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SOME THOUGHTS CONCERNING LARGE LOAD-CARRYING VEHICLES

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SUMMARY

Some implications relative to combat operations and force sustainability into the twenty-first century are discussed. The basic conjecture is that, sometime in the future, secure oversea basing may be denied to the United States by the Soviet Union or by unfriendly, unstable governments. In that event, the support of future battle, if not the battle itself, may be conducted from the continental U.S. and would introduce requirements for large, long-range, efficient, and, sometimes, fast, air vehicles. Some unusual design concepts and the technology requirements for such vehicles are suggested. It is concluded that, while much of the required technology is already being pursued, further advances should be expected and sought in improved aerodynamics, propulsion, structures, and avionics--with a view toward increased efficiency, utility, and affordability.

INTRODUCTION

In order to consider the implications relative to combat operations and logistical support in the future, it would be extremely helpful to know what those combat forces may be required to do. While it is not at all difficult to review the combat logistical support problems of the past or to examine the current logistical environment, it must be considered somewhat hazardous to project the requirements into the future. Notwithstanding, some projections of the possible nature of future wars will be made on the basis of the military buildup, the past and present expansion trends, and on some doctrinal statements of the Soviet Union. These projections do not reflect a NASA view but are based primarily on the Department of Defense document "Soviet Military Power." Sources of information drawn on are listed in the bibliography. On the basis of "what if" situations, some possibilities for future force operations and sustainability will be indicated. In addition, some possible vehicle types and the impact of advanced technology on meeting the future vehicle requirements will be discussed.

DISCUSSION

Soviet Doctrine and Trends

Soviet military doctrine has periodically changed as their relative capability changes. In particular, the global nature of their doctrine was asserted by Marshall A. A. Grecho in 1974 when he wrote that the Soviet Armed Forces were not restricted simply to the defense of the Soviet Union and the other socialist countries but would operate in any region of the world where Soviet interest might be at stake (ref. 1).

Some past, present, and possible future areas of Soviet expansion include the control of Eastern Europe which began in the 1930's and continued with the participation of the U.S.S.R. in World War II after which several nations of Eastern Europe came under Soviet rule. The bulk of those countries formed the Warsaw Pact in 1955.

The Soviet Union, as early as 1920, aided China in the establishment of a revolutionary party along Leninist lines. After years of struggle, the communist People's Republic of China (PRC) was formed in 1949. Effective control of the PRC by the Soviet Union never appeared to exist but efforts to improve relations with China continue to be a part of Soviet foreign policy. The U.S.S.R. does have treaties or agreements with other Asian countries--North Korea, Mongolia, India, Sri Lanka, Vietnam, Laos, Kampuchea--thus a degree of control by the U.S.S.R. could exist in the Sea of Japan, the South China Sea, the Bay of Bengal, and the Arabian Sea.

Other regions of possible conflict or control by the U.S.S.R. are essentially worldwide. Soviet influence in the Middle East, Africa, Cuba, the Caribbean, Central America, and South America are apparent. While perhaps less apparent at the moment, events in the vicinity of South Korea and Japan bear watching. Thus control, either directly or indirectly, of vital points on the globe tends to increase the ability of the U.S.S.R. to control sea lanes, control the flow of critical materials, and to deny U.S. presence or influence.

Direct conflict in Western Europe which might be expected to provoke a U.S. response is an event that the Soviet Union would probably prefer to delay or avoid. The preferred approach with regard to the U.S. (and NATO nations) would appear to be diplomatic, economic, or subversive means of weakening the Western structure without giving rise to a military response. A possible sign of this type of activity is the emergence of Eurocommunism in countries where there is some communist strength such as France, Italy, Spain, and the Federal Republic of Germany (ref. 2).

Some of the major thrusts of the Soviet Union over the past four decades that appear to support their doctrine are:

- Homeland defense - continues to grow as a land- and air-based system but is also expanding to include sea-based systems and perhaps space systems.

- Multiple projection of power - new items of military equipment now indicate the potential to project power by air and sea to points far distant from the homeland.

- Increased amphibious capability - a force not generally thought of as defensive but rather for offensive power projection.

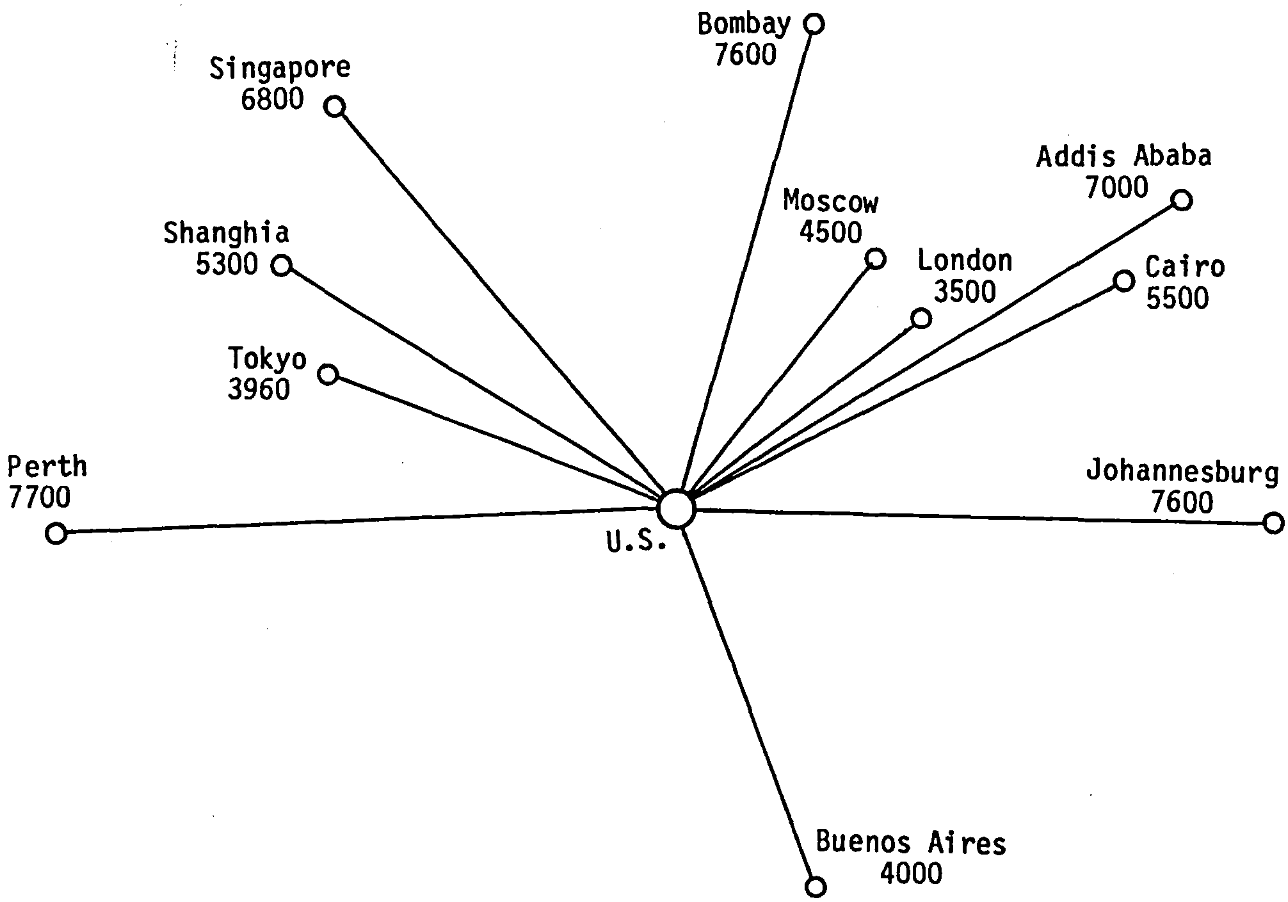
- Improved logistic support with a variety of aircraft and helicopter types (including the assets of Aeroflot). The Soviets have alluded to the development of an AN-40 airplane that would have a greater range and payload capability than the C-5A (ref. 3). The Soviet merchant marine is also among the world's largest ocean-going fleets.

- Sea power - changed over the past two decades from a force of little significance to perhaps the world's most powerful Navy.

Consideration of the Soviet trends and the commitment to military has led to:

- Numerical superiority (and possible narrowing of technology gap).
- Potential control of ground, air, sea, space, and critical materials.
- Potentially increased adventurism or boldness.
- Possible denial of oversea basing to the U.S.

