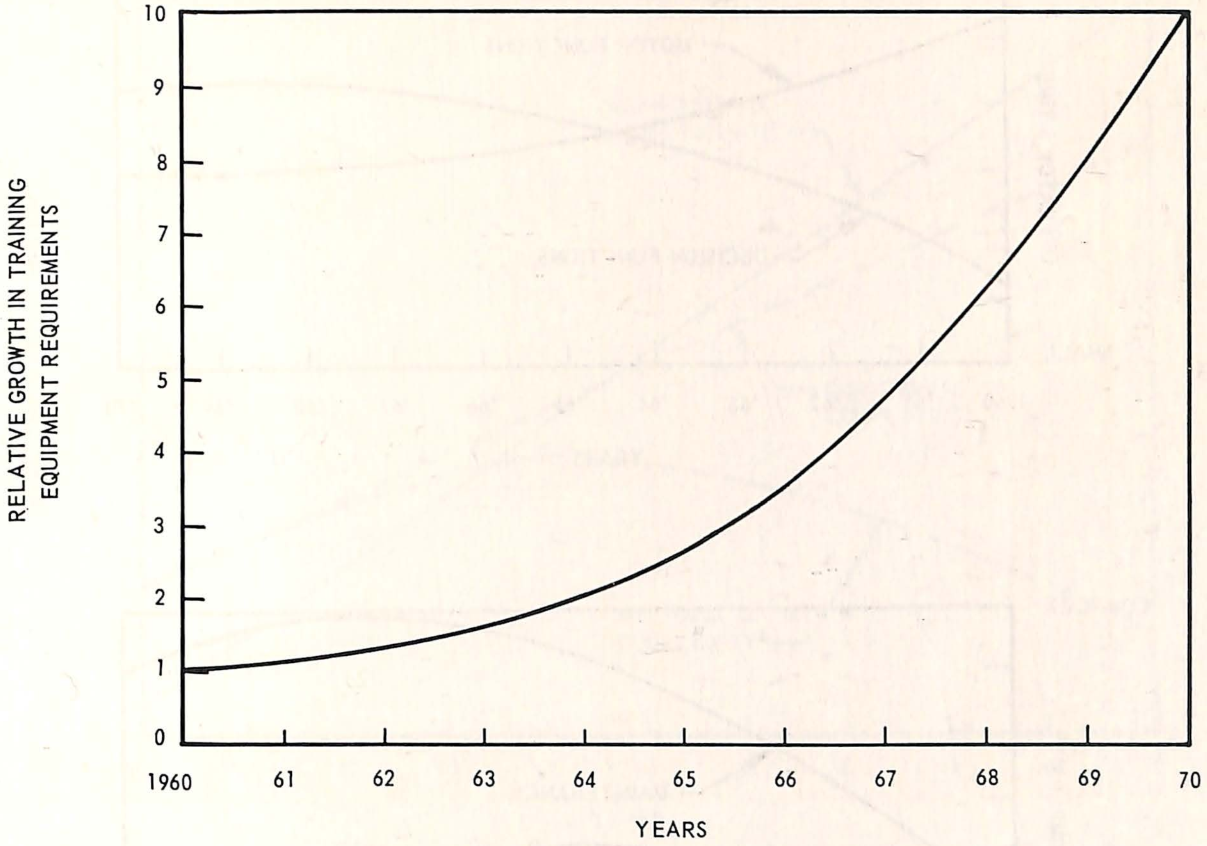


This chart reflects the anticipated manpower expenditure required in various human factor areas during the period 1960 – 1970.

Major human factors effort for the next 10 years will be applied to problems of escape/survival and to the performance of operators as components within systems loops. A relatively modest effort will be devoted to basic research in human capabilities and limitations, per se, since the trend is, and will continue to be, to determine these capabilities within the context of specific systems (i.e., systems analysis/synthesis). Critical research problems are those involving complex aspects of human behavior, e.g., information processing, decision making, detection and recognition. The study of human environmental problems will continue with most of the effort being devoted to space vehicle environments. Training, particularly for space flights, will be given increasing attention (see following pages). Among the miscellaneous problem areas, emphasis will be placed on human reliability and accident prevention.

Estimates indicate 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 under increasingly severe environments and in ever more complex systems.

Note: See also page 82, Simulation Facilities for Man-Vehicle Evaluation.

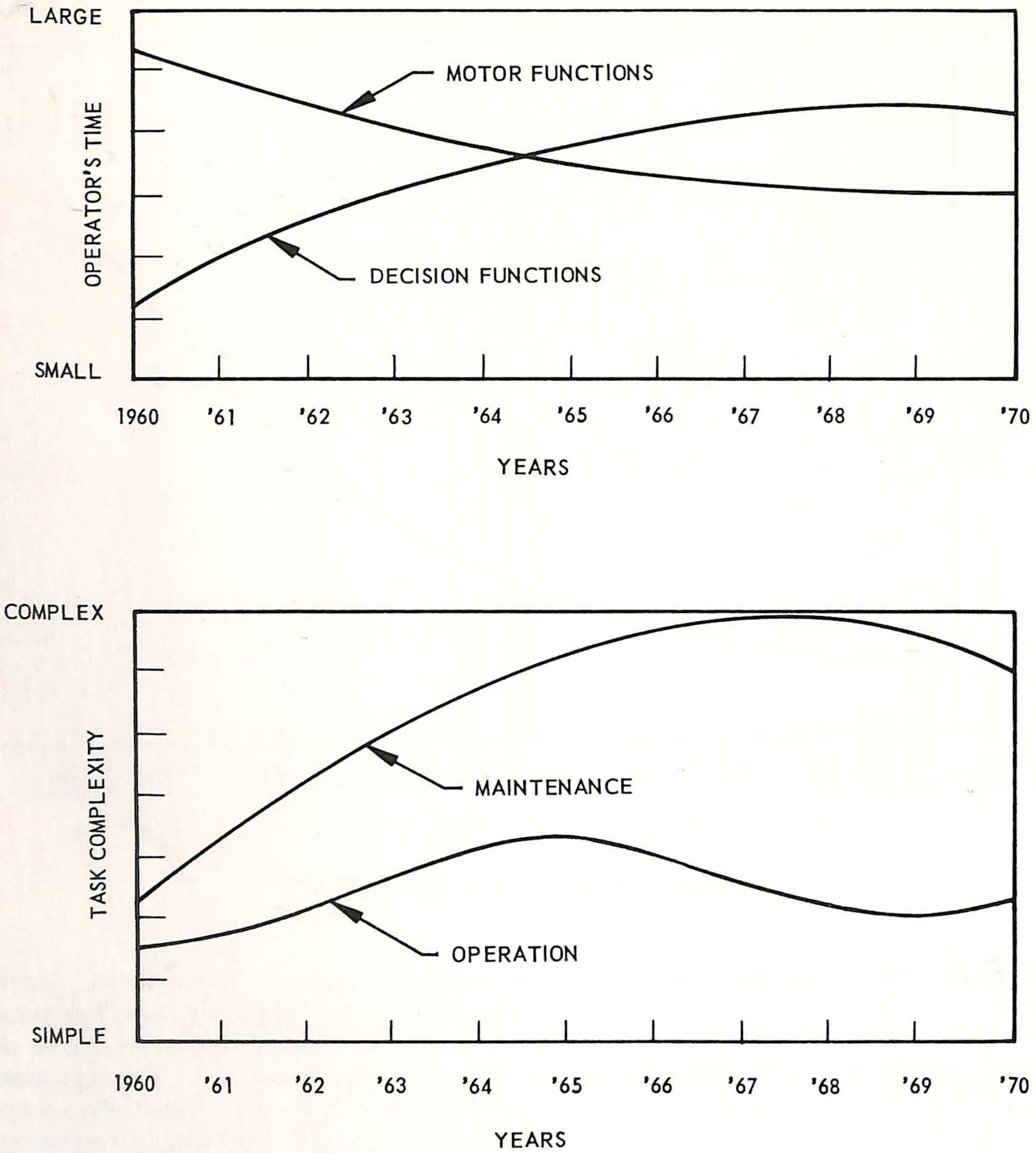


TRAINING EQUIPMENT – MAN IN SPACE

Trainers for space flight are receiving more attention as space travel becomes more imminent. Space flight trainers will require tremendous originality and diversity. Electronically generated displays and control stimuli will be used to provide close precision and reproducible-stimulus systems for space vehicle simulators. There is a growing trend toward the use of digital computers to describe the dynamic equations of motion, but the requirement most often expressed is for analog-to-digital and digital-to-analog conversions to permit simulation of more complex flight characteristics with greater fidelity.

As we progress from unmanned and minimally manned earth-orbital and space vehicles to more manned missions and larger crews, there will be increasing requirements for space simulators, training for personnel performance tasks, and use of life support systems for space flight. The buildup will start slowly until training requirements are defined, then will accelerate rapidly as we become more sophisticated.

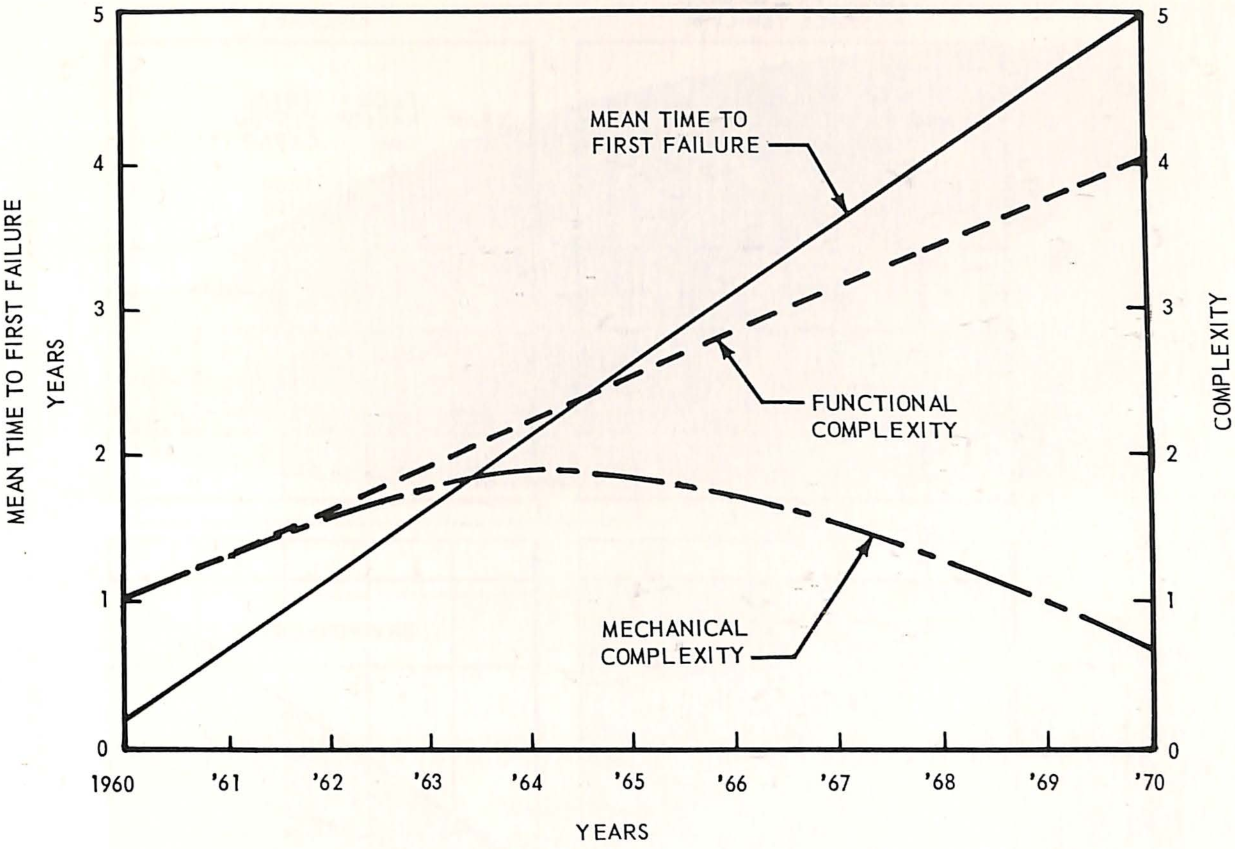
Extreme "g" response and zero gravity will continue to be simulated in such equipment as the NADC Centrifuge, Langley Field Water Barrel and Pensacola Disorientation Trainers. Electronic equipment will be required for presentation of stimuli and analysis of the pilot's response, as well as the pilot's physiological status.



TRAINING SKILLS FOR HUMAN OPERATOR

The space age, nuclear technology, and other scientific and engineering advances will increase the demand for human skills in operation and maintenance.

Initially, the man in space will be primarily a passenger, but as his vehicle becomes more sophisticated, he will be given more operating tasks. The operating tasks will then be automated and the human will be used for decision-making and maintenance. Further design evolution will seek an optimum balance between human skills and the complexity of automatic equipment, resulting in less maintenance training time and more operation training time near the end of the decade.

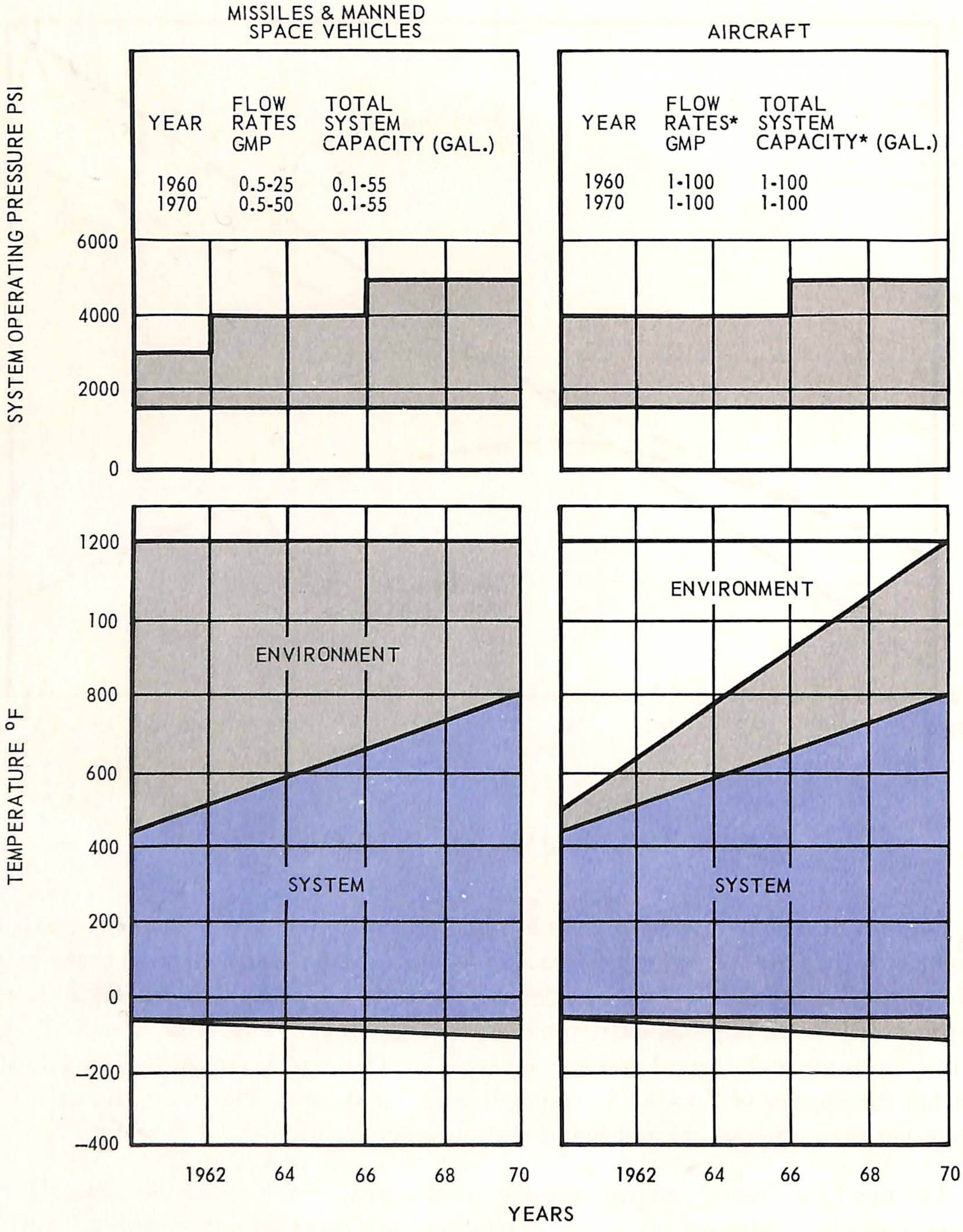


EQUIPMENT RELIABILITY REQUIREMENTS

In the next decade the most critical requirement of aerospace equipment will be attainment of reliability to assure performance of tasks required by developments in other technologies. The Sixties will see the development of highly specialized devices, although there will be no large-quantity production runs. Modules must be standardized to permit the application of logical design techniques. The complexity of the module increases but the number of "parts" in the device is decreased. The chart illustrates this difference between mechanical and functional complexity.

The need for "robot" control and the environment of the space mission will require more compact equipment of highly specialized and increasingly complex function. Present reliability programs concerned with achieving system reliability by attention to the reliability of parts and their application will not provide the complete answer, although these techniques will be improved and expanded to allow procurement to specific reliability levels at specific user confidence levels for the specified operating conditions.

An entirely new methodology must be developed to obtain the necessary reliability for these space missions. It is virtually certain that redundant systems incorporating self-checking, fault-locating-and-indicating, self-organizing and adaptive features will have to be devised to meet the reliability needs of the future.



MISSILES & MANNED SPACE VEHICLES

YEAR	FLOW RATES GMP	TOTAL SYSTEM CAPACITY (GAL.)
1960	0.5-25	0.1-55
1970	0.5-50	0.1-55

AIRCRAFT

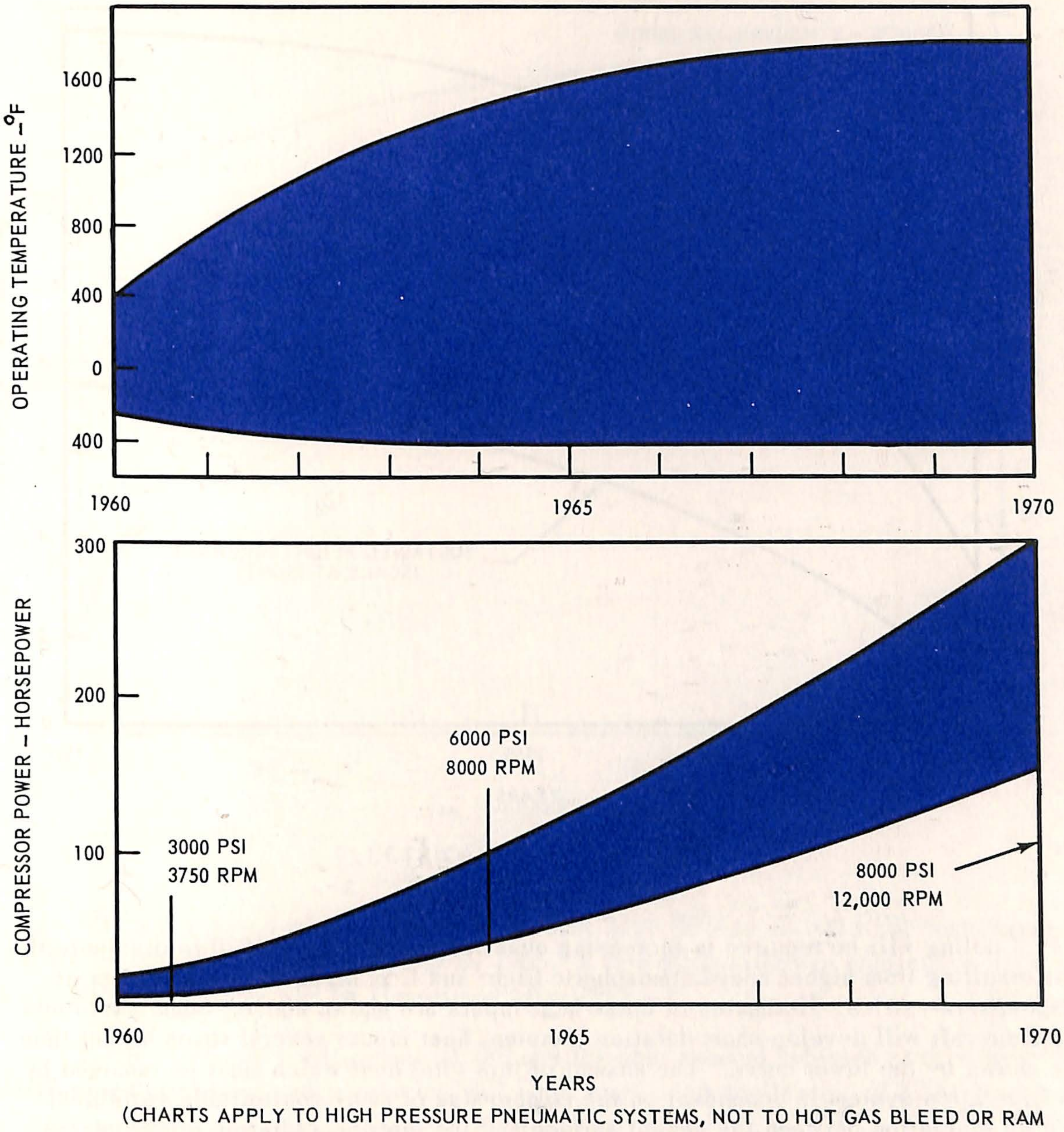
YEAR	FLOW RATES* GMP	TOTAL SYSTEM CAPACITY* (GAL.)
1960	1-100	1-100
1970	1-100	1-100

HYDRAULIC SYSTEM TRENDS

Flow rates are maximum anticipated short-time demands. Aircraft environmental and system temperatures correspond to highest performance vehicles only, and exceed those anticipated for transport-type aircraft.

"Environment" means maximum anticipated structural (exclusive of cladding, insulation, etc.) conditions or those adjacent to hydraulic components.

* In unique cases, these figures may be considerably exceeded.



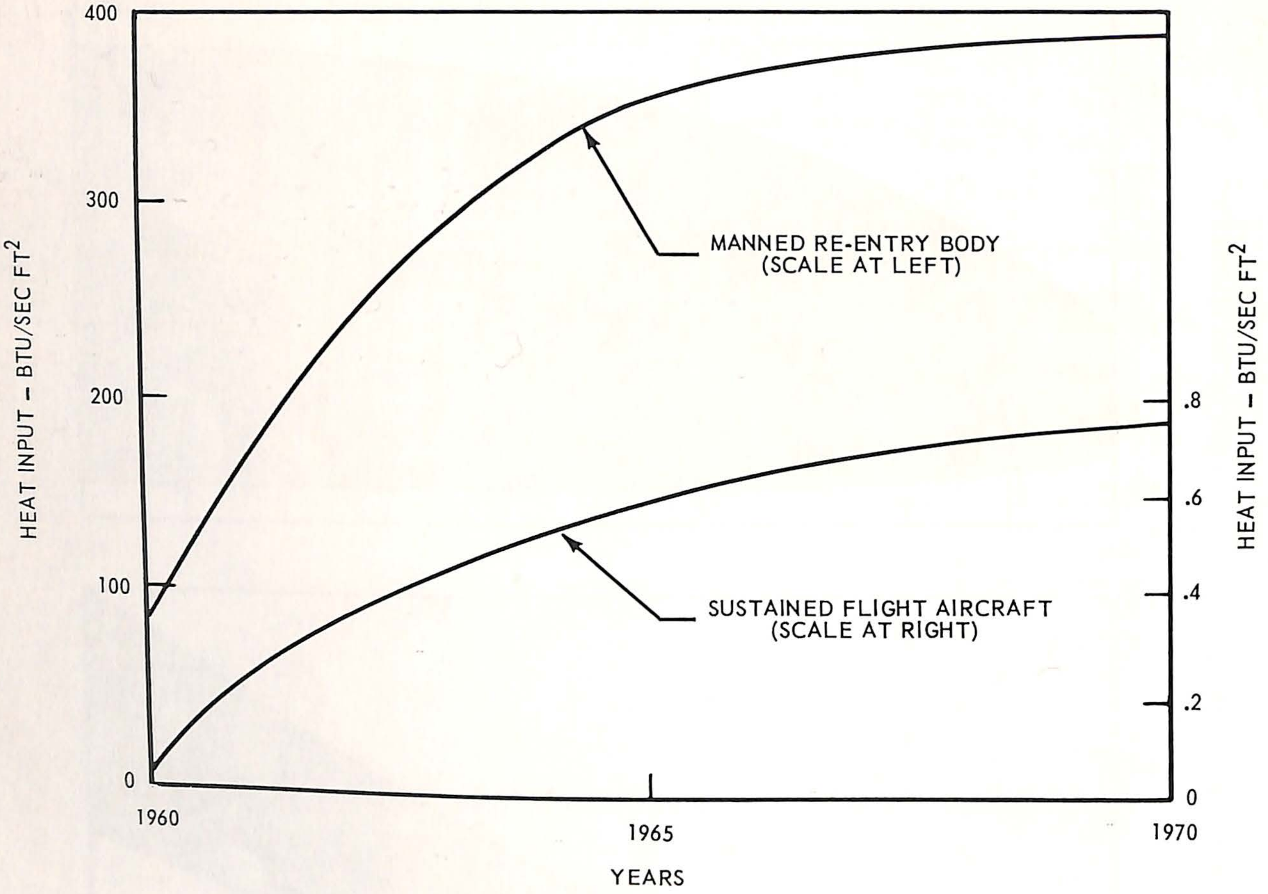
(CHARTS APPLY TO HIGH PRESSURE PNEUMATIC SYSTEMS, NOT TO HOT GAS BLEED OR RAM AIR TURBINE SYSTEMS)

PNEUMATIC SYSTEM TRENDS

The most significant trend of the next decade is the increasing maximum operating temperatures. These higher temperatures will result in pneumatics taking over many functions now utilizing hydraulics. The increased capacity requirements for pneumatics is shown by the lower curve. This increasing power requirement in turn will result in higher system pressures and compressor speeds as indicated.

Significant improvements in the following areas are required during this period:

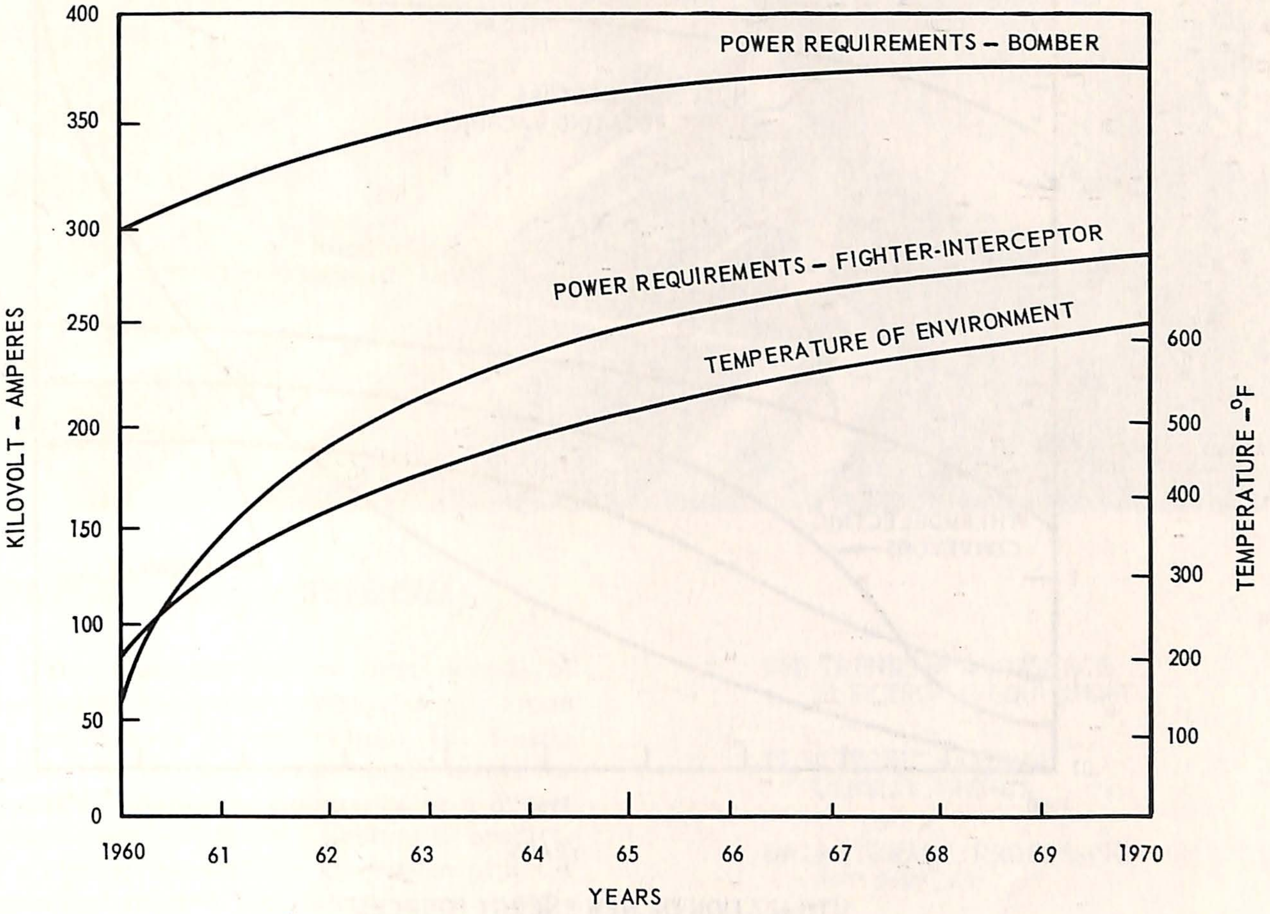
a) Explosion resistance
b) Moisture removal
c) Dessicants (service life, efficiency and cost)
d) High temperature lubricants for compressors



COOLING SYSTEMS

Cooling will be required in increasing quantity during 1960 – 1970 to dissipate the heat resulting from higher speed atmospheric flight and from higher energy, steeper atmospheric re-entries. Estimates of these heat inputs are shown above. Some sustained flight aircraft will develop short duration transient heat inputs several times higher than that shown by the lower curve. The amount of this total heat which must be removed by a refrigeration system is dependent on the compromise of many controllable variables, such as insulation between the heated surface and the interior, radiation effectiveness (dependent in turn on emissivity and surface temperature), temperature tolerance of material requiring the cooling and the heat sink available to absorb heat.

Additional heat will be generated by the operating equipment and by onboard personnel. These heat loads will be the most critical for certain space vehicles. Solar heat can be controlled within acceptable limits by proper use of surface emissivity-absorptivity relationships.



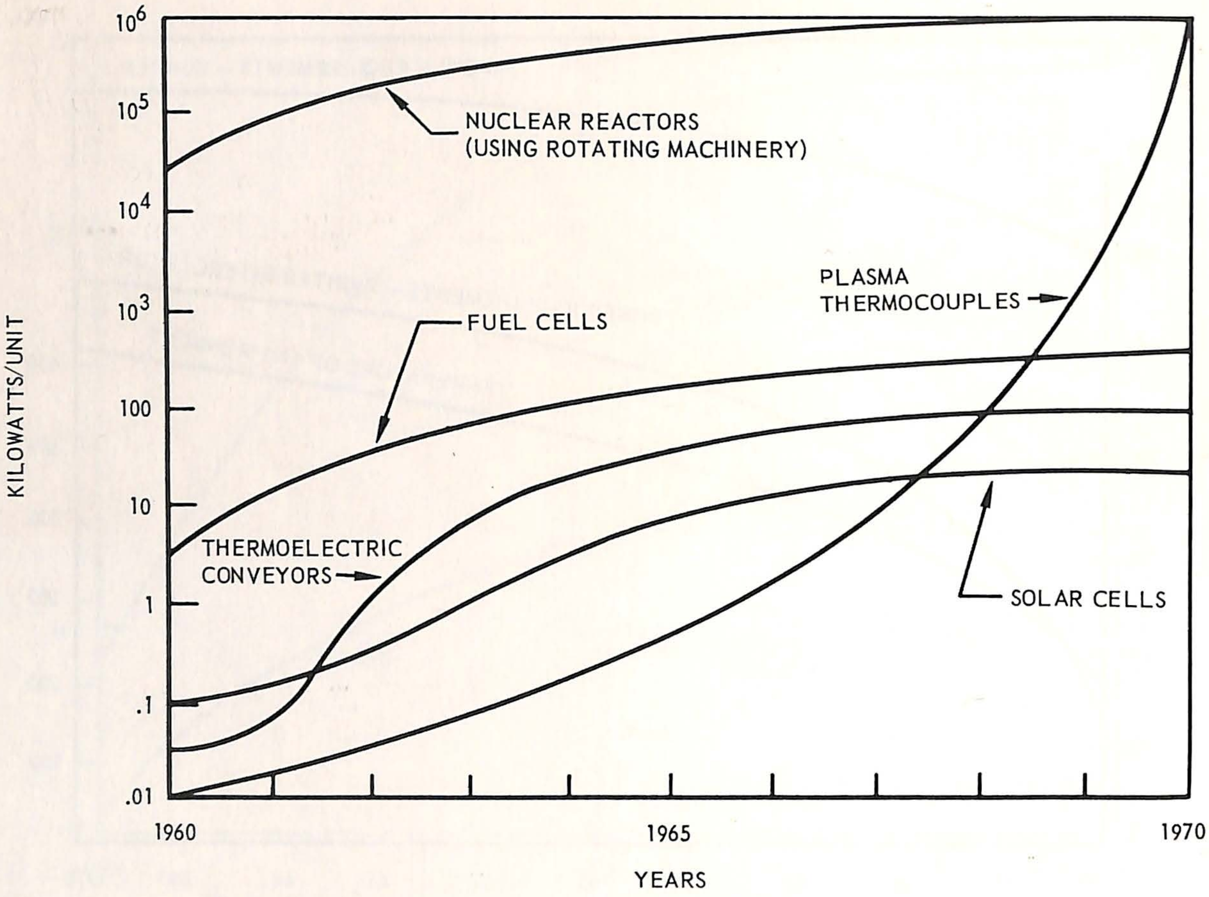
ELECTRICAL SYSTEMS TRENDS

Alternator speed will vary from the present 8000 RPM to 12,000 RPM continuous duty and 24,000 RPM intermittent duty by 1965. A few applications of continuous duty 24,000 RPM alternators will be operational after 1965.

