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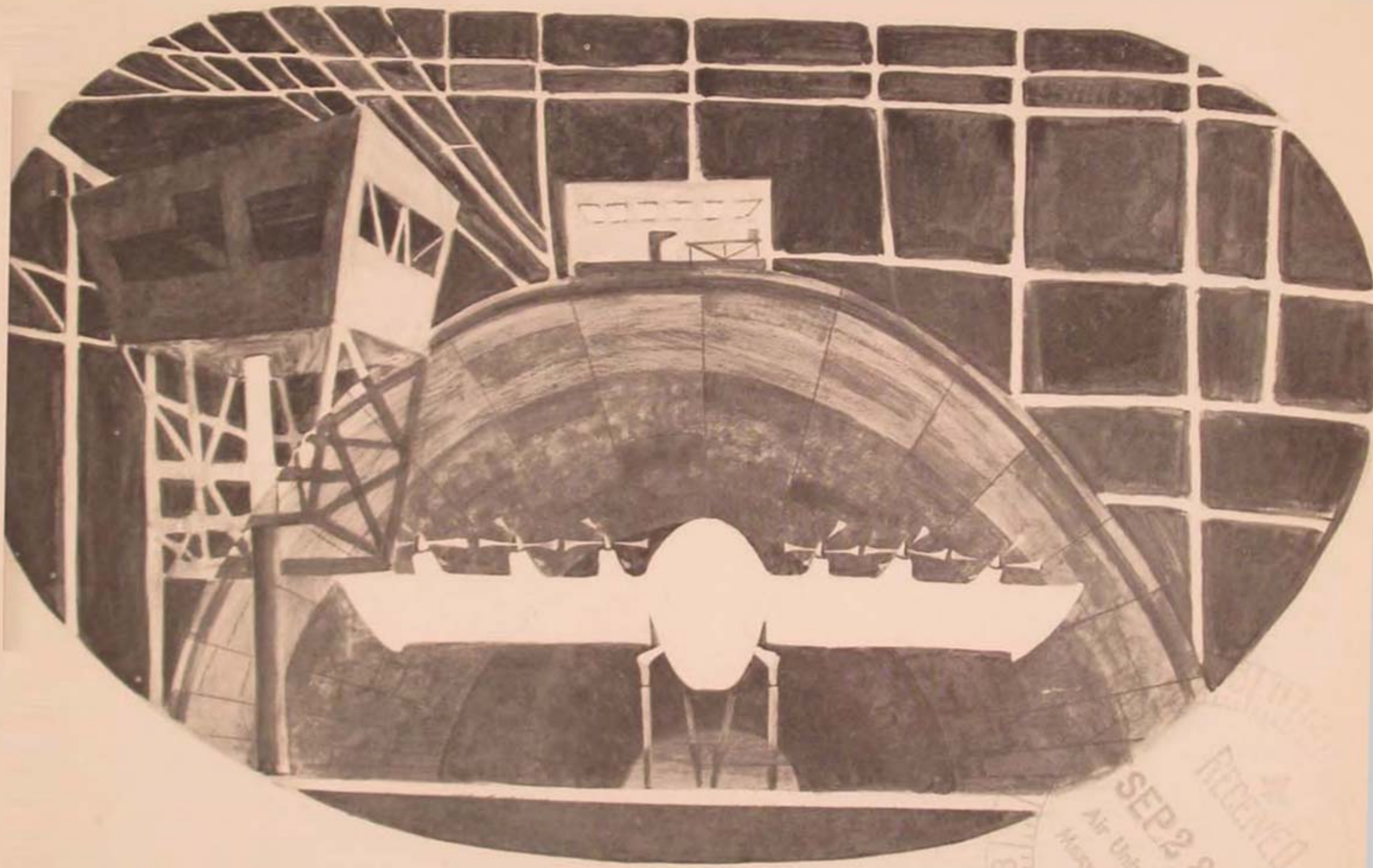

VTOL Testing

THE MILITARY PROFESSION, A COMPETITIVE ENVIRONMENT...
VTOL FLIGHT-TEST CHALLENGE...COMMUNICATIONS SATELLITES

SEPTEMBER-OCTOBER 1965

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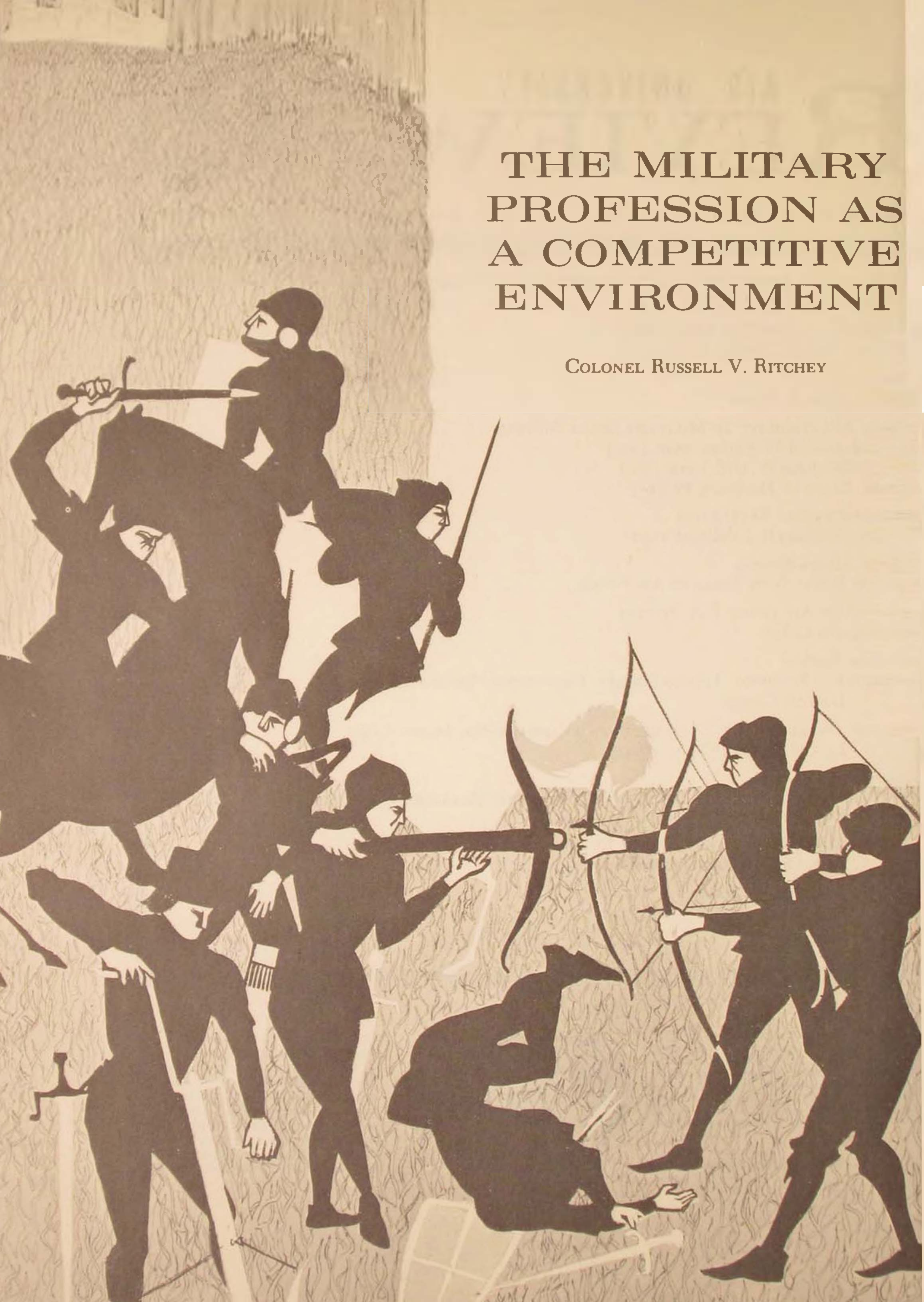
the cover

Since the early days of powered flight, wind tunnels have been an essential tool in developmental testing of airplanes. The aerospace age required supersonic and hypersonic tunnels for testing space vehicles. Aircraft with capability for vertical take-off and landing are also having their day in the tunnel. Major Philip E. Neale, Jr., spotlights them in "The VTOL Flight-Test Challenge."



THE MILITARY PROFESSION AS A COMPETITIVE ENVIRONMENT

Colonel Russell V. Ritchey

THE MILITARY art or science spectrum is confined to those activities which constitute the military profession. Essentially, military activities are similar in nature in all nations, and as a result a similarity exists in the organization and role of all armed forces. Over the centuries this similarity has resulted in the acceptance of common principles of war by all nations, which in turn have made common the ways of conducting war.

In a sense, the opposing forces in a war conduct their operations in a like manner, using weapons, equipment, personnel, and tactics similar in nature. Infantry is normally used against infantry, artillery against infantry and artillery, armor versus armor, aircraft against aircraft, and now missile against missile. History is replete with examples of nations' striving for similarity in weapons and armament. Separate armies have similar branches, and if one service develops a new arm or branch of greater range, speed, or power to augment a lesser force in its own service or to overcome a lesser force in an opposing service, it is usually countered by other armies to the degree that greater forces must engage one another while attempting to apply their strength against lesser forces. The German development of the panzer division for use against infantry and artillery forced the rapid development of armored forces in the United States and Britain, resulting in similarity.

Tactics are a basis for similarity, and when an offensive tactic is developed, it is eventually countered by a defensive tactic. Also, principles and techniques of leadership, strategy, organization, terminology, ranks, units, etc., are generally similar.

Therefore, if the national military services which constitute the military profession are generally similar, then the basic difference which determines the victor is usually in the knowledge of the art of war and the ability of the leadership which applies it. This difference, then, provides us with the prime purpose for a professional military college of any service: that purpose is the study of war, the conduct of war, and the advancement of military expertise within the profession.

The military profession is unique in that, unlike law or medicine, its members are in competition with one another, whether as colleagues, allies, or potential enemies. Branches of one service are in competition, each to play as important a combat role as the other, each to explore and develop the best means of applying its power through effective tactics. Services of one nation are in competition, each to develop the art of war as it applies to its environment and expertise. Nations especially strive in a competitive atmosphere to develop armed forces which surpass those of a possible opponent, to study new developments, new tactics, new weapons, so as to emulate and outstrip. Backing up all of this are the professional military colleges, which exist for the purpose of studying the spectrum of war and preparing leaders and staff officers to plan for war and carry out war plans, giving them the opportunity to learn all the implications of the conduct of war through knowledge gained and through practice and application.

To be more specific, the competitive atmosphere within the military profession leads those who recognize the fact to greater study in greater depth and breadth within the confines laid down by the common principles and practices of war. Hence, the service which devotes itself to the study of war, study of wars, study of planning and conduct of war, within its environment and in cooperation with other services, is more capable in war than one which neglects its fundamental purpose for the pursuit of nonprofessional abilities.

Those elements which activate the corrosive process leading to deterioration of the competitive stance are not easily recognized in the contemporary environment. For example, the rapid changes in the military aspects of international relations so concern the average officer that he finds difficulty in adjusting himself to contemplation of long-range trends and implications or to studying current implications within the context of military history. Faculties themselves, swept up by current events, often find great difficulty in freeing themselves from the chains of current events to direct their attention to serious study of the phenomena of war.

There are several conditions which cause the military professionals to deviate from their basic purpose. We will examine these now.

- domination by an individual

Professional military colleges traditionally have had an impact either positive or negative upon the officer corps. In the absence of strong central direction or interest, individuals can and often do strongly influence the doctrine and other military theory and concepts taught in the colleges. One major example of the negative impact of an individual was the "spirit of the offensive" taught in French military schools by Foch. His teachings were so dominant that dissenting voices could not be heard. Blind acceptance of the offensive led to a stagnation of thought which took France and even England out of competition in the profession for some time. Ultimately, in World War I, this doctrine led to the significant weakening of the power of the French army—a blow from which it has not yet fully recovered. Many other examples exist. It would be a reasonable assumption that in such instances the seeds of ultimate defeat are sown by the military colleges prior to the opening of the war.

Unlike other professions, in which one member's personal views may affect only a small group of willing followers with no visible effect upon the profession as a whole, the military profession is different for two reasons. First, such singular views often influence or subdue the thoughts of a captive group that is responsible for defense of the nation. Second, such influence leads to a stagnation of inquiry and hence a noncompetitive stance in a competitive environment.

- preoccupation with areas of study which currently enhance opportunity for advancement

The basic example of the competitive nature of the military profession is the competition for advancement. Captive in a structure dominated by a single staff, confined by the procedures, practices, and policies which are common to all members, officers seeking ways of advancement are alert to statements, views, etc., that may enhance their chances. If opportunity seems to lie in areas which are not a part of the primary mission of the service, ambitious officers, their professional expertise notwithstanding, may devote themselves to such areas, not because it improves them as military leaders but because it is a means to higher rank. This type of competition is not in the best interest of the service or its primary mission. Obviously, if such preoccupation is prolonged, the study of war becomes stagnated, and the service becomes noncompetitive. Finally, even military teachers are no longer capable of imparting true professional knowledge. Overemphasis on nonprofessional subjects serves to reduce the importance of the military art in the minds of the officers. If, at the same time, another service or another nation is devoting its full time to the study of the art, it is obvious that its leaders will be more conversant with the implications of war and hence more able in its conduct.

Armies and navies, because of the large numbers involved in potential contact with the enemy and the ability to exercise their forces in great numbers, have the opportunity to be more competitive as a force than does an air force. On the other hand, an air force with a small percentage of its force in contact or contemplating contact with an enemy appears much more apt to engage in nonmilitary-oriented studies than do the other services. Therefore, in order to ensure a competitive status, an air force must emphasize and enforce the study of war and associated subjects in its military colleges.

- traditional practices

A force or service may become noncompetitive because of its adherence to a traditional weapon, tactic, or philosophy which, although effective in the past, no longer applies. The maintenance of horse cavalry in the U.S. Army up to 1940 illustrates this point. British experience with the same branch was similar according to Major General John Frederick Charles Fuller, who said, "The Cavalry would rather lose a war than give up their horses." The British and United States navies have had similar experience in connection with the vested interests of the so-called "battleship admirals."

The impact upon a service of hidebound traditionalism is felt to a great extent in the military colleges where study and inquiry into the values and roles of traditional activities are blocked or directed in a manner that discourages dynamic inquiry. Naturally the competitive status of that service is thus reduced, since studies in such areas are nonproductive, and the consequent obsolete weapons are not competitive in the prosecution of a war.

- domination over the combat element

An unusually high percentage of officers who are not assigned to activities that bring them into direct contact with operations or operational planning will, in any given course, lead to a lessening of combat or operational type of studies. The fact that this group's role is somewhat disassociated from the conduct of war tends to degrade its study. Faculty members similarly will find themselves unable to teach meaningfully in the war environment or prepare problems to further learning in that area.

This group, highly specialized, will more readily study areas which seem to relate more closely to their specialty or to fields of interest to them in the future. In any case, this situation, unless curbed, will detract from the competitive standing of that service in the military community. Such subjects as International Relations, Business Administration, Public Administration, Communicative Skills, etc., are not subject areas which enhance the competitive standing of a fighting service. The value of these subjects is undeniable, but only if the officer is otherwise proficient in the competitive area of the military profession.

- a fixed and rigid strategy

Military colleges have traditionally provided their students with experience and practice in the planning for and conduct of war. Future leaders were thus provided with knowledge of their profession and incentive to study it. In other instances students actually made war plans, and their thinking benefited both themselves and the service. If it is not the role of a war college to contribute to or introduce the student to the real problems of strategic planning, then it is difficult for the officers to maintain the competitive attitude. If the weapons, the plans, the personnel are all assembled and made into one elite command of a service whose members have assured themselves and the rest of that service that they have the sole capability and responsibility for victory, it renders futile in the eyes of the war college and student alike the effort to study and plan for war. Under these conditions the vital competitive team-producing ingredient for all is lacking.

A service which rigidly advances and supports a doctrine that it alone or a segment of its force is the sole agency capable of planning, conducting, and winning a war, to the degree that its military colleges cannot conduct inquiry into or advance new thought, is creating a noncompetitive attitude.

If traditionally a service teaches that it alone was responsible for victory in a previous conflict, it at the same time discourages inquiry into the conditions which set the stage for that victory. A more realistic claim would be only that its efforts provided the cap to the bottle of victory. That is no reason, then, to teach that the cap alone is necessary while disregarding the container which held the ingredients for victory.

However, while a fixed and rigid strategy lowers the incentive for a competitive professional attitude, it at the same time increases the competitive attitude of any possible opponent and allies alike. If a nation or service has a firm and long-time strategy, it becomes a form of deterrent to dynamic strategic thinking by its members. Possible enemies, however, are motivated competitively in order to circumvent the well-known and rigid strategy. Allies, wishing to regain a voice in the control of the one strategic technique, will also become more competitive. The English at Lexington suffered from an inflexible tactic which they could not apply. France at Crécy and Poitiers suffered from a loss of competitive thought, as she did later in World War I (offensive) and World War II (Maginot Line). In summary, total faith in a rigid strategy, tactic, or weapon creates stagnation of the competitive outlook in military colleges, an outlook essential to effective and creative military leadership.

- noninvolvement in operations or operational planning

Centralization of control of forces and limitation of information to a need-to-know basis (and that limitation enforced beyond necessity) can serve to reduce those officers not immediately concerned to a group of military robots. If a major headquarters controls all units down to the squadron and no lower unit is expected to plan or conduct independent operations, there is little reason to expect officers below the grade of colonel to have an inquisitive and competitive attitude toward the study of war. Instead, an increasing reliance is placed upon "they." The colleges, divesting themselves of the responsibility for the study of war, seek other outlets that are interesting and unclassified but not their particular professional responsibility. Under these circumstances a major portion of an officer corps can become decidedly noncompetitive, and other than military studies will appear to them to be more interesting and profitable.

- basic belief in the probability of peace without end

Lack of knowledge of war creates a fear of war which makes more digestible the philosophy of permanent peace. In the competitive environment of the military profession, such a condition is intolerable. When this belief becomes imbedded in officers, it manifests itself by an increased interest in nonprofessional subjects, associations, and studies more useful to the individual than to his service. Rather than being competitive within the profession, the service becomes a form of military haven in which an officer can prepare himself for his second chosen career.

This is not to advance the thought that to be competitive one must want war. Rather the proposition is that a military professional must be conditioned to anticipate the possibility of war. The people of a nation support their armed forces for the purpose of ensuring protection. To repay their trust, the professional must anticipate the possibility of war, else he will not be motivated to prepare for it.

- political involvement of the military

The impact of political involvement of the military as it affects the competitive attitude is a matter of history. Politically motivated officers may be grouped into as many factions as there are political parties in the government. The competitive attitude so necessary to an effective force is spent in the political arena rather than in the study of the profession. Such a trend manifests itself in the increased emphasis on political affairs and a decrease in time devoted to the military art.

- conversion of purpose of professional military institutions

Any military professional college which for any reason deviates from its primary mission to areas of concern unrelated to its stated purpose not only becomes noncompetitive itself but also contributes to the noncompetitive stance of the service to which it belongs. Remedial education in the nonprofessional field is certainly not the purpose of the professional military college, and any such deviation merely reflects the degree to which the noncompetitive stance of that service has infected its officer corps.

- lack of definitive wartime mission for the whole

If no clear picture exists in the minds of all officers of a force as to their role in a war, they tend to picture themselves as spectators to the act of war and as having no particular role once it has begun. Officers not directly associated with combat or combat support units have difficulty in visualizing for themselves a planning, operating, or support role in any major war. Since this conception may involve a high percentage of officers, it aids in the growth of the noncompetitive attitude.

- emphasis on administration, finance, and management

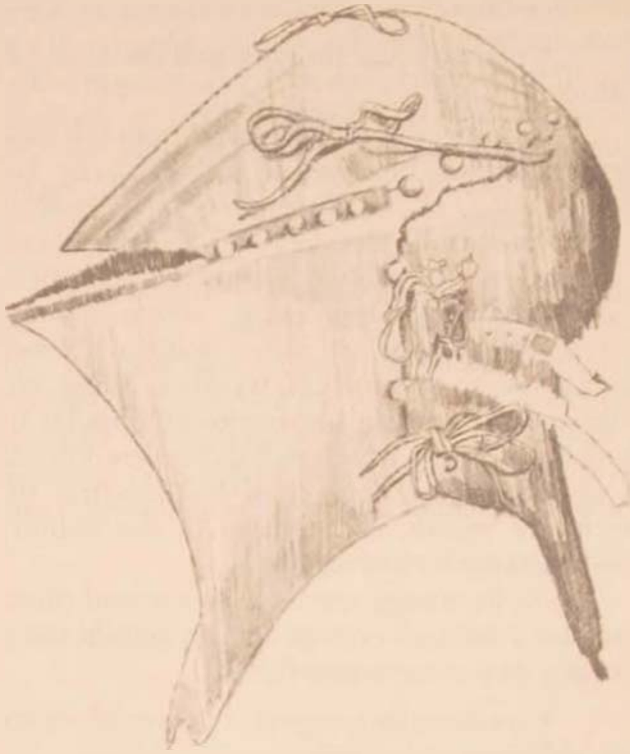
Day-to-day peacetime operations serve to emphasize effective administration, economy, and management of personnel and other resources. As De Tocqueville once said, "You cannot be both learned and make a living." By comparison, if officers are compelled through many external sources to devote their full time to administering, financing, and managing peacetime forces, they have no time left for study, thought, and examination of the primary business of the conduct of war. Military strategists, scholars, teachers, or tacticians cannot very well appear under such conditions; consequently little impact is made upon the development of the competitive attitude.

- fascination with new but as yet nonexistent equipment

It is not often recognized, but is occasionally mentioned, that in the continual search for new and more effective equipment there is a tendency among officers to look upon the unit combat equipment in their service as obsolete. This tendency in thought can affect the manner in which officers study the conduct of war with existing equipment. Weapons which are not in existence are only useful in wars which may never be fought. This tendency is illustrated in professional curriculums which devote extensive time to new developments and little time to exercises involving existing equipment. A reasonable balance is essential, with the colleges teaching not only principles and current weapons and tactics but also possible future developments—not so far into the future, though, that none of the students will see the arrival of the weapons as organization equipment in their service time. Officers must be knowledgeable and competitive within an environment of reality and must possess a perspective which provides current capability as well as future.

- the deadening effect of the "push-button" philosophy

The unchallenged philosophy of the push-button war has made its contribution to the noncompetitive stance by an aura of futility related to the examination of war. Without thinking, officers often accept the push-button elixir as a release from such study. Actually, the "push-button" philosophy should more aptly be applied to those activities which relate to the preparation for war. There is no doubt that a full-strength missile complex, operationally ready, contains within itself the former steps of mobilizing, equipping, training, and moving to the battlefield. However, its state of readiness is no more a war than are two bodies of troops confronting one another with rifles pointed awaiting the command to fire. War begins when the command "Fire" is given or the button is pushed. What follows is "war," and that is what we should study.



- lack of understanding of war

Hand in hand with the problem is the fact that there is very little understanding of the nature of war, its origins, and the strands of fundamental factors necessary to relate the past, present, and future of warfare. Since faculties have in the past been permitted to determine curriculum content, they have been reluctant to institute a bloc of study which few can teach. There are no chairs in the colleges devoted to the study of war. Students are not encouraged to enrich their knowledge of the military profession through grants in money, travel, or time.

- similarity of military and civilian specialties

It is quite easy to drift away from the military profession because of the similarity between some of its specialties and civilian vocations, such as medicine, law, management, comptroller, manpower; electronic, electrical, and mechanical engineering; police, maintenance, and supply activities; political science specialties; transportation, weather, flying, etc. Military colleges can become more popular by teaching subjects which will gain accreditation in civilian institutions than by assisting the service to remain competitive in the military environment.

Only by strong service concern and direction can a military college remain significant in keeping its service competitive.

- increase in range and power of weapons and communications

This factor has necessitated the reassessment of the philosophy of and conduct of war in order for a service to remain competitive. The Germans, as one example, are already engaged in such studies.

These developments vitally affect services, staff, and strategy. In colleges not devoted to the study of war, the effect of these developments does not as yet appear to be recognized. A lack of military scholars, and hence military students, may in part account for this situation.

The fact that the elements of water, land, and air have been responsible for the creation of three services in most of the major countries of the world is no more valid than that branches within these services are created by the mobile base of fire which transports the weapons. As the range of a weapon increases, the need for the base of fire to move it within effective range becomes less and less essential.

As the time involved in launching the weapon and in its ultimate destruction of the target is lessened, the more important becomes the requirement for a high state of readiness. The more complete the readiness and the less lapse of time from total peace to total war, the less need there is for the high-level "staffs." As the power, speed, and range of weapons increase, the larger the battlefield becomes and the less we see of the purely military decision. The more significant the power of any given weapon, the more centralized will be the decision to use it.

The greater the range, speed, power, and readiness of a weapon, the more technical it becomes and the less able the military is to maintain it. Hence we see a centralizing trend in command and control, a lessening of the importance of the traditional staff which we have known since World War I, a weapon complexity so great that the military cannot alone maintain it, a weapon so powerful that the decision to use it is political at the highest level, and a weapon with such range, power, and speed that it threatens to negate the need for separate combat branches or services. The problem is not one of granting more time to research and development in the service colleges, or of improving and copying industrial management practices, or of more pay or benefits, or of understanding the psychosocial and ethnic aspects of the uncommitted nations. Rather, the problem is an understanding of the impact of speed, range, and power of weapons upon the battlefield, upon war and the philosophy of war. This is our problem, and to remain competitive we must face it.

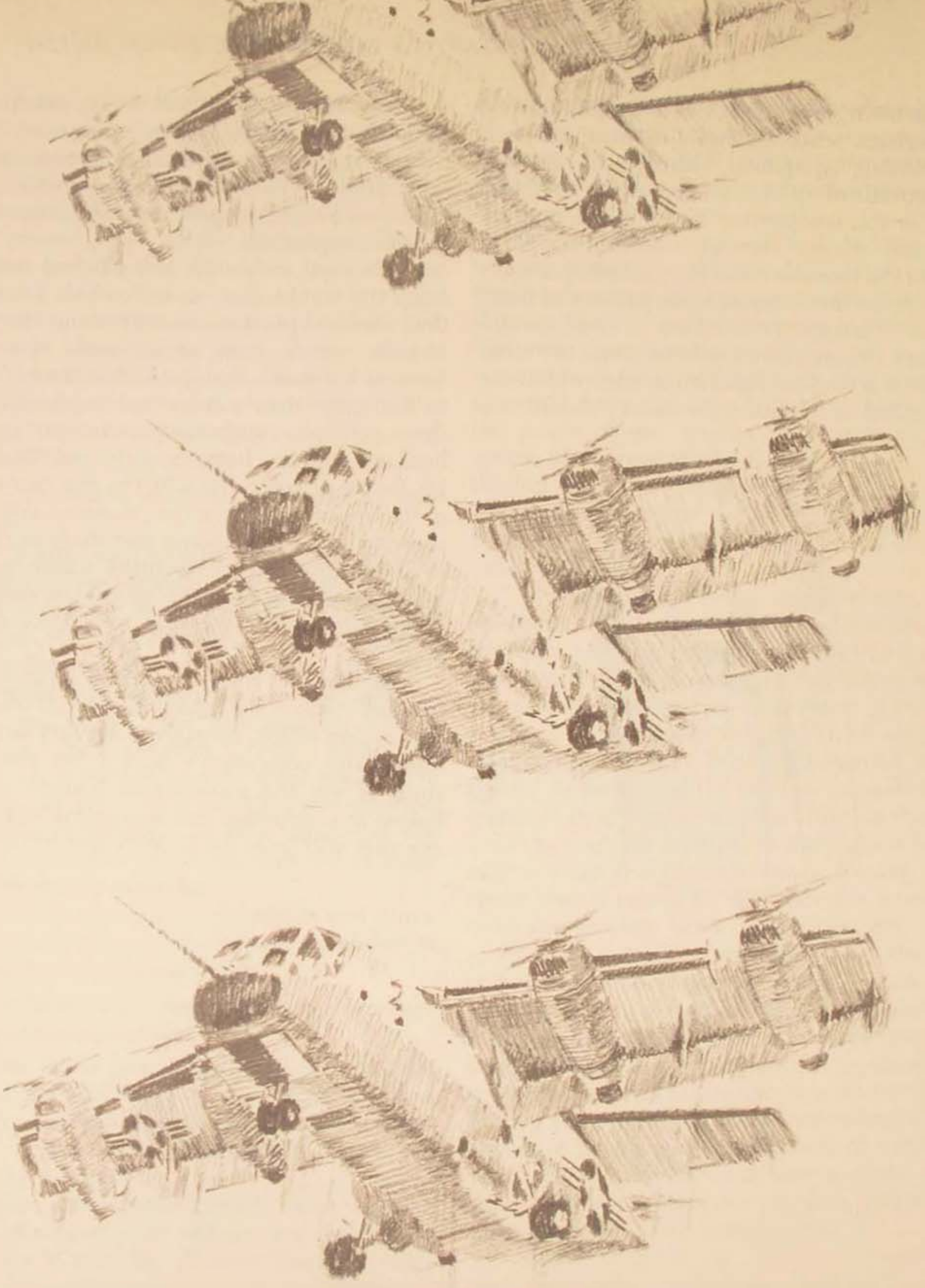
THE COMPETITIVE environment within the military profession maintained by the various branches, services, and in particular nations, both allied and enemy, is the fundamental difference between the military profession and others. The very life of a nation depends upon the competitive stance of its services. This competitive environment is a continuing one throughout peace and war. It manifests itself in training, equipment, strategy, tactics, and the attitude of military personnel. As a foundation for this competitive stance lie the military colleges, which, through educational effort within the boundaries of the professional spectrum, foster the dynamic examination and study of war. Through these efforts in every service in every nation, each strives to outdo the other to ensure a readiness and knowledge which can be applied in the quest for victory should war come.

Any service or nation which permits its military colleges to become distracted from their primary purpose through preoccupation with studies lying outside the competitive environment is giving unearned advantage to its possible opponents.

We must constantly bring before our colleges the truism that, as in football, the team that doesn't practice doesn't win; that the victor's wreath rests precariously upon the brow of last year's champion; that there is more to the game than a huge and impressive stadium, publicity campaign, parades, past heroes, hotdogs, popcorn, helmets, pads, and Wheaties. It's the inner spirit, the will, the constant study of the opponent's plays, size, reserves, skill, and strategy, and the planning and study of means to beat him. This competitive stance cannot begin on the day of the game but must be present throughout the year, in practice and in play.

In a service, the same is true. There is only so much time equally available to all services. The nation which, through its military services, builds the competitive stance by thorough study of war and possesses the knowledge and finesse in conducting and supporting war is the one that will have the best chance for victory.

Extension Course Institute



THE VTOL FLIGHT-TEST CHALLENGE

Major Philip E. Neale, Jr.

Like all novices we began with the helicopter (in childhood) but soon saw that it had no future and dropped it. The helicopter does with great labor only what the balloon does without labor and is no more fitted than the balloon for rapid horizontal flight. If its engine stops it must fall with deathly violence for it can neither float like the balloon nor glide like the aeroplane. The helicopter is much easier to design than the aeroplane but it is worthless when done.

Wilbur Wright
Dayton, Ohio
15 January 1909

As WE all know, the helicopter has developed into an extremely versatile vehicle despite some rather high-powered skepticism. It was developed primarily because it filled a very real transportation need in the vertical take-off and landing (VTOL), short-haul area. It cannot compete with fixed-wing aircraft in any other respect, and I doubt whether it ever will. Because the helicopter successfully demonstrated the advantages inherent in a VTOL machine, a great deal of emphasis has recently been placed on a vehicle that can fly vertically as efficiently as the helicopter and horizontally as efficiently as the fixed wing. This emphasis has resulted in numerous VTOL vehicles that are flying today in an experimental status, some of which are the forerunners of future operational VTOL aircraft. As before, a great deal of skepticism has been voiced about the feasibility of VTOL vehicles. Nevertheless, considerable progress has been made and the rate of progress is increasing rapidly.

The purpose of this article is to discuss some of the unique problems facing all flight-test organizations as they begin flight-testing VTOL vehicles. No attempt has been made to separate civilian and military flight-test problems, since both groups must obtain solutions in the same general areas.

One of the major problems associated with testing VTOL vehicles is directly related to how we can best gather needed data. In other words, we have a good idea of what data we want but are not quite sure which method we should use to obtain information in each instance. This problem applies to flight-test techniques, special flight-test instrumentation, and special test facility requirements. Easy standard solutions are not attainable, since practically every present-day VTOL machine is based on a different design concept. Fortunately many of the less practical designs will fall by the wayside after tests have proved their impracticality, and some of our testing problems will disappear. However, it should be noted that a present-day impractical design may suddenly become highly practical because of propulsion, aerodynamic, or other technical breakthroughs. Other test problems of major importance include VTOL test pilot qualifications and VTOL handling qualities during hover and transition to horizontal flight.

The following descriptions and illustrations will provide an insight into various VTOL concepts. This list is by no means complete, but it is representative and helps clarify some of the testing problems to be discussed. I have not attempted to discuss advantages and disadvantages of each concept, primarily because few data are available for comparison and any reasonable discussion would require a rather lengthy discussion of that subject alone.

- The X-19 is a light utility VTOL transport that employs the tilt-propeller concept. The four propellers are powered by two turboshaft engines rated at 2250 shaft horsepower (shp) each and are mechanically interconnected to the propellers by a system of drive shafts and gearboxes. The forward propellers rotate through an arc of 99 degrees from horizontal; the aft propellers rotate through an arc of 84 degrees. In hover flight the forward and aft propellers are tilted slightly toward each other for yaw control. Yaw control is achieved by increasing thrust on diagonally opposed propellers. Pitch control in hover is achieved by increasing thrust on the forward propellers and decreasing thrust on the aft propellers for a nose-up moment and by the opposite actions for a nose-down moment. Roll control is achieved by increasing thrust on the propellers on one side while decreasing thrust on the other side. The propellers are attached to comparatively short wings designed to provide an optimum lift-to-drag ratio for horizontal cruise. Transition from vertical to horizontal flight is accomplished by slowly rotating all four propellers toward horizontal as speed increases. Reconversion to vertical flight is achieved by reversing this procedure. Control during transition is a combination of the hover control system and conventional elevator, ailerons, and rudder. The hover control system is deactivated once the aircraft has achieved horizontal flight. Basic design performance includes:

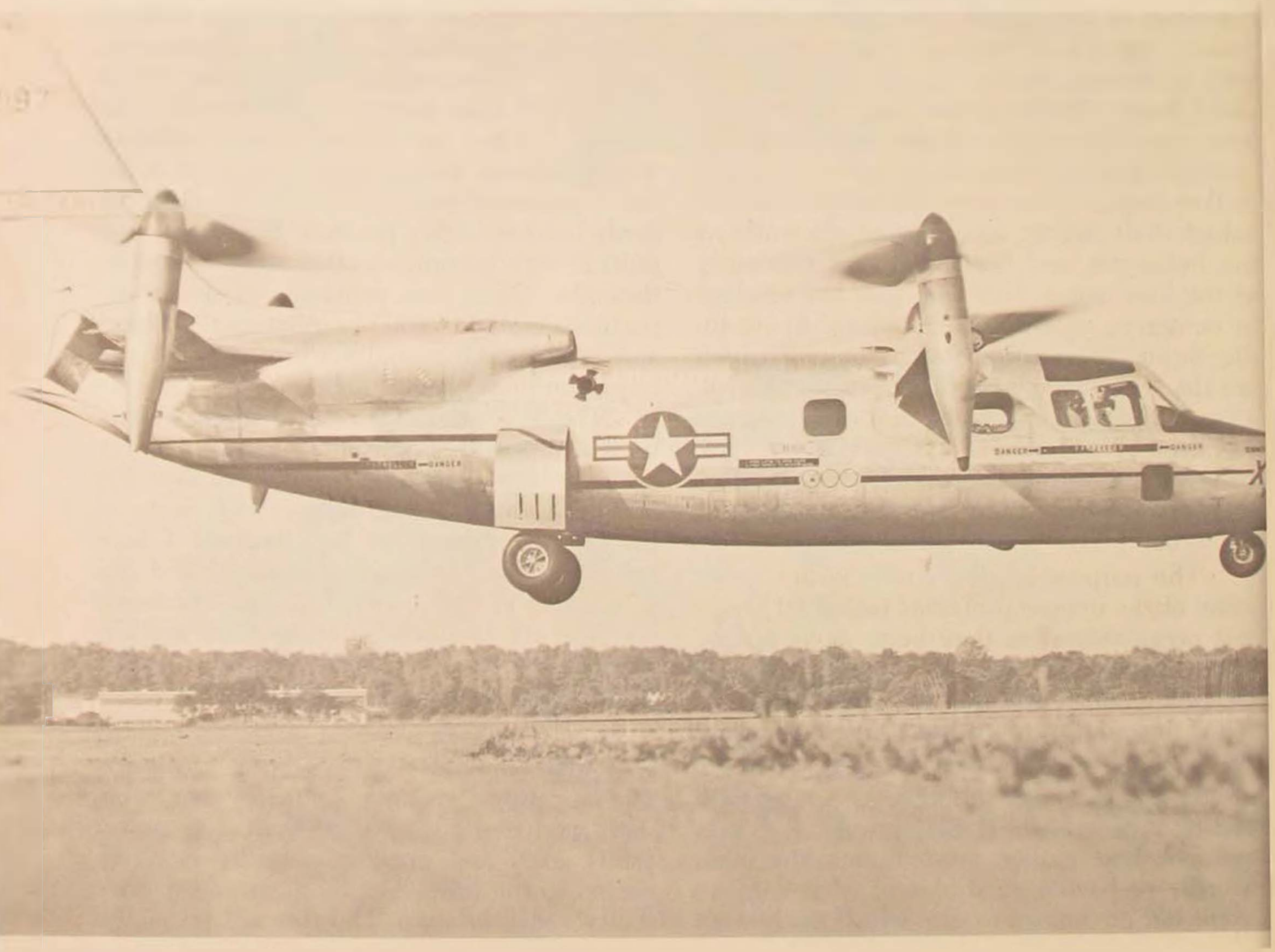
a. Gross weight for vertical take-off — 13,600 pounds.

b. Maximum payload with vertical take-off — 2000 pounds.

c. Maximum speed at 17,500 feet mean sea level (msl)—345 knots true airspeed (ktas).

d. Cruise speed — 280 ktas.

