FACTORS INFLUENCING THE CHOICE OF FACILITIES AND TECHNIQUES FOR AERONAUTICAL DEVELOPMENT

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INTRODUCTION

The facilities and techniques used in the development of aeronautics are as numerous and as varied as the problem areas. Even with the wind tunnel, which is the basic tool of aeronautical development, we find that there are many kinds of wind tunnels, and they have associated with them a variety of more detailed pieces of equipment that are varied from time to time as different research investigations are needed. To attempt to discuss all of the facilities and techniques currently being used in aeronautical development, even if confined to the subsonic regime, is clearly impractical. The attempt in this introductory paper will be to examine only some of the newer developments that appear to be most significant.

The first part of this paper will review a few of the basic factors that have influenced the development of the facilities and techniques which will be discussed in the later papers in this session. These are factors involved in the mainstream of aircraft development and include those arising from interest in V/STOL performance as well as those arising from the problems of low-speed flight of the newer conventional take-off and landing configurations. A short section on dynamic test facilities is also included. The second part of the paper will deal with facilities and techniques for the study of operational problems, such as noise and IFR trafic control.

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AIRCRAFT DEVELOPMENT

Low-Speed and Hovering Flight

One of the factors that has had a great impact on both wind-tunnel and flight-test technology has been the interest in V/STOL aircraft (such as the tilt-wing XC-142 and deflected jet P-1127 aircraft shown in fig. 1). These and other V/STOL aircraft support themselves at very low speeds by deflecting air downward at a large angle to the direction of flight (vertically for hovering) as depicted in figure 2. These large deflections of the flow have a first-order effect on both wind-tunnel and flight testing.

All aircraft support themselves by deflecting air downward; however, for conventional flight, even at the stalling speeds of conventional aircraft, the deflection of the air is only a few degrees. These small deflections simplify the analysis and testing of conventional aircraft. Unpowered models of conventional configurations can be tested in wind tunnels in which the tunnel width is only about 50 percent greater than the wing span of the model (and the floor and ceiling of the tunnel can be as close as half a wing span from the model) without affecting the measured results beyond the point where they can be corrected by conventional wall-effect theory. In tests of models of V/STOL configurations, however, the jet or slipstream from a V/STOL model would impinge on the floor or have its path drastically altered, with attendant alterations to the rest of the flow field around the model, if the floor were as close below a V/STOL model as is permissible for conventional unpowered models. For V/STOL testing, therefore, the wind tunnel must be much larger, with respect to the model, than for conventional unpowered model testing. This is the primary factor which is sizing the new crop of tunnels that Mr. Templin will be discussing (ref. 1). An alternate to the use of oversized wind tunnels is the use of specialized towed rigs as will be discussed by Mr. Michaelsen (ref. 2).

Although in wind-tunnel testing V/STOL models can be kept much smaller, with respect to the test section size than is the practice for conventional unpowered models, it is generally not possible to increase the size of the tunnel (or decrease the size of the model) to the point where the constraint due to the tunnel walls will be completely negligible. A method of correcting for the effects of the tunnel walls is needed. For conventional unpowered models, classical wall correction theory has assumed zero deflection of the wake. This assumption is clearly not permissible for V/STOL testing. The large wake deflections must be accounted for in wall-effect theory as Heyson has done in references 3 and 4. Additional work of this type as well as experimental and analytical work on ventilated test section designs aimed at reducing the effects of wall constraints is continuing and will be discussed by both Messrs. Templin and Heyson (refs. 1 and 5).

At the low speeds associated with these large flow deflections, the normal aerodynamic surfaces used to provide stability and control in conventional flight lose their effectiveness. Also, due to the airflow into the lifting-propulsion systems on most V/STOL aircraft, these configurations encounter a region of dynamic instability at low speeds (fig. 3). It is necessary, therefore, to use power in the form of bleed air control jets, differential propeller thrust, or some other related system to provide both stability and control in the V/STOL regime. This has brought with it the need for an entirely new method of defining control and damping requirements and the development of new techniques of flight and preflight testing. Various aspects of this preflight and flight testing are reviewed by Messrs. Michaelsen and Anderson (refs. 2 and 6).

New Conventional Flight Configurations

Although subsonic aerodynamics is the oldest discipline of aeronautical development, it is not a completely known area. Each new advance in subsonic, supersonic, or hypersonic configuration development, such as the examples shown in figure 4, brings with it the need for additional subsonic testing.

The introduction of variable sweep required a reevaluation of the entire longitudinal stability area. Sharp leading-edge delta wings for supersonic flight brought a new emphasis on studies of vortex flows and vortex lift. Lifting bodies required a whole new look at lift and control problems. What is more, most of these, and other problem areas intoduced by new configurations, are highly configuration dependent and require an ever-increasing amount of both wind-tunnel and flight testing as will be discussed by Messrs. Templin and Anderson (refs. 1 and 6). Even in the development of the now conventional subsonic transport, as shown in figure 5 (courtesy of the Boeing Company), Boeing has found that with the introduction of each new configuration their rate of expenditure of wind-tunnel time has increased to the point where in 1 year they have spent as much tunnel time on the 747 as in 13 years on the 707 series.

One of the factors responsible for the proliferation of the new tunnels that are being built around the world is simply this need for the additional availability of tunnel time. V/STOL requirements have sized the tunnels but would not in themselves have been sufficient justification to warrant all of the tunnel construction projects currently going on.

Another potential problem area which the introduction of the jumbo jets has highlighted is the gap between the Reynolds number capability of existing tunnels, and the actual flight Reynolds numbers are shown in figure 6. The need to duplicate Reynolds number cannot be as explicitly stated as the need, for instance, to duplicate Mach number or the need for tunnel size in V/STOL testing. Nevertheless there are disquieting differences showing up between wind-tunnel and flight data, such as the effect of Reynolds number on shock position as shown in reference 7 and the differences in control effectiveness, or control interactions, between what was expected from wind-tunnel data and what was experienced in flight on the B-70. Construction of a superfacility to achieve full-scale Reynolds number capability would probably cost on the order of one-half billion dollars. On the other hand, the development costs of some of the new aircraft are of the same order of magnitude. The cost of such a superfacility, spread over many aircraft development programs, may not be exorbitant.

An entirely different type of facility problem has arisen with the development of completely flexible lifting systems such as flexible wings. The performance of these wings, as pointed out by Mr. Rogallo in reference 8, depends upon the shape of the canopy which is a function of the pressure distribution and the weight of the canopy material. For the results of wind-tunnel tests to be strictly correct, the airstream should be inclined to correspond to the flight-path angle appropriate to the data point being taken.

Dynamic Test Facilities

Conventional wind-tunnel tests of models provide data necessary for the performance and control analyses on new aircraft but do not provide all of the aerodynamic derivatives that are necessary in the study of the dynamic motions of aircraft. A number of specialized facilities have been developed for this purpose. These range from free-spinning tunnels, where the dynamic behavior of dynamically scaled models can be qualitatively assessed, to specialized free- and forced-oscillation rigs where quantitative measurements of rotary derivatives can be made. A comprehensive review of the various dynamic stability and control research techniques is presented in reference 9. Only three will be reviewed here; the free-flight model technique, the semi-free-flight track technique, and the model oscillation technique.

The free-flight model technique in which a powered model is dynamically scaled to represent the full-scale article and flown in free flight has been found to be extremely valuable in uncovering significant dynamic stability problems early in the development phase of a new aircraft type. Figure 7 shows an early variable-sweep wing model being flown in the 30- by 60-foot full-scale tunnel at Langley. The triple exposure shows the remotely controlled wing in three different sweep positions as the test progressed. Figure 8 shows schematically the test setup employed in this case using a VTOL model. Power and control signals are brought into the model through the umbilical chord suspended above the model. The safety cable operator maintains this chord in a slack condition during the test. Four additional operators are used; one to control power to keep the model positioned in the tunnel and one on each of the three axes. The model could be flown by one pilot; however, the use of multiple operators has been found to be desirable in that it gives each man time to study the motions of the aircraft about the axis that he is controlling, thus resulting in a better understanding of the characteristics of the configuration. The stability, controllability, and the general flight behavior are determined qualitatively from the pilots' observations, and motion-picture records of the flight tests are made also as an aid in the pilots' evaluation. The assessment of the general flight behavior is, in effect, much the same as a test pilot's feel of an airplane or his qualitative opinion of the flying qualities and indicates whether stability and controllability are adequate and properly proportioned. If the behavior of a configuration proves to be unsatisfactory in any way, methods for achieving satisfactory characteristics can be studied by changes in piloting technique, by geometric changes to the model, or by the use of artificial stability augmentation. A more complete description of the technique is given in reference 10.

A related technique, but one aimed at acquiring more quantitative data on the stability characteristics of a new configuration, is the semi-free-flight track facility at Princeton University (refs. 11 to 13). This unique facility was developed primarily for the testing of VTOL models in hovering and low-speed flight. The facility uses a servo-controlled carriage which runs along a straight horizontal track 750 feet long. (See fig. 9.) Mounted on this horizontally moving carriage is a vertical track on which runs a vertically moving servo-controlled carriage with the model support boom installed. The model is attached to this boom with angular freedom in pitch and also with ±9 inches of fore-and-aft freedom along a horizontal track and ±3 inches of vertical freedom.

During a test, the propulsion system of the model provides the lift to support the model weight and the thrust to overcome the model drag in forward flight. The model support strut is moved horizontally and vertically by the two servo-controlled carriages in response to signals from position indicators at the model so that the model stays in the center of its small range of horizontal and vertical freedom. The model support strut therefore provides no restraint to the model in the horizontal or vertical direction (unless, of course, it reaches one end of its rather limited range of freedom in the horizontal or vertical direction). Extensive work was required to develop a system which would respond rapidly and accurately enough to keep the model motions from being affected to an unsatisfactory extent by the support boom. Since the model is restrained in lateral displacement and in bank and yaw attitude, it has the limitation of permitting only studies of longitudinal characteristics. (It is possible to study lateral characteristics, in hovering flight, by making tests with the model turned 90° about its vertical axis.)

For computer or simulator studies, numerical values for the stability derivatives are required. The static derivatives can be obtained from conventional wind-tunnel tests. The rotary or dynamic derivatives, however, require the use of specialized apparatus such as that shown in figure 10. With the type of apparatus shown in figure 10, the model is forced to oscillate about a chosen axis and the damping and cross derivatives related to that motion are obtained by proper resolution of the forces and moments measured during the oscillation. A separate setup is required for each group of derivatives desired. References 10, 13, and 14 present further details of the various rigs that are currently available.