If it became necessary to conduct military operations from the continental U.S., the distances involved become significant as illustrated below:



Western Response

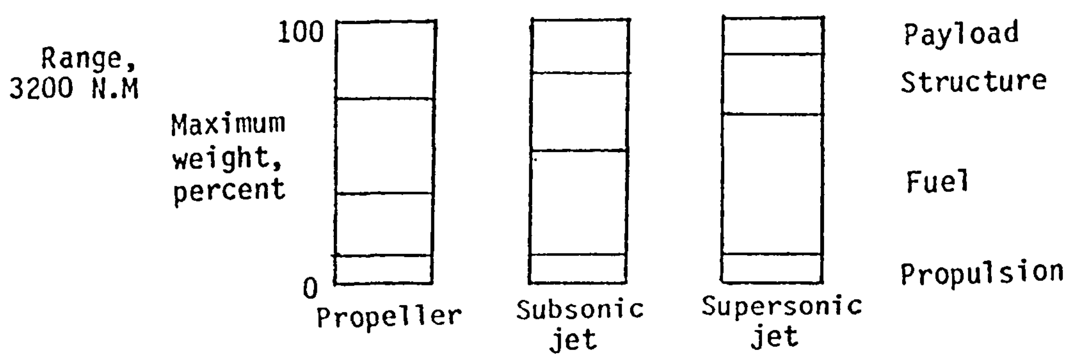
Needs and requirements.- Consideration of the potential threat to the free world and, in particular, the possibility of the denial of secure oversea basing to the U.S. suggests some needs such as:

- A creditable deterrent - meaning a force response that would result in unacceptable damage to an attacker and, hence, would tend to prevent an attack.
- A response that is rapid, flexible, and has a worldwide operational capability.
- A meaningful payload - meaning that the fraction of vehicle weight devoted to payload should be enough to provide unacceptable damage in the case of munitions, or, in the case of logistics, sufficient supplies to sustain the pace of battle.

Vehicle requirements that are dictated by these needs include long range; volumetric efficiency; endurance; speed; and basing flexibility. Variations in specific mission requirements (strategic, tactical, logistics) suggest that more than one type of vehicle may be required. The implications are that large vehicles may be necessary in order to achieve long ranges and to accommodate a meaningful payload. In addition, it may be necessary to carefully consider trades between speed (for responsiveness) and a meaningful payload.

Characteristics of Load Carriers

Some characteristics of various load carriers operating in water or air (fig. 1) show a measure of the efficiency of such vehicles as a function of speed. The efficiency is the total weight sustained (vehicle, fuel, payload), W, divided by the thrust required, T, to move the vehicle at a given speed (V). One measure of the hydrodynamic or the aerodynamic efficiency is the product of V(W/T). A theoretical constant limit line of V(W/T) for bodies operating in a fluid is included on the figure. Large ships are efficient and are tremendous load carriers but are restricted to low speeds. Submarines are less efficient due to the resistance resulting from complete immersion (as opposed to surface ships). Partially lifting a vessel from the water (hydrofoils and hydroplanes) permits increased speed but the loss in buoyancy and a generally smaller size reduces the efficiency. In free-air operation, the helicopter is relatively inefficient as a load carrier. Propeller-driven airplanes, however, produce an increase in efficiency with significant increases in velocity. With jet aircraft, speed continued to increase and the efficiency for subsonic and supersonic jets is relatively high. In the initial transition from propeller aircraft to jet aircraft, a penalty was suffered in payload primarily because of the fuel required to maintain speed and range. This is illustrated below.



Jet aircraft efficiency has since been progressively improved.

Technology Implications

The needs and vehicle requirements that have been suggested may very well lead to dramatic changes in future aircraft design and concepts. Some of the research and technology fields of opportunity by discipline areas include:

Aerodynamics

- Exploit favorable interference flow fields
- Reduce drag
- Enhance lift
- Laminar-flow control
- Aeroelastic and thermal tailoring
- Variable camber wing

Propulsion

- o Variable-cycle engines
- o Multi-mode engines
- o Propfan
- o Advanced structural components
- o Digital controls for airflow/fuel-flow management
- o Advanced and/or alternate fuels
- o Alternate power sources (nuclear, electric, solar)

Structures

- o Advanced composites
- o Advanced metallics
- o New materials
- o Superplastic forming/diffusion bonding of titanium
- o Net shapes
- o Light weight
- o High strength
- o Temperature tolerance
- o Manufacturing techniques
- o Producibility

Avionics

- o Microminiaturization
- o Digital flight controls
- o Active control systems

Concepts

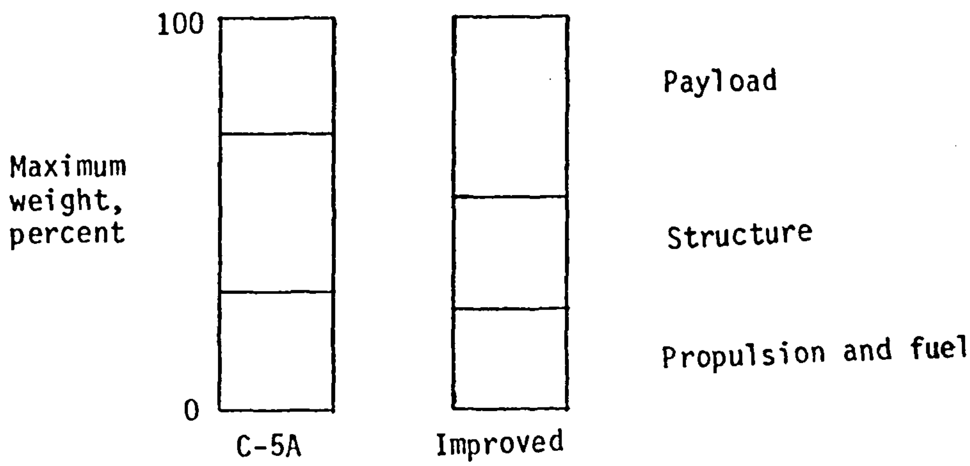
- o Blended shapes
- o Multibody
- o Distributed load
- o Airframe/propulsion integration
- o Mission adaptive wing
- o Thrust augmented lift and control
- o Simplified variable geometry
- o Basing alternatives - land/sea
- o Vertical/short takeoff and landing
- o Wing-in-ground effect
- o Air cushion
- o Modular
- o Lighter-than-air
- o Space

Integrated technologies.- Over the past several years, NASA has been conducting studies of the technology requirements and options of air cargo systems (refs. 4 and 5, for example). One NASA program was directed toward integrating several advanced technology features into a conceptual aircraft system aimed at improving the aircraft energy efficiency (ACEE). Figure 2 illustrates the program and shows some of the technologies that were considered. The expected benefits of the technologies in the form of fuel efficiency (fig. 3) can, of course, be translated directly into increased range and endurance.

Technology advances offering future gains that were identified in the 1982 study conducted by the Office of Science and Technology Policy (ref. 6) include:

- o Laminar flow control for a 20-40 percent reduction in friction drag.
- o Composite materials to reduce structural weight by 20-30 percent.
- o Increase thrust-to-weight ratios by 20 percent.
- o Reduced specific fuel consumption by 15-20 percent.

The potential effect of such improvements on the weight distribution of a C-5A-type aircraft are illustrated below in bar graph form.



Using a weight reduction of 25 percent and a propulsion improvement of 20 percent, the payload increased from about 30 percent of the gross weight to about 50 percent of the gross weight. Ranges for these weight and propulsion changes, and also for a 40-percent improvement in aerodynamic efficiency (reduced drag, improved lift) indicated the following with a 50-ton payload.

Current C-5A	-	6000 NM
Improved weight	-	7500 NM
Improved propulsion	-	7200 NM
Improved aerodynamics	-	8400 NM

These incremental improvements are not additive but, if the technologies were carefully integrated, a potential range of about 11,000 nautical miles might be achievable for an improved C-5A.

The fact that some of the benefits in reduced weight and cost through improved manufacturing and structural techniques are at hand has been known for some time. At a triservice Manufacturing Technology Advisory Group conference in Miami in November 1980 (ref. 7), for example, among the items reported were:

- o U.S.A.F. Foreign Technology Division estimates that centrifugally cast titanium inlet panels on the TU-144 supersonic transport cost 37 percent less than a similar structure on the Rockwell B-1 made of aluminum sandwich construction.

- o Soviets reduce weight and cost by forming metal to near net shape, eliminating much machining and assembly, by using composite materials and advanced welding techniques.

- The Soviet 75,000 metric-ton hydraulic forging press produces shipsets of twenty transport wing-box forgings that replace hundreds of conventional wing-box components.

- Grumman achieved a one-third saving in man hours and improved strength-to-weight ratios with automated fabric layup of composite structures.

- Boeing used blended-composite structure to reduce combined wing-body structure weight by 25 percent.

Future Concepts

With the prospect of having to transport large payloads over extremely long distances and, in some cases, with the prospect of having no secure turnaround base, some concepts for systems that might enhance force sustainability in the future will be mentioned.

Some technology options.- Some vehicle options, shown in figure 4, are:

- New turbofan - the adoption of a more efficient engine to existing airframes to increase the range.

- Propfan - new research in the use of propfans can result in improved fuel efficiency and increased range.

- Laminar flow control - increased fuel efficiency and range through reduced drag obtained by maintaining some regions of laminar flow.