X-19



e. Range (one way) for vertical take-off and landing, two crew members, no payload – 735 nm.

First flight occurred 14 November 1963 and lasted approximately one second. The second flight occurred 26 June 1964 and lasted two seconds. The aircraft has flown numerous times since then and is still being flown during development flight tests.

- The XC-142 is a small, three-to-four-ton-payload VTOL transport that uses the tilt-wing, deflected-slipstream concept. Its four wing-mounted propellers and a pitch tail-mounted propeller are powered by four turboshaft engines, each rated at 2850 shaft horsepower. All propellers are interconnected by a special drive system that prevents loss of one or more propellers in the event of engine failure. The wing rotates through an arc of 98 degrees from horizontal and is rotated to the 90-degree position for hover flight. Pitch control in hover is achieved by increasing or decreasing the thrust of a pitch propeller located just aft of the tail assembly. Roll control in hover is provided by increasing wing propeller thrust on one side while decreasing thrust on the other. Yaw control in hover is achieved by deflecting conventional ailerons into wing propeller slipstream. Control during transition is provided by a combination of the hover control system and conventional ailerons, rudder, and elevator. Yaw control during transition is further supplemented by asymmetric thrust on wing propellers. Transition from vertical to

XC-142

horizontal flight is achieved by slowly rotating the wing from the vertical to horizontal position as speed increases. The wing is completely washed by propeller slipstream and thus remains unstalled throughout the entire transition maneuver. Reconversion to vertical flight is achieved by reversing this procedure. Basic design performance includes:

a. Maximum gross weight for vertical take-off — 37,500 pounds.

b. Maximum payload for vertical take-off — 8000 pounds.

c. Maximum speed at 20,000 feet msl — 274 ktas.

d. Cruise speed at 20,000 feet msl — 220 ktas.

e. Radius with 8000-pound payload, unload ½ cargo at destination and return — 200 nm.

The first flight was made on 29 September 1964 in the conventional mode with the wing rotated 10 degrees up. Since then it has flown in the hover mode and made full transitions in both directions. The aircraft is currently being flown in a development flight-test program.

- The VJ-101C (X-1) is a research VTOL fighter that employs the direct-lift concept. It is powered by six turbojet engines, each with 2750 pounds of thrust. Two are mounted vertically with respect to the longitudinal axis in the fuselage forward of the center of gravity, and pods with two engines are mounted on each wing tip aft of the center of gravity. The wing-tip engines are free to rotate through 100 degrees from horizontal and are in the 90-degree position for vertical flight. Pitch control in hover is achieved by modulating thrust between the two fuselage engines and the wing-tip engines. Roll control in hover is provided by increasing thrust on one set of wing-tip engines while decreasing thrust on the other set. Yaw control in hover is achieved by tilting each set of wing-tip engines a small amount in opposite directions, i.e., one set forward and one set aft. Transition from vertical to horizontal flight is achieved by rotating the wing-tip engines toward horizontal as speed increases. Once horizontal flight is achieved, the fuselage engines are shut down. Reconversion to vertical flight is achieved by reversing this procedure. Control during transition is a combination of conventional aerodynamic controls and hover controls.

Much of the VJ-101C (X-1) basic performance is classified; however, it is capable of making a vertical take-off at approximately 14,000 pounds. Its maximum level flight speed is low supersonic. First flight, which was in the hover mode, occurred 9 April 1963. First conventional take-off and landing flight was completed 31 August 1963. First full transition from vertical to horizontal flight was accomplished in April 1964. As of 1 June 1964 it had accumulated 54 flights and approximately 10 flying hours. In early September 1964 it suffered major crash damage during take-off. A follow-on version with afterburning engines in the wing-tip pods is under construction and scheduled to begin flight test in 1965.

- The P-1127 is a light VTOL direct-support aircraft that employs the deflected-jet con-

VJ-101C (X-1)

P-1127

cept. It is powered by a single 15,200-pound-thrust turbofan engine. Vertical lift is achieved by directing cold gases from the fan and hot gases from the exhaust into two louvered deflector nozzles on each side of the fuselage. The louvered deflector nozzles rotate through an arc of 100 degrees from horizontal and are positioned to the 90-degree point for hover flight. Control in hover is provided by reaction nozzles that use compressor bleed air. It has an up-down reaction nozzle on each wing tip for roll control, a down nozzle on the nose and tail for pitch control, and a left-right nozzle on the tail for yaw control. Transition from vertical flight to horizontal flight is achieved by slowly rotating the deflector nozzles to the horizontal position as speed increases. Reconversion to vertical flight is achieved by reversing this procedure. Control during transition is effected by a combination of conventional aerodynamic controls and the reaction nozzles. The aircraft is capable of high subsonic speeds with a maximum VTOL gross weight of approximately 11,500 pounds. Its range is a function of payload, since fuel must be offloaded to accommodate any payload other than pilot and fuel. A follow-on engine development program will increase its maximum VTOL weight to approximately 13,500 pounds.

The P-1127's first hover and conventional flights occurred 21 October 1960 and 13 March 1961, respectively. The aircraft has been flying continuously since then in research and development tests and is currently being evaluated in an operational environment by a tripartite evaluation group composed of German, British, and American military pilots and engineers.

- The XV-5A is a light VTOL research aircraft that employs the lift-fan concept. Three fans, one in the nose and one in each wing, provide vertical lift. It is powered by two turbojet engines, each developing approximately 2650 pounds of thrust. The fans are driven by exhaust gases ducted through pneumatic tubes, which then exhaust against turbine blades around the circumference of each fan. Each wing fan has exit louvers beneath the fan that are capable of vectoring through an arc of 45 to 90 degrees from horizontal. The exit louvers serve two functions, as they are used for aircraft control during hover and for thrust vectoring during transition. The louvers are set at 90 degrees for hover and are vectored from 90 to 45 degrees during transition. The pitch fan has two variable-position thrust-reverser doors, one on each side of the fuselage, that can change the direction of fan thrust for pitch control in hover and during transition. Roll control in hover is achieved by increasing the thrust on one wing fan while decreasing thrust on the other. Wing fan thrust modulation is obtained by increasing or decreasing mass flow through the fans by partially opening or closing the exit louvers. Yaw control in hover is achieved by vectoring exit louvers on one wing fan toward the 45-degree position. Transition from hover to horizontal flight is accomplished by slowly vectoring exit louvers on each wing fan from the 90-degree position towards the 45-degree position as forward speed increases. Once the aircraft has accelerated to a speed safely above stall, diverter valves in each engine tailpipe are opened, and the aircraft converts to a conventional jet mode of flight. Reconversion to vertical flight is accomplished by reversing this procedure. Control during transition is a combination of both the aerodynamic and hover control systems. Approxi-

XV-5A

mate basic design performance includes:

a. Gross weight (maximum) for vertical take-off – 13,500 pounds.

b. Maximum vertical take-off payload with full fuel and two crewmen – 500 pounds.

c. Maximum speed at 20,000 feet msl – 475 ktas.

d. Approximate range (one way) with vertical take-off and landing – 500 nm.

The XV-5A's first conventional and hover flights occurred 25 May 1964 and 16 July 1964, respectively. First hover take-off, full transition to conventional flight with retransition, and hover landing occurred 5 November 1964. One of the two XV-5A's crashed 28 April 1965 during flight test at Edwards AFB, California. The second aircraft is continuing the original scheduled program of flight-testing at present.

- The XV-4A is a light research VTOL aircraft that employs the jet ejector principle. Vertical lift is achieved by ejecting turbojet exhaust gases vertically through a manifold in the fuselage. Secondary air is entrained by the high-velocity primary air, which effectively augments primary thrust. The XV-4A is powered by two turbojet engines, each with 3300 pounds of thrust. The hover flight control system is similar to that of the P-1127 and uses reaction nozzles powered by bleed air from the compressor for roll and from the manifold for pitch and yaw.

Transition from hover to horizontal flight is accomplished by first lowering the nose to provide a forward component of thrust, then

XV-4A

maintaining level flight with power as speed increases. Upon reaching 75 knots the nose is raised to a level attitude, and one engine is diverted from the lift to the thrust mode. As the aircraft accelerates to 110–120 knots, the second engine is diverted to the thrust mode. Ejector doors are closed, and the transition maneuver is complete. The landing transition reverses the take-off procedure. Control during transition is achieved by a combination of the hover flight control system and conventional aerodynamic flight control system. A unique feature of the transition flight control system is a boundary layer control installation on the horizontal tail which improves aerodynamic pitch control during transition by keeping the tail unstalled to very slow speeds.

The XV-4A has an approximate VTOL maximum gross weight of 7200 pounds. No useful payload can be carried other than crew and fuel for a vertical take-off and landing. Range for a VTOL mission is very limited, and maximum conventional level speed is approximately 350 ktas.

The XV-4A's first conventional and hover flights occurred 7 July 1962 and 24 May 1963, respectively. The first low-level full transition flight from vertical to horizontal and back to vertical was successfully completed 8 November 1963. The original contractor flight-test program involved approximately 29 hours of flight time with 53 conventional flights and 61 hover and transition flights. A follow-on contractor and military flight-test program was terminated in the summer of 1964 after one of the two test aircraft suffered major crash damage. Additional wind-tunnel studies were then completed on the second aircraft. The resumption of flight-testing is still under negotiation.

The following discussion on problems associated with flight-testing VTOL aircraft is rather general and in some instances may not reflect the considered opinions of recognized authorities in the VTOL field. In other words, when the discussion represents an opinion, the opinion is mine.

flight-test instrumentation

The problem of flight-test instrumentation is not limited to VTOL aircraft, but in VTOL aircraft it is complicated by limitations and special requirements. In many instances marginal lift-to-weight ratios and restricted space dictate the use of small, lightweight flight-test instrumentation systems. An equally important consideration is the number of parameters which the instrumentation systems are required to record. VTOL aircraft generally require the recording of many more parameters than conventional aircraft, for several reasons:

a. Each VTOL aircraft has essentially two flight control systems, one for hover and one for conventional flight. During hover some VTOL aircraft use additional levers for height control, which requires measurement and recording of forces and positions for that lever. Also moment-producing mechanisms in hover are different from those in conventional flight, e.g., reaction nozzles, thrust-reverser doors, variable-position louvers, propeller pitch, engine thrust, etc. Each mechanism requires some type of special instrumentation pickup.

b. Aircraft of the X-19 and XC-142 type have interconnected drive shafts and gearboxes that require numerous temperature, torque, and oil-pressure pickups.

c. Most VTOL aircraft require stability augmentation systems for adequate control during hover. These systems must be closely monitored and generally require numerous pickups for quantitative data.

d. Aircraft vibration problems are anticipated in many VTOL aircraft, necessitating a large number of vibration pickups.

e. Finally, all unique VTOL aircraft features, such as tilt wings, tilting propeller pods and engines, exit louvers, reverser doors, ejector doors, etc., require flight-test instrumentation pickups.

To meet these requirements, most flight-test instrumentation organizations are installing magnetic tape and telemetry equipment, which will best satisfy the special flight-test instrumentation criteria for VTOL aircraft. Since telemetry and magnetic tape are also in a developmental status, the usual problems associated with relatively new and untried equipment can certainly be expected. Further development of these systems will be a valuable fallout of the early VTOL aircraft flight-test programs.

flight-test techniques

Flight-test techniques, or in other words the in-flight pilot procedures used to collect data and fly the aircraft, are well developed for conventional and helicopter aircraft. The procedures are generally applicable to VTOL aircraft in pure hover and pure conventional modes of flight but are practically nonexistent in the flight region between vertical and horizontal flight. Although I shall discuss only one representative problem in this section, there are numerous other similar problems that I have not mentioned because of space limitations. One problem that all flight-test organizations try to avoid until the last moment is how to make the first transition. Should the transition be from horizontal to vertical flight first or from vertical to horizontal? Should the transition take place close to the ground over the runway or at a safe altitude? What is a reasonable envelope expansion program that does not waste valuable flight-test time but still provides enough data to enable avoiding trouble when the moment of truth arrives?

A summary of the actual steps taken prior to the XV-5A's first full-scale transition and retransition is perhaps the best way to illustrate how this particular problem was successfully solved in one instance. The XV-5A was first flown in the pure hover and conventional modes of flight. Design deficiencies were corrected in each mode. The aircraft then made a STOL take-off in the vertical or fan mode but at a speed above or near aerodynamic stall, climbed to a safe altitude at the same speed, converted to the conventional mode, and made a conventional landing. Next the XV-5A took off in the conventional mode, climbed to a safe altitude, converted to the vertical or fan mode at a speed above aerodynamic stall, and landed in the vertical mode at a speed still above stall. Until that time the aircraft had not flown in the 20–70-knot region, but it had proved that it could fly safely in both modes outside that speed region, that the conversion system worked properly, that conversions could be made with little loss in altitude, and that it could maintain a safe altitude in the hover mode.

With this information it was decided to investigate the 70–30-knot region at a safe altitude. This was done by taking off and climbing to a safe altitude in the conventional mode, converting to the vertical mode, and investigating handling qualities and performance in 5–10-knot decrements down to 30 knots. No attempt was made to fly at a speed below 30 knots at altitude because that speed region requires nearby outside visual references for precise aircraft control. This problem may not appear obvious to a fixed-wing pilot, but if one can imagine trying to fly a fixed-wing aircraft with little tendency to right itself from any roll, pitch, yaw, altitude, or attitude excursion, he can begin to appreciate why nearby outside visual references are highly desirable. Even with stability augmentation working properly, the pilot's task is appreciably greater than during higher-speed flight.

The 20–30-knot region was then investigated in the hover mode at low altitude over the runway, which effectively completed the transition flight region investigation. After all data were thoroughly reviewed for possible problem areas and no important ones were discovered, a complete transition and retransition flight was successfully performed. An interesting aspect of this particular procedure, which was developed during the XV-5A test program, is that it was not then and is not now directly applicable to most VTOL aircraft. Hence each VTOL test project officer has to develop a plan leading to the first full-scale transition that meets the objectives of the particular test program while remaining within the aircraft's limitations.

ground facilities

Ground facilities can be considered as a unique VTOL problem primarily because of their cost and developmental status. One of the more important ground test facilities is the vertical thrust stand wherein the aircraft is operated while firmly mounted on a cradle attached to the stand. If properly designed, it can determine the vertical lift, the control power in each axis, and the recirculation and hot gas reingestion problems both in and out of "ground effect."

A short discussion of the "ground effect" phenomenon seems in order before continuing with ground facilities problems. Simply stated, ground effect is the aerodynamic phenomenon that manifests itself as either an increase or decrease in power required when the aircraft is close to the ground. The change in power required is caused by a change in airflow about the aircraft due to ground interference. Ground effect is highly beneficial for helicopters in that power required to hover while in ground effect is greatly reduced. For this reason helicopters have a higher hovering ceiling in ground effect and can thus make vertical take-offs and landings in mountainous terrain higher than their out-of-ground-effect hover capability. Unfortunately this is not generally the case with other than helicopter-type VTOL vehicles. In fact, just the reverse is true in many instances, as high-velocity gases impinging on the surface create a low-pressure area beneath some VTOL aircraft. This is called negative ground effect or suck-down effect. Since suck-down is highly undesirable. considerable effort is being devoted to discover practical solutions for it.

Ground effect should not be confused with hot gas reingestion, although hot gas reingestion is sometimes caused by the flow pattern in ground effect. Hot gas reingestion results in loss of thrust caused by a rise in compressor inlet gas temperature, and in severe cases even compressor stall may result.

It is readily apparent that investigation of these effects prior to first flight is desirable. The vertical thrust stand that raises or lowers the aircraft out of and into ground effect by hydraulic ram provides that capability. Measurement of hover control power in each axis, again in and out of ground effect, can also be accomplished through installation of force measurement devices on the stand. It is important to measure control power in ground effect, since it is also affected by ground effect flow patterns.

In the past, hover control power has been determined by using other devices and procedures. For instance, several programs determined hover control power merely by hovering the aircraft and measuring control power by on-board instrumentation. This method worked well in one instance I know of when the aircraft hovered with no problems, but it did not work at all in another. One program used a loose tether rig that allowed limited movement in height, horizontal translation, and in roll, pitch, and yaw. This was not satisfactory, since the aircraft was stopped abruptly by the tether cables, which then introduced gross aircraft movement and sometimes marginal aircraft control.

Perhaps the most successful method was one that used a "flying bedstead" constructed to match the aircraft mass distribution, hover control system. thrust location points, and direct-lift engines. This particular rig was first checked out and optimized on a type of vertical-thrust stand with a single attaching point, like a telescope, before its free flight hover investigation. Although this approach was very successful, it was comparatively expensive and one that may not be required in the future if new vertical-thrust stands prove practical.

Another ground facility used to investigate out-of-ground-effect hover capability safely is a ground effect disperser. It is nothing more than a shallow pit covered with a heavy-duty grill, with large exhaust ducts installed in the pit to channel downwash gases out and away from the immediate vicinity of the aircraft. The aircraft can then be safely hovered a few feet over the grill without experiencing ground effect problems. Since this device is relatively inexpensive to build and maintain, it will probably be used as a backup or supplemental facility for quite some time.

A particularly important type of ground test facility, still in the early development stages, is the flight simulator capable of realistically simulating hover and slow-speed flight with the pilot in the loop. This type of simulator is important for test pilot training, for test mission planning, and for evaluating hover-transition handling qualities. Although there are numerous other valuable uses for this equipment, these three are the most important. Problems associated with realistic hover-transition flight deserve comment because they are not generally appreciated except by personnel directly associated with VTOL aircraft.

If a pilot is to provide usable handling quality evaluations through flight simulators, the simulation itself must be more accurate and realistic than that provided by procedures simulators used to train pilots for operational aircraft. The basic problem confronting all VTOL simulator design engineers appears to be deciding what represents the most feasible approach or design.

In my opinion the best current design is one that has a fixed-base, general-purpose cockpit with standard flight instruments and a realistic out-the-window 180-degree field-of-view visual display. The out-the-window VFR visual display is primary for aircraft control during hover and transition. My opinion is based on several considerations. First, moving bases used to provide realistic motion cues in every situation are complicated and so far have not been completely successful. In other words, extraneous movements, which have so far been impossible to eliminate, result in unrealistic motion vector directions that often destroy the intended illusion. Second, although considerable progress has been and is being made in the development of a cockpit display that will allow hover under zero zero instrument conditions, a great deal of homework still needs to be done in this area. Even if a good in-the-cockpit display were available, I sincerely doubt whether it could compete with the 180-degree out-the-window display. This statement is better understood if one considers that the pilot must be able to recognize and correct for dynamic pitch, roll, and yaw movements of 1 to 2 degrees and for translational velocities in any direction of 1 to 2 feet per second. Simply stated, the out-the-window display provides the pilot with error information faster than an in-the-cockpit display because of its much larger scale. Perhaps a better R&D VTOL simulator will be developed in the future, but until then the type I have described will probably contribute more useful information and training than any other.

VTOL test pilot flying qualifications

The basic philosophy concerning flight experience for fixed-wing test pilots applies also to helicopter test pilots. When a military test pilot is assigned to an experimental flight-test organization, his previous operational flying experience usually determines what type aircraft he then tests. The reasoning behind this is obvious and to my mind quite valid. Also, to increase the test pilot's ability to evaluate experimental or prototype aircraft effectively, flight-test organizations try to provide each test pilot at least some experience in all types of aircraft. The objective is to provide each with as much experience as possible on which to base future test reports, recommendations, and conclusions. This philosophy is still valid for VTOL test pilots and is not the area causing most of the current discussion. It should be noted, however, that recent standardization/evaluation efforts to reduce the number of aircraft which test pilots are authorized to fly may create a new problem in the future. The main problem area concerns the importance of helicopter experience. One faction contends that the VTOL test pilot should be fully qualified in helicopters while the other believes helicopter experience is unnecessary.

My position is somewhere in between: I do not think that full helicopter qualification is necessary, but I do think that general experience in helicopters is important and that proficiency in hovering a helicopter is particularly important. I disagree with the "full helicopter qualification" theory because

—Full qualification accomplishes little, since there is little similarity between the mechanics of flying a helicopter and a VTOL aircraft in any flight region other than in hover and perhaps in the early portions of transition.

—Few experienced test pilots are qualified in helicopter aircraft, and training each to be fully qualified would be expensive and time consuming.

—Experienced VTOL test pilots readily admit that while the mechanics of hovering a VTOL aircraft and a helicopter are very similar, the physical sensation or environment is quite different.

I disagree with the "no helicopter experience" theory because

—The mechanics of hovering a helicopter

and VTOL aircraft are pretty much the same.

—Some helicopter experience is readily available.

—Experience in flying comparatively unstable aircraft will certainly be valuable for early VTOL aircraft test pilots.

—The great majority of experienced VTOL test pilots say that some helicopter experience is necessary.

I admit that advances in new VTOL hover control systems may make hovering a joy rather than a chore, but even the best systems require that one push or pull on the stick to translate fore or aft, etc. Further, I have observed experienced conventional test pilots attempt their first hover in a helicopter that could hover hands-off, and the results were unsatisfactory, pointing up the need for hover experience.

Expansive statements to the effect that conventional operational pilots have hovered a given VTOL aircraft without any previous helicopter hover experience are dangerously misleading. These statements may be technically correct, but they do not take into account all the facts. For instance, the particular hover control system may have allowed complete hands-off hover so that even a person with no flight experience whatsoever could hover it when the system was *operating properly*. These last two words are very important and really the basis for my position in regard to helicopter experience for VTOL operation. VTOL pilots not proficient in hovering or unstable handling qualities will be much more apt to commit major pilot errors during marginal control situations regardless of whether the control problems are due to poor design or system failure. It should be remembered that not all currently flying VTOL aircraft are easy to fly during hover and transition, because of poor design or lack of specific design requirements as to handling qualities.

Thus, I believe that each VTOL test pilot should have experience in a wide variety of aircraft, including helicopters. Full helicopter qualification is not necessary, although proficiency in helicopter hover is. Further, each test pilot, VTOL or otherwise, should continually fly and evaluate all types of aircraft. Finally, I think previous experimental test experience is highly desirable, even necessary, since current VTOL vehicles are based on untried concepts and equipment and thus require a more experienced approach to their flight-testing.

VTOL handling qualities

Not being able to define specifically the minimum standards of controllability during hover and transition is the basic problem as to handling qualities for VTOL aircraft. The current specification defining military handling qualities for helicopters is not considered adequate or applicable in many areas for all types of VTOL aircraft. Until more VTOL experience and information are available, standards for handling qualities in the hover and transition flight regions will be in a continuous state of flux.

DESPITE a rather hesitant start, the VTOL era has begun. Doubts as to VTOL aircraft feasibility will continue to be voiced, but with decreasing frequency and authority as the more promising designs prove their worth. Numerous VTOL aircraft experimental flight-test problems are currently being encountered. Those discussed in this article are by no means the only ones, but they are considered to be some of the most important ones. Resolution of each problem will certainly occur as VTOL experience and knowledge are accumulated.

Air Force Flight Test Center

Note: Because of a lack of flight-test data and the fact that much VTOL equipment is in a developmental status, specific performance figures listed in this article should be considered only as approximate.

RELIABILITY

Dr. James A. Fraser

IMAGINE a booster with its spacecraft payload sitting on the launch pad. The booster is fueled, everything is checked, and the countdown has been completed. All systems are "go." Will the spacecraft and booster perform their mission? Actual experience shows that most do but a few do not. However, before the actual launch, the project directors will need a good estimate of success probability. This estimate predicts the reliability of the system.

Let us suppose that a booster is undergoing design, development, and production. With the thousands of component parts that must be assembled into one operating system, it is highly probable that some mistakes will be made both in design and in the process of production. Some of these mistakes may cause a component to fail in a very short operating time. Others may cause whole subsystems to fail after a very short useful life. Both the engineers and the production supervisors will desire an estimate of the success probability for each component. This estimate is component reliability.

Reliability, a word heard with increasing frequency in space and missile language, is a probability idea. It is defined as the probability that a system will perform a required function under specified conditions, without failure, for a specified period of time. This idea can be applied to a whole complex system consisting of a multistage booster, a spacecraft, and a recovery system, or it can be applied to one stage of a system, or even to one single component part, such as a transistor or a valve.

The basic ideas of reliability theory and practice are not new and are not a product of the space age. However, the designer of space systems is faced with reliability requirements that are so exacting as to be almost beyond human capability. Space systems must function for long periods of time without maintenance and in a harsh environment, the precise characteristics of which are frequently unknown. It is estimated that the vacuum of space can be as low as 10^{-11} mm of mercury. At this pressure lubricants vaporize and absorbed gases bleed off through a phenomenon called "outgassing." When metal touches metal, "cold-welding" occurs so that bearings seize. Even switches and electrical contacts and relays are subject to this sort of failure due to the extreme environmental conditions. Solid materials may sublimate, and some may evolve corrosive gases which in turn may reduce the reliability of adjacent components of the system. Penetrating radiation in the Van Allen belts or from solar flares may severely alter the physical and chemical properties of materials. Temperature control is complicated by the fact that convection and conduction are no longer available as heat transfer mechanisms, radiation being the only method for dissipating heat from the space vehicle. Collision with space particles such as meteoroids and micrometeoroids is a possibility. The probability of collision with a large meteoroid is small. The probability of collision with micrometeoroids (which would not be catastrophic) is significant. These dustlike high-speed particles act like a sand blast and in time may roughen the outside surface of a space vehicle. This, in turn, will alter the balance between heat absorptivity and radiation.

Because of this harsh environment and the comparatively long periods of operation without maintenance, acceptable reliabilities in space systems require very long mean time to failure. For example, to achieve a 96% reliability in an aircraft that has to operate 8 hours without maintenance requires 200 hours mean time to failure, but to achieve 96% reliability in a satellite that has to operate one year without maintenance, 219,000 hours mean time to failure are required. Because of this long mean time to failure, reliabilities much less than 96% are often accepted. The power supply on Mariner IV has an estimated 0.711 probability of operating successfully throughout its 6213-hour mission. The power system of Mariner II had an estimated reliability of 0.716, and it operated successfully throughout its Venus mission.[*]

Since reliability is so important and so difficult to obtain, let us consider two methods of measuring reliability and how it can be improved.

Reliability of a space system can be measured, or estimated, in two distinctly different ways. First, a sample of the whole system can be exercised in an environment that approximates the actual expected operational environment as closely as possible. Inferences are then made from the sample to the population from which it was drawn. Second, samples of each of the parts that enter into the system may be exercised in environmental conditions that approximate as closely as possible the conditions of system operation. Inferences are made from the samples to the populations of parts from which they were drawn. The probabilities so obtained are considered as contingent probabilities, and the reliability of the operational system is calculated from these estimated component reliabilities. Both methods are used.

estimating the reliability of a whole system by sampling the whole system

Let us illustrate this method with a ballistic missile that is also used as a space booster. The entire inventory of missiles will be called the population. If we fired the whole population, we would know the proportion of them which succeeded and hence the reliability, but we would have no missiles left! So we must try to estimate the figure less accurately, but more economically, by sampling the population and then using the results from the sample to estimate the reliability of those that are left. Let us use the symbol n for the number of missiles in the sample; the symbol s for the number in the sample that succeed. Then, of course, $n - s$ is the number that fail. Let the symbol π stand for the proportion of missiles in the population which would succeed if the whole population were fired. That is, π represents the reliability figure we would like to know.

The first thing we must realize is that we cannot know π with 100% confidence. A risk of error is always inherent in the sampling and inference process. What we can do is find a value for π determined in such a way that we can state our confidence in its accuracy. Thus we could use mathematical techniques to arrive at a statement something like this: "We are 95% confident that the reliability is at least 60%."

To do this we use the binomial distribution. Using the symbols already defined, the binomial distribution is as follows: The probability of obtaining s successes in a sample of n is equal to

$$\frac{n!}{s!\,(n-s)!}\;\pi^{s}(1-\pi)^{n-s}$$

Suppose $n = 10$ and $s = 4$. The problem is to find a value of π such that we are 95% confident that the true reliability is π or greater. Another way of stating this 95% confidence is to say that we are willing to accept a 5% risk that we are wrong. Since in the actual test 4 successes were obtained from a sample of 10

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[*] "The Countdown," *Missiles and Rockets*, 8 March 1965, p. 9.

boosters, the problem can be further refined to be as follows: Pick a value for π so low that in a sample of 10 there will be only a 5% probability of obtaining 4 or more successes. Then, since we actually obtained 4 successes, we can be (100 — 5)% or 95% confident that π is either the selected value or higher.

Use the binomial distribution to calculate the cumulative probability of 4 or more successes out of 10 trials:

$$\sum_{s=4}^{s=10} \frac{10!}{s!\,(10-s)\,!}\,\pi^{s}(1-\pi)^{10-s}$$

where $s = 4, 5, 6, 7, 8, 9$, and 10, successively.

Since this expression has two unknowns, the solution can be obtained by iteration, i.e., assume a value of π, solve the seven equations, add the results, compare the answer with 5%, and, depending on this comparison, make another and better estimate of π. Repeat this until the sum is 5%. To illustrate, assume $\pi = .15$. Then one must calculate

$$\sum_{s=4}^{s=10} \frac{10!}{s!\,(10-s)\,!}\,(.15)^{s}\,(.85)^{10-s}$$

Thus the probability of 4 successes out of 10 trials is

$$\overset{4}{P}(10) = \frac{10!}{4!\,(10-4)\,!}\,(.15)^{4}\,(.85)^{6} = .0395$$

$$\overset{5}{P}(10) = \frac{10!}{5!\,(10-5)\,!}\,(.15)^{5}\,(.85)^{5} = .0063$$

$$\overset{6}{P}(10) = \frac{10!}{6!\,(10-6)\,!}\,(.15)^{6}\,(.85)^{4} = .0011$$

$$\overset{7}{P}(10) = \frac{10!}{7!\,(10-7)\,!}\,(.15)^{7}\,(.85)^{3} = .0001$$

$$\overset{8}{P}(10) = \frac{10!}{8!\,(10-8)\,!}\,(.15)^{8}\,(.85)^{2} = .00006$$

$$\overset{9}{P}(10) = \frac{10!}{9!\,(10-9)\,!}\,(.15)^{9}\,(.85)^{1} = .00000$$

$$\overset{10}{P}(10) = \frac{10!}{10!\,(10-10)\,!}\,(.15)^{10}(.85)^{0} = \underline{.00000}$$

$$\text{Total } .04706$$

Since .047 is a little less than 5%, π must be a little more than .15.

In this example, the first guess at the value of π was very close. Usually one would not be so fortunate and the process would have to be repeated numerous times. Since this process is tedious, tables have been produced by machine calculation. Tables I and II are examples. It will be noted that at the 95% confidence level, 4 successes out of 10 trials indicate a reliability of at least 15%. It is true that 4 successes out of 10 is a 40% reliability in the *sample*. But when the inference is made from the sample to the population, all that may be said with 95% confidence is that the reliability is at least 15%. From Table II it can be seen that the same sample results could be interpreted as 75% confidence that the reliability is at least 26%.

estimating reliability by testing components of a system

Reliability of component parts of a system is frequently estimated by selecting a random sample of a component and operating it until all its elements fail. Operating conditions should be as close as possible to the conditions of operation for which the component is designed. From the frequency distribution of failures at various times, a mean time before failure (MTBF) is calculated. The reciprocal of MTBF is failure rate (λ). For example, suppose MTBF is 100 hours. The failure rate is $\frac{1 \text{ part}}{100 \text{ hours}}$ or .01 parts per hour. When this is done, three types of failure can usually be identified: initial failures, random failures, and wear-out failures. Initial failures occur because an item was faulty from the beginning, often as a result of substandard components, poor design, or careless production. Such failures usually take place during the "debugging" period. Random failures are those which occur during the useful life of a component. After debugging is complete and production procedures have been standardized, failures will occur at random times. These cannot be anticipated or entirely avoided by preventive maintenance. This is the portion of a component's life cycle that is the subject of reliability analysis. Wear-out failures occur when the com-

Table I. 95% Confidence Levels for Reliability

Number of Successes, s	Sample Size, n											
	1	2	3	4	5	6	7	8	9	10	15	20
1	.05	.02	.02	.01	.01	.01	.01	.01	.01	.01	0	0
2		.22	.14	.10	.08	.06	.05	.05	.04	.04	.02	.02
3			.37	.25	.19	.15	.13	.11	.10	.09	.06	.04
4				.47	.34	.27	.22	.19	.17	.15	.10	.07
5					.55	.42	.35	.30	.25	.22	.14	.10
6						.61	.49	.40	.35	.30	.19	.14
7							.65	.54	.45	.39	.24	.18
8								.69	.58	.49	.30	.22
9									.72	.61	.36	.27
10										.74	.42	.31
11											.49	.35
12											.56	.39
13											.64	.45
14											.72	.49
15											.82	.54
16												.60
17												.66
18												.72
19												.79
20												.86

ponents are operating past their useful life span. Wear-out failure times can be predicted rather well because of the small standard error of the mean. Thus a component entering the wear-out period can be replaced before it fails. However, in space operations, probability analysis in the initial period is of no value because the reliability is not sufficiently high, and in the wear-out period it is of no value because replacement is impossible. So, from another point of view, only in the random-failure period is probability analysis useful for space application. Fortunately, in this period the failure rate is constant, which permits probability analysis to be based on the Poisson distribution. Figure 1 illustrates a typical plot

Table II. 75% Confidence Levels for Reliability

Number of Successes, s	Sample Size, n											
	1	2	3	4	5	6	7	8	9	10	15	20
1	.25	.13	.09	.07	.06	.05	.04	.04	.03	.03	.02	.01
2		.50	.33	.24	.19	.16	.14	.12	.11	.10	.06	.05
3			.63	.46	.36	.30	.25	.22	.20	.18	.12	.09
4				.71	.55	.45	.38	.33	.29	.26	.17	.13
5					.76	.61	.51	.44	.39	.35	.23	.17
6						.79	.66	.57	.50	.45	.29	.22
7							.82	.70	.60	.54	.35	.26
8								.84	.72	.65	.41	.31
9									.86	.75	.48	.35
10										.87	.55	.40
11											.61	.45
12											.68	.50
13											.76	.54
14											.83	.60
15											.91	.65
16												.70
17												.76
18												.82
19												.88
20												.93

of failure rate compared to component age.

If P_t symbolizes the probability of a component part surviving over time t, then the Poisson series may be written as follows:

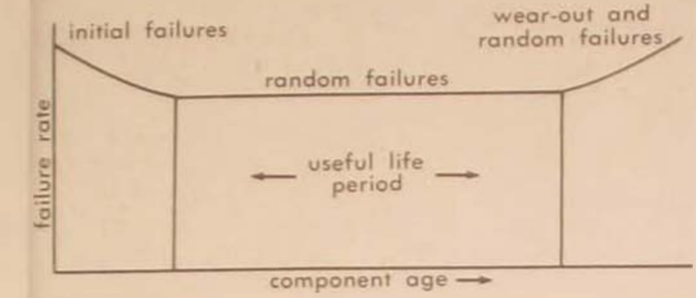

Figure 1

$$P_t = e^{-\lambda t} + e^{-\lambda t}(\lambda t) + \frac{e^{-\lambda t}\ (\lambda t)^2}{2!} + \frac{e^{-\lambda t}\ (\lambda t)^3}{3!} ----- + \frac{e^{-\lambda t}\ (\lambda t)^n}{n!}$$

As previously defined, λ is the measured failure rate. Now, the first term, $e^{-\lambda t}$, is the probability of *no failures* in time t. The second term, $e^{-\lambda t}(\lambda t)$, is the probability of one failure in time t, etc. Thus reliability in the sense previously defined, to mean the probability of no failures in a specified time t, is represented by the first term of this distribution:

reliability over time t equals $e^{-\lambda t}$

So when a random sample of a component is tested under conditions closely approaching the expected operational conditions and when MTBF is measured and failure rate is calculated and desired operation time (t) is specified, reliability can be estimated rather well.

To illustrate the above method, let us suppose that the measured mean time before failure was 1000 hours. Then the failure rate would be $\frac{1 \text{ part}}{1000 \text{ hours}}$ or .001 parts/hour. If this component were expected to operate for 10 hours, the reliability would be

$$e^{-(.001)(10)} = e^{-.01} = \text{approximately } 99\%$$

calculating the reliability of a system from the reliability of its parts

If a system is so designed that its successful operation depends upon the successful operation of each of the parts, the system reliability is contingent upon the reliability of the parts. In this case reliabilities of the parts are multiplied together to obtain reliability of the system. For example, if we consider a very simple system with only two parts and the reliability of part A is 90% while the reliability of part B is 80%, the reliability of the two-part system is $90\% \times 80\% = 72\%$.

Consider a system of 10 parts with each part having a reliability of 90%. What is the reliability of the system? It is $(.90)^{10} = 35\%$. Clearly a component reliability of 90% is much too low to produce an acceptable system reliability even in a ten-component system. In a system with 100,000 parts, the reliability will be so low as to be ridiculous unless the component reliability is very much higher than 90%. For the operation of some space systems, component reliabilities in the order of 99.9999% are often needed in order to obtain an overall system reliability that is even marginally acceptable.

improving low reliability

If the reliability of a system or the reliability of a component part of a system is too low to be acceptable, what can be done to improve it? There are many things that can be done. In fact, most large manufacturing companies have a staff of engineers and statisticians whose sole job is to study the reliability of the company's products and recommend procedures to improve it. Methods employed usually include quality control and redundancy.