OPERATIONAL FACTORS

Up to this point in time, the development of aeronautics has been generally paced by the development of the aircraft itself. As the aircraft became faster, larger, and acquired longer range, the use of aircraft grew apace. Operational procedures were tailored to meet the demands of the aircraft. There are signs that this process may not continue indefinitely. Operational considerations such as noise and traffic control may soon have an equal place with aircraft performance in determining the rate of development of the aeronautical system. The facilities and techniques used in solving the operational problems, therefore, become of prime significance to the general area of aeronautical development. The FAA-NAFEC facility at Atlantic City (fig. 11) incorporates many of the necessary tools, from air guns for hurling birds at aircraft windshields, to phototheodolite systems for evaluating instrument approach systems (ref. 15).

Traffic Control and IFR Approach Systems

Traffic at our major airports has been increasing dramatically (fig. 12) (ref. 16) and at some stations saturation conditions are developing. Under IFR conditions, the peak hour demands at the New York airports exceed their IFR capability and serious landing delays result. According to reference 17, Kennedy Airport will be running out of good weather capacity in a few years.

Adding to the problem is the promise, or threat, from the point of view of the air traffic controller, of the introduction of V/STOL aircraft as a means of significantly shortening the point-to-point travel time. If V/STOL aircraft are to fulfill their promise, they may have to operate below the conventional traffic as depicted schematically in figure 13. This over-under traffic system may or may not prove feasible, but in any event, procedures will have to be devised to minimize the traffic delays and instrument approach time required if V/STOL aircraft are to realize their potential point-to-point travel time advantage over conventional aircraft.

A primary tool for investigating and evaluating new means and procedures of traffic control is the air traffic control simulation facility at NAFEC. This facility was used recently in evaluating the effect of traffic control systems on the supersonic transport (ref. 18) and the effect of the supersonic transport on the air traffic control procedures (ref. 19). A project to use the traffic control simulator in the evaluation of V/STOL procedures is currently being contemplated.

The facility is shown schematically as it was used in the supersonic transport simulation in figure 14. It consisted of four major components: the simulated supersonic transport cockpit, the SST analog computer, the simulated air traffic control center, and a battery of aircraft target generators. In the supersonic transport traffic control simulation, the cockpit and its associated analog computer were located at NASA's Langley Research Center in Virginia and the traffic control center and target generator complex at FAA's NAFEC at Atlantic City. The elements were tied together by telephone lines. The characteristics of the supersonic transport were fed by the analog computer into the cockpit simulator which was flown by airline crews. Various types of approaches under varying conditions were flown and the position information automatically fed into the traffic control center. In order to make the traffic control situation realistic, radar targets representing other traffic were fed into the simulated traffic control center by the target generators. In this manner, the traffic control center is presented a realistic traffic situation and various procedures can be investigated and evaluated. The characteristics of the aircraft under investigation can be evaluated against the demands of the traffic control system, and the characteristics of various assumed traffic control systems can be evaluated with realistic aircraft inputs.

Landing approach guidance and pilot's displays.- A factor closely related to air traffic control is that of information display to the pilot. At the present time, a pilot on instruments must read and interpret the readings of a number of dials in order to determine the condition and attitude of his airplane as well as its position with respect to its intended flight path and destination. This scanning of the instruments takes appreciable time and severely limits the maneuvering the pilot may do on instruments. In general, he is constrained to fly a given flight path and make only one deviation at a time. That is, he may make a turn onto the ILF localizer. He requires a minute or so to properly bracket the localizer before he can be expected to pick up the glide slope, and again he must have a minute or so to bracket the slope properly.

A number of systems for presenting attitude and position information to the pilot are currently being investigated both in industry and by government agencies. An interesting piece of research equipment is being used at the NASA Wallops Station to study the types of information a pilot needs in IFR flying and the best method of presenting the information to him. This equipment (ref. 20) is shown in figure 15 and includes a special radar which serves two purposes; it provides guidance information to the airplane that can be used to drive an ILS cross-pointer or any other type of display the investigators may wish to study, and also simultaneously presents plots of the course and glide path which the pilot has flown. Thus the equipment provides the important dual function of driving the displays and evaluating the pilot's performance with these displays. The equipment has considerable flexibility in the area of both tasks and displays. As shown in figure 16, straight approaches of any desired slope or curved approaches can be presented to the pilot and the displays can be anything from flight director to displacement type or so-called contact analog displays. This equipment is currently being used in conjunction with the Bell 204-B helicopter and Hawker P-1127 shown in figure 17, in studies of the VTOL approach problems. It has also been used with conventional jet transports in evaluations of the steep angle approach noise abatement procedures. NASA is currently conducting design studies toward the eventual acquisition of a jet V/STOL research airplane to be used in conjunction with this radar equipment in studying the total terminal area operations problem under both visual and instrument flight conditions.

Related work is being done in the JANAIR program at Bell Helicopter using a UH-1A helicopter and the six-degree-of-freedom simulator shown in figure 18. This program as stated in reference 21 is aimed at "an evaluation of the instrument display problems for steep gradient type flight vehicles and development of displays to provide a pilot with full instrument flight capabilities to exploit the total capability of the flight vehicle." The combination of the flight-test helicopter and the groundbased simulator provides realistic environments for investigating and evaluating various types of displays and human factors involved. Further information on these techniques is contained in references 22 and 23.

Noise.- One of the most troublesome problems facing aircraft development today is that of noise. The attack on the noise problem requires investigation on three fronts (fig. 19): (1) reduction of noise produced by the aircraft, (2) determination of levels and qualities of noise that are tolerable under varying conditions, and, because there are limits to both the reductions which can be achieved and the level that people will tolerate, (3) determination of operating procedures that will minimize the exposure of the community to aircraft noise. The facilities and techniques used in each area are different.

Simulators and flight tests are the primary tools in the area of operating procedures. As already discussed above, the installation at the NASA Wallops Station has been used in support of studies of approach techniques as a means of alleviating noise on the ground. Approach paths of varying steepness and using various flare techniques were flown by test pilots and by airline crews using several different types of airline aircraft. The noise patterns on the ground, the flight path actually achieved, and pilot's comments were recorded and evaluated. This work ties in closely with work on traffic control and instrument flight displays as well as on improvements in aircraft characteristics which are needed before such procedures could become operational.

In the area of investigation of means of reducing the noise at its source, the available tools consist of anechoic chambers, such as those described in reference 24 for engineering studies of noise generation and suppression, various full-scale outdoor ground test setups where the noise transmission from engines with various acoustic treatments can be evaluated, and finally flight tests to determine and demonstrate the overall noise reduction achieved in practice.

Two interesting techniques are being developed in the area of investigation of human response. Both involve subjective evaluation to determine not only the tolerable level of the noise, but to also evaluate the effect of the quality of the noise. In one of these, Mr. Sternfeld, of Boeing-Vertol, is developing a technique for synthesizing noise of various aircraft types and using human subjects to rate the quality as well as the level of the noise. The noise of an existing airplane or the expected noise of an airplane under design is built up electronically from its frequency content and recorded on magnetic tape. By playing the tape at various levels along with a reference (perhaps an existing jet transport) the quality of the sound can be evaluated. Also by varying the frequency content, it should be possible to isolate the more objectionable components and produce engineering data for use in engine and suppressor design to minimize noise. This is basically a laboratory technique.

A real world technique has recently been developed at Edwards Air Force Base in California for the evaluation of the sonic boom and airport noise problem (ref. 25) and is currently being considered for the evaluation of V/STOL aircraft noise. For this work, two houses were constructed with conventional frame construction and insulation. Subjects were placed inside and around these houses as illustrated in figure 20 (but the automobiles were excluded) and asked to rate the intensity or nuisance value of the sonic boom and noise produced by flybys of various aircraft. Simultaneously with their subjective ratings, records were taken of the intensity of the noise, of the sonic boom incremental pressure, and associated building vibrations. Correlation of the comments of the subjects with the measured noise levels was made in relation to their position inside or outside the building, atmospheric data, aircraft path, etc.

CONCLUDING REMARKS

As indicated in the introduction, the tools to be used in the development of aeronautics, as in the development of any technological area, must be revised and developed as the technology progresses. This paper has attempted to illustrate only a few of the more significant factors that are controlling the development of aeronautics and, therefore, dictating the development tools. It has been pointed out that while the pace of the development of aeronautics in the past has been set by the development of the airplane itself, in the future the operational considerations will take on increasing significance and the tools for solving the operational problems may become as important as the wind-tunnel and flight tests have been in the development of the aircraft.

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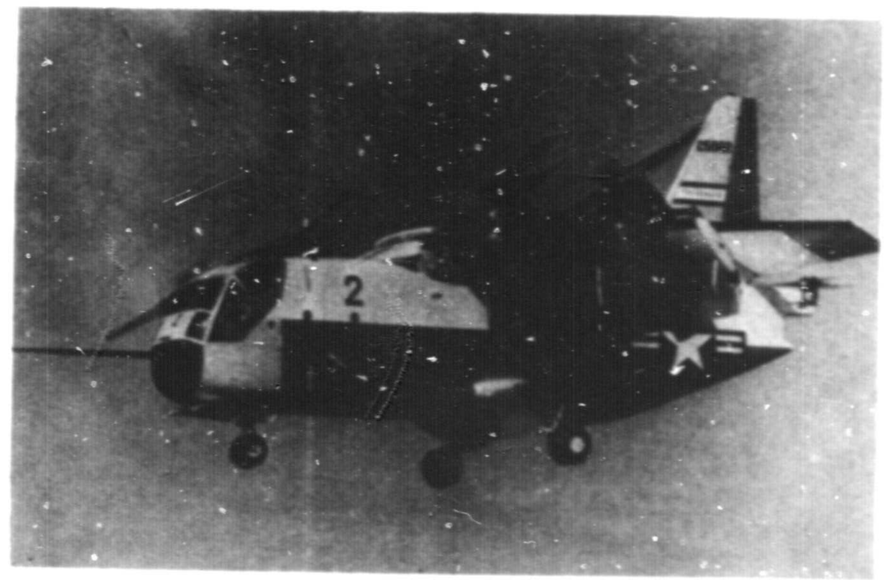


VOUGHT XC-142

Figure 1.- V/STOL configurations.

