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Aerodynamic testing using special aircraft

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(1) AERODYNAMIC TESTING USING SPECIAL AIRCRAFT.

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(2) WHY FLIGHT RESEARCH

Full-scale flight research has been utilized from the earliest days of aeronautics when it was required to demonstrate that such a thing as heavier-than-air flight was even possible. Up to the early 1930's, virtually all research was done in ground facilities. Consequently, flight research was generally limited to testing of production aircraft, usually with little modification. Starting in the 1930's, flight testing became of greater importance, particularly to investigate problems of stability and control and high-speed performance.

Since World War II full-scale aerodynamic flight research has become a necessity. Some of the main reasons for full-scale flight research are to:

- Verify theory, ground facilities, and design
- Investigate flight in the true environment
- Encounter new, or overlooked, phenomena
- Develop operational procedures
- Study the atmosphere, earth, and space

All of these reasons existed in the past, but are much more imperative now when aircraft are flying at such extremes of performance that ground facilities capable of complete full-scale simulation are prohibitively expensive. No facility other than full-scale flight test exists which can test at the proper Reynolds number, pressure, temperature, Mach number, atmospheric composition, and dynamic structural characteristics. This is, of course, particularly true

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at the highest speeds; however, even at transonic speeds both theory and wind-tunnel offer poor guidance for configurations that encounter separation.

Related in some degree to the ability to test in the actual environment is the ability to encounter new or overlooked phenomena. This usually occurs near the extremes of performance or as a result of a dynamic phenomena which has been inadequately analyzed. It is much more usual to find overlooked manifestations of old problems than to find completely new problem areas. An example of such a phenomenon is inertial coupling which was predicted (ref. 1) on the basis of dynamics years before it was encountered in actual flight. Its existence and importance, however, were not recognized until it had caused the near loss of several aircraft (ref. 2). Full-scale flight research also provides the opportunity to obtain information on the manner in which aircraft and their systems are actually used (ref. 3), as opposed to the assumptions on which they are designed. Such research is usually most applicable to structural and loads criteria. However, in some instances, for example, inertial coupling and pitch-up, such information is necessary to establish the importance of a problem. In other cases, such research may change the operational basis on which a system, such as a landing system, is designed. In this regard, flight research also serves as a means of sampling the actual environment to establish such environmental design factors as turbulence, atmospheric composition, and radiation. Other applications of flight research in the areas of meteorology (cloud seeding, thunderstorms) and astronomy (eclipse observation, etc.) might be mentioned.

WHY SPECIAL AIRCRAFT

Much of this flight research can be done, and is done, by utilizing production aircraft; however, in many cases, a greatly modified production aircraft or a special aircraft is required. A special aircraft is usually obtained to (1) extend performance, (2) study a special feature, (3) aid the development of mission aircraft, (4) simulate future aircraft, or (5) because of a lack of a defined mission. These various reasons will be discussed in detail later, but some general introductory remarks are in order. The first three items stem from the extremely high development cost of high-performance mission aircraft. High performance with efficiency, as required by a mission vehicle, is extremely expensive both in skill and money. It is much less expensive to provide this performance in a research aircraft which is not required to carry an appreciable payload or to operate at a high level of efficiency. In the same manner, a special feature, such as configuration, propulsion, laminar-flow control, or control system, can be investigated using a special aircraft without having to commit a mission vehicle to design. Such special aircraft can also aid in the development of mission aircraft in many ways, including investigation of operational procedures (ref. 4), aerodynamic characteristics (ref. 5), and propulsion (ref. 6).

Another reason for special aircraft is to enable the simulation of future aircraft. The special aircraft may be designed with a great degree of flexibility in order to enable the simulation of a wide variety of aircraft and are, thus, versatile general research tools.