Quality Control. Part of the process of quality control is discipline, procedure, and correction of the manufacturing process. Still another part is statistical. In the first category come such actions as inspection to ensure close adherence to design specifications, control of dust, dirt, grease, and other debris that might degrade the functioning of a component, training programs for employees so that each will know the correct procedures and each will be motivated to employ the correct procedures, incentive programs for employees not only for speed of production but also for quality of production. In the second category come such actions as sampling a product to determine whether or not the engineering specifications are being met. Sampling a product in order to maintain a control chart will show whether or not the manufacturing process is operating properly or is producing too great variations in the product.

Quality control is a tremendous subject and one that can be only briefly introduced here. Attention is merely called to its importance in ensuring and maintaining good reliability and to the fact that quality control alone is often insufficient to produce the very high component reliability needed in space systems.

Redundancy. One of many design methods for improving reliability is the use of redundancy. Certain critical parts of a system may be so designed that two or more alternate, or redundant, components are provided. The system may be so designed that it fails only if both or all of the redundant parts fail. In other words, the system is so designed that it will operate correctly if at least one of the redundant components operates correctly.

The principle of redundancy may be illustrated by a two-channel system in which the reliability of each channel is R_c. Active redundancy is the system in which both channels are working at the same time. Standby redundancy is the system in which only one channel operates at a time, the other one being switched in upon failure of the first.

The effect of active redundancy can be understood by working out the probability that at least one channel will operate. Probability of at least one channel operating equals:

$$1 - (1 - R_c)^2 = 2R_c - R_c^2$$

Suppose $R_c = 90\%$. Then reliability of the two channels

$$\begin{aligned} &= 2(.90) - (.90)^2 \\ &= 1.80 - .81 \\ &= 99\% \end{aligned}$$

Thus active redundancy has increased the component reliability from 90% to 99%. This is not the whole story, however. Active redundancy makes additional gains because the two channels operating simultaneously share the load and hence decrease the chance of failure. Further, active redundancy in some circumstances might *reduce* reliability. For example, if we had two electrical switches in parallel, each with a reliability of .9, and the system required an *open* circuit to operate, the probability of the system working would be $.9 \times .9 = .81$. On the other hand, standby redundancy has disadvantages. It requires a switching device to eliminate the channel that fails and to activate the standby channel, and it requires a decision device to instigate this action at the right time. Both these devices will be less than 100% reliable themselves.

Reliability is an increasingly important subject to the Air Force. It has implications for almost every Air Force operation in terms of success or failure, safety and cost effectiveness. Yet the subject is not generally understood. It is hoped that this brief introduction will stimulate further study.

Warfare Systems School

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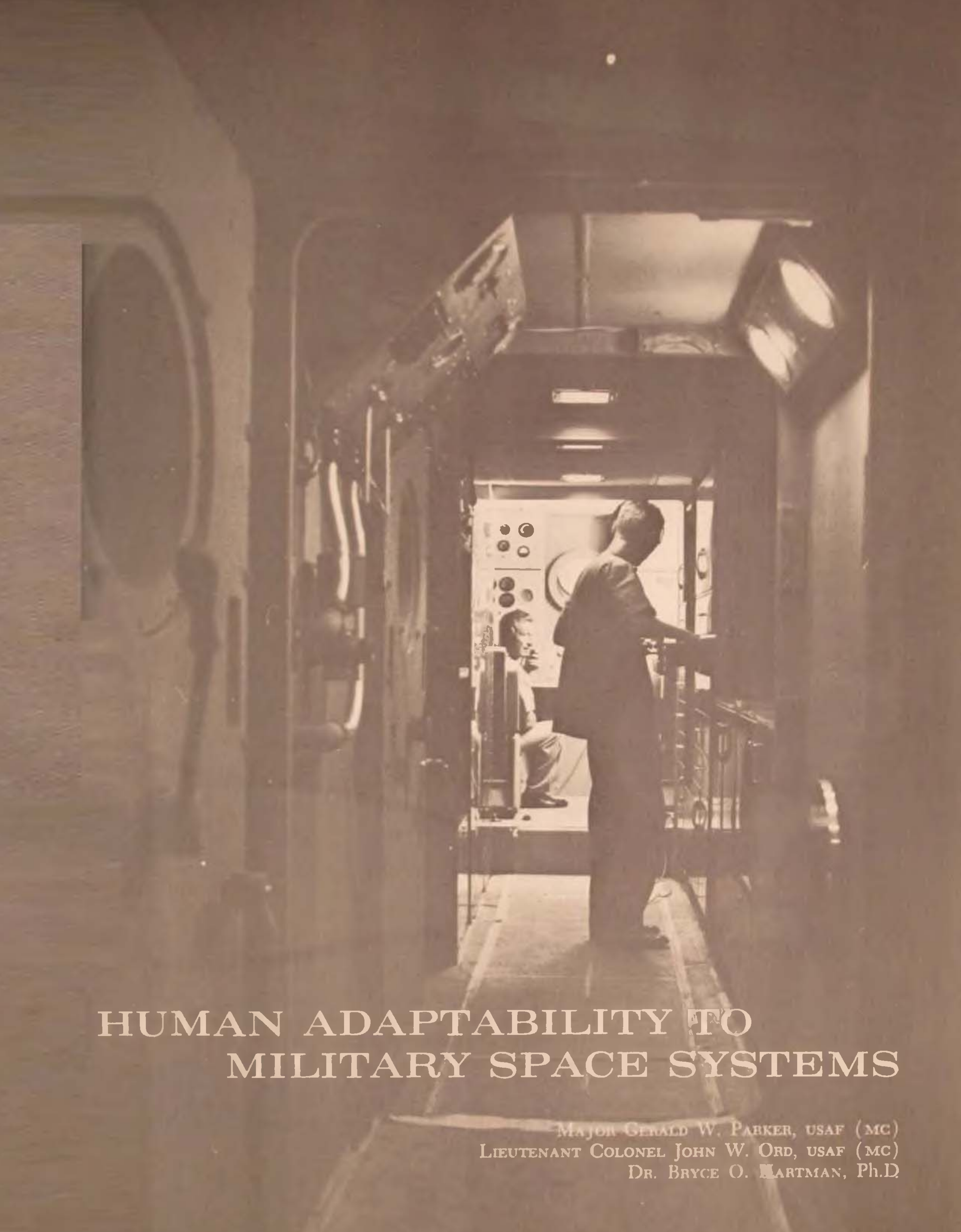

HUMAN ADAPTABILITY TO MILITARY SPACE SYSTEMS

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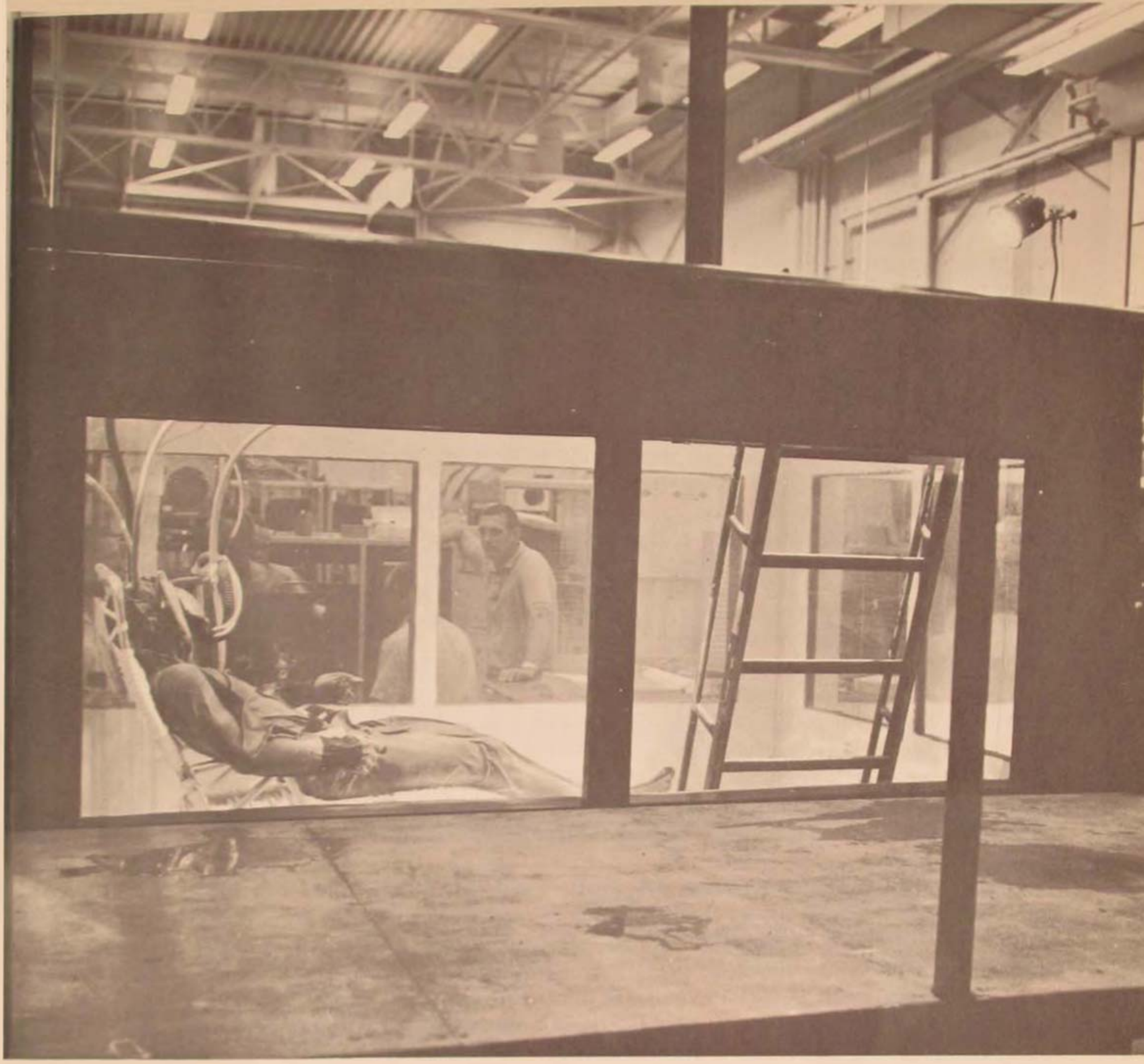
SINCE the Soviet Union launched Sputnik I on 4 October 1957, the technological race between the two leading world powers has involved national prestige, accumulation of scientific information, and national security. The development of manned orbital flight has led to the consideration of utilizing the "man-machine mode" to achieve some of the goals. The problem of the effective use of man in space remains unsettled. The question of primary importance is whether he can be adapted to space flight of sufficient length to be effectively utilized.

The ultimate goal of the Soviet technologists to put man into space was made readily apparent to the interested observer with the unrecoverable launch and orbit of Sputnik II carrying the medically instrumented canine Laika. The Soviet scientists had selected a dog to occupy the space vehicle for the same reasons that physiological experiments aimed at understanding man's responses have utilized dogs as subjects for many years. The sophistication of their investigations was clearly demonstrated to the scientific world by the flights of Sputnik V, which carried aloft 2 dogs, 2 white rats, 40 mice, cultures of human skin, and a variety of living bacteria. Sputnik VI contained essentially the same experimental animals as Sputnik V and helped to identify the effects of vibration, acceleration, radiation, prolonged weightlessness, and other factors on living creatures. Sputnik IX and Sputnik X, both containing dogs, mice, and guinea pigs together with seeds, bacteria, and even frog sperm and eggs, laid the groundwork for the Soviet's oncoming flights. There was no question that Soviet Russia planned to put a man into space, and they readily demonstrated their capability by launching Cosmonaut Y. A. Gagarin in Vostok I on 12 April 1961.

Shortly after the first Sputnik flight, the decision was made in the United States to develop a massive assault on outer space. Unmanned probing satellites were flung into orbit with considerable frequency. Then, in rapid succession, the Americans followed the Russians with manned orbital flights. The 4½-year life of Project Mercury was brilliant in its accomplishments, culminating in a 34-hour manned orbital flight during which Astronaut Cooper proved man's adaptability to overcome mechanical failures when he was compelled to control his space vehicle manually. Inasmuch as the malfunction of Cooper's flight was unexpected, it gave further impetus to the utilization of man in space. Moreover, Cooper's reports of identifying houses and ships on earth led to heated discussions in interested circles concerning the utilization of man on a military mission. Did man have a *military* mission in space? Could man perform tasks not able to be performed as readily by the most sophisticated type of unmanned satellite?

It is significant, perhaps, that at about the time man's usefulness in space was being questioned seriously in the United States Premier Khrushchev announced that the Soviet Union was not particularly interested in a "moon race." Apparently, at that time as now, the Soviet Union was concentrating on *earth orbiting* manned flights. As far as the Russians were concerned, the technological race in space centered primarily on the useful function of man and machine in the fringe of space near earth. Furthermore, they apparently consider that this race in the foreseeable future will revolve about the use of the man-machine mode in military space ventures.

From the outset no question existed in the minds of the Russian scientists as to man's having a place in space. Each step was taken with a deliberate effort to allow the astronaut to be a part of the space system. Aided by the early capability of producing more powerful boosters than the Americans, the Russians parlayed this capability into the orbiting of larger, roomier, more heavily instrumented capsules. They made extensive efforts to obtain data on the adaptability of man's physiologic processes to the hostile environment of space. Instinctively they provided the occupant of the vehicle with a gaseous environment which was the same as that on earth. During their three-man Voskhod flight of October 1964, the crews enjoyed the much more normal living and working conditions of the shirt-sleeve environment substituted for the formerly essential space suits. This change in operating conditions was readily understandable. The less that man



The water immersion tank is a useful tool in simulating weightlessness in a 1-g environment, so that the test subject's losses of salt and body fluids, cardiovascular involvement, etc., may be measured.

needs to rely on encumbering environmental controls, the more readily he can be integrated into any space system.

Although handicapped by smaller boosters, the American technologists rose to the challenge and devised highly sophisticated, miniaturized systems. The engineers were taxed to the utmost in their efforts to provide environmental control systems within the constraints of minimal power, weight, and volume. The capability of American technology developed during this period began to be apparent as booster rockets, such as the Titan III and the Saturn series, became available for larger payloads. These achievements will make possible the complex Gemini and Apollo manned space flight programs.

Added impetus to the development of a military space system came with the announcement in December 1963 that the Air Force would be assigned the task of developing a study to determine the usefulness of man in space. It seemed only natural that the Air Force should develop such a program, since it was a strong advocate of placing man in space on a military mission. At the present time an exhaustive analysis of man's potential adaptability and utilization in space is under way. The joint efforts of NASA and USAF in the Gemini and early Apollo flights promise to aid considerably in acquiring the ultimate knowledge of the capabilities of man in space.

problems of adaptability

The proof of the value of the man-machine mode in military space systems depends upon the satisfaction of two boundary conditions: (1) that man can live and function with complete physical and mental integrity for sufficiently long periods of time to make the system economically and practically feasible and (2) that uniquely valuable contributions to the effectiveness of the system will result from the presence of man. The order of these two conditions is appropriate in that the second depends completely upon the first.

There is no doubt that the use of man in military space missions will impose significant costs. These result from the requirement to provide special systems to support his life and to protect him from hostile environmental factors. The stresses of heat, vibration, acceleration, and noise during launch; null gravity, confinement, radiation, cold, and vacuum while in orbit; and heat, acceleration, and impact during deorbit were among the major problems to be solved. Means of escape in the event of uncontrollable malfunction during launch had to be provided. The concept of redundancy was formulated, resulting in the development of multiple independent systems to ensure successful management of vehicle functions and life support in order to "man rate" the space system.

Reduction in the cost of placing man in space depends upon the development of more reliable hardware and also upon obtaining a detailed measurement of man's adaptability to the environment so that the simplest but most efficient life-support systems can be developed.

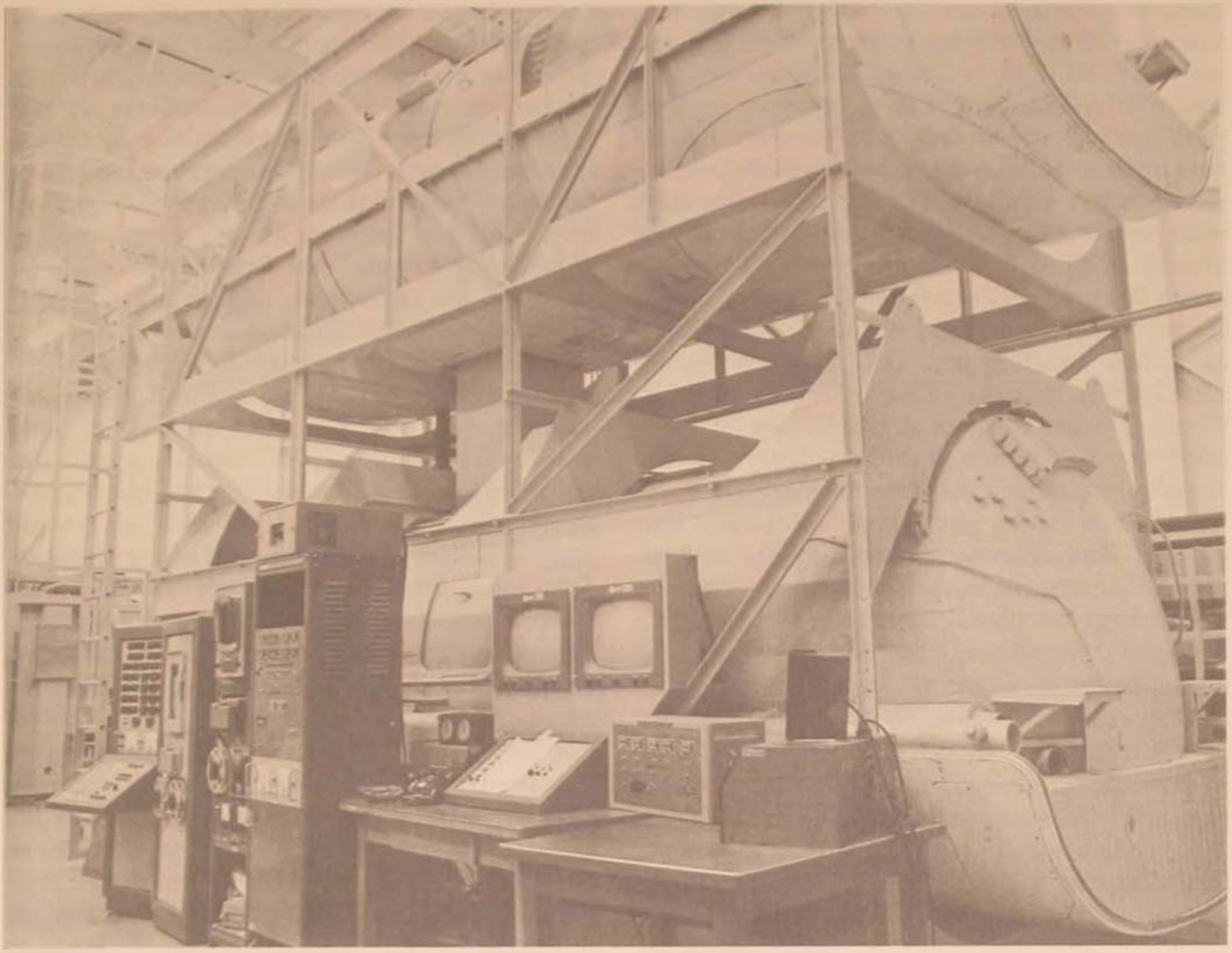
For purposes of discussion, the problems which may limit man's ability to cope with the total environment of prolonged space flight can be divided into physiological and psychological.

physiological problems

Weightlessness is the least understood of the environmental stresses. The requirement for man to support himself against, and to function in, the presence of the earth's gravitational field produces effects within his body. Relative displacement of organs, tissues, and fluid occurs as a result of their different densities and varying orientation to the direction of the gravitational force. Any physiologic changes resulting from weightlessness must depend upon the removal of these effects.

Gravity, therefore, imposes a requirement upon the heart and blood vessels, and upon their regulating reflexes and controls, to provide a suitable volume of blood flow directed selectively to the various body regions according to the needs. An example is the maintenance of brain circulation when standing erect. Furthermore, gravity influences the total volume of blood within the arteries and veins of the body and simultaneously requires that the distribution of the blood volume in the body regions be regulated constantly. The adjustment of the return of blood to the heart from the veins is of critical importance in the body's response to the gravitational force.

Gravity also imposes many stimuli upon the sensing apparatus of the nervous system, including any sensors that may be contributed to by the weight of the parts of the body—touch, pressure, the tension of muscles, and the position of body parts. It also includes the sensors of the inner ear, which operate on the differen-



The double-decker isolator at the USAF School of Aerospace Medicine is a two-cabin space-vehicle simulator used in studying stress and fatigue of test subjects during complete isolation. Cut off from contact with the outside, the subjects are monitored by TV.

tial density principle and are concerned with equilibrium, control of the motion of the eyes, and the tension and coordinated contraction of the muscles.

Gravity imposes an additional workload on the muscles by requiring them to maintain body position and permit motion. It has an influence on the structure of the bones in that the mechanical forces imposed stimulate formation of the protein matrix upon which the minerals are deposited for bone strength.

These are only the more important considerations in an analysis of the impact of zero-gravity on the human body. It is important to realize that these body functions are *influenced* by gravity but are not dependent upon it for their function. Any mechanical force will produce qualitatively similar effects if applied in a similar manner. Thus it is expected that an active man in the weightlessness of space flight will deadapt the functions of his body only to the extent appropriate to the conditions imposed. This implies that no physiologic problem should exist for the duration of weightlessness provided that rest, nutrition, and health are good. However, it also implies that significant difficulties may arise at the time of re-exposure to such mechanical forces as acceleration, impact, and gravity. These very forces are encountered during re-entry, landing, and recovery. In light of these considerations it is informative to note that the astronauts actively participated in control and communication functions during re-entry and in their own recovery after landing. The Soviet cosmonauts were reported to have landed by parachute after ballistic injection from their Vostok spacecrafts and were described as having doffed their pressure suits and donned sports clothing while awaiting arrival of recovery teams. This implies that the effects of relatively short-term exposures to space flight did not seriously limit the crewmen's ability to deal with the re-entry/recovery functions and stresses.

The possible physiologic problems that emerge from the foregoing analysis revolve about changes that can be anticipated in (1) effectiveness of the regulation and distribution of blood flow, (2) volume and distribution of blood and body water, (3) strength and work capacity of muscles, (4) bone composition, and (5) integrated nervous system performance. Biomedical measurement of flight crew members must be directed toward the definition of these problems. It will be not only important to detect and quantify these deadaptive processes; it will be just as important to see whether these changes get worse as flight continues. This will be essential in order to predict the effects on man when he is involved in flights of longer duration.

approach to physiologic problems

After careful study of the stress-response system based upon known facts or logical premises, the approach to a research problem in biology should proceed to (1) the repeated measurement of the phenomenon under the actual conditions of interest and (2) the development of an experimental model related closely enough to allow cautious application to the basic problem. With the exception of weightlessness (and possibly the radiation environment), the conditions of space flight can be reproduced in ground research. An experimental approach to zerogravity is possible to a restricted degree through the reduction of energy expenditure and the diminution of gravitational effects upon body fluid systems. These concepts have been implemented in human research by placing subjects at bed rest in a strictly horizontal position or by immersing them in water. Both procedures have serious deficiencies as analogs of weightlessness, but they have produced information of value in developing theoretical predictions for practical use in measuring man and ensuring his safety in space flight.

It is fitting now to examine briefly experimental results pertaining to the five possible problems identified in the preceding paragraphs. The problems of regulation and distribution of blood flow and of volume and regional distribution of blood and body water cannot be separated with respect to their effects upon resistance to stress. All the astronauts and cosmonauts on whom adequate measurements were reported demonstrated a transient postflight decrease in tolerance to the effects of gravity when standing quietly or positioned passively in the upright position. The most dramatic example was Astronaut Cooper, who while standing quietly on the ship's deck immediately after egress from his capsule appeared to be near fainting.

All the American and Soviet space pilots lost body weight, which in the short time span of their flights must have been due to loss of water. (See Table I.) Failure of the Mercury system to provide adequate temperature control undoubtedly aggravated the astronauts' loss of body water through sweating.

From a comparison of the duration of flight and the amount of weight lost by the cosmonauts, it appears that the effect of weightlessness upon water balance terminated within 24 hours or less. Similar changes in circulatory regulation and fluid balance are produced by bed rest and water immersion.

Some loss of muscle work capacity, but not of muscle strength, was reported in the cosmonauts. This appeared to be another transient phenomenon. It is not known whether this loss was related to the loss of body fluid or the change in circulatory performance, or whether it was a specific change in muscle function. Similar effects were noted with the

Table I. Changes in Body Weight of Crewmen Following Space Flight

Crewman	*Flight Duration*	*Weight Prior to Flight (lb)*	*Weight Loss (lb)*	*Percentage Loss*
J. Glenn	4 hr 56 min	171	5.3	3.1
M. Carpenter	4 hr 44 min	153	5.9	3.9
W. Schirra	9 hr 13 min	176	4.5	2.5
G. Cooper	34 hr 20 min	146	7.7	5.3
Y. Gagarin	1 hr 48 min	153	1.1	0.7
G. Titov	25 hr 18 min	138	4.0	2.9
A. Nikolayev	94 hr 22 min	150	4.0	2.6
P. Popovich	70 hr 57 min	164	4.6	2.8
V. Bykovsky	119 hr	146	5.3	3.6
V. Tereshkova	71 hr	127	4.2	3.3

weightless analogs. However, it was demonstrated clearly that the capacity for moderately vigorous physical activity was not depreciated and that this stabilized circulatory performance. This gave reassuring indication that blood flow was adequate for body needs except in the extreme (and unnatural) situations of the "crucifixion" posture (inactive and parallel to the earth's gravity field) or when at or near the maximum work performance level.

No information about bone changes resulting from space flight has been reported. The amount of mineral loss from the skeleton has been measured carefully during bed rest for prolonged periods on several occasions, and the effect on bone strength has been shown to be insignificant.

No definite evidence of change in nervous system function resulted from space flight. Adaptation of coordinated movement (such as writing) to weightless conditions developed quickly and completely. It may depend simply upon readjustment of reflexes to the diminished energy requirement necessary to produce motion of body parts while in space. It is certain that recumbency fails to simulate the probable changes in the sensory nervous function resulting from zerogravity. No detrimental alteration in the nervous system has been observed in bed rest studies.

Extensive application of the weightlessness models is being made in the United States and Russia to better explain the mechanisms and the magnitude of physiological changes resulting from recumbency, inactivity, and diminished gravity. An important part of this effort is directed toward developing the means to prevent, control, or repair the detrimental changes experienced during actual space flight. Devices designed to duplicate some of the internal effects of gravity on the body are being designed, and their effectiveness is being determined. Inasmuch as some already show great promise, it may not be necessary to provide artificial gravity until large crews occupy a much more advanced space station for very long periods of time.

Although it has been shown that man can eat and drink in space, no American astronaut consumed sufficient food to maintain caloric balance while in space, and all were deliberately fed a special low-residue diet prior to flight. Eating food while weightless was found to be troublesome because the food tended to crumble and break apart before being eaten unless it was properly packaged. Liquids tended to form a floating ball of fluid and were not only objectionable within the cabin but quite possibly might be hazardous to the flight. Data from Project Mercury suggested that the astronauts had extremely low caloric intake. Their difficulty might have been associated with the tremendous amount of time required to perform tasks during flight. On the other hand the cosmonauts were able to eat all their meals, which were composed of a wide variety of foods and had a normal caloric composition. They reported no difficulty with biting, chewing, swallowing, or assimilation.

the threat to man

Thus it is an established fact that space flight will have definite effects upon the body of man. These effects are properly viewed as normal and appropriate readaptations of bodily function to new conditions. Exposure to the usual stresses of living on the surface of the earth after adapting to space may cause transient minor disability. On the other hand ample reasons exist for the belief that the integrity of man's function in the man-machine mode in military space missions will be unaffected by the readaptation. It is also likely that control of the readaptation processes is possible if required.

The major threat to man in space now and in the future is the sudden exposure to the lethal environment surrounding him in the event of failure of the systems provided to support his life.

psychological problems

Early ground-based work aimed at defining possible psychological problems in manned space flight revealed what appeared at that time to be almost overwhelming psychological obstacles. The two primary problems predicted were gross disruptions of the astronaut's emotional state as a result of prolonged isolation and difficulties in maintaining high levels of skilled performance as a result of weightlessness.

The concern over isolation and sensory deprivation arose from the remarkable effects obtained in laboratories employing conditions of extreme isolation. Mental changes reported in subjects who endured sensory isolation approached an almost complete disintegration of emotional status, including repeated hallucinations and other equally dramatic changes as well as a persistent decrease in emotional and intellectual efficiency. The emotional breakdown sometimes lasted as long as a week after exposure to such bizarre situations. However, subsequent studies at in-service laboratories, primarily at the Aerospace Medical Laboratory, Wright-Patterson AFB, and at the School of Aerospace Medicine, Brooks AFB, placed this problem in its proper perspective for space flight. It was demonstrated that mature, intelligent subjects experienced far fewer and less severe effects than less mature subjects and that subjects given meaningful tasks to perform under conditions of isolation rarely experienced any of the effects described. The current concept regarding isolation and sensory deprivation in space flight can be summarized as follows:

(1) Emotional alterations in response to unusual environments (including space flight) can occur in perfectly normal, emotionally healthy people. (2) These emotional responses can range from simple irritability to emotional breakdown. However, in the space flight setting involving stable personnel with highly meaningful tasks to perform, there is little likelihood of other than minimal changes. (3) Finally, any such effects resulting from isolation are invariably transient. Recovery is rapid when the unusual environment is attenuated, and the effects that occur have little bearing on the subsequent psychiatric status or emotional health of the individual. Appropriate psychologic support from ground-based crews or a fellow astronaut will be particularly effective in minimizing the problem. In general, we cannot say that detrimental effects resulting from isolation or some modified form of sensory deprivation will *never* occur, but we can say with confidence that such effects will rarely be other than minimal and that appropriate psychologic support will be readily available.

The concern over the maintenance of high levels of neuromuscular efficiency in the face of weightlessness has undergone a similar evolution. Early data from brief periods of weightlessness, produced by flying Keplerian trajectories in various types of aircraft, demonstrated significant increases in errors in arm-hand aiming tasks, together with mild visual disorders. These findings suggested important alterations in neuromuscular and visuo-motor function, but even early researchers recognized that they were dealing with only brief periods of zero-g and predicted that man would adapt rather rapidly. Subsequent studies involving repeated exposures during Keplerian trajectories, as well as water-immersion studies, have shown that adaptation occurs and that neuromuscular function is not a major problem area.

Psychological research since those early days has changed in emphasis. At the present time problems of crew performance in space are considered within the context of the systems management point of view and are basically questions of operator reliability. Three general aspects of operator reliability appear to be sufficiently important to warrant study: proficiency during the period of adaptation to the space environment and the constraints imposed by the space station and life-support systems; maintenance of proficiency (in a day-after-day sense) for extended periods, once adaptation has occurred; and finally, the effects of work/rest schedules upon operator reliability. Two considerations need to be made explicit before these problems are discussed further. First, a wealth of data has been derived from psychological studies of operator reliability in weapon systems in general and from experiments in simulated space flight, which indicate that no significant problems in operator reliability will occur. Second, no physiological or medical considerations to date lead us to predict any loss of operator reliability while in orbit. In fact, our general psychological prediction is that man will perform as well in space as he does on earth. Therefore, psychological studies in space should be conducted in a sparing manner and should be aimed at verifying our reliability estimates in the same sense that reliability estimates of electronic components are validated. However, as information is extracted from each flight in the Gemini and Apollo programs, it will be important to reappraise our current estimates of operator reliability. Otherwise excessive confidence may be placed in man's reliability for flights of extended periods, such as those proposed for the Air Force's Manned Orbiting Laboratory, now under consideration, and the NASA long-range goals.

Astronaut reliability during the initial period in orbit is no problem; in this we have considerable confidence. As indicated earlier, adaptation apparently proceeds rapidly, but there is a requirement for a more formal demonstration of this evidence than has been possible to obtain in space flights to date. The recording of certain selected detailed procedures on a few future flights would amply verify the present prediction of rapid adaptation.

Maintenance of proficiency for extended periods of time is a problem about which more data are needed. Of particular concern is proficiency in key tasks during re-entry. During flights of long duration, such tasks will be performed after many days without the opportunity to practice. A considerable portion of the required research aimed at overcoming this problem can be conducted as part of the ground-based support program prior to prolonged space flights, but some verification in space will be required. The picture is hopeful. A limited amount of data obtained recently by the Aerospace Medical Research Laboratory indicates good retention of key skills after as long as a month without practice. Probably some type of on-board refresher training device will be used until our estimate of high reliability has been verified. Such a device will constitute a load on the system as a whole and is likely to be eliminated as soon as the systems managers can view this question with confidence.

The question of optimal work/rest schedules is one which appears regularly in the operation of all weapon systems, and one which has received considerable emphasis in recent preliminary work on problems of prolonged flight. Despite 40 years of research on work/rest schedules, no recognizable optimal schedule has been determined. The most explicit recent investigations of this problem have occurred in simulated space flight studies, where the routine is under firm control, i.e., where the alternation is definitely work/rest rather than the more uncontrolled work/nonwork/sleep schedules characteristic of our normal daily routines. It appears probable that the only limitation is a "ceiling effect." One cannot maintain reliability when the work schedule is prolonged until significant fatigue effects develop or the time allotted to rest is insufficient for adequate recovery. Within these limits, many schedules are feasible, and the selection of any one can be dictated by other considerations, such as the mission profile or crew size.

In our view, the most significant constraint on work/rest schedules is the number of hours on duty before significant fatigue effects appear. Laboratory and field experiments under conditions of continuous performance at complex tasks (e.g., piloting) have demonstrated that man can maintain an acceptable proficiency in many kinds of skilled performance for as long as 20 to 24 hours. In addition, laboratory studies of simulated weightlessness suggest that extended periods of work can be achieved at the same time that recovery periods are shortened. Specifically, it appears that man in the weightless environment can perform for up to 24 hours continuously with periods of rest and sleep that are shorter than normal, or he can perform continuously for more than 24 hours without any appreciable change in the eight hours of sleep and rest that is conventional on earth. If it is true that man requires less rest per unit of work in space, the performance capabilities of a space crew member are critically underestimated, and sleep and other recovery periods are overprogramed for him. Only an experiment in a true zero-g environment can yield the data required to evaluate this problem.

The crucial information from such research on performance and sleep will have at least three major applications. It will permit us not only to designate specifically the time periods and mission profiles permissible for a one-man system but also to indicate the point at which a second man must be added. It will permit us to work out schedules realistically for minimum size of crew and maximum utilization of manpower. Finally, it will permit us to extend one-g results to zero-g performance problems with a reasonable amount of confidence and at considerable savings, because studies in space are so expensive. If the research demonstrates that considerably longer duty times are possible in the weightless environment, it will pose a problem not being considered by the biomedical specialists in space programs today. Suppose we find that man in space can perform effectively on a 30-hour day instead of a 24-hour day. Then it will be necessary to decide whether to take maximum advantage of this or to restrict him to a 24-hour day in order to keep him in phase with his earth-bound requirements and with his ground-based coworkers.

the next conceptual advance

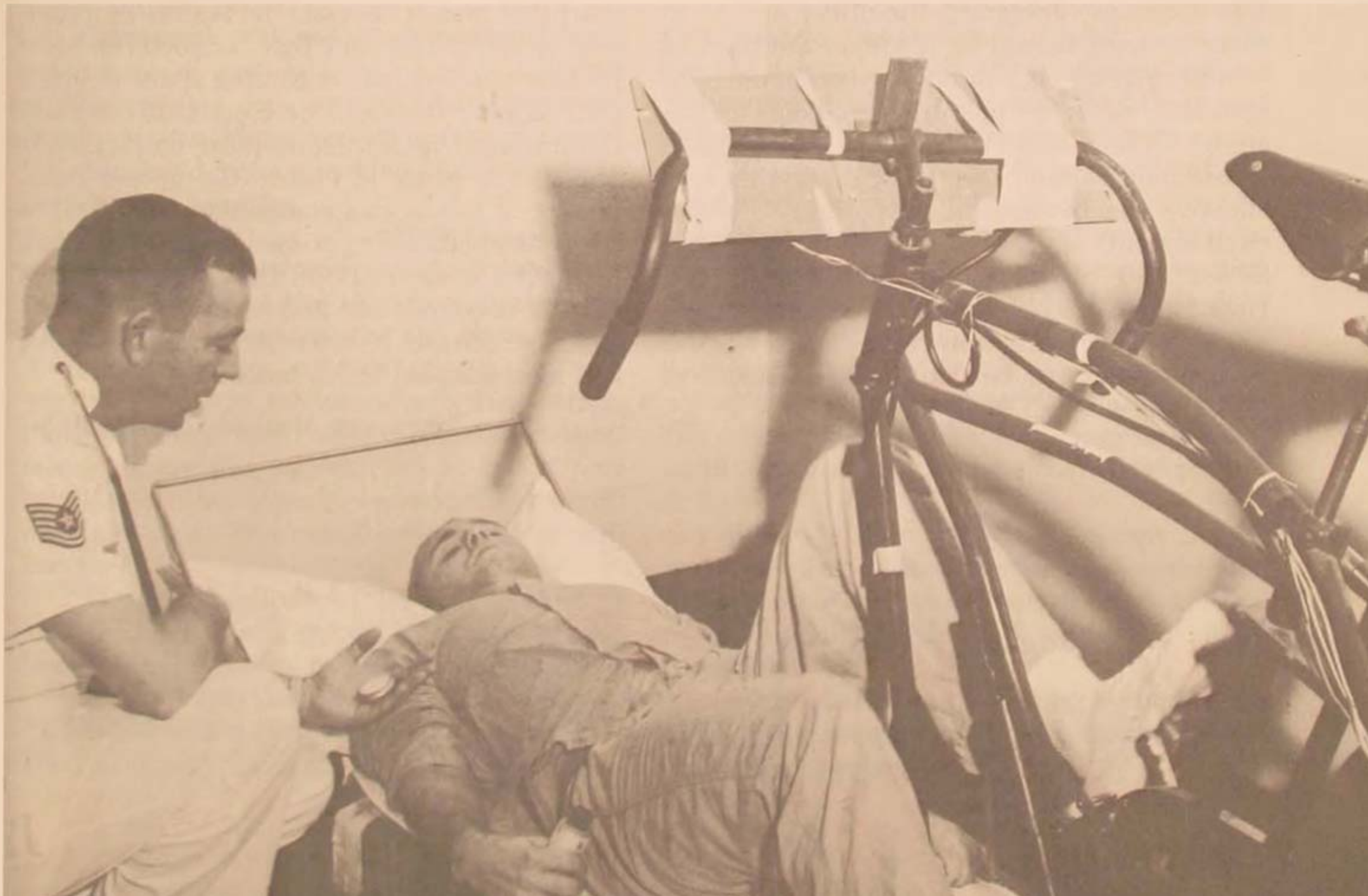
Because of the pressures created by the need for prolonged mission-oriented space flight, we are face-to-face with the next psychological advance in aerospace medicine. Recent programs emphasize tests of the *utility* of man in space. This requires an analysis of the two considerations previously mentioned —we must demonstrate that man can make unique contributions to space systems and we must show at the same time that the cost of providing a suitable environment within the capsule and supporting him throughout the flight does not outweigh what is gained from the addition to the system. These two requirements have resulted in a major emphasis on the biomedical and human performance aspects of the program. The duration of cost-effective flights of 30–120 days makes the biomedical aspects even more crucial, although these longer flights do not alter substantially human performance considerations.