- Distributed load - a concept in which the payload is distributed within an essentially all-wing design to maximize on lifting capability and minimize drag producing elements.

Multibody.- Multibody concepts (fig. 5) have indicated that large volume increases are achievable with good efficiency through the exploitation of favorable aerodynamic and structural benefits. Multibodies with wing-body blending may also be useful in providing the volume requirements for high-energy cryogenic fuels. A preliminary study of a multibody, a distributed load, and two conventional concepts (fig. 6) illustrates the conceivable characteristics for a 3000 nautical mile range. Shown is the current C-5A; a 1.1-million pound, two-lobe body, conventional concept; a 2.8-million pound distributed load concept; and a 5-million pound multibody concept. The corresponding payloads for a 3000 nautical mile range are about 240,000 pounds; 470,000 pounds; 1,428,000 pounds; 2,350,000 pounds. Reducing the payload for the multibody to about 1,000,000 pounds would extend the range to about 10,000 nautical miles (see refs. 8-11).

Wing-in-ground effect.- A subsonic wing-in-ground effect (WIG) concept is shown in figure 7. The concept illustrated represents a large vehicle (on the order of about 2 million pounds maximum gross weight) and is depicted as a sea-based system. The concept pictorially shows blowing-over-the-wing and vectored-thrust, both of which enhance the lift capability. Such a vehicle, flying in ground effect, can achieve increases in aerodynamic efficiency of about 100 percent over that obtainable out-of-ground effect. Such vehicles may have the capability of flying either in- or out-of-ground effect. Through a combination of flight modes, as well as being able to operate in water, such a vehicle could perform a variety of missions and could achieve long ranges or long endurance.

A concept for a multibody WIG (fig. 8) depicts a 900-ton vehicle projected to carry a 400-ton cargo load for a range approaching 6000 nautical miles. Variations in cargo and fuel load indicate an "all-out" range of about 19,000 nautical miles (ref. 12).

Modular.- One modular-type concept is shown in figure 9. Such a concept envisions large-wing cruise liners coupled wing-tip to wing-tip to form, in effect, a distributed load vehicle. The flight efficiency would increase as the overall span was increased (modules added). The entire system is not required to take off or land since the modules are attached or detached in flight. Large load-carrying capability and extremely long range or endurance is conceivable. Feeder aircraft might also be employed to add or remove small quantities of cargo or supplies.

Lighter-than-air.- While not to be discussed in detail, a possible future load carrier that should be mentioned is the lighter-than-air type or any similar type that sustains its weight through means other than the classic aerodynamic or hydrodynamic buoyancy forces. Such vehicles need not be confined to low speed. Through the use of low-drag body shapes and powerful propulsion systems, such vehicles could conceivably achieve very high speeds.

Space.- For the future look, the use of space vehicles and space platforms must not be forgotten. Such vehicles, after surmounting the atmospheric launch regime, are no longer restrained by aerodynamic or propulsive limitation, and extremely large load-carrying structures could be placed in space. Some implications of such systems are included in the High Frontier study (ref. 13).

In an Associated Press release in November 1982, Soviet space officials were quoted as saying they would have a large, permanent, manned space station in Earth orbit by 1985. The space station will require the most powerful rocket engine ever developed. According to Soviet officials, the rocket will be test-launched in 1983.

What's New

While some of the concepts depicted may seem unusual, a brief look into the past may encourage more thought. Figure 10 shows some lifting-body concepts of Burnelli (1924, 1935); some flying wing concepts (Northrop, 1946 and Horten, 1938); some multibody concepts--including sea based (Bleriot, 1930 and Savio-Marchetti, 1931). In addition, some U.S. patents (fig. 11) reveal multibody (two, three, and four) concepts based on the Douglas C-47 as well as a tandem-wing version of the same airplane (fig. 11a). In figure 11b, a large-body multiwing concept and a multibody airship are shown. These concepts are interesting--it may just be time to refine.

EPILOGUE

While the nature of this paper does not permit definite conclusions or recommendations, it is hoped that some thought will be provoked concerning force sustainability into the twenty-first century. The basic conjecture is that the support of future battle, if not the battle itself, may be conducted from the continental United States. This is based on the possibility that secure oversea basing may be denied by the Soviet Union or by unfriendly or unstable governments. The requirement for large, long-range, efficient and sometimes, fast, air vehicles may become real. Basing restrictions, as well as weight considerations, and performance requirements may lead to unusual concepts such as distributed load vehicles, multiple bodies, water basing, modular designs, and lighter-than-air vehicles. If theater battle is conducted in remote areas of the world, then such unusual conceptual vehicles may warrant consideration for logistic support. If future ground battle is such that logistic support to the theater is not feasible, then the battle itself may involve operational vehicles of similar unusual conceptual design and logistic support of the forces would then be maintained in the continental United States.

Much of the technology required for large, efficient, long-range air vehicles is already being pursued. Further advances should be expected and sought in improved aerodynamics, propulsion, structures, and avionics--all with a view toward increased efficiency, utility, and affordability. However, it must be pointed out that the extreme requirements of range, volume, basing, and so on, that are discussed herein are military in nature and there does not appear to be a reasonable civil requirement. Hence, the integration of the various technological advances into an operational system is not likely to occur unless the Department of Defense becomes actively engaged in leading the development. The situation today and for the future, as envisioned, is quite different from what has existed over the past several decades. More than thirty years ago, the Air Force actively took the lead in the development of large jet bombers such as the B-47 and B-52, for example. The required technology moved forward and was also adapted to the development of our civil jet transport fleet. Foreseeable projections of today's civil aircraft fall far short of the projected military needs, however, and it appears that an assertive DOD position is required to provide the technology focus for vehicles to meet the possible combat and sustainability requirements into the twenty-first century. Moreover, the possible ascent of future warfare into space must not be overlooked and, again, a strong DOD position would be required for such a development.

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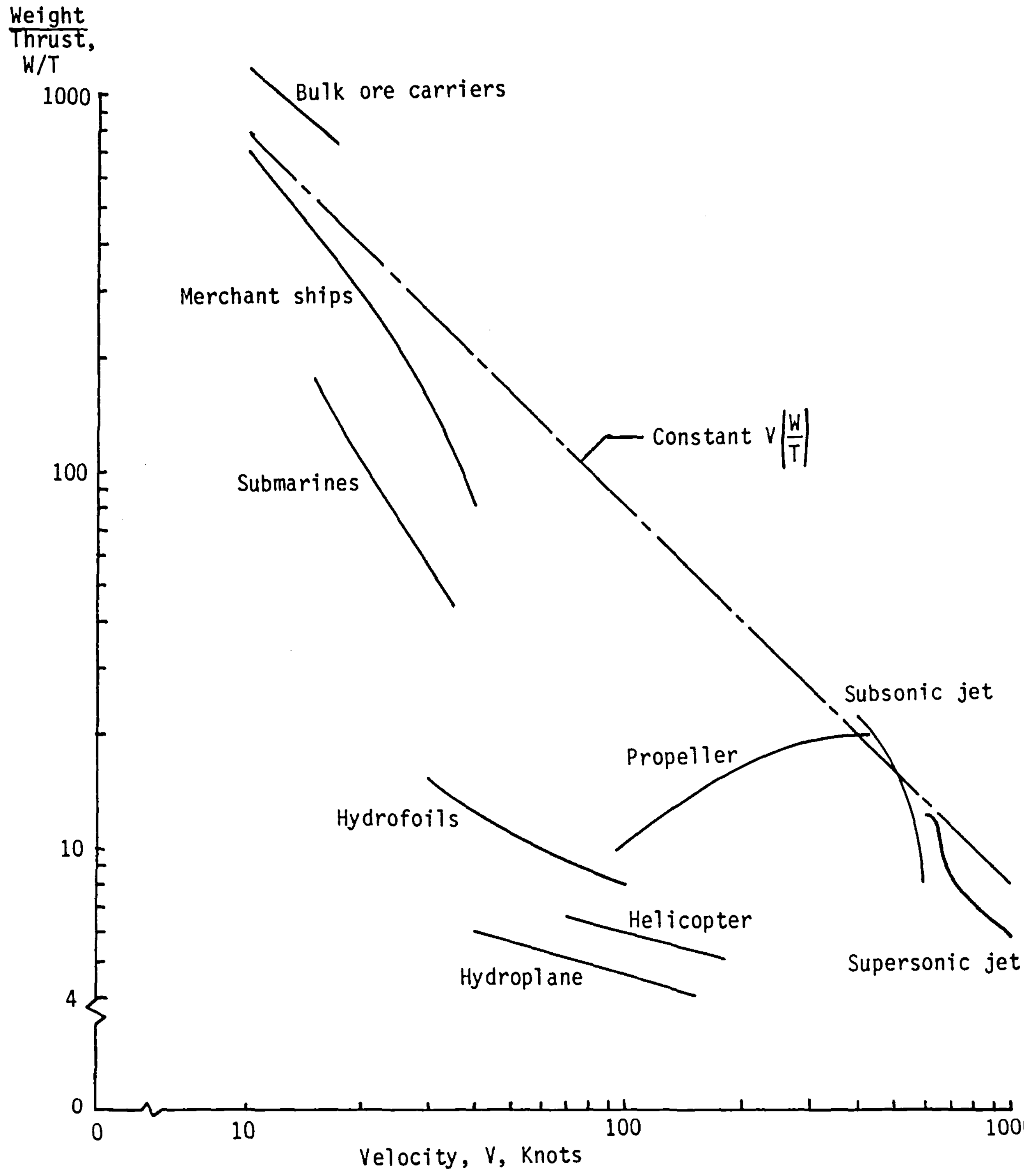


Figure 1.- Efficiency for load carriers in water and air.