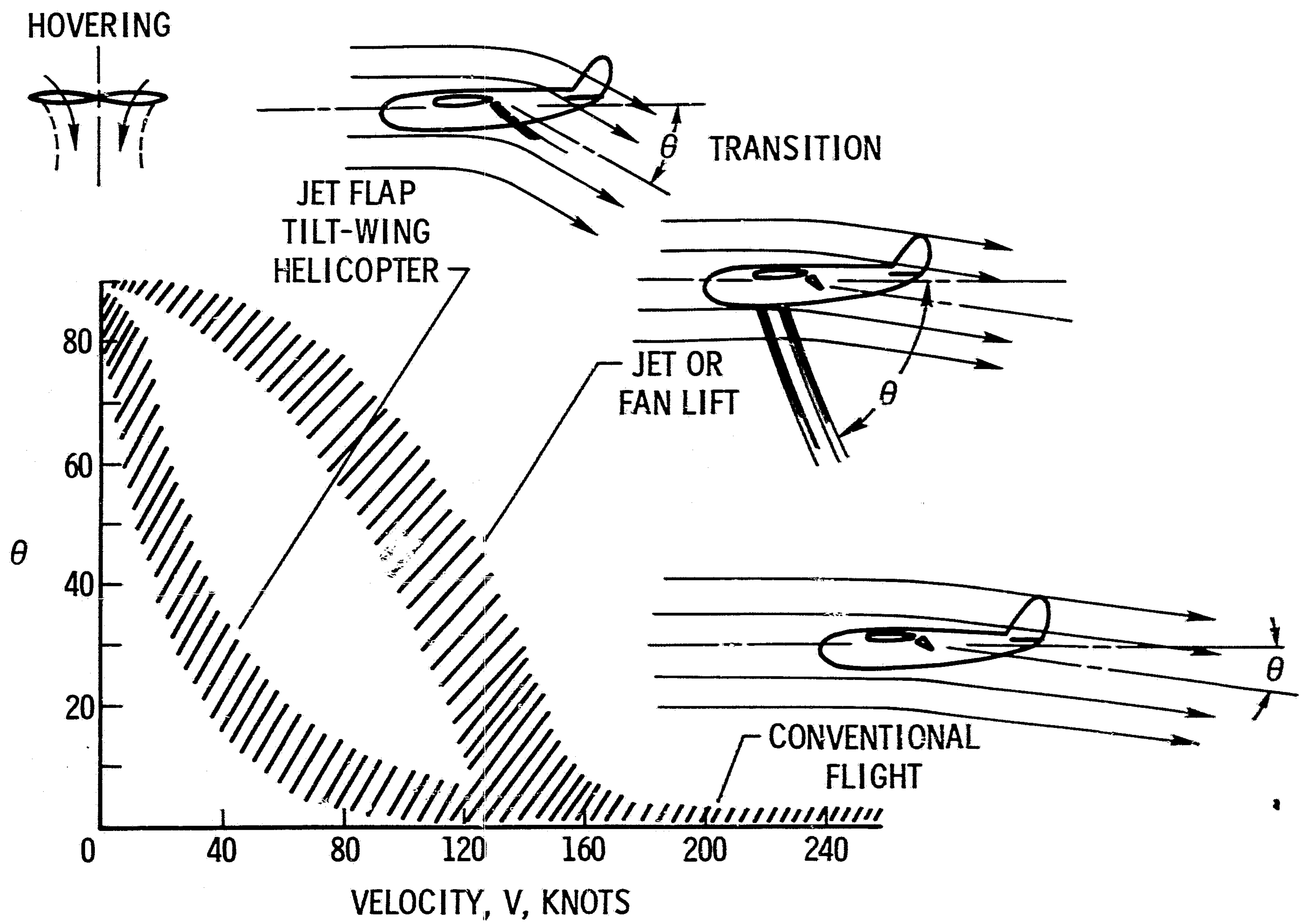


Figure 2.- High lift - low speed flow fields.

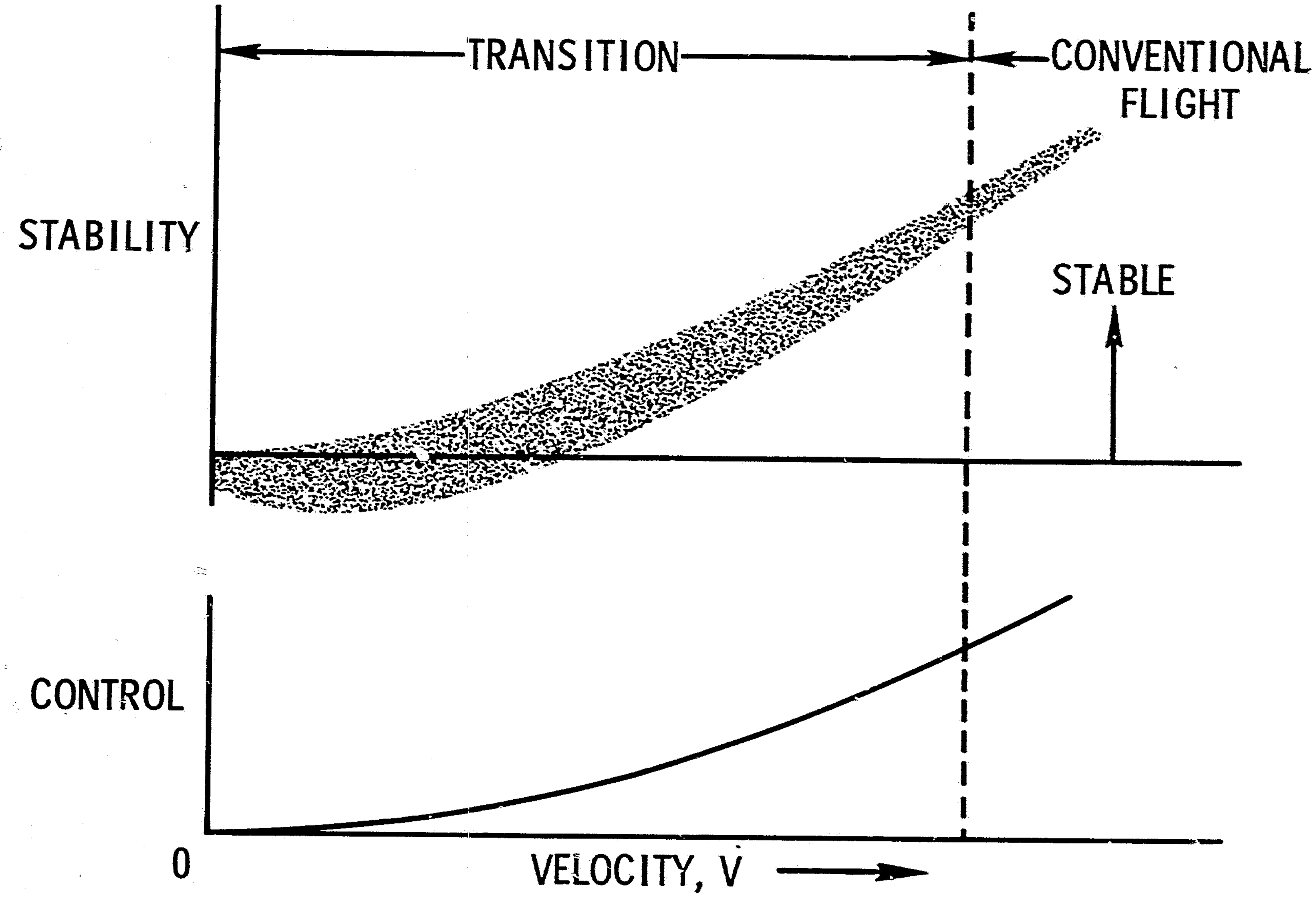


Figure 3.- Low speed stability and control.

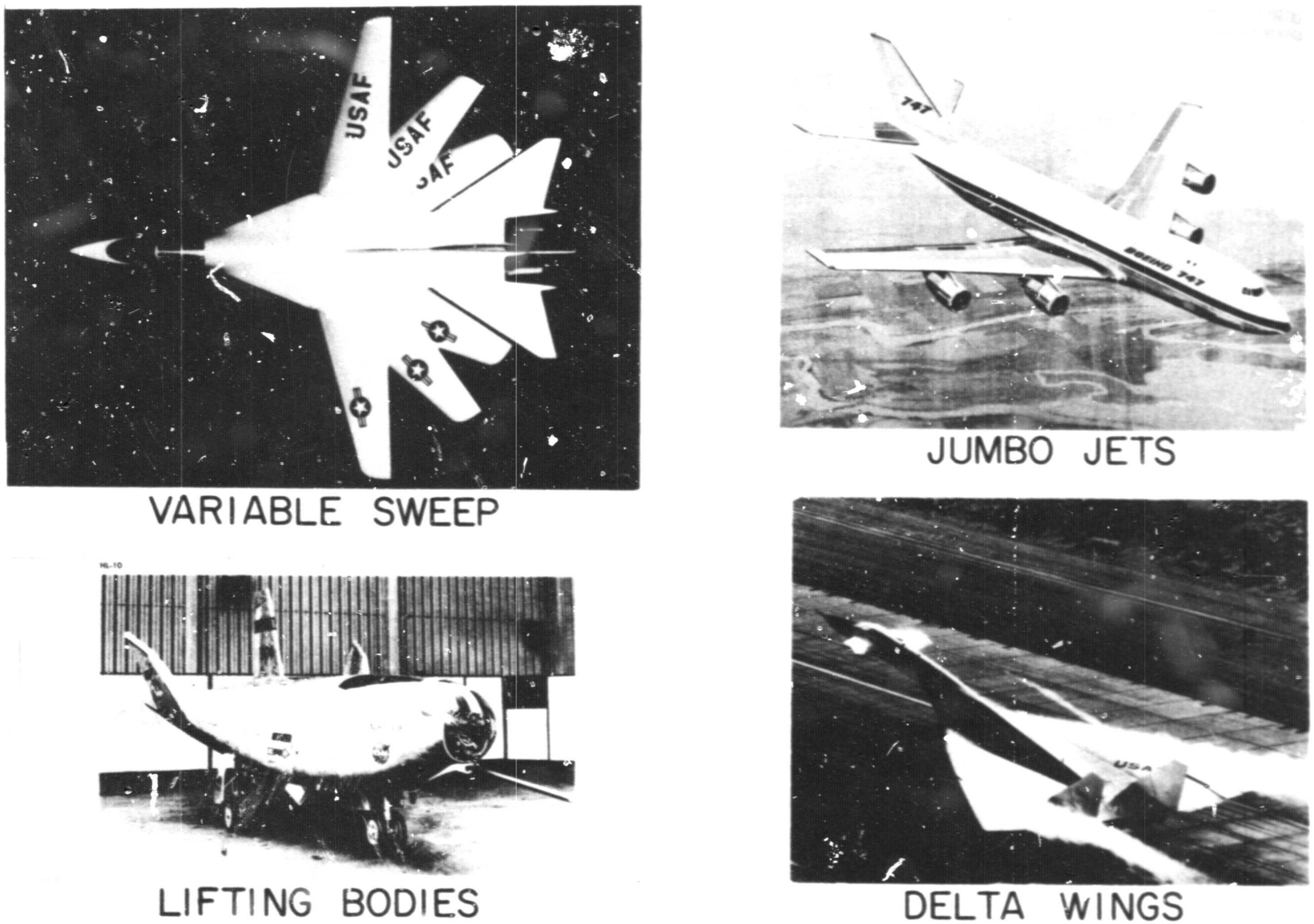


Figure 4.- New configurations.