Partly because of some preliminary experience in the Mercury program but more importantly because both psychological and biomedical resources exist within the Aerospace Medical Division in substantial quantities, these two elements were combined, and a joint bioastronautics attack on such problems was placed in support of the Manned Orbiting Laboratory study operation. From the beginning of the study this was seen as an integrated effort. Although a biomedical subpanel composed of physicians and physiologists and a human performance subpanel composed of psychologists were organized, *human efficiency* was identified as an adjunct to the biomedical and human performance studies and was designated as the common ground through which the integrated effort would be achieved. General human efficiency rests upon two sets of parameters: (1) the biomedical, including such functions as musculoskeletal, gastrointestinal, respiratory, central nervous system, cardiovascular, and metabolic; and (2) the psychological, including selection, classification, training, and maintenance of skill. It is obvious that human efficiency is more closely related to some elements than others: e.g., neurological considerations affect efficiency more directly than kidney function.

The study of the Manned Orbiting Laboratory accelerated the use of general efficiency measures in biomedical studies, but this concept was already emerging in its own right in much of the applied research within the Air Force. In-service psychologists have been particularly active during the past decade in developing general-purpose testing devices designed specifically for a broad spectrum of human efficiency studies under a variety of environmental and operational conditions, such as missile sites. They have also been increasingly active in experimental programs on environmental and physiological stress, as in space cabin simulators. Early efforts tended to concentrate on psychological effects, insulated from physiological or medical findings. Later work has become increasingly team-oriented, and many recent laboratory programs show the sort of integrated effort established for the Manned Orbiting Laboratory now under consideration.

The identification of general efficiency in an astronaut as a component of biomedical status is an advancement in bioastronautics, but it poses some problems in methodology which have not been fully appreciated. One problem is the necessity to predict overall levels of proficiency, i.e., general level of efficiency for an entire day, from brief periods of psycho-

In "Operation Bedrest" at Wilford Hall USAF Hospital healthy subjects were confined for 16 days, their physiological changes observed. Three times a day they exercised 20 minutes on a bicycle ergometer. Isometric and isotonic exercises may enable men to withstand some effects of weightlessness also observable in prolonged bed rest.



motor testing. Another is the relationship between performance and physiological changes. And there is the problem of transient losses in efficiency without concomitant physiological changes. The cost of space studies is such that each flight must accomplish as many experiments as possible. In all U.S. programs to date, only a small portion of the total flight time has been allocated to biomedical studies, and only a small portion of the biomedical time may be devoted to psychological studies. With this limited testing time, the proficiency specialist must assay the overall state of general efficiency of the astronaut, as well as identify trends suggesting the onset of generalized physiological and/or psychological degradation. Prediction research has demonstrated clearly that small packages of psychological data are relatively imprecise. The confidence with which efficiency measures from brief periods of testing can be extrapolated to long periods on the job is considerably less than is desired.

It is appropriate now to return to the initial psychological consideration. What can we say about man's psychological adaptation to space flight? Several conclusions appear valid. (1) The decisions concerning the utility of man in space systems should be made on the basis of overall systems considerations (economic, operational, etc.), disregarding problems associated with man himself. (2) Once the decision to use man is made, we must determine how effective the biomedical support (i.e., sealed environment) is. How long can he be maintained in a physiologically *intact* condition? How close is his cabin to the shirt-sleeve environment? (3) Deviations from the shirt-sleeve environment must be considered in terms of duration and quality of productive work. All personal protective gear must be viewed first as encumbrances that cost in both duration and quality of work. (4) Having achieved the necessary compromises between biomedical and system requirements, we can proceed with only minor adjustments for psychological problems. Within the limits of point (3), performance *during* the flight is probably already nearly 100 percent ensured. At this point the problems remaining are the biomedical disturbances which occur on blast-off, injection, and re-entry. Strategic regrouping of biomedical capabilities should enable us to solve most of these problem areas.

Many questions concerning the problems of prolonged manned space flight cannot be answered in an earth environment and can be answered only in space. Man's adaptability and ultimate utility in space require well-planned experimentation and an objective appraisal of the resulting data. The Project Mercury flights answered an important question concerning man: he can exist in space. But for how long? Can he be useful in a military space system? Can instrumentation and automation supplant him? It is the conviction of the authors that man *is* the essential feature of a military space system and that, as such, he must be incorporated into oncoming space devices. Furthermore it should be clear that the early Gemini and Apollo flights must be medically oriented in order to ensure the proper functioning of the human component. It is vital to stress biomedical experimentation even more than mission capabilities. Only by the process of data accumulation and analysis may problems be solved, countermeasures developed, and man adapted to his machine.

Aerospace Medical Division, AFSC

COMMUNICATIONS SATELLITES

Major William B. Liddicoet

A COMMUNICATIONS satellite is "an orbiting vehicle, either active or passive, which relays signals between communications stations," according to Air Force Manual 11-1.

Compared with more conventional communications methods, a communications satellite system has certain advantages and disadvantages. These and other factors should be considered before making the decision to deploy such a system.

The most striking advantages of a communications satellite system are those based on the survivability of the spaceborne relay and the flexibility of service that can be provided. A communications satellite system is much less vulnerable to nuclear attack than cables, high-frequency radio, etc. True, the ground terminals are just as susceptible, but a new terminal can be flown in or redundant terminals provided. The spaceborne repeater will survive.

The communications satellite system is also much less susceptible to solar activity than high-frequency radio, tropospheric scatter, etc.

A very important advantage in a cold war or crisis situation is the flexibility provided by such a system. Communications can be provided to a crisis spot by flying in a ground station and setting it up.

On the debit side, spaceborne systems are relatively expensive to establish and maintain.

Once a decision to deploy a satellite system is made, the factors that must be considered in determining the most suitable type for the purpose are why, cost, reliability, frequency and bandwidth, and available boosters.

Why is a question of the intent of the system.

What is the geographical coverage intended? The area covered is a strong function of satellite altitude up to approximately 5000 miles. Above that altitude, it is no longer such a strong function.

What continuity of service is required? Is the commander satisfied with a few hours of service each day, or does he require 99 percent or better?

What is the maximum circuit length required? The different types of systems vary in the maximum circuit length available and in their north-south and east-west circuit capability.

With what types of existing systems is the satellite system required to interconnect?—with three-wire, two-wire, etc.?

How many stations will require access to the system? Will there be a fixed number of stations, or will multiple access of many stations be required?

Cost is a question of how much can be spent on the system. Does the requirement justify the establishment of a satellite system? If so, will one of the simpler, cheaper satellite systems suffice?

Reliability is a function of the number of satellites in the system, the power supply duty cycle of the individual satellite, the operating schedule of the system, the antijam capability of the system, and the flexibility of the channel capacity of the system. Another important reliability factor is launch pad scheduling. This factor determines how long it takes to replace a failed or failing satellite.

Frequency and bandwidth assignments for communications by satellites were negotiated at the extraordinary administrative radio conference of the International Telecommunications Union in Geneva in 1963 (Figure 1). All of the frequency assignments except the two exclusive bands (7250–7300 down and 7975–8025 up) are shared with other services; e.g., surface microwave links, tropospheric scatter, radar, air traffic control, etc. In those areas where satellite communications interfere with one or more existing systems, the system which was in-being first takes precedence. In addition, all except the two exclusive bands have limits on the maximum power density at the surface of the earth. These power limits could severely restrict the ability to communicate with small mobile ground terminals in these bands.

Available boosters—One factor that can keep the overall cost of a system down is the ability to launch more than one satellite per booster. At present, until the Titan III and Saturn S-1B become available, the Atlas-Agena is the only vehicle that really possesses such a capability.

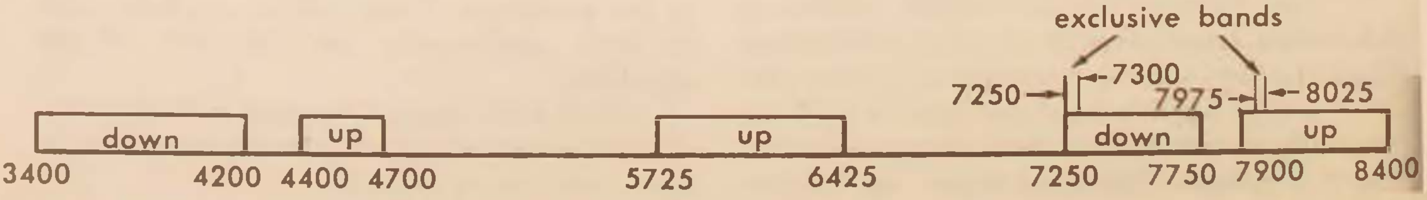
Communications satellites are classified as either active or passive. An active satellite is one that receives, regenerates, and retransmits signals between stations. A passive satellite is one that reflects communications signals between stations. For example, if you and a friend are trying to communicate by hand signals around a corner and you station a third friend at the corner to receive the signals, turn around, and retransmit them, he is an active satellite. If the third friend merely holds a mirror that reflects the signals, he is a passive satellite

passive satellites

There is one outstanding example of a passive communications satellite which we have all seen many times and, particularly in our younger days, have spent a good deal of time contemplating: the moon.

Moon. The U.S. Navy uses a moon relay for communications between Washington, D.C., and Hawaii. This system employs 84-foot antennas at 100 kw in the UHF region. Present capacity is 4 teletype channels, but it is estimated that the system could be expanded

Figure 1. Communications satellite frequencies agreed on at the International Telecommunications Union administrative radio conference in Geneva, 1963. All except the two exclusive bands are shared with other services (e.g., surface microwave links, troposcatter, radar, air traffic control), and they have limits on maximum power density at earth's surface. These power limits would severely restrict communications with mobile terminals.



to 16 100-word-per-minute teletype channels. Of course communications on this circuit are limited to 4–8 hours per day depending upon the mutual visibility of the moon.

The Navy is presently experimenting with ship-to-shore communications using the moon. The ship-to-shore link uses 16-foot antennas at 2285 mc. The shore-to-ship link uses the present 84-foot antennas and operates at 400 mc. Ship-to-shore transmission with 4-foot antennas at 7–8 kmc appears feasible.

West Ford. Another passive system, which we have all heard about as "space needles," is Project West Ford of the Lincoln Laboratory. This system utilizes orbiting dipoles as a microwave scattering medium. An established system of this type would have two belts of orbiting dipoles, one belt in polar orbit and the other in equatorial orbit.

This system requires large ground stations (60- to 120-foot antennas) and complex signal-processing equipment. Voice would be transmitted in digital form at a rate of 20,000 bits per second, and it has been determined that such transmission would be possible with a 2000-mile belt and 120-foot antennas, such as the Haystack antenna, transmitting at 8 kmc.

The orbiting elements for experimental systems have been sized by proper use of space mechanics not only to operate at the proper frequency but, through solar pressure, to clear themselves after the experiments are completed.

Experiments in 1963 successfully demonstrated transmission using a dipole belt at rates up to 50,000 bits per second.

Spherical Reflector. The classic passive satellite and the simplest system is the spherical reflector. The sphere scatters radiation in all directions, and a certain amount of it reaches the receiving antenna. The amount received is sensitive to the orbital altitude (4th power) and the sphere diameter (square). The Echo series is an example of the spherical reflector.

Echo I is a 100-foot sphere of aluminized mylar. This satellite was placed into a 900-nm orbit inclined 47 degrees to the equator on 12 August 1960. Many communications experiments were carried out via Echo I, using different modulation techniques. Voice, music, and facsimile transmissions were all accomplished satisfactorily. No deviations from propagation theory were observed, and returned signal strength from Echo I was within 1 decibel (db) of theoretical during its pressurized lifetime.

Besides these communications experiments, Echo I contributed significantly to understanding of the space environment and the causes of orbital perturbations. The satellite proved very sensitive to atmospheric density and solar radiation pressure. In addition, it has been found that the balloon, which was stored folded prior to inflation, exhibits a plastic memory and tends to return to its original folded shape after the inflating gas is lost.

Echo II, launched on 25 January 1964, was a 135-foot sphere of aluminized mylar almost 100 times stiffer than that of Echo I. This sphere did not deploy as well as Echo I, but successful experiments have been carried out.

Lenticular Shape. Present effort in the field of passive satellites is directed toward improving the cross-section-to-weight ratio of their structures. One such approach uses the lenticular shape or spherical segment, which gives the effect of a much larger sphere. A 267-foot-diameter segment has been calculated to be equal to a 1000-foot sphere at 2000 miles. However, spherical segments must be oriented with the axis of symmetry aligned with the vertical. Some form of passive stabilization (such as gravity gradient) is mandatory for their practical application.

Pseudo Passive. A pseudo-passive satellite recently proposed by Rome Air Development Center would utilize the lower surface of a lenticular shape covered with small antennas terminated with negative-resistance reflection amplifiers. Negative resistance is obtained by biasing of a tunnel diode. Gains in excess of 23 db are promised for this technique. A 30-foot array of this type has been calculated to be equivalent to a 1000-foot sphere.

active systems

Active systems are usually classified according to the altitude of the orbiting element

low – less than 4000 miles
medium – 4000–12,000 miles
high – above 12,000 miles.

Low-Altitude. A low-altitude system does not offer great promise because of the large number of satellites required for coverage and the short links available. Thus the low-altitude regime has been used mostly for experimental purposes.

Low-altitude experiments in the past are NASA's Relay and Bell Telephone's Telstar. It must be emphasized that these were experiments to develop techniques and prove theories. They were not systems. Both these satellites were in elliptical orbit because the booster used (to keep the cost down) could only establish an elliptical orbit. An elliptical orbit is not too good for a system, as the best communications are possible only at the apogee of the orbit. Characteristics of these satellites are as follows:

Relay	10 watts—one TV channel one-way or 600 one-way voice channels or 12 two-way voice channels
Telstar	2 watts—one TV channel one-way or 600 one-way voice channels or 12 two-way voice channels

It should be noted that Bell Telephone Laboratories have not discovered the secret of the universe by obtaining the same capability with one-fifth the power. They used 3600-square-foot horn reflectors while NASA used considerably smaller antennas for its Relay experiments.

High-Altitude. The high-altitude system which has been most dramatized is the synchronous equatorial or stationary system. Arthur C. Clarke in 1945 first proposed a communications satellite in stationary orbit. The fact that an earth satellite in a circular equatorial orbit at 19,300-nm altitude remains stationary with respect to the earth's surface, like tall relay towers, has intrigued communications satellite system designers ever since. (See Figure 2.) This interest is due largely to the ground station simplification that is possible with a truly stationary orbit when compared to other orbits.

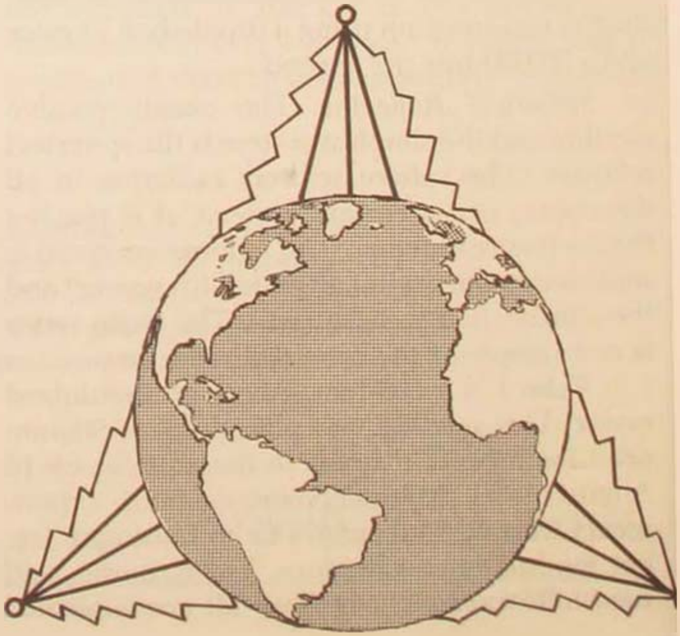
To attain and maintain a truly stationary orbit, each satellite must be equipped with means to compensate for injection errors and to correct for perturbations caused by external forces. It must also include a means for attaining the proper orientation in space of its antenna and propulsion system. A control link must be provided between the ground and the satellite for command of the station-keeping function.

A typical communications system using synchronous stationary satellites would require three satellites, over the Atlantic, Indian, and Pacific Oceans. Certain major technical problems require solution in order to establish such a system:

(1) Difficult Launch Mission. The stationary-orbit launch mission is a difficult one. The basic major steps in the launch sequence consist of the launching of a booster vehicle from the Atlantic Missile Range (AMR) into a nominal 100-nm parking orbit, the ascent from that orbit into a Hohmann transfer ellipse to the 24-hour orbit altitude, elimination of the orbit inclination, positioning of the satellite into the required longitude, and, finally, maintenance of the satellite at that longitude by periodic orbit adjustment.

(2) Orbital Perturbations. The sensible orbital perturbations are due to sun-moon gravity effects and to lack of symmetry of the earth's gravitational field (triaxiality effects). These two factors produce requirements for correc-

Figure 2. In the synchronous stationary concept, fixed satellites act just as repeaters do on towers.



tion in satellite position amounting to 180 fps/yr and 7 fps/yr, respectively. This means that regardless of how carefully the satellite is injected into synchronous orbit, some kind of on-board control system must be carried. The amount of fuel carried for this control system establishes a definite satellite lifetime.

In addition to fuel for position control, command links and attitude sensors must be available to accomplish the control functions.

(3) Communications Path Length. The maximum range encountered is 22,200 nautical miles. This means that, with the expected transmitter powers available on satellites for the next few years, the directional gain of an antenna with a beam width equal to the angle subtended by the earth is required for a many-channel capacity. This implies some form of orientation control and antenna beam-pointing capacity on the satellite. Three methods of accomplishing this have been proposed. The first involves full three-axis stabilization. The second involves spin-stabilizing the satellite with orientation controlled by precessing. In this method the satellite antenna must be rotationally similar about the spin axis or means must be supplied to "design" the antenna pattern. The use of a spinning antenna results in the loss of approximately 10 db antenna gain from the optimum. The third method involves sensing the direction of the earth and electronically steering the beam toward the earth without attempting to stabilize the satellite itself.

(4) Effects of the Environment. Very little is known about the environment at synchronous altitude. Data to date have indicated that the radiation level is acceptably low during normal periods of solar activity, but data are not available on the effects of solar flares.

(5) Multiple Access. The problems of multiple access for stationary satellites are not different from those for a medium-altitude satellite, but they are multiplied appreciably by the fact that all the traffic from one-third of the earth must go through a single satellite. This problem of implementing a multiple-access capability in a stationary satellite is alleviated somewhat by the reduction in Doppler frequency shifts.

(6) Transmission Delay. The distance from the satellite to the nearest terminal is at least 19,300 nautical miles. Consequently a round trip (38,600 nautical miles) will take at least 0.24 seconds. Preliminary experiments indicate that this delay is noticeable but not objectionable. However, its acceptability in telephony is not as yet fully determined.

Associated with this problem is another crucial one, echo suppression. Without echo suppressors, time delays of the order that would be experienced in satellite systems, when combined with existing two-wire telephone long lines, would yield completely unsatisfactory service. But great progress has been made in recent years in the development of high-quality echo suppressors, and this research may permit an acceptable solution to the echo-suppression problem.

(7) Reliability. The reliability problems common to all communications satellites are compounded in stationary satellites by the additional requirements for satellite antenna gain and station keeping. From a parts-count standpoint alone, this complicates the reliability problem and dictates a lower theoretical reliability. Another system-reliability consideration is that the failure of a satellite markedly degrades the system because there are relatively few satellites in the system.

Project SYNCOM and its Comsat Corporation counterpart Early Bird are the current programs utilizing synchronous orbital flight. Both spacecraft are of the spin-stabilized type, using pulsed gas jets for orientation and station keeping. They carry an integral separate rocket stage to provide the additional energy for injection into synchronous orbit. The launch vehicle used is the Thor-Delta, which lacks sufficient energy for an equatorial-orbit mission when launched from AMR. As a result they are in synchronous nonstationary orbit. Since the minimum inclination that the Thor-Delta can give the satellite is 33°, its path is a figure eight between 33° north latitude and 33° south latitude. The excursion in longitude is only a few degrees east and west of the meridian passing vertically through the center of the figure eight. The SYNCOM antenna pattern is rotationally symmetrical about the spin axis and subtends an angle of 17½° at its 3 db points. As the output power of the SYNCOM transmitter is only 2 watts, only one full duplex telephone channel is possible when operating with a ground station with 30-foot parabolic antennas and system temperatures of 250° K.

According to the Communications Satellite Corporation, the Early Bird satellite is capable of handling 240 two-way telephone voice channels, high-speed data, telegraph, or television transmissions. This channel capacity is due in part to the use of a limited number of large, sophisticated fixed ground stations. Transmissions will be conducted between the U.S. station at Andover, Maine, and European stations at Goonhilly Downs, Great Britain; Pleumeur-Bodou, France; Raisting, West Germany; and Fucino, Italy. The Andover station is the one originally used for Telstar.

The SYNCOM II launch on 26 July 1963 was highly successful. Live intercontinental voice communication tests were conducted five days later between the United States and Africa. Subsequently many additional voice, facsimile, and both simplex and multiplex teletype messages have been relayed successfully. This vehicle was also used for television coverage of the Olympics in Tokyo during the summer of 1964.

The launches of SYNCOM III and Early Bird on 19 August 1964 and 6 April 1965, respectively, were both highly successful. Satisfactory experiments have been carried out with both vehicles. SYNCOM is now in position over the Pacific. Early Bird is in position slightly east of Brazil and inaugurated service on 2 May 1965 with a one-hour television program from 35 locations in North America and Europe, which was viewed live in both continents.

The DOD Project Advent was to have been a full synchronous stationary vehicle. The satellite was to be three-axis stabilized, using cold gas jets and momentum wheels for orientation, gas jets for station keeping, and a solar-cell array directed continuously toward the sun for electrical power. The launch vehicle was to have been the Atlas-Centaur, without a special injection stage.

The advantages of a stationary system are (1) simplicity of ground equipment, (2) minimal tracking and acquisition, (3) flexibility in arranging multistation networks, (4) relatively small number of satellites, and (5) no outages for normal operation. These advantages must be weighed against the disadvantages previously considered when determining the type of system to be utilized.

A system of random, drifting satellites at near-synchronous altitude has been chosen by the Department of Defense for its deployment of an operational communications satellite system. This system has the advantages of a less difficult launch mission than a stationary system; no corrections for orbital perturbations; reduced multiple-access problems because of the larger number of satellites planned for the random system; increased reliability of the individual satellites because station keeping is not required; and reduced effect on the reliability of the system by the failure of a single satellite. However, such a system has some disadvantages. A random system at near-synchronous altitudes will still have the previously noted problems of communications path length, environmental effects and transmission delay which are functions of satellite altitude. In addition, any random, drifting system possesses (but to a lesser degree) some of the tracking and handover problems discussed under medium-altitude systems in the following paragraphs.

medium-altitude systems

When Project Advent was canceled, the Department of Defense announced that a medium-altitude system was being planned in its place. This system was to provide voice and teletype communication between about 10 to 30 ground stations located around the earth. A comparison of the orbits and coverages of such a system with those of a stationary system is shown in Figure 3. This system has since been superseded by the near-synchronous altitude random system previously described. Such a system, together with a synchronous system, is presently also under consideration by the Communications Satellite Corporation.

A medium-altitude random system has certain major disadvantages:

(1) Handover. A characteristic of the

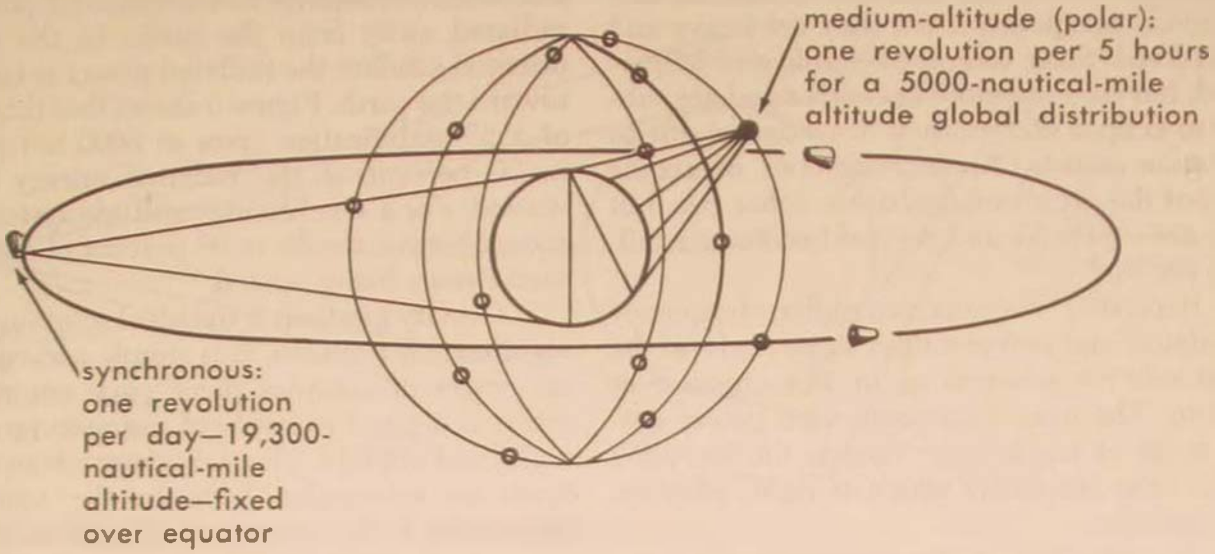


Figure 3. Medium-altitude (polar) and synchronous stationary orbits and coverages

medium-altitude system is the requirement for handing over the communications from a "setting" satellite to a "rising" satellite. The ground stations must have at least one more antenna than the number of links being served simultaneously to accommodate handover.

(2) Tracking. The fact that the satellite "rises" and "sets" requires tracking by the ground antennas and orbital data, look angles, and communications schedules. It is expected that this information can be worked out by computer for several weeks into the future, but it is a limitation in both equipment and operating procedures.

(3) Doppler Frequency Shift. The velocity of the satellite with respect to the ground station causes a Doppler frequency shift much like that which occurs with a train's whistle as the train approaches, passes, and then recedes from the listener. This phenomenon requires additional compensating equipment in the ground station.

(4) Number of Satellites. A medium-altitude random system requires a relatively large number of satellites for near-continuous service. It has been stated that the DOD medium-altitude system would have consisted of from 24 to 30 satellites for an altitude of between 5000 and 10,000 nautical miles. As compared with the 3 to 6 satellites required for a stationary system, this is a large number of satellites.

(5) Temporary Outages. A medium-altitude random orbit system is subject to certain predictable temporary outages unless an unreasonable number of satellites is placed into orbit.

A medium-altitude random orbit system also has certain advantages:

(1) A simpler satellite is possible.

(2) Orbital placement is not critical.

(3) Service degrades gradually as satellites fail.

(4) Existing launch vehicles can be used to launch multiple-satellite payloads.

(5) Early worldwide limited capability is possible.

subsystems of active satellites

Any discussion of active satellites would not be complete without considering those subsystems which are common to all active systems. These are power supply, receiving antenna, receiver, amplifier, frequency translator, power output stage, and transmitting antenna. Other subsystems which may or may not be required, depending upon the system, are for stabilization and station keeping.

Power supplies generally considered for communications satellites are batteries, solar cells, and nuclear isotopes. Batteries have the advantages of being reliable, available, and relatively inexpensive, but they are heavy and short-lived. Solar cells are reliable and longer-lived, but they are more expensive and are subject to eclipse and gradual degradation due to radiation effects. Nuclear isotopes overcome most of the disadvantages of the other two, but they are expensive and are just becoming available for use.

Receiving antenna, amplifier, frequency translator, and power output stage perform the same relative function as in any repeater or beacon. The most commonly used power output stage at the present time is the traveling wave tube amplifier, which is light, efficient, and reliable.

The function of the station-keeping system is to overcome the earth's effects and keep a stationary system in place. This is usually accomplished by a command link from the earth that commands an on-board propulsion system such as cold (nitrogen) or hot (hydrogen peroxide) gas jets.

The purpose of a stabilization system is to increase the antenna gain. The stabilization methods commonly considered are spinning, three-axis, and gravity gradient.

The advantages of a means of orienting the antenna are shown in Figure 4. In the spinning satellite, the majority of the radiated power is radiated away from the earth. In the earth-oriented satellite the radiated power is beamed toward the earth. Figure 5 shows that the effect of a 5° stabilization error at 5000 nm results in 30 percent of the radiated energy being wasted. For a synchronous altitude system, the same 5° error results in 60 percent of the radiated energy being wasted.

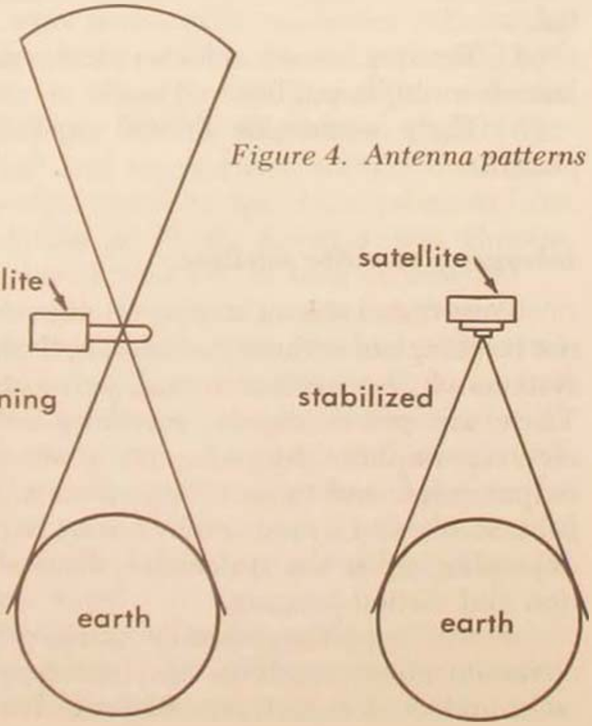


Figure 4. Antenna patterns

Gravity gradient is the ideal solution to the stabilization problem. It is simple and requires no power or complex piece parts count. The moon is a good example of a gravity-gradient stabilized satellite. The stabilizing torque arises from an interaction between the imperfect sphericity of the moon and the existence of a substantial gradient in the earth's field across the dimensions of the moon.

A qualitative feeling for the source of the stabilizing can be gained in considering a satellite consisting of two separate spheres joined by a reasonably long rigid rod, like an exaggerated dumbbell (Figure 6). In orbit about the earth, such an object experiences a balance between the centrifugal force and the gravitational attraction at its center of gravity, at any given moment. Suppose the axis of the dumbbell is neither vertical nor horizontal, but inclined at some intermediate angle. If we consider the force acting on the outermost end of the dumbbell (M_1), we find the gravitational attraction somewhat less than at its center of gravity, simply because it is farther from the earth. On the other hand, the centrifugal force is slightly greater, since it has the same velocity as the center of gravity at a slightly larger radius. Thus the forces acting on the outermost end of the dumbbell are out of balance, and there is a tiny residual force tending to push it outward. In exactly the same way the innermost end (M_2) experiences a force tending to align the long axis along the maximum gradient, the local vertical.

The stumbling block that has delayed practical achievement of passive gravity-gradient stabilization until fairly recently has been the difficulty of providing adequate damping. The normal sources of damping for earth-bound mechanisms, such as bearing friction and aerodynamic drag, are all absent, and there

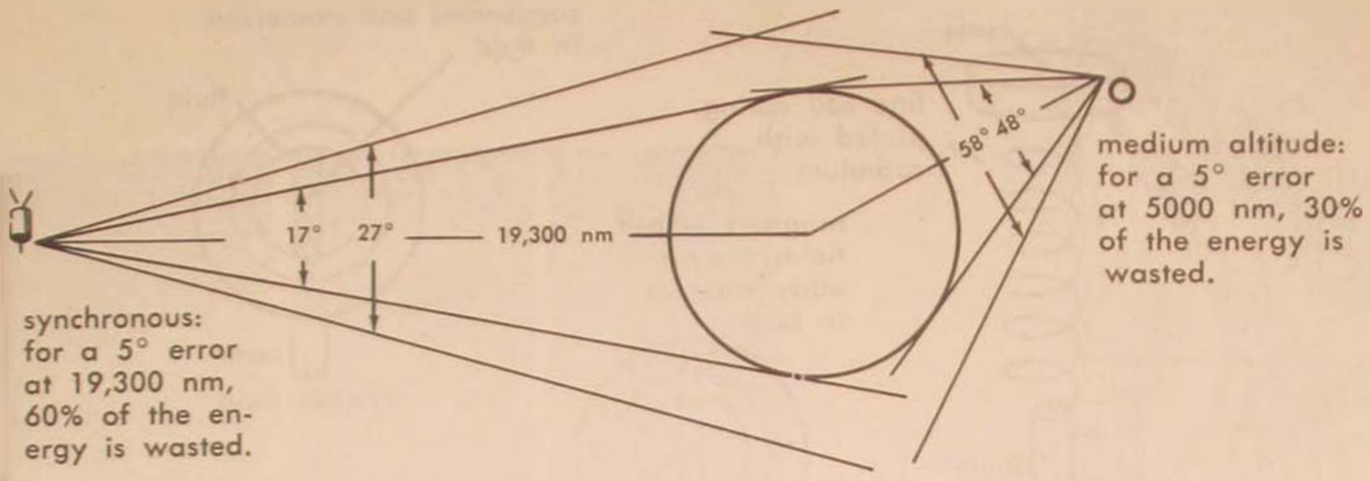


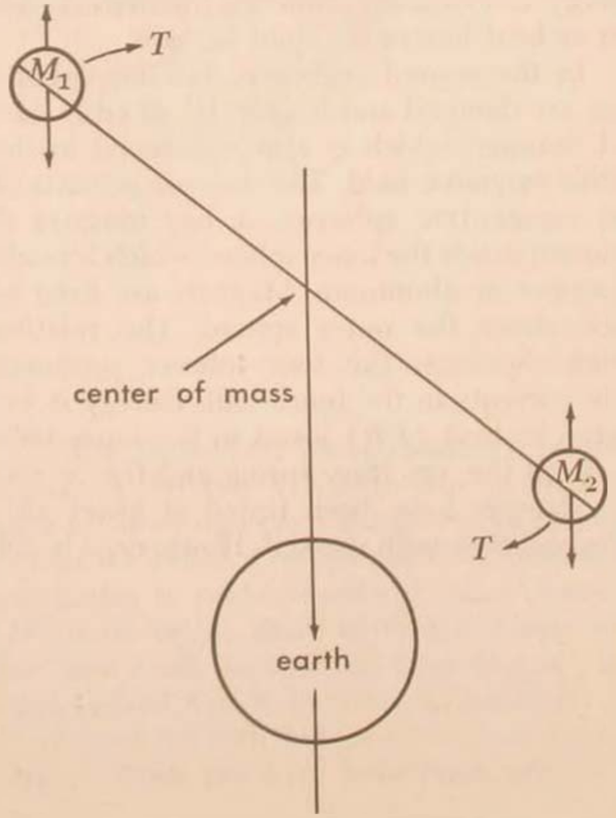
Figure 5. Effect of stabilization errors on link performance

is nothing to prevent a satellite from oscillating almost indefinitely about an average vertical position. Indeed with any substantial extraneous torque that might arise as a function of satellite attitude, it is quite possible for the oscillations to diverge and cause eventual tumbling. It is clear that some specific mechanism for damping out oscillations about the main vertical position must be incorporated to achieve a practical design. A number of possible methods have been considered (Figure 7).

The Applied Physics Laboratory (APL) focused attention on the use of a lossy (high friction losses) spring attached to the end of the boom with a weight on the end of the spring. With this device the varying centrifugal force resulting from libration should cause a variation in the tension and therefore in the length of the spring, so that the spring-and-mass system would "pump" as a result of libration. Any hysteresis loss in the spring would result in a mechanical energy loss, which would have to come from the energy of libration. The lossy spring used is made of beryllium-copper wire plated with cadmium. These springs have now been developed so that they exhibit energy losses of up to 50 percent per cycle.