TECHNOLOGY OBJECTIVES

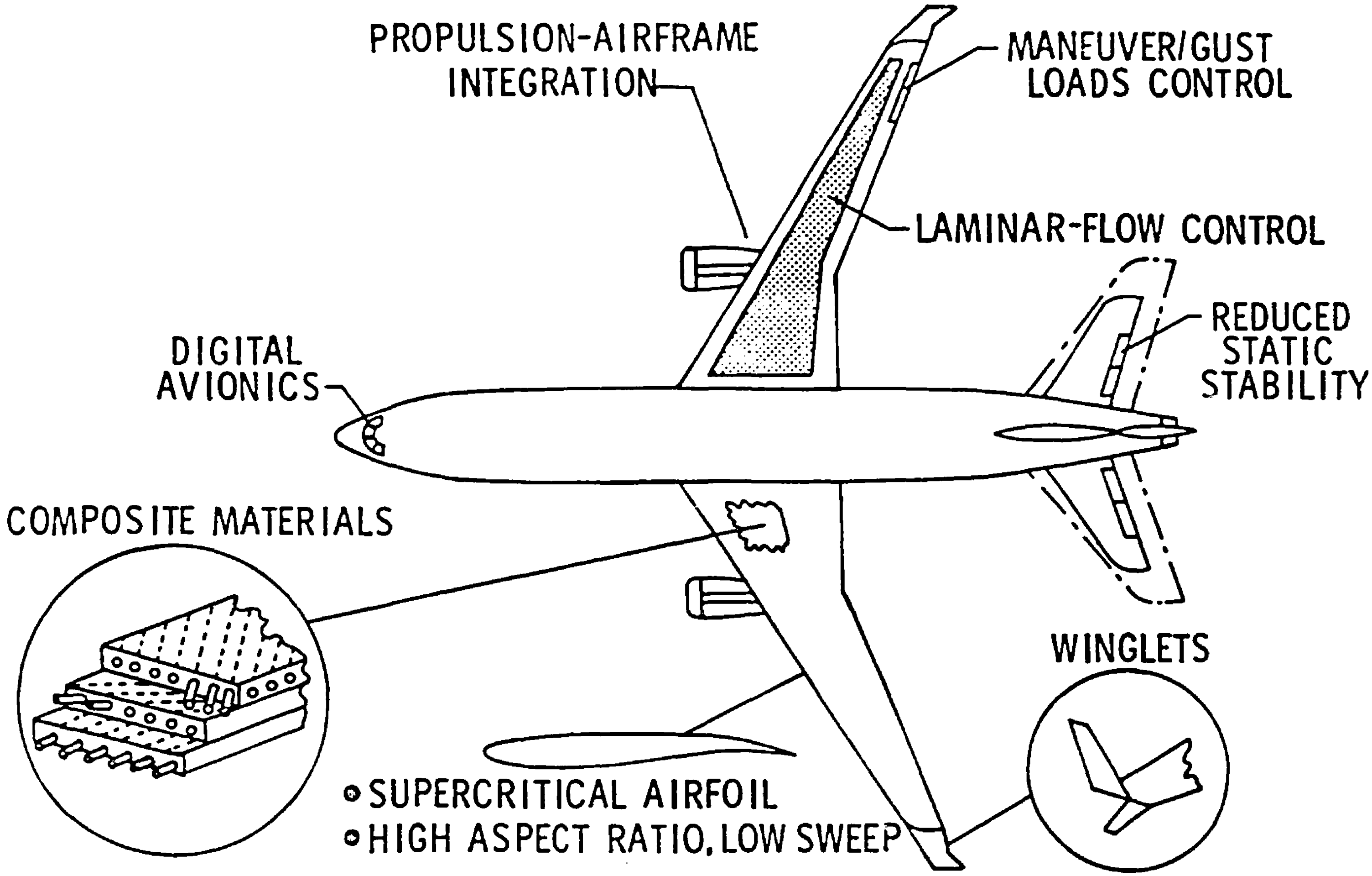


Figure 2.- NASA aircraft energy efficiency (ACEE) program.

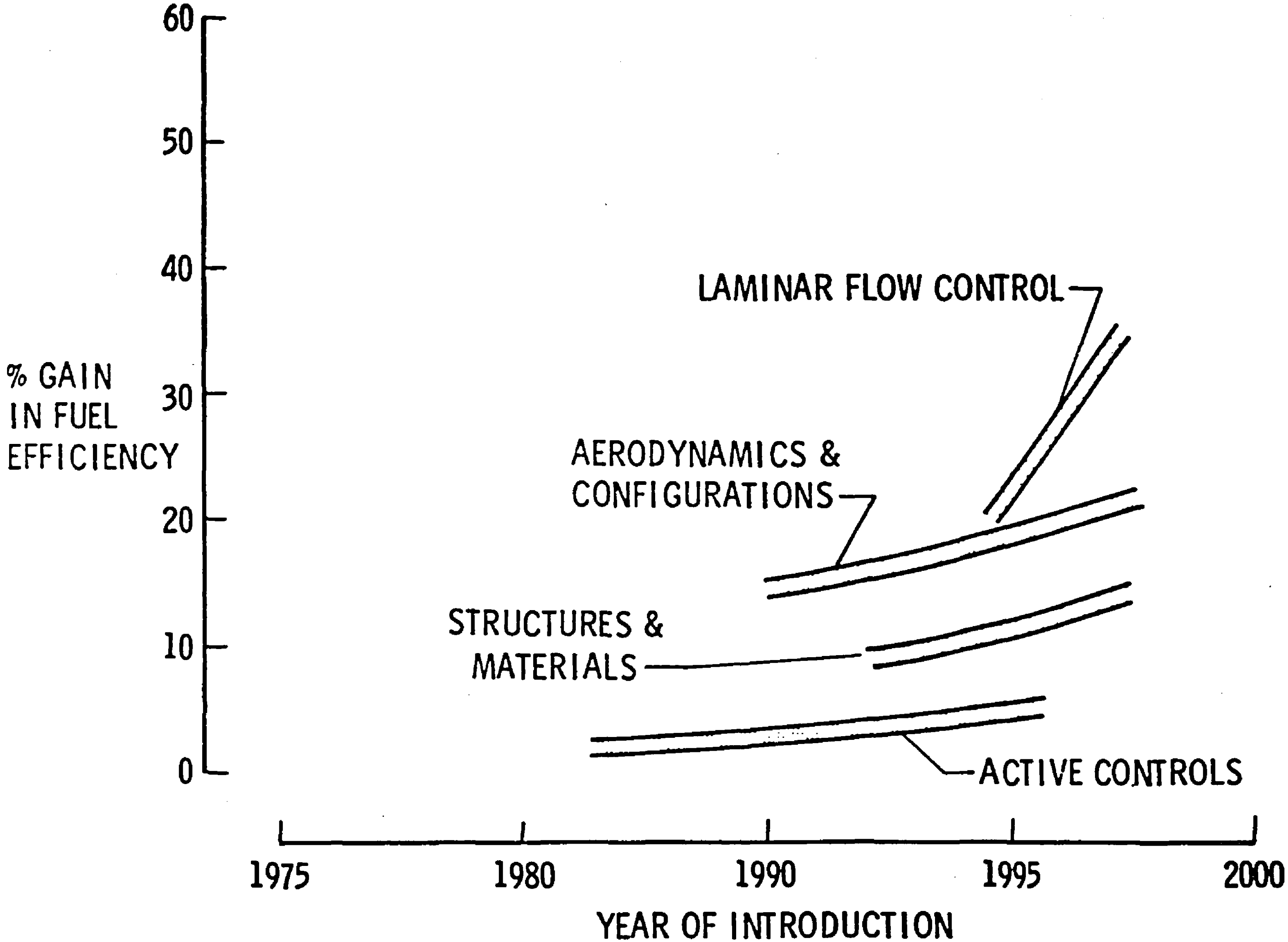


Figure 3.- Fuel efficiency benefits from ACEE technologies.