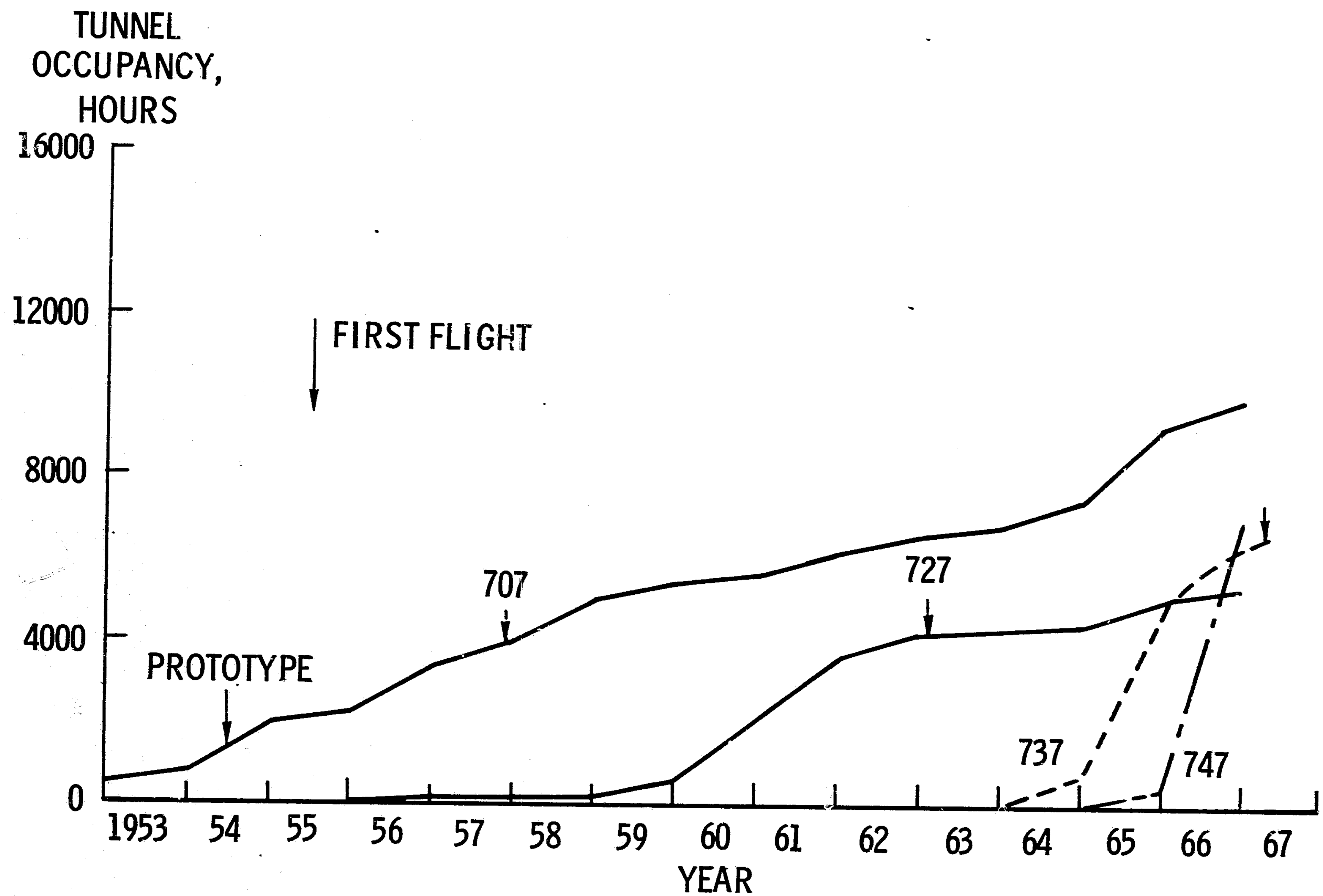


Figure 5.- The increasing need for tunnel time.

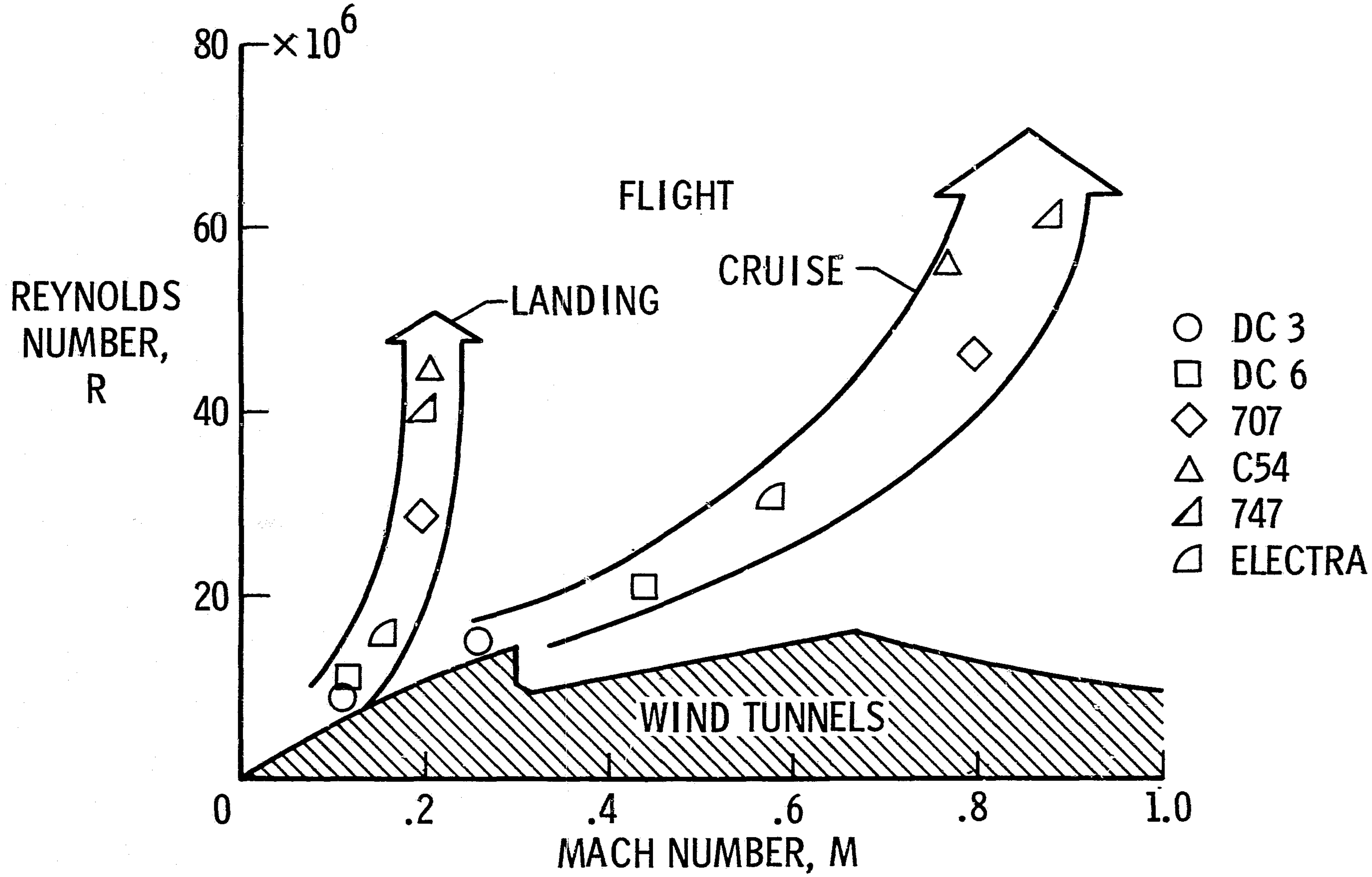


Figure 6.- The Reynolds number gap.