The final general reason which has justified the building of a research aircraft is the lack of a defined mission for a particular flight regime which it was felt would be of future utility when more was known. Examples of this might be the X-1 and X-15 aircraft. At the time it was decided to build the X-1 there was no mission for a supersonic aircraft, but after the X-1 achieved supersonic flight it was found that supersonic aircraft were a military and, possibly, a commercial necessity. Again, in the case of the X-15 there was no established mission for a hypersonic aircraft but it was apparent that a number of potential missions could use the research information generated by such an aircraft. The X-15 has been flying for 4 years now, and, although the mission vehicle is still ill-defined, the X-15 work is providing much valuable research information in a speed regime unattainable by any other aircraft.

Of course, a special aircraft will usually be obtained for a combination of these reasons, that is, higher performance will not be obtained for its own sake, but to extend configuration tests or to obtain structural or aerodynamic information for a mission aircraft. In this paper it is intended to limit consideration of special aircraft to those primarily intended for aerodynamic research--high performance, special aerodynamic features, and simulation of future aircraft characteristics.

TYPES OF SPECIAL AIRCRAFT

Special Aircraft for Performance Improvement

Although many varying performance-expansion areas exist which might require the use of a special aircraft for research, as, for example, velocity or Mach number, altitude, dynamic pressure, duration, takeoff, and structural mass fraction, the present discussion will be limited to speed and altitude improvement, since these are the factors most commonly in demand.

Probably the most well known series of special aircraft obtained for performance exploration have been the rocket research aircraft resulting from the joint Air Force-Navy-NASA (NACA) research airplane program. This program (refs. 7 to 9) was initiated toward the end of World War II with the procurement of the X-1 airplane for flight tests in the transonic speed range and has continued to the present X-15 project. Figure 1 gives a chronology of the performance achievements of this series of aircraft and indicates that in this time period they normally possessed a 3 to 6 year performance lead over service aircraft. It should be pointed out that special aircraft obtained for performance improvement are usually considerably more expensive than those obtained for other purposes. This usually results from the increased performance requiring simultaneous advances in many different fields of technology, such as aerodynamics, structures, materials, and propulsion. The necessity to keep costs at a level consistent with the research purpose of the aircraft requires many compromises and much ingenuity. In many cases, design and operational features are utilized which would be completely unacceptable for a production aircraft.

In this regard it would be of interest to consider the X-15 airplane as an example of a special aircraft for performance expansion and examine the simplifications and compromises which were acceptable in the absence of a service mission. The X-15 procurement was initiated in 1954 in order to extend the capability of flight research to hypersonic speeds and altitudes above the sensible atmosphere (ref. 10). The original flight research objectives were to investigate:

Aerodynamic and structural heating
Hypersonic stability and control
Control at low dynamic pressure
Piloting problems
Landings
Aeromedical factors

It is obvious that these objectives were oriented toward exploratory evaluation of the design, and the conduct of research on the vehicle and crew in this higher performance environment. Consequently, as previously indicated, a premium was placed on simplicity, reliability, and ingenuity in order to obtain an acceptable research aircraft as early as possible and at a reasonable cost.

Figure 2 shows an inboard profile of the X-15 with notes indicating some of the features that were acceptable to a research aircraft but that would probably be totally unacceptable in an aircraft built for service use, except, perhaps, for a very limited, specialized mission. The use of the rocket engine allowed the use of a nonoptimized configuration, thus avoiding the necessity of a long, expensive, development program for a hypersonic air-breathing engine and enabling the use of a more or less conventional aerodynamic configuration. More efficient aerodynamic configurations had been proposed, but would have required extensive and lengthy wind-tunnel test and development. Although an efficient aerodynamic configuration and an air-breathing engine, or even a more efficient rocket, would have greatly increased the range, duration, and payload of the X-15, the project cost and development time would have been doubled or perhaps tripled. More important, there is no assurance that the particular configuration or engine used would have a mission application after the expenditure of this time and effort.