General Electric has focused attention on two approaches. In the first approach, the satellite oscillations are damped and limited by means of a spherical viscous fluid damper that has the unique feature of being referenced to the earth's magnetic field. The damper consists of two concentric spheres separated by a viscous fluid. A bar magnet is mounted inside the inner sphere in order to lock the inner

Figure 6. Gravity-gradient theory



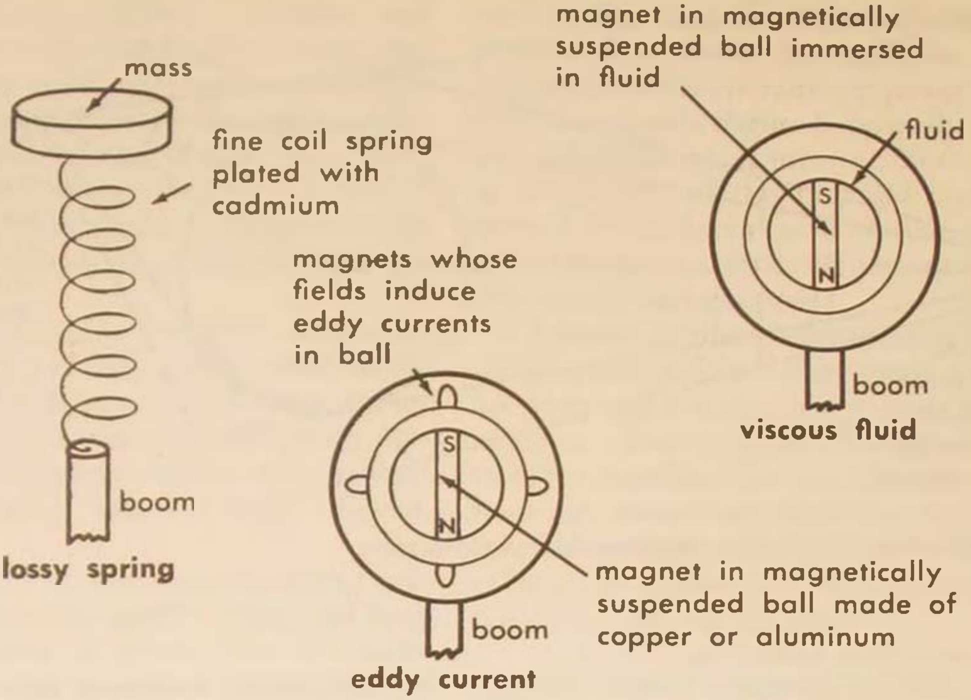


Figure 7. Passive damping techniques

sphere to the earth's magnetic field and maximize the relative motion between the damper surfaces and thus maximize the damping. Energy is extracted from the oscillation system as heat loss in the fluid friction.

In the second approach, satellite oscillations are damped and limited by an eddy current damper, which is also referenced to the earth's magnetic field. The damper consists of two concentric spheres. A bar magnet is mounted inside the inner sphere, which is made of copper or aluminum. Magnets are fixed in place about the outer sphere. The relative motion between the two spheres produces eddy currents in the inner ball. Energy is extracted as heat (I^2R) losses in the inner ball.

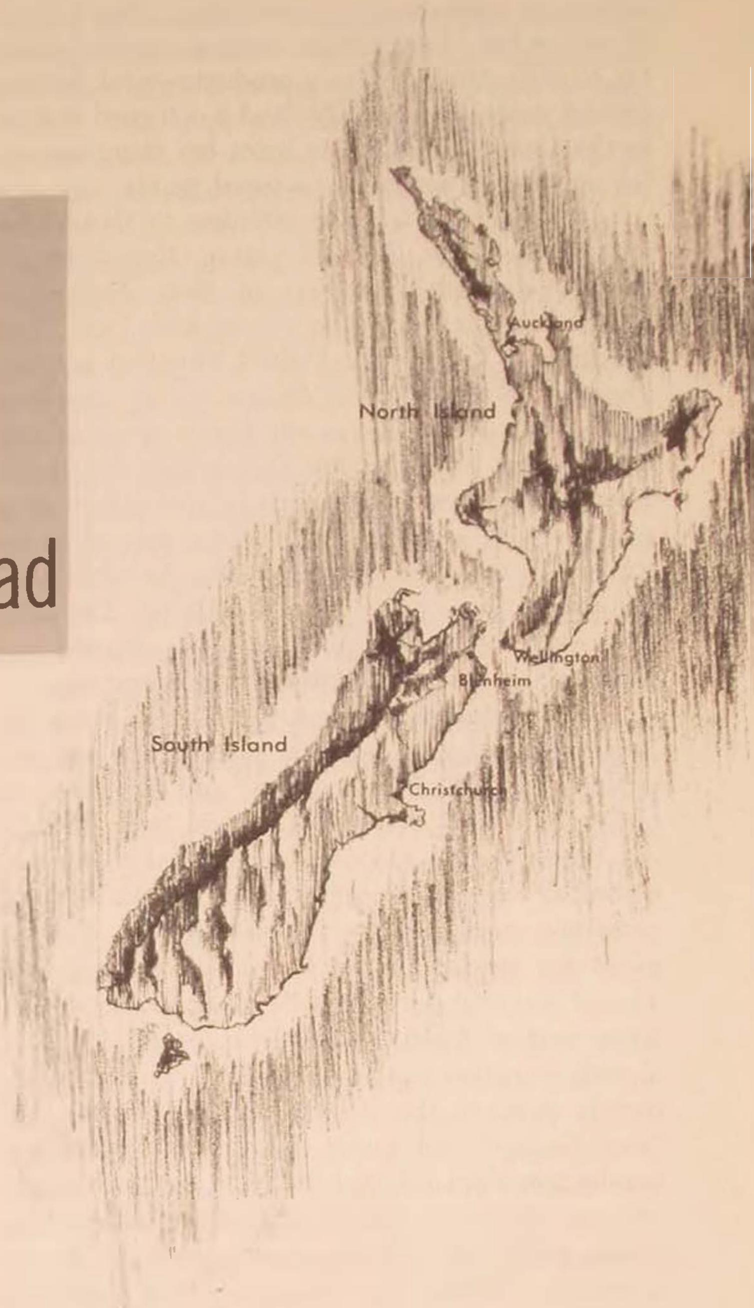
Both the APL lossy spring and the GE viscous damper have been tested at lower altitudes and they both worked. However, it is not yet known whether this knowledge can be translated to medium-altitude and high-altitude satellites.

IT IS HOPED that the reader has gained some insight into the types of communications satellites, some of their advantages and disadvantages, and some of the factors that should be considered in deciding which type should be used—if a communications satellite should be used at all. The technology is available, and it will be only a matter of time until communications satellites provide another means of command and control for the military commander. Properly understanding them will enable him better to utilize their capabilities and recognize their limitations.

Hq Air Force Systems Command

Military Affairs Abroad

THE ROYAL NEW ZEALAND AIR FORCE



IN SPITE of their remote position in the South Pacific, the response of New Zealanders to the call to arms has never been insular. Because of her size, small population, and dearth of heavy industry, New Zealand has placed her faith in agreements for world peace and collective security. New Zealanders enter into measures of collective security from a long heritage of playing their full share in international cooperation, both in war and peace.

New Zealand is a young country. It became a colony of the British Empire only in 1840 and later achieved status as a self-governing Dominion within the British Commonwealth of Nations. Its population is predominantly of either British or Polynesian origin. Since its earliest history there has been steady immigration from England, Scotland, Ireland, and Wales, with the result that New Zealanders' ties with these countries have remained strong. These ties have been reinforced by the nature of New Zealand's economy. The United Kingdom has always been a major export market for New Zealand's primary products—meat, butter, cheese, wool—and New Zealand has turned largely to the United Kingdom to meet her requirements for machinery and manufactured goods.

In World War I, in addition to those who joined the New Zealand Army Expeditionary Force, substantial numbers of New Zealanders served in the forces of the United Kingdom. After World War I numerous United Kingdom ex-servicemen migrated to New Zealand, many of whom had served in the Royal Air Force or its predecessors, the Royal Flying Corps and the Royal Naval Air Service. In the years between the wars a small regular cadre of an air force existed as an adjunct to the New Zealand Army. In addition a number of those pilots from the United Kingdom with war experience constituted a citizens' reserve and undertook regular refresher training.

The formation of the Royal New Zealand Air Force (RNZAF) as a separate arm of the services dates from 1937. Between 1937 and the outbreak of World War II in 1939 the Royal New Zealand Air Force had developed a substantial flying and technical training program which, in addition to providing personnel for its own service, trained pilots for service in the Royal Air Force (RAF). Thus it was that during the Battle of Britain, in the latter part of 1940, many New Zealanders were already in action in the European Theater. Immediately prior to the outbreak of World War II, New Zealand had taken delivery of Wellington bombers in England, and the New Zealand squadron was in the process of working up when hostilities broke out. The squadron remained in the European Theater as No. 75 (New Zealand) Squadron of the Royal Air Force and operated continuously from United Kingdom bases from 1939 to 1945.

Prior to the entry of Japan into World War II, the development of the RNZAF proceeded speedily, with the emphasis on training to meet the requirements of both the New Zealand and the United Kingdom forces. Operational Squadrons were also developed and deployed; at the time of Japan's entry there was a New Zealand fighter squadron based in Singapore and two reconnaissance squadrons based in the Fiji Islands. During this period, and until 1944 when the scheme was abandoned, considerable numbers of New Zealand airmen were trained in Canada under the Commonwealth Air Training Plan. These airmen served mainly with Royal Air Force units and could be found in every theater of war where the Royal Air Force operated.

As the war in the Pacific progressed, the development of the Royal New Zealand Air Force quickened considerably, and New Zealand squadrons were in service alongside American and Australian units throughout the whole campaign in the Southwest Pacific and afterwards in the occupation of Japan. In the Pacific Theater the Royal New Zealand Air Force deployed at various times six bomber reconnaissance squadrons, two flying-boat squadrons, fourteen fighter squadrons, and three dive-bomber squadrons. In addition two transport squadrons operated continuously between New Zealand and the Southwest Pacific bases in the Solomons and the Bismarcks.

In every sense the young RNZAF played a full part in the prosecution of the war, and its airmen won distinction in every theater of operations in both hemispheres.

In the early postwar years there was no obvious threat in the Pacific other than the distant possibility of resurgent Japanese militarism. In consultation with the United Kingdom it was agreed that New Zealand's most effective contribution would be to make available in the event of war an augmented infantry division and certain air force units in the Middle East, as well as naval units for use where required.

Following the signing of the peace treaty with Japan in 1951, the New Zealand government, faced with the clear evidence of Communist determination to dominate the world, entered into the Australia—New Zealand—United States (ANZUS) treaty.

Agreement had already been reached to establish a Commonwealth regional planning body in the Western Pacific and Southeast Asia areas, known as ANZAM. This arrangement provided the United Kingdom, Australia, and New Zealand with a means of coordinating military plans and exchanging views on defense problems in the area.

The direct threat to the Southeast Asia area was greatly increased by the victory of Communism in China and the emergence of that country as a major military power. As a result it was decided, after consultation with the United Kingdom and Australian governments, that New Zealand's wartime commitments should be transferred from the Middle East to Southeast Asia and that a Commonwealth Far East Strategic Reserve should be established.

New Zealand's contribution to the Strategic Reserve was fixed at a Special Air Service Squadron (New Zealand Army), one or two frigates or a cruiser, a squadron of day-fighter/ground attack aircraft, and transport and maritime aircraft.

In 1954 New Zealand became a member nation of the Southeast Asia Treaty Organization (SEATO), and this step clearly established her focus of defense in the Southeast Asian area.

New Zealand's military planning now had to take account primarily of the danger of Communist aggression. The shape and size of the armed forces had to be adjusted to meet the country's commitments. It was recognized that New Zealand, along with other less powerful countries, could make its best contribution to collective defense by providing conventional forces adequately equipped and able to move quickly to any trouble spot. The value of any contribution would be directly related to the speed with which it could be made available.

To meet its general obligations it was decided that New Zealand should maintain:

(a) An effective, highly mobile, well-equipped contribution to the forces-in-being in peacetime in Southeast Asia.

(b) Other forces at a state of readiness which would make it possible to deploy them quickly in the event of an emergency. (These forces were to be able to operate in conjunction with allied forces while preserving their national identity.)

(c) Elements suitable for the defense of New Zealand.

It was in line with this defense policy that the Air Force rules were redefined and the basic tasks recognized as:

(a) Tactical air forces for deployment in the Southeast Asian theater.

(b) Forces for the defense of the ANZAM region.

(c) Home defense forces.

(d) Training establishments.

It was essential for the operational elements of the Air Force to be equipped, organized, and trained in peacetime for immediate action in war. The past pattern of a peacetime nucleus upon which to expand in war was recognized as outmoded. The most effective operational roles for the RNZAF in conditions of war were seen to be light bomber/interdictor, maritime, and transport.

Arrangements were under way at the time for the fighter/ground attack squadron to have its Vampires and Venoms replaced by Canberra aircraft, which were admirably suited for a light bomber/interdictor role. Some reorganization and redistribution of units were commenced to gear the RNZAF to its changed role of a force-in-being. A prime objective was to reduce administrative overheads by concentrating like functions together at stations best suited to these functions so that the Air Force would be more compact and have an increased operational effectiveness. The personnel establishment was set at 4300.

A special problem for all the services under the new concept was the provision of equipment, which was becoming increasingly costly and which drew heavily on limited overseas funds. Action was accordingly initiated to draw up a long-term program adequate for the foreseen service requirements.

Changeover from fighter/ground attack to light bomber/interdictor commenced in July 1958 when the Venoms of No. 75 Squadron in Singapore were replaced with Canberra B-2's. These aircraft were operated on a hire basis from the RAF and were identical with those of RAF squadrons in the area. The RNZAF and RAF were able to integrate maintenance arrangements to their mutual benefit. The Canberras were actively used in antiterrorist operations, which were still required in Malaya at that time.

A later mark of Canberra, the B(I)-12, had been ordered for the New Zealand-based No. 14 Squadron, and with delivery of these aircraft late in 1959 the changeover from fighter/ground attack was completed. The operational effectiveness of the B-12 equipped with high-velocity rocket batteries as well as a range of bomb stores was definitely superior to the B-2 Canberra.

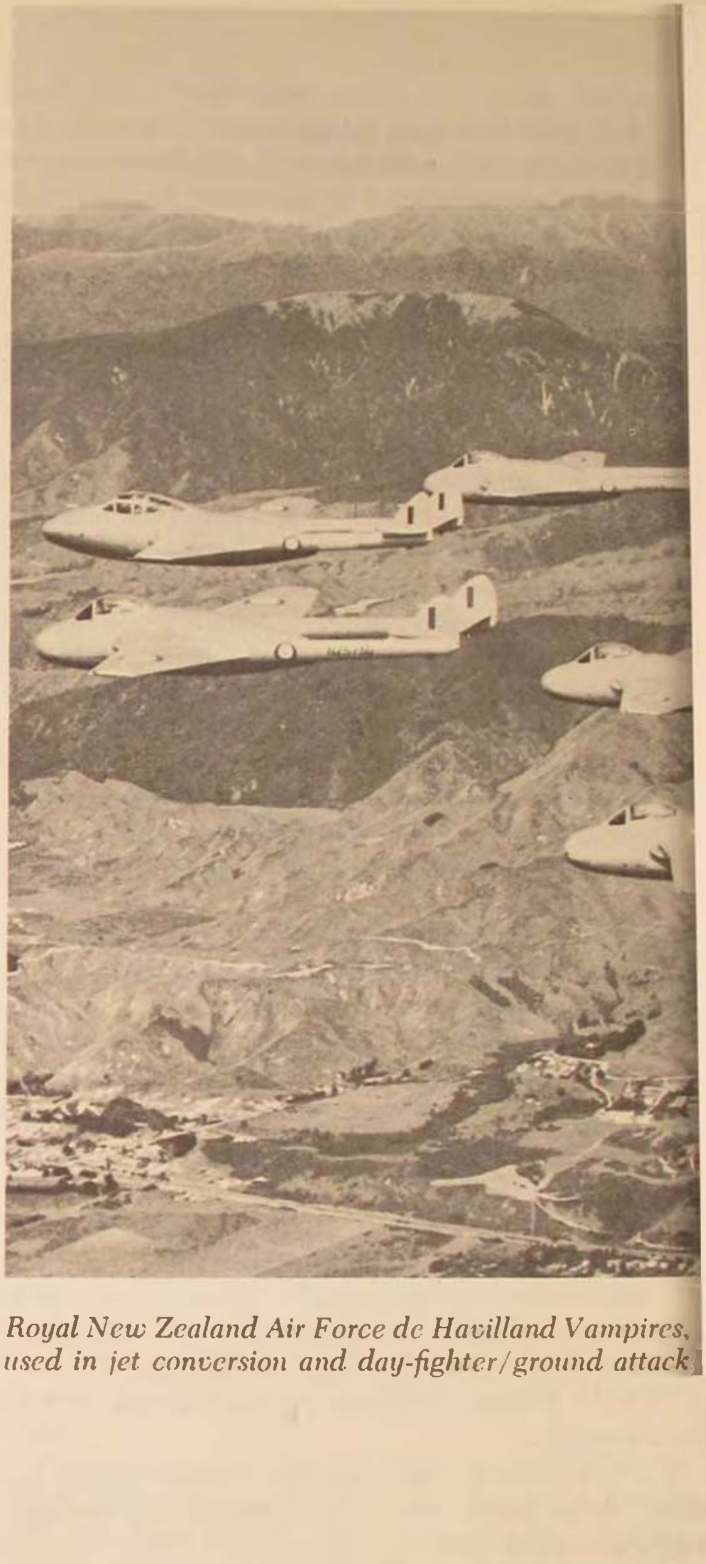
The reshaping of the Air Force saw the disbandment of nonregular units, which under the earlier concept had been held as a nucleus upon which to expand in war.

The year 1961 was one of great financial stringency for New Zealand. A further review of defense was undertaken, and some deferment and retrenchment resulted. In addition to deferring plans to re-equip the long-range transport squadron and the maritime force, the RNZAF saw the termination of the hiring arrangement whereby No. 75 Squadron B-2 Canberras were stationed at Singapore.

These measures were severe blows to the RNZAF. However, the New Zealand-based No. 14 Squadron with B-12 Canberras was by this time in a state of operational readiness for speedy transfer to the Southeast Asian theater should the need arise. Regular mobility exercises began in September 1961, when the squadron was deployed to Singapore for exercises with the Far East Air Force. Deployments have since been maintained so that the squadron is retained at a high state of operational readiness for immediate call as required. No. 14 Squadron has participated in all major SEATO air exercises in recent years.

On its return to New Zealand, No. 75 Squadron took over the training functions of the Bomber Operational Conversion Unit using T-4 Canberras and B-12's. Since the return of this squadron there has been further evolution in the roles of Nos. 14 and 75 Squadrons. All Canberra aircraft are now held by No. 14 Squadron, which has been reorganized with an operational flight and a training flight. No. 75 Squadron, equipped with Vampires, has reverted to a day-fighter/ground attack squadron responsible for its own conversion training and for producing an operational DF/GA unit.

When in 1961 Government deferred the purchase of new long-range transport aircraft for the RNZAF, as a temporary measure it arranged for the purchase of three DC-6 aircraft from the New Zealand airline Tasman Empire Airways Ltd. This step, to supplement the Hastings aircraft of No. 40 Squadron, ensured that forces could be speedily moved to any likely theater of operations. It was recognized, though, that when financial conditions were more favorable it would be necessary to replace the DC-6's with new aircraft capable of carrying heavy equipment as well as troops. In June 1963 transport re-equipment was finally approved, with the announcement that the RNZAF would purchase Hercules C-130E aircraft. This was heartening progress for the RNZAF, and plans are under way for the phasing-in of these aircraft

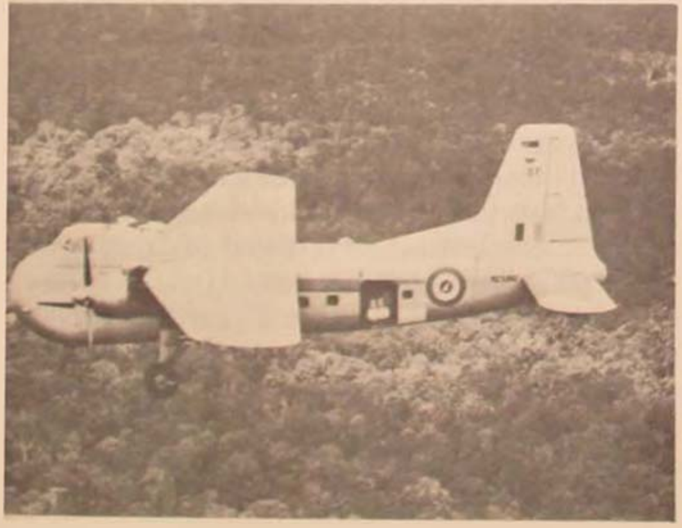


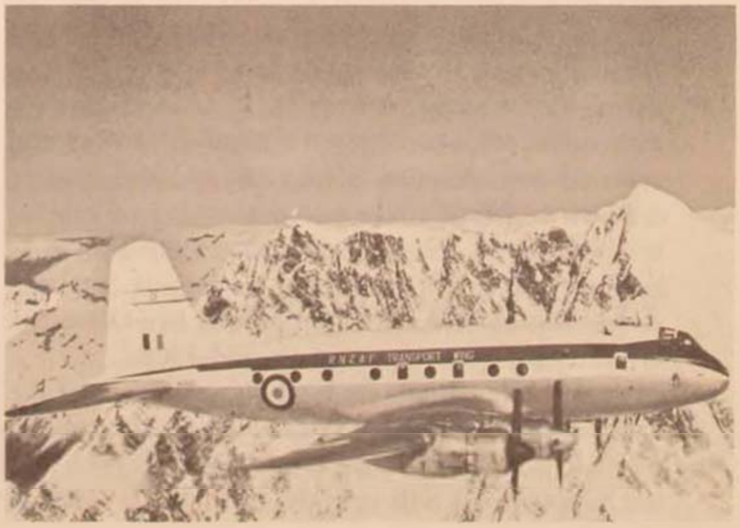
Royal New Zealand Air Force de Havilland Vampires, used in jet conversion and day-fighter/ground attack

The Bristol Freighter has fulfilled the tactical trans
role for over ten years, including active duty du
the Malayan emergency. One squadron of them
in Singapore continuously as an RNZAF componen
the Far East Air Force. . . . The Handley-Page Hastin
mainstay of RNZAF long-range transport for m
than a decade, flies before a backdrop of Southern Al

Canberra light bombers of No. 14 Squadron, RNZAF, on flight line at their base, Ohakea. Canberras are the "teeth" of the RNZAF and since 1962 have regularly carried out deployment exercises to Southeast Asia, taking their part in the Far East Air Force.

A Sunderland flying boat of RNZAF No. 5 Squadron flies low over a South Pacific island. Sunderlands served in the Transport Force during the war, and more were purchased in 1953 for the maritime role. They will soon be replaced by Orion P-3 ASW aircraft.





early in 1965. In preparation, two DC-6's have already been withdrawn so that ground and air crews can be made available for Hercules training.

A most effective contribution to medium-range transport within the Southeast Asian theater has been made by basing No. 41 Squadron, equipped with Bristol Freighters, at RAF Changi on Singapore Island. The Bristols have built up a fine reputation over a number of years in the area, during which they have performed a great variety of supply-dropping and route-flying operations. As examples, in May 1962 three aircraft from the squadron were moved to Thailand where for seven months they operated in support of forces deployed there in connection with the crisis in Laos. They returned to Thailand in January 1963 in support of the United States Special Logistic Assistance-to-Thailand program. At present the squadron is playing an active part in support of operations in Borneo.

Maritime aircraft re-equipment approval "in principle" was given by Government at the same time as approval for the purchase of C-130 transport aircraft. The RNZAF had sought approval to investigate the practicability of acquiring maritime versions of C-130 aircraft as replacements for the Sunderland flying-boat force. This concept had an obvious appeal. It would have enabled a reduction in maintenance overheads; the excellent landing characteristics of the C-130 would have been useful for Pacific island working; and the aircraft would have had some additional transport capacity to supplement the transport fleet if required.

Following detailed examination, however, it was concluded that it would be unwise for the RNZAF, as a likely sole user, to risk the inevitable development and the subsequent equipment updating that was foreseen as being a continuing requirement. Consequently, attention was turned towards consideration of the Orion P-3 maritime aircraft, which as a new and proven antisubmarine warfare (ASW) aircraft established itself as clearly the best choice for the RNZAF. In August 1964 approval was given for the purchase of five Orion aircraft. Delivery is expected in mid-1966.

The acquisition of a land plane in place of the flying-boat for maritime duties will result in much internal air force reorganization. It is planned that the Orion force will operate from RNZAF Station Whenuapai, near Auckland. This means that eventually the Lauthala Bay flying-boat base in Fiji will no longer be required. The RNZAF has operated flying-boats from Lauthala Bay for almost 25 years. The function of the other maritime base at RNZAF Station Hobsonville, near Auckland, will also undergo complete changes. It is planned that a new light aviation unit consisting of a mixed force of helicopters and STOL aircraft will be based at Hobsonville. Studies of suitable aircraft for this unit have been under way for some time, and already the nucleus of the unit has been established there.

The lines for development of the RNZAF towards a ready and effective force capable of rapid development have been indicated.

In support of the operational roles there has been a continuing evolution in home organization, support arrangements, and ground and flying training to match and sustain these roles.

It has always been policy to train some personnel overseas. For many years the United Kingdom was the natural choice for overseas training and exchanges. More recently Australia and the U.S.A. have shared in increasing measure in this field. The majority of training is undertaken within New Zealand, and a wide range of courses, from boy entrant to command and staff level, endeavors to ensure that a stream of well-qualified staff is available for the range of duties required.

Because of the demands of service life and the competition for labor in New Zealand, there are not always sufficient recruits offering—a problem common to all three services in New Zealand. Increasing attention is being given to recasting the conditions of service to ensure that adequate numbers of the labor force will be motivated towards service careers.

Besides having a continuing requirement to train personnel overseas, during recent years both flying training and ground training have been given in New Zealand to service members of other countries. Small numbers of Royal Malaysian Air Force personnel have been trained, and in future it is planned that four officers a year will receive full flying training to RNZAF "wings" standard. Ground training has also been given to Thailand servicemen under a Government Skilled Labour Award scheme for member nations of SEATO.

Flying training continues to operate at Wigram, Christchurch, where basic training is provided on Harvards and Devons. The Transport Support Unit, based at Whenuapai and equipped with Bristol Freighter aircraft, continues the operational training of transport crews, routine communication flights, and freight-carrying within New Zealand. Tactical aircraft operational training is provided through No. 75 Squadron, which is equipped with de Havilland Vampires, and maritime conversion has been undertaken at Hobsonville on Sunderlands. A transport squadron, No. 42, based at Ohakea (90 miles north of Wellington), with Dakota and Devon aircraft, provides internal communications, VIP flights, and cooperation with the Army and Navy.

New measures have been introduced in support areas to increase efficiency. Work Study was instituted in 1959 with the object of subjecting all aspects of service activity to critical analysis.

Steady progress has been made in all phases of equipment supply and administration, particularly since a changeover to punch-card data processing and accounting in 1960.

RNZAF technical tradesmen have established a high reputation for initiative and adaptability in overseas theaters. The RNZAF Repair Depot at Woodbourne (near Blenheim, in the South Island) is capable of handling a wide range of overhaul work and provides an excellent training ground for technical tradesmen. It has been policy over the years to retain in the service a range of basic air force overhaul work, experience in which serves to ensure that high standards of skill are retained and passed on to other tradesmen.

RNZAF relationships with the USAF are on the increase, particularly since the decision was taken to purchase Hercules and Orion aircraft. The first officer exchange of recent years was recently made when a USAF major joined the RNZAF Command and Staff School at Whenuapai and an RNZAF officer joined a USAF Hercules unit.

The USAF has notably supported Air Force Day flying displays in New Zealand. In 1958 General Curtis E. LeMay, at that time USAF Vice Chief of Staff, with a large contingent, participated in the twenty-first anniversary air display at Ohakea. In 1964 a similar contingent participated in the RNZAF's "Open Day" flying display, which was staged again at Ohakea. The last year has seen also the full-time establishment of a USAF military attaché's office in New Zealand, to support the increased working relationships that are developing between the air forces of our two nations.

New Zealand has recently established a new Ministry of Defence as a unitary department combining not only all joint-service functions but also the Departments of the Army, Navy, and Air as distinct components. These new defense arrangements will have far-reaching effects on the Air Force and the other two services in the next few years.

The new national defense approach has already made itself felt in logistic and re-equipment programs. The Ministry of Defence has also organized and coordinated discussions with United States officials on possible forms of New Zealand/United States cooperation in logistic matters.

The centralization of financial control over all the operations of the Department has been initiated with the creation of a single vote in the Government Estimates, combining the three former service votes.

For the RNZAF there are requirements for training aircraft as well as operational replacements in medium-range transport and tactical aircraft to be considered in the next few years. The RNZAF objective will be to replace first the Vampires about 1967–68 with a modern tactical aircraft with an interceptor capability.

Concentration on the equipment needs and the operational roles of the RNZAF also serves to bring the current service organization under review. Both the RNZAF structure and organization will continue to be subjected to examination and refinement to ensure that the service is as efficient a force-in-being as is attainable within the budget and size limitations possible for a country of 2½ million people.

Royal New Zealand Air Force

pay system, the Air Force still looked for a sound accounting and reporting device.

From the many pay studies and tests undertaken by Air Force pay system specialists came two basic concepts. The first called for centralized control, maintenance, accrual accounting, and reporting of all Air Force military pay accounts using a high-speed communication system linked to a large-scale computer at the Denver Center. The other approached the problem through the use of desk-size computers at paying bases. Both systems prescribed mechanized record-posting and provided for accumulating and reporting pay management data on an accrual basis.

In early 1962 Air Defense Command at Ent Air Force Base began a test of the base-level system. This test, using the NCR 390, demonstrated that the system and the hardware could do the job. Preliminary estimates were that a single computer configuration could handle a payroll of at least 6500 members. The test showed that pay service would be prompt and accurate, management data and current allotment reconciliation information would be quickly and easily accessible, while tedious and costly manual record-posting could be virtually eliminated. Further, the system could be readied for Air Force-wide implementation by July 1964.

On 2 October 1962 Department of Defense Directive 7040.3 directed that all military services implement an accrual accounting system for military pay within two years, that is, by October 1964. Since the central computer system could not be ready to go within this tight time frame, the Comptroller of the Air Force directed that the so-called "Ent system" be implemented and fully operational by 1 July 1964. The detailed planning, programing, and systems and procedural development required to meet this target date began immediately.

In joint planning sessions during January and February 1963, representatives of Hq USAF staff directorates met with those of the Center and major air commands. During these discussions the joint planning body wrestled with the many problems of systems refinement and amplification, computer assignments and delivery schedules, training requirements and responsibilities, accessory equipment, supplies, forms design and delivery, and a host of other devils. This planning body also recommended assignments of responsibilities. Its recommendations were ultimately incorporated in Air Force Letter 177-1, Accrued Military Pay System, 20 June 1963, the formal announcement of AMPS. Essentially, Hq USAF was responsible for policy guidance, systems and program approvals; the Air Force Accounting and Finance Center for systems, procedures, and program development and implementation; and the major air commands for full program support and execution at command and base levels.

Air Force Pay—
Old and New

In March 1963 the Director of Accounting and Finance, Hq USAF, announced a satellite program for military pay. This program was designed to achieve maximum computer utilization at minimum rental, consistent with high-caliber pay service. Simply stated, the satellite program prescribed that pay records of two or more bases reasonably close

old manual method of pay computation was slow, ous, and left a wide margin for error. The Ac- d Military Pay System (AMPS), using the NCR computer (below), is both rapid and more accurate.

together would be maintained on computer equipment located in the accounting and finance office of a single prime base. Because of mobility requirements of Strategic Air Command and Tactical Air Command, satellization of their bases was held to absolute minimum. A handful of bases, too small or too remote either to computerize or to satellite, remained on manual operation.

The proposed satellite program was thoroughly reviewed by the major air commands. Then, during a series of command workshops at the Accounting and Finance Center in May and June 1963, they presented their proposed amendments. The workshops accomplished far more than concluding negotiations on satellite arrangements. Command representatives received in-depth briefings concerning the AMPS concept and design, as well as demonstrations of the computer gear. From these workshops, too, came a detailed mutual understanding of the total implementation program and schedule, including several key points that should be listed here:

—AMPS was to be a functional computer program; that is, the hardware would be located in and operated by Accounting and Finance offices. However, data systems personnel had a definite role in collaborating with Accounting and Finance in matters of site readiness, machine testing and acceptance, machine scheduling, and utilization reporting. Their equipment management experience was to prove highly useful to the relative fledglings in the computer business.

—Computer deliveries and installation would be scheduled incrementally, beginning in November 1963, with delivery to the final bases in May 1964.

—Training, correlated to equipment deliveries, would be conducted by Air Training Command. Computer operators would not be trained as programmers; rather, their instruction would be limited to equipment operation, machine program understanding, and first-level machine hang-up clearance procedure.

—Standard machine programs, program tapes, and operator instructions would be prepared centrally and distributed to all bases in advance of machine delivery.

—Instructions and detailed schedules for converting to the new individual pay record would be provided well in advance of 1 January 1964, the implementation date for using the new record at all bases, mechanized and manual.

—Procedures manuals would be issued in draft form and in limited quantity well in advance of 1 January 1964. Use of these draft manuals for operation of the system until issuance of final printed manuals was authorized.

—Virtually all new forms and major items of accessory equipment would be centrally procured and distributed as initial issue without requisition. Site preparation and procurement of small supply items (tapes, tape cores, and containers, for instance) would be the responsibility of the bases.

—A project officer and alternate would be appointed by each command to ensure closest possible day-to-day liaison and to provide command program management control.

—Simple progress-reporting would be required from the make-ready period through implementation to ensure that all program requirements were in place, and on time, to meet operational target dates.

—An overall Air Force master program for implementation would be prepared for direction and guidance to commands in constructing their own programs.

Interrelated to the equipment delivery schedule was the training program. Within the overall time schedule and established training quotas, each command originally established its own priority order for training and equipping. In general, the base upon which the command headquarters is located was nominated by the command as the first base to be mechanized. This allowed for fullest command systems surveillance and support in the initial installation.

AIR TRAINING Command's Department of Comptroller Training, located at Sheppard Air Force Base, Texas, was responsible for training more than one thousand key military pay personnel in the AMPS system. Starting from scratch, the school had to ready and equip a computer site and expand and train its instructor staff—not only in the minute details of the AMPS system but in the art of instruction itself. Working stride for stride with the pay specialists writing the procedures manuals, these instructors prepared training materials from copies of the typed drafts. Only by keeping up this pace—virtually snatching copy from the typewriters—could the school meet its training start date, 2 October 1963.

Training alone presented its full share of schedule challenges. While it would have been ideal to train an entire military pay office as a unit, this could not be done. Paydays still had to be met; there could be no moratorium on pay to accommodate training.

Therefore the training for each base was scheduled in increments. Supervisors from each base were the first trained so that they could return and instruct others in their office. Then the computer operators from the bases were trained, and so far as possible they completed training within a week or two of the date for equipment installation at their base. Perhaps this is best illustrated by the accompanying extract from the actual consolidated computer installation and training schedule.

The supervisors entering on 2 October completed their four-week course on 27 October. Console operators in the 30 October increment from these bases completed their three-week instruction period on 18 November, returning to their bases to find the gear they were to operate all set to go.

Personnel from ConUS, Alaska, and Panama were trained in residence at Sheppard, while traveling instructor teams trained overseas base students at Rhein-Main Air Base, Germany, and Tachikawa AB, Japan.

The precise scheduling required to take full advantage of classroom, instructor, and training equipment, all in accord with delivery of 174 computers at 125 sites, was by no means easy. But it was accomplished, and the training program was executed completely, successfully, and on time. During one year, June 1963 through June 1964, the Department of Comptroller Training recruited and trained instructors in the total AMPS system, prepared training materials, and guided over a thousand students through their courses.

Standard machine programs, program tapes, and related instructions were developed by a team of manufacturer and Air Force programmers at the Air Force Accounting and Finance Center. Programs were tested first on Center hardware. Then they were further tried out at Lowry Air Force Base as well as at Ent AFB, the original test site. As a result of continuing program refinement, the original test tapes had passed through several generations by the time the first programed bases went "live." And, frankly, despite extensive and successful testing on live pay accounts at the test sites, some programs failed to function perfectly when applied to the full gamut of intricate pay combinations at other bases. Reports of such failures poured in immediately by telephone and wire, but with the burning of much midnight oil remedies were prescribed by fastest means available. Program improvements, aimed at reducing both manual and machine processing time, continue today.

THE AMPS system introduced a new military pay record, AF Form 470, designed for the NCR 390 computer but also capable of manual posting. Before the new record was placed in use 1 January 1964 at all bases, a detailed conversion guide, containing "follow-the-arrow" instructions for inaugurating the new record, had been distributed to all bases the preceding October. In addition, pay specialists from the Center held a series of brief workshops throughout the Air Force to supply firsthand guidance in introducing and posting this new record.

On 29 August 1963 the Air Force Master Program for AMPS had been distributed to all commands and bases. This document was designed to bring together under a single cover the essential elements of guidance and direction for AMPS implementation. The Master Program enumerated major program milestones and covered the full spectrum of information concerning progress control, manuals, machine programs, manpower, conversion, audit, publicity, equipment delivery, training concepts, schedules, and the satellite program.