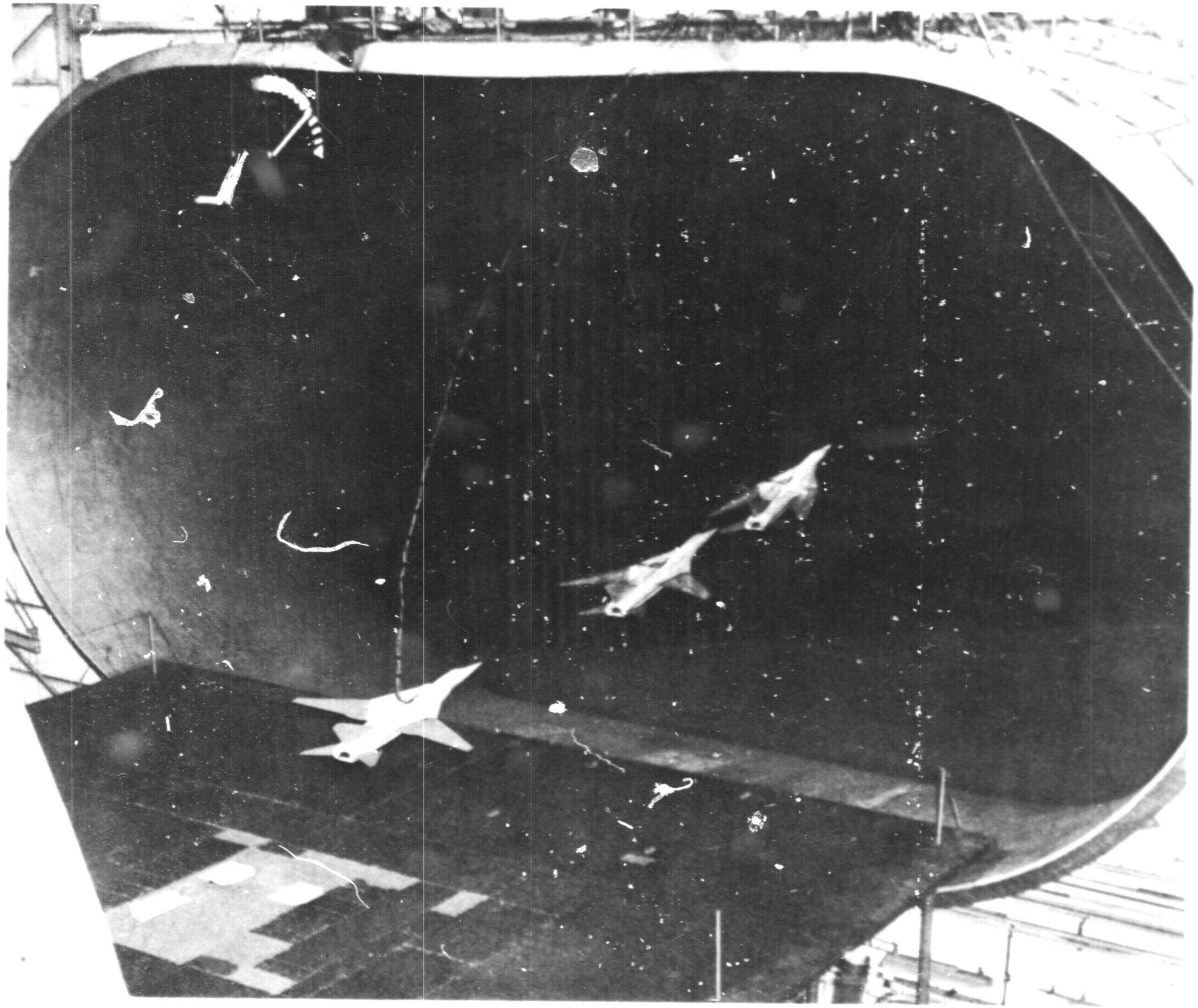


Figure 7.- Free-flight test of a dynamically scaled model of a variable-sweep wing model.

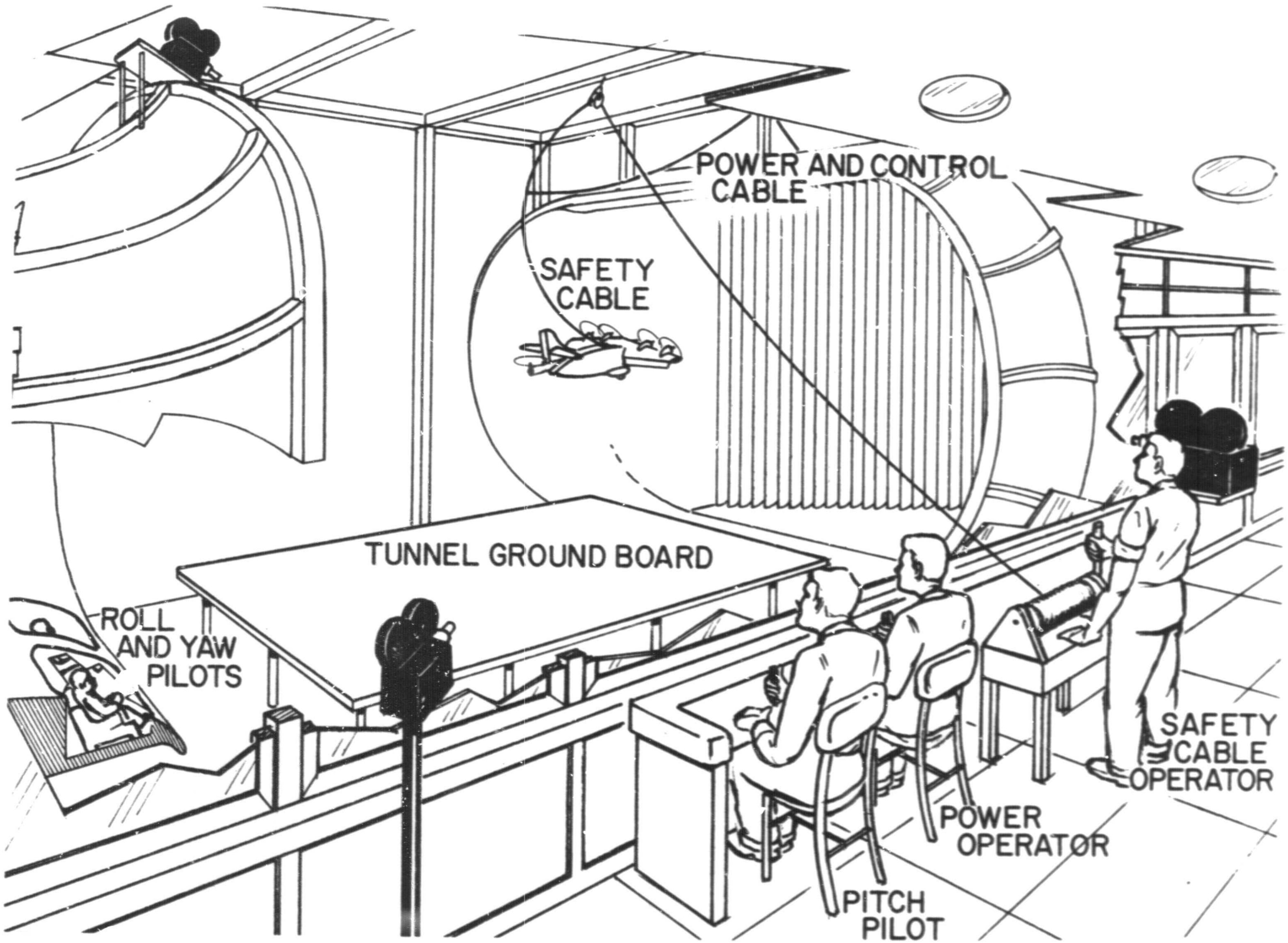


Figure 8.- Test setup for free-flight model testing in NASA Langley full-scale tunnel.

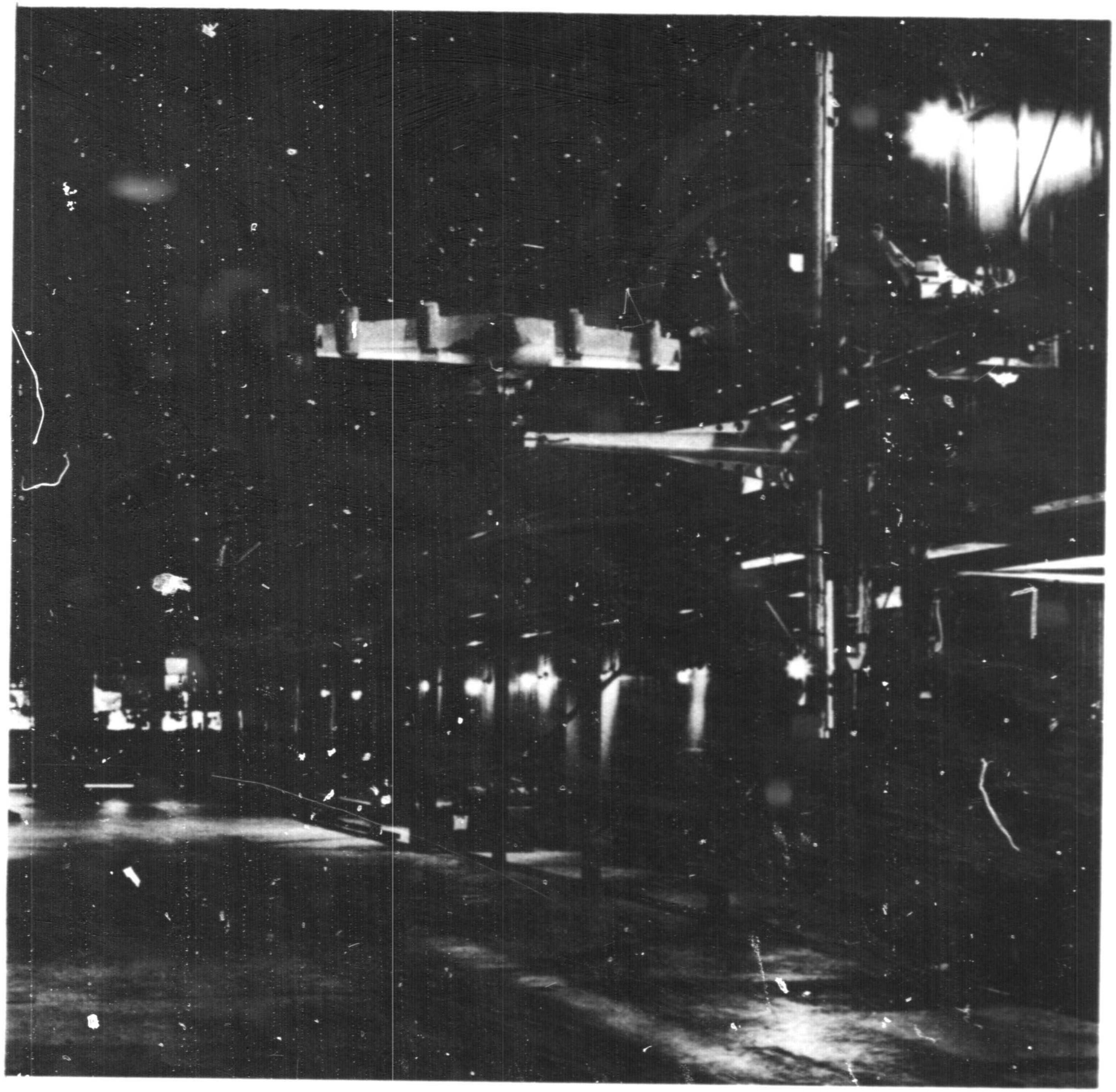


Figure 9.- Princeton University Forward-Flight Facility used for semifree-flight tests of V/STOL aircraft models.