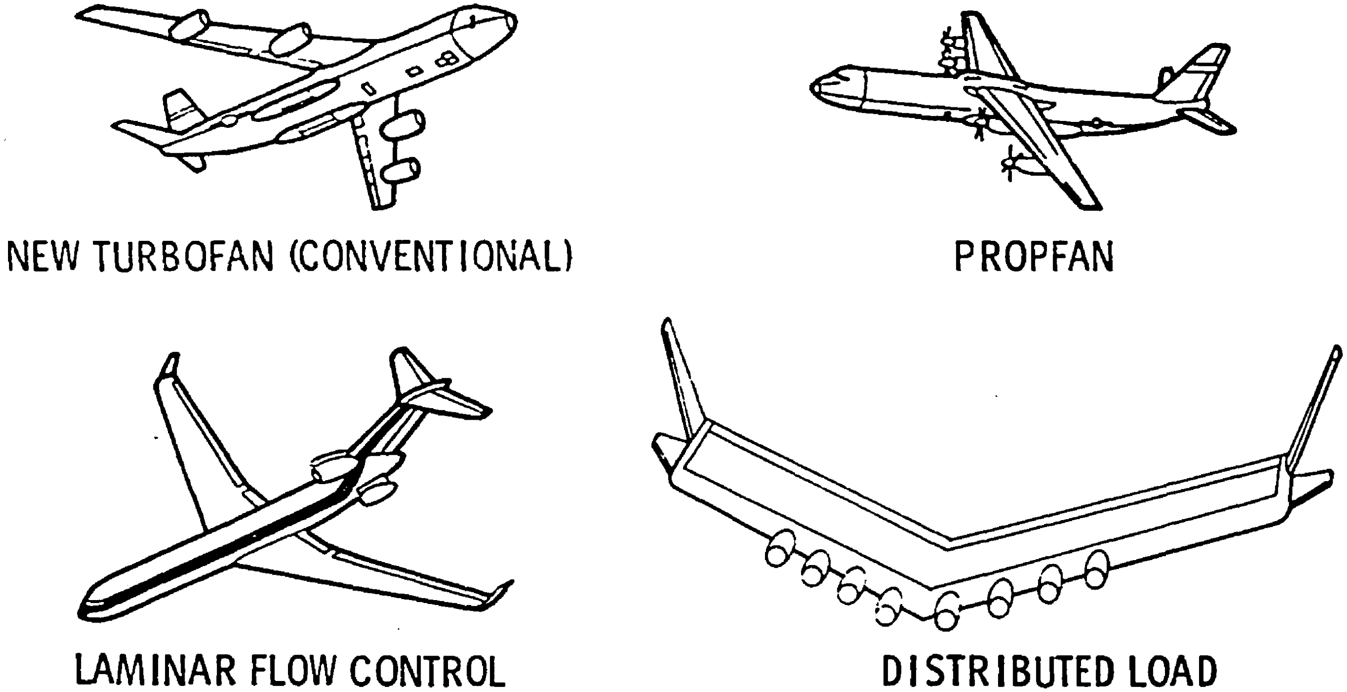
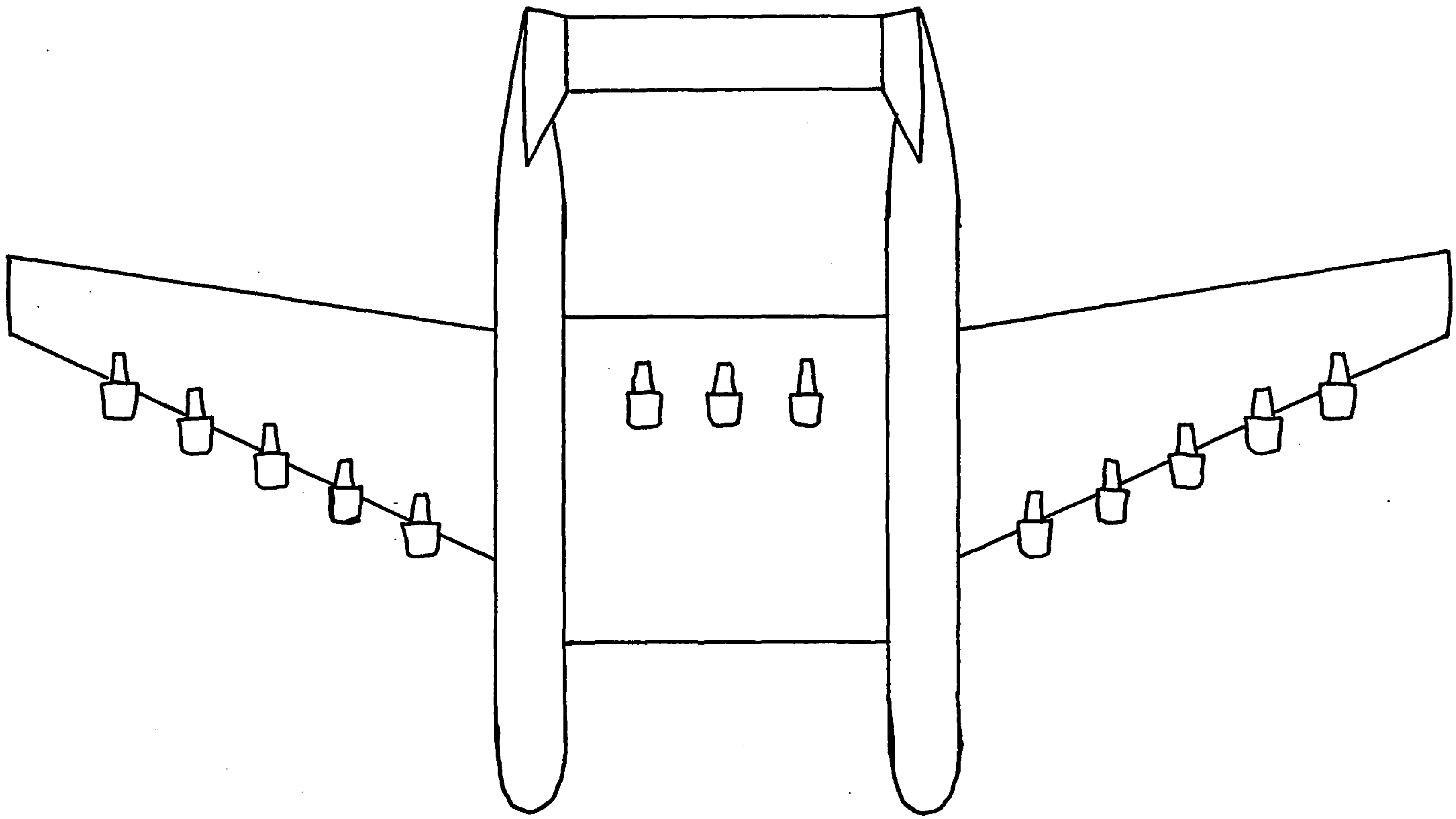
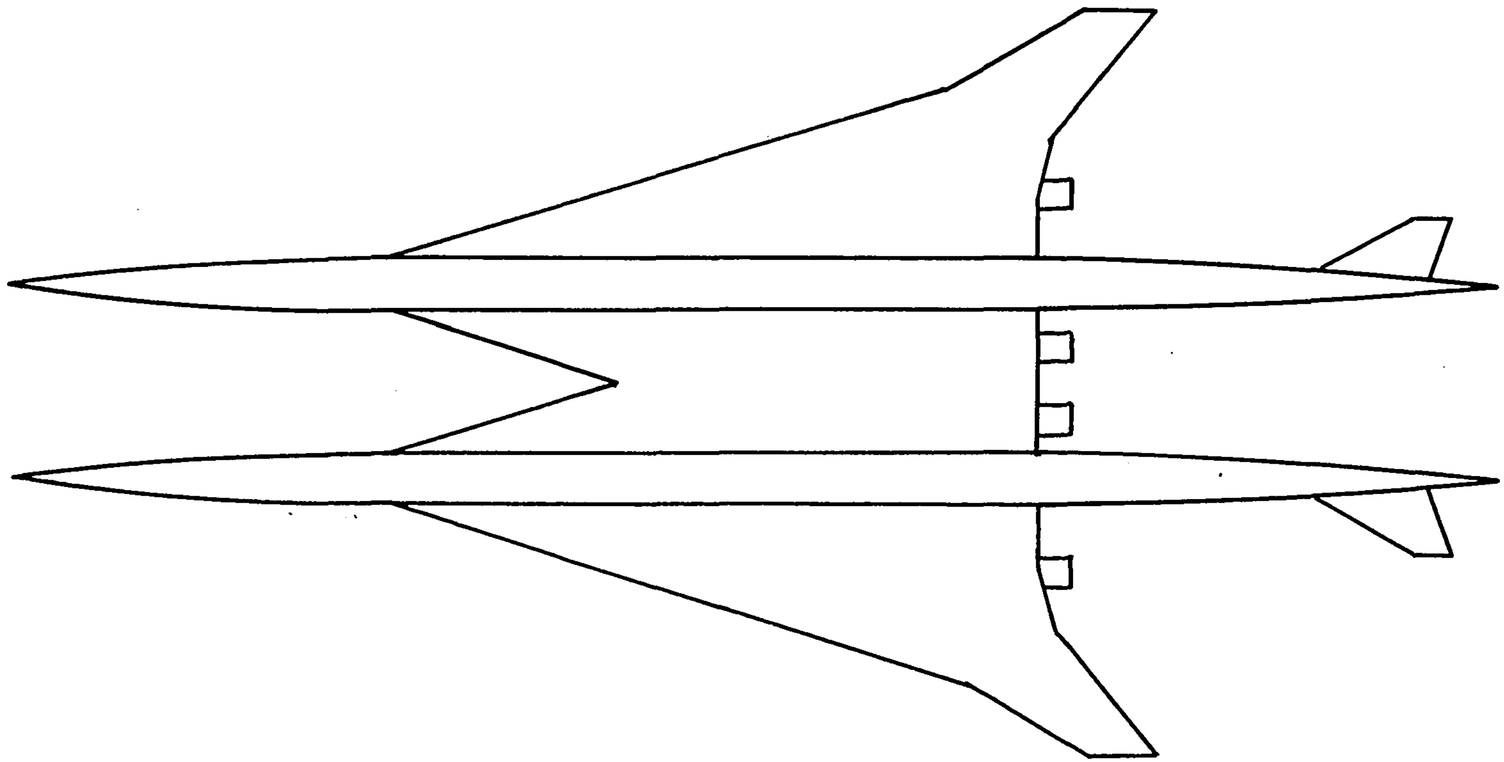