System frequency will remain at 400 cps for most manned vehicles of this period. Missiles and unmanned space vehicles will show increasing application of 3200 cps equipment after 1963.

The power requirements of ballistic and space vehicles are not plotted because of the wide variation expected in vehicle size and mission. Power developed within 1970 space vehicles can conceivably vary between 100 KVA and 1000 KVA.

A transition from 208 volt to 440 volt systems is expected in both fighter and bomber aircraft about 1963.



UTILIZATION OF NEW ENERGY SOURCES

These data represent estimates of the power capacity of the indicated systems. Statement of the required output must await definition of the characteristics of the specific applications.

Solar Cells will always have application for low power unattended use (beacons, relays, etc.).

Thermoelectric Converters have application as a low power source whenever a considerable temperature differential (from waste heat or solar radiation) exists within the vehicle.

Fuel Cells are useful for short periods of high power or extensive periods of lower power.

Nuclear Reactors (with rotating machinery) have power capacity limited only by considerations of practical reactor size and the ability to transmit the power through the turbine machinery.

Plasma Thermocouples convert nuclear heat directly into electricity. This represents the best prospect for a massive power source.

Solar cells and thermoelectric converters are small and lightweight, adaptable to present space vehicles. Nuclear reactors for rotating machinery or plasma thermocouples are much heavier and are suitable only for very large vehicles with very long mission duration. Fuel cells lie between these two weight extremes.

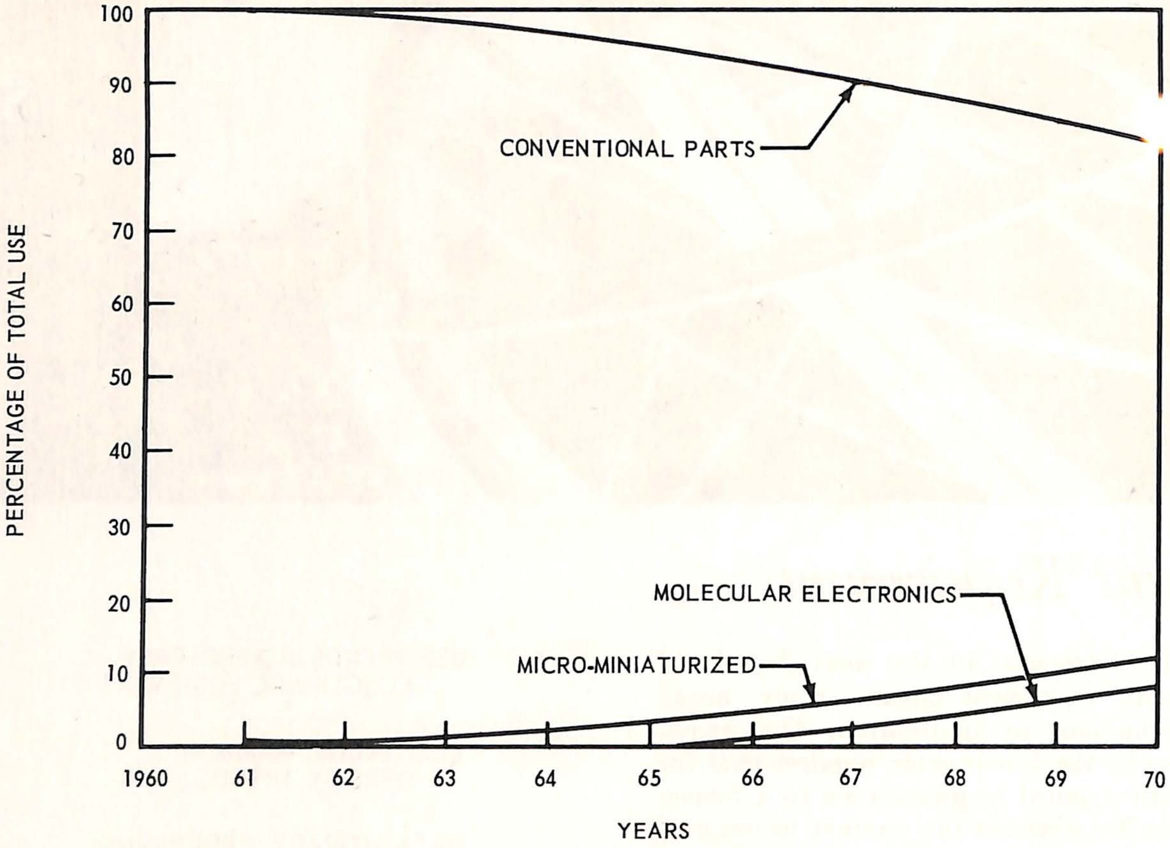
SECTION

3

Equipment Requirements

The Forecast for the next decade of electronic equipment covers many areas and techniques of application. The trends dictated by the foreseeable requirements for automatic control or assistance to a human operator are perhaps the easiest to predict. In a similar manner, the knowledge of solid state and related techniques permits estimates of the gains that can be made in space reduction and improvement in efficiencies.

The addition of fundamental knowledge and major discoveries that are not known today are the elements which probably will cause the greatest modification in the trends shown in future forecasts. Technological breakthroughs such as the parametric amplifiers, tunnel diodes, and maser or laser techniques not only give us new tools to accomplish existing tasks, but also stimulate our thinking to provide instrumentation and functions previously considered impossible or uneconomical. New power sources or energy conversion systems also may lead to greater equipment capabilities.

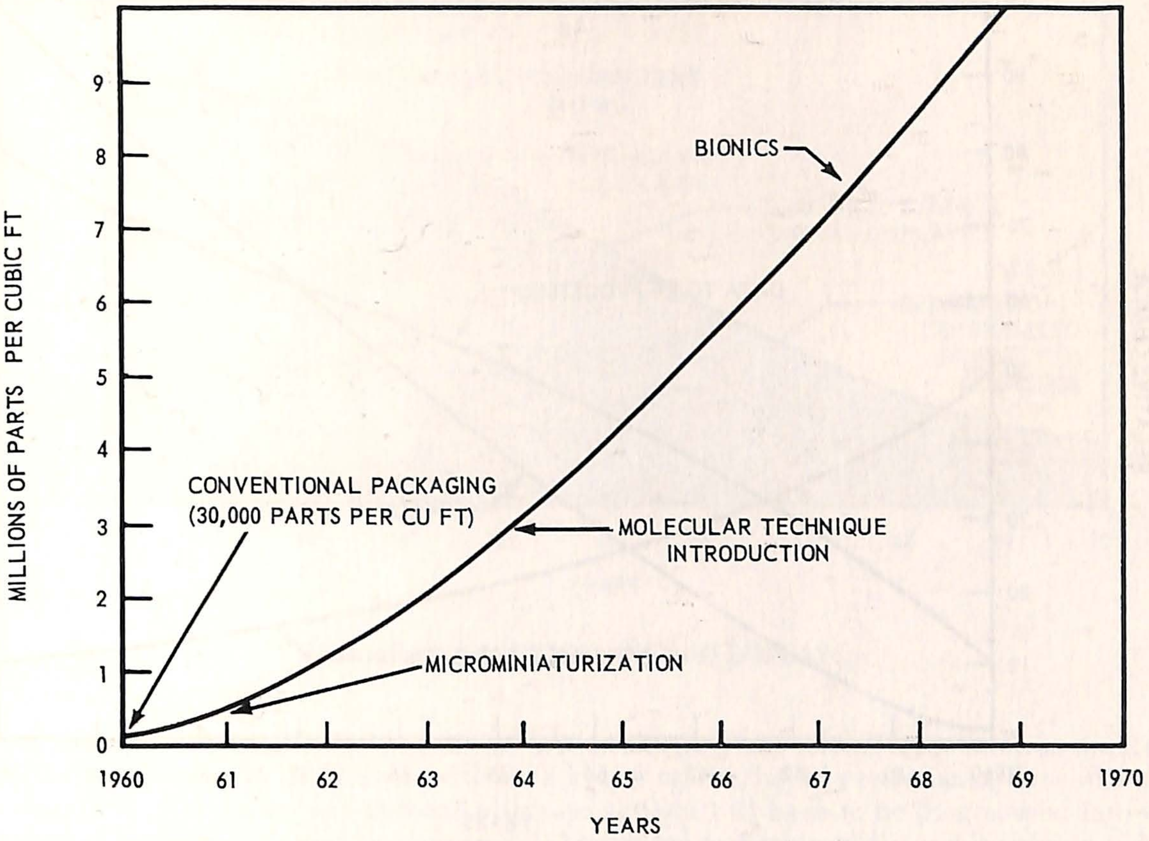


USE TRENDS IN AEROSPACE ELECTRONIC EQUIPMENT

The chart shows the use trend comparison between conventional and "micro" techniques. Use of micro-miniaturized parts and molecular electronics will increase in certain types of equipment where (1) weight and size are of primary importance,(2) requirements for precision tolerances have been somewhat lessened, and (3) heat generating parts can operate at low power level. In specialized applications, such as space craft, missiles and certain aircraft, the use of micro-miniaturization or molecular electronics yield markedly higher reliability than conventional techniques; the fractional utilization may be considerably larger than shown. The combined percentage may be as high as 50% in these applications.

There will be a requirement for development of high-temperature (above 125°C) conventional parts, but in 1970, as now, the usage of such parts will be limited to special applications and will constitute only about 5% of the total requirements for all electronics.

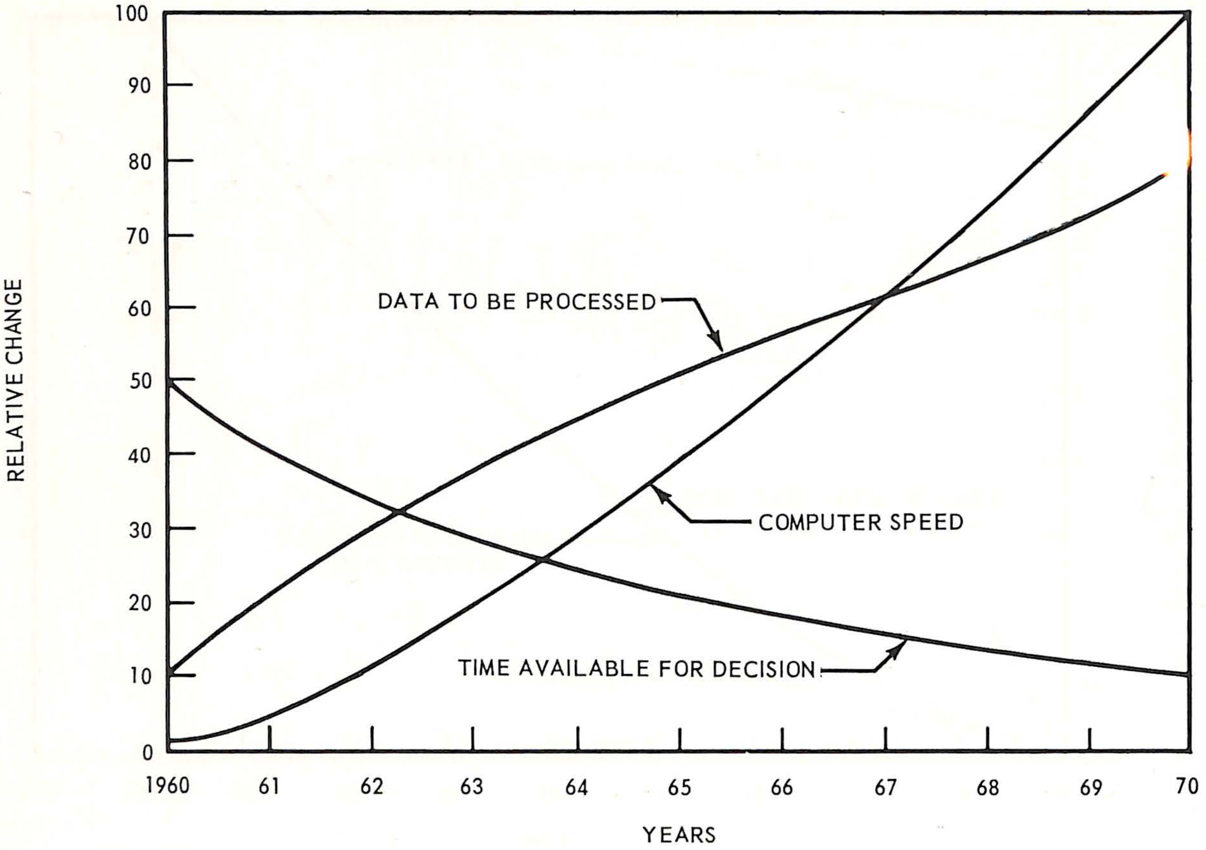
The search for new materials, new materials techniques and new material design concepts must be accelerated. The purity, crystalline structure and basic properties of materials must be more widely understood. Synthesis of new materials having desired properties not formerly available should be an objective of intensified research.



ELECTRONIC MAXIMUM DENSITY TRENDS

Current airborne electronics can be described as having a maximum parts density of approximately 30,000 parts per cubic foot. Welded module construction will increase the maximum density by about 60% and will represent the best efforts with conventional components. True microminiaturization begins with vacuum deposited resistors, conductors, and capacitors with microsized transistors as the active elements. Serious production of this ½ million-part-per-cubic-foot-equipment will begin in 1961. Semi-conductor (molecular electronics) circuitry with another magnitude of parts density will follow closely. Microminiaturization will grow from the modest proportions of 1960 to large scale industry operations within the next ten years.

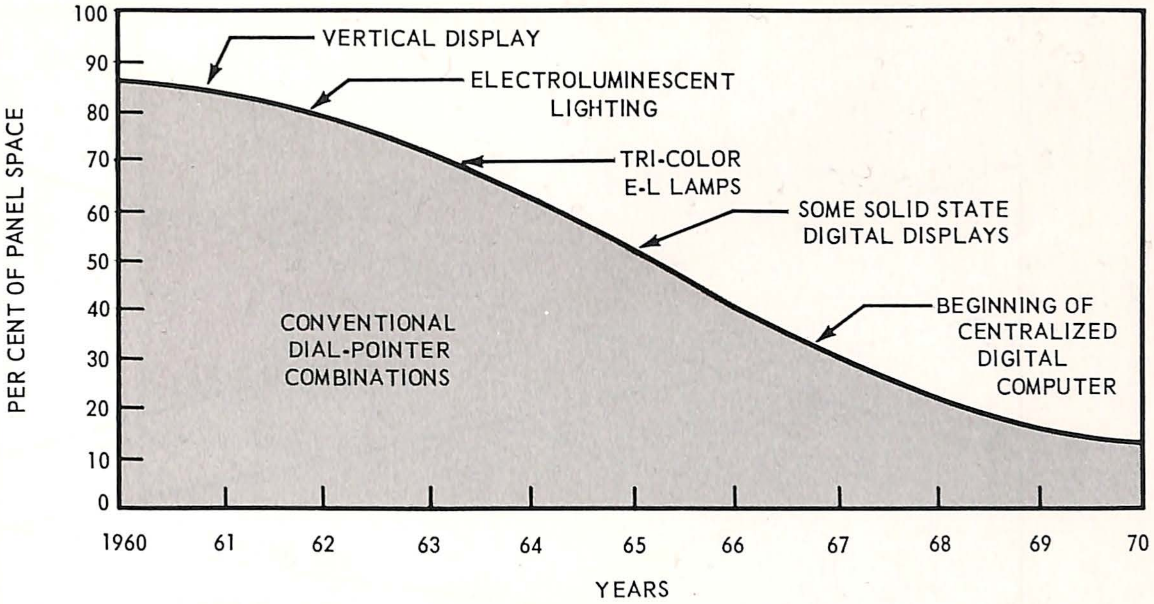
A significant departure from "Component Orientation" to Function Orientation" will occur when molecular electronics enter the commercial picture. In the chart above, density of the function-oriented designs is compared to the density of existing designs. Landing on and return from nearby planets in the 1970 – 1980 decade will require miniaturization and weight reduction far in advance of current developments and will require the development of entirely new technologies, such as Bionics.



DATA STORAGE, PROCESSING AND DISPLAY

Aerospace vehicles will become larger and more complex to span an increasingly wide range of flight conditions. In this growth, the time available for data correlation and decision making will decrease, as shown on the chart. Control will be accomplished largely automatically with the aid of computers using programmed procedures or optimizing techniques. Programming techniques are limited because the stored data are not always valid for the conditions encountered; thus self-adaptive computers and control systems, automatically adjusting their actions to achieve optimum results, will become increasingly important. The need for maximum payload will exert continuing pressure to reduce computer size, weight, and power requirements in spite of the equal requirement for more data and faster computation. The solution appears to be the development of new types of components, notably the tunnel diode and the variable capacity diode, which promise large increases in computer speeds and reduction in space and power requirements.

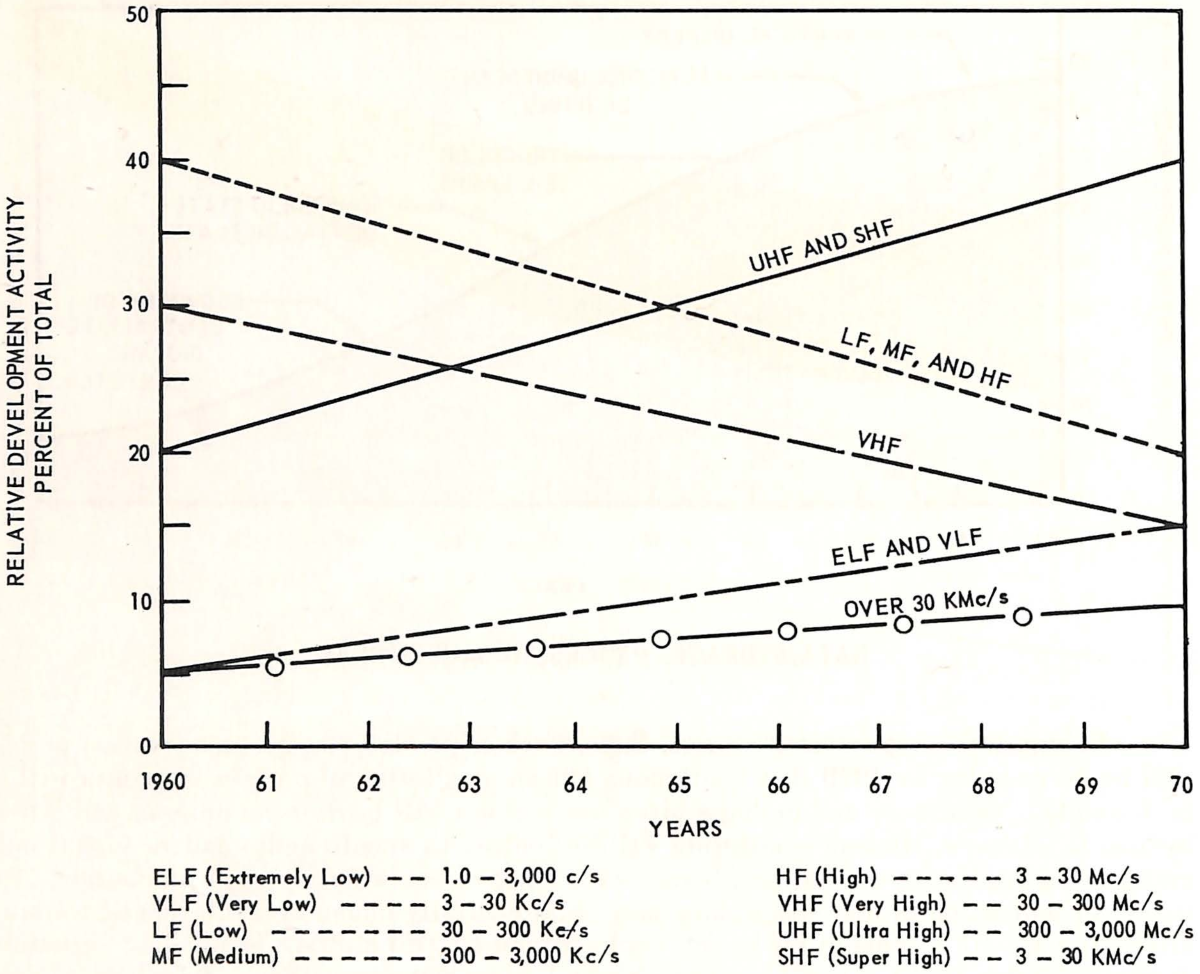
Current and planned developments in tiny deposited film circuits, molecular electronics, thin magnetic film memory devices, and the new science of bio-electronics offer intriguing possibilities for computers having power levels, part densities, size, weight, and operating life approaching the characteristics of the human brain, but perhaps more accurate and readily repairable. One of the more urgent problems is the need for large capacity, inexpensive, storage devices which are small, yet readily accessible for read out. As tiny components are developed, a major difficulty which must be overcome is the connections to the tiny parts and random access to the stored bits of information. Research must be conducted to expand multiple use of computer parts in order to reduce the total number of parts, reduce weight, reduce power requirements, and increase reliability.



DATA, STORAGE, PROCESSING AND DISPLAY

Navigation, temperature, control, flight mechanics, and energy conservation problems will be so complex by 1970 that continuous human monitoring of performance data will not be feasible. Necessary and perhaps alternate actions will have to be programmed into the system in advance. Human monitoring will be limited to simple audio and/or visual indications of compliance or non-compliance with planned operation or optimum courses of action. An indication of non-compliance may coincidentally cause presentation of possible alternatives, with a request for human decision and control action. Panoramic situation displays for detailed but rapid monitoring of all essential navigation and performance information will be available at the flick of a switch if the crew is obliged to assume manual control of the vehicle.

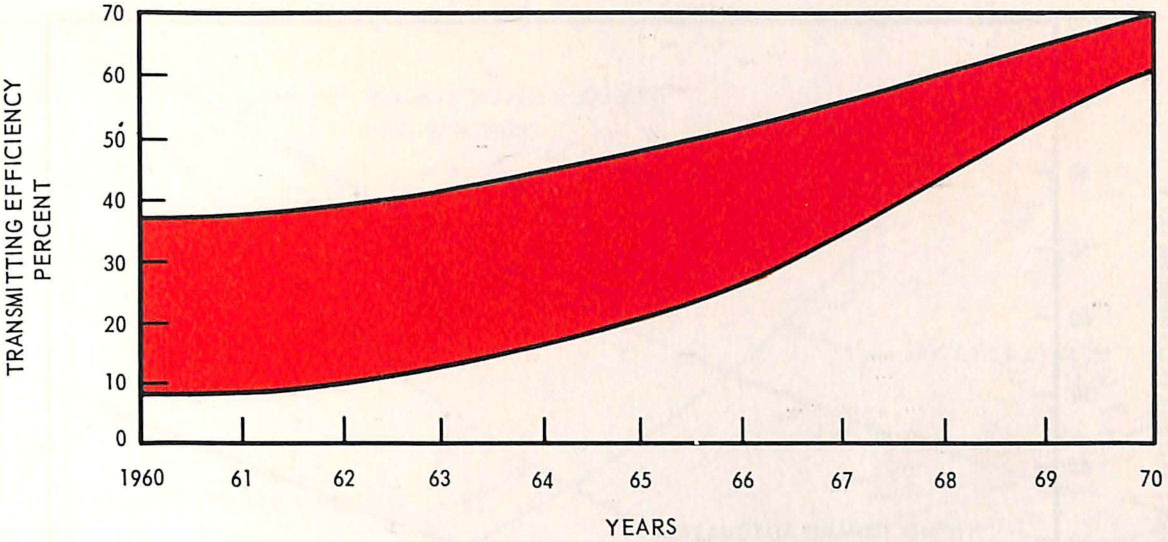
Advances in the techniques of data presentation will facilitate human comprehension and aid rapid decision making and control action. Present day dial-pointer combinations are being replaced to some extent by vertical type displays that utilize tapes to present an expanded scale in a condensed space. As electro-luminescent (E-L) light sources are improved, they will be used first to replace conventional integral lighting and next to provide entire displays. Tri-color E-L lamps will be used to indicate warning modes or danger areas. More sophisticated, micro-miniaturized digital logic networks will make it possible to centralize the computers and allow integration between separate indicators or whole sections of the panel. These trends are shown in the chart as a reduction in the percent of available panel space occupied by conventional dial-pointer instruments and a corresponding increase in the percent of panel space occupied by the new display techniques.



COMMUNICATIONS – OPERATING FREQUENCIES

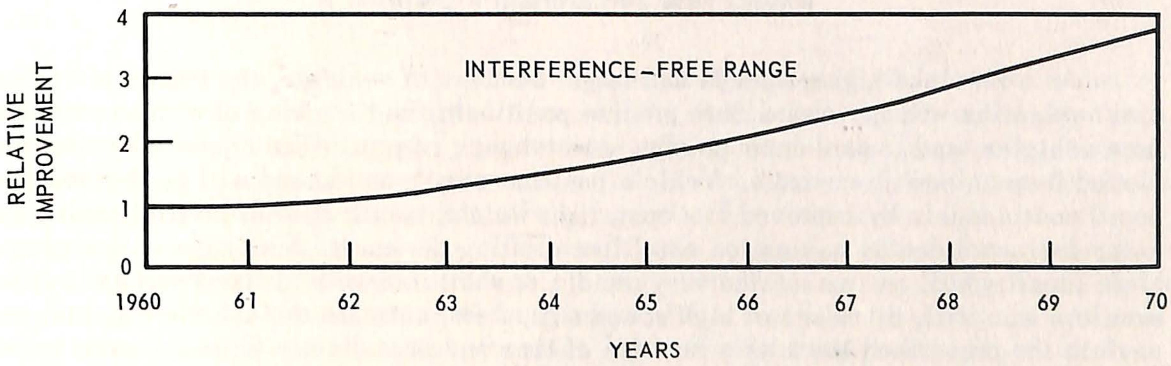
During the 60's we can expect a much higher activity in the 1,000 to 10,000 megacycle range of the radio frequency spectrum. This range appears best for piercing the ionosphere and for minimizing atmospheric attenuation. The trend to the higher frequencies is accelerated by the need for higher data rates in telemetry and data link. The increased bandwidths afforded in the 1 to 10 kilo-megacycle range greatly increase the rate at which data can be transmitted over a given channel. Requirements for new and better transmitters, receivers, data handling devices and antennae for operation at microwave frequencies will steadily increase during the next decade. The crowded radio frequency spectrum and the rising importance of secure and private wireless communication will bring about increased attention to (1) transmission at very low frequencies (below 30 KC), (2) use of the earth as a communication system, (3) modulation of waves in the visual and infrared ranges, and (4) use of scatter or "bounce" techniques from natural or artificial reflectors (e. g., satellite "mirrors").

The curve illustrates relative development activity expected to occur in broad categories of the radio frequency spectrum as related to communications equipment. Although emphasis decreases in some categories, actual monetary expenditures may increase or remain nearly constant because of an anticipated overall increase in spending for developments in communications.



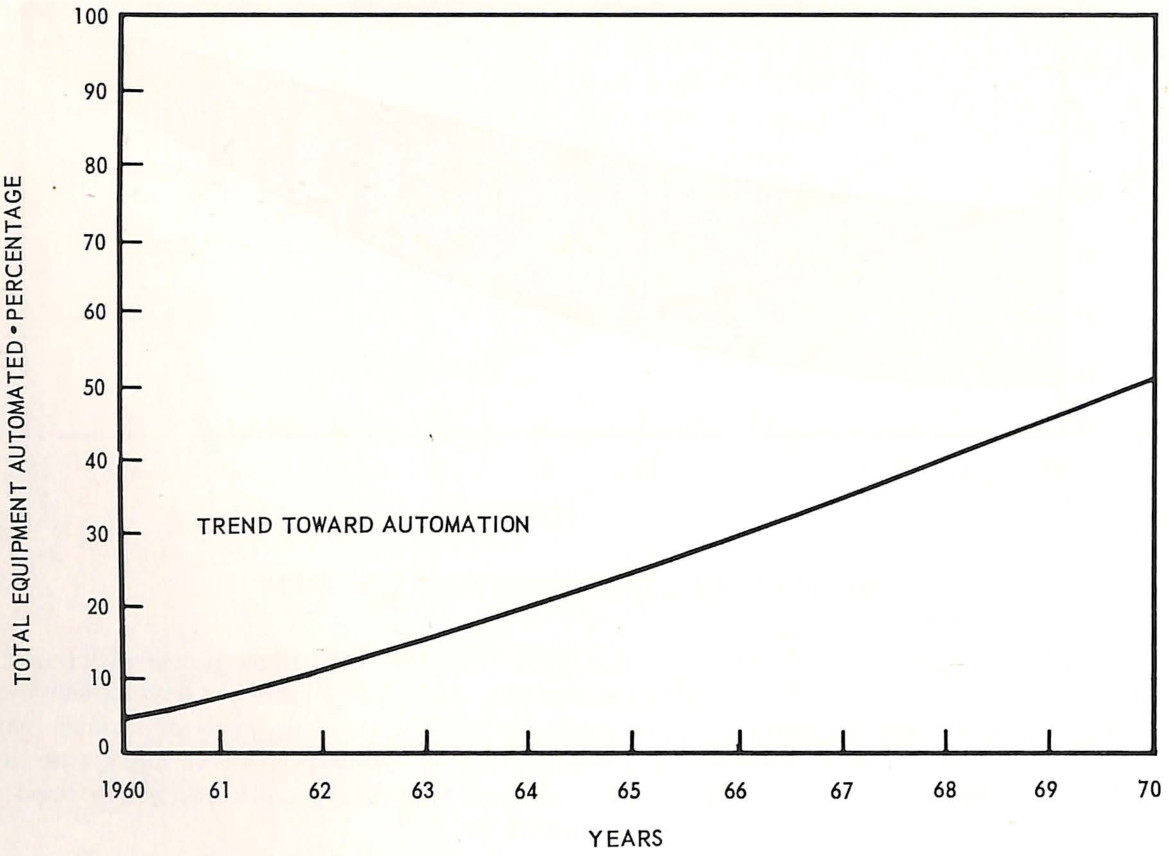
COMMUNICATIONS – TRANSMISSION AND RECEPTION

Transmitting Power Efficiency – Significant improvement in the power efficiency of radio transmitters is required over the next decade. Although our rocket development will soon permit much higher payloads, the demands for electrical energy in spacecraft and manned aircraft will continue to increase at least as rapidly. Improvements in solid state devices, such as tunnel diodes, and application of them to radio transmitters, will be required to raise deficiencies to the 60 – 70 percent range by 1970.



COMMUNICATIONS RANGE

Range – Internally generated noise causes a serious limitation in distance of radio communication. Our entry into space has focused attention on this problem since we now have requirements for communicating over millions of miles. Solid state masers, non-linear reactance amplifiers and tunnel diodes are used in an effort to obtain the required gain and bandwidth with little internally generated noise in the amplifier output. In contrast to an equivalent noise figure of about 1000° K for recently produced receivers, 290° K is obtainable without cooling, in the new reactance amplifiers at 5,000 megacycles per sec. Considerable improvement in semiconductor diodes and quantum mechanic tunneling is required to provide low-noise amplifying devices without the complication and weight of masers and non-linear reactance amplifiers. Receiver noise figures in the order of 20° K should be obtainable.