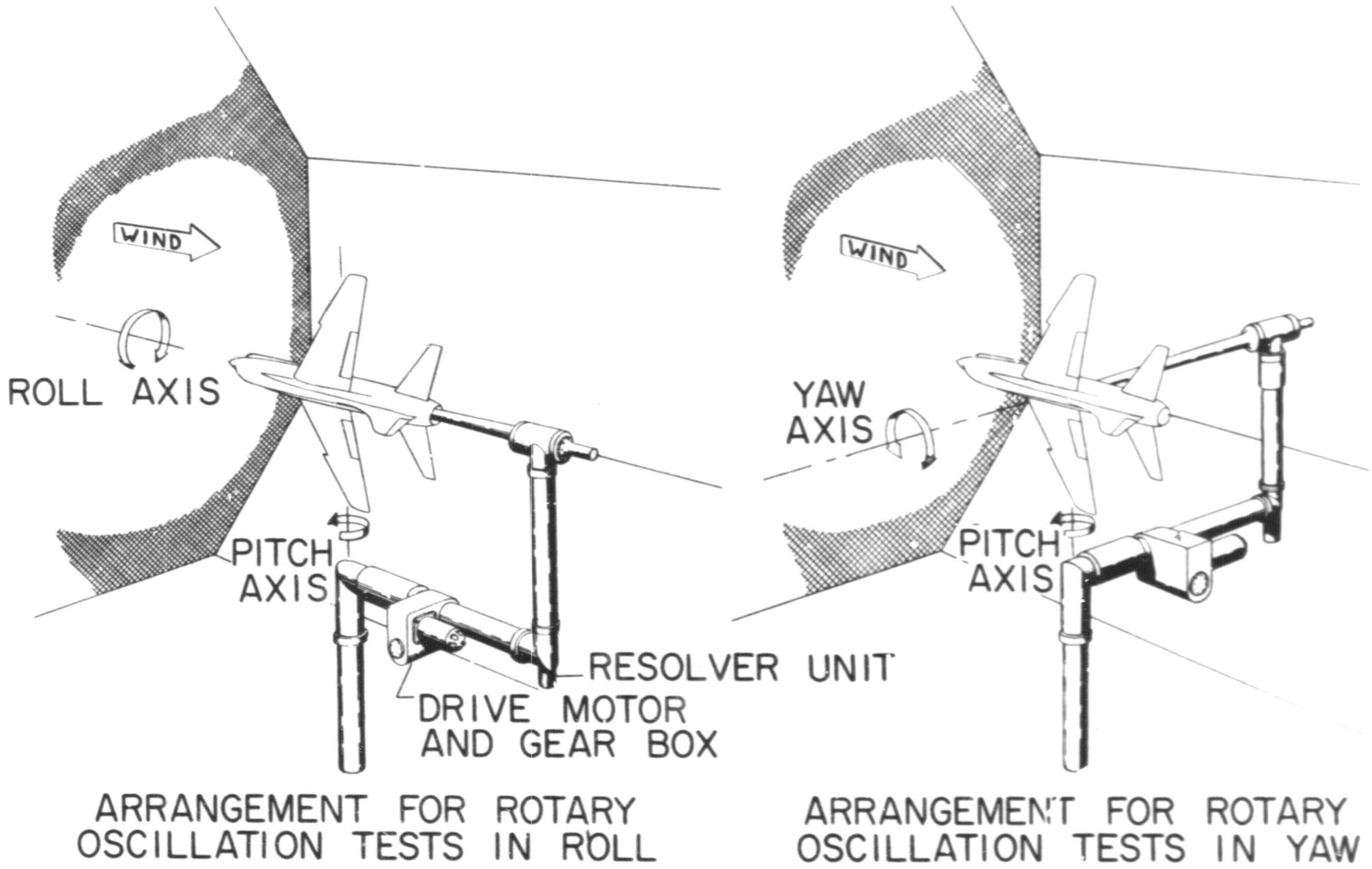


Figure 10.- Schematic sketch of the oscillation test apparatus.

Figure 11.- The National Aviation Facilities Experimental Center.

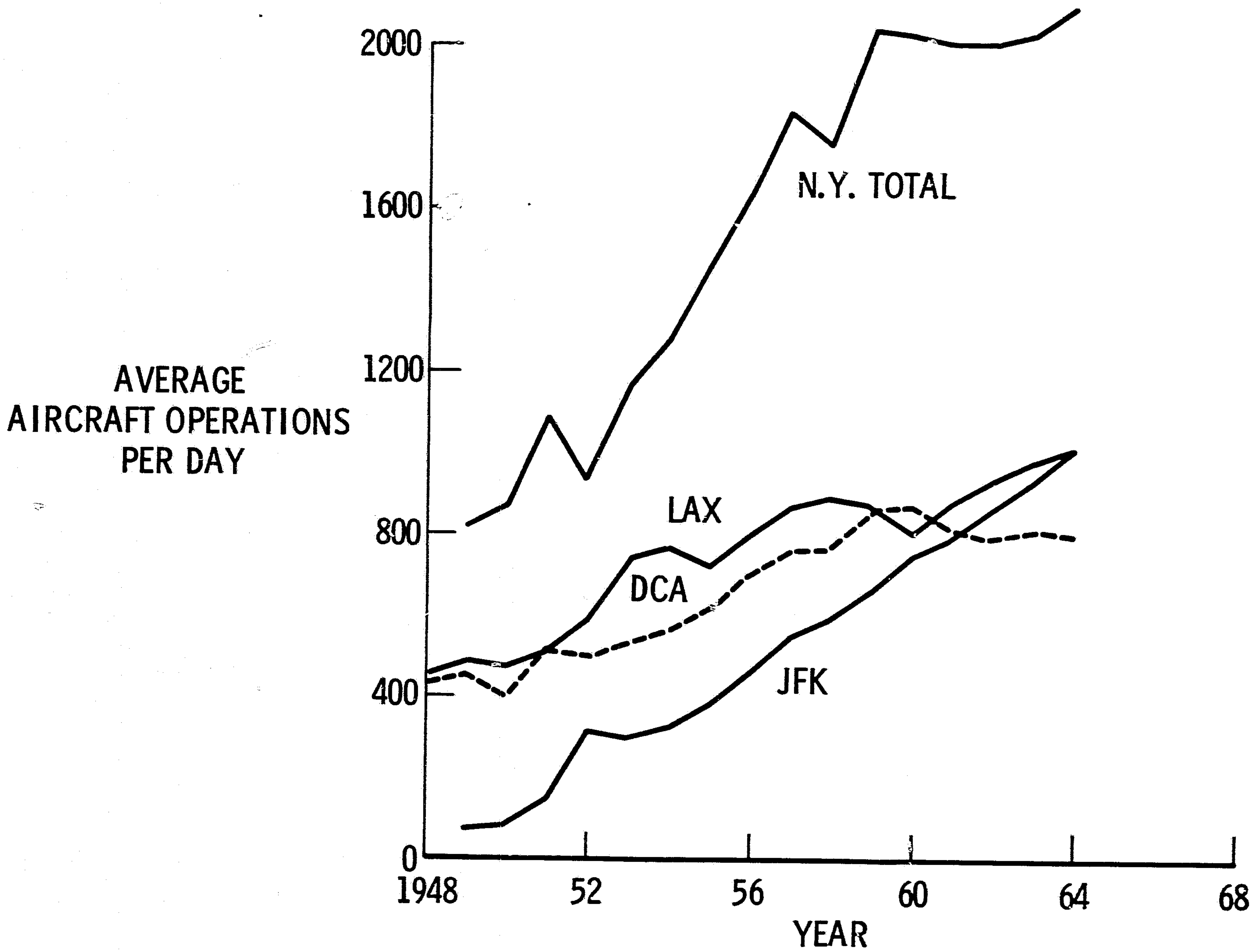


Figure 12.- Traffic at our major airports is increasing rapidly.

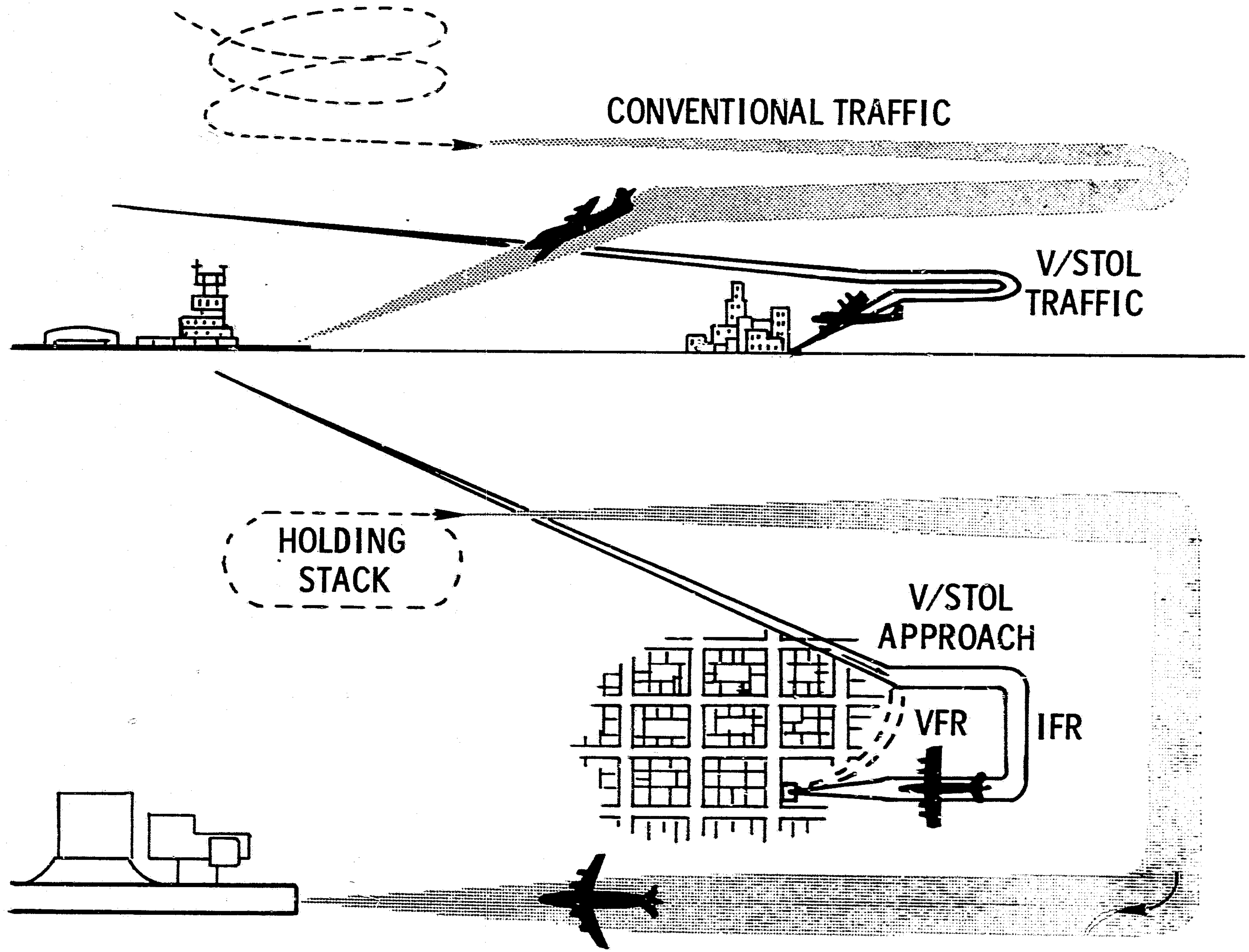


Figure 13.- To minimize delays from traffic congestion V/STOL and STOL aircraft will probably have to operate under conventional traffic in the terminal area.