The use of air-launching is an example of an operational procedure, acceptable for research aircraft but usually not economical for service use, that has a considerable effect on cost, simplicity, and safety. In order to obtain the same speed and altitude performance from a ground takeoff, the X-15 would need to have a mass ratio $\left(\frac{W_g}{W_e}\right)$ of at least 3.3 instead of the 2.2 value that is sufficient with air-launching. This would require a much larger and efficient aircraft and would be a much more difficult problem of structural design. Air-launching avoids the dangers of a ground takeoff using rockets and permits use of a simple, reliable, gravity-fall landing gear and a jettisonable fin for stability, both features which would have been greatly complicated if ground takeoff had been utilized. Further examples of the simple, reliable systems utilized are the use of comparatively inefficient monopropellant (H_2O_2) reaction control systems and the dualized stability augmentation system with gain adjustable by the pilots.

Similar requirements of simplicity and reliability apply to the research instrumentation utilized on the research aircraft. The instrumentation should be allotted sufficient weight and volume at the initiation of the design to enable the use of adequate instrumentation to obtain the research information required. In the interests of reliability, previously developed instrumentation should be utilized as much as possible; the use of experimental instruments in an exploratory flight program on an experimental aircraft with possibly a developmental engine may reduce the probability of satisfactory data to the vanishing point. In some cases, it is not possible to utilize standard instrumentation; for example, in the X-15 standard NASA (NACA) instrumentation was utilized but a new airflow-direction sensor had to be developed to withstand the aerodynamic heating. This instrument, however, was not utilized on the early X-15 flights; installation was delayed until it was thoroughly proven on the ground. It was used on a number of noncritical X-15 flights for test before being used on the high-performance flights for which it was obtained. Even on these flights, backup procedures were developed (ref. 11) for use should the instrument fail.

Although it is not intended in this paper to describe flight testing procedures, which have been covered in great detail in a number of texts and reports (for example, refs. 12 to 14), a word might be said with regard to flight test technique in general and performance expansion in particular. A guiding rule for all exploratory flight testing has been to test incrementally to the greatest extent possible. It is, of course, not possible to insure complete safety, but incremental testing by capable flight crews, with continuous, capable, data analysis insures the closest approach to complete safety feasible in this imperfect world. In the case of X-15 performance expansion, flights to increased speeds were interspersed with flights to increase angle of attack, to obtain stability derivatives, and to obtain aerodynamic- and structural-heating information. The same was true in the case of altitude expansion. Similar approaches apply in the case of other flight research areas, for example, references 15 and 16 which indicate this approach as applied to investigation of inertial coupling and directional stability. On occasions this incremental testing philosophy has been insufficiently well applied and incidents and/or accidents have occurred (refs. 17 and 18). In recent years the use of analog simulation and analysis has been of tremendous assistance in the performance of safe flight testing. Its application in the X-15 program is described in references 19 and 20.

After the performance-expansion aircraft has completed its original mission, it is quite possible that its useful life has not ended. It is a developed aircraft perhaps possessing performance capabilities appreciably better than any other contemporary aircraft and having the capability of carrying a good instrumentation payload. It is logical then, for simple economy, to examine other means of making use of this research aircraft. An example of such application is the X-15. Three years after its first flight it had completed its original mission; however, its performance capabilities have led to its utilization as a facility for numerous investigations in a wide range of areas such as aerodynamic research, including airflow characteristics, aerodynamic noise, and transition; propulsion systems; hot structures; space observations; environmental measurements; and subsystems development. Although many of these investigations require relatively small modification to the airplane, the X-15 was sufficiently promising in this utilization that it was decided to rebuild the X-15-2 aircraft, following its crash landing, to a higher-performance configuration with expanded research facility capabilities. It now appears that the utilization of the three X-15 aircraft in this type of special aircraft work will be of greater duration than the program for which they were originally obtained.

Investigation of a Special Feature

Although special aircraft can be utilized to investigate many special features, such as configuration, propulsion, mode of operation, subsystems, and aerodynamic innovations, including boundary-layer control, this paper will consider only their application to configuration testing. Although all new aircraft are to some extent configuration-test vehicles, a number of aircraft in the past have been obtained to specifically investigate radical deviations from the then accepted normal configuration. During World War II the incentive for increased performance led to the development of a number of unconventional aircraft and since World War II the requirements, first of transonic flight and then supersonic flight, resulted in a number of special configuration aircraft. Many of these were a part of the previously mentioned Air Force-Navy-NASA (NACA) research aircraft program. A listing of some configuration exploration aircraft is given in figure 3. It might be noted that many of these configuration features have been utilized on service aircraft, or are projected for such use. It can be expected that further special configuration aircraft will be obtained to satisfy the requirements of flight at all speeds from subsonic to reentry.