Figure 4.- Technology options for future airfreighters.



(a) Subsonic

Figure 5.- Multibody concepts.



(b) Supersonic

Figure 5.- Concluded.

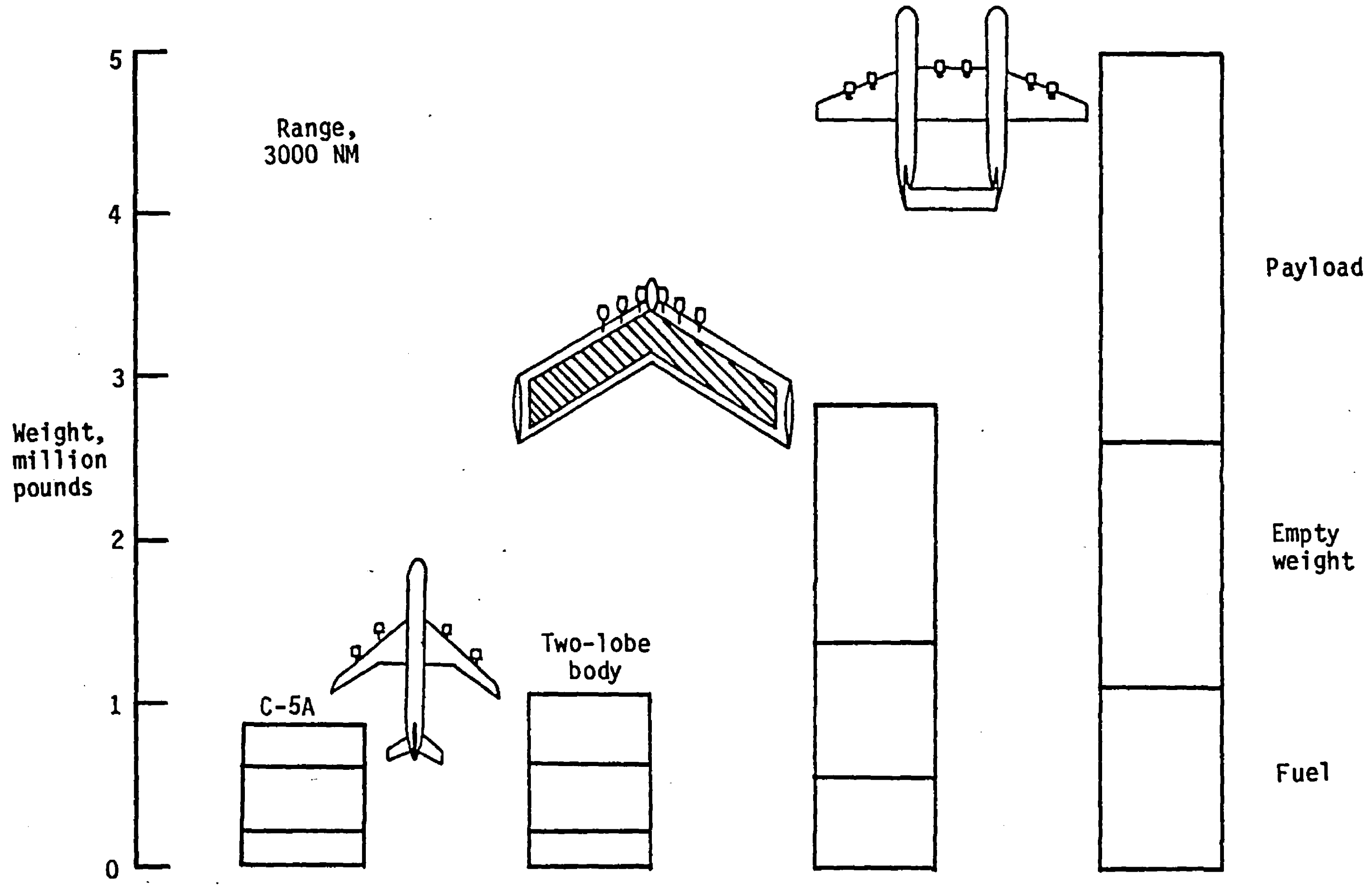


Figure 6.- Comparison of various load carrier capabilities for 3000 NM range.

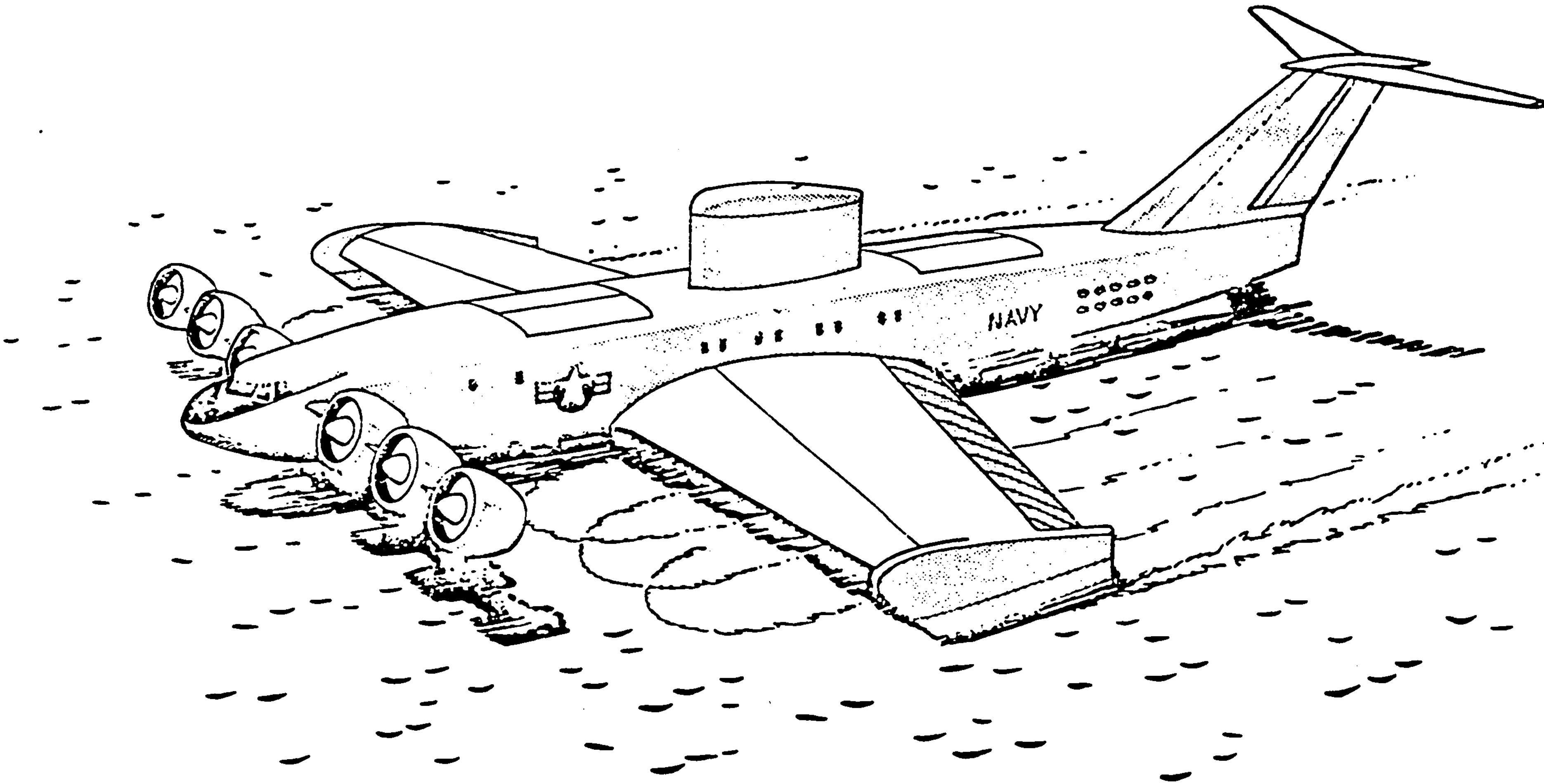


Figure 7.- Wing-in-ground (WIG) effect concept.

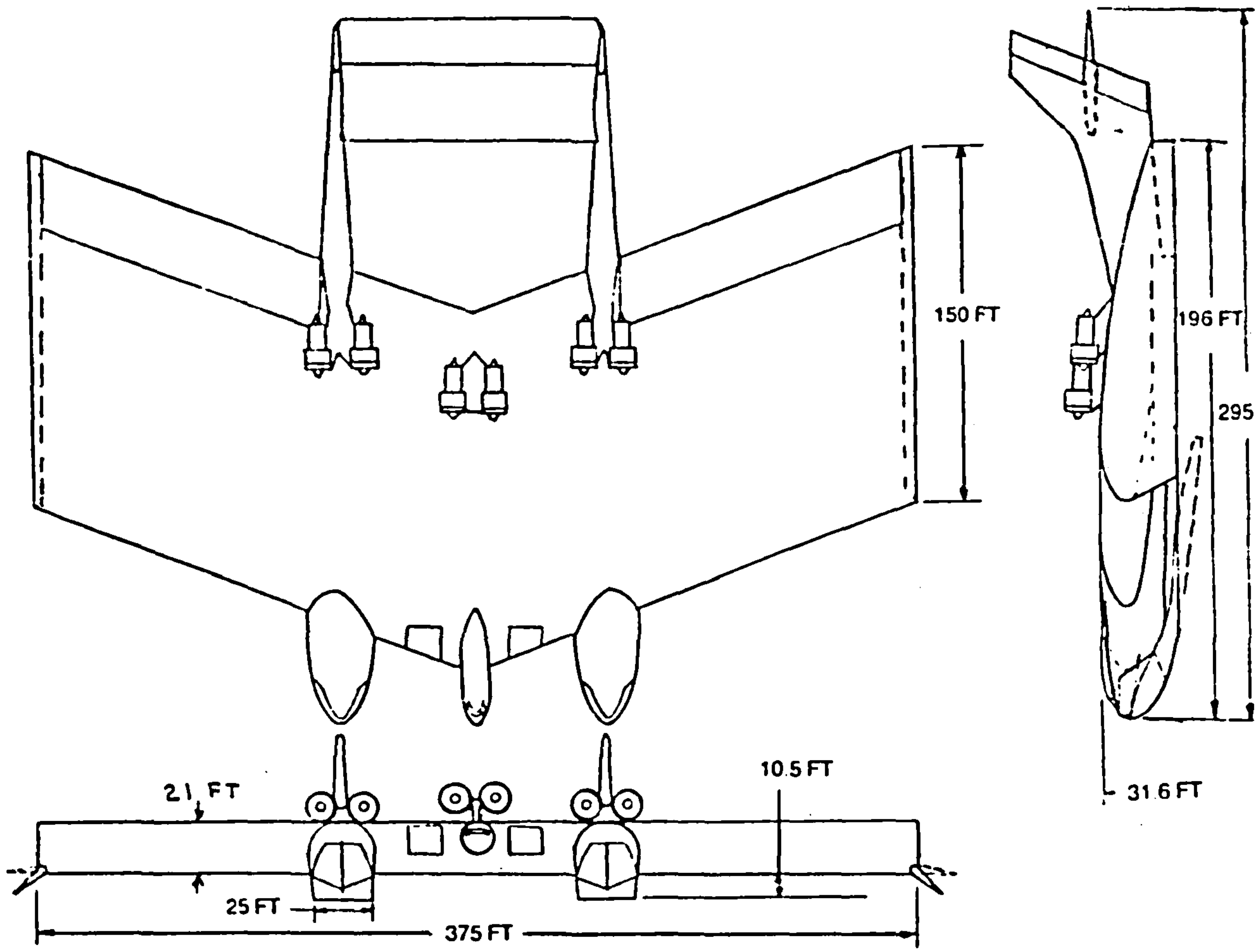


Figure 8.- Multibody WIG concept.

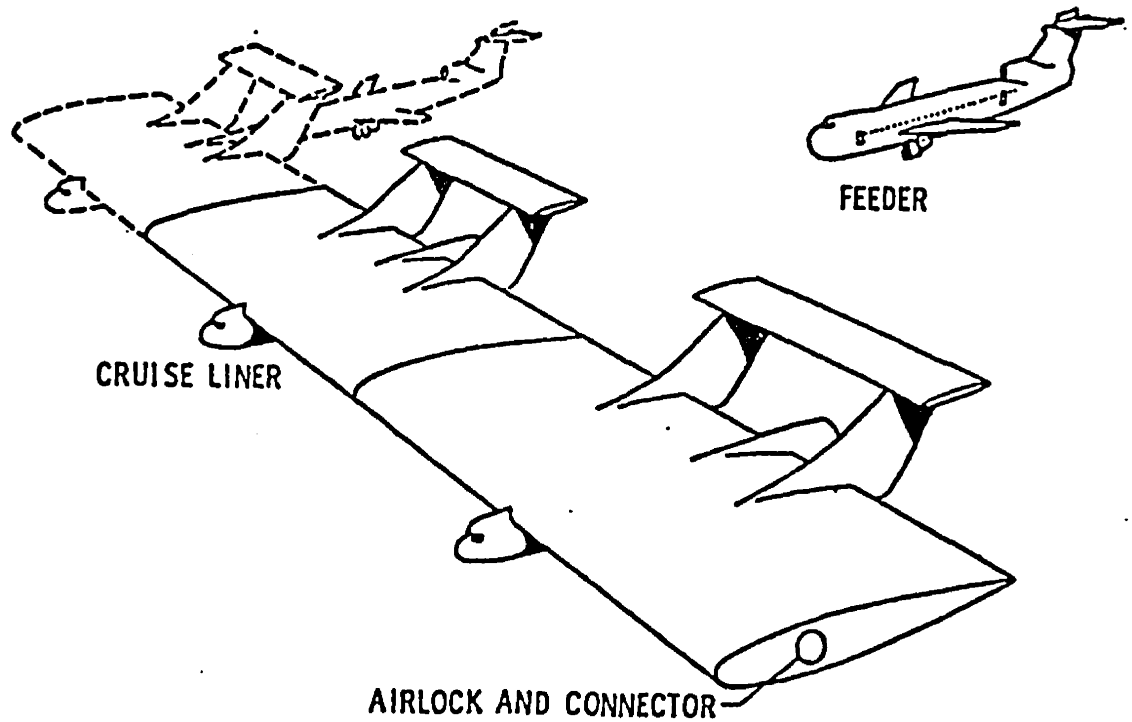


Figure 9.- A modular concept.