Procedures manuals were printed and distributed in October 1963. For many, this was the first glimpse of the totally new method of maintaining individual pay accounts and the somewhat perplexing features of accrual accounting. The questions (and perhaps some misgivings) that arose at first cleared up during the coming months. Formal intense training, coupled with the disciplines of operating experience, brought the new system into sharper focus. With increased understanding of the system and improved facility in applying it, benefits flowed both ways. Products of the system, admittedly less than perfect during the early months of operation, constantly improved in direct ratio to comprehension, experience, and meticulous adherence to prescribed procedural controls. And with this, many bases spotted system weaknesses and promptly recommended easier, simpler, more efficient ways to describe and operate AMPS. Their "better mousetraps" ranged from household hints to broad changes in pay and accounting processes. Their recommendations were heard and acted upon; nearly a score of changes were made to the basic manual, and many lesser ideas were circulated in the Center's AMPS Information Digest (AID), issued roughly every two weeks since the implementation program began.

While there were delays in delivery of some accessory equipment and supplies, none critically delayed conversion and implementation. Sites were readied and computer deliveries made either on or ahead of schedule, training went according to plan, and every base went live on its target date. AMPS was fully operational on 1 July 1964, a significant achievement in program development and execution. It was a clear manifestation of know-how, dedication, teamwork, and plain hard work at every level in every office. But the implementation and shakedown were not without headaches and heartaches.

During the conversion and early months of operation, personnel in the pay offices worked round the clock. Weekends and holidays were simply work days. Not until September 1964 did the mountainous overtime start to decline,

ConUS Consolidated Computer Installation and Training Schedule

			Supervisor Course		*Console Course*		*Computers*		
Order	**Base**	**Command**	**No.**	**Date**	**No.**	**Date**	**No.**	**Delivery Date**	**Installation Date**
7	Kelly	AFLC	2	2 Oct 63	2	30 Oct 63	1	6 Nov 63	25 Nov 63
			2	30 Oct 63	1	27 Nov 63			
8	Edwards	AFSC	3	2 Oct 63	1	30 Oct 63	1	6 Nov 63	25 Nov 63
			3	30 Oct 63	1	8 Jan 64			
9	Nellis	TAC	1	9 Oct 63	2	30 Oct 63	1	6 Nov 63	25 Nov 63
10	Wurtsmith	SAC	2	2 Oct 63	1	30 Oct 63	1	6 Nov 63	25 Nov 63
			2	9 Oct 63	1	27 Nov 63			

yielding to the impact of learning, experience, and refinement.

The Air Force Auditor General directed a two-phase audit program for AMPS. The first phase dealt with preparatory and conversion actions; the second with actual operations. The principal finding of resident auditors at the computer bases was noncompliance with prescribed procedure, particularly in document and accounting controls. This early audit result, though not heartening, was not altogether unpredictable. For the first time military pay people were encountering, head on, the rigid control disciplines of mechanization. Faced with the time press of conversion and the absolute necessity of meeting paydays as they relentlessly rolled around, pay personnel attempted shortcuts as the only solution. Perhaps in some cases this was the only short-term answer, but the efficacy of the built-in controls was soon proved. Designed to detect imbalances, the controls did precisely that; ultimately, the remedial adjustments had to be made.

The need for improvement was not confined to base operations. The auditors also pointed out the lapses, ambiguities, and discrepancies in the procedures. From their on-site observations, they proposed dozens of systems improvements for ultimate incorporation into the manuals. Follow-on itinerant instructor teams from the Department of Comptroller Training added their observations to those of the auditors. Command and Center staff assistance teams visited almost every base during the first few months of AMPS operation and supplied still more improvement ideas.

The heart of any pay operation is its ability to pay every member, accurately and on time. We saw AMPS meet every payday on time, yet many officers and airmen remained far from convinced that AMPS would continue the high-caliber pay service enjoyed under the less sophisticated manual system. Under the AMPS satellite program, it is not now uncommon to find a member stationed at one base, his personnel record at another, and his pay record at still another. This demands of the personnel officer and the accounting and finance officer close coordination and cooperation for accurate, timely submission and processing of pay documents. The rigid routines of mechanization, admittedly essential to overall accuracy, claimed their price in reduced responsiveness. Gone was the day when a pay entry involved one simple stroke of the pen. This was a lesson neither easily taught nor easily learned in the early days of AMPS, but is has been learned in AMPS just as in any automated system undertaking.

A salient and certainly the most sensitive shortcoming of AMPS pay service came from an early decision to mail pay records of personnel involved in a permanent change of station. The objective, of course, was to maintain maximum inventory control for accounting purposes. The procedure laid out for the mailing process was sound, on paper, but it often collapsed in actual practice. Separation of members from their records soon became a serious morale factor. Not that members could not draw pay, for they could and did, and casual pay procedures enabled them to draw certain prescribed amounts almost anytime. But quite naturally and properly, these members expected full, accurate, and timely payment of all money earned. Moreover, mailing pay records in cardboard-reinforced envelopes proved unsuccessful. Damage rate was high, and bases spent costly man-hours reconstructing and creating new records to replace those battered in the mails. The mailing procedure was short-lived; hand-carrying of records was reinstituted, this time in specially constructed tubes. The problem quickly subsided and has all but disappeared. Those few records still mailed are mailed in the tubes. Damage rate is so low as to be insignificant.

Today amps is a going concern. The hardware has proved tough and thoroughly reliable. Manufacturer support has been superb. Procedures refinement and skilled management by the pay office of work flow and scheduling have eliminated backlogs and unnecessary manpower expenditures. Service to members and to customer agencies is prompt and accurate. Allotment reconciliation processes operate successfully. Timely, precise, and complete accrual accounting data, which have been needed and wanted by the budget planners, the fund manager, and the decision-makers for so many years, are now available every month. But the story does not end here; it never ends. The Air Force continues to improve amps all along the line.

As for the future, the Air Force is collaborating with the other services in a test of a uniform, centralized, automated system for military pay. Sponsored by the Department of Defense and under project leadership of the Department of the Army, the test program and system development are under way. That is another story. Someday it, too, will be told.

Air Force Accounting and Finance Center

Air Force Review

PROJECT SCORPIO

Liquid-Rocket Propulsion Technology

Daweel George

WHAT is believed to be the first firing of a clustered-combustion-chamber liquid-rocket engine of significant thrust size took place recently at the Air Force Rocket Propulsion Laboratory, Edwards AFB, California. The firing culminated the laboratory's largest in-house exploratory development project, officially known as the Cellular Combustion Chamber Program. The program is nicknamed Project Scorpio for its space connotation (suggested by the constellation Scorpio) and because of the location of AFRPL in the Mojave Desert; another reason for the Scorpio designation is that the original project name was the Segmented Engine Program and the tail of a scorpion has discrete segments.

The eight thrust chambers, clustered around a zero-length plug nozzle, formed a rocket engine that produced 200,000 pounds of thrust. Each 25,000-pound-thrust chamber used film cooling and an advanced, simplified propellant injector. Only two propellant valves were utilized for the entire cluster feed system for the liquid oxygen/liquid hydrogen propellants. For the short-duration, steady-state checkout firing, start transients were smooth with all chambers priming within 80 milliseconds of each other. A second successful firing was conducted several days later to confirm the original test data. Scorpio-type engines promise a simple and reliable liquid-propellant rocket system singularly free of combustion instability and can be designed and fabricated quickly with minimum effort and cost.

Project Scorpio was originated for the primary purpose of investigating methods to reduce the development time and cost of large liquid-rocket engine components, utilizing the high-energy cryogenic propellant combination of liquid oxygen (LO_2) and liquid hydrogen (LH_2). The investigation involved three distinct tasks:

Task I – To demonstrate feasibility and evaluate highly simplified injector patterns for liquid propellant

Task II – To determine the maximum thrust per element which can be utilized and still attain high performance

Task III – To investigate a simplified method for clustering discrete thrust chamber assemblies.

Task I

The conventional multiorifice liquid-propellant injector already in use is quite complex, costly, and time-consuming to fabricate. (See Figure 1.) The problem becomes more acute from the size and scrappage rate standpoint as higher thrust injectors are required to launch larger payloads. What could be done to alleviate the situation? The decision was to investigate simplified injector patterns. (See Figure 2.)

Our approach to Task I was to experiment with large thrust per element (LTE) injectors, which are highly simplified and very unconventional. Because of their simplicity, the cost and fabrication time of these injectors are markedly reduced, being approximately one-third that of multiorifice patterns of comparable thrust. Also the tolerance requirements for the injector elements are less

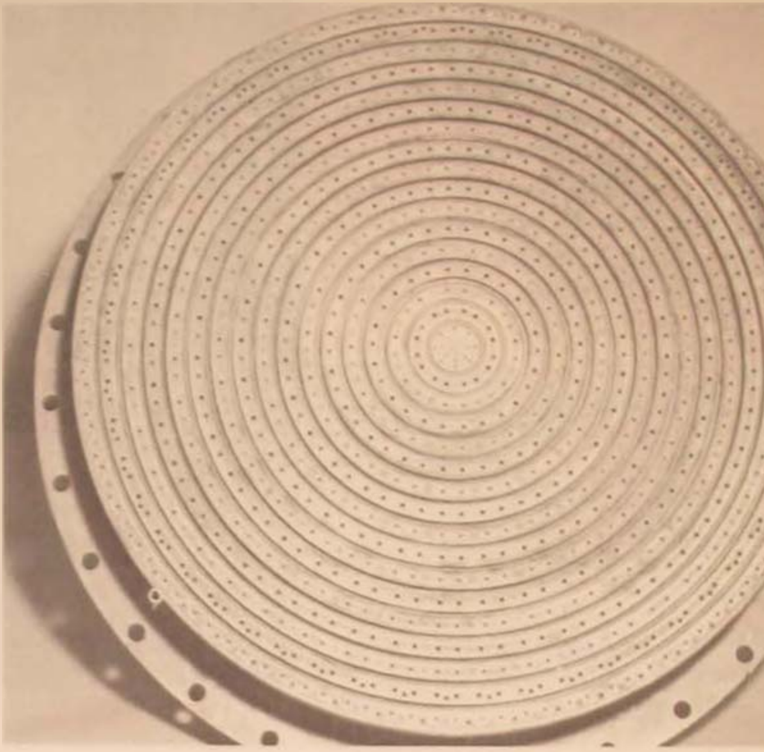
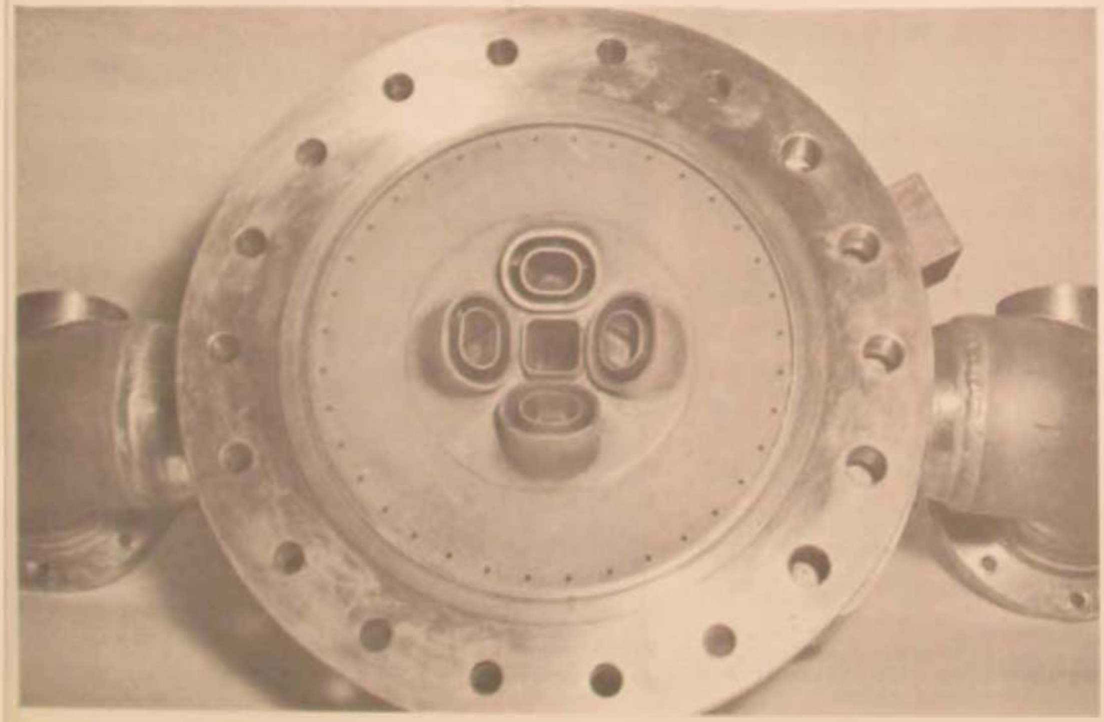


Figure 1. Conventional injector, 50K

Figure 2. Single-element concentric pentad injector, 50K



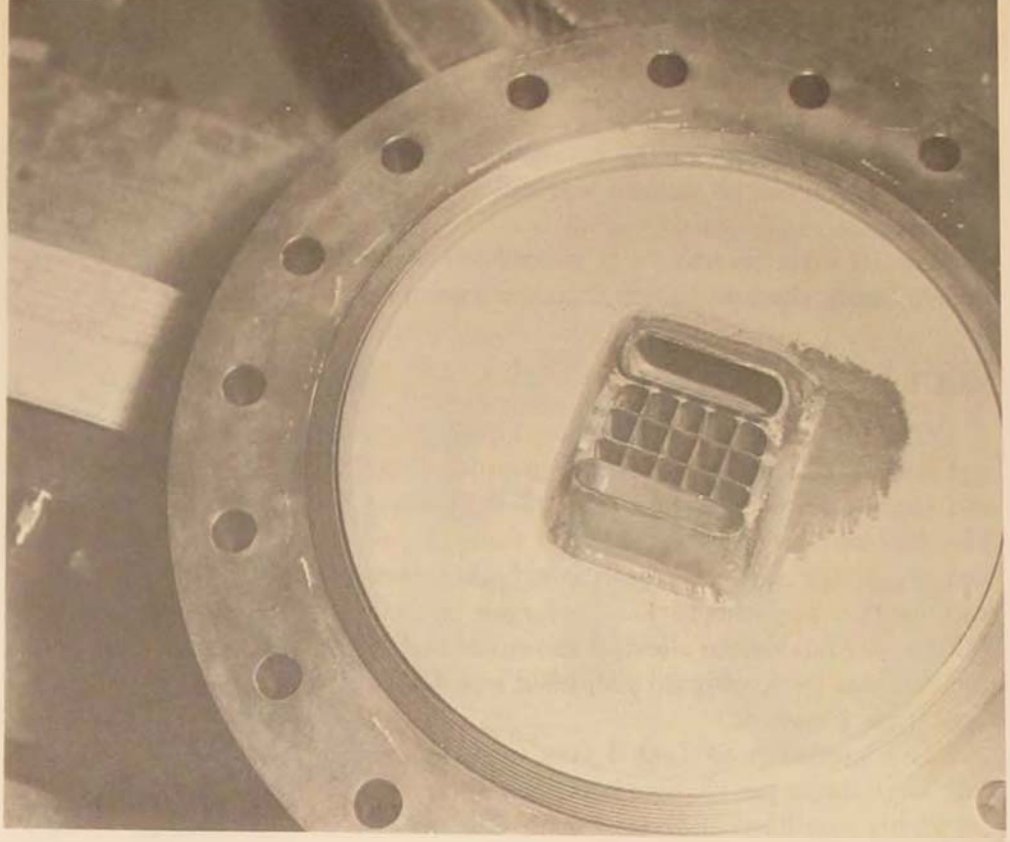


Figure 3. Single-element triplet injector, 50K

stringent for the LTE injectors. Twelve injector patterns, each developing 50,000 pounds of thrust, were designed and tested, with thrust per element* ranging from 1400 to 50,000 pounds of thrust. Design parameters, which are varied to determine their effect on performance, are as follows:

Mixture ratio – $\dot{W}_o/\dot{W}_f$
Momentum ratio – $\dot{W}_o V_o/\dot{W}_f V_f$
Pressure drop across the tubes or orifices – ΔP
Propellant exit velocity – V
Orifice length to diameter ratio – L/d
Tube impingement angle – θ
Tube configuration – round, square, oval, etc.

Three of the injector configurations tested were the single-element concentric pentad, single-element triplet, and 36-element coaxial patterns.

In the single-element concentric pentad (Figure 2), fuel is injected into the chamber from the center tube and from each annulus shrouding the four impinging oxidizer tubes. The fuel injected from the annuli is primarily used for cooling the oxidizer tubes to keep them from eroding. A later modification of this pattern reduced the amount of fuel used as coolant, resulting in an increase in performance. The tubes were designed square and oval to provide a larger contact line between the propellants to promote better mixing. A later design utilizing circular tubes was tested, and results revealed no performance degradation. Therefore, circular tubes can be used and are better from the standpoint of ease of fabrication.

The single-element triplet (Figure 3), which also develops 50,000 pounds of thrust, consists of a fuel center tube and two impinging oxidizer tubes. This injector is the simplest pattern investigated in the program and hence the most easily fabricated. Therefore more interest is expressed in this pattern than in the others. The L/d ratio with this configuration becomes a major concern because of the size of the orifices. The recommended L/d ratio of 10 for fully developed turbulent flow in the tubes, especially the fuel tube, would require a long injector, which is unacceptable. Ratios as low as 3 have been used with no problem. A further aid to shortening the height of the injector for compactness and better propellant flow characteristics is the use of flow straighteners, which in essence lengthens the L/d ratio. The pressure drop across the fuel tube and the impingement angle of the oxidizer tubes are other variables of

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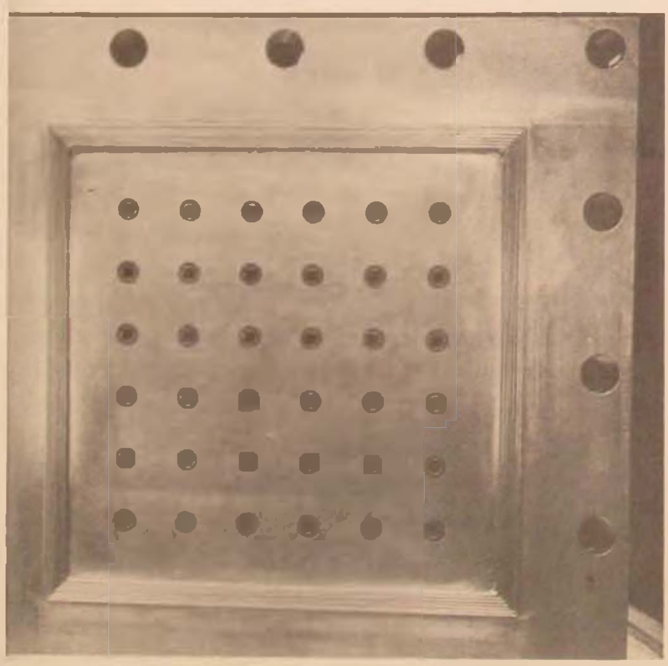
*An element is defined as one set of oxidizer and fuel tubes. For example, a four-element triplet injector has four sets of three tubes grouped together to form the injector pattern.

major concern. The original design fuel tube pressure drop was only 2 percent of chamber pressure, which is much lower than present-day conventional injector pressure drops. However, it was observed that performance increased with increase in ΔP_f, which is now approximately 6 percent of chamber pressure. The impingement angle of the oxidizer tubes was varied from 60° to 90°. Performance increased with the larger angle, probably due to better mixing achieved from greater momentum exchange.

The 36-element coaxial configuration, which consists of an annulus of fuel surrounding each oxidizer tube (Figure 4), was used as the reference injector although its thrust per element is on the order of 10 times larger than similar injector patterns being evaluated for advanced rocket engine systems at the time of its design. Unlike the patterns in Figures 2 and 3, propellant mixing takes place by a shearing action and interaction between elements.

Of the twelve injectors tested, four have demonstrated high combustion efficiencies. In addition to performance investigations, stable combustion and injector heat transfer characteristics are major considerations.

Figure 4. 36-element coaxial injector, 50K



Thrust Chambers. Two different thrust-chamber configurations have been used: a square chamber with a two-dimensional nozzle and a cylindrical chamber with a conical nozzle. (See Figures 5 and 6.) The square chamber, in which the first 55 test firings of Project Scorpio were conducted, approximates the truncated wedge of an annular combustor and has the possible application of being clustered around a plug nozzle or grouped in line to serve as thrusters for a rocket-powered plane. (See Figure 7.) The cylindrical chamber has a circular throat, and this configuration can be clustered around a common plug nozzle or a forced deflection nozzle. Both chambers are uncooled, and the inner walls are coated with molybdenum, tungsten, and zirconia to provide a thermal barrier between the combustion products and chamber wall. The same injector patterns test-fired in both configurations yielded 2 to 3 percent lower

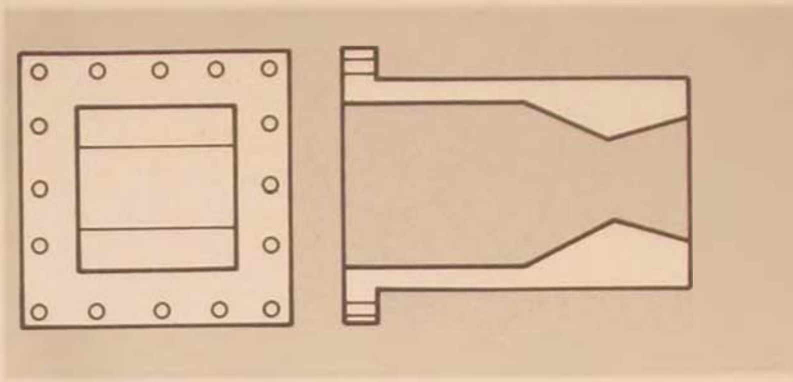
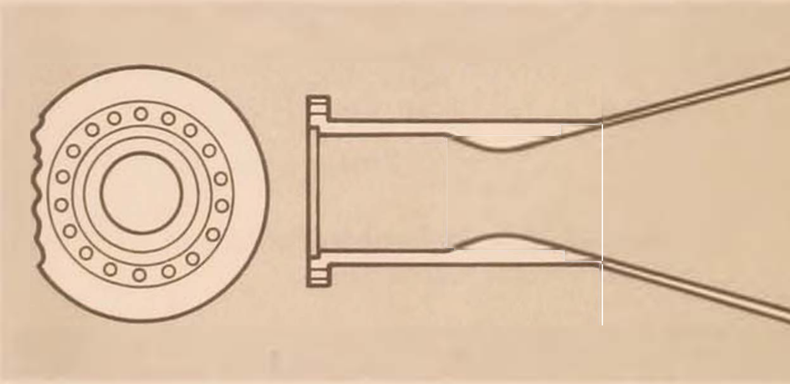


Figure 5. Square thrust chamber, two-dimensional nozzle

Figure 6. Cylindrical thrust chamber, conical nozzle



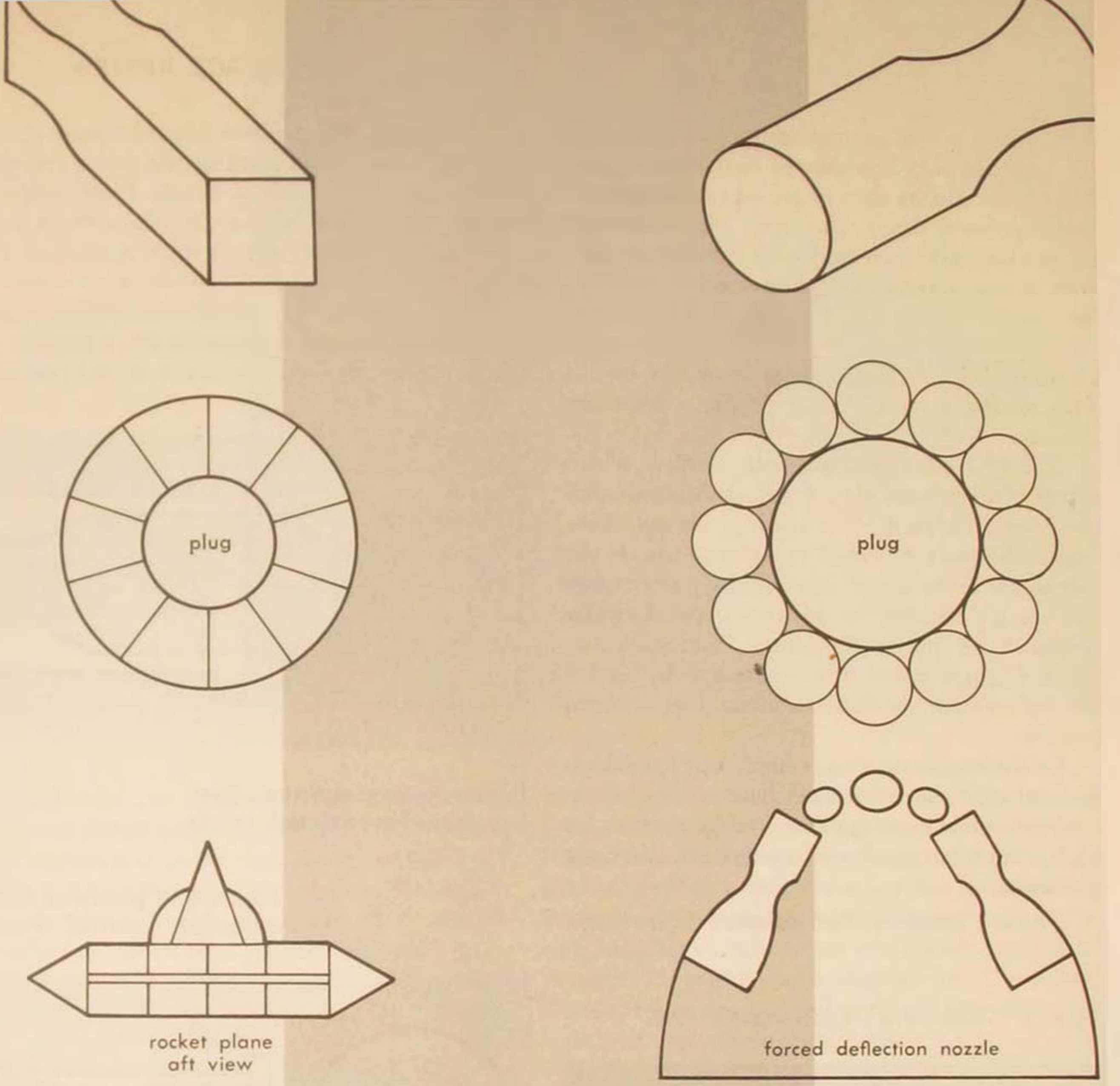


Figure 7. Thrust chamber applications

performance with the cylindrical chamber. This could be due to an aerodynamic throat being formed with the square chamber, thereby indicating higher performance than was actually achieved. It was also observed that performance increased with increase in L*. A typical performance plot for a particular injector fired in chambers with different L*'s is shown in Figure 8.

Simulated Liquid Air/Liquid Hydrogen Tests. This series of tests was conducted to provide support data for determining whether liquefied air with various concentrations of liquid oxygen could be used as an oxidizer. The square chamber and coaxial pattern injector were used for the tests. It was determined that as the amount of liquid nitrogen in the LO_2 was increased, the percent of theoretical performance decreased. Ignition was readily attained in all cases and combustion was stable.

Task II

Prior to the Task I investigations, a contractual effort was initiated to investigate LTE injectors with cryogenic propellants (LO_2/LH_2) at the 20,000-pound-thrust level. Both efforts produced encouraging results. The question arose as to how large the thrust per element can be and still achieve high combustion efficiency. This stimulated the advent of Task II, to determine the maximum thrust per element which can be utilized and still attain high performance. These studies are conducted at the 200,000-pound-thrust level.

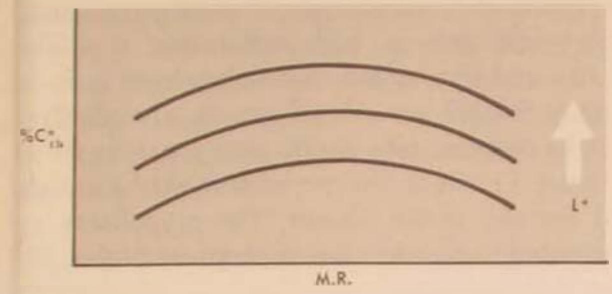


Figure 8. The percent of theoretical combustion efficiency, $\%C^*_{th}$, increases as the L^* is increased and reaches a maximum at a particular mixture ratio.

Our approach was to build on the information obtained from Task I injector evaluations, which served as the preliminary basis for the design of three injector patterns yielding 200,000 pounds of thrust. Each of them has been tested and evaluated. The configurations shown in Figures 9 and 10 are the single-element concentric pentad and the four-element concentric pentad. The third injector pattern, not shown, is a four-element concentric triplet configuration, each element consisting of a fuel center tube with two impinging oxidizer tubes shrouded by an annulus of fuel. The performance parameters under investigation were the same as those under Task I. In addition to determining the maximum practical element size, multielement patterns were investigated. The LTE injectors, unlike the conventional multiorifice injectors, do not have a uniform flame front. Recirculation of the combustion products takes place, and localized hot spots appear on the chamber wall which can be directly associated with the injector pattern. Tests conducted under this task did not yield performance as high as was achieved with the Task I injectors.

Task III

The objective of Task III is to investigate a simplified method for clustering discrete thrust chamber assemblies to provide the high thrust required to put greater payloads into orbit or into a ballistic trajectory. The classical approach to attaining high thrust has been to develop very large single engines such as the F-1 and M-1. This approach has some inherent problems:

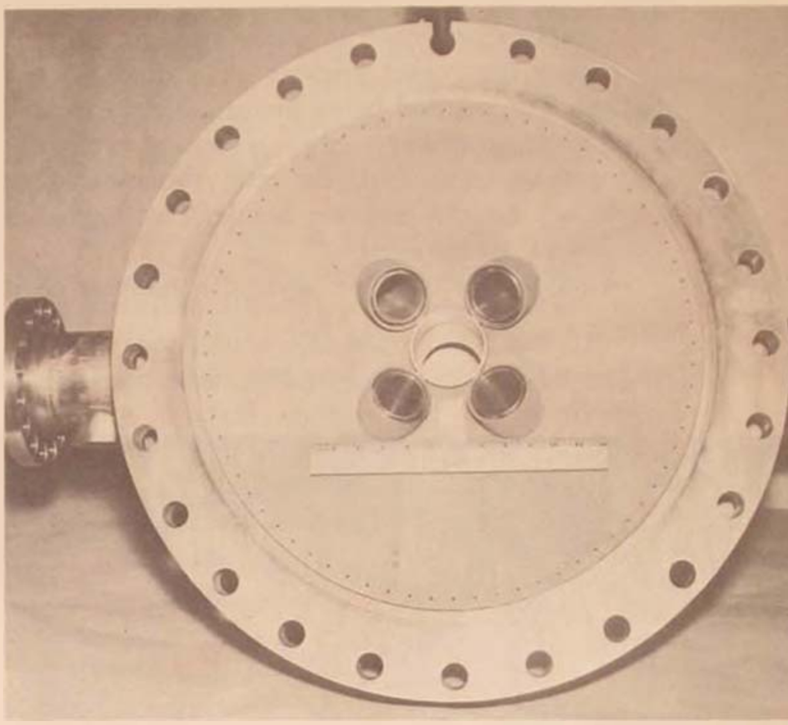
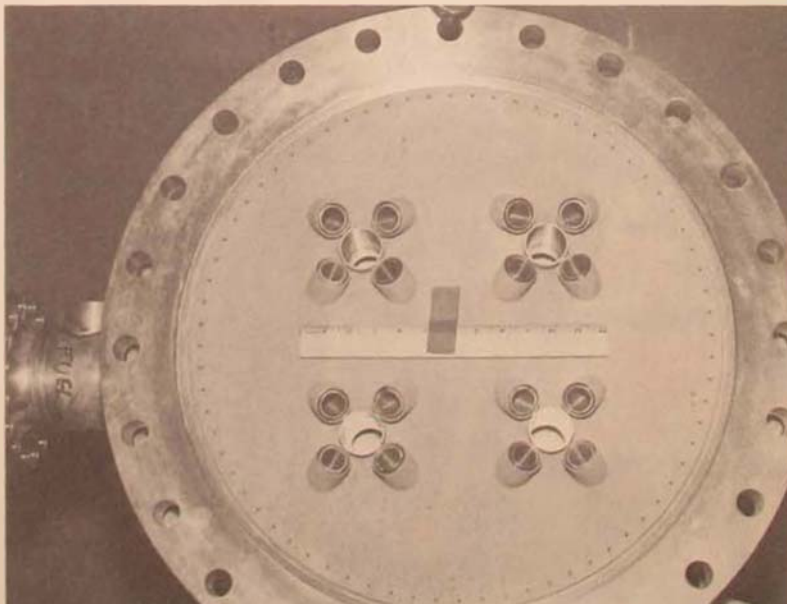


Figure 9. Single-element concentric pentad injector, 200K

Figure 10. Four-element concentric pentad injector, 200K



—Combustion stability, since no really successful injector scaling procedures have been established.

—The cost and time for fabrication of multiorifice injectors are extremely high because of tolerance requirements and the number of orifices, which in turn influence the scrappage rate of material.

—Transportation and handling problems are encountered with very large engines.

—The facility and testing costs for feasibility demonstration and development of large liquid-rocket engine components are high.

Another approach to attaining high thrust is to cluster the rocket engines as is done on the Saturn. The method being investigated in Project Scorpio is the cellular combustor concept of clustering proven, simplified, discrete, thrust-chamber modules around a common nozzle. This approach has several advantages:

—Combustion is stable, since the modules have been previously proven to perform satisfactorily.

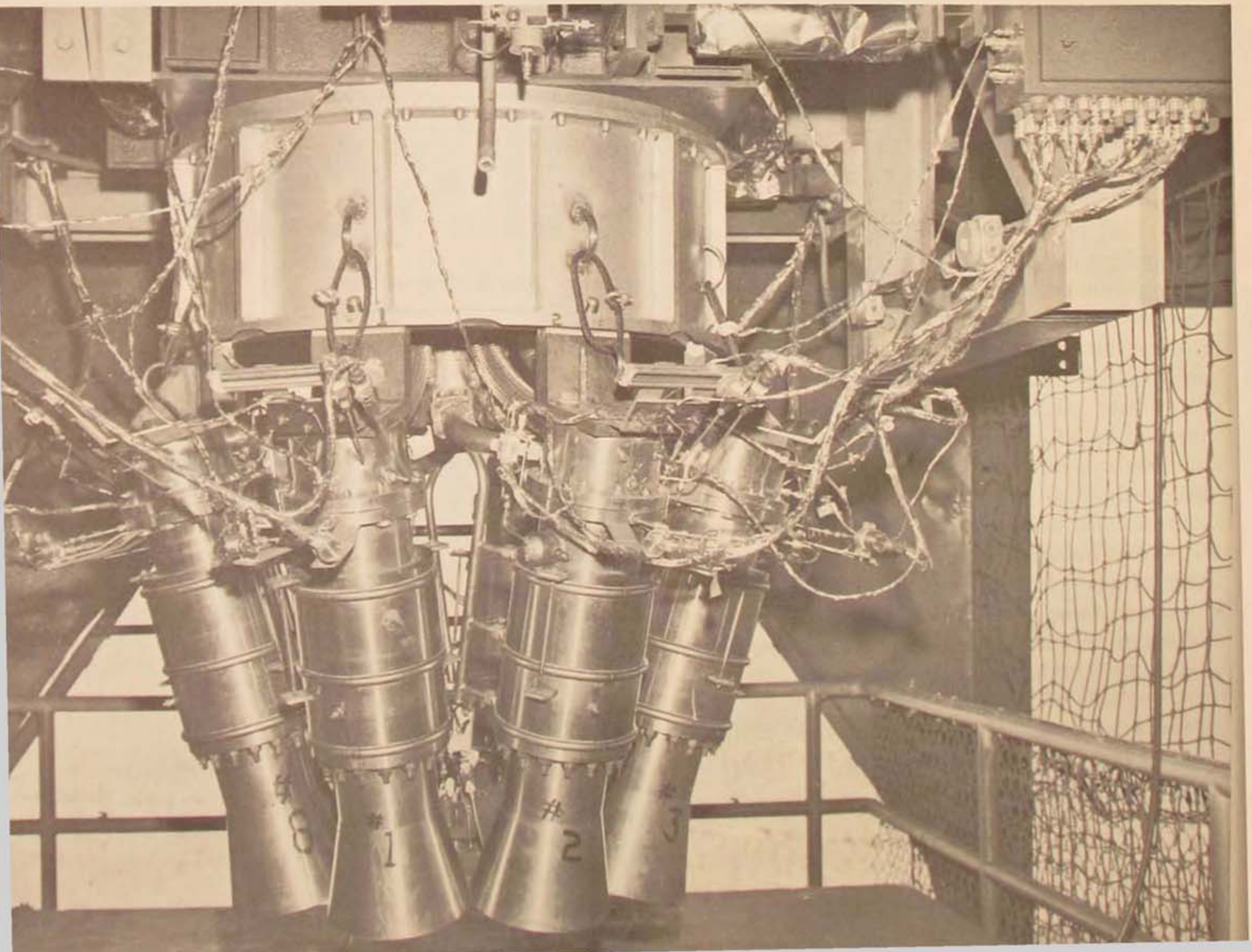
—Flexibility in thrust level is easily rendered by changing the number of modules.

—Segmented testing (partial cluster) in the early phases of feasibility demonstration reduces the cost of testing.

—Altitude-compensating nozzles—plug or forced deflection—can be utilized.