In order to keep the cost of configuration research vehicles to a minimum, they should be kept as simple as possible and have no more performance than necessary. Although this approach to a flight research program will be discussed more completely later, its application will be illustrated by reference to two recent NASA flight projects, the Paresev and M-2 (fig. 4). These vehicles were constructed by the Flight Research Center for the sole purpose of exploring the flight characteristics, at low speeds and landing, of configurations representative of the paraglider class (ref. 20) and the lifting-body class of vehicle. In each case, the simplest approach feasible was used. The vehicles are unpowered, have unboosted controls, fixed landing gear, are of the simplest construction, and utilize readily available components. Since determination of low-speed flight characteristics was the goal of these programs, it was unnecessary to have more than a minimum performance capability. This was provided by towing the aircraft to altitude and performing the tests in gliding flight. In order to keep costs low and minimize danger of pilot injury, the wing loading was kept as low as possible. With the paraglider, it was possible to vary the wing loading sufficiently to cover the probable range of some applications; however, the M-2 wing loading is perhaps only one-fifth or one-sixth of that to be expected of a mission vehicle. This element of compromise in the configuration was felt to be acceptable in an exploratory program such as this.

It might be noted here that the more lightly loaded vehicles are probably considerably more difficult to land than they would be if they had the same aerodynamics and higher wing loadings. This can be seen by reference to figures 5 and 6 which indicate the effects of lift-drag ratio and wing loading on the landing maneuver when performed at a constant flare acceleration of 1.6g. Increasing wing loading increases flare speed, increases the altitude required, increases the time during the flare, and increases the time available between the end of the flare and touchdown. Lift-drag ratio has a rather small effect on landing speed, but low lift-drag ratio greatly increases the altitude required and time required during flare and greatly reduces the time between flare completion and landing. These effects of lift-drag ratio are most pronounced at the higher wing loadings. It is apparent that an aircraft having a wing loading of 50 psf and a lift-drag ratio of 3.5 will initiate the flare at an altitude 10 times as high, and have 3 times as much time to perform the flare and adjust the flight path for the landing as for a wing loading of 5 psf.

Some flight data illustrative of these points are shown in figure 7 in which the landing flares of a number of aircraft of varying wing loadings are compared. All but the M-2 with 40 psf wing loading are flight data. The increase in time available for landing with increased wing loading is very evident and very much appreciated by the pilot. It was decided to utilize a low wing loading on the M-2 because it was expected that the M-2 would be difficult to fly and it was desired to reduce risk of pilot injury, in this exploratory phase, by keeping the landing speed as low as possible.

It might be of general interest to recount the cost for the first 12 months of these two projects as representatives of such simplified approaches to flight testing (all figures are approximate):

	Paresev	M-2
Total flights (ground and air tow)	200 ?	90 ?
In-house man-hours	11,445	28,270
Total cost	$52,919	$157,160
Aircraft	4,278	28,880
Test operations	6,141	15,680
Man-hours	42,500	112,600

These costs do not include use of equipment that was available in-house and do not include the overhead costs that a private company would have to include. It does include Paresev tow plane rental, purchase and modification of a tow automobile, and reconstruction of the Paresev four times and the M-2 once.

It is not expected that all such projects can be performed so inexpensively. The follow-on aircraft in these programs will more nearly approach mission vehicles in their requirements and, consequently, will be substantially more expensive. The next step in the lifting-body program will serve to illustrate this. The next phase of the lifting-body aircraft project will be directed toward the investigation of the effects of high wing loadings. The aircraft will have the capability of being ballasted from a wing loading near 20 psf to a wing loading in excess of 40 psf. In these tests it will still be operated as a glider but, in order to improve safety and simplify operations, the aircraft will be launched from a B-52 (the same one used in the X-15 program).

In order to keep the cost of this heavyweight, higher performance aircraft to only one order of magnitude greater than the lightweight M-2, it will be necessary to employ unconventional techniques. It is not intended to employ normal highly optimized aircraft design and construction procedures but, instead, to apply well known, proven, and reliable techniques, components, and methods to bring the vehicle to full flight test with a minimum of special development, paper work, or formality and with heavy reliance on experienced engineering judgment. The aircraft will not be required to meet the usual detailed service specification, and there will not be a requirement for formal data and drawing submittal. Maximum use will be made of systems and components available from service inventory. NASA will be responsible for all aerodynamic work and will maintain responsible engineering and inspection representation at the contractor's plant.

These procedures are acceptable for a configuration research aircraft project where high performance, structural efficiency, and subsystem optimization are not required and where only one or two aircraft are going to be built for restricted use. These procedures should enable the procurement of these aircraft for only a fraction of the cost if conventional procedures were utilized.

Before closing this discussion of configuration special aircraft, it might be well to emphasize several points. The configuration special aircraft should have as low performance as will allow the obtaining of the required data; if the performance approaches that of a mission vehicle, the cost will also. Keeping the cost down will enable the testing of more configurations in a fixed budget. Good, complete flight instrumentation and ground facility backup should be utilized to enable the best possible analysis and interpretation of the flight data for extrapolation to mission aircraft. In this regard, the aerodynamic configuration should be compromised as little as possible in order that the results be of greatest value.

Special Aircraft for Flight Simulation

Just as all new aircraft are to some extent configuration special aircraft, all special aircraft are flight simulators when viewed from the standpoint of a possible future service aircraft utilizing a feature of the special aircraft. In this section, however, it is intended to treat only those types of special aircraft utilized specifically for simulation.

Flight simulation is used to investigate characteristics which cannot be adequately investigated in ground facilities. The inadequacies of ground facilities usually result from their inability to apply all the proper environmental factors to the aircraft or, to the pilot, all the sensory cues which he receives in normal flight. Quite often the ground facilities supply some sensory cues correctly and others in a contradictory fashion, thus raising the need of flight tests for verification of conclusions. In other cases, the simulation is just beyond the capability of ground facilities, for example, zero g, and can only be done in flight.

Flight simulation is most commonly utilized in two areas: performance and operation, and handling qualities. Both of these areas will be discussed but only in general, since many references exist in each area.

Some representative examples of flight simulation in the performance and operations area are tabulated in figure 8. The use of the F-104A to simulate the landing of the X-15 for pilot proficiency is well known (refs. 21 and 22);

however, the other simulations mentioned are less well known. There was some doubt as to the performance requirements of the X-20 abort rocket, so the Flight Research Center performed an investigation (ref. 4) utilizing the F5D aircraft to simulate the X-20 performing the abort. In this simulation, the F5D was flown at high speed close to the ground and then pulled up into a vertical climb in such a manner that its speed and altitude matched that of the X-20 at abort rocket burnout. The F5D lift-drag ratio was adjusted at that point to match the X-20, and the pilot performed the planned recovery to a landing at the proper geographical location to simulate the skid strip at the X-20 launch site. By performing a number of such maneuvers under varying conditions (including restricted visibility), it was possible to establish the abort rocket requirements.

In the case of the supersonic transport, it was desired to determine the impact of this type of aircraft on air traffic control in the terminal area. This was done (ref. 23) by utilizing an A5A aircraft to simulate an idealized supersonic transport and flying it in and out of a congested terminal area (Los Angeles International Airport) under normal air traffic control but operating as the supersonic transport would be expected to operate. By doing this a number of times under varying conditions, some of the critical areas of supersonic transport air traffic control operations were established.

The final example of performance and operations simulation is one that is being considered at present. The X-15 has performance capabilities approximating those required of an aircraft-type recoverable booster and, consequently, could be used to simulate such an aircraft. Provisions are being incorporated on the X-15A-2 for test of sub-scale air-breathing engines