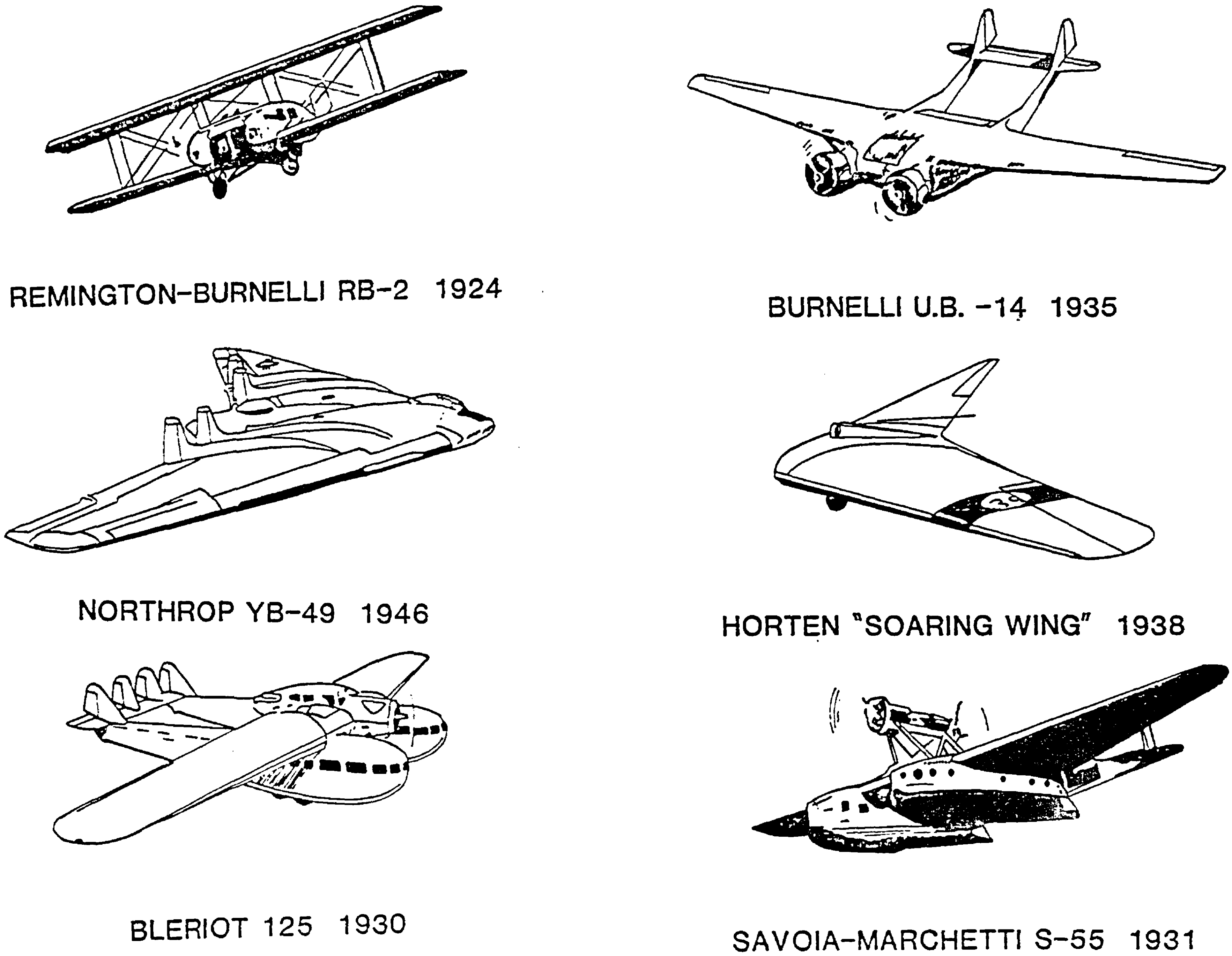
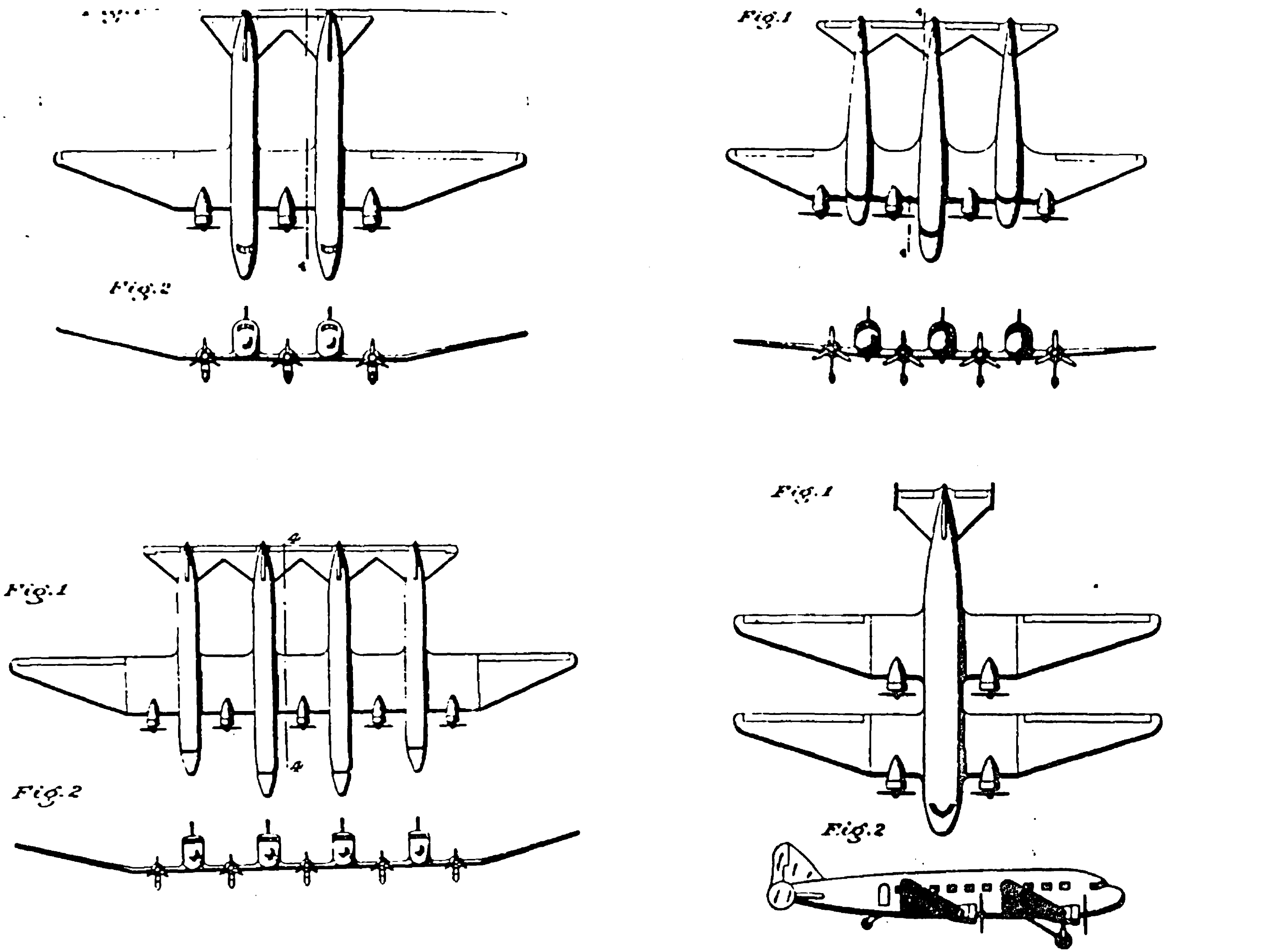
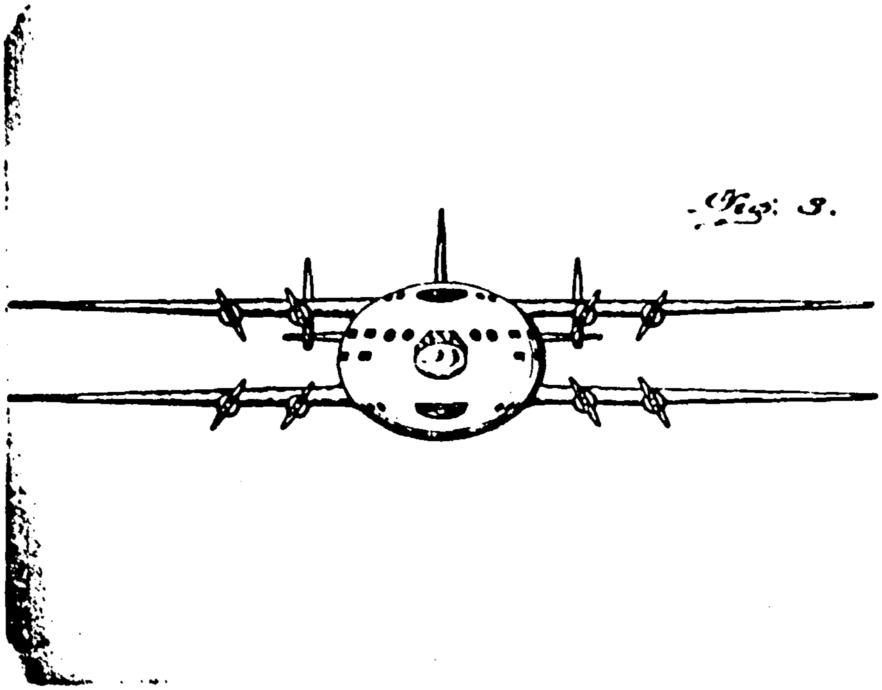


Figure 10.- Some past concepts.



(a) Concepts based on Douglas DC-3 (C-47).

Figure 11.- Some U.S. patents.



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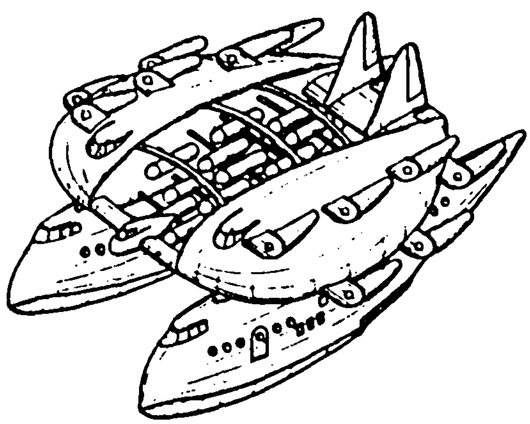

(b) Large body concepts.

Figure 11.- Concluded.

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Justus W. Fry

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15. Supplementary Notes

16. Abstract

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