To demonstrate the simplified clustering technique, eight proven, high-performing, simplified injectors and film-cooled thrust chambers, each developing 25,000 pounds of thrust, are clustered around a common zero-length plug nozzle as shown in Figure 11. Only two propellant valves are utilized for the entire cluster; the propellants are transported to each injector through manifolds. The injector chosen has a coaxial pattern and transpiration-cooled face with film-cooling holes around the periphery. A film-cooled thrust chamber was de-

Figure 11. Cluster of eight 25K thrust chamber assemblies



signed to investigate further and obtain more data on this simplified cooling technique. The coolant (liquid hydrogen) is introduced into the thrust chamber at three stations along the chamber length. A passageway is provided from the manifolds to a series of small holes at each station, through which fuel is injected axially along the inside chamber wall. An orifice in each inlet to the manifolds is sized to regulate the amount of coolant supplied. The orifice sizes are determined by observing the temperature profile along the chamber wall by using quick-response high-temperature probes. A representative temperature profile is shown in Figure 12.

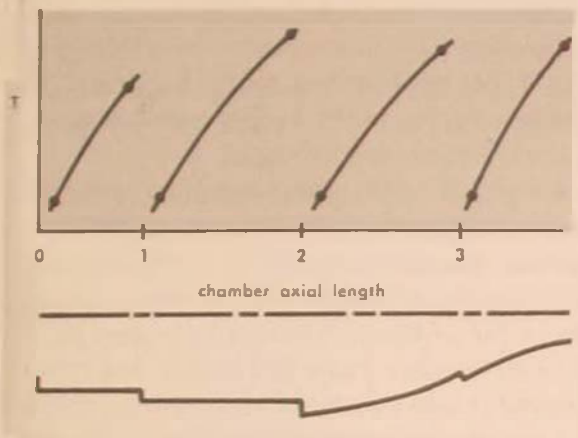


Figure 12. The chamber wall temperature increases with distance from one film coolant station to the next. A sudden drop in temperature occurs at the plane of coolant injection, and the temperature rises as the fuel is consumed along the way to the next point of injection. The objective is to supply sufficient coolant so that the maximum temperature reached is tolerable.

Single engine tests were conducted before the cluster firings commenced, to check out the injector/chamber combination and determine the coolant orifice sizes. In two early cluster firings, all eight chambers primed within 80 milliseconds of each other. Start and cutoff transients, which are primary items of investigation, were smooth. Other items of observation and study are chamber interaction and manifold priming times. The effect of exhaust gases reacting on the base-plate (plug nozzle) is observed by instrumenting the plate with pressure taps and temperature probes. One chamber will be pulsed to determine the effect of the disturbance on the whole cluster system. In addition, studies will be conducted to determine the effect of an "engine out."

Injector Water Flows. After the injectors are designed and fabricated, they are sent to the Hydrodynamics Laboratory to be water-flowed. Here the actual pressure-drops across the injector orifices are determined and compared with design values. The discharge coefficients are calculated from the data obtained and are compared with design assumptions. Also stream momenta are simulated to permit observation of the injector spray pattern and degree of mixing. Hot-spot areas on the thrust chamber wall can be predicted from the water flow tests.

Ignition System. A pyrotechnic system utilizing a solid-propellant charge is used to ignite the propellants. In actuality a small solid-rocket motor is used. (See Figure 13.) An initiator and pyrocore are used to start the grain burning. When igniter chamber pressure reaches half its steady state value, a signal is sent by means of a pressure switch to initiate the start sequence and open the propellant valves. The system is very positive, in that if

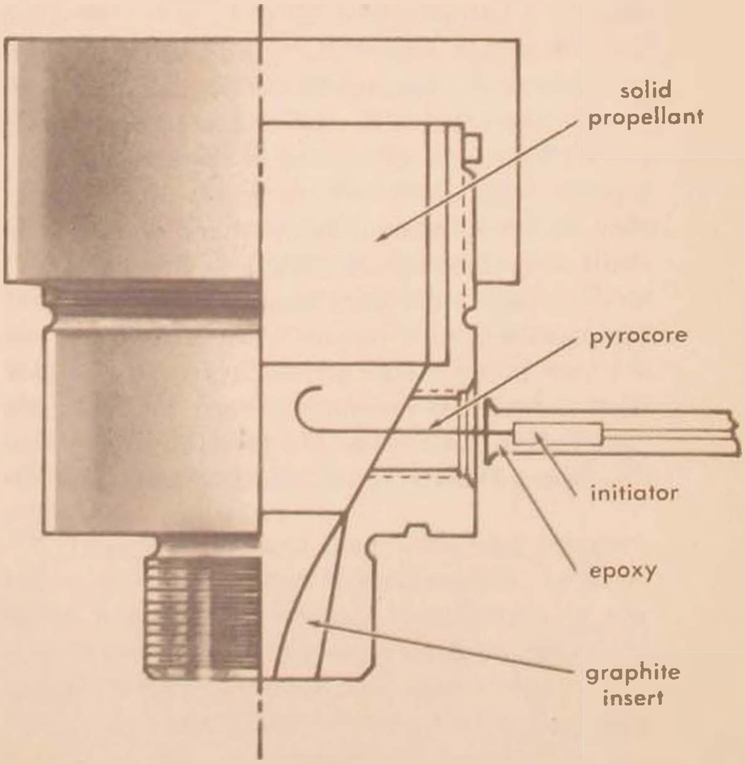


Figure 13. Igniter

igniter chamber pressure is not achieved, propellant flow will not commence.

Experimental Facility. Two firing positions, both capable of sustaining 200,000 pounds of thrust, are utilized to conduct the test portion of the project. One position is the standard vertical, and the other, unique to liquid-propellant test stands, is inverted. That is, the nozzle exhausts vertically upward. The main advantage of the inverted firing position is economy. For component testing, a pronounced cost reduction is realized in that (a) no flame deflector is required and hence no cooling water pumps, (b) the amount of superstructure required to restrain the engine's thrust is reduced, and (c) the placement of the test stand is not terrain limited. The 1100-gallon insulated liquid-oxygen tank is pressurized with gaseous nitrogen from two 300-cubic-foot, 6000-psig-rated pressure vessels. The 3400-gallon vacuum-jacketed liquid-hydrogen tank is pressurized with gaseous hydrogen from two other 300-cubic-foot, 6000-psig-rated pressure vessels. Electrical switch-over from one position to another, for valve actuation, can be accomplished in less than 20 minutes. Propellant flow is monitored by a volumetric flowmeter in each oxidizer and fuel feed system. Each side has a line bleed, which is used to chill down the system and ensure that good-quality liquid is available at the injector at the beginning of each firing. Ninety-five of the more than 185 test firings to date have been conducted in the inverted firing position, some of which have been with the single-element 200K injector. Ignition and shutoff transients were smooth, and analysis of data has shown no difference from data obtained with the same components fired vertically down. Prior to the use of either position after a modification, the propulsion systems are pressure-checked for leaks and cold-flowed to calibrate the pressure drop versus flow rate. With this information, tank pressure settings can be determined for different flow rates, mixture ratios, and chamber pressure desired.

OVER 185 test firings with LO_2/LH_2 have been conducted at thrust levels ranging from 20,000 to 200,000 pounds in both the vertical and inverted firing positions. Chamber pressure and mixture ratio have been varied over a wide range. As a result the following statements can be made:

1. It has been demonstrated that high performance (combustion efficiency) and stable combustion can be achieved with highly simplified, LTE injectors having a single element yielding 50,000 pounds of thrust.
2. Simulated liquid air/liquid hydrogen is readily ignitable and combustion-stable over a wide range of mixture ratios.
3. The feasibility of test-firing large liquid-rocket engine components inverted with cryogenic propellants has been demonstrated.
4. A simplified technique for clustering thrust-chamber assemblies has been demonstrated.
5. Information about injectors and film-cooling test results has been supplied to industry, so as to disseminate the experience gained in Project Scorpio and assist in other programs and studies.

Successful completion of the Cellular Combustion Chamber Program will result in a radically simplified injector-chamber combination and have the effect of

—reducing the cost and fabrication time of large liquid-rocket engine components

—increasing reliability through component simplicity

—increasing selectivity in thrust level through the use of the cellular chamber concept

—reducing the cost of static facilities for component testing with cryogenic propellants by utilization of the inverted or vertically upward firing position.

Rocket Propulsion Laboratory

Addenda

Two major reports on Project Scorpio have already been published:

Unique Injector Design and Chamber Cooling Techniques, by H. V. Main, 1/Lt D. George, 1/Lt D. Mitchell, 2/Lt K. Smith; LPIA, November 1962, LPS 62-1 (classified).

Simulated Liquid Air Combustion with Liquid Hydrogen in a Two Dimensional Thrust Chamber, by H. V. Main, 1/Lt K. Smith, 1/Lt D. Mitchell, 1/Lt D. George; May 1963, RTD-TDR-63-1041 (classified).

Reports are currently being written on the recently completed Task I and Task II efforts.

OUR DEVELOPMENT ENGINEERING CAPABILITY–AN INSIDE LOOK

Lieutenant Colonel Byron P. Spears

Nestled in the foothills of the Colorado Rocky Mountains at an industrial production and test facility, a small detachment of dedicated Air Force people is busily engaged in the acquisition of missiles and space boosters. This detachment, similar to the many Air Force plant representative offices (AFPRO) throughout the United States, is performing normal contract administration, quality assurance, production control, and management support functions. A new element has been added in the last four years, an Air Force engineering capability known simply as Development Engineering (DE). Today DE engineers are pioneering a new dimension in the Air Force procurement efforts, an analytic understanding of procured items designed to give the Air Force greater confidence.

To do this was an easy matter. It meant putting well-qualified engineers in proximity to exciting new engineering activities. The resultant enthusiasm and effort have provided greater confidence for the Air Force and have paid dividends in terms of reliable operation of equipment and excellent professional training for Air Force engineers in preparing them for future technological undertakings.

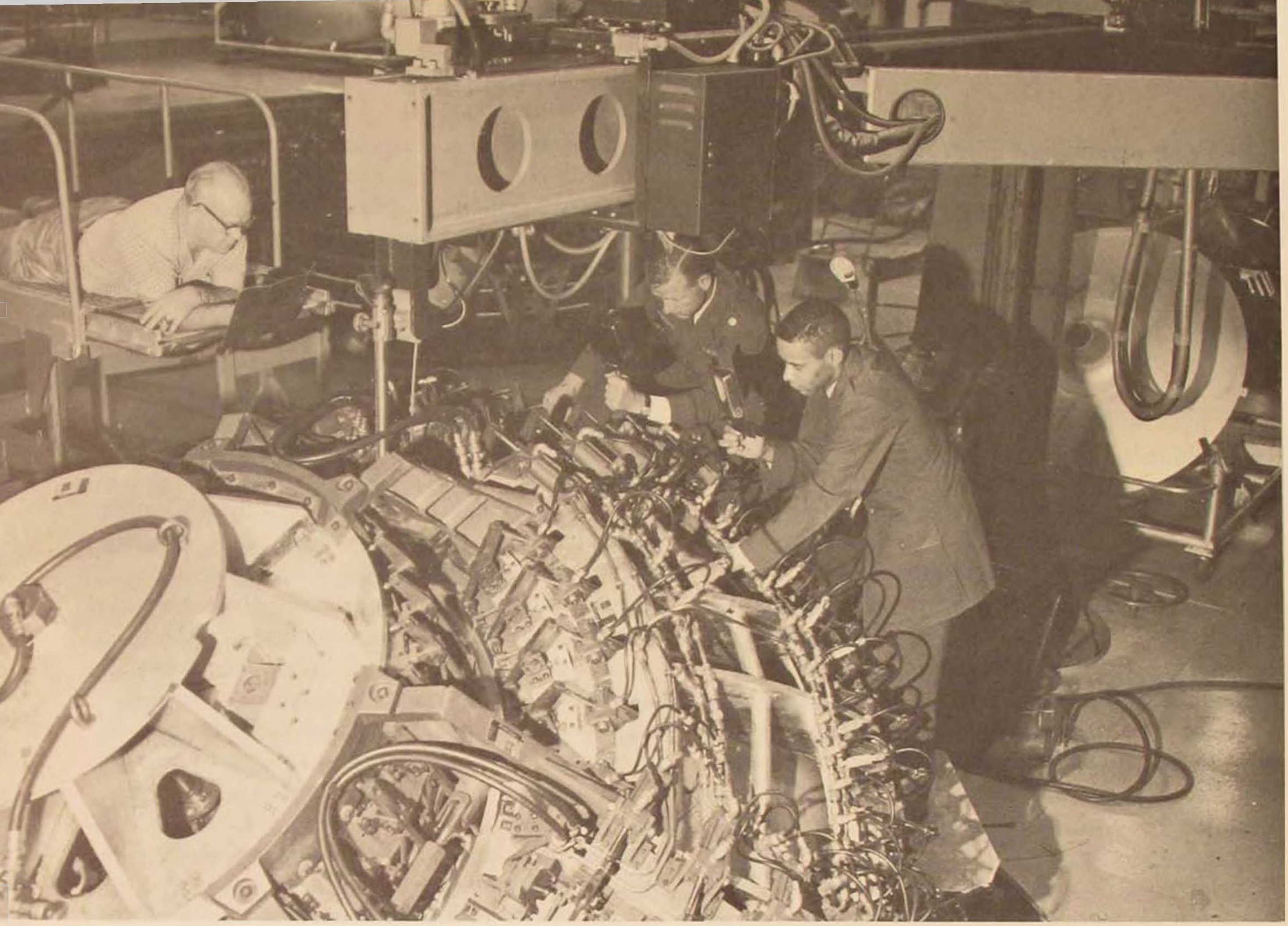
origin of DE

Prior to the establishment of an engineering capability in contract management organizations, engineers from system program offices (SPO) traveled to contractor plants throughout the entire nation to perform the same functions which DE engineers are now doing. The frequency of visits depended upon such things as contract requirements, complexity of the program, stage or phase of the program, etc. On such programs as the ICBM's, SPO engineers traveled to contractor plants every week, and in many instances they traveled twice a week to a single contractor plant. Normally these visits took place even though one or more engineers from the system program office were assigned in residence at various contractor plants.

Prior to 1961 the desirability of an engineering capability in the contract management organization was apparent to many people. Early in 1961 the commander of the Western Contract Management Region recognized this need as being urgent and expeditiously accomplished the many actions required preliminary to establishment of the Development Engineering divisions.

At the direction of the Air Force Systems Command, studies were completed in 1961 to provide an analysis of the need and appropriateness of establishing DE organizations. Following detailed studies of objectives, functions, and required manpower, the DE divisions became a reality in the latter part of 1961. At first they were manned primarily from the system program offices. The SPO engineers in residence at contractor plants were administratively transferred to the Air Force plant representative offices already there. These engineers naturally served as the nucleus of the newly formed DE elements. This method of manning materially assisted in developing a team concept of operation between the SPO's and the AFPRO's.

Implementation of the engineering representation in the contract administration activities better qualified the in-plant organization to provide responsiveness to system program offices. An important premise which was adhered to was that the contract administration organization would, so to speak, serve as an extension of the buying activities. The application of this system is in consonance with the proven principle of management which establishes the point of decision-making at the low-



DE engineers observe the automatic welding of Titan III space booster orange peels, which will compose a propellant tank dome. By meticulous study of procedures and equipment on the factory floor, DE engineers improve the factory scrappage rate.

est level where the information exists on which a decision can be based.

DE engineers established working relationships to exploit this principle, thereby enabling contractors to proceed with a minimum of delay and with a corresponding reduction in the flow of detailed paper work between contractors and buying activities.

typical duties of the Air Force DE

At any time of any day, one of these engineers may depart from the main plant to a test stand quite similar to a launch pad. Here the giant missiles and space vehicles do everything but fly. The engines fire in the exact sequence they will later repeat in space, and the innumerable signals and maneuvers planned for tomorrow's mission are exactly simulated. This dress rehearsal must be perfect before the curtain will be permitted to rise for an actual launch, and the DE engineer is in the blockhouse to make this final determination.

The barriers are closed on the road leading to the test stand, the blockhouse is locked, and the countdown continues: "T minus 30 and counting" . . . Although it is only the second firing on the captive stand, there is an air of calm. All crew members have been certified by the Stand Board, and as a team they have completed many dry runs and know precisely what to do and when to do it. This could end up being another dry run because the DE engineer has yet to sign the authorization to fire.

DE engineers meticulously check propellant loads, ullage pressures, propellant composition and temperature, and start-cartridge temperatures compared with required starting impulse. The crew then continues the predetermined functions of the countdown. The count and all systems prove perfect, and there is confidence that in a very few minutes the DE engineer will sign the authorization to conduct this critical test in the development of Titan III space boosters.

The DE engineer has been a crew member occupying various positions in more than two dozen ICBM development launches at the Air Force Eastern Test Range. He has since been placed in-plant as a member of the AFPRO contract management organization. The momentous decision to give the Air Force go-ahead for firing is his and his alone.

In the background at this critical moment, other members of the DE team are standing by to advise or work a specific problem. Both civilian and military electronic, mechanical, and aeronautical engineers with hardware and managerial experience compose the subsystem teams and are immediately available to provide assistance to the DE engineer on the test stand.

The erector is still up and the umbilicals are still engaged, since this is a captive firing instead of a launch; but one malfunction could result in a catastrophic loss of the test stand and its extensive instrumentation as well as the loss of a multimillion-dollar launch vehicle.

The flame deflector deluge controls will be actuated seconds before ignition, and a flood of water will flow over the blast plates, where the high-temperature exhaust flames will generate clouds of steam. All personnel have been cleared from the area to ensure safety. The deer still graze beside the drainage trenches, but at the first roar of the powerful engines they will hightail it to the safety of the nearby woods.

In another test facility less than a mile away, a second vehicle is being prepared by the contractor for delivery to the Air Force. Prior to delivery, the contractor must demonstrate the ability of the entire vehicle to function with its complex interface of intricate associated gear. The contractor is ready to start a test of the combined subsystems, in accordance with Air Force approved test pro-

DE civilian and military engineers evaluate data derived from a test of the combined systems of a space booster. Results of the analysis will determine if the space booster has met contract requirements and is ready for Air Force acceptance.

cedures, upon the DE engineer's approval. Upon completion of this combined systems test, data are collected, reduced, and reviewed by the contractor. A team of DE engineers reviews the data and decides whether they fulfill contract specifications. Should the data prove acceptable, the respective DE engineer will recommend to the system program office that the vehicle is ready for Air Force acceptance.

the system program office/DE interface

The system program office is established by Headquarters Air Force Systems Command and works under the direction of a system program director. Such an organization is normally located at a facility remote from the contractor's plant. However, the AFPRO is located at the contractor's plant and maintains the assigned engineering capability. This office works closely with the system program office, particularly in the conceptual and definition phases of a program. Working agreements are formulated and the system program office authorizes the DE division to perform specific functions related to design assurance testing, procedure changes, hardware changes, hardware acceptances, etc. The DE division performs functions which are mutually agreed upon between system program offices and respective DE divisions, in addition to those specified in Air Force Systems Command Manual 375-6. These additional functions are published in a Memorandum of Agreement signed by the system program director and the Air Force plant representative. (See sample Memorandum.)

responsibilities of the DE

Air Force Systems Command Manual 375-6 is a systems management publication which states DE responsibilities in definitive terms consistent with AFSC Regulation 23-39, which states DE functions in broad terms. Some of the 24 specific DE responsibilities stated in the manual are the following:

> Evaluate and monitor the contractor's engineering budget control system and compare budget with actual expenditures. Keep the System Program Offices/Buying Activities informed of progress through the Administrative Contracting Officer.
>
> Evaluate and monitor the development and establishment of the contractor's reliability program. Monitor the contractor's engineering activities concerning reliability.
>
> Evaluate engineering studies and proposals and make recommendations to the System Program Offices/Buying Activities.
>
> Provide analyses and recommendations to the System Program Offices/Buying Activities regarding design approaches and development schedules.
>
> Assist the System Program Offices/Buying Activities in the review and approval of test plans.
>
> Review and approve the contractor's test directives to assure compliance with System Program Offices/Buying Activities approved test plan.
>
> Provide local interpretation of the System Program Offices/Buying Activities approved test plan as authorized by the Memorandum of Agreement.
>
> Continually review and evaluate the contractor's engineering test activities for essentiality, adequacy, and effectiveness.
>
> Conduct or participate in investigations of test accidents or incidents.
>
> Review and evaluate the adequacy of the contractor's procedures for configuration management.
>
> Perform management surveillance of the contractor's engineering change system. Process and control Class I and Class II changes within the AFPRO. Evaluate and make recommendations to the System Program Offices/Buying Activities on the necessity for and engineering feasibility of Class I changes (ECP's). Review Class II changes for proper classification.
>
> Investigate conditions or equipment considered to be unsatisfactory from any engineering standpoint, ascertain contractor-planned action, provide recommendations to the System Program Offices/Buying Activities, and provide follow-up action.
>
> Evaluate and monitor the effectiveness of the contractor's value engineering program.

typical DE accomplishments

DE engineers' activities in the areas of developing, manufacturing, test conducting, etc., have yielded many invaluable accomplishments. Some specific instances during the development of Titan III may be of interest.

MEMORANDUM OF AGREEMENT 10 July 1964

Memorandum of Agreement for Development Engineering (RWRVE) and System Program Office

SPO: 624A
AFPRO: Martin Company, Denver, Colorado
SYSTEM: Titan III
CONTRACT: AF 04(695)-150

I. PURPOSE: The purpose of this document is to define the responsibilities of the Development Engineering (DE) Division of the AFPRO, Martin/Denver. This document supersedes the Memorandum of Agreement (App A) dated 8 February 1963.

II. SCOPE: This document is written in accordance with AFSCR 375-9 and defines the specific authorities and responsibilities to be performed by DE in support of the 624A Program. The authorities and responsibilities contained herein are in accord with the general terms of WCMRM 375-1.

III. EXPLANATION OF TERMS: Acceptance Test Procedures: Those procedures used by the contractor to demonstrate acceptance testing at the Martin/Denver plants and other locations.

IV. FUNCTIONS AND RESPONSIBILITIES:

A. Engineering Approval.

1. Review and approve, as determined necessary, the Martin Company's (MC) Change Operations Directives covering in-scope changes and scheduled for incorporation into deliverable and non-deliverable end items prior to baseline.

2. Review and approve changes to SSD-approved acceptance test procedures when such changes do not alter contract scope or contract price.

3. Review and approve contractor's test procedures as required by SSD-CR-63-86, paragraph 7 and SSD-CR-63-117, paragraph 1.0. Also review and approve as warranted, test procedures utilized in demonstrating proper incorporation of modifications into the core vehicle.

4. Review and approve Captive Test Directives for each vehicle firing at Denver Test Stand D-1. DE will issue the "Authorization to Fire" to the contractor upon the contractor's demonstration of complete readiness to fire. During the countdown and countup sequences of the captive firings DE will have a "no-go authority" over the contractor.

5. Review and approve Engineering Test Orders as necessary for control purposes or as specifically authorized by the SPO.

6. Review and approve all hardware changes in the T-III vehicle during VTF testing prior to acceptance.

7. Review and approve in conjunction with the HAT Recorder unprogrammed deviations presented by the Martin Company during the acceptance cycle.

B. Review and Evaluation

1. Review and evaluate the following: (a) Specification Change Notice Proposals to model specifications; (b) Interface Change Notice Proposals to interface specifications; (c) Engineering Change Proposals (ECP's); and (d) Program Plans (SSD-CR series) submitted under the contract. Comments on these items will be forwarded to the SPO as deemed necessary by DE or as requested by the SPO.

2. Review and evaluate all Acceptance Test Procedures and Acceptance Orders as they are generated by the contractor. Comments on each of these items will be forwarded to the SPO on a timely basis.

3. Provide support to the SPO for the function of hardware acceptance. Provide technical inputs to the SPO as warranted in this area. Chair the following functions when delegated to DE by the SPO: (a) First Article Configuration Inspection (FACI); (b) Hardware Acceptance Team (HAT); and (c) HAT Advisory Team.

4. Provide local support in the area of pack and ship. DE will attend pack and ship meetings to insure the completeness and integrity of the core vehicle prior to the shipment from Denver.

C. Management Surveillance

1. On a surveillance basis, witness and review contractor tests and test results to insure timely and efficient management by the contractor of his overall test program. Emphasis will be given to subsystem and system tests performed at the Vertical Test Facility and at D-1 (captive test stand).

2. Survey the contractor's methods and modification testing. Assure proper configuration of tooling.

D. Additional Responsibilities: DE will assume such other transitory engineering tasks as are mutually agreed to between the AFPRO and the SPO.

V. COMMUNICATIONS: In performing the above outlined functions, DE will seek the assistance of the SPO as deemed necessary. DE will also keep the SPO informed on all significant developments of the program.

VI. TERMS OF THIS AGREEMENT: This delegation will be written as necessary to add or delete specific responsibilities which may change during the program.

/s/ Byron P. Spears
BYRON P. SPEARS
LtColonel, USAF
Chief, Development Engineering

/s/ Otto C. Ledford
OTTO C. LEDFORD
Colonel, USAF
System Program Director
for 623A and 624A

In Manufacturing. On the factory floor a DE engineer observed several weld defects in the Titan III space booster propellant tanks. Further investigation of radiographic records and Material Review Board actions revealed that the number of weld discrepancies was increasing rather than decreasing as tank production progressed. Following a letter to the contractor from the Chief of the DE Division, a meeting was convened and several recommendations were made for improving the quality of welds. In less than two months the trend was reversed, the scrappage rate was reduced, and the contractor's Major Weld Department has since been presented a Zero Defects award. The scrappage of a single tank normally means a loss of $30 to $50 thousand.

In Value Engineering. The Department of Defense policy on Value Engineering was not properly filtering down to subcontractors. Consequently, Value Engineering change activity among subcontractors was practically nonexistent. Local DE divisions throughout the country sponsored seminars inviting contractors and subcontractors to attend. Nationally recognized speakers from both the Department of Defense and the Air Force Systems Command served as keynote speakers, to project Value Engineering policy and details pertaining to its implementation as well as to create interest.

In Accident Investigation. A missile translation rocket initiator accidentally fired on a test launch facility, indicating a hazardous condition probably existing at all Titan missile sites which could at any time result in a catastrophic accident. DE engineers worked with the respective contractors in planning, testing, and analyzing and arrived at a confirmed conclusion. A design change resulted, and a fix was quickly incorporated into the hardware to prevent the recurrence of such an accident.

In Electrical Problem Identification. The initial sequenced captive firing of the first two stages of the Titan III space booster was ready, pending the DE's authorization to fire. A data review team of DE engineers was reviewing data of a previous combined systems test, and close analysis revealed the existence of a ground power transient. Study of the entire power supply system revealed that a recurrence of this type of transient, at a time when the space booster internal power source was being used, would probably result in loss of control from the blockhouse. This in turn would result in a loss of shutdown capability and consequently possible loss of the space booster and test stand. Because of the extensive time required to isolate, identify, and correct such a problem, the contractor installed a straight wire auxiliary shutdown capability, and the test was conducted without delay.

In Flight Control System. While monitoring failure analysis reports of the Titan III flight control system, the DE engineer noted a number of failures of modules caused by poor welding of component leads. The contractor tightened the weld inspection requirements, but system failures continued to occur. When an unacceptable weld was found in the flight control computer in the first vehicle, the DE engineer contacted his counterpart at Aerospace Corporation and discussed the matter with him. The problem was then pointed out to the contractor as one requiring further investigation. The contractor first proposed replacing all modules made prior to the effective date of the tightened inspection. However, when the DE engineer pointed out that failure had occurred on modules made since that date and that a marginal weld had been induced to fail during temperature cycling in design assurance tests, the contractor agreed with his recommendation to schedule the first computer through a temperature cycle to verify its integrity. The DE engineer then discussed the broad problem of welding with the Titan III quality project manager. As a result of this conference and again on the recommendation of the DE engineer, all computers have been or will be subjected to temperature cycling as a part of the normal test sequence.

In Instrumentation. The contractor was authorized to use lightweight wire for the Titan III space booster to save weight. This lightweight wire was in the process of being developed by several companies but had not been used or proved for any large-scale program. During the fabrication and assembly of the first Titan III space booster, handling caused wire damage. It became apparent that the wire insulation was highly susceptible to abrasions and that corrective action was necessary. Abrasions cause loss of propellant compatibility and can impair the electrical characteristics of the wire. Through Material Review Board action, the DE engineer became familiar with the problem and promptly brought it to the attention of the contractor's management. Through his efforts, top management initiated a many-sided program which included (a) personnel indoctrination in handling and installation of lightweight wire, (b) optical examination of all wire after installation, and (c) use of propellant-compatible Teflon tape to repair outer-layer damage. It was determined that the susceptibility to damage was caused by the vendor's process of dyeing the outer layer of insulation. At the DE engineer's insistence, the contractor changed the procurement specification to require that a sample from each lot of wire pass a stringent abrasion test. The DE engineer was also involved in developing a repair technique for damaged wire. The wire repaired in this manner has better electrical characteristics than the original wire. His actions have eliminated the lightweight wire problem on Titan III space boosters.

In Identification of Moistureproofing Problems. A DE engineer was assigned as the engineer in charge of the AFPRO effort at the contractor's Vertical Test Facility. In this capacity he coordinates the efforts of the system engineers, represents the DE Division in meetings and conferences, and takes charge of engineering matters pertaining specifically to the facility. During the performance of the single-point-to-ground acceptance test on the vehicle, the DE engineer observed that the Hysol-Butyl moistureproof coating had not been applied to the electrical terminal boards. Upon investigation, he determined that the contractor normally withheld the moistureproofing until just prior to shipment of the vehicle in order to permit ease of disconnecting and reconnecting terminal lugs. The discrepancy pointed out by the DE engineer was that no check of the internal resistance of the wire was made after moistureproofing—an oversight which undermined the confidence ascribed to the single-point-to-ground test. Lack of complete Hysol coverage can provide an electrical leakage path between terminals through the graphite-impregnated Butyl. The DE engineer recommended to the contractor's engineers that a retest of single-point-to-ground wiring be performed after moistureproofing to ensure its integrity. The contractor then published a directive specifying that an electrical leakage test be performed after moistureproofing is applied.

THE MOST valuable contribution that the DE divisions make is in the early stages of a program. The technical adequacy of the design of an item of hardware bears directly upon its capability to perform its intended function with a minimum number of design changes and consequently the lowest possible additional costs. It is not within the capability of DE divisions to analyze all component or subsystem drawings, but analyses of a few critical drawings can result in tremendous benefits to a program. Drawing discrepancies and design inadequacies can be pointed out to the contractor's program manager, who in turn can use this as a management tool in improving the quality of work by his engineers. On the Titan III space booster program this effort proved to be of material benefit, as evidenced in a statement made by W. G. Purdy, General Manager, Launch Vehicles, Martin Company (Denver Division): "The Air Force engineers' evaluations of our engineering drawings have had an electrifying effect toward improving the quality of our people's work."

DE engineers participate not only through the design and development phases of a program but also throughout production, inspection by the Material Review Board, acceptance testing and acceptance, modification, and pack and ship activities. Because of their knowledge of systems and subsystems, these DE engineers are invariably called upon to assist during preparation for launch and the evaluation of data after launch.

Although the DE program has been in existence less than four years, the basic objectives have been achieved, as indicated by Lieutenant Colonel Floyd W. Kniss, Deputy Director for System Development, Program 624A/624B: "We wouldn't be able to conduct the Titan III-X program with our present manning if it weren't for the tremendous contribution the AFPRO engineers are making."

The usefulness of the development engineering element in contract management organizations has been proved, and there is no longer any doubt that its origination was essential. It is fulfilling the basic objectives set for it in Air Force Systems Command Manual 375-1, which summarizes these objectives as to—

Provide engineering support to the System Program Offices/Buying Activities.

Make in-plant engineering evaluation.

Reduce total decision-making time.

Provide engineering assistance to the AFPRO Commander and his staff elements.

Perform in-plant engineering management surveillance.

Integrate more closely the Air Force/Industry team efforts.

The development engineering story is just beginning. It is anticipated that our dynamic new Air Force engineering capability will continue as a vital arm of the system acquisition teams. Even greater benefits are expected in terms of confidence, responsiveness, and monetary savings.

AFPRO, Martin Company, Denver

Books and Ideas

ROUGH WEATHER OVER THE NORTH ATLANTIC ALLIANCE

BRIGADIER GENERAL NOEL F. PARRISH, USAF (Ret)

AMERICAN veterans of NATO service in the Fifties may recall an incident of the Suez crisis. Our principal allies, Great Britain and France, had just made a secretly planned and, as it turned out, a very ill-advised attack on Egypt. General Alfred Gruenther, one of the great commanders of NATO forces, called a hurried meeting of Americans who were in his headquarters. After shaking his head sadly, he gave this advice: "Try to understand why they did it. We have to understand. We are still their allies and they are ours."

Placing his hand on a map of Europe, General Gruenther continued: "The freedom of this area is essential to our own survival. This key area in the center, where we are now, happens to be France. Regardless of who lives here—whether Eskimo, Chinese or French—their cooperation is indispensable to us, as ours is to them. Western Europe can only be defended with their help. You do not have to approve of them. You do not even have to like them. But it will be easier, on you, if you do."

This was the kind of advice and the kind of leadership that made the Nineteen-fifties the most successful period of American influence in Europe. In his new book, *The Troubled Partnership*,† Professor Henry Kissinger explains that our remarkable achievement during the Fifties has enabled the Atlantic Alliance to absorb our blunders of the early Sixties, but he warns that there is a limit. He sees our diplomacy of the Fifties as appropriate for the circumstances, and he argues

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†**Henry A. Kissinger, *The Troubled Partnership: A Reappraisal of the Atlantic Alliance* (New York: McGraw-Hill, for the Council on Foreign Relations, 1965, $5.95), 266 pp.**

that our "pre-emptory" demands of recent years must either be softened or abandoned.

Although he is writing principally about strategy, Professor Kissinger quotes no military men. He is writing about the Nineteen-sixties—a period of military silence. His book is well studded with quotes from diplomats, statesmen, and civilian representatives of the Department of Defense. These statements are not a cause for jealousy, especially in the context of their unfortunate impact and consequences as analyzed by Professor Kissinger. In *The Troubled Partnership*, those who made the fewest pronouncements have the best record.

Professor Kissinger's basic method is a simple one. He quotes what was claimed or proposed on each issue and goes on to relate what actually happened. He repeats what we have demanded in Europe and how we demanded it, along with his list of what we have not been granted. Discrepancies between the bugle calls and the direction of march are thus made apparent. So well-organized is his presentation that no elaborate explanations are needed. No very close examination of the record is required to discover that our trumpet was indeed uncertain.

Our European troubles of the Sixties, so it would seem, were compounded by high-level jugglings of words and figures, by "an erratic quest for ever more refined formulas." These formulas were derived from abstract "models" of reality and from finely spun calculations. Each problem was "solved" separately, and each solution was presented as final. A prime example was our sudden cancellation of the Skybolt missile, which wrecked a program that had cost the British some $10 billion.

This cancellation caused a crisis in Britain that threatened to bring down a government. The Nassau Conference was an attempt to patch up the damage we had done. The imminent result was the ambiguous Nassau Agreement, which forswore independence for Britain's nuclear forces except in certain undefined circumstances and officially launched the concept of a "NATO multilateral force." The British immediately assumed this to mean only the assignment of national nuclear forces to NATO, while U.S. officials insisted it meant a commitment to the old idea of a mixed-manned fleet.

In a most surprising maneuver, the agreement arbitrarily reversed the famous "sword and shield" principle of NATO strategy which had been the basis of NATO planning and deployment for ten years. Without consulting the other allies, and therefore without justification, the Nassau draftsmen claimed that the nuclear "sword" had somehow become a "shield"; the thin line of NATO conventional forces, never intended for anything but defense, suddenly became a "sword." Such verbal tricks cannot change reality. They serve only to confuse and disturb.

President de Gaulle was especially disturbed, and with reason. Although he was a member of the NATO "Big Three," he had not even been consulted about the "private agreement" at Nassau which aspired to overturn NATO strategy. He learned of the mysterious outcome, on which the participants could not agree, after it was released to the press. He could not help noting that the proposed multilateral force would have left France out of the nuclear picture for years and would have left her forever dependent upon American weapons. The embarrassment caused to the British government by the abrupt cancellation of Skybolt was in itself an argument against such dependence.

In Professor Kissinger's view the Nassau Agreement "exacerbated an already difficult situation" and encouraged President de Gaulle to veto Britain's entry into the Common Market at the same press conference in which he rejected the multilateral force proposal. The Franco-German Treaty of Collaboration followed within two weeks. To all this "the first United States reaction was stunned outrage . . . followed by a deliberate policy of wooing the Federal Republic away from its French ties . . . giving the impression of a special United States–German relationship. . . . Finally another change of course restored more balance to our European policy. By then, however, many German leaders had staked their careers on following our lead and found themselves in an extremely exposed position."

Thus did the cancellation of Skybolt, which had been advertised as a great saving and as based on a careful weighing of all considerations, surprise and shock our strongest ally. In Professor Kissinger's reconstruction of events, efforts to minimize this damage produced the bewildering conflict of terminology and concepts that came out of Nassau. The entire process caused unpremeditated but serious difficulties for our three principal allies. Yet Skybolt, it should be noted, was in itself a relatively minor issue.

Professor Kissinger makes it clear that neither we nor the Europeans created the basic difficulties that face the Alliance today. The unresolved problem of German reunification, for instance, was created by the Russians, and they are not likely to permit its solution. The vulnerability of West Berlin is another sore point which can be eliminated only with the unlikely cooperation of the Russians. The control of atomic weapons is yet another problem which will remain difficult as long as these weapons exist. The Common Market, with or without England, will create serious economic problems for the United States despite our friendly admonition that it should be "outward-looking." The loss of world interest and responsibility by European nations that have given up their colonial ties, often at our urging, is another inescapable fact.

The existence of these stresses and difficulties in Europe called for caution and patience in the early Sixties rather than new demands and pressures. Often much trouble arose, as in the case of Skybolt, from the combination of our policies and projects when the friction arising from just one of them might have been absorbed. Our stepped-up agitation for the "great conventional buildup," for instance, might have been received with the same tolerant procrastination as in the early Fifties had we not at the same time expressed a new hostility toward national atomic forces (other than our own). Europeans could scarcely believe that we had not related these ideas.