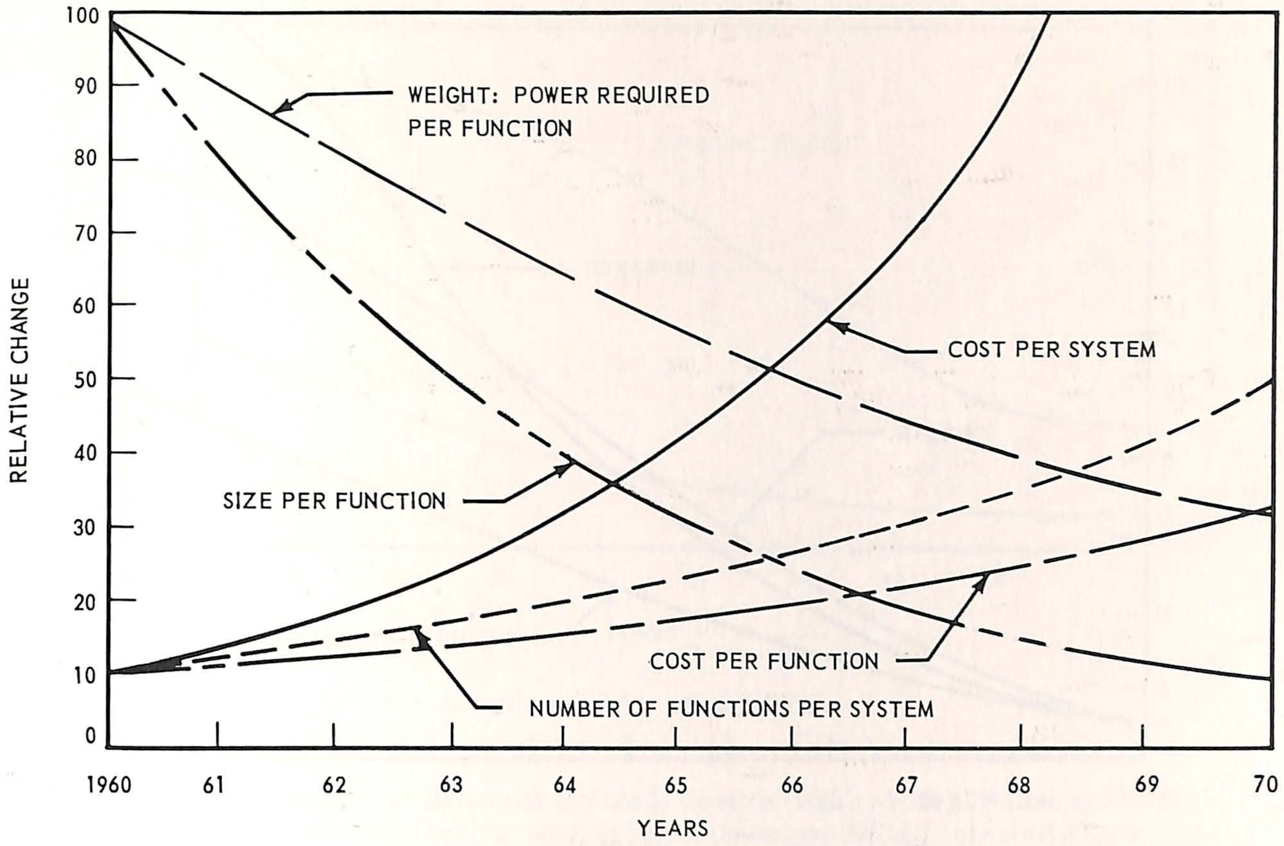


NAVIGATION AND GUIDANCE – SURFACE

As a result of higher speeds and larger numbers of vehicles, the trends in commercial navigation will be toward more precise positioning and tracking of airborne and surface vehicles, and toward more precise maintenance of prescribed courses by means of closed loop automatic controls. Vehicle position course and speed will be derived on board continuously by improved low cost, light weight, small volume, inertial, radio, and radar devices aided by navigation satellites orbiting the earth. Such information plus vehicle identity will be transmitted very rapidly at short intervals to fixed surface traffic monitors who will, by means of high speed computers, compare the vehicle's actual track against the prescribed track as a function of time and immediately furnish corrective signals as necessary. Precision departure, terminal guidance, and landing or berthing will be automatized by an inter-related closed loop system of surface and vehicle-borne sensors and controls.

The development of hydrofoil craft presents some attitude and control problems which will very likely borrow solutions from aircraft and missile techniques in the area of inertial devices, and submarines of the future will have automated guidance and navigation systems similar to those now planned for aircraft.

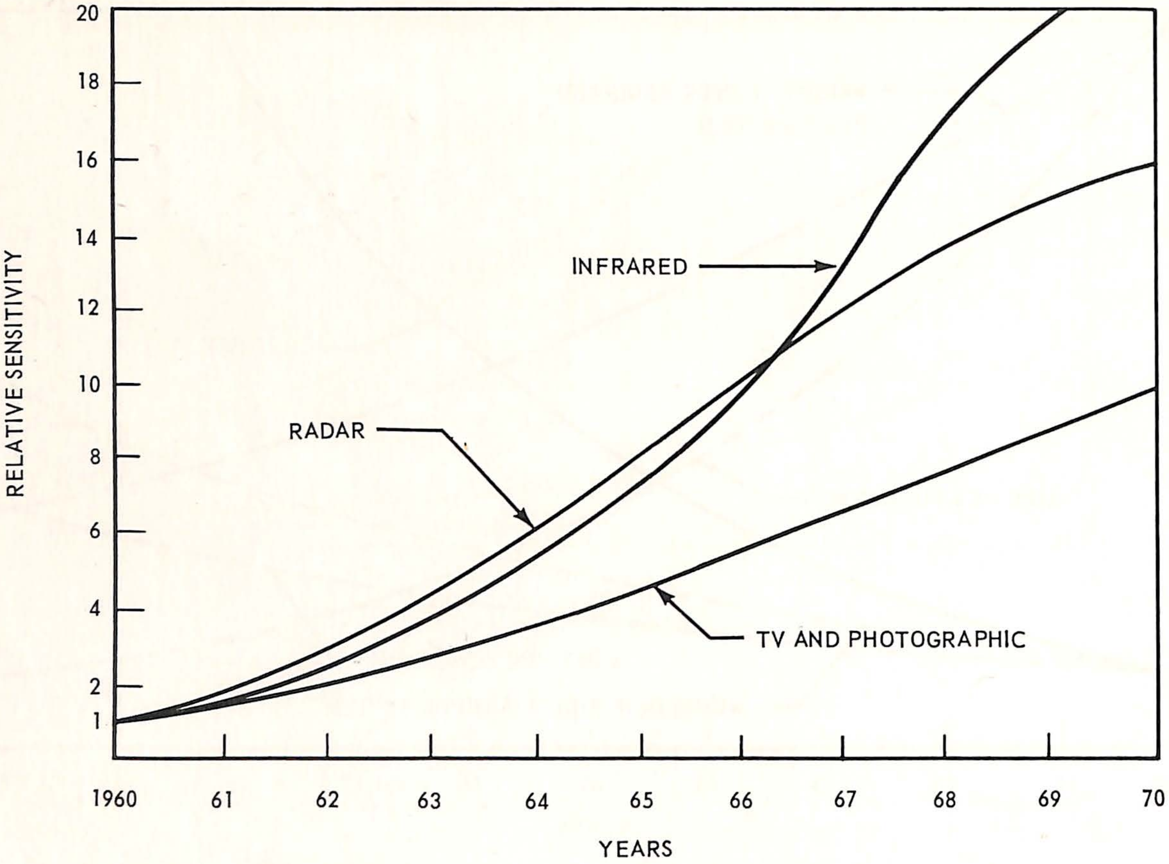
The concept of automatic guidance and control of vehicles will be extended to battlefield guidance and positioning of small elements of a dispersed, fast-moving army.



NAVIGATION AND GUIDANCE – SPACE

The economics of space exploration require navigation and guidance equipments of extreme accuracy and with minimum size, weight, and power requirements. As these equipments are primarily electronic and electro-optical sensing and processing devices, solutions can and should be made possible by continued support of developments already under way in the fields of microminiaturization, molecular electronics, infrared optics, cryogenics, and solid state physics. There will be a continuing search for new techniques and fabrication methods to reduce cost and manufacturing time of presently understood navigation tools such as inertial devices and star trackers; however, the extra effort required to achieve necessary reductions in size, weight and power will result in a net increase in the cost of performing a given function. There will be a substantial increase in the number of functions required for complex and automatic space navigation and guidance, and overall system cost will rise sharply. Inherent accuracies are adequate for most known needs, but these accuracies must be produced in more rugged equipment and at lower cost.

The relationships between time and space will be more widely understood. Space buoys orbiting the sun will contain atomic clocks and transmit time signals to supplement electro-optical observation of apparent planetary positions in the star field for accurate interplanetary navigation. Terminal guidance on planets will require improved horizon scanners to sense verticality and measure distance to the surface. Accurate knowledge of surface features will be obtained with multi-frequency scanners at microwave, infrared, visual and ultraviolet wavelengths.

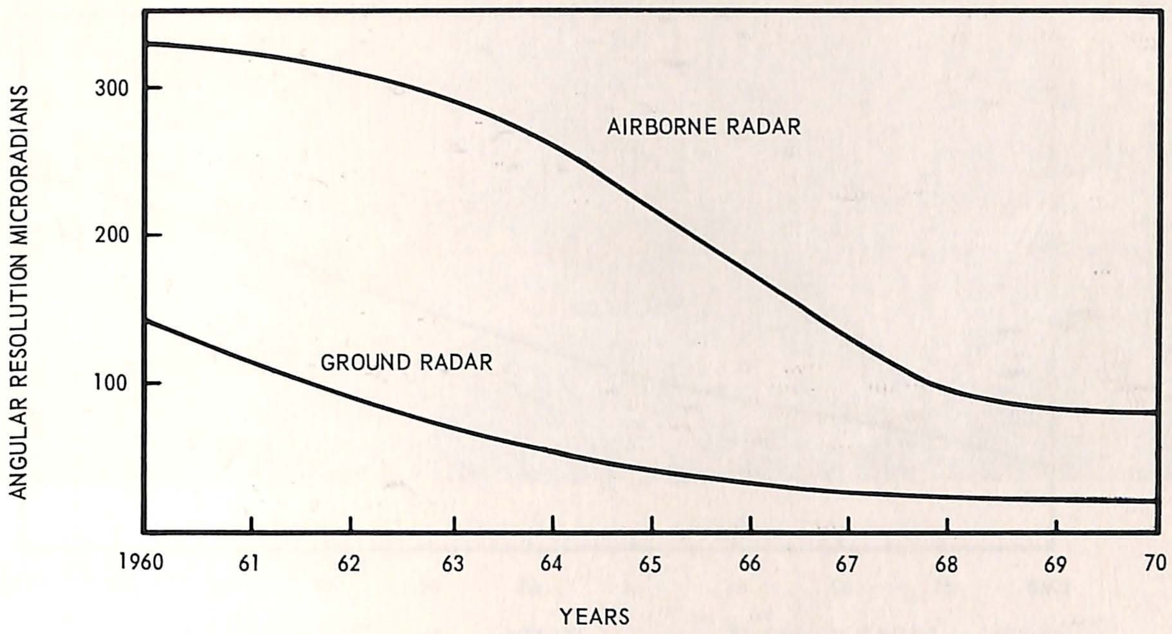


SURVEILLANCE AND TRACKING-SENSITIVITY

Forecasts of the capabilities of surveillance and tracking equipment indicate that some rather startling improvements will occur during the next ten years, particularly in the area of sensitivity. The growth trend of each technique is presented. However, the chart does not indicate relative performance of the various techniques. One reason for the expected growth is that many advanced concepts already conceived for sensor and data processing improvement remain to be reduced to practice.

The primary threat in the next decade will be IRBM's launched from beneath the sea and ICBM's launched from the surface. Systems are required to detect and plot submarine traffic over entire ocean basins. A technological breakthrough in high altitude submarine detection is urgently required.

Although recent satellites have been very successful in collecting weather data, the performance of satellite-borne and aircraft-borne surveillance and ferret equipment working in various spectral regions must be increased in the next few years to provide continuous knowledge of surface activities all over the world. A complete family of advanced satellite-borne surveillance equipment, each with specialized missions, represents a most important area of needed development.

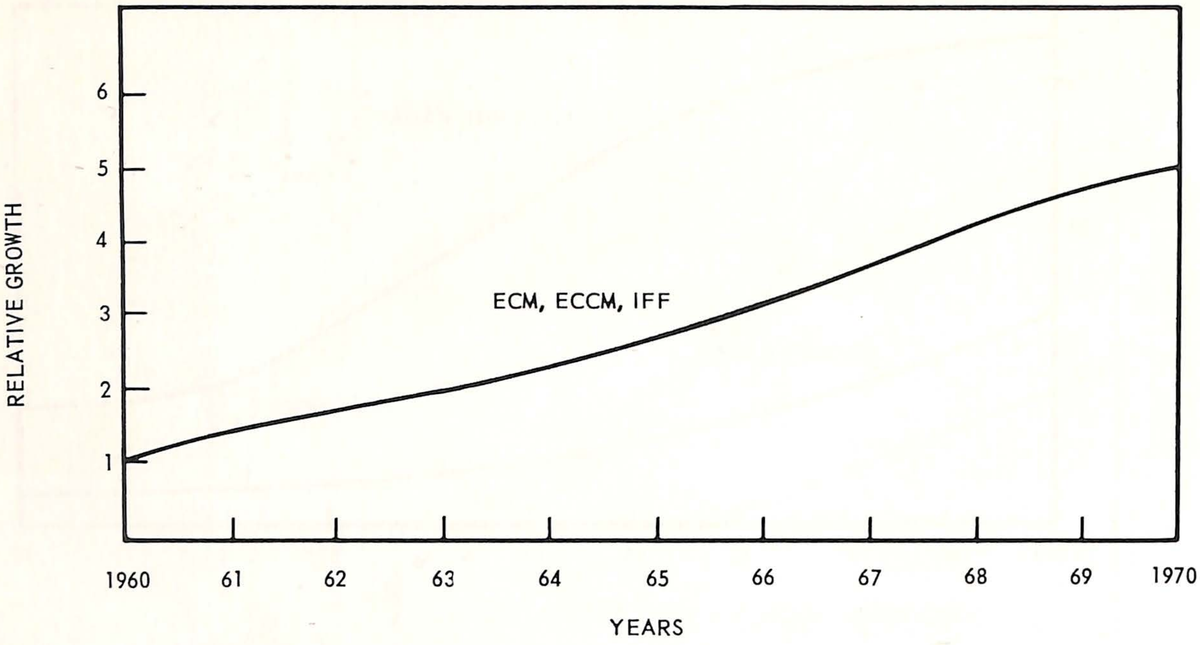


SURVEILLANCE – RESOLUTION

In the next decade, surface activities will be observed by both satellite and aircraft-borne surveillance equipment using radar, infrared, photographic and television techniques. The optical resolution obtainable today with photographic, IR, and TV equipment is at least equal to the maximum permitted by the turbulence of the atmosphere which limits resolution to several microradians. A resolution of this order, or better, is required for observing significant detail at distances comparable to satellite altitudes.

Radar resolution is a function of the wavelength employed and the antenna design. Airborne radar angular resolution is further limited by vibration and aircraft swaying. The present practical resolution obtainable is about one-third of a milliradian. Improvement can be expected in the next five years to one-fifth of a milliradian. Expected breakthroughs should provide a rapid increase in resolution by the end of the decade and ground radar resolution of a few microradians can be predicted. However, this may be achieved at a loss in sensitivity due to less efficient use of radiated power.

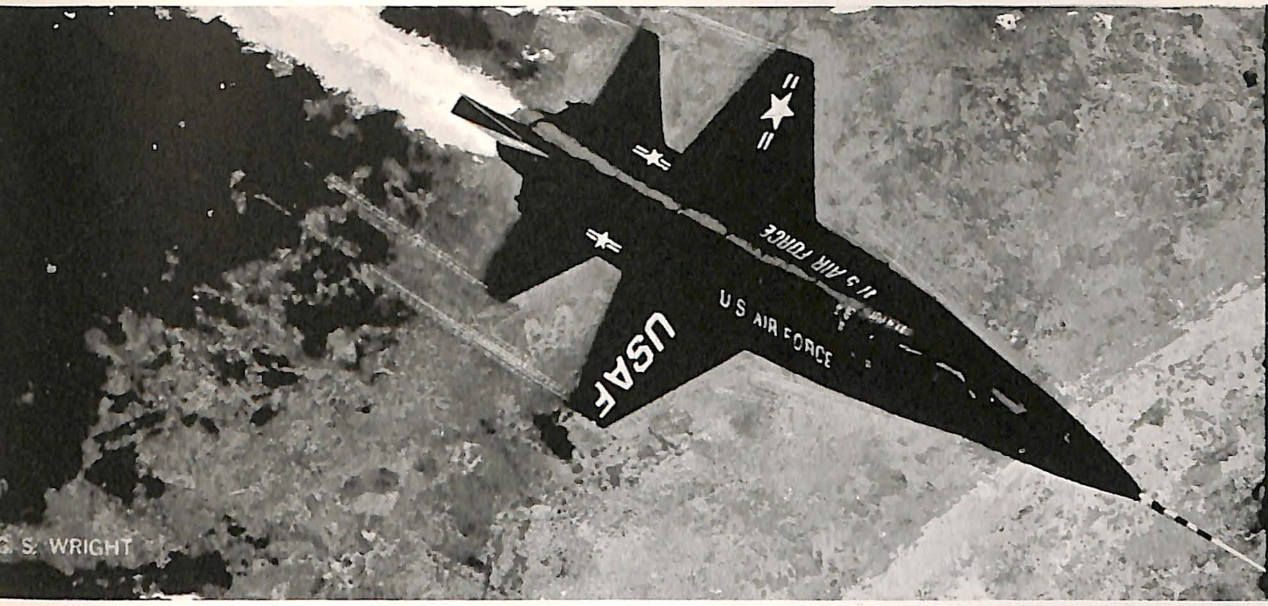
Assuming radar resolution can be achieved that approaches that of the optical systems, the problem of storing, transmitting, and analyzing the tremendous quantity of data obtained by large-field, high-resolution systems is a critical problem which must be solved. Present methods using film and magnetic tapes as data storage media are cumbersome. Phosphor and electrostatic techniques show promise. New methods of encoding wide bandwidth data are required. Techniques of transmission for wide bandwidths, greater than a thousand MC, are required. There is a need for improved displays presenting a total picture synthesized from a composite of all measurements.



EMPLOYMENT OF ELECTRONIC WARFARE EQUIPMENT

During the next ten years it is expected that increased emphasis will be placed upon the development and application of electronic warfare techniques (ECM, ECCM, IFF). Employment of electronic equipments utilizing both active and passive countermeasures will take place on an increasing scale during this time era. However, the emphasis of this employment will shift from airborne to space environments during the period. Although the trend of employment of electronic warfare systems will increase on an individual weapon system basis, manned tactical and strategic weapon systems will be replaced in substantial numbers by missile and space weapon systems by mid-decade.

It is believed that the specific tasks of Airborne Early Warning and Anti-Submarine Warfare, which will increase in national importance, cannot readily be performed by other than manned vehicles. Hence, there will continue to be increasing requirements during the coming decade for the performance of the AEW and ASW missions by manned aircraft. As a consequence, increased efforts will be devoted to improving the capabilities of these vehicles to perform such missions. Increased sophistication in the automatic detection of countermeasures and the automatic employment of counter-countermeasures represents a large, almost untouched area of need.



SECTION 4

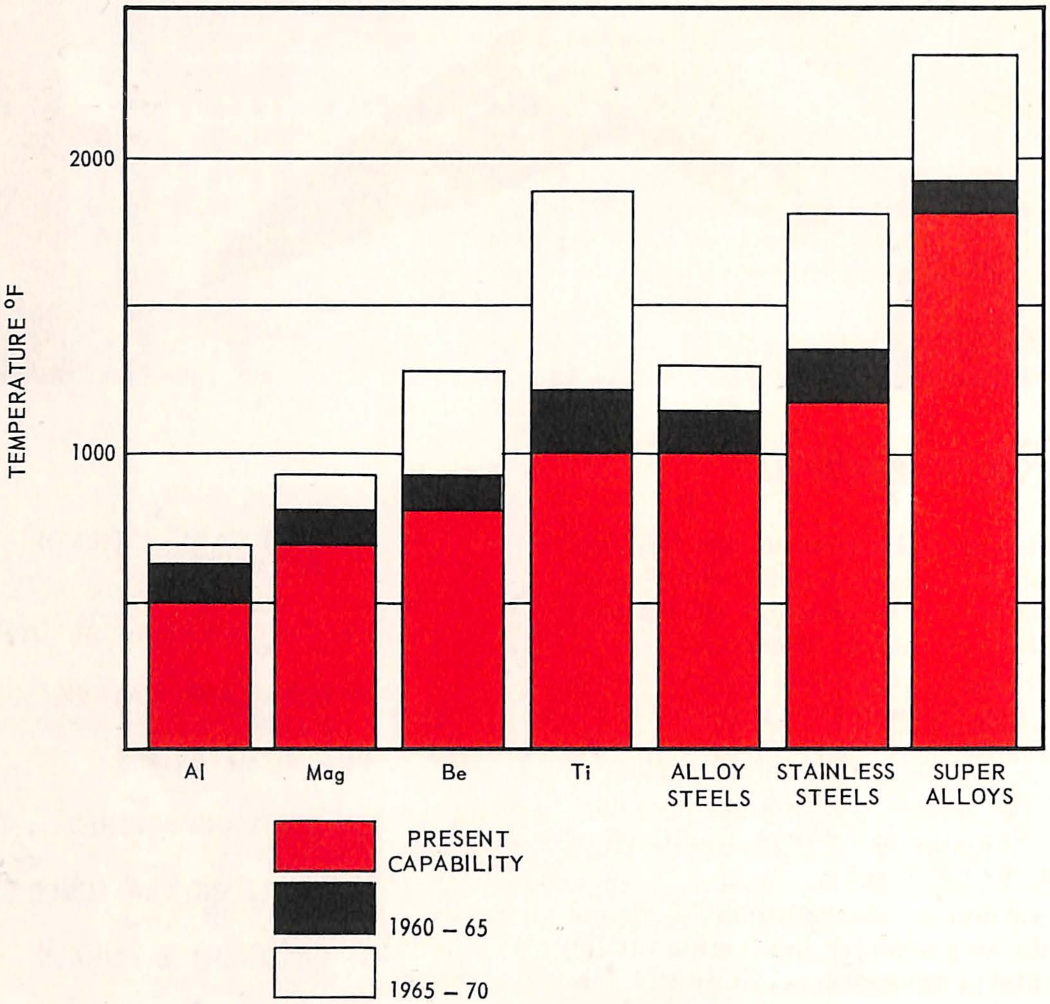
Material Requirements

A recent formal report to the National Academy of Sciences concluded that "major end-item programs in all areas of national security (defense, atomic energy and space) are now up against a serious materials road block. The properties of most presently available materials are inadequate for the high-performance end-items that must be made to withstand the severe temperature, pressure, radiation, corrosion and stress conditions of space-age environments."

The governing consideration in choice of materials for particular applications is the environmental circumstance. However, fabricability and cost are critical factors. Uses of plastics, ceramics and the rare metals are expected to increase significantly.

The reader will note that the required developments frequently 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.

THERMAL CAPABILITIES OF METALS



Elevated Temperature Properties

Structural requirements still continue to exhibit a need for lower density materials having a useful life at higher temperatures. As a result, the strength to weight ratio at the higher temperatures is becoming more critical. Further research needs to be accomplished on short time elevated temperature evaluation of these materials and resistance to oxidation at high temperatures.

Since the publication of the 1959 AIA Forecast Report, considerable progress has been made in the capability of the Beryllium and Titanium alloys. All other alloys show little change. Sufficient data have not yet been released on the sintered aluminum powders to increase the projected capabilities.

The requirements for all future designs are:

1. Lower densities with increased temperature resistance.
2. Improved fabrication characteristics.
3. More complete structural design data.

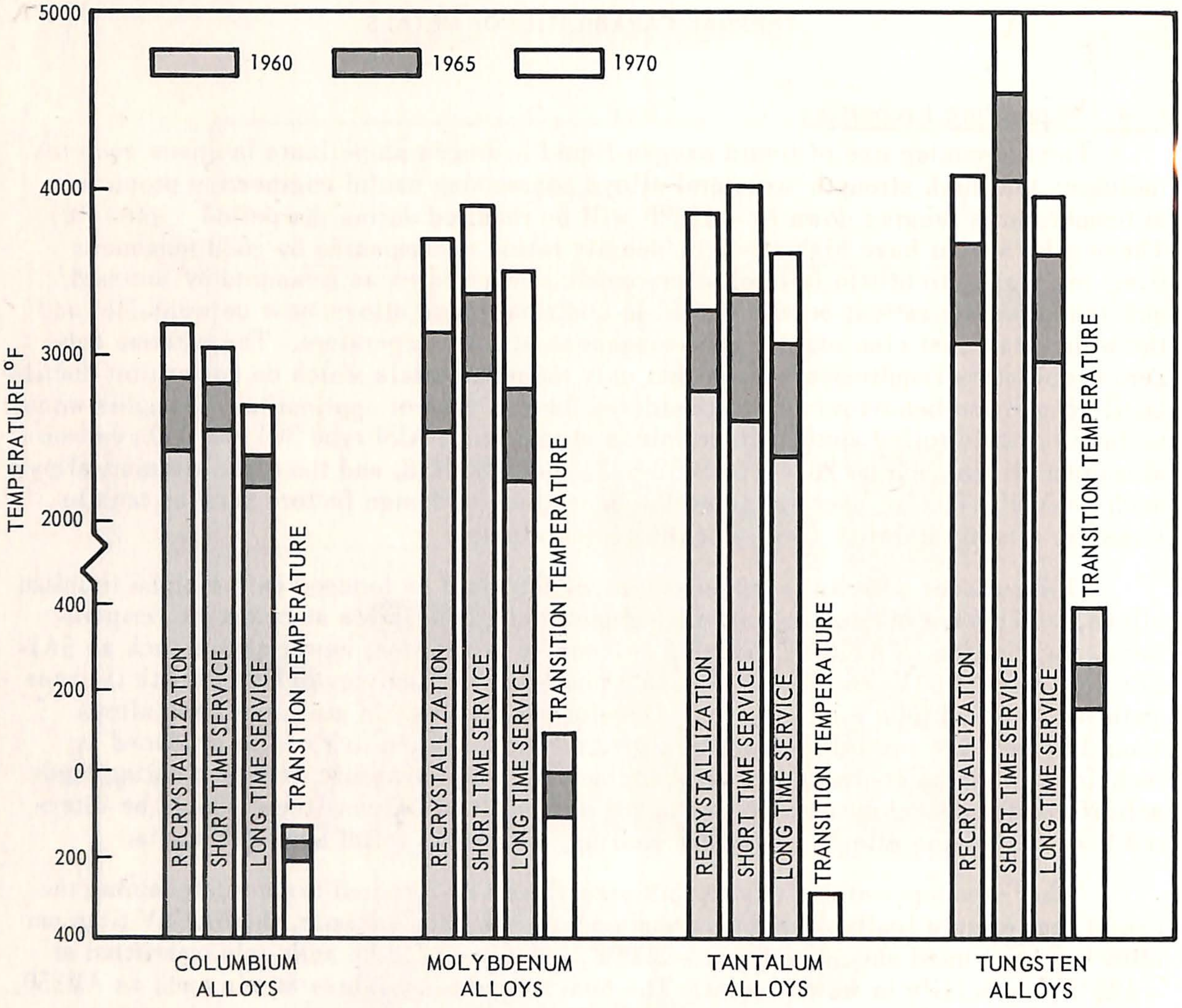
THERMAL CAPABILITIES OF METALS

Low Temperature Properties

The increasing use of liquid oxygen-liquid hydrogen propellants in space vehicles indicates that high strength structural alloys possessing useful engineering properties at temperatures ranging down to $-423^{\circ}F$ will be required during the period 1960 – 70. These alloys must have high strength/density ratios accompanied by good toughness (i.e., resistance to brittle failure) at cryogenic temperatures as measured by notched/ unnotched tensile ratios, or tear tests. In addition, these alloys must be weldable, and the weld joint must also exhibit good toughness at low temperature. The extreme subzero temperature requirements mean that only those materials which do not exhibit ductile-brittle transition behavior can be considered for this type of application. Examples would include the cold-rolled austenitic stainless steels (e.g., AISI type 301 and 310), certain aluminum alloys such as 2014-T6, 5052-H38, and 5456-H38, and the alpha titanium alloys such as A110AT, with specific selection depending on design factors such as tensile stress or elastic stability (e.g., buckling) limitations.

Development activity in the next ten years should be focused on the alpha titanium alloys, which have outstanding strength/density characteristics at cryogenic temperatures. In addition to A110AT (5Al-2.5 Sn) now in production, newer alloys such as 5Al-5Zr-5Sn, 8Al-1Mo-1V, and 8Al-2 Cb-1Ta should be thoroughly evaluated in both the base metal and welded joint configuration. Development activity in aluminum base alloys should be directed toward high purity alloys such as 7275, which can be produced by techniques such as controlled atmosphere melting, and ultrasonic treatment during ingot solidification. Development activity in the austenitic stainless steels should be directed toward studying effects of vacuum melting, and stress relief heat treatments.

Other development activity in this area should be directed toward determining the useful temperature limits of certain promising alloys. For example, the 6Al-4V titanium alloy has been used successfully at $-320^{\circ}F$, but appears to be seriously embrittled at $-423^{\circ}F$, especially in welded joint. The heat treatable stainless steels such as AM350, AM355, A286 have shown promise at $-320^{\circ}F$, but display decreasing toughness at $-423^{\circ}F$, although heat treatments intended to condition these alloys for service at $-423^{\circ}F$ show promise. Other alloys may also be found to possess useful properties for specific applications at moderately low temperature as a result of special heat treatment or other special processing.



REFRACTORY METAL ALLOYS

The above histogram illustrates the property improvements considered feasible for the alloys of the four most available refractory metals. The tantalum and tungsten systems obviously provide the greatest opportunity for advancement. Present alloys of these metals are useful only to temperatures of less than half the melting point of the base metals, while columbium and molybdenum alloys are approaching useful homologous temperatures of 0.65. Refractory metals other than those shown in the graph (e.g., ruthenium, iridium, osmium, and rhenium) should experience similar advancements, particularly as alloying elements for the four major metals.

Oxidation preventive coatings should be developed to take advantage of the full useful strength ranges of all refractory metal alloys. Improved fabricability (i.e., forming and welding) is another requirement which is particularly important in the molybdenum and tungsten systems. The sizes of various mill products of these alloys should also be increased. Tungsten sheet material is a specific item which particularly requires larger widths and lengths.

MATERIAL APPLICATIONS

Material Forms

Chart I shows the use of typical forms of wrought and cast products as a percentage of the structural weight empty of all classes of air vehicles. It is indicated that high strength, high temperature missile and spacecraft airframes will employ a greater proportion of built-up structure and a reduced amount of integral structure. This trend is reflected by the increase in use of sheet materials and a corresponding reduction in requirements for other cast and wrought forms. The relationships are affected by the fact that there will still be continuing demands for a wide variety of subsonic aircraft for Military purposes. Current trends in V/STOL aircraft of every type are cases in point.

The use of glass fibered reinforced plastics as shown by a dashed line in Chart I serves to indicate the growth potential of these materials due to the present intensive development and research being applied to their use in motor cases and nozzles for solid fuel missiles and applies principally to this class of vehicle.