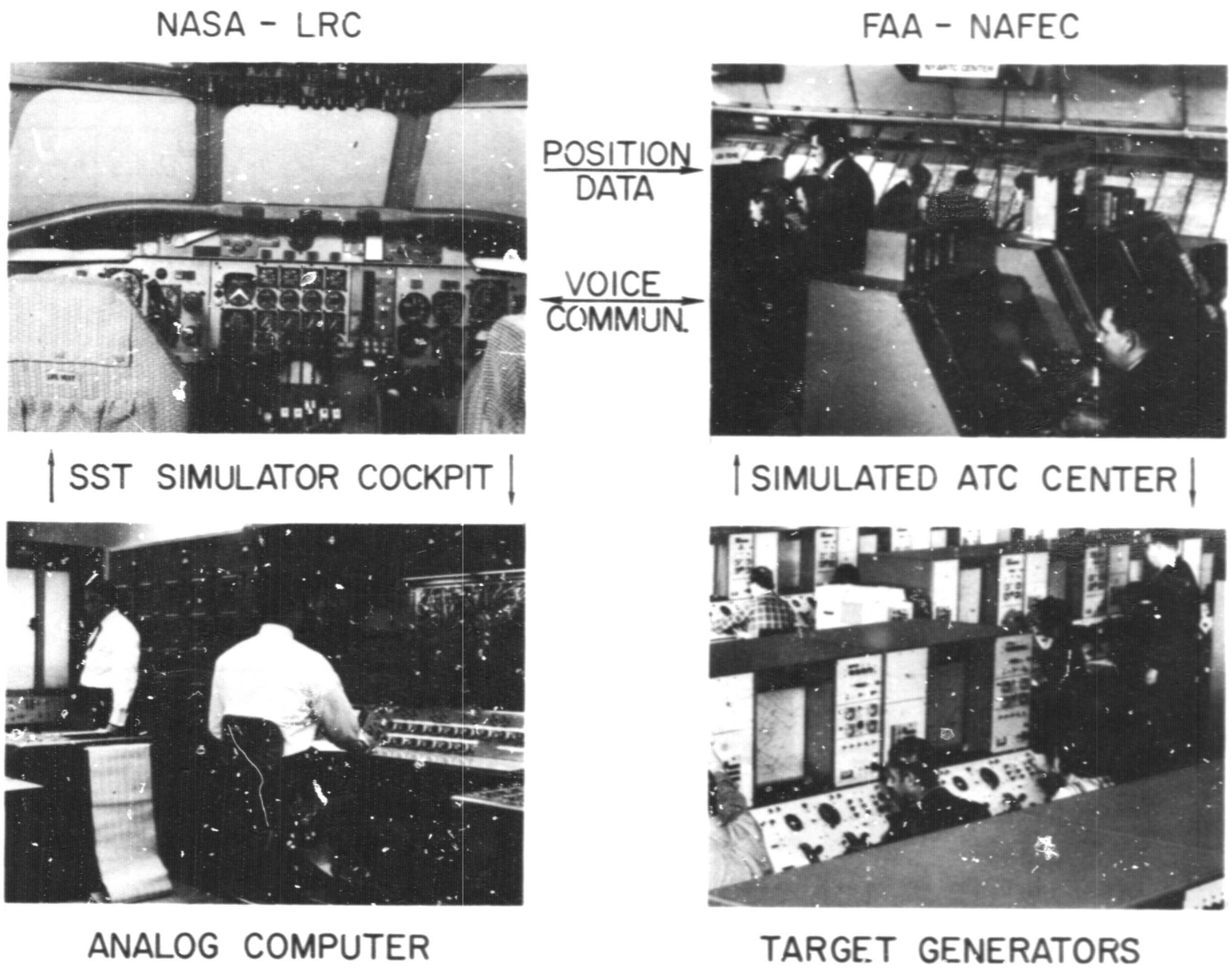


Figure 14.- SST - ATC simulation method.

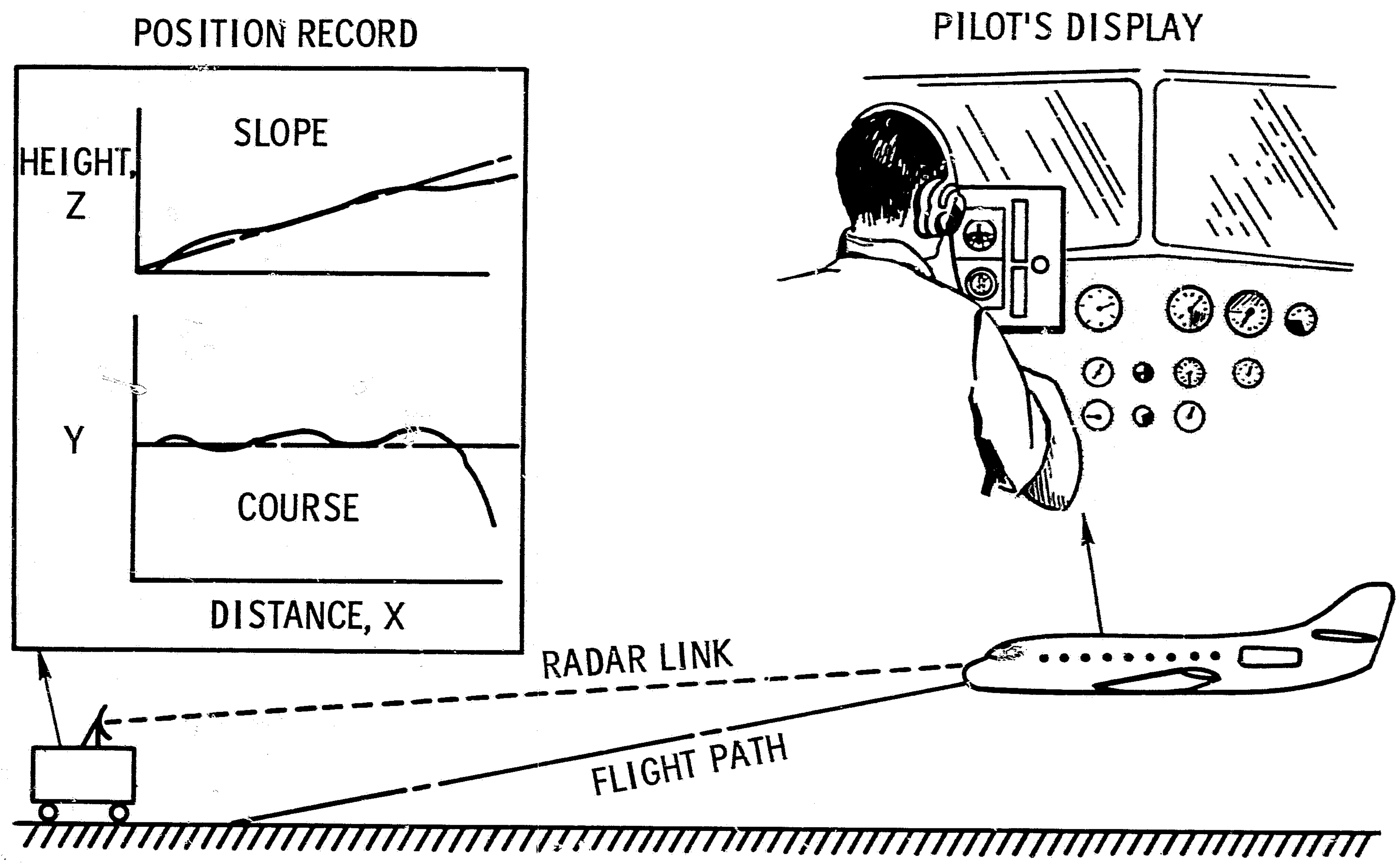


Figure 15.- NASA landing approach guidance research equipment.

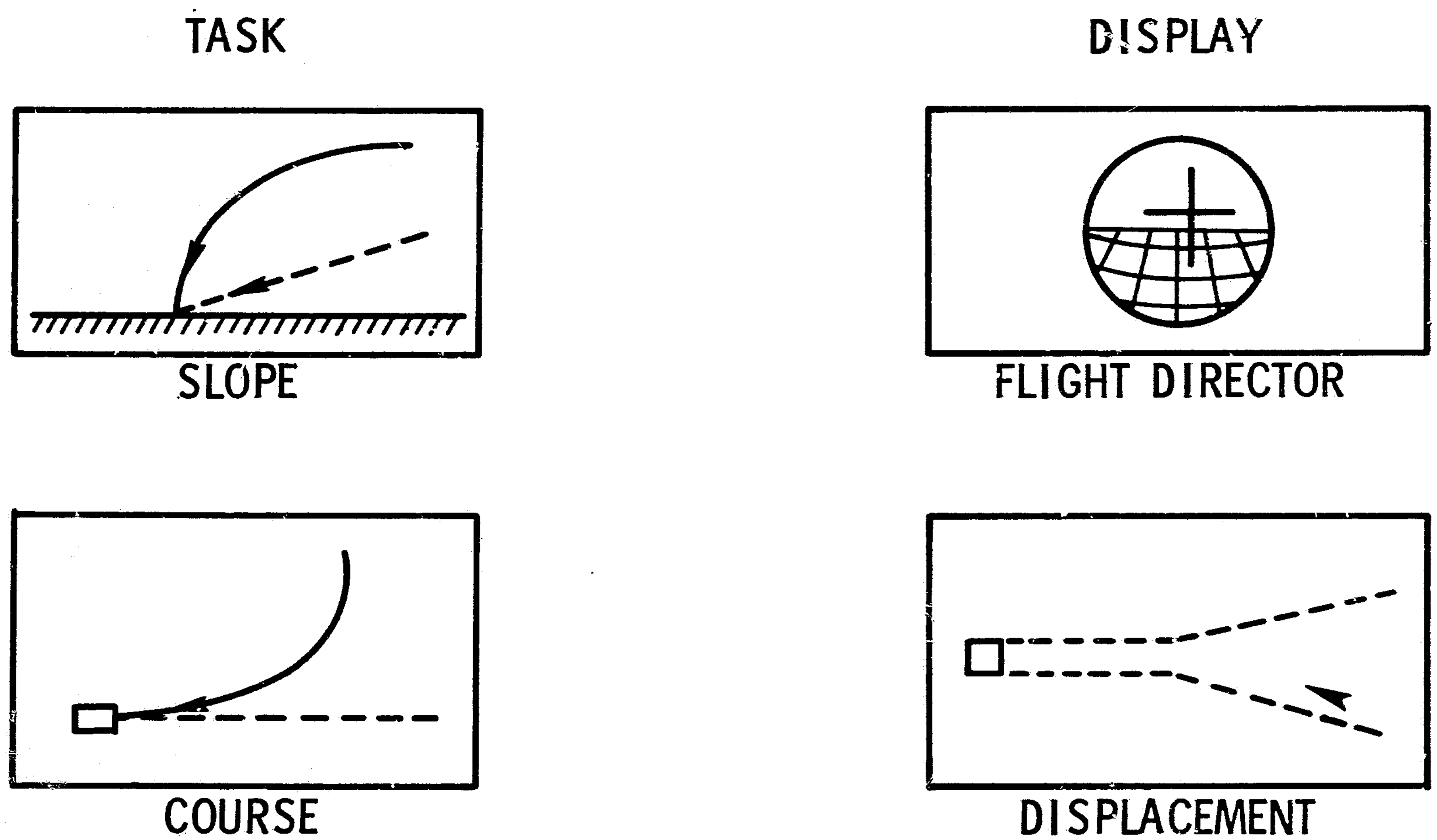
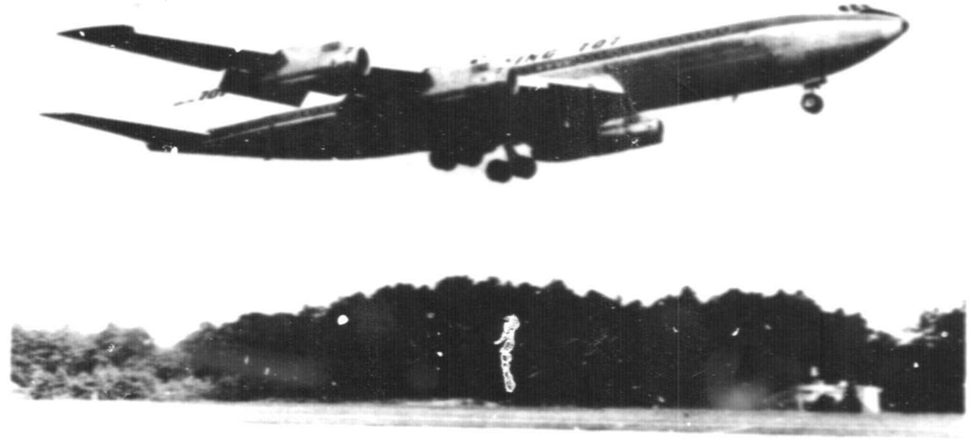