"The American attempt to strengthen conventional forces," says Professor Kissinger, "brought to the fore the issue of nuclear control, which for many Europeans had always been the crux of the matter." His explanation of the importance of our conventional forces in Europe, and of European interest in keeping them there, may disillusion some of Professor Kissinger's readers. He was once considered a prophet of the renaissance of conventional war. Whatever may have been his past views —and he has admitted helping to reinflate the conventional boom after its deflation in Korea—Professor Kissinger is habitually candid with facts. After all, there must be an explanation of why "United States proposals for strengthening conventional forces have been treated with the same panic as later hints that some American troops might be withdrawn."

The explanation in *The Troubled Partnership* is unequivocal: "Most Europeans do not want to give conventional forces a larger role because they fear that it will diminish the effectiveness of the nuclear deterrent. But they also have resisted a reduction of United States forces because they believe these represent the surest guarantee of American nuclear protection." The "pre-emptory way in which the United States proceeded with its demands" did not stop with our new conventional requirements. It was evident also in our attempt to stop France's nuclear program and in our restricting the British nuclear force. What combination of moves could have been better calculated to promote suspicion that we are losing our nuclear nerve?

Many American military men have long been deeply concerned lest our conventional ground forces be reduced. Their enthusiasm for a conventional buildup in Europe is understandable. Logically, the concentration of our forces there should either be considerably increased, along with European forces, or decreased to some extent. One division should be as valid a hostage as four. According to Professor Kissinger, "the European refusal to assign a meaningful military mission to conventional forces in Europe is incompatible with the retention of large United States forces there."

Questions which have been asked repeatedly in Europe over the past seven years, and virtually ignored in the United States, are reported without distortion in *The Troubled Partnership*. "Our Allies ask why, if the reliance on nuclear deterrence remained unimpaired, conventional forces had to be strengthened?" Even if NATO, with greatly augmented conventional forces, could halt a Soviet invasion, what would happen then? "What if at that point the Soviets offered to negotiate after having gained possession of their prize?" (In Europe this has been called the "Hamburg gambit.") Professor Kissinger reports the big and unanswered question: "If nuclear war is too risky for the West at the start of the conflict why should it not be even more risky when the local issue has in effect already been decided . . . ?"

In summarizing the results of our most recent and most expensive campaign to produce more divisions in Europe, Professor Kissinger says: "The issue of conventional defense has been muted since early in 1964 because the United States has apparently had second thoughts. But it lasted long enough to make the issue of nuclear control one of the central unresolved problems of the Alliance." Nuclear control is now an issue with regard to our own "tactical" weapons in Europe as well as those of the French, the British, and the long-discussed "jointly owned" ones which appear to have been lost at sea.

We are reminded in *The Troubled Partnership* that more than one spokesman of our Department of Defense "rejected the notion of tactical nuclear war" even as tactical nuclear weapons were being deployed in greater numbers. No one has stated, and our allies do not understand, just what is the mission of these tactical nuclear weapons in Europe. "This has raised the question," says Professor Kissinger, "about which is a better key to United States intentions: the pronouncements of our highest defense officials or the disposition of our forces." Evidently the pronouncements are not taken seriously by anyone. Our European allies see this force as a token of our nuclear commitment there, and we have solemnly promised to maintain it. Since the Soviet army has these weapons, we have no option, and we may not have the final choice as to whether they will be used.

Our deployment of nuclear and conventional forces has been as mixed as our doctrine regarding their use. This fact makes our tactical nuclear forces as vulnerable as our conventional forces and necessitates their immediate use in war if they are to be used at all. Because of this, Professor Kissinger recommends a separation of the two kinds of weaponry, with nuclear forces increasingly specialized, concealed, and mobile. General Norstad was working toward this end several years ago, and recently Brigadier General Bob Richardson has advanced definite proposals of this nature. It remains to be seen whether the pen is mightier when no sword is attached.

Since we have "proliferated" our own nuclear weapons over various seas and shores and have boasted of our ability to control them, Professor Kissinger feels we are in a poor position to tell the British and French they cannot be trusted to control their own tiny and concentrated arsenals. It should be remembered that Professor Kissinger was bold enough to express this view when the opposite opinion was as popular as it was futile. The French nation and its stubborn president were being subjected to a flood of criticism, both official and unofficial, with an effect opposite to that intended. Professor Kissinger recalls that "United States policy, which had been tolerant of the nuclear programs of its Allies, grew increasingly hostile from 1961 onward. The French nuclear program was described as irrelevant and harmful to the Alliance . . . We might ask ourselves how an American administration would respond if an allied government publicly and repeatedly insisted that one of our major programs was 'divisive,' 'dangerous,' and 'useless.' "

The discrimination against France had begun years earlier when France was refused the nuclear assistance which had been extended to Britain. Just what has motivated the virulent campaign against the French force since 1961 Professor Kissinger does not attempt to explain.

Anyone who knew France was well aware that the attack by American officials would practically force the French government, in bitter defiance, to complete its nuclear program. Arguments in favor of allied nuclear forces were seldom repeated here. Professor Kissinger insists our European nuclear allies "are convinced that several centers of decision will complicate an aggressor's calculations and thus enhance deterrence." He calculates that the British and French nuclear forces are as great a counterthreat against the Soviets as that nation's forces were against us at the time of the Korean War. Finally, there is no evidence that China was in any way influenced by the British or French programs, or that any other nation was so influenced, except negatively. Other members of the British Commonwealth would feel a greater need for the nuclear weapon should Britain abandon it.

The long campaign to suppress the new "Force de Dissuasion" has now ended in complete failure. The effects of the campaign, and of the manner in which it was conducted, will linger for many more years. Its harmful impact upon more positive efforts was as serious as the loss of American prestige suffered through its defeat. Our anti-nuclear campaign, which became anti-French, anti-De Gaulle, and almost anti-European, helped to doom our own proposal for an increase in conventional forces. In addition our "flexible response" (counter-force) policy was degraded into a minor debating point when it was first announced as part of an argument against the French force. Credit which should have devolved upon Defense Department leaders for this desirable development of optional targeting was thus irretrievably lost.

There was one "monumental" product of our hostility to national nuclear forces, although it never appeared in any of its various forms. That old sea chestnut the multilateral force (MLF) was finally floated, in theory, shortly after the Nassau Agreement failed to win acclaim in Europe. First rejected when it was proposed as a fleet of mixed-crewed Polaris submarines, this plan was finally brought to the surface. Had it ever come into being, it would surely have been the most confused and confusing military structure ever to spring, nuclear armed, from a nonmilitary brain. Professor Kissinger's carefully balanced account of "the checkered career of MLF" explains that the force was intended to solve a real and serious problem, but he records that "just six weeks after our highest officials had declared the MLF militarily unnecessary," it was "resurrected and pushed with increasing passion." Alastair Buchan is quoted in the observation that the MLF proponents engaged in "a public relations campaign to gain official, political and academic support, of an energy and ruthlessness unknown since Harriet Beecher Stowe. . ."

In each of its forms, the MLF unfortunately retained its two fatal flaws. Most obvious was the mixed-crew provision which was intended to prevent "withdrawal" of units of the fleet, with no recognition that withdrawal of key elements of the crews would be more disastrous to its functioning. There was the further misunderstanding of military and especially of naval requirements. Objections by naval persons were muted in this country, but in Europe the entire idea was received with good-humored disbelief. As one NATO admiral put it: "At sea, the captain even of a tramp steamer is a king who is unconcerned with the nationality of his subjects." Professor Kissinger, however, is concerned principally with the basic contradiction of the entire concept as described by its proponents. Dr. Robert Bowie, its recognized brainfather, has pictured MLF as independent of American control or veto, while our official salesmen have stated the opposite. Obviously, as long as we control the warheads, the expensive project has no special value for Europeans.

More concisely than other critics, Professor Kissinger points out that a globally dispersed atomic force to be triggered by some kind of majority vote in NATO would be more uncertain in every respect than the tightly controlled national forces for which Britain and France accept individual responsibility. He further explains that "the MLF was ridiculed by many when it first appeared, doubtfully received even under American pressure, perhaps accepted, except in Bonn, with the hope that it would never come to pass. . . ." The pressure was unrelenting, for as late as September 1964 the United States representative to NATO was saying: "As goes this fleet may go the defense of the West and our efforts to prevent war." American prestige was heavily committed and heavily compromised until there occurred what Professor Kissinger calls "the wise, if abrupt decision of President Johnson to reduce the pressure. . . ."

For the future, Professor Kissinger recommends we admit that MLF was a mistake and base NATO strategy on the existing nuclear forces. He points out that President de Gaulle has agreed to coordinate targeting and that there remains a need for a nuclear force under NATO command. The place to resolve problems of national sovereignty in an alliance is its political headquarters, not in a submarine or a ship at sea. Professor Kissinger's study has now been supplemented by a recent edition of the magazine *Paris Match*. The French bomb of 60 kilotons is pictured in color along with the neat and SAC-like headquarters at Taverny. There is a description of safety and control procedures no less ingenious than our own, designed to prevent any possibility of "l'impensable aventure cinématographique du Dr. Folamour" [the unthinkable movie adventure of Dr. Strangelove].

While his exposition of history since 1960 is all but flawless, one of Professor Kissinger's key references to the period of the Fifties deserves at least a quibble. He states that "in 1957 the United States submitted to NATO what came to be known as the Radford plan—initially to the dismay of the Europeans." He says that under this new plan "the defense of NATO should depend on nuclear weapons. Any attack on Europe would involve general nuclear war." Actually, the defense of Western Europe had been dependent upon nuclear weapons from the beginning. No attempt to build conventional forces to equality with "hordes of easily mobilized Soviet manpower" was ever made. The first proposal to design and deploy NATO forces specifically in accordance with our plans for a general nuclear attack was brought to Washington by the British Chiefs of Staff as early as 1953. Within months General Gruenther at SHAPE was announcing candidly that the defense of NATO depended on our use of nuclear weapons "whether the Russians use them or not." Even so, Professor Kissinger's account is more accurate than most. It is a common misconception that reliance on nuclear weapons developed some five years later than was actually the case.

This point is worth mentioning only because the "innovations" of 1961 are generally presented as having no precedent. The length and scope of *The Troubled Partnership* do not permit a correction of this misapprehension, but its excellent coverage of the early Sixties points up the fact that nothing similar has been written for the preceding decade. Surely an equally pointed account of the failure of General Ridgway and others to stir up enthusiasm for a great conventional buildup ten years earlier would have discouraged a repetition of the effort. A general account of continued American pressures for more conventional forces throughout the Fifties would have indicated that the subject was a sore one. A well-told history of the British and French nuclear programs through the Fifties should have indicated that the issue was already settled and that it was deeper than any personalities involved. A simple account of how and why all the NATO governments shifted to an "atomic" strategy in 1953 despite American warnings that the decision was irreversible would have corrected the popular misconception of that event. A sound and critical history of these issues might have eliminated some of the naive assumptions behind the costly failures of the early Sixties.

Another regret is that someone like Professor Kissinger did not publish a study of the "Bowie Report" to Secretary of State Herter near the end of the last Eisenhower administration. This lengthy and historic document demanded a conventional buildup to 30 divisions, the suppression of the national nuclear forces of our allies, the "multilateral force" with its mixed crews and equally mixed financing and control, and more pressure on our allies to subsidize their lost colonies. All these and other important projects and policies which were "developed" in 1961 are in this report, often down to the last phrase and figure. An early analysis of these prophetic and influential visions would have been more useful than a postmortem on their failure as policies. To say that there should have been more and earlier studies like *The Troubled Partnership* is only to praise it.

Since Professor Kissinger ranks among the boldest and the most accurate commentators on international affairs, his concern for the sensitivity of his colleagues is understandable. Only a very sensitive individual with delusions of infallibility (and there are some) could take personal umbrage at Professor Kissinger's impersonal analysis. He has tried to guard against this by apologizing in advance, merely for his disagreement. In his preface is the statement: "I have been more detailed in my criticisms of American attitudes or policies . . . This is not because I believe we are primarily to blame for existing difficulties." Regardless of blame, ". . . our acts have greater consequences, for good or ill . . . I have stressed the changes in our policies and attitudes which seem necessary. . . ." Thus Professor Kissinger accepts, as must all good Americans, responsibility for the mistakes of our officials which we failed to prevent, even as we all must suffer from such mistakes.

In some cases it was not originally an official who formulated and inspired the ill-advised efforts; it was one or another of Professor Kissinger's own academic colleagues. He is at pains to apologize to those individuals who should be happy enough just to remain anonymous, however much they may have enjoyed their reputations for influence in high places while their brainchildren seemed to have some hope of success. In behalf of these presumably disgruntled men, Professor Kissinger says graciously: "In recent years, the subject of Atlantic relationships has produced strong passions. To my regret, I find myself in disagreement with some men, including colleagues, whose views I respect very much. . . . I have tried to sum up their views fairly. . . ." In this he has succeeded beyond reproach. His attitude is neither bitter nor indignant. He never strikes at those with whom he disagrees; he merely dissects their publicly stated positions. Sometimes no dissection is necessary; merely to assemble a few selected statements is sufficient.

Indeed, Professor Kissinger does not attack people at all. He disapproves only of statements, proposals, policies. If some prominent or proud official is inescapably identified with a statement that proved foolish, a proposal that backfired, or a policy that miserably failed, his name must, of course, appear; but little else is said about him. Problems of personality, prejudice, and emotion are left by Professor Kissinger to the journalists who must present a more personal drama for a wider audience. His hands are never stained, for he wears always the resistant gloves of impersonal objectivity. This habit saved Professor Kissinger from ostracism and retaliation during the easy-going governmental atmosphere of the tolerant Fifties. His friends will be interested to learn whether doors are closed against him and strictures placed upon him as a result of this new assessment of how and why our most important alliance is troubled.

In more than one respect Professor Kissinger is less vulnerable than are most critics of high policy who must live in those circles where policy is made. He has not achieved the Olympian stature of Lippmann or Reston, but he does not need the clouds as protection. Since he is no journalist, he is not dependent upon "most-favored-reporter" treatment in the Pentagon and elsewhere for those day-to-day personal contacts so essential to every top-level journalist's livelihood. Since he was wise enough not to abandon his ideal academic seat at Harvard for assignment as "counselor" or "consultant" in Washington, he cannot be charged with disloyalty or banished as an ingrate. In addition, his command of languages (including English), his well-established European as well as American relationships, and his unassailable academic status in a civil-military contact point at Harvard assure him of continued access to facts and judgments which are not readily available in print.

Consideration of these circumstances is important because we need to know why informed and outspoken critics such as Professor Kissinger are so scarce. *The Troubled Partnership* is more than unusual; it is unique. Basically, it is a brilliant work of contemporary history, which is undoubtedly one of the rarest and most difficult forms of literature. It should have a sequel, published in annual installments. Five more years is longer than we can afford to wait.

Houston, Texas

ONE MAN'S OPINION OF WAR IN EUROPE

Brigadier General E. Vandevanter, Jr., usaf (Ret)
Consultant to the rand Corporation

The HISTORICAL experience of the nuclear age, though far from conclusive, serves to make us mindful of the fact that hostilities can develop in unforeseen ways. Furthermore, the diversity of strategic views, each held strongly by one school of thought, makes it clear that, no matter what develops, a great many people are bound to be wrong in their prognostications.

In one sense, this diffusion of opinion can be wholesome; it prevents us from adopting inflexible doctrinal views and putting all our eggs in one conceptual basket. It also magnifies the problems of the operator. Military commanders have to be prepared to fight under a number of conditions (and possibly to switch as well as fight).

The European Theater has always presented a particularly acute problem for the Air Force planner. Of the three services, Air Force doctrine has placed most emphasis on nuclear weapons. At the same time, an Air Force thinker is more likely to appreciate the vulnerability of the nato forces in a nuclear war—particularly in the face of an enemy surprise attack. In the zi we long ago grasped the overriding importance of maintaining a survivable force, and, at no little expense, we added a strong second-strike feature to our strategic posture. In Europe, no such alternative is available. Active air defense, hardening, dispersal, zero-launch, mobility — measures which might be worthwhile in the Western Hemisphere —seem futile in the face of the Soviet short-range nuclear threat. Only a highly efficient alert system for nuclear delivery forces—which has been instituted—seems to offer a margin of protection commensurate with its cost.

For a conventional war, on the other hand, much could and should be done in Europe to prepare air forces for what would probably again be a dominant role. With iron bombs, thousands of sorties would be required. Expensive offensive missiles with limited warhead yield, usable only once, would probably be uneconomical. Hence, logistical and tactical arrangements for large-scale aircraft operations should be worked out. Simple passive defense measures (such as dispersal sites and revetments) would be worth their cost. Active air defense would again offer a payoff.

But the numerous things that can be done to prepare for conventional war still add up to a sizable bill. Many of them would contribute little or nothing to an ability to fight a nuclear war. Hence, the problem of the military planner gets no simpler. He still has to allocate scarce resources among a variety of tasks.

How does the military planner in peacetime solve the allocation problem? He cannot do everything. He must consider the uncertainties, translate them into relative probabilities, weigh the options, and make certain hard decisions. Some projects would obviously take precedence over others. Thus we know that when the planners decide, as they recently did, to install a nato Air Defense Ground Environment (nadge) system, to cost some $310 million, they are thinking seriously of conventional war. nadge will be an advanced model of the American sage-type system, with only incidental applicability to nuclear war. We must assume, therefore, that many other conventional war defense measures, with better cost-effectiveness ratios, have already been instituted.

If serious consideration is being given to fighting conventional war in Europe, what form do we visualize it will take? Will it be a replay of World War II, or will it follow some new and different pattern? The picture in the planner's mind will condition his system of priorities for the all-too-numerous jobs to be done.

There are many techniques and tools available today to help calculate cost and effectiveness. But many decisions must be based on personal evaluations and intuition. Often the commander must make decisions based on impressions gained from experience, war games, surveys, historical analyses, and discussions. Gathering the type of background material needed for these evaluations should be part of an officer's day-to-day education. In short, we need to talk, write, and read more about the concepts, tactics, techniques, and constraints of conventional war in the nuclear age.

Unfortunately, I must get down to the business of this review by reporting that Dr. Heilbrunn's book† will provide little assistance to the Air Force planner; the author's coverage of air activities can most charitably be described as "meager." Nowhere does he attempt to visualize the tactical air campaign. Counter-air operations are not mentioned. I found two isolated references to interdiction (p. 77 and p. 107), both of which implied that defensive missiles would make the task impossible. Instead of considering how offensive air forces might combat and overcome defensive missiles, the author assigns the role of battlefield interdiction to the ground forces. The most useful remark on close support of ground operations occurs on page 120, where he proposes that an Air Force representative be assigned to the theater commander to "advise" him on the use of the consolidated theater air forces.

Although such obvious neglect of the impact of air power on conventional war constitutes more than a minor flaw, it would be parochial to evaluate this treatise solely from a service standpoint. Obviously, the author is much more concerned with his major hypothesis, which he summarizes (on p. 139) in three steps:

(1) "The troops fighting a conventional war against a nuclear power must be so deployed as if they were fighting a nuclear war, that is they must be dispersed over a greatly extended battlefield."

(2) "The conventional war against a nuclear power is characterized by purely mobile operations; there is no fixed front line, no static defence system, no defence zone . . ."

(3) From these two premises, which he establishes through very straightforward and unsophisticated analyses, the author deduces his tactical concept: the theory of "concentric dispersion." In essence, this concept holds that, to avoid concentrating his forces, the defender must always send a portion of his troops to attack the enemy rear. These troops (from one-sixth to one-half the defensive force) must fight their way overland to get behind the enemy.

I leave it to the reader to evaluate Dr. Heilbrunn's new concept. If conventional war in Europe should become the wide-open, disjointed imbroglio he imagines, it would probably be a good idea to send large contingents of allied forces to roam the enemy rear areas. But what if combat conditions should take any one of a number of other possible forms? In his single-minded devotion to this one conception of how the war should be fought, the author produces a less profound analysis of the generic subject of conventional war than we would expect from his title.

We never really come to grips with the war Dr. Heilbrunn visualizes (nor with any other specific set of conditions). He rules out, as do most other commentators today, a massive Soviet conventional attack. (p. 28) Yet his subsequent pronouncements seem predicated on just such a large-scale campaign taking place on a "vast" battlefield in a war so confused and uncontrolled that it may at any instant turn nuclear. His only specific force posture recommendation (p. 142) suggests increasing NATO's combat-ready reserves so as to be able to contain some 60 Soviet and satellite divisions—a fairly sizable attack in my definition.

An author who would study conventional war must devote some attention to the conditions under which his adversaries might fight. After all, conventional war is limited war, and the restrictions on combat activities will exert a critical influence on how it is fought. These Dr. Heilbrunn dismisses in a single paragraph (p. 58).

"There is no substitute for victory on the battlefield" he declares; only in the "exploitation of victory should moderation be shown." The latter qualification represents a more sophisticated approach than the uncompromising statement of a

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†**Otto Heilbrunn, *Conventional Warfare in the Nuclear Age* (New York: Frederick A. Praeger, Inc., 1965, $5.75), 164 pp.**

similar nature made by General MacArthur in the Korean War. MacArthur, however, was rejecting the whole thesis that war should be limited. Dr. Heilbrunn is advocating limited war but shrugging off limitations. Are there no sanctuaries? Where is the "battlefield"? Does it include Paris and London? Are there no constraints on weapons or tactics? Why, then, do opponents not use nuclear weapons? His doctrine of unrestricted limited war may have merit, but it deserves a fuller explanation.

The author laces his text with historical documentation—mostly from World War II experience in the China-Burma-India Theater—and with frequent references to the works of other strategic writers. Thus, his style creates the impression that the book represents a synthesis of related experience and scholarly opinion. Actually, numerous examples from the outposts of the last great war probably contain much that is irrelevant to the central arena of a future European war. Moreover, the reader should know that Dr. Heilbrunn's views on the tactics of defense are held by only a small minority. One could divide those who countenance and write about conventional war in Europe (a category which, itself, leaves out many notables) into three general schools: the proponents of (1) all-static defense, (2) defense in depth, and (3) all-mobile defense. Dr. Heilbrunn's adherents would appear at the far end of the spectrum and might be called the "ultra all-mobility" clique. As in any normal dispersion pattern, the majority opinion lies much nearer the center of the continuum, which in this case represents a more balanced blend of static and mobile contingents. Malcolm Hoag, the skillful champion of barrier defenses, summarizes it in this way:

> The all-mobility proponents need a different answer. The defense envisaged by Miksche as well as by Buchan and Windsor is not rigidly static. It would not be a mere line, but defense in depth. The fortress units would be able to maneuver locally within their assigned areas. . . ."*

In short, we are indebted to Dr. Heilbrunn for some provocative thoughts. His views should prevent us from becoming so complacent as to adopt rigid conceptions or doctrines. Indeed, he may even have succeeded in his purpose of finding out "how conventional forces can best meet a conventional attack" in the nuclear shadow. (p. 27) But in his neglect of fundamental considerations, and in his disregard of the numerous alternative developments, he fails to demonstrate why his solution is "best." In fact, one is hard put to figure out what the "others" are. We are still lacking an impartial but objectively graded appraisal of how *all* the possibilities for conventional war in Europe might line up.

Washington, D.C.

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*Malcolm Hoag, "Rationalizing NATO Strategy," *World Politics*, Vol. 17, No. 1 (October 1964), p. 136.

WALTER MILLIS'S 1984

HERMAN S. WOLK

> *So long as totalitarianism survives,*
> *so long the danger of total war*
> *will persist.*
>
> —Stefan T. Possony

WHETHER one agrees with all of what Walter Millis has to offer, or with none of it, Mr. Millis deserves our thanks. In *An End to Arms*[†] he has distilled and organized his thinking and writing of the past thirty or forty years and provided us with an unusually provocative book. As Millis suspected, the book raises many more questions than it answers. But how could it be otherwise? He is dealing with the entire range of the war-peace syndrome. He is discussing the history of war; the background of the cold war; the problems of power and the international community. Indeed, he also gives us a chapter on the language of international politics.

All this is stimulating. Several basic questions arise. What weight does one give to ideology when considering the operative forces in international politics? What factors have made the post-World War II period, the age of cold war, so remarkably stable as far as the outbreak of general war is concerned? Has the United States arrived at a true détente with the Soviet Union. Precisely what has the influence of nuclear weapons been on international politics since 1945, and what role have they played in the absence of general war? Is conflict inherent in the nature of man? Needless to say, these questions are bound to provoke a wide range of discussion. A massive and continuing debate has been raging for the past several years and has intensified as a result of the war in Viet Nam and the seeming détente between America and Russia.

Walter Millis has devoted many years to a study of military-political matters. Among other works, he is the author of *Road to War*, *This Is Pearl!*, and *Arms and Men*. With Harvey Mansfield and Harold Stein, he wrote *Arms and the State*. With James Real, Mr. Millis was coauthor of *The Abolition of War*, which, like the present volume, was an outgrowth of Mr. Millis's study at the Center for the Study of Democratic Institutions, Santa Barbara, California.

Over the years Millis has made the transformation from a historical and analytical approach to one primarily of advocacy. *An End to Arms* is the culmination of this synthesis. Since he has assumed the advocate's posture, one must ask: What is Millis advocating? Simply, he argues for a demilitarized system of international politics. In this vein his present volume is obviously an expansion of *The Abolition of War*. One of the distinctive and important differences between the two books, however, is that *An End to Arms* is free from much of the irrelevant polemics of *The Abolition of War*, which was more in a class with Fred J. Cook's *The Warfare State*, a bitter attack on the American military and, indeed, on American democratic society itself.[*]

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[*] Millis, however, does allow himself a swipe at the USAF. Commenting on the American interest in guerrilla warfare since Korea, he declares that "while the Air Force has generally continued to withdraw into its unmanageable mystique of the giant weapons systems, the Army and Navy have been devouring the works of Mao Tse-tung, Che Guevara . . . and other exponents of 'peoples' and guerilla warfare." (p. 86) Thus Millis, along with George Lowe (*The Age of Deterrence*), shows himself not to have an understanding of present-day USAF thinking and doctrine.

[†] Walter Millis, *An End to Arms* (New York: Atheneum, 1965, $5.95), 301 pp.

In proposing and sketching a demilitarized international political structure, Millis makes it clear that his is not a book about arms control or disarmament. Indeed, he has performed a real service by pointing out that the essential problem in the world today is not technical or military—it is political. His entire thesis evolves from this central fact. Thus, Millis trains his guns on the structure and language of international politics. To him, the cold war has been essentially a jockeying for "power positions" by East and West. It has exhibited the kind of psychology, myth-making, and language that must be destroyed if a demilitarized politics is to be established. For, according to the author, one of the major results of the cold war has been a stance of rigid ideological positions by both sides, marked by "the old disastrous pattern of military rivalry, though on a much higher level of potential catastrophe." (p. 76)

But into this environment was thrust the Korean War, which for Millis is of transcending importance. "In retrospect," he argues, "the Korean War may well seem to have been a far more decisive turning point in world history than was recognized at the time." (p. 76) Why? Because Korea set the pattern: Both sides accepted peace without victory and settled for the *status quo ante*. Thus, says Millis, the international order was transformed and a new system of international politics emerged. The strategy of nuclear deterrence evolved; and Millis admits that it has been both "rather remarkably successful" and "oddly effective."

The new kind of world politics which evolved from the Korean stalemate was stable enough, according to Millis, to prove itself during the Cuban missile crisis of October–November 1962. For, like Korea, Cuba ended in peace without victory. Too, he finds it noteworthy that the Cuban missile crisis was followed by the signing of the limited nuclear test ban treaty. Millis declares:

> As a concrete step toward disarmament, this treaty was a very small achievement; but its significance was great in that it was the first instance—at least since the Washington naval treaty of the early 1920's—in which even a small measure of arms control was attainable, not through a precise balancing of the military strengths and hazards, but through a recognition that in this particular context the military factors were irrelevant. (pp. 89–90)

The author assumes that Cuba demonstrated "the real inutility of the weaponry in practical international politics . . ." (p. 90) Interestingly, he avers that the Communists did not bend Castro to their wishes but that rather it was Castro who took over the Communists. Korea and Cuba have shown then, says Walter Millis, that, since both sides have accepted peace without victory, a political process has been emerging out of which a system of demilitarized world politics will develop.

But in order to reach the plateau where this system will become truly operative, it will be necessary to reconstruct the language of world politics. "One cannot escape the fact," Millis observes, "that most of the language commonly used in the current discussion of international affairs is essentially worthless for our purposes." (p. 97) It is our mistaken apperceptions as expressed through "defective" language that have been moving the world toward the precipice. We live by myths, and although this may be necessary, it has muddied the waters of international discourse. Indeed, the author notes, "the invention of the phrase 'cold war' was to give a warlike cast to everything that followed. . . ." (p. 100) The cold war has been dominated by the language of military power, from which neither side has been able to extricate itself.

Millis is realist enough to recognize that establishment of a world government complete with a global police force is not yet possible. But some kind of world order that will make it possible to decide issues without violence is within our reach. A world force, according to Millis, could not have done as well over the past 20 years as we have without it. In small part, he grudgingly credits the "supergiant weaponry" with making this possible.

Before meaningful disarmament evolves, it will be necessary that a system of demilitarized international politics be established. This is a political problem. And, "if the Russian and American leaders and their peoples . . . really want, as they say they do, a state of general and complete disarmament, there is nothing inherent in either human nature or the nature of politics to prevent their getting it." (p. 210) But how, asks Millis, do we get from here to there? First, he believes that the nuclear stalemate will go on indefinitely. The proliferation of nuclear weapons—the Nth country problem—has been exaggerated. The trend today is clearly toward nuclear stability.

Although arms are the cause of current tension, they are increasingly irrelevant to normal international power politics. The actual demilitarization seen by Millis will begin with a conference of nations designed to promulgate a constitution that would operate on a global scale under a state of demilitarization. The author envisions that the U.S., Western Europe, the Soviet Union, China, and India will form the basis for the new international order and constitution. The framework would perhaps be worked out in the early 1980's after settlement of the German problem and the conflict in Viet Nam. The present division of Indochina would have been ended through establishment of a confederation under Ho Chi-minh's successors, free from Chinese domination.

A new world Authority would possess a global police force in order to enforce a general disarmament treaty. A political conference in Moscow might originate the constitution for a disarmed world, while a technological conference in Washington could grapple with the precise technical problems of disarmament. The premise would be that disarmament is both desirable and politically feasible.

Millis is not saying that this is exactly the way things will work out. He argues that his post-1984 world will become a probability given the direction of present world politics. He admits that this will only be possible if the phenomenon of war is in fact political and cultural. If, however, war is inherent in the psychology of man, then his projections are without validity. To those who are skeptical of his thesis and projections, Millis has a rejoinder. His argument, he admits, ". . . has no ramparts of scholarly fact behind which to defend itself from those who do not wish, or cannot bring themselves, to believe it." (p. 242) However, he argues, "it does . . . have one answer to skepticism that the Utopian cannot usually command: what is your alternative? And it is a fairly crushing answer when it is backed by all the awful authority of the fifty-megaton bomb." (p. 242) In his final appeal, Walter Millis summarizes:

> So far as I am able to analyze the war problem, it seems to me that the future must rather closely follow along the lines here indicated, or else end in a general catastrophe of civilization. Those who believe that catastrophe is the only possible outcome are unquestionably entitled to their belief, but they should state it frankly. Those who believe that there is some middle road (through perpetual deterrence or 'arms control' for example) are equally entitled to their view but are under an even more imperative obligation to say just what they conceive this middle road to be, just where they expect it to lead and just how they anticipate it will achieve the destination. (p. 292)

One of the central difficulties with Millis's analysis is that he bends everything toward his argument. This is demonstrated by his feeling that in Viet Nam, while the U.S. has become involved to some extent, "there has still been no suggestion that the United States should intervene by military means to reverse an adverse outcome." (p. 86) This statement is, of course, no longer true at all and demonstrates that the author's cold war reasoning is faulty as well as dangerous and that it is almost certain to end inconclusively. It is as difficult to mold history as it is to predict it.

The example of Viet Nam indicates that it is exceedingly dangerous to attempt to predict the future with any sort of assurance. For many, Millis's design will have to await solid evidence that Communism has renounced aggression and wars of national liberation. American Ambassador at Large W. Averell Harriman has recently observed that the danger of Communist aggression has increased as a result of the Moscow-Peking struggle. In the meantime, it is not unreasonable to assume that today's world is not so bad after all and that we might in fact be doing well indeed to preserve the *status quo*.

Too, Millis exaggerates the problem of language. Obviously, he does have a point. Too often we react emotionally to the language of cold war politics. This is as true of the American Left as of the Right, a point the author neglects. But many times the language and terms of reference are apropos. It depends on the case in point. Millis's wholesale indictment is difficult to accept. He observes that the international community must live by certain myths. If one accepts this premise, how does one do away with the language supporting a phenomenon which is inherent in man? It is simply asking the impossible.

If Walter Millis says that we must live with our myths, then one of his own myths is that nuclear weapons have served little useful purpose and are only in small part responsible for the remarkable viability and staying power of the world since 1945. Yet when he observes that the present trend is toward conflict at the lower end of the spectrum, he is saying that nuclear weapons have revolutionized warfare and politics. He is saying that *because* of the possession of nuclear weapons in the hands of the Big Two we have had no great war since 1945.

Millis sees no reason why deterrence should not work into the foreseeable future. Indeed, he predicts that it will. The problem he is up against, therefore, is simply that many will be unwilling to give up present-day stability for something as nebulous as that which Millis sees as possible. But, of course, he sees the demilitarized world evolving naturally out of our present situation. Perhaps he is correct. My own opinion is that Millis has read too much into the test ban treaty and not enough into conflicting ideologies. There is danger in giving either too much weight or not enough to ideology. Millis downgrades ideology and therefore sees a great opportunity for demilitarization. I believe he is jumping the gun. I believe that it will be impossible to implement a system of demilitarized politics by the early 1980's.

Time is the key. And I have the feeling that one of the major world problems today is a chronological one. We are living in a period in which several civilizations—American, Soviet, and Western European—are much more advanced than others—technologically, socially, economically, and politically. Meanwhile, individuals, nations, and societies will have to learn some hard lessons. We shall probably have to wait for the Soviet Union and Red China to catch up with us in our thinking and planning for a world free from the specter of war. Because of our technology and advanced centers of social science, we have been far advanced over the Soviet Union in strategic studies. Similarly, because of the nature of our society, we are far out in front in systematic writing on the subject of a world under law. It will take great changes and a very long time for the U.S.S.R. and Red China to catch up.

But even this assumes that Russia and Communist China are interested in catching up with the West in serious, systematic peace research. The weight of evidence to date is heavily against such a development in the near future. Regrettably, recent history suggests that the Communists are more interested in fomenting subversion, revolution, and unrest than in stabilizing the world situation for a transition to demilitarization. It will not be as easy for others to belittle the difficulty involved in ideology as it is for Millis.

The author's challenge (What is *your* alternative?) is not an adequate answer to the shortcomings of his work. Perhaps his plan is the best that can be sketched, but he cannot evade certain questions by attempting to thrust the burden of proof on others. One does not think seriously of alternatives unless the present situation is pretty untenable. As Millis agrees, this is obviously not the case. The difference revolves around the future. Since he feels that the great weapons are the *cause* of present-day tensions and that, if we continue on, the world will be destroyed, Millis clearly sees the need for alternatives.

In a sense, the greatest single weakness of his book comes precisely when he challenges us with the question: What is *your* alternative? I say this because it seems to me that this is one "problem" which might well not have a complete solution now or in the foreseeable future. Is it not possible —nay, probable—that the imperfect, often threatening world of today may be preferable to the "utopias" of tomorrow? Is it not possible that a world in which nuclear weapons exist but are not used may be preferable to a so-called "demilitarized" world complete with an international police force? I do not know the answers to these questions—and neither does Millis. I only raise them to suggest that we and our children are doomed to live in a world replete with tension and threats which will continually demand courage and sacrifice. When has it been otherwise?

Some of us will admit to a bias against grand schemes or prognostications. The historians, perhaps especially, will be wary of the admonition that we must do such and such by this or that date or we shall be doomed to catastrophe. The obvious—maybe even emotional—response is: Nonsense!

Although one of the several primary questions that Millis raises is whether or not war is inherent in human nature (if it is, he says, then a demilitarized world will not be possible), one major shortcoming of *An End to Arms* is that the issues that divide the U.S. and the U.S.S.R. are not merely a matter of semantics. They are real and substantive. They cannot be swept under the rug by transforming the international language, even assuming that this could be accomplished.

Nevertheless, if Millis's optimism is not always convincing, it is at least refreshing. The reason why many will not be as optimistic and willing to go so far as Millis in the specified time period ahead is quite simple: we are dealing with the very survival of the United States.

And that's no myth.

Omaha, Nebraska

The Contributors

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Dr. James A. Fraser (Ph.D., Columbia University) has been Professor of Physical Science, Warfare Systems School, Air University, since 1955. After teaching in U.S. and Canadian schools, 1927-41, he enlisted with the Royal Canadian Air Force, was commissioned, and served as a navigation instructor and ground instructor for pilots until his release in 1945. Subsequent positions have been as Dean, Ferris Institute, Big Rapids, Michigan, 1945-46; professor and head of Science Department, State Teachers College, Troy, Alabama; in research and writing, Eastman Kodak Company, Rochester, New York, 1947-48; and on active duty as a reserve officer with the Evaluation Staff, Air War College, Maxwell AFB, 1951-53. Dr. Fraser also has served as professorial lecturer in the George Washington University Center at Maxwell AFB since 1962 and retains his commission as a colonel in the USAF reserve with assignment to Office of Aerospace Research, Wright-Patterson AFB, Ohio. He is a graduate of the Air Tactical School, the Air Weapons Course, and the Air War College.

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