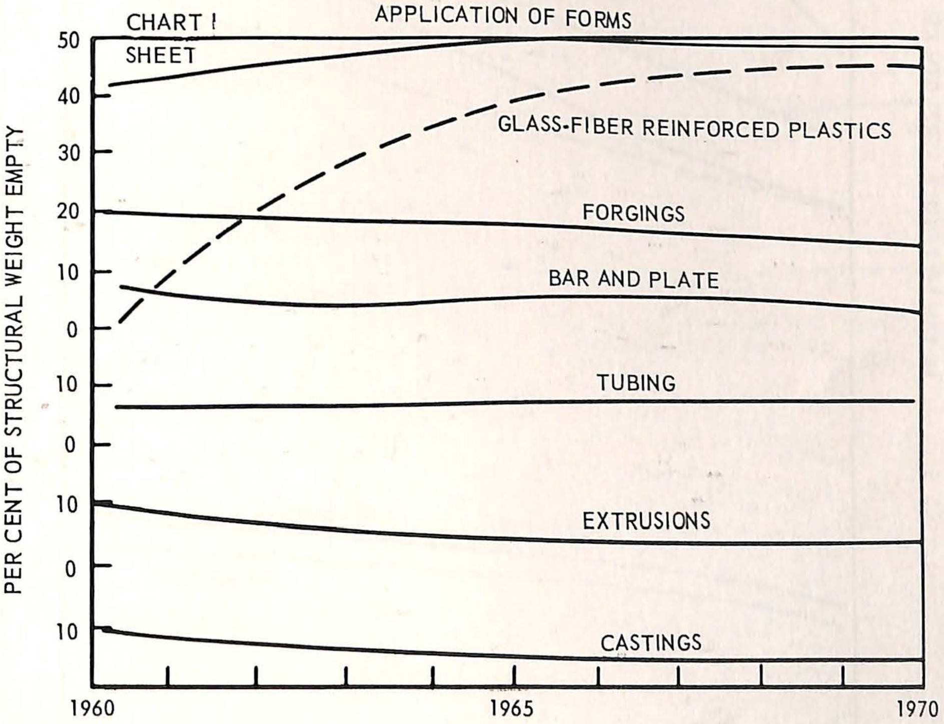


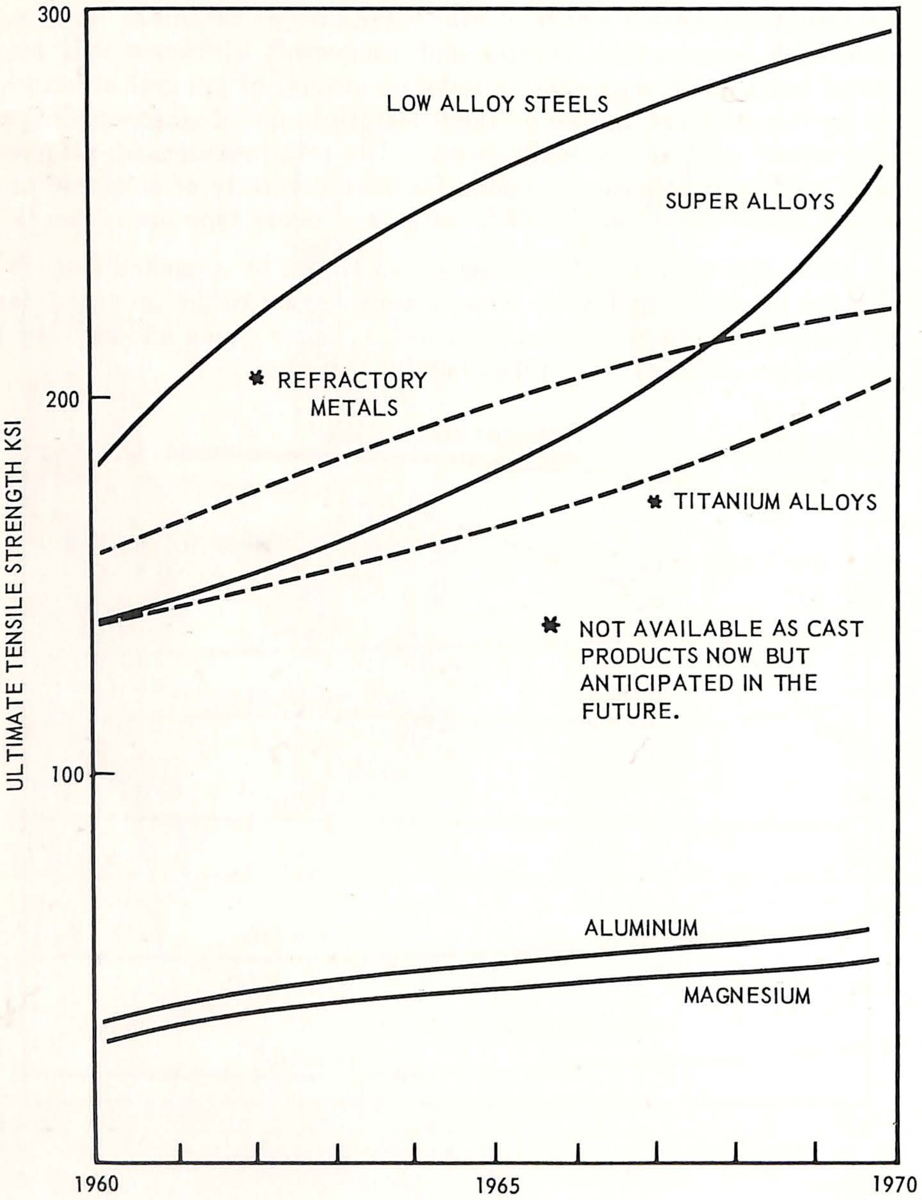
CHART I APPLICATION OF FORMS

Material Properties

Charts II and III indicate the increase in mechanical properties of cast metal alloys and glass reinforced structural plastics anticipated during the next five to ten year period. The strength properties reported are for tensile coupons. While other parameters may be used in the selection of materials (i.e., yield strength, modulus/density ratios, creep and stress-rupture, etc.) the increasing trend toward higher strengths and more efficient structures is well represented by the tensile ultimate strengths. Ductility of castings, as an indication of structural integrity in ever more critical applications, will receive more and more attention. However, as the ductility of castings is not solely dependent upon the chemical composition and metallurgical structure of the casting but is greatly influenced by the foundry techniques used, no attempt has been made to include ductility in these charts. As shown in Chart I, sheet metal components in the form of built-up structures will increase during this period but the sensitivity of such structures to design variations precludes the possibility of estimating their strength potential.

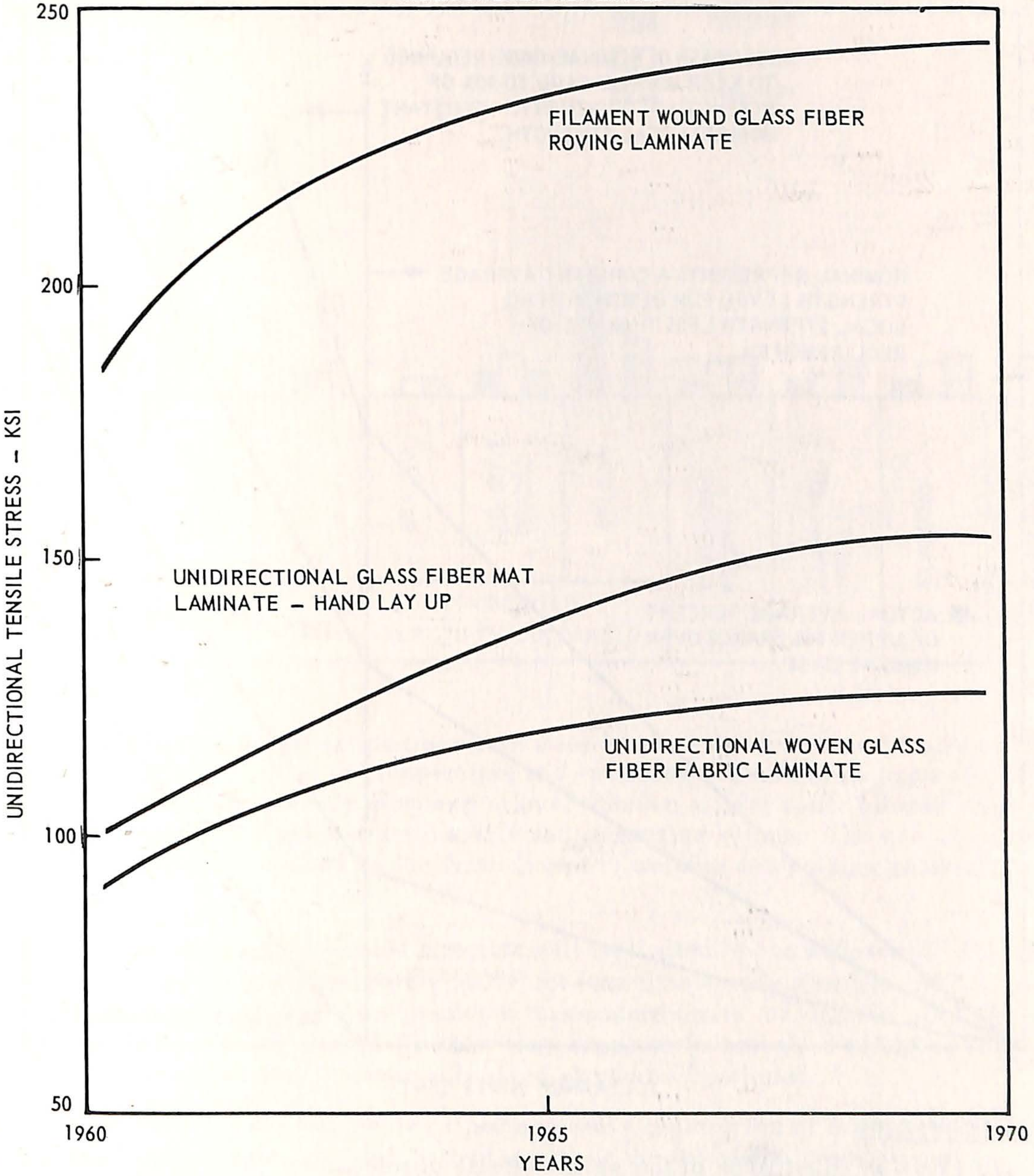
CHART II

CAST ALLOYS
MECHANICAL PROPERTIES



Generally the use of castings will reduce and in many applications weldments will be used in place of them. In high strength, high temperature applications relatively small forgings will be assembled into larger, complex, built-up components since it is not in-indicated that the cost and time to produce very large forgings will be acceptable. Aluminum and magnesium alloys will still be the basic materials for subsonic vehicles and for advanced types, will continue to be used for internal structures due to the environmental protection requirements.

CHART III
GLASS FIBER REINFORCED PLASTICS
MECHANICAL PROPERTIES

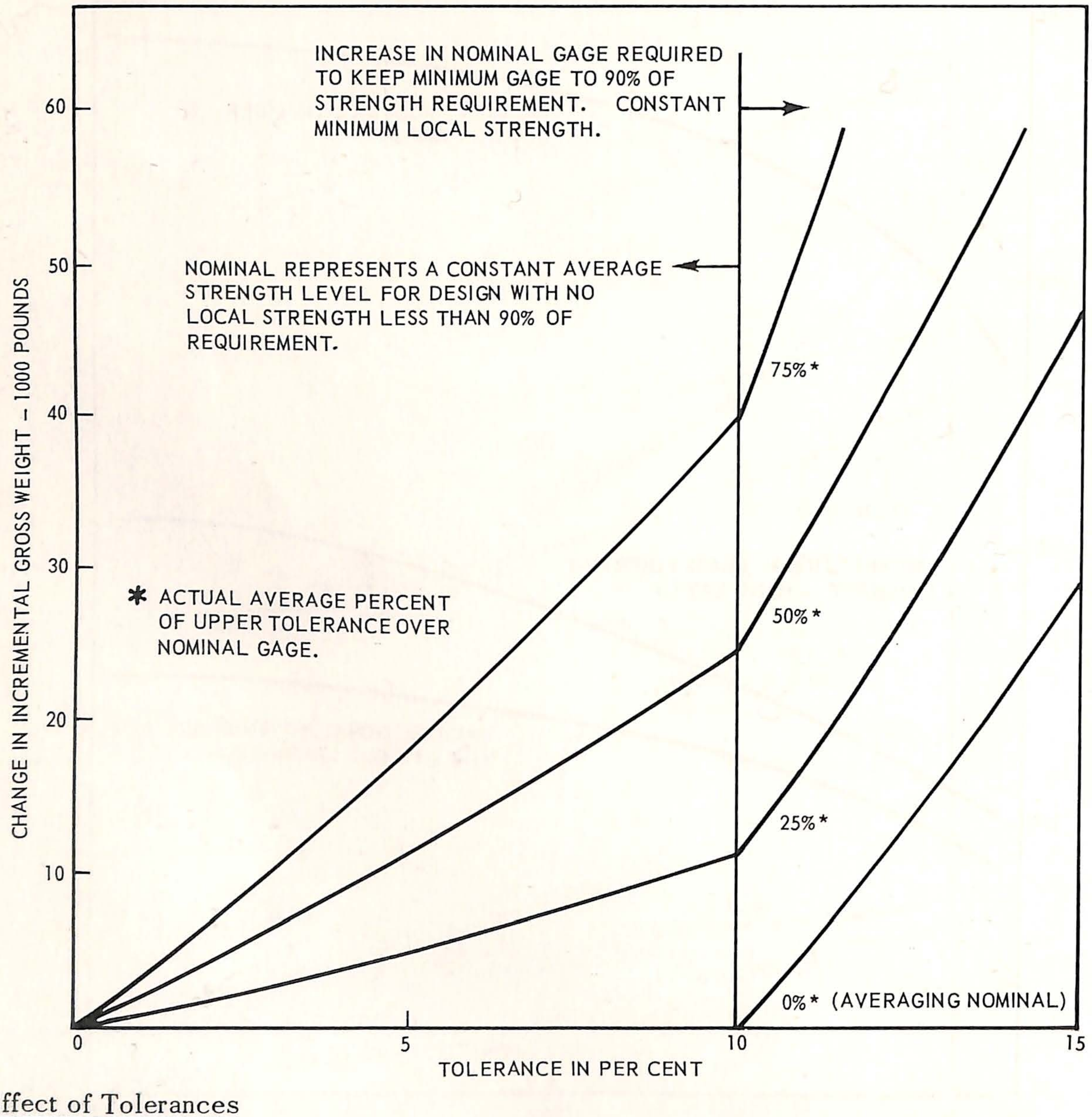


The use of plastics and ceramics for thermal protective systems, i.e., insulation, ablation, sublimation, etc., will also increase, particularly in advanced space vehicles of all types. However, it is not indicated that these materials have the potential to be used for other than non-structural applications, and, therefore, they are not included in the charts.

The basic change in design trends of greatest importance is the fact that the high mechanical properties of the future sheet materials can be most efficiently utilized by built-up structures, much of which, particularly in space vehicles, will employ ultra thin gages on the order of .010 inch and less. To achieve an equivalent efficiency in integral structures employing other forms would require practically complete machining. Also, the trend indicates the need for closer dimensional tolerance controls, improved surface finishes and constantly increasing reliability and integrity of all forms for the entire period.

CHART IV

EFFECT OF MATERIAL TOLERANCES ON GROSS WEIGHT OF TYPICAL SUPERSONIC TRANSPORT FOR GIVEN MISSION



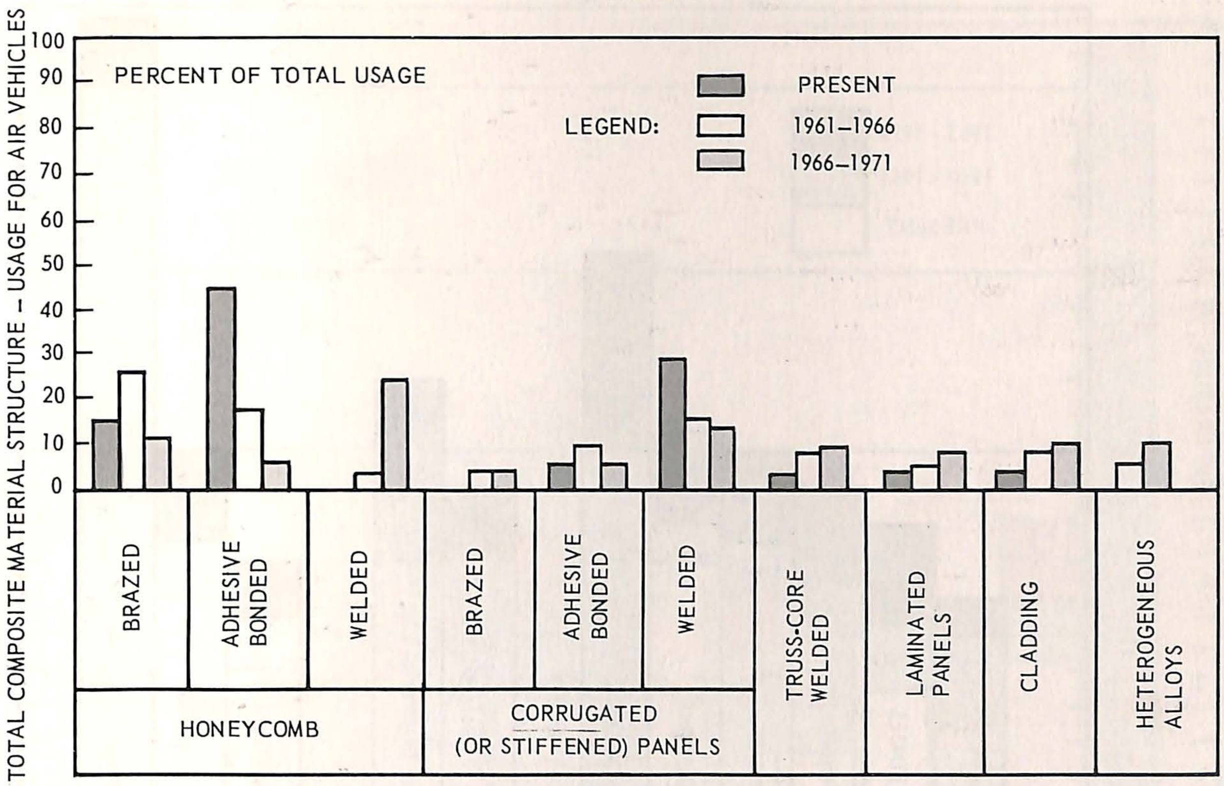
Effect of Tolerances

Chart IV is an illustration of the weight effects of tolerances. The curve identified as 0% (average nominal) indicates the required gross weight increment necessary to maintain a given strength level. The other curves indicate the required gross weight increment necessary to recover the payload loss resulting from overweight of sheet stock averaging greater than nominal, and the drop in these overweight penalties as tolerances below 10% are used.

Composite Structures

In composite structure, Chart V, 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 1961 to 1966 period Mach 3 aircraft will be in production.

CHART V



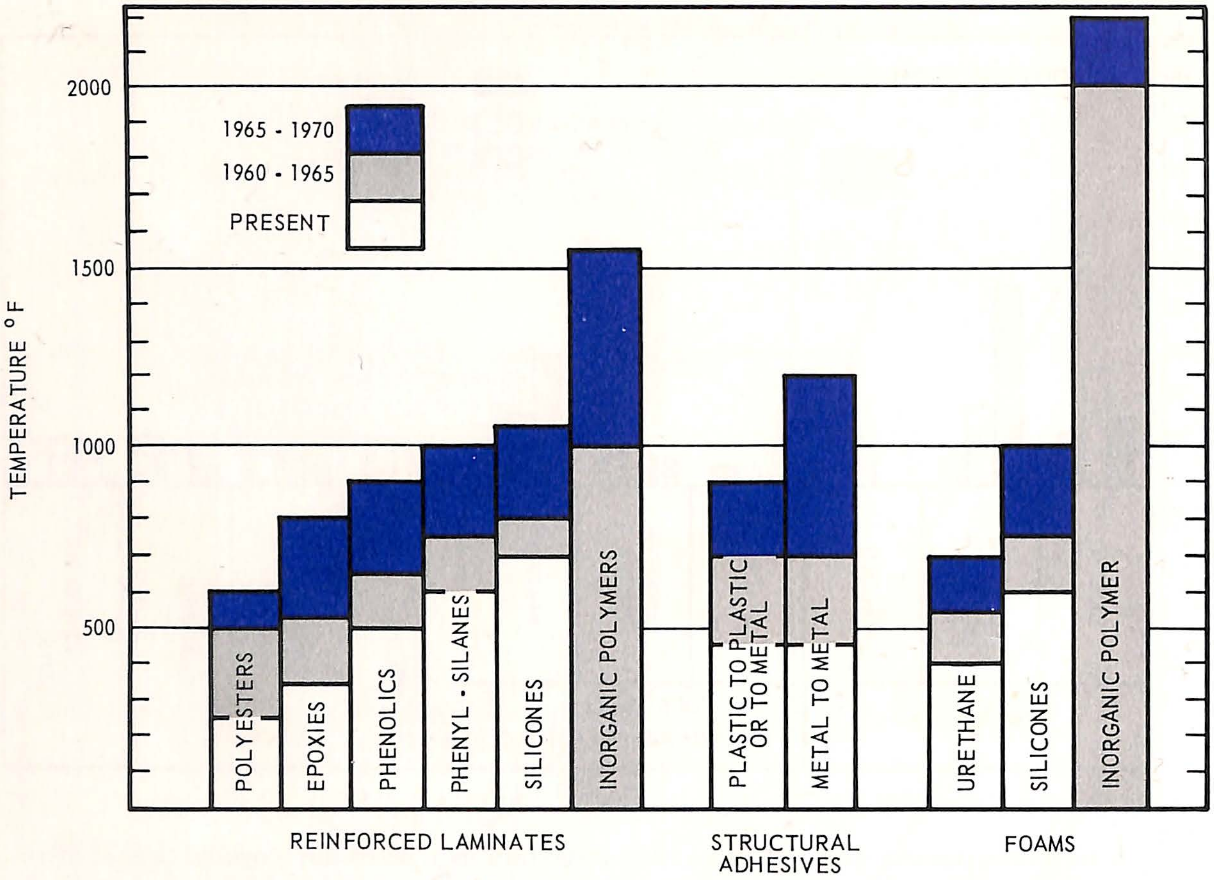
Honeycomb, corrugated and truss core materials may be of any combination of materials which can be used in the temperature and environment existing for supersonic flight vehicles. These may include aluminum alloys, titanium alloys, super alloys; and with surface protection low alloy and die steels and magnesium alloys. The use of brazed or welded structure will depend on the development of welding and brazing materials and processes.

The use of adhesive bonded structure will be limited by the adhesives. Present adhesives are limited to approximately 500°F for long time exposure and to 1500°F for short time exposure (minutes). Future predicted temperature limits of organic adhesives is 900°F for long time and 1800°F for short time exposure (minutes). For higher temperatures (2000°F and above), ceramic adhesives should be developed.

Laminated panels may be described as panels constructed of laminates of different materials bonded by any suitable method to utilize the individual properties of each separate material. For instance the stiffness of beryllium might be utilized by being laminated with another material of greater ductility. The methods of bonding might include adhesive bonding, brazing, welding, or diffusion bonding but is not intended to include cladding or plating.

Cladding is expected to increase the usefullness of alloys that are (1) too brittle for normal use at present, such as beryllium and (2) too easily oxidized at elevated temperatures such as molybdenum.

Heterogeneous alloys is a term used to describe materials in which fibers or particles of another material are dispersed throughout the matrix for the purpose of adding strength at higher temperatures. Titanium alloys with dispersed particles of Ti_2Cu have been reported showing over 100,000 psi ultimate tensile at 1200°F.



PLASTIC MATERIALS

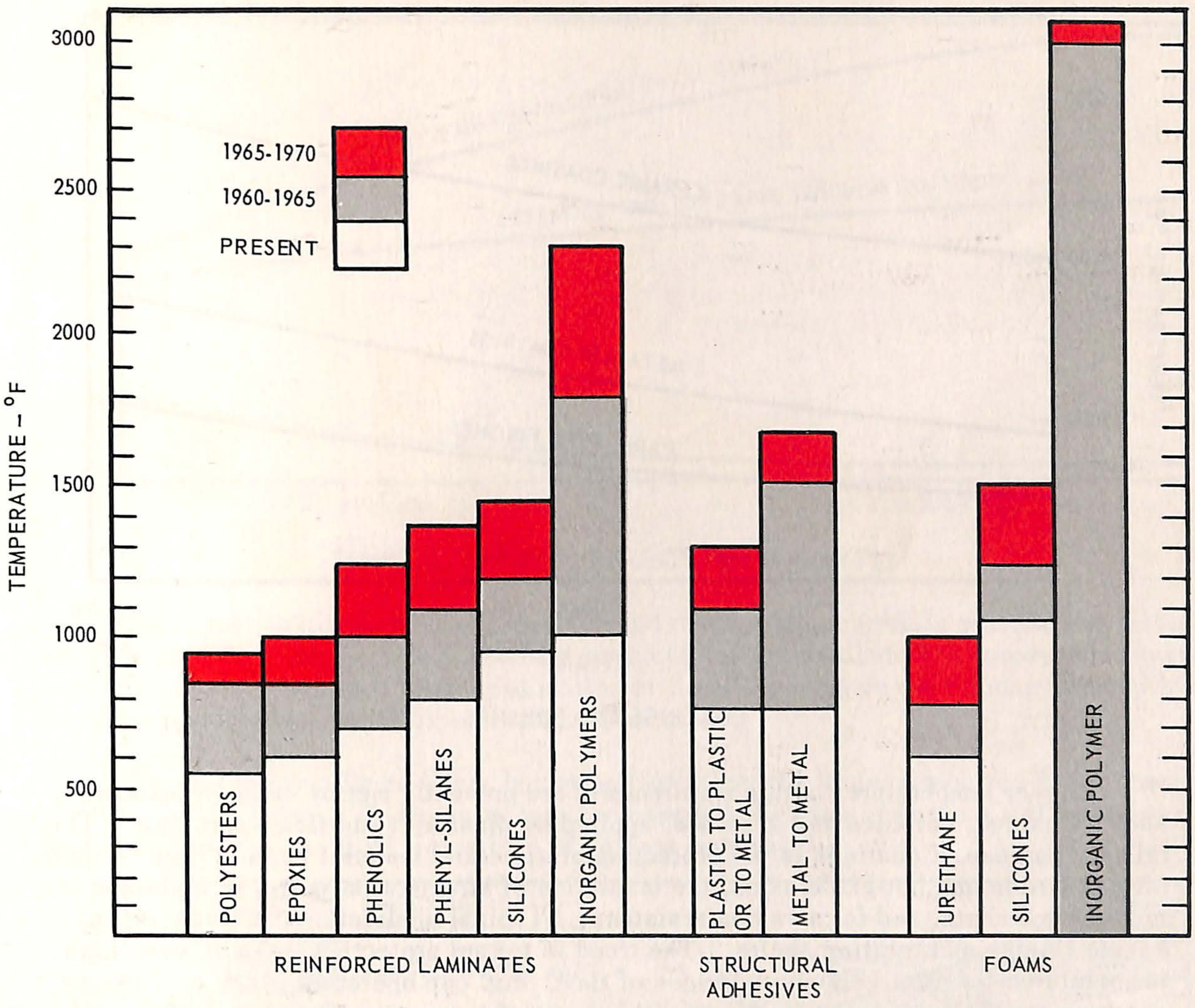
LONG TIME (1000 HR) SERVICE

As with most materials used in flight vehicles, the plastics usage trend is toward higher service temperatures. With the increasing use of plastics in missile structures, the requirements are divided into two categories: long time and short time exposure periods.

The chart above presents the present capabilities and the future requirements for structural plastic materials exposed to temperature for 1000 hours. The material strengths required during and subsequent to environmental exposure are 30 – 35 percent of their room temperature properties. Typical design applications for reinforced plastics under such conditions are secondary and selected primary structure, hot gas ducts, heat barriers, and radome walls.

Latest research and development related to structural adhesives indicates satisfactory progress in meeting the current needs. The present rate of development must be maintained, however, if future needs are to be satisfied.

Foam technology development is lagging behind industry needs. In addition to serving as wall stabilizers in radomes, these materials are efficient heat barriers. Increased usage in such applications will result from the availability of higher heat resistant foams. As with reinforced plastics, the inorganic polymers promise superior heat resistant qualities and offer a desirable area for research and development efforts.

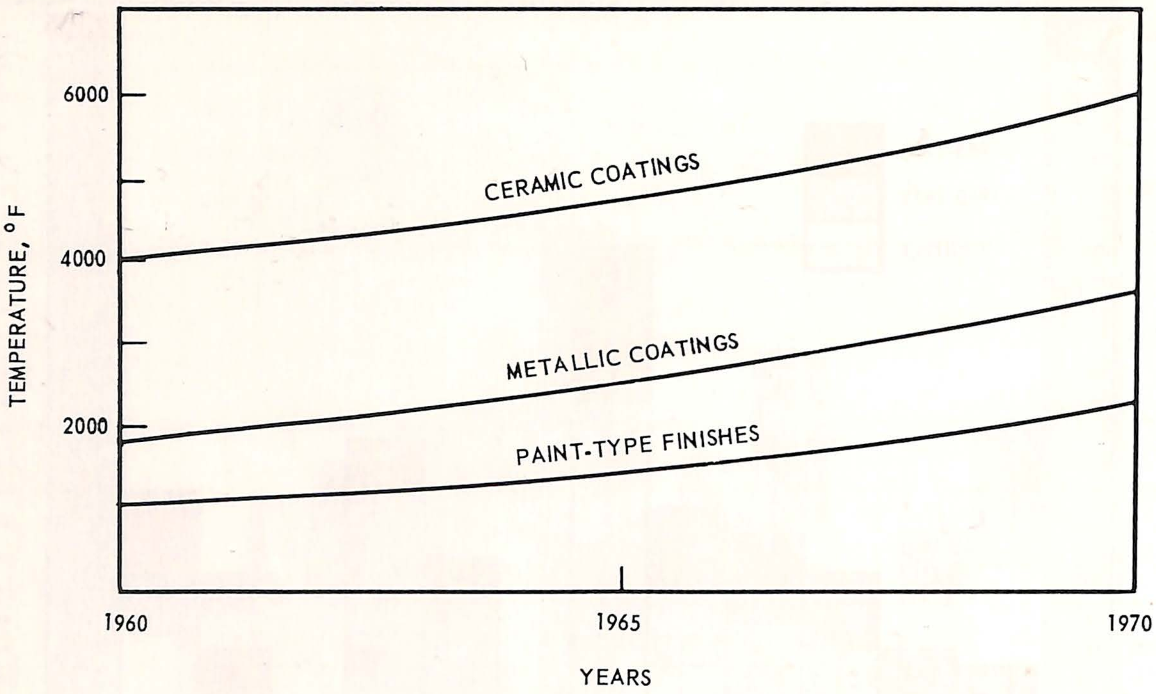


PLASTIC MATERIALS
SHORT TIME (0.1 HR) SERVICE

The chart above presents the plastic materials requirements for short time exposure to temperature. These requirements are primarily related to rocket missile and re-entry vehicles. Ablation applications are mainly a matter of specialized selection of design and materials and are not considered here.

The strength criteria at elevated temperatures are similar to those described with the long time exposure plastic materials chart, as are the areas requiring the greatest advances in research and development.

Future plastic design especially related to space and upper atmosphere vehicles may require consideration of environments other than temperature as having primary significance. These environments are: electromagnetic and particle radiation, induced mechanical and acoustical vibrations, thermal and mechanical shock, cyclic temperature differentials, vacuum, and ozone degradation.

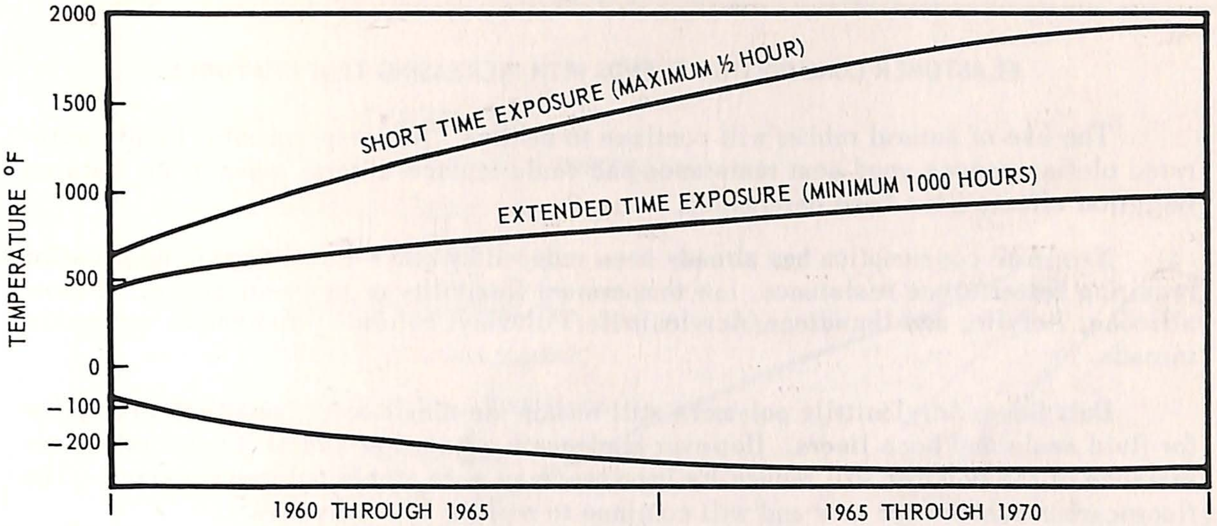


COATINGS AND FINISHES

Higher temperature coating requirements are presently met by ceramic materials, such as oxides, carbides and silicides, applied by plasmajet and flame spraying. The primary purpose of coatings is the protection of structural material against high temperature oxidation and hot-gas erosion, the insulation of structural members in high-temperature environments, and for abrasion resistance. Typical applications include rocket nozzle linings and rotating shafts. The trend is toward protection against very high temperatures for relatively short periods of time, e.g. one operating cycle . Tailored coatings for specialized applications will become of increasing importance, with self-healing characteristics required in some cases. Rapid heating requirements will result in emphasis on more ductile coatings and on matching of coefficients of expansion. Special high-temperature materials, such as organics for protection by ablation , will be improved.

Intermediate temperature coating requirements are currently met by thin metallic coatings applied by electro- and electroless-plating, dipping, spraying, vacuum deposition and arc deposition. These coatings are used to provide oxidation and corrosion protection, wear resistance, altered emissivity properties, diffusion barriers, etc. Metallic coatings, with their inherent ductility, are generally more durable than ceramic coatings. The trend is toward increased usage of metallic coatings for specialized applications, and precious metal coatings and multilayer coatings to achieve a combination of properties in one coating. Coatings will be developed for use at liquid-gas low temperatures as well as for use at higher temperatures.

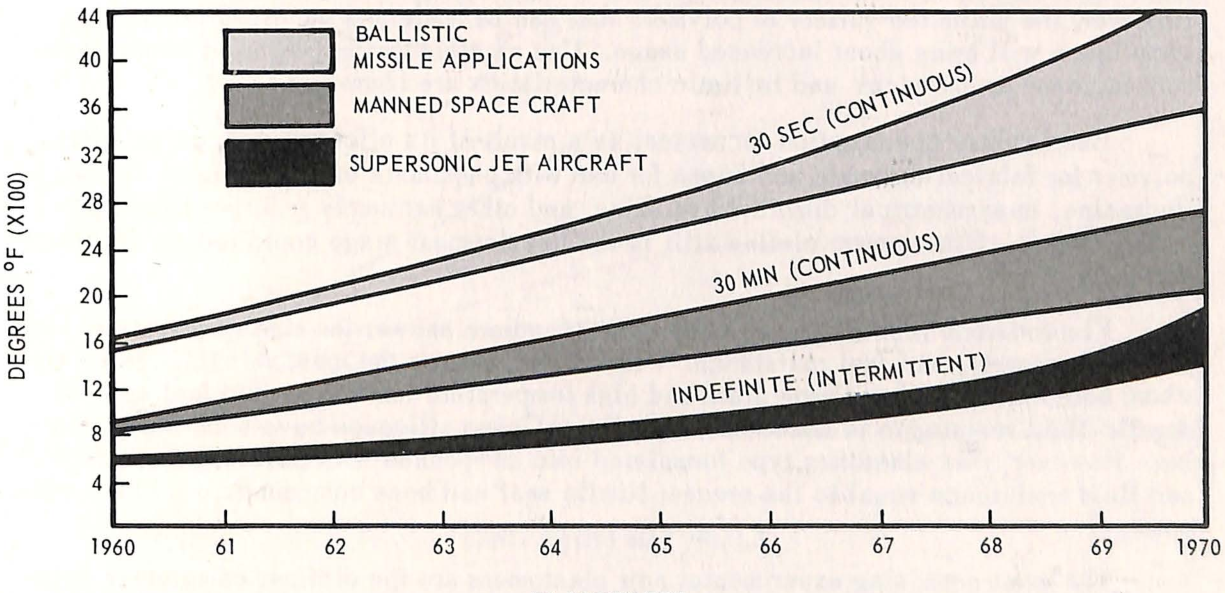
Paint-type finishes, of the solvent-release inorganic-filler type, are presently used for lower temperature protection. The ease of application results in an economic advantage over other coatings. These finishes are used primarily for oxidation and corrosion protection. Special temperature-control paints are available. Future requirements will result in the extension of the upper temperature limit of these finishes.



TEMPERATURE REQUIREMENTS FOR SEALANTS

This chart indicates the temperature trend that sealant materials will have to withstand to perform their function. The high temperatures are attributed to aerodynamic heating. The low temperatures are a combination of flight temperatures and those induced by environments such as liquid oxygen and hydrogen.

The usage trend for sealants indicates that there will be less requirement for these products in the future. This results from increased application of brazing and welding in fuel tanks and the physical limitations of sealant materials.



ELASTOMERS

The trend in elastomer applications continues to shorter exposures and higher temperature. As temperature requirements become more stringent, the low-temperature flexure temperature also will advance; thus elastomers for these high temperature environments may have physical attributes of rigid thermoplastics at ambient. Cross-linked polyethylene is an example of such a material.

ELASTOMER CONSUMPTION TRENDS WITH INCREASING TEMPERATURES

The use of natural rubber will continue to decline New experimental highly saturated olefins posses good heat resistance and could replace natural when more data on radiation effects have been determined.

Neoprene consumption has already been reduced by other elastomers in applications requiring better ozone resistance, low temperature flexibility or fuel resistance. Fluorosilicone, Acrylic, and Butadiene/Acrylonitrile/Polyvinyl chloride terpolymers are making inroads.

Butadiene/Acrylonitrile polymers still remain the single most important elastomer for fluid seals and hose liners. However inadequate ozone, low and high temperature resistance of the polymer will reduce its importance as more stable polymers appear. The fluorocarbon rubbers are now and will continue to replace B/A polymers.

Use of Polysulfide rubber is declining. As a solid propellant binder/fuel, it is being challenged by polyurethane, polybutadiene, carboxynitrile and other polymers. Use as a tank and cabin pressure sealant remains high because no other material has been able to match its proven qualities and offer in addition the higher temperature resistance needed.

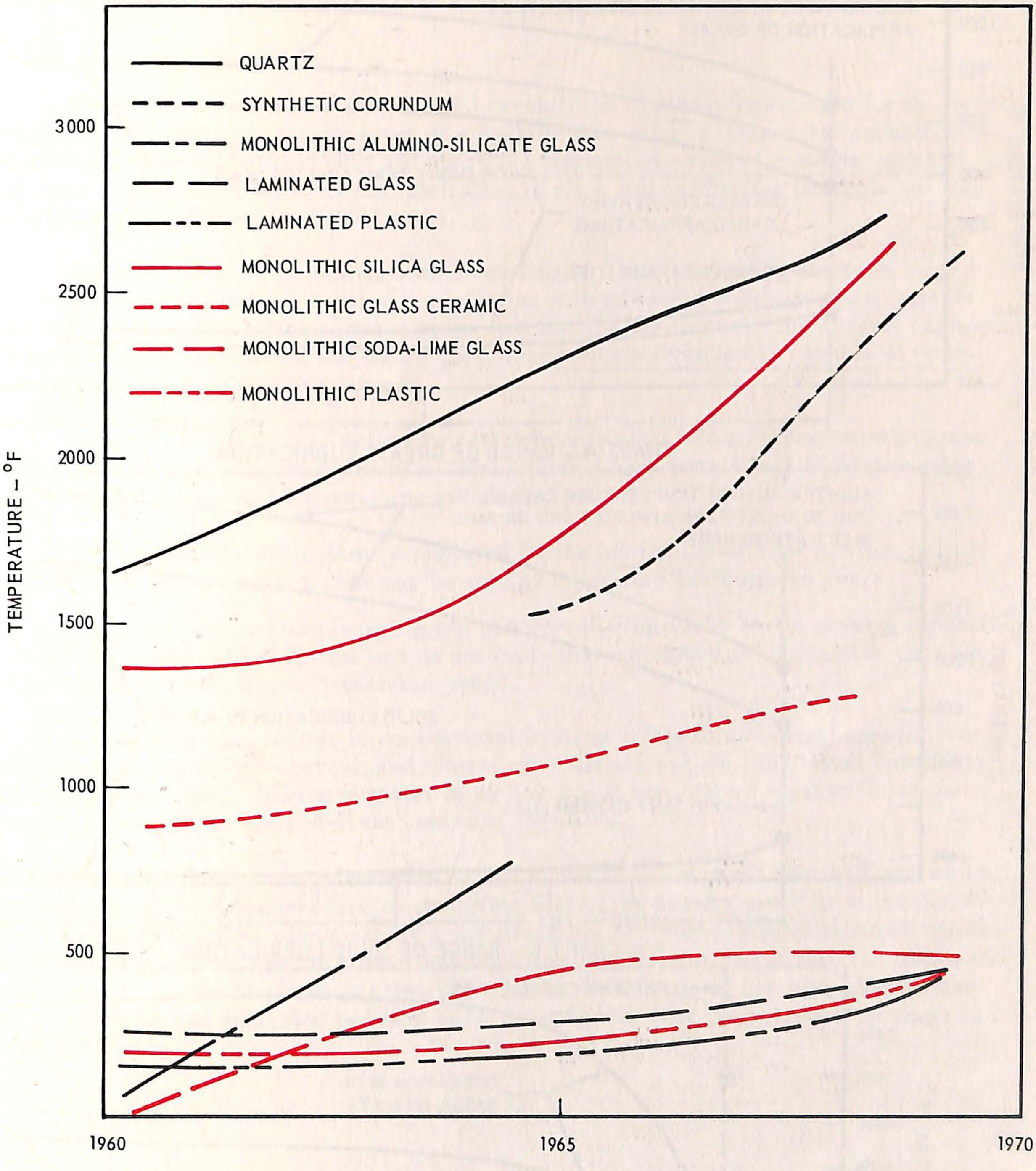
Silicone use will continue to increase, particularly the fluorosilicones. A high strength version of presently available fluorosilicone compounds would be welcome and would replace Butadiene/Acrylonitrile rubber in high temperature seal and hose problem areas.

The progress of solid polyurethanes has not been rapid. High temperature limitations coupled with non-conventional manufacturing techniques has retarded their growth. However, the unlimited variety of polymers that can be made and improved processing techniques will bring about increased usage. Use as a binder/fuel in solid propellants may increase as physical and ballistic characteristics are improved.

Butyl rubber consumption increases, as a result of its effectiveness as an inert polymer for fabricating seals and hoses for use with phosphate ester hydraulic fluids, Hydrazine, unsymmetrical dimethyl hydrazine, and other extremely reactive liquid propellant fluids. Other newer olefins still in the development stage could reduce its importance.

Fluorocarbon rubbers are still the best immediate answer for high temperature, high physical property, and fuel resistance. Fluorosilicones are the most valuable materials where both extremely low temperature and high temperature conditions and fuel and hydraulic fluid resistance is necessary. Nitrile or Cyano silicones have been disappointing. However, this elastomer type formulated into compounds with physical properties and fluid resistance equal to the present Nitrile seal and hose compounds would be welcome.

The most promising experimental new elastomers are the olefins, completely saturated or with low unsaturation. These lack fuel resistance but have heat stability up to 400 °F. They could be a low cost replacement for silicones in nonfluid applications. They are chemically inert, but can be cross linked by radiation or other known techniques.



TRANSPARENT MATERIALS

The above chart depicts the expected useful temperature limitations of transparent materials based on present trends in improvement and development. The intended use of the materials is assumed to be for passage of light and in nonstructural applications. Transparency to infrared or electro-magnetic waves is not considered. Temperature resistance of organic materials is limited by the chemical nature of the material, and as design temperatures increase there must be a transition from use of plastic to glass to ceramic.

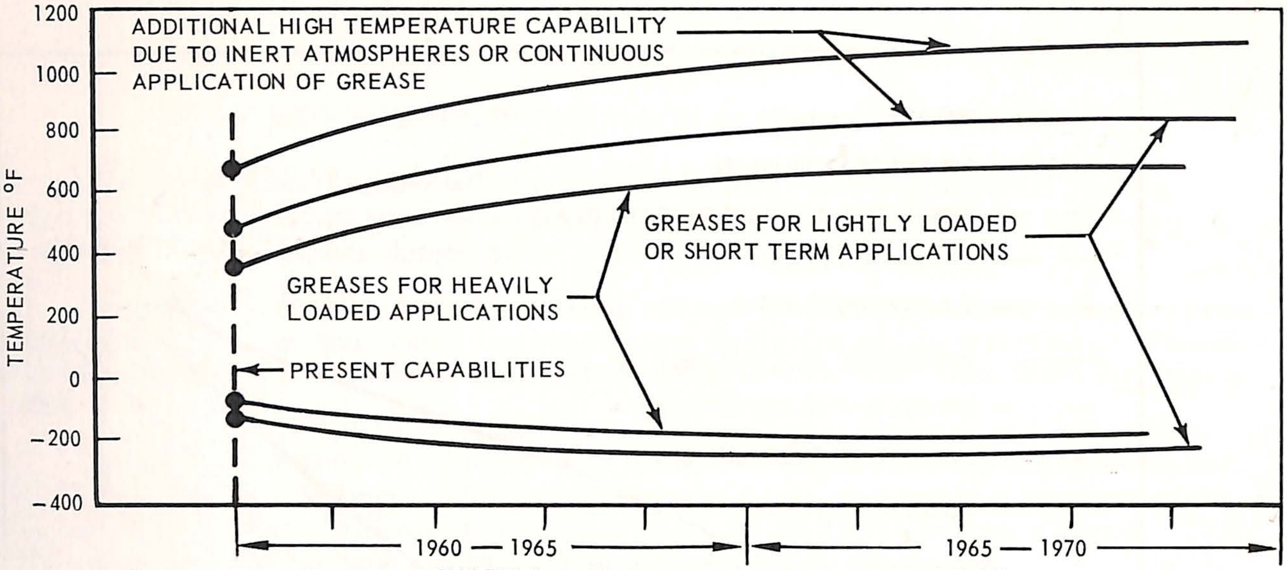


CHART A – RANGE OF GREASE LUBRICATION

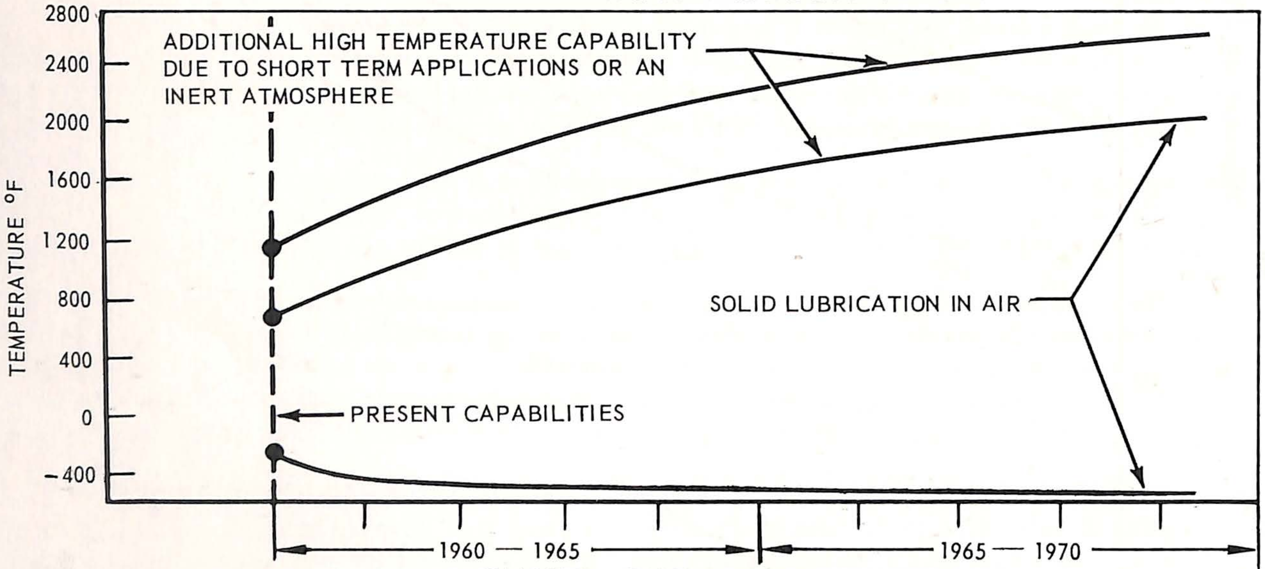


CHART B – RANGE OF SOLID LUBRICATION

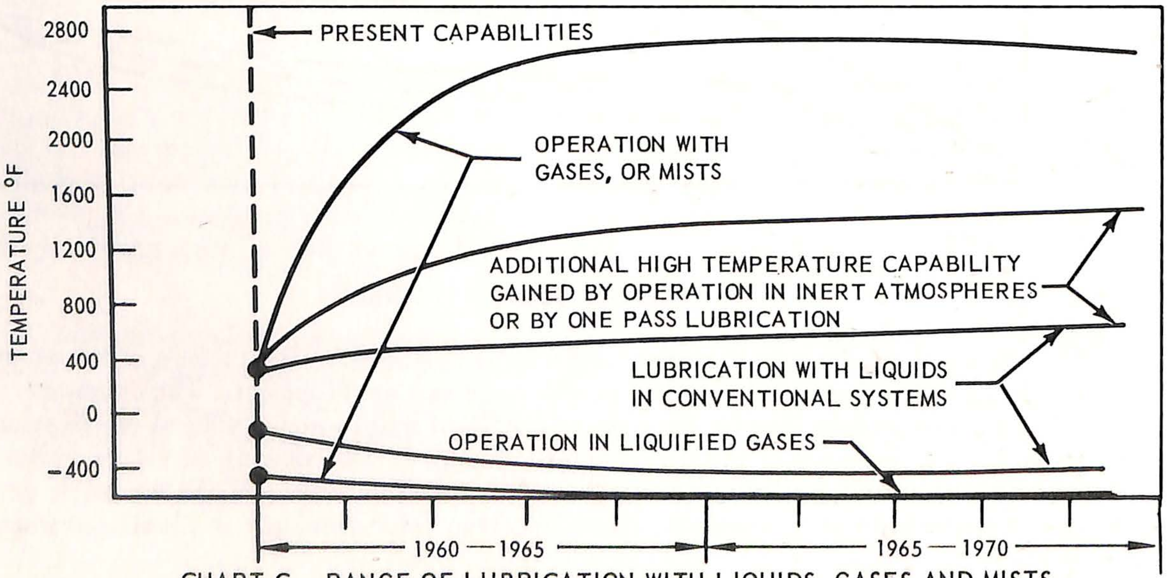


CHART C – RANGE OF LUBRICATION WITH LIQUIDS, GASES AND MISTS

LUBRICANTS

Chart A is a forecast of the required 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 B 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.

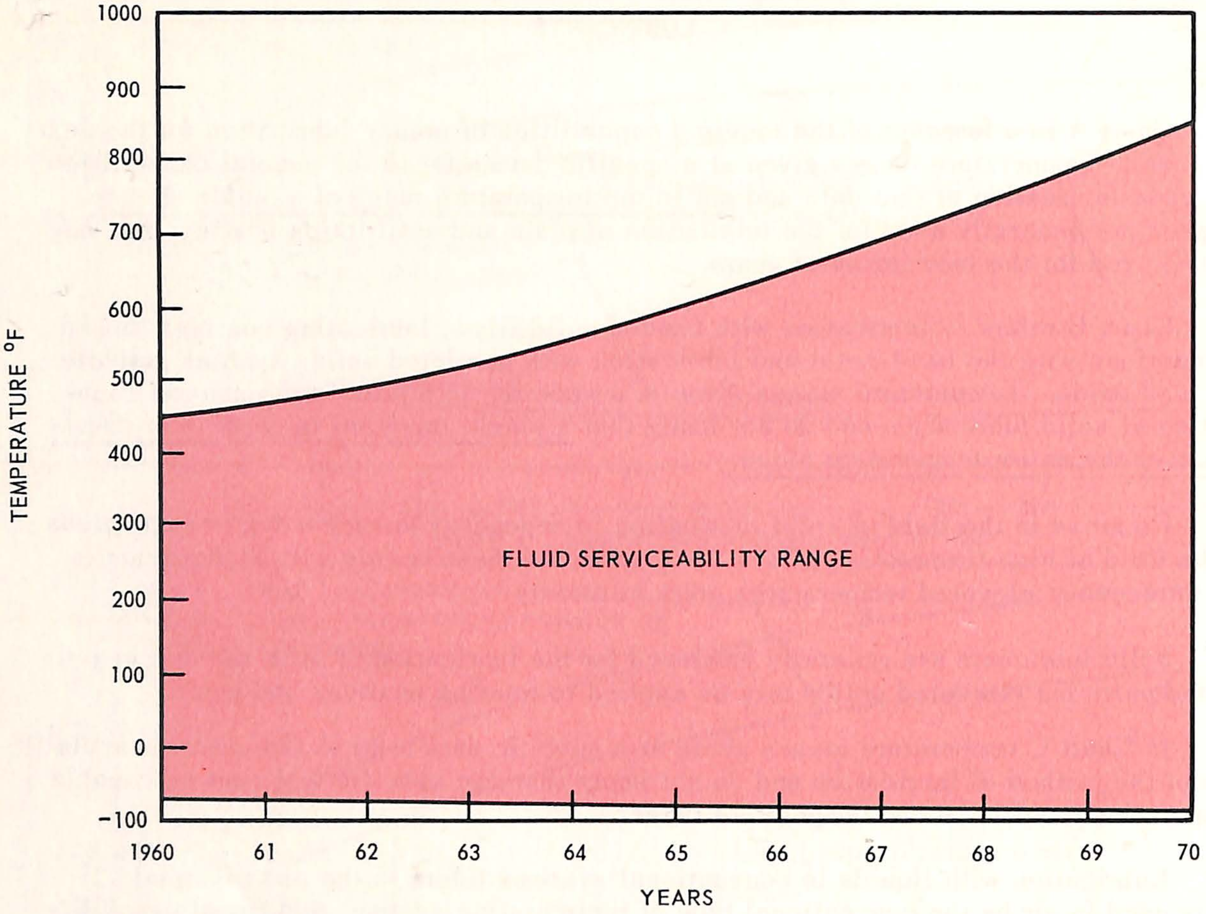
Progress in the field of solid lubrication is dependent to a great degree on progress in the field of high temperature alloys. Non-oxidizing base metals with high strengths and hardness at elevated temperatures are a necessity.

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 C 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.



HYDRAULIC FLUID SYSTEMS

The fluid operative range required of hydraulic fluids is expected to increase from -65 to +450° F in 1960 to -50 to +850° F by 1970. Since it appears probable that no one fluid which is serviceable over the entire range will be available, no single system is likely to operate over the entire range.

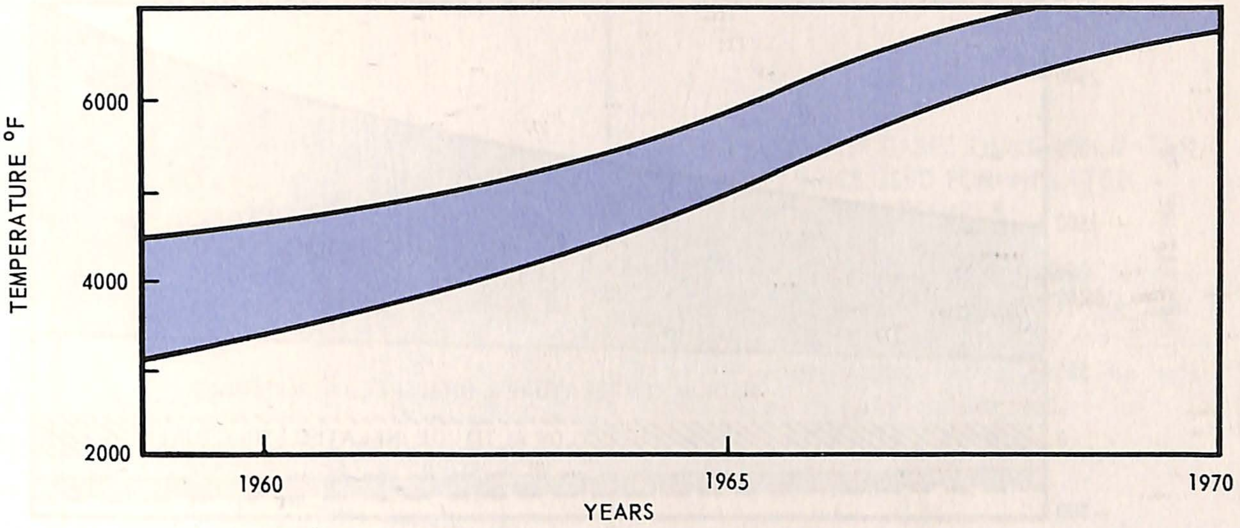
Other requirements for fluids are:

1. Compatibility with servicable non-metallic and metallic materials at operating temperatures.
2. Sufficient lubricity at operating temperatures.
3. Fire resistance or a minimum fire hazard at operating temperatures.

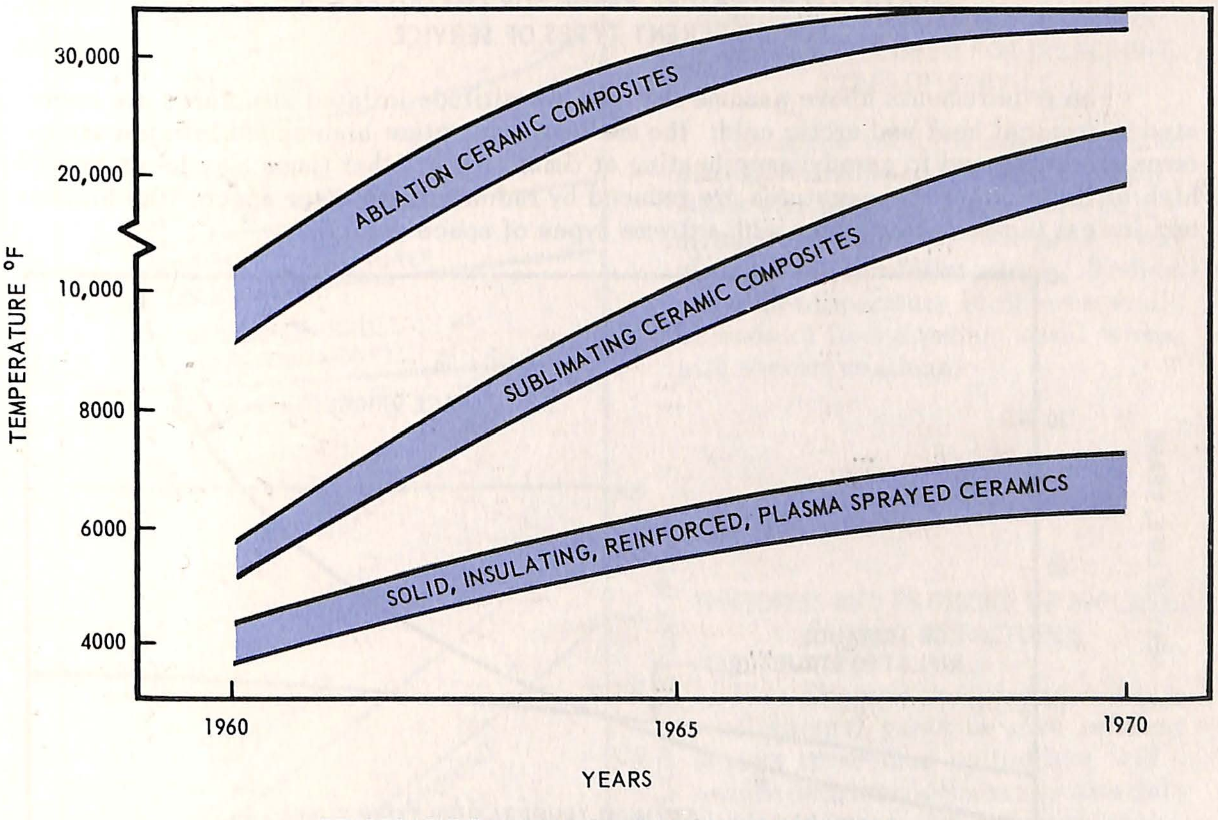
Most presently used materials appear to have sufficient radiation resistance until nuclear powerplants come into use.

Present systems cleanliness requirements vary widely. Cleanliness of some systems is checked by visual examination of coarse filter paper after sample filtration. At the other extreme, systems containing low power, critical tolerance values must be free of particles in the 2 to 5 micron range to achieve sufficient reliability. As system temperatures increase, the challenge will be to maintain present levels of system cleanliness.

Note: See also page 24, Hydraulic System Trends.

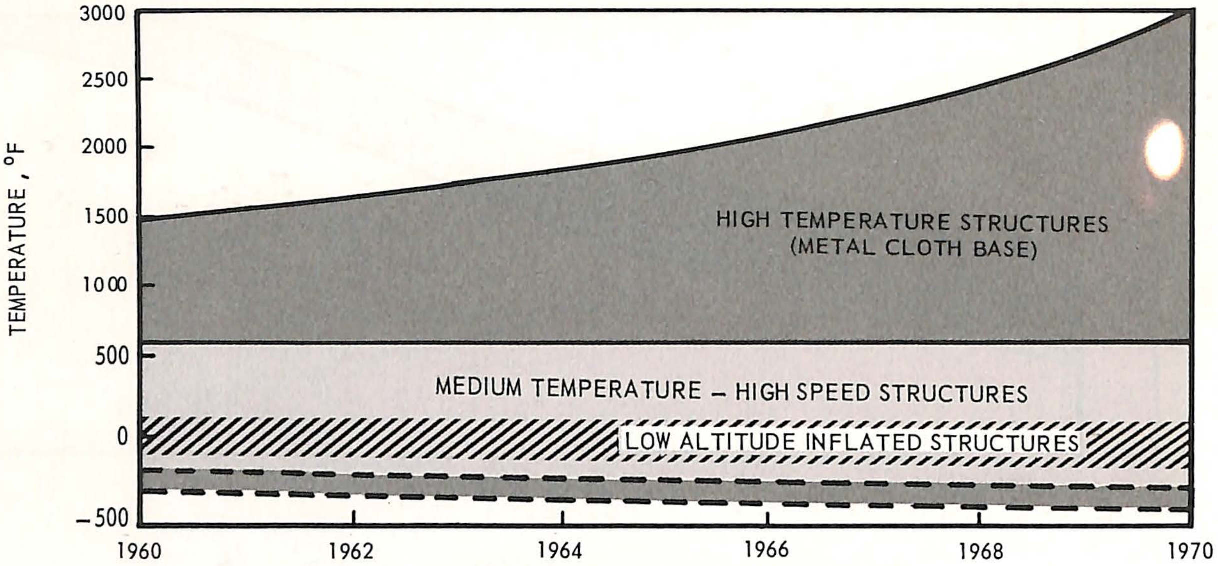


MAXIMUM OPERATING SPECTRUM CERAMICS AND CERMETS



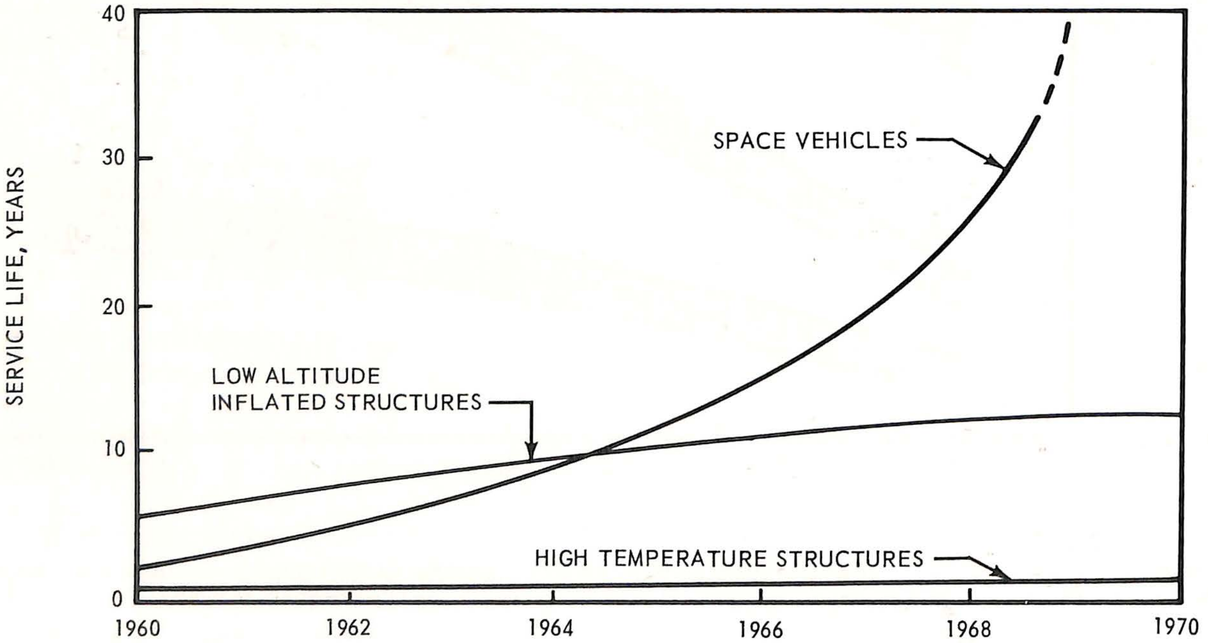
TEMPERATURE LIMITATIONS OF CERAMIC MATERIALS

The technology of utilizing ablation, plasma sprayed, and metal reinforced ceramic coatings in composite systems has been realized. Developments should be completed to take advantage of high melting point materials as either protective systems or materials of construction.



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

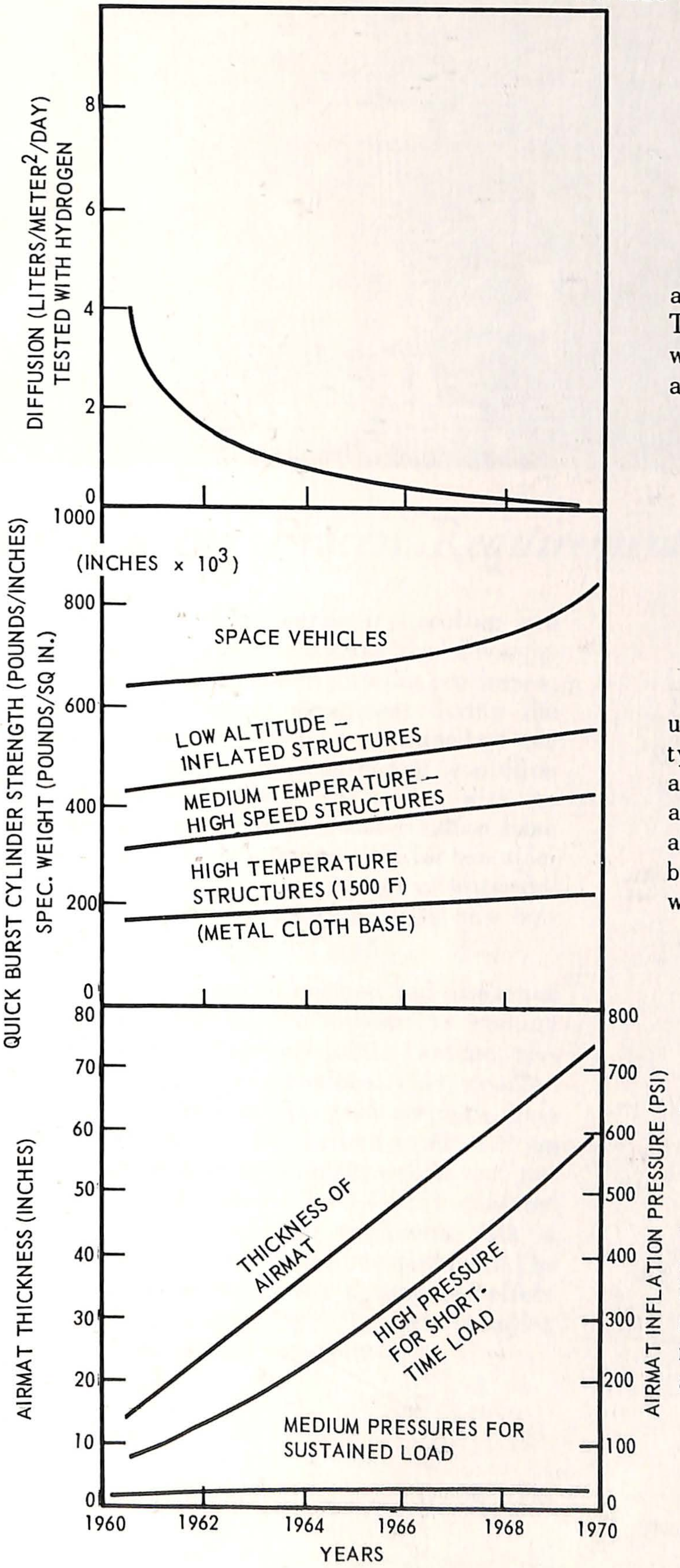
The requirements above assume that the low-altitude inflated structures are operated in tropical heat and arctic cold; the medium-temperature high-speed inflated structures are subjected to aerodynamic heating at times, but at other times may be at very high altitudes where temperatures are reduced by 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 GASES THROUGH COATED FABRICS USED FOR INFLATED STRUCTURES

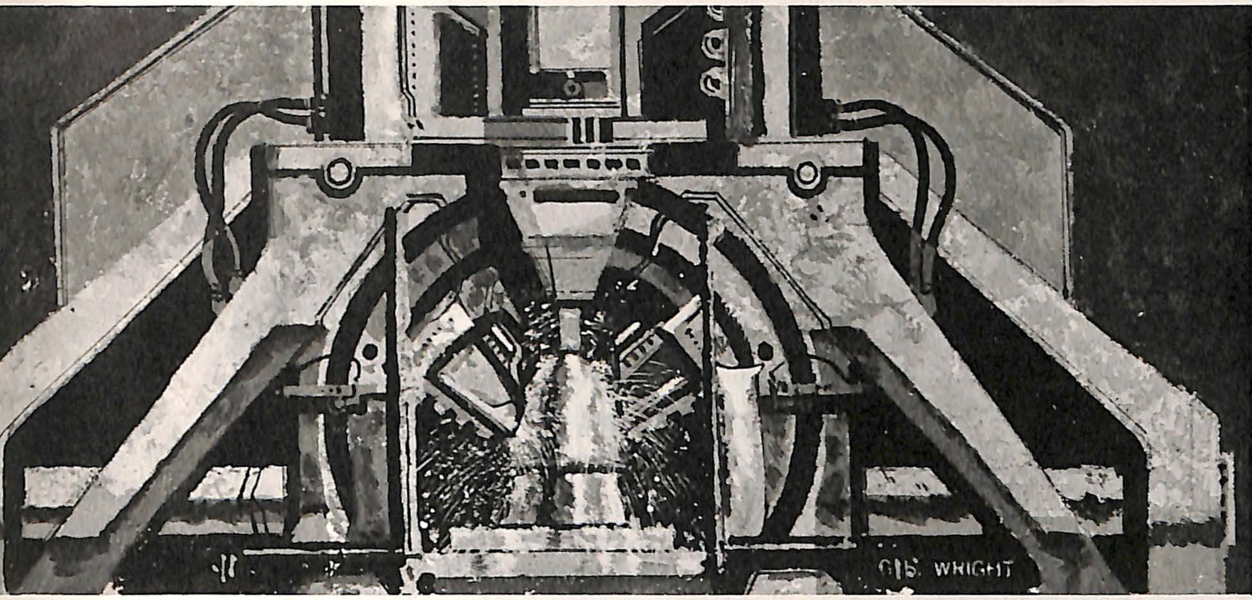
It is assumed that pre-1960 fabrics are for airships which use lifting gas. The 1970 fabrics are for space vehicles with air-breathing passengers, as well as for airships of that period.

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.



SECTION 5

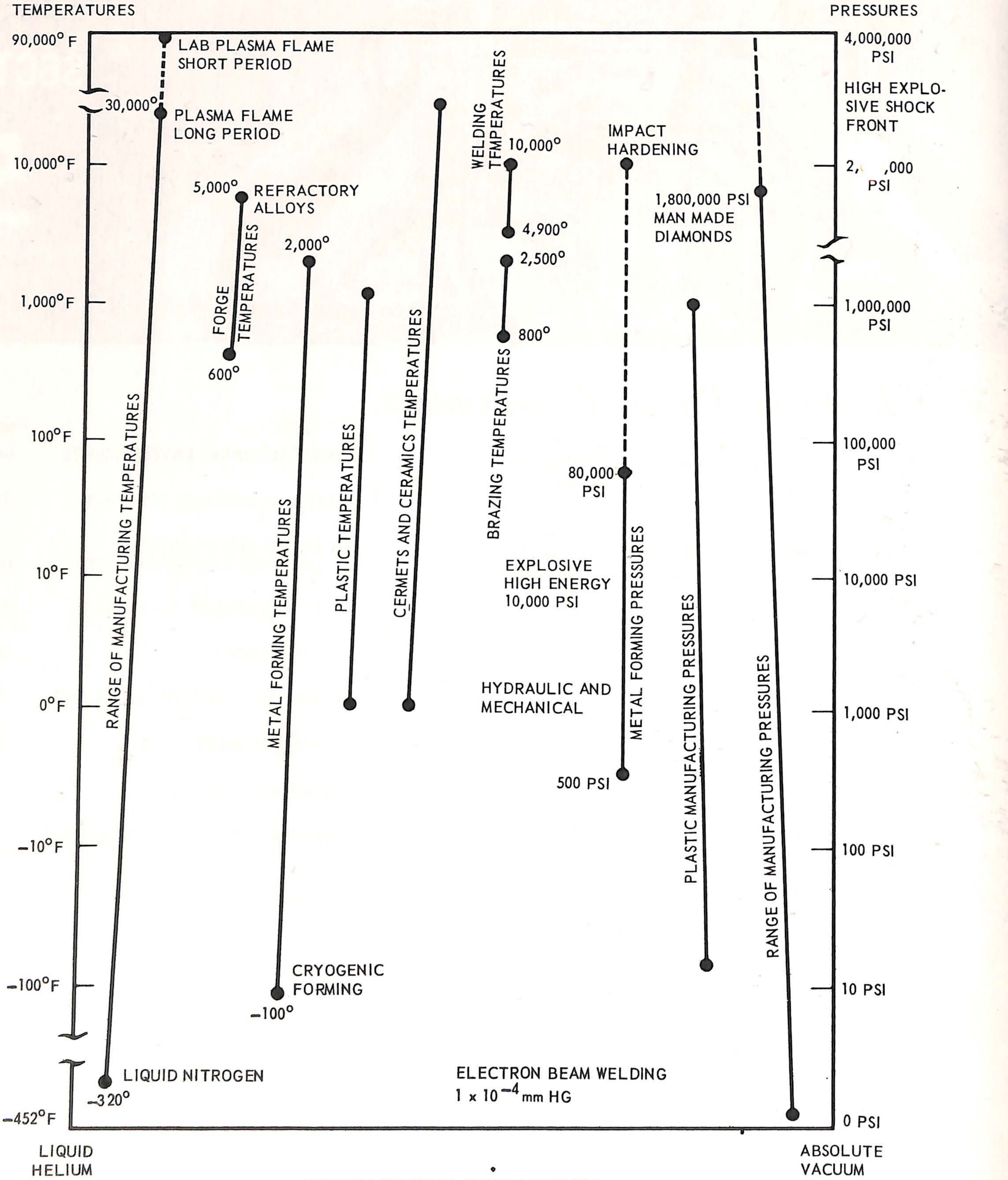
Manufacturing Process Requirements

In this section, aerospace tooling and equipment engineers forecast the advancements necessary in manufacturing processes, machine and factory equipment during the coming decade. Predictions are based on two current trends — the continuing evolution toward limited quantity production with its inherent narrowing of the amortization base and — the ever-decreasing time for manufacturing development, a by-product of ultramodern weapon systems evolving from new scientific and technological gains.

In the design of manned and unmanned aerospace vehicles, the industry is working toward as few structural joints (welded, riveted and bonded) as possible. This, coupled with the requirements for high strength, high temperature materials, worked to ultra-close precision; thinned to minimum weight and procured in small quantities — will confront aerospace manufacturing engineers with a host of new challenges and new problems. The following pages depict the anticipated effect of these trends upon particular manufacturing methods and factory equipment.

AIA

MANUFACTURING PROCESS REQUIREMENTS



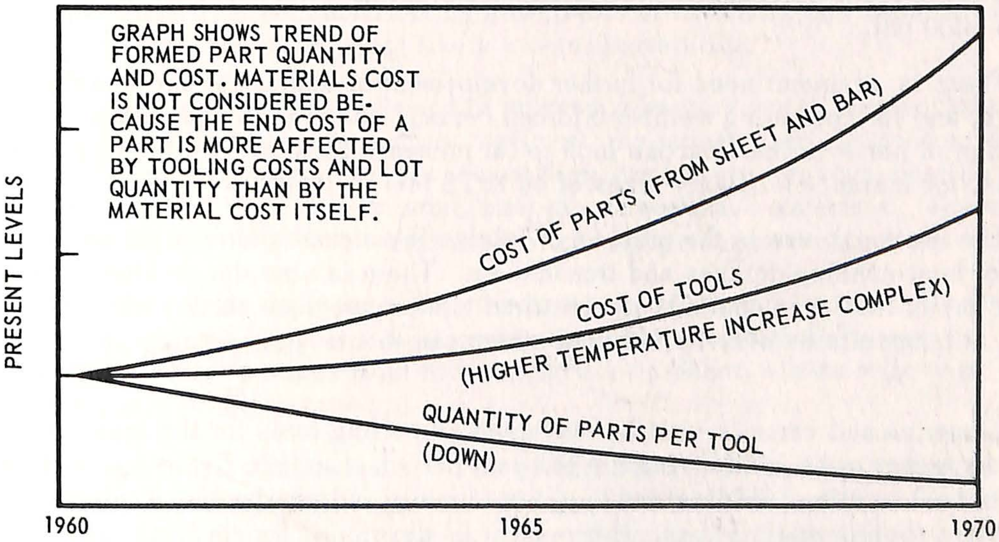
MANUFACTURING ENVIRONMENTS

MATERIAL FORMING EQUIPMENT

Increasing forming complexities, coupled with the overall trend to small production quantities, will have a sharp effect on tool costs and amortization rates. During the next five years, the required high-yield alloys (to 350,000 psi) will be available only in sheet and bar form. To minimize rising costs, sheet forming equipment being developed will have to produce parts closer to final configuration. In addition to high-energy forming and precision and spin forging, some advances will be made in extruding, casting, and deep drawing.

Other related areas being investigated include:

Hot Forming of wide sheet material
Dies to withstand over 35,000 psi
Heated Forming Tools to 2000°F
Dies with quick heat surfaces as bulk remains cool
Creep Forming at 1200° to 1500°F for 5 to 15 minute cycles
Hot Application Tooling Material – dimensional stability under repeated and continuous heating cycles
High-Temperature Hot Hydroforming Blocks – rubber cast form
Forming Materials Immersed in heat treating solution
High-Temperature Sheet Vacuum Forming
Straightening welded sheet metal assemblies
Plating Forming – Intricate shapes, low or moderately stressed
Hi-Temp Forming of New Materials up to 2000°F
Tolerance Maintenance – gap and smoothness of high-strength rigid materials
Tooling Steels for high-energy rate forming
High-Energy Forgings and Extrusions of high-strength metals
Fluid and Arc Discharge High-Energy Forming
Cryogenic Metal Forming – super fluid temperature ranges
Powder Metallurgy Techniques
Toxic or Radioactive Materials Forming
Vacuum Casting of high-strength components
Expanded use of heated dies and radiant heat



Promising results are indicated for ceramic tool applications falling in two categories:

1. Room temperature to 600°F, requiring
    a. Steel-hard smooth surface
    b. Zero expansion — original and tool cycling
    c. No fire hardening
    d. Vacuum or positive pressure reliability
    e. Slip-castability, trowellability, and castability
    f. Machinability in green state
    g. Controlled electrical and heat conductivity
2. 140 to 2750°F, requiring all of the above plus
    a. Tolerance to tool firing process
    b. Thermal shock resistance

In sheet forming, the predominant development area is explosive or high energy forming. Most of the operations, however, must be conducted outside the factory buildings (often in remote areas). Greater economic benefits of this method will be realized with the expanded development of machine tools which may be operated on the factory floor.

In precision forging, the problem area is small forgings for high strength components (such as impellers for high speed rotating machines). Research and development are required to advance the state of the art of forging under controlled atmospheric conditions; utilizing vacuum systems in the furnace, the storage chamber, and the forging chamber.

CERAMICS AND PLASTICS FABRICATION EQUIPMENT

In order to achieve the high temperature, 1000-hour service for reinforced laminates, structural adhesives, and foam plastics, the industry needs development in two areas.

One is to develop adequate instrumentation to measure the degree of polymerization as it occurs. This could be a measure of the dielectric constant of the material, or the measure of some other material factor which changes markedly from the monomeric to the polymeric stage.

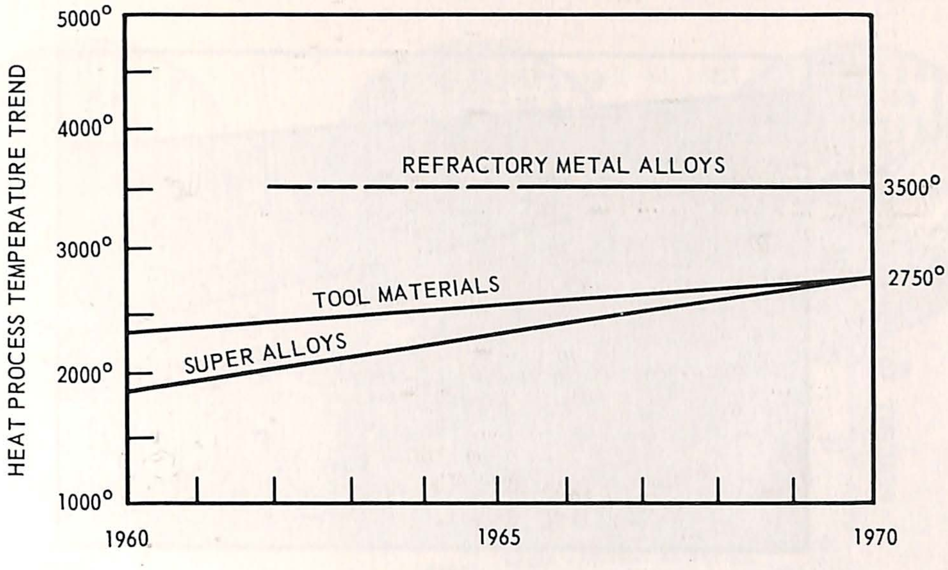
Another critical need in the equipment area is suitable heat sources which may be controlled to a fine degree of accuracy within the temperature range of plus or minus one degree, and a pressure range of plus or minus one psi at such upper limits as 1400°F and 4500 to 5000 psi.

There is an urgent need for further development of equipment for spraying ablative coatings, and for combining metal-reinforced ceramic coatings in composite systems. The size range of parts varies from one inch to (at present) 20 feet. Future design (missile sections, for instance) call for sizes of 40 to 75 feet in length.

The other extreme is the problem of fabricating almost microscopic ceramic components for heat-sensing devices and transducers. There is also the problem of applying ceramic insulations and coatings to electrical equipment, such as tiny electric motors operating at temperatures over 1000°F and other components withstanding up to 2500°F heat.

Ceramics and cermets must be evaluated as cutting tools for the high-strength materials expected to be used during the ten year period. Ceramic fixtures must be developed for heat treating, welding, brazing, hot forming, and similar close tolerance, high temperature tooling applications. Means must be developed for applying ceramic and cermet sealants.

Ceramic materials in the massive form have low yield strength in tension. For this reason, some means must be developed to accommodate the growth of the metal substructure over wide temperature ranges without transmittal of tension loads to the ceramic structure.



TEMPERATURE REQUIREMENTS

HEAT TREATMENT EQUIPMENT

The industry is presently confronted with tooling material problems for tempering and heat treating fixtures (preferably minimum mass) to control parts to sharply reduced tolerances at heat treating temperatures.

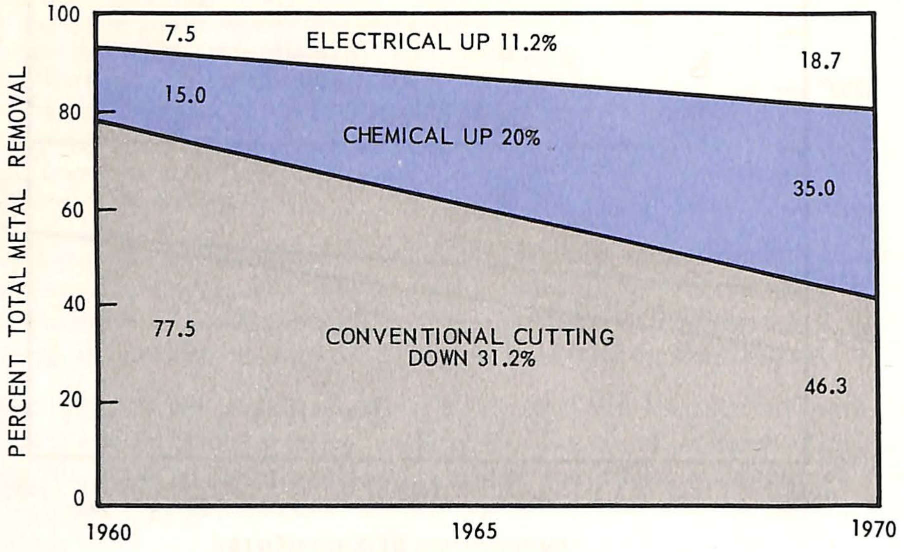
Superalloy materials, such as Rene 41, J-1570, Inconel 90, are heat treated in the 2000° range. Fixture materials should be thermal shock resistant, reasonably impact resistant, have high heat conductivity, be trowellable or castable, and capable of being machined in the "green" state, most likely a ceramic material.

When higher temperatures are used to process refractory metal alloys (Columbium, Molybdenum, Tantalum, Tungsten and their alloys), the industry will be confronted with entirely new material problems. High vacuum, high temperature furnaces must be developed for heat treating high melting point, atmosphere sensitive materials. These will, in turn, evolve the development of high temperature equipment and tooling materials.

Heat sources using radiant heating, resistance heating, or induction coils are needed to heat treat "localized" portions of assemblies too large for furnace treatment. Specialized automatic heat sources must be developed for preheat, stress relieving, and heat treatment in welding fixtures.

Thermo-chemical techniques could be developed to provide a controlled atmosphere around workpieces, allowing utilization of existing furnaces and facilities for the bright heat treatment of nickel and cobalt alloys. These techniques could eliminate pickling requirements. These same techniques might be used to provide a protective coating on tungsten and molybdenum by metal diffusion at high temperatures. Fluidized bed systems could solve the problem of fast heat-up rate, temperature uniformity and quenching rates during heat treatments of advanced alloys. (A fluidized bed system consists of a furnace in which inert particles such as sand are suspended by the heating gas.)

METAL REMOVAL METHODS



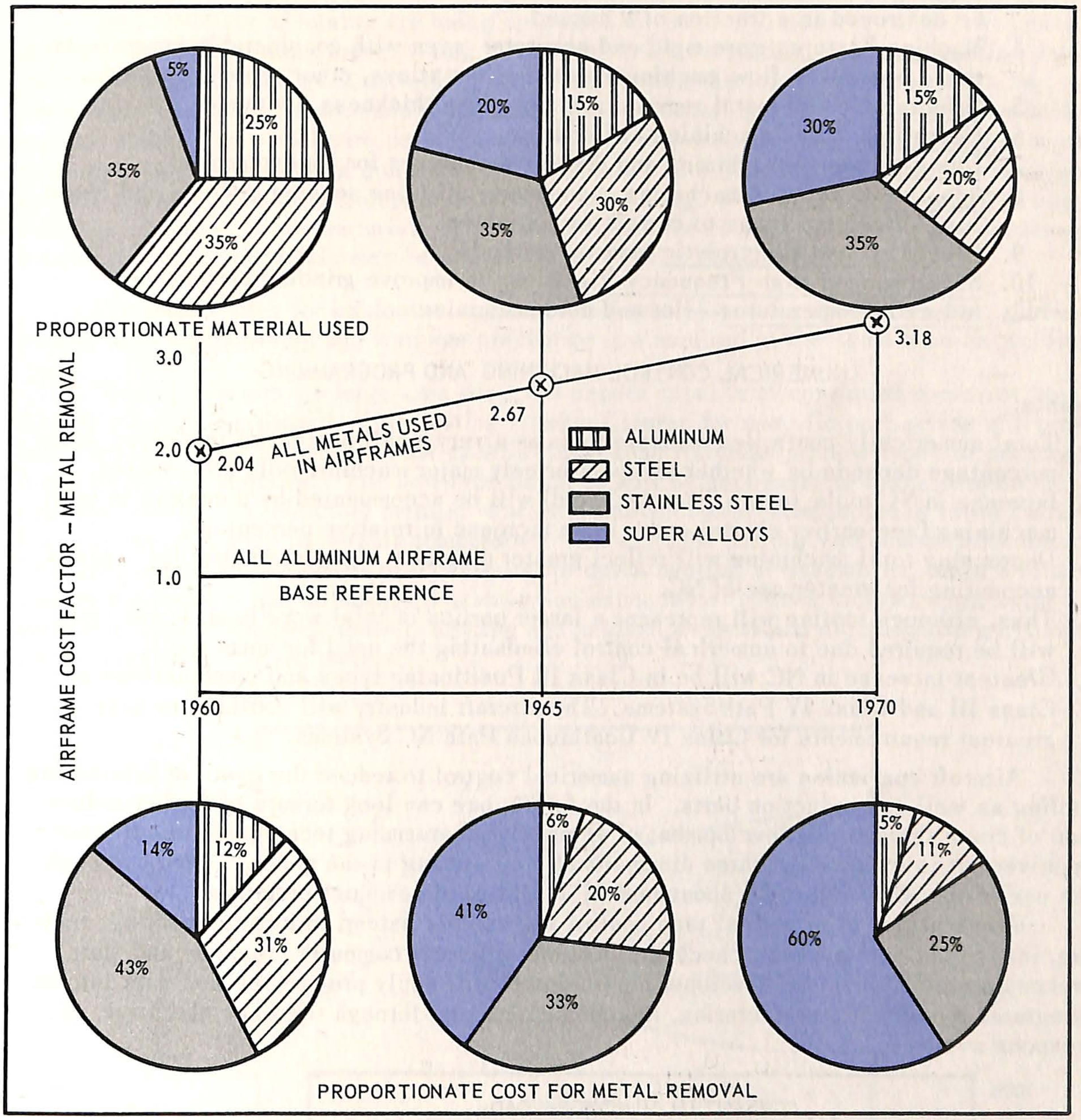
REMOVAL METHODS TRENDS

The trend is away from conventional cutting equipment, particularly in environmental problem areas. Some operations such as shearing, blanking, and machining presently performed at room temperature will have to be done with material and tools at elevated or sub-zero temperatures. Where high temperature machining is developed for super strength alloys, methods for localized heating, sensing devices to maintain operation within plastic range, and cutting lubricants and methods of application must be developed. Many metals and practically all of the ceramics and cermets will require special machining methods. This will include ceramic tools, abrasive grinding, ultrasonic machining, chemical milling, or electrical discharge machining. A comparison of conventional, electrical, and chemical methods is shown in the graph.

Chemical milling should be further developed for use as a "finish" process to remove all excess weight from structure fabricated from high strength materials. Mechanical machining methods now used for this purpose on aluminum will not be suitable. Chem-milling equipment should be further mechanized or new techniques developed to provide the contouring of complex tapered surfaces including honeycomb and other core materials. Masking techniques must be improved. By 1970, 25 percent of chemical milled parts will require tolerances of 0.001 to 0.002 inch, and 50 percent will require tolerances of 0.002 to 0.005 inch.

Development of tools and equipment to support electrical metal processes is progressing at a rapid rate. Previous limitations are being overcome in new equipment designs; but the emphasis is still on (1) improved metal removal rates and reduced tool wear in electrical discharge machining, and (2) better electrode designs and electrolytes in electrolytic cavity machining.

Industry shift from aluminum alloys to greater proportions of high-strength thermal resistant materials is causing a continual rise in machining costs. This curve shows how metal removal costs are expected to rise during the next ten years. The top "pie chart" series shows the increased usage of the different common airframe materials and the bottom series shows the effect of this proportionment on cost of metal removal. Note that the cost of machining varies considerably among airframe materials. By 1970 nearly



REMOVAL RATES VS COSTS

30 percent of all metals used for airframes will be super alloys. At the same time, metal removal costs for these super alloys will require 60 percent of the total funds earmarked for all types of metal removal.

As the hardness of the new alloys increases, machining these and the non-treatable and refractory metals will require special attention in the following areas.

1. Machine Tools more rigid and smoother running.
2. Flexible Spindle Speeds of 30 to 10,000 RPMs.
3. Cutting Tools harder, tougher, more rigid, more accurate, and longer lasting using diamonds, improved ceramics and carbides. Numerical controlled machine tools are now in use with motion in five axes, but cutter geometry and development have not kept the pace. By using a machine tool well within its

hogging capability, but way beyond the cutters's, any now known cutter may be destroyed in a fraction of a second.

4. Machine Fixtures more rigid and accurate; even with considerable progress in these areas, the flow machining speed of the alloys, other removal methods.
5. Grinding for high metal removal rates to close thickness tolerance
6. Ultra-High Speed machining and drilling
7. Close-tolerance machining and drilling techniques for honeycomb
8. Adaptive Control of machining operations - utilizing sensing devices and feedback correction loops to correct for variables
9. Electrical and Electrolytic removal methods
10. Superimposed High Frequency Vibrations to improve grinding performance
11. Induced Temperatures - Hot and cold machining

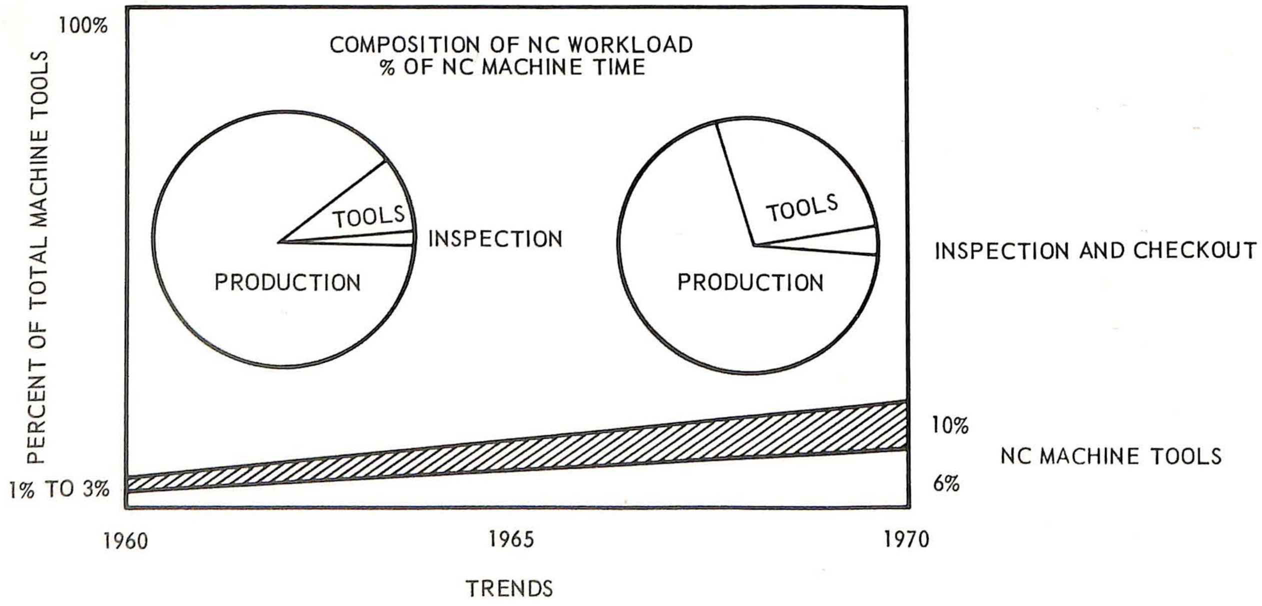
NUMERICAL CONTROL MACHINING AND PROGRAMMING

Points:

1. Total numerically controlled machine tools is a very small percent of total now; exact percentage depends on whether all tools or only major machine tools are counted.
2. Increase in NC tools (approximately 3-fold) will be accompanied by a decline in total machining (see earlier charts) and a large increase in relative percentage.
3. Decreasing total machining will reflect greater diversity of parts, smaller lot sizes – accounting for greater use of NC.
4. Thus, although tooling will represent a larger portion of total work load, fewer tools will be required due to numerical control eliminating the need for some tools.
5. Greatest increase in NC will be in Class III Positioning types and combinations of Class III and Class IV Path Systems. The aircraft industry will continue to have greatest requirements for Class IV Continuous Path NC Systems.

Aircraft companies are utilizing numerical control to reduce the costs of fabricating tooling as well as production parts. In the future, one can look forward to further reduction of costs through the development of automatic programming techniques. Significant improvement is expected in three dimensional programming in the next two years through the use of the Air Force, AIA sponsored APT system of computer programs.

Applications of numerical tape control will rapidly extend to lofting, drafting, testing, inspection, and systems checkout. As more efficient computer programs and data processing techniques are developed, the industry will apply pre-programmed data into an integrated system of manufacturing, from design concept through the final checkout of weapons system.

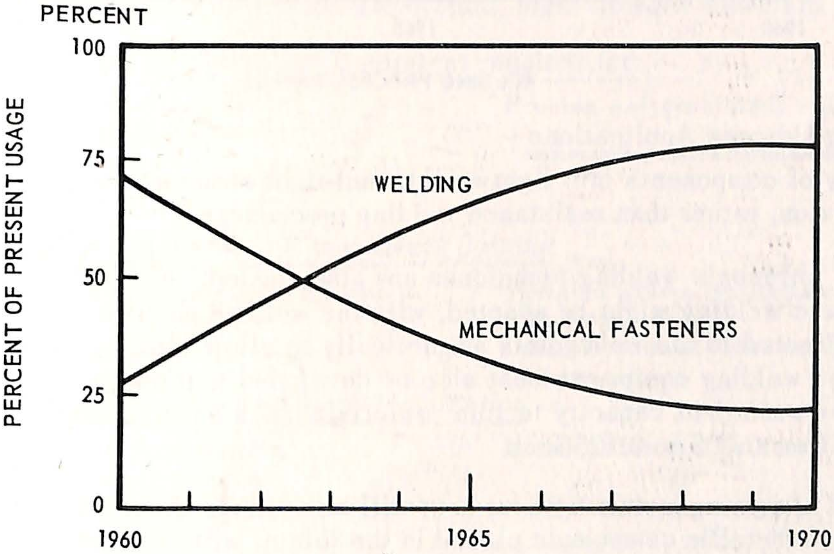


JOINING

Many methods of joining are being up-graded as greater joint strength requirements are foreseen. To obtain proper joining by such methods as bolting, bonding, brazing and welding, complications such as tooling instability during the joining process must be overcome. Clamping fixtures and positioners must be developed to provide positive holding and stabilizing of delicate parts. These will be required to enable attainment of more uniform speed when welding thin sheet in thicknesses of 0.005 to 0.020 inch. Lightweight holding devices must be developed for ultrasonic welding. For weld fixtures used in sheet butt-welding, new fixture materials must be developed for chilling, clamping and locating. Improved ceramic materials may be adaptable for welding fixtures.

Fixtures or dies for explosive welding will be developed for production use, particularly where part sizing and warpage prevention are required at the same time as welding.

Brazing fixtures for large-area parts and panels capable of continued operation to 3500°F must be developed. Self-heating brazing fixtures for specific part series will probably replace large furnaces. 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. Non-expendable fixtures incorporating rigid support, close tolerances, uniform heating and minimal deformation during heating cycles are needed for contoured panels.



WELDING VS MECHANICAL FASTENERS USE

Joining-Welding Vs Mechanical Fasteners

Although there will be advances in mechanical fastening, the trend toward welding, especially automatic weldments, will continue following the needs for sub-zero and high-temperature treatments of 350,000+ psi materials.

Low-Temperature Upset Riveting of 350,000 psi Materials

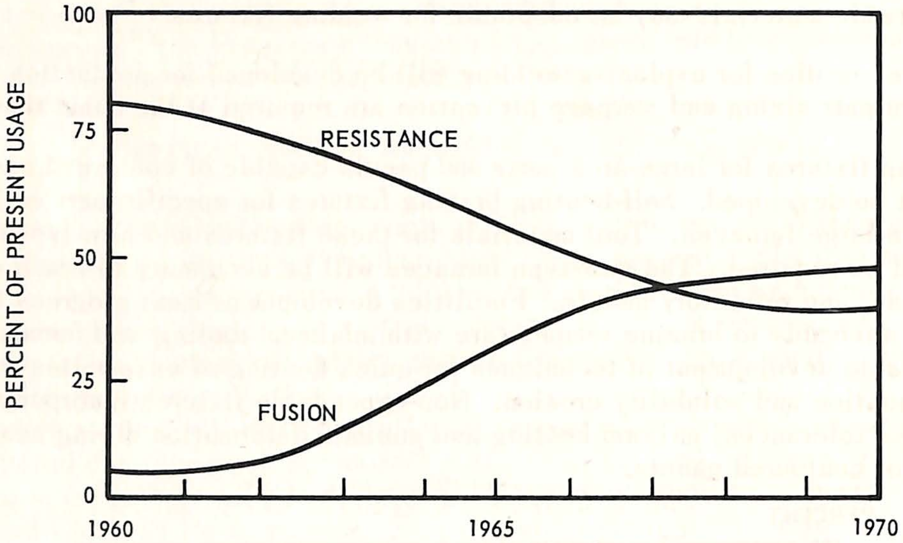
High-strength corrosion-resistant fasteners.
Squeezers and dimplers – much higher force and operating temperature.
Hot forging techniques utilizing resistance heating.
Rivets capable of one side upset only and shear strengths of 200,000 psi.
Machines requiring minimum operation space to reduce flange widths and lands.
Ultrasonic upset riveting tools.

Dimpling High-Strength Materials (Low Ductility at Room Temperature)

Cold flow dimpling — 280-350,000 psi (4 to 10 percent elongation).

Hole Piercing Methods

- Punch holes in conjunction with controlled heat cycle.
- Produce holes; assembly conditions 320-350,000 psi, tensile high-work hardening and low ductility.
- Explosive piercing.
- Electrical discharge machining.
- Electrolytic deplating.
- Ultrasonic machining.



WELDING PROCESS TRENDS

Joining-Welding Process Applications

Assembly of components into lightweight, fuel-tight structures will put increasing emphasis on fusion, rather than resistance welding processes.

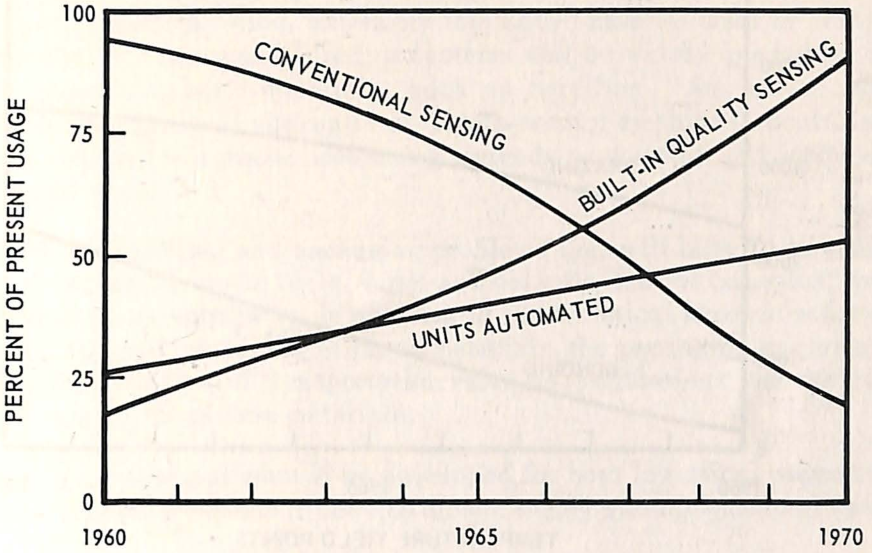
Improved ultrasonic welding techniques are also needed. For joining honeycomb panels, ultrasonic welding might be adapted, with the welding medium being powdered or granular and attracted to the weld joints magnetically to allow welding at a low temperature. Ultrasonic welding equipment must also be developed to produce consistent weld quality and have sufficient capacity to join materials such as titanium, pH steels, etc., in thicknesses from 0.005 to 0.125 inch.

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. "Braze" alloys capable of solid state diffusion will become a fertile development area.

The welding of fibrous materials used for transpiration cooling must be investigated and developed as a reliable, economical process.

Techniques and equipment must be developed for welding refractory metals to dissimilar metals, and for welding metals to glass.

High impact welding by use of explosive and spark discharge pulse apparatus will be developed. The use of metallic self-burning powder in jig and other heavy welds will come into use to save labor and time.



SENSING METHODS AND AUTOMATION TREND

Joining-Welding Sensing and Automation

The trend for increased automation and built-in sensing devices follows the need for precision and quality control in high-temperature, high-strength materials welding.

Mechanized Numerically Controlled Equipment required for:

Control of weld variables.
  Current input and time.
  Travel speed.
  Wire feed.

Precise and consistent weld quality.

Mechanized Equipment for Major Components Joining

Semi-portable inert gas, final assembly stages.
Quench and cold roller.

Portable weld-edge preparation and localized treat.
Induction heat and localized gas heat treat.

Weldment Behavior Investigation for Mechanization

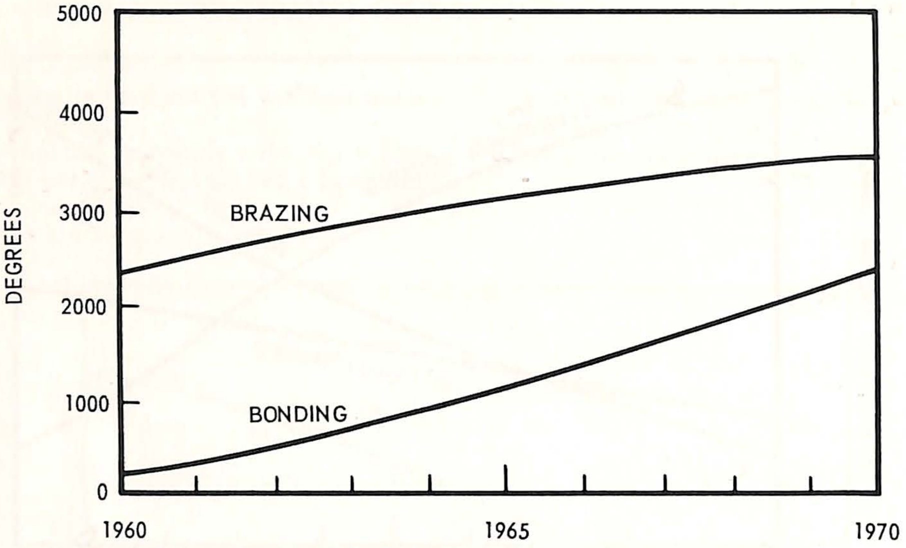
Restrained and unrestrained.
Before and after heat treat.

Localized heat treat feasibility.

Quality Sensing and Control

Built-in monitoring system determining weld quality as it is made.
Low-temperature ultrasonic or pressure welding to reduce shrinkage.

High-frequency resistance or induction heating to reduce weld areas's time at temperature.



TEMPERATURE YIELD POINTS

Joining Sandwich Panels

The joining of sandwich materials (as in metal to metal) puts increasing emphasis on brazing. However, the very nature of the sandwich construction invites further investigations in bonding, resulting in a somewhat parallel development trend.

High-Temperature Brazing Problems

- Atmospheric contamination control.
- Improved facilities for new materials and larger units.
- Larger tolerances in panel details (no weight penalties involved).

Systems Development Requirements

- Environmental control to maintain purity of inert or reducing gases.
- Stabilizers evaluators for node flow and diffusion control.
- Control of rapid cooling rates for superior material properties.
- Portable brazing units for localized brazing of large final assembly panels.
- Detail parts fit-up, reducing filler alloy.

Panel Bonding Requirements

- New tooling concepts for new designs and materials.
- Emphasis of ceramic adhesives replacing organic metallics.
  - Bonding extremely large contoured parts and assemblies (wings or fins).
  - Steels and structures withstanding 500^{o}F and above.
- Lightweight curing fixtures with thermal properties similar to material being bonded.
- More economical and reliable structures thru mechanization and numerical control.
- Non-destructive testing systems.

MATERIALS HANDLING

Techniques and equipment will have to be developed for special handling and storing of many materials. 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 gauges; and waste disposal equipment and techniques.

Among the handling and packaging problems that will have to be overcome will be: handling-packaging of exotic fuels, large and delicate control consoles, and complete missiles and their components. In addition to the technical know-how for effective, economical handling and packaging of these materials, the packaging engineer of tomorrow will have to be familar with transportation rules and regulations and the safety rules for handling extremely dangerous materials.

Off-highway systems should be developed for both logistical support and operational maneuvers. It seems desirable to develop atomic energy electric-powered transport systems.

Support equipment will become weight-critical because of the need to "take-it-with-you" in space vehicles. Further, complication is expected as bulk is reduced – through the use of collapsible structures and development of miniaturized equipment. Precise manufacturing techniques will be required to attain the required degree of reliability. Remote controlled ground equipment will be required for nuclear powered vehicles. The design of the remote control systems will add to the manufacturing complexity of this equipment.

PRESSURE VESSEL FABRICATION

Fabrication of pressure vessels is oriented toward solution of problems associated with both non-metal and metal vessels. Nearly all vessels presently proposed or actually in the development stage will be required to store either liquid propellants, solid propellants or other rocket fluids for extended periods.

Basic work in non-metal vessels will be mainly concerned with fiberglass filament wound vessels. Methods will have to be developed which will allow mass production of these vessels in one continuous closed-end unit. This will require either breakable, soluble, or meltable mandrels for small vessels and light foam or breakdown mandrels for larger vessels. Winding equipment will also require intense investigation. It must be versatile to the extent that it can be used for both R and D and production. Other means than ovens will have to be found for curing these vessels because as the vessels become larger it will not be feasible to purchase or build larger and larger curing ovens. A rapid means of curing while the vessels are on the mandrel must be found. Lastly, non-destructive testing will have to be perfected if mass fabrication is to become reality.

Just as differences in size present future challenges in non-metal vessel fabrication, so too, is the problem of developing large metal vessels. Future requirements call for large, thin-wall, balloon type metal vessels. Not only are we presented with the problem of vessels which are not self-supportable but these vessels (some as large as 350 inches in diameter and up) will require machining. Because of their large size and "non-self-supportability," before loading, future vessels may be assembled and tested at the launch site. Also, these vessels will have to be used in the as-welded condition (without heat treatment). To sustain great loads, joint problems arise, which require stiffeners and doublers, and these in turn will require combinations of fusion and resistance welding. Because of extremely low operating temperatures these vessels will require jettisonable external insulation systems and internal insulation systems which are impervious to a variety of fluids. To avoid contamination, which is highly critical because of chemical reactions with the propellant, extreme cleanliness will be necessary in vessel construction.

Fabrication materials will be alloys such as all Beta titaniums. These alloys are applicable for both liquid and solid propellant systems. Too, liquid vessels will be pressure stabilized structures and the greatest challenge lies in the future ability to handle the vessel during fabrication, assembly, erection and test.

ELECTRICAL HARNESS AND CABLE FABRICATION

Electrical components and wiring which can withstand temperatures up to 2000°F will be needed. The requirements are so severe that a complete revision of wiring concepts is foreseen. This may include (1) all-welding wiring terminations (no connectors), (2) insulations encased in pressure sealed metal jackets to exclude moisture, (3) components that must be heated to over 1000°F and then sealed, and (4) potting compounds that require several curing steps at temperatures up to 300°F. The primary problem areas appear to be welding methods and handling-installation procedures. The type of electrical wiring employed in such high temperature areas may not be adaptable to automatic processing equipment, thus requiring emphasis on skilled manpower rather than automated equipment. The number of such components and harnesses per vehicle is quite limited, so that new manufacturing methods must be geared to low volumes.

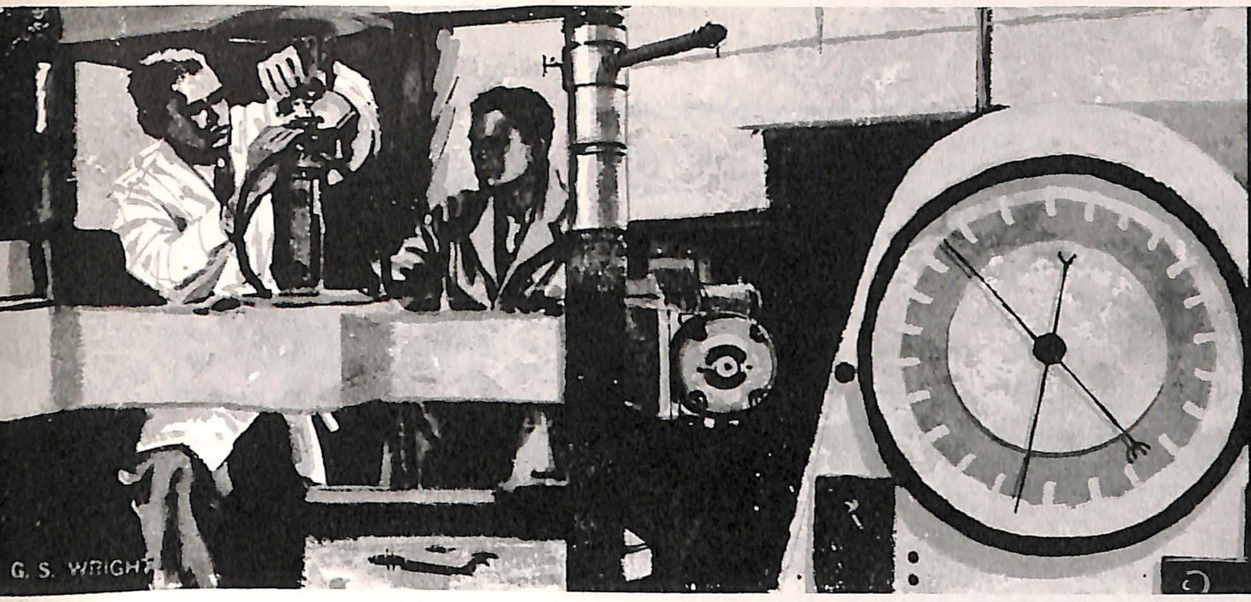
Conventional wiring harnesses will be phased out in favor of flexible ribbon circuitry for connections both within and between component packages. Flexible etched circuits, primarily for use within, will require more etching facilities in place of present shop package wiring operations.

In the ten-year period, there will be further development of flexible and/or multiple layer circuit cards. The associated processes and equipment for operating temperatures in the 1000°F range will be needed. 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 1000°F range.

A method must be developed for manufacturing potted and encapsulated assemblies with emphasis on ease of repair and modification, while maintaining system reliability. As electronic equipment becomes more sophisticated, the "throw away" concept of defective components becomes too expensive and repairs will definitely have to be made.

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 developed to improve present types of circuit cards for operating temperatures in the 700°F range.

Because of more sophisticated circuits and limited production runs, there is a mandatory requirement for "component checkout" under operating condition to increase reliability and reduce inspection time. The equipment required should be of the Numerical Control type, as opposed to continuity checkout; that is, predicted performance of components should be programmed into a pre-recorded process for operating the inspection equipment.



SECTION

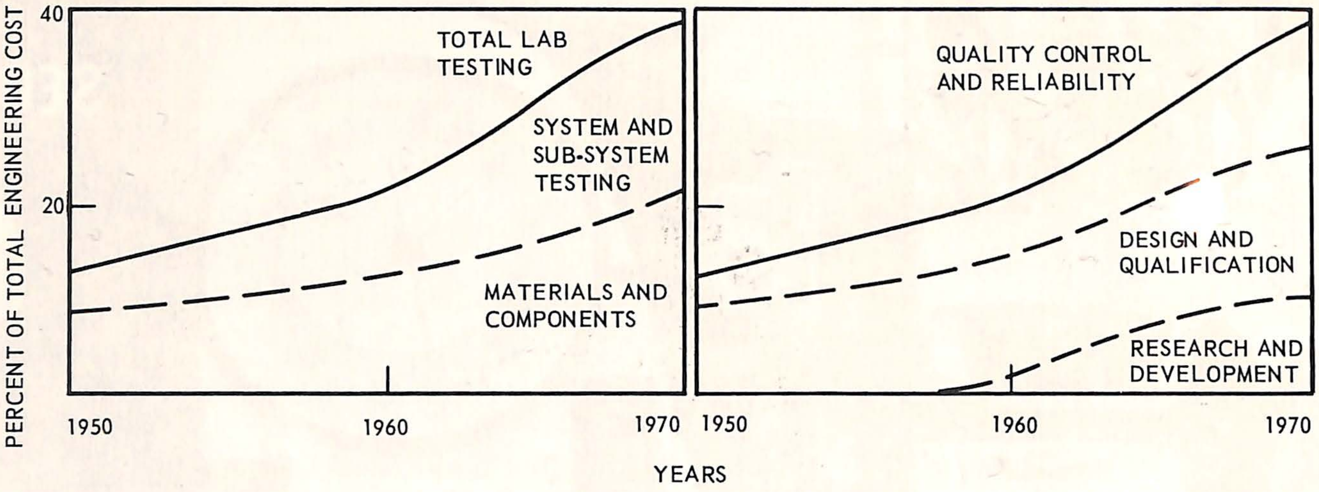
6

Testing

Testing is an integral part of the aerospace product cycle. Beginning with the laboratory investigation of materials, processes, and lately, human factors, testing accompanies the product through concept and design, through manufacturing and checkout, through development and verification, and even as a daily requirement of operational life.

The following pages consider the three major aspects of testing; in the laboratory, in conjunction with the manufacturing process and in support of field operations. Each area creates its own requirements and developmental needs. Major considerations during the next ten years are: the new environments created by our entry into space (Section 1) — the tantamount requirement for the ultimate in reliability — the emphasis on cost reduction.

Meeting the environmental requirements, both in terms of laboratory simulation and field equipment capabilities, will dictate new design concepts. The stress on reliability requires that test equipment stay several steps ahead of the best in airborne systems. Such adjuncts to reliability and simplicity as solid state devices, modular design, self-test features and improved accuracy must be incorporated. The stress on cost savings will be all the more stringent in view of the demands for greater capability, automation and related increases in personnel skills.



LABORATORY TESTING TRENDS

Revolutionary changes in the nature and performance of flight vehicles will continue during the next decade, and will be accompanied by a marked increase in the amount of experimental effort in vehicle systems development. Increased performance requirements have embodied higher operational stresses, new environmental regimes, and greater reliance on vehicle system automaticity and reliability rather than a human pilot. These, together with the increasingly prohibitive cost to verify or extrapolate laboratory results by flight testing, have necessitated major changes in laboratory testing philosophy, which is being evidenced by more stringent laboratory test requirements in procurement specifications. These changes have considerably lagged vehicle development requirements, and the testing trend will show its greatest change during most of the next decade.

The primary goal is to greatly increase confidence in laboratory experiments as assurance of operational performance and reliability. The most significant trends are in four categories.

Increased experimental research and development of components prior to system design and evaluation.

Increased system testing with close simulation of operational conditions.

More accurate and complete simulation of operational and environmental stresses, combined where possibility of interrelated effects exists.

Greater emphasis on correlation between flight and laboratory tests, and on realistic design of laboratory test conditions and procedures to represent flight objectives, operations, and environmental regimes of an individual vehicle system, to best identify effects of stresses on performance and reliability.

EXPERIMENTAL FACILITY REQUIREMENTS

A major percentage of the growth in laboratory testing is in technical areas requiring development of new experimental tools and techniques. Each of the significant testing trends prescribes a capability beyond past facility requirements.

> Increased system testing prescribes facilities of larger physical capacity equipped with extensive accessory equipment for systems operation, control and measurement.
>
> More accurate and complete simulation involves complex combinations of environmental variables programmed to simulate operational flight regimes, and advanced instrumentation techniques for data acquisition and reduction. Space vehicle environment simulation and variables measurement require radically new facilities technology in the advanced physical sciences.
>
> New vehicle propulsion and power media involve facilities for storage, conditioning, distribution and control of high energy fuels, cryogenic fluids, special lubricants, high voltage D.C. and R-F power, and nuclear energy sources.

Ground Environment simulation developments will be largely limited to increased size or capacity to accommodate major portions of the vehicle system. The greatest needs for improvement are in categories of vibration, shock, acoustics, and combinations thereof.

Atmospheric Vehicle Flight simulation will generally not require new facilities, except for (1) capacity and (2) combination of aerodynamic heating with other thermal and structural effects variables, respectively.

Space Vehicle Environment simulation will account for the bulk of facility development activity in the 1960 – 1970 period. Space regime variables are unique with relatively unknown effects, and vehicle launch, boost, re-entry and recovery phases induce higher energy levels of vibration, acceleration, shock and aerodynamic heating when traversing through atmospheric regimes.

System Operating Media for new vehicle types require development of specialized generating, storage, distribution and control equipment to provide media for operation of systems or components during test.

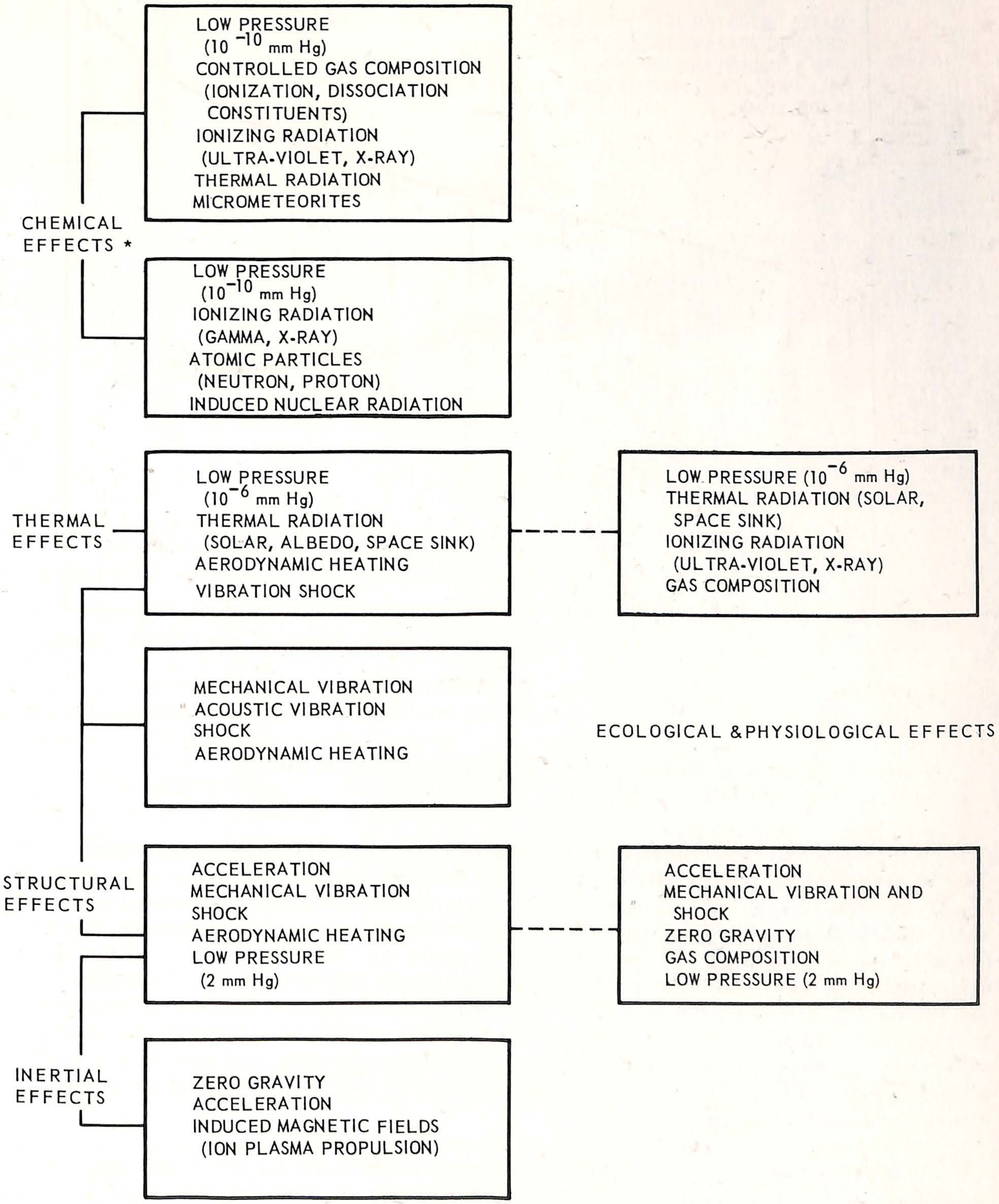
> Cryogenic facilities to supply liquified gases or high-energy fuels at extreme low temperature (-320° to -450° F).
>
> High pressure pneumatic facilities (3,000 – 10,000 psi) for air, nitrogen, helium and other gases.
>
> High temperature hydraulic facilities (275° – 1000° F).
>
> High velocity, high temperature gas flow facilities at relatively low pressure.
>
> High capacity, specialized A.C. and D.C. power sources.

COMBINED ENVIRONMENT SIMULATION

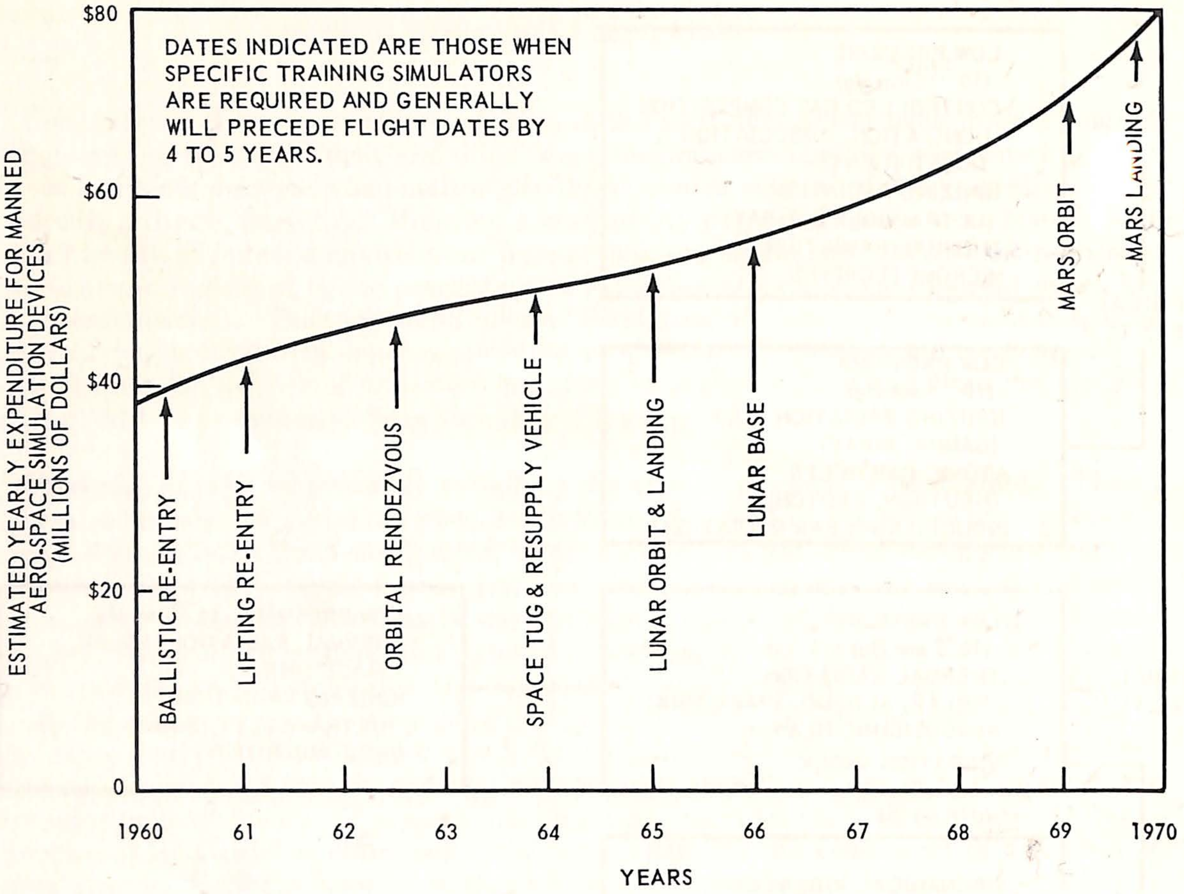
Combination of environmental variables in the past decade has been largely limited to the category of interdependent variables (e.g., temperature-humidity, temperature-altitude), and to an increasing extent, combination of vibration with several of the natural variables: temperature, altitude, humidity. Missiles and similarly propelled space vehicles encounter increased levels of induced environment from propulsion media and transitional regimes, and the ultimate regime of space presents new variables of natural environment which are highly interdependent. Thus the trend toward simulation of combined environment will be primarily in conjunction with space vehicle developments. Technical and economic problems will limit the number of variables combined in practical facilities, and the scale of tests (components or systems) for which they are designed.

Prescription will be primarily guided by the type of problem to be studied. Thus only a limited number of variables need be combined for each of the somewhat separate chemical, thermal, structural and inertial effects areas. Within these categories practical problems will require some further division, and other combinations will be required for overlapping problems; particularly the ecological and physiological problems of manned flight. The following chart illustrates this approach; the variables in each block being representative of a desirable and currently feasible combination in a single facility. Although the extent of combination indicated is justified for environmental effects research, it currently does not appear economically practical to apply such extensive combinations to large scale vehicle systems development except perhaps on a "single facility for industry use" basis. Thorough investigations must be made to evaluate (1) the relative merits of single vs combined variables testing, (2) the component or system level at which combined effects must be evaluated, and (3) the effect of individual vehicle system objectives or characteristics in determining the value of combined simulation.

During the next decade, unmanned orbital "space laboratories" will allow limited experiments within complete space environment. By 1970, manned space laboratories will provide comparative data for improved simulation and effects study.



* (MOLECULAR SURFACE EFFECTS, FRICTION, CORROSION, EROSION)

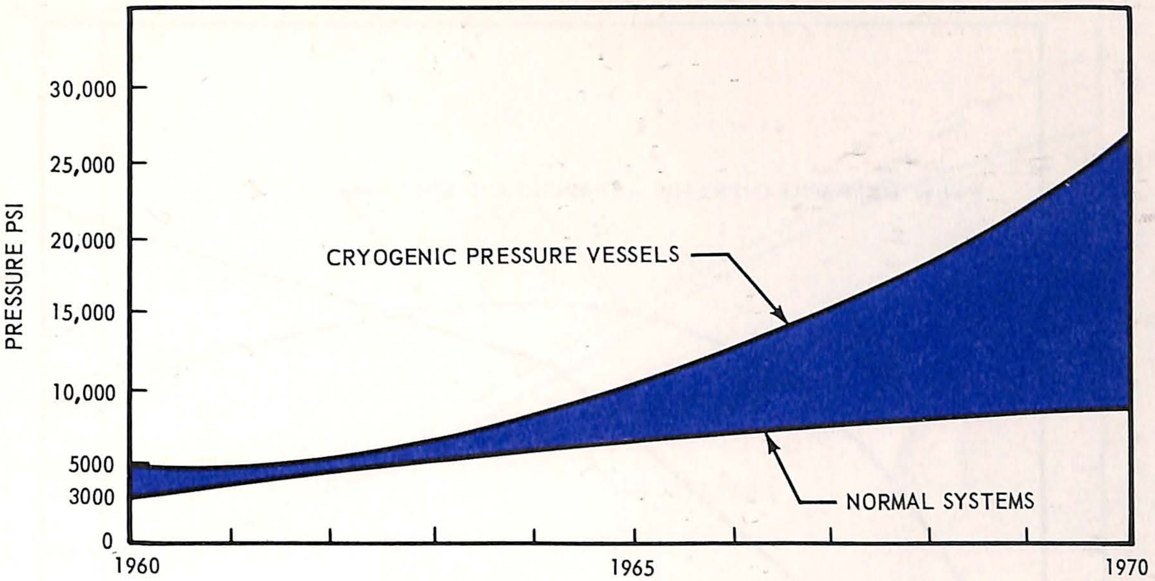


SIMULATION FACILITIES FOR MAN-VEHICLE EVALUATION

With the increasing complexity and operating costs of manned aero-space vehicles, there is generated an ever-expanding requirement for high fidelity flight simulation both from the research as well as training view points. More knowledge is needed as to man's ability to control and navigate these vehicles throughout the entire mission profile and to cope with emergency conditions while under the combined stresses of hyper-environments. Considerable data are available on man's performance and capability under individual stresses, but very little is known on his performance under combined stresses such as noise, vibration, acceleration, high temperature, isolation, etc. As man's performance is not adequately expressable for analytical solutions, real time flight simulators are needed from the study and design phases of vehicle development up to and including complete mission flights.

In addition to research simulators a requirement will exist for elaborate training simulators or "holding facilities" at launch and recovery sites of rocket boosted vehicles to develop and maintain crew efficiency. The present annual expenditure of approximately 40 million dollars for aero-space simulation devices may be expected to double over the next ten years as flight training becomes more expensive and an increasing number of manned space flights are programmed.

Note: See also pages 20 thru 22, Human Systems, Training Equipment and Training Skills.



PNEUMATIC TESTING

Size and complexity of test equipment will increase approximately 300%. Requirements will include the simulation of aero-space conditions and actual rocket systems.

Larger pressure vessels and tubing systems used with new fuels and cryogenic applications will be tested with inert gases to reduce contamination.

Increased pressures and temperatures will demand foolproof safety devices. Automatic shut-down and malfunction detection systems will be required. Test facilities will require improvements to reduce dangers.

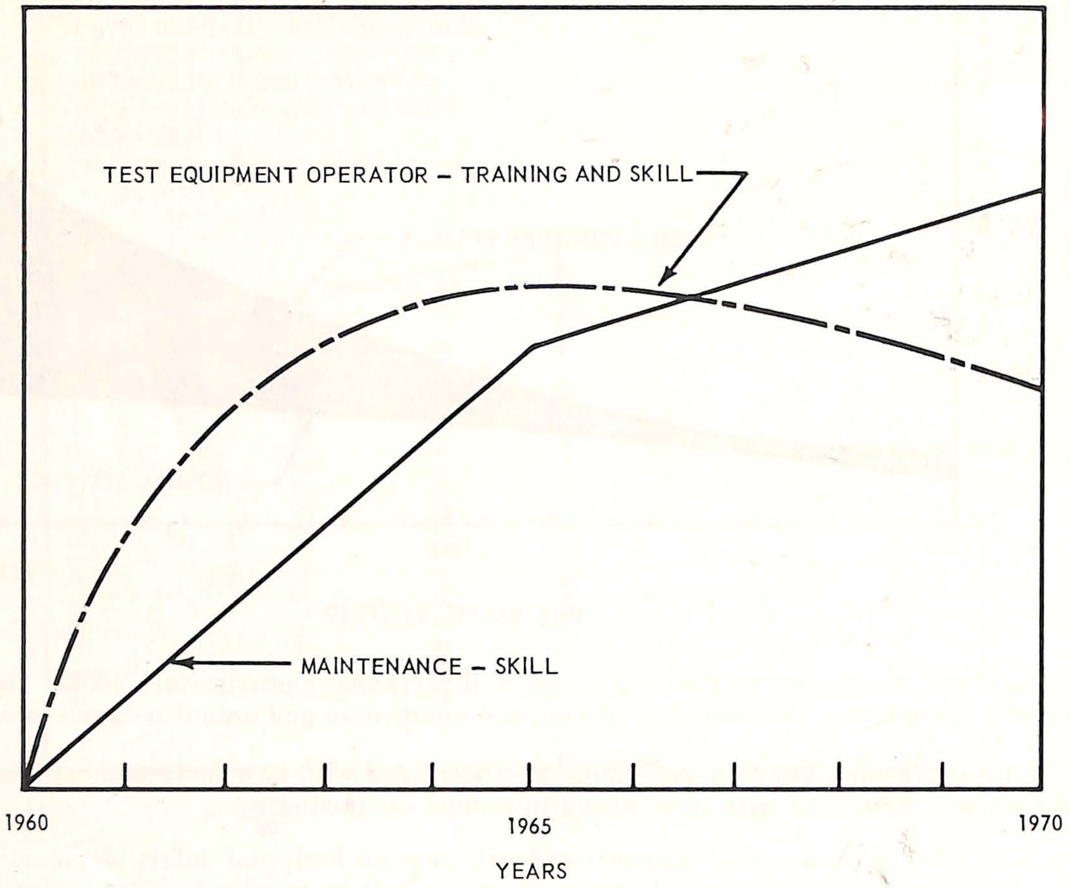
Higher pressures will be obtained by cascade booster or compressor systems. Gas streams will be "polished" by improved molecular sieve desiccators.

To keep pace with new system requirements, test equipment will require a great improvement in dynamic seals, continuous monitoring of gas streams for contaminant detection, greater resolution, improved repeatability, higher degree of sensitivity, and improved instrumentation accuracy.

Because atmosphere sensing devices will be operating in vehicles at higher altitudes, additional emphasis is required on pressures and increments in the range of .01 to 2.0 inches of mercury absolute.

Primary standards and working instruments with accuracies, sensitivity and repeatability to better than .0001 inch of mercury are envisioned.

Increased complexity of test equipment, additional safety requirement and high pressure hardware will contribute to the anticipated higher cost of test equipment.

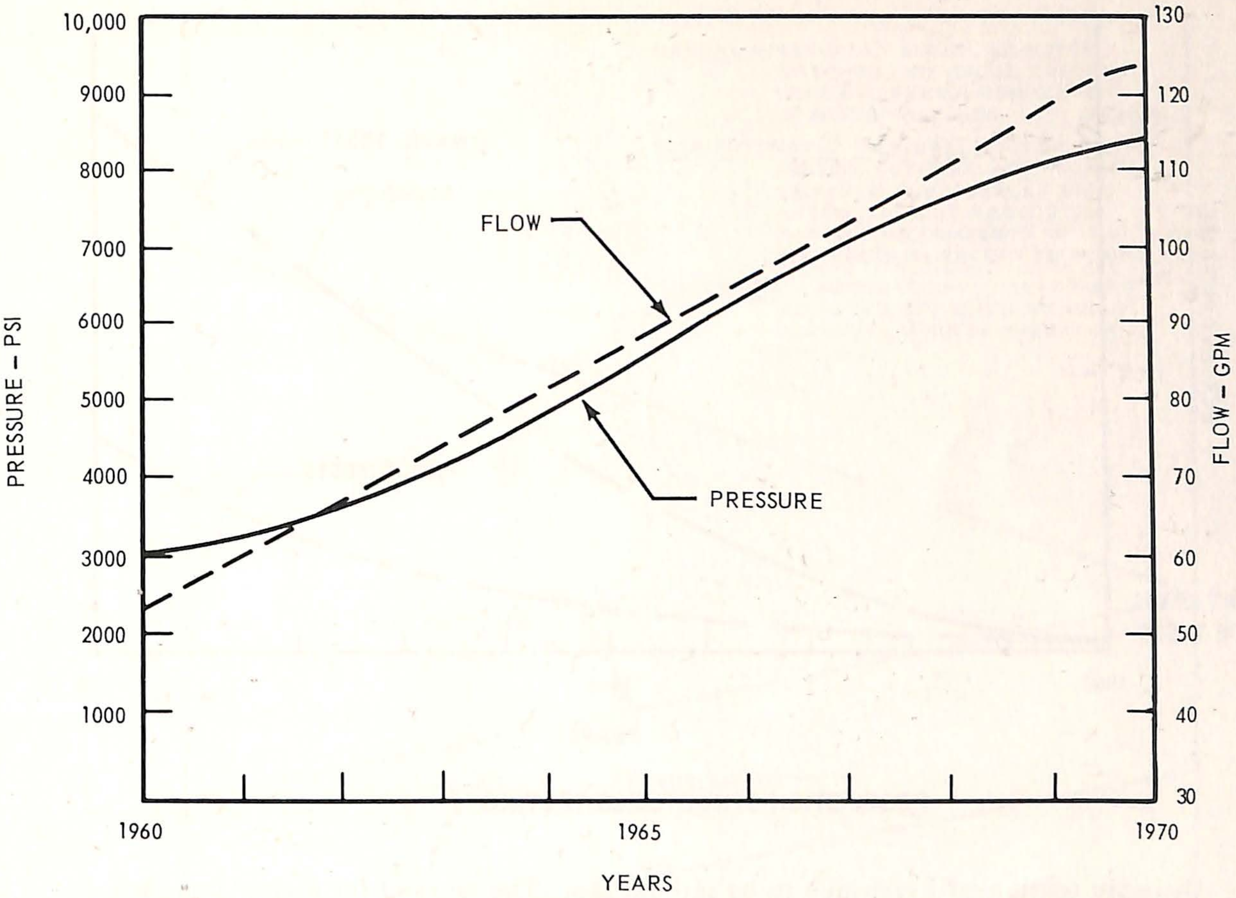


TEST EQUIPMENT PERSONNEL SKILL LEVEL REQUIREMENTS

Increased automation, complexity, state of the art, technology, and fabricating skills and techniques will necessitate the employment of higher skilled technicians in test equipment fabrication and maintenance, and will necessitate the employment of engineer-technicians for trouble-shooting.

Advancing state of the art and technology, and decision-making circuitry in products will necessitate an increase in skill levels of supervisory engineers and subordinates employed in engineering of Manufacturing Test Equipment. Whereas perhaps 25% of current test equipment personnel are trained engineers, this figure is expected to reach 75 percent by 1970.

Operator technical training and skill level requirements are expected to increase due to pressures of automation and the need to build confidence in the man-machine relationship. Once manufacturing confidence in automated equipment has been confirmed, a gradual reduction in skill level requirement will follow. For the next 5 years, the ability of the man to verify the machine rejection appears to be a necessity. Improved reliability of automated equipment will assist in the reduction of training and skill requirements for the operator.



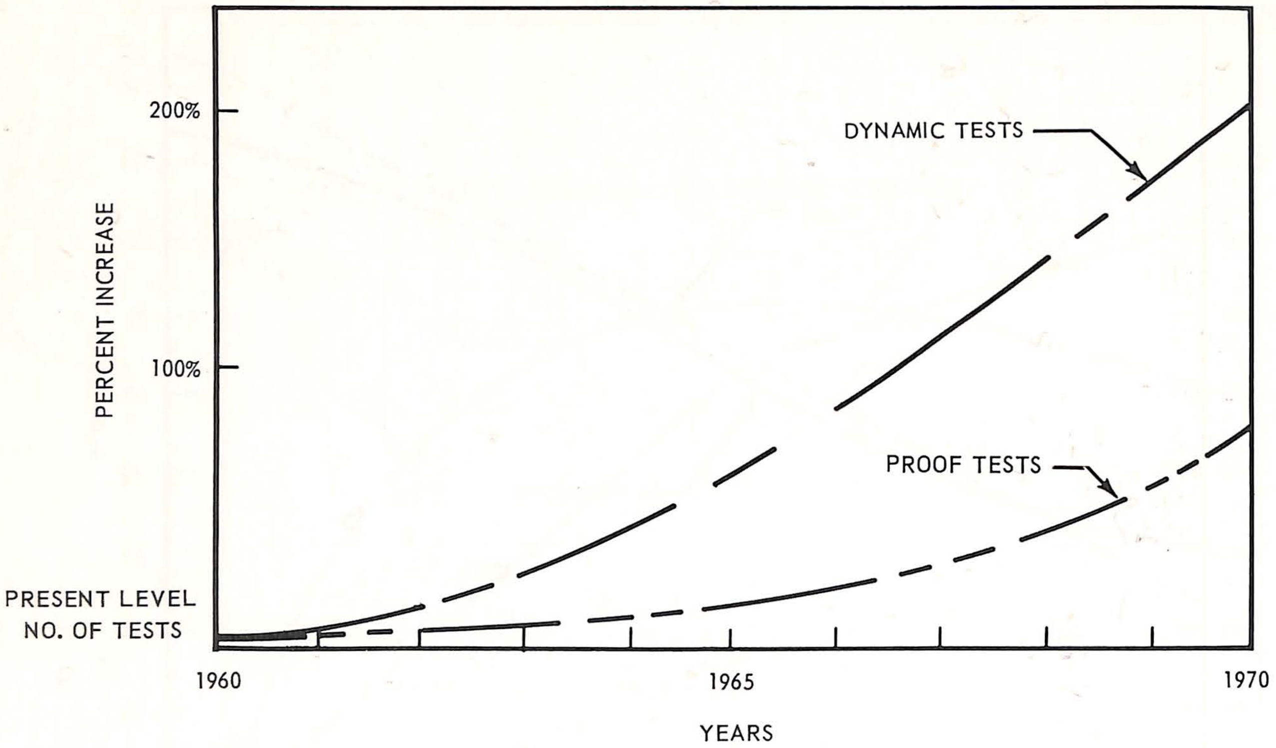
HYDRAULIC TEST EQUIPMENT

New fluids of high viscosity must operate continuously at high temperatures and high pressures. Filters of ceramic and metallic materials will be required to reduce contamination. Continuous analysis of fluid streams in test equipment is indicated. Compatibility of materials and metal seals with exotic fluids must be assured.

Improved reliability will be assured by refined design, component improvements, and self test circuits.

Training requirements will definitely be increased. Due to drastic changes in instrumentation complexity, test procedures, Hydraulic Test Equipment operators will require higher level education and continuous in-plant training will be compulsory.

It is foreseen that training requirements will increase from 50 to 80 percent above present day requirements.



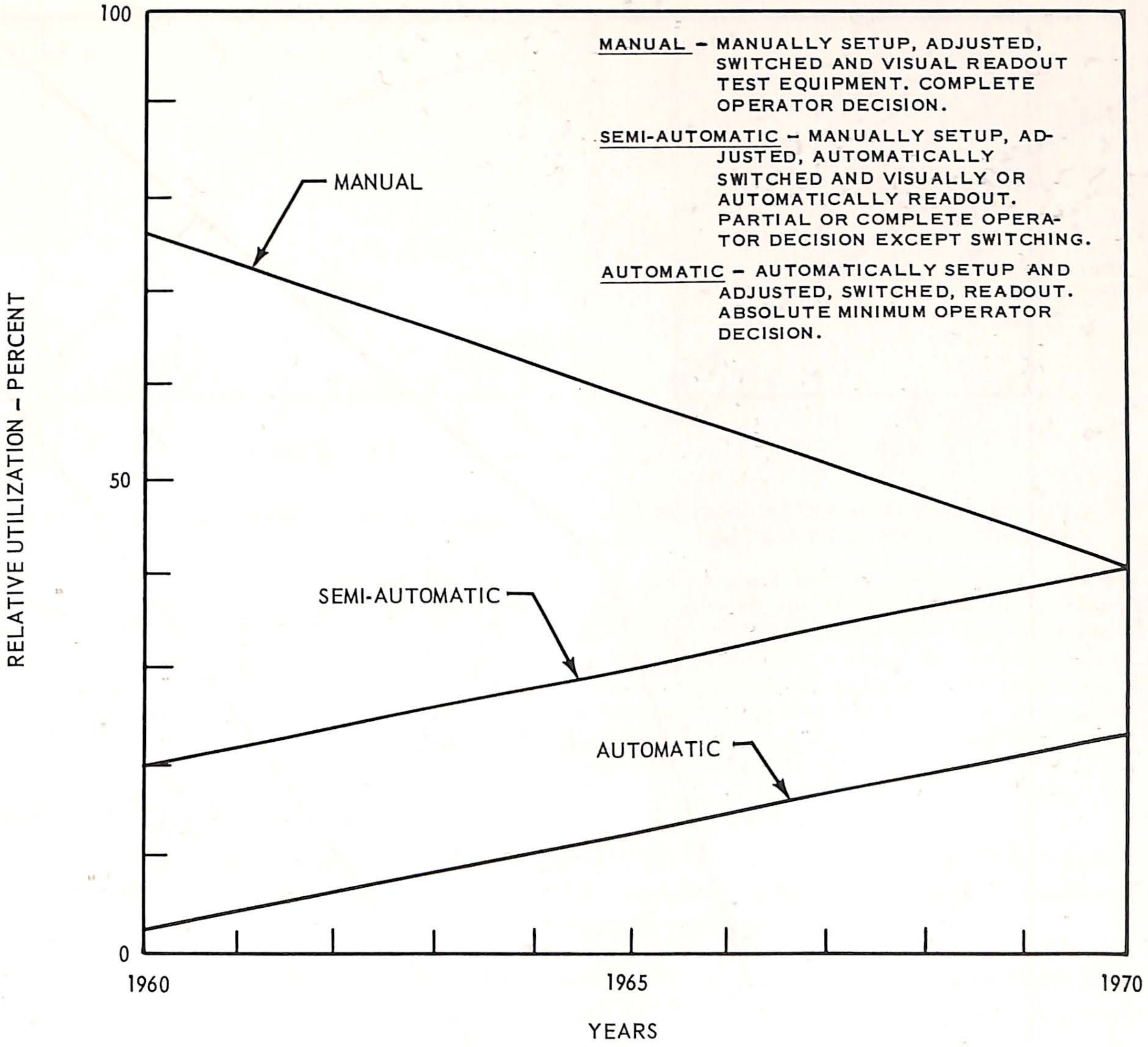
PRODUCTION STRUCTURES TESTING

Dynamic testing will continue to be intensified. The demand for higher strength, greater shock absorption, and less weight from new alloy materials will increase the need for these tests.

Captive dynamic tests of entire missiles and major missiles assemblies will be emphasized, using rocket sleds as the test facility.

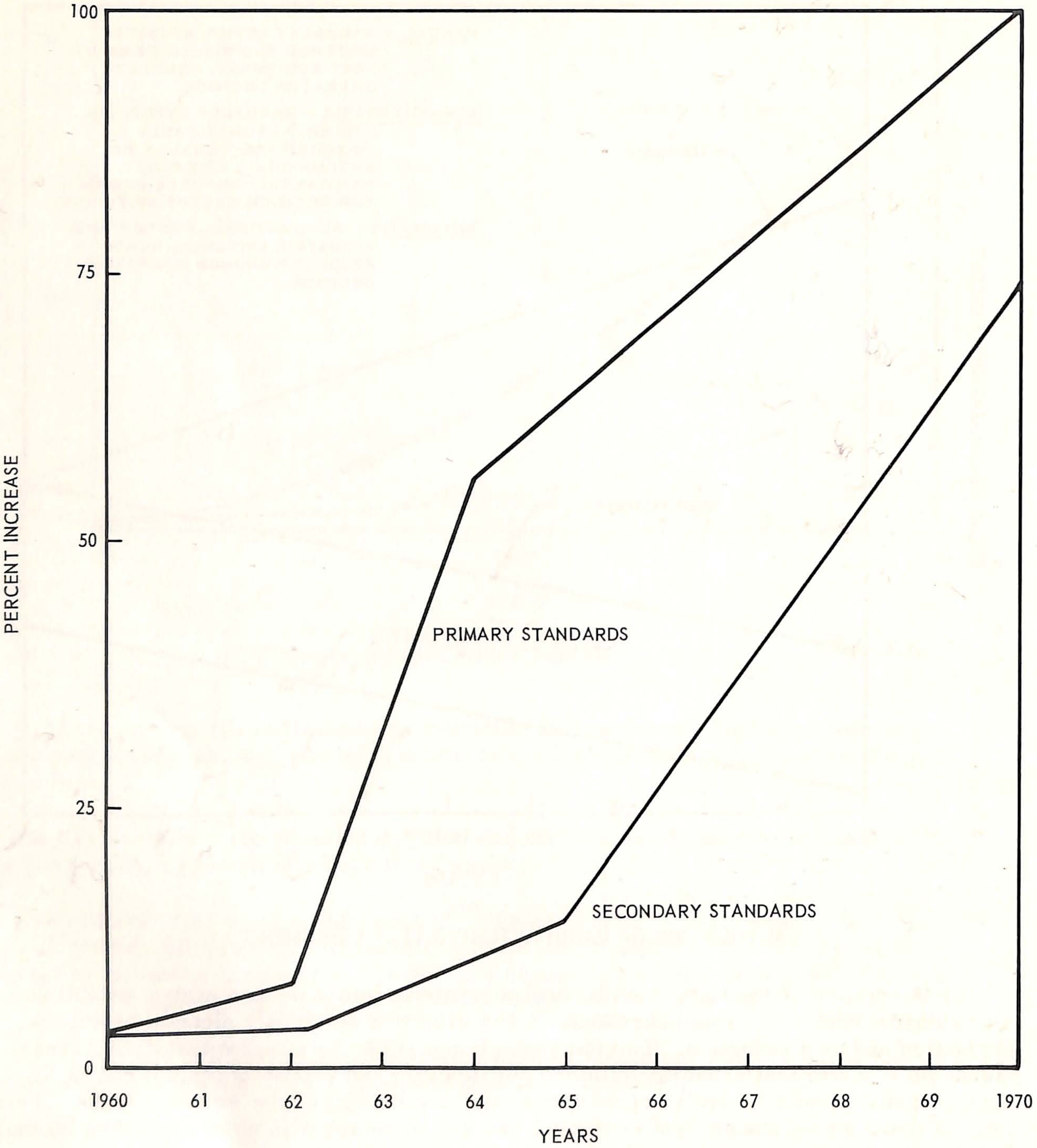
The ratio of proof tests to life tests of pressure vessels will increase. Test devices with greater reliability and sensitivity will be required to ''sense'' stress conditions prior to rupture or destruction. As the cost of fabricated items increases, a greater percentage of sectional testing will be accomplished.

Dynamic tests will be performed by automatic test equipment which will rapidly and accurately compare test data with pre-programmed standards.



AUTOMATION OF MANUFACTURING TEST EQUIPMENT

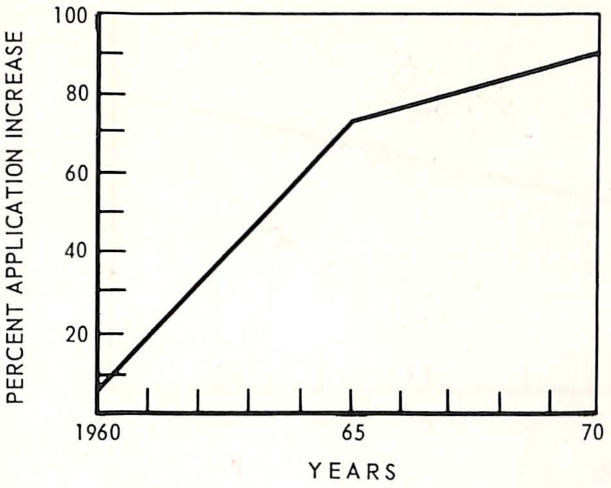
The integration of the many complicated subsystems into a weapon system establishes a new requirement - - - - rapid checkout. Automation was previously dictated by volume production and cost reduction. It is increasingly necessary to compare test data versus standards at a rate that cannot be attained physically. The volume of tests required, if done manually, would severely impair operational availability of the weapon system. Therefore, in these areas, manual test equipment use will decrease with a corresponding increase in automatic test equipment.



ACCURACIES OF STANDARDS IN TEST EQUIPMENT

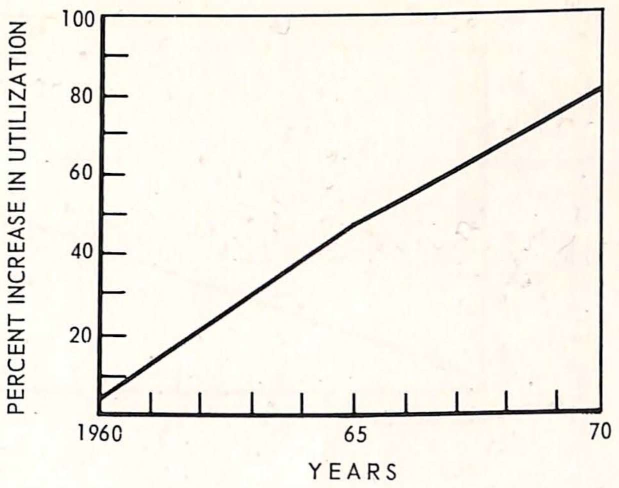
Industry is faced with an urgent requirement for improved primary standards – many areas still do not have primary standards established. Only after such primary standards are available, can secondary standards be correlated and used by industry. The secondary standards must be accurate as possible and should show continuous improvement.

SUPPORT TEST EQUIPMENT



SOLID STATE DEVICES IN SUPPORT TEST EQUIPMENT

Solid state devices perform readout functions by transforming changing conditions into frequency or voltage functions. These devices may be magneto-strictive, thermal-frequency, radiation-current, or pressure-voltage or other combination of these characteristics.



USE OF MANUFACTURING AND OFF–THE–SHELF TEST EQUIPMENT FOR FIELD OPERATIONS

A wider acceptance of manufacturing test equipment for service use is indicated. Rising costs, a direct result of increasing test equipment requirements, will dictate a need for careful study of Military specifications. This could permit the acquisition of more test equipment for an equivalent budget allocation with no loss of testing capabilities.

Support Test Equipment

Test equipment is used for preflight, postflight, periodic inspection, shop, depot, maintenance, repair, and calibration of manned weapon systems. Increasing in magnitude is the requirement for test and evaluation of missile systems.

The advent of manned space projects poses the same critical problems plus new environmental requirements.

New Conditions Will Include:

High G's required of portable space type support test equipment
Nuclear Radiation
Extremes of atmospheric pressures and temperatures
Increased levels of sonic and ultra sonic noises
Packaging limitation
(a) Environmental conditions (b) Miniaturization
Test accuracy versus weight

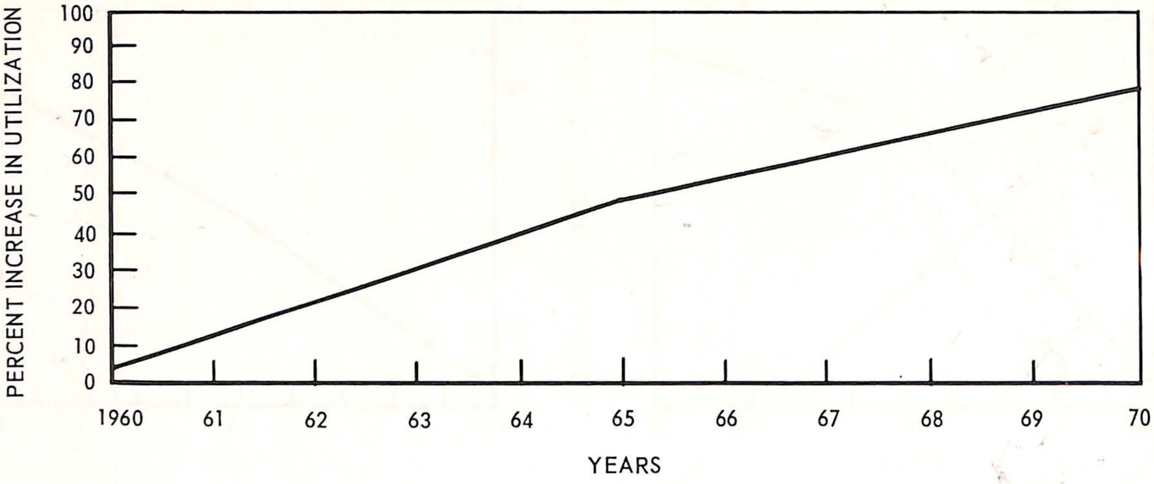
New Materials Will Be Utilized Such As:

- Solid state elements
- Ceramic coatings
- Radiation absorption
- Ultra-pure metals

Application Of New Power Sources Including:

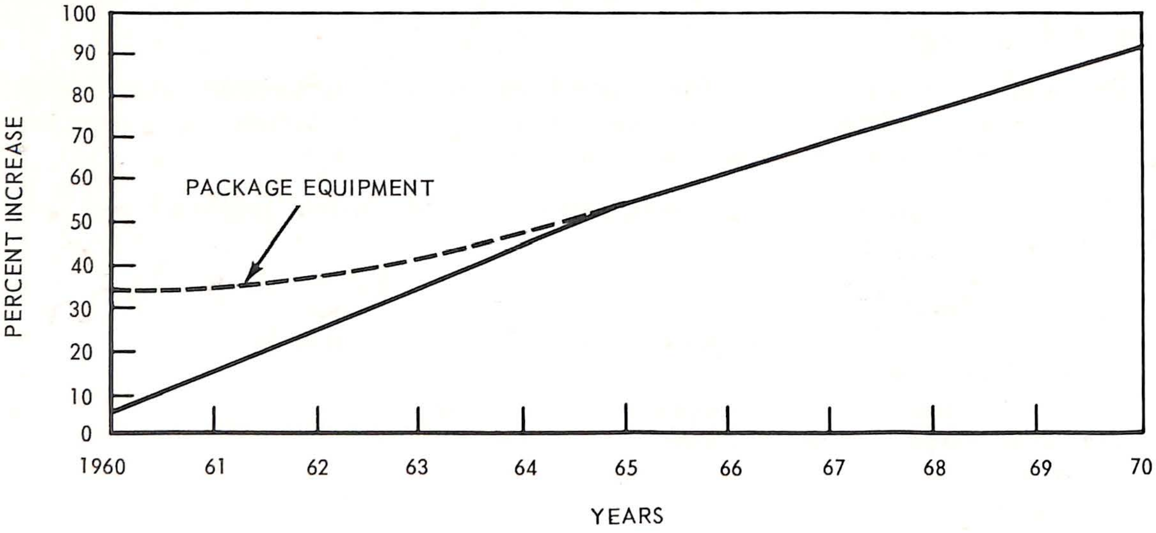
- Chemical power
- Solar conversion
- Nuclear power
- Hydrogen fusion sources are envisioned for test equipment.
- Radiation conversion

Future requirements will necessitate consideration of new conditions, accuracies, environments, endurance and skills required to operate, maintain, and transport test equipment.



USE OF MANUFACTURING AND OFF-THE-SHELF TEST EQUIPMENT FOR FIELD OPERATIONS

Rising costs, a direct result of increasing test equipment requirements, will dictate a need for careful study of Military specifications. A wider acceptance of manufacturing test equipment for service use is indicated. This will permit the acquisition of considerably more equipment for the same budget allocation with no loss of testing capabilities.



AUTOMATION OF SUPPORT TEST EQUIPMENT

The need to compare test data to known standards at a rate that can only be attained by automation will result in a steady increase in the use of automatic equipment.

The rate of increase of automation of support test equipment will be comparable to the rate of automation of manufacturing test equipment. (see page 87)

Data relating to automation (page 87), Accuracies of Standards (page 88), and Skill Level Requirements (page 84), are also applicable to Support Test Equipment and should be considered in the use of this information.

A I A

The following Technical Committees of the Aerospace Industries Association
participated in the preparation of this report

- AEROSPACE RESEARCH AND TESTING COMMITTEE
- ELECTRONIC EQUIPMENT TECHNICAL COMMITTEE
- MANUFACTURING EQUIPMENT COMMITTEE
- MANUFACTURING TEST EQUIPMENT COMMITTEE
- TOOL ENGINEERING COMMITTEE

AEROSPACE INDUSTRIES ASSOCIATION AIA