Figure 16.- Research flexibility of the landing approach guidance equipment.

HELICOPTER USED IN V/STOL APPROACH STUDIES



JET TRANSPORT USED IN NOISE STUDIES

P1127 USED IN JET VTOL STUDIES

Figure 17.- Aircraft being used with approach research equipment.

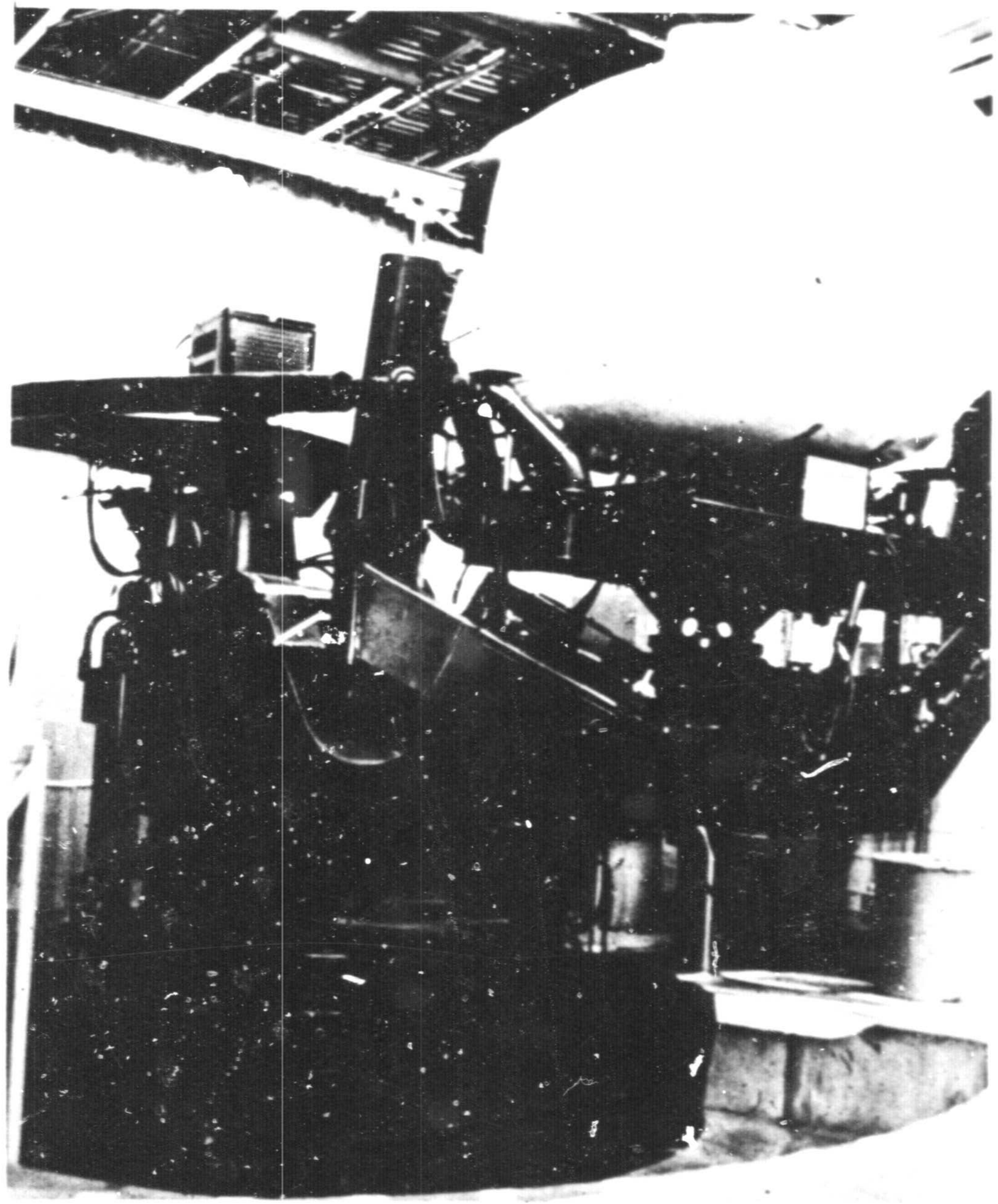


Figure 18.- Bell helicopter six-degree-of-freedom simulator used in human factors research.

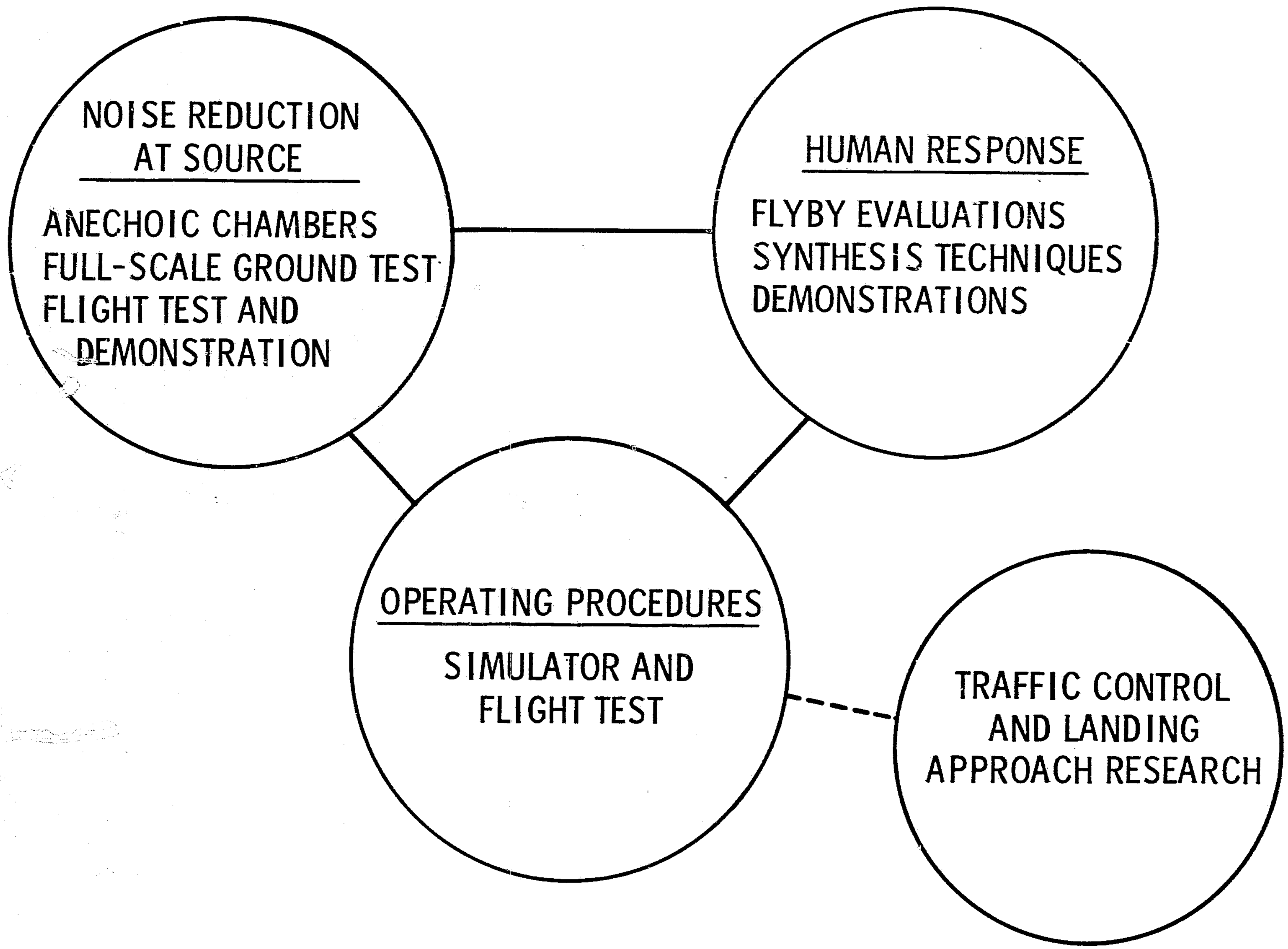


Figure 19.- Factors involved in aeronautical noise alleviation research.

Figure 20.- Studies of human response to aircraft noise.

NASA-Langley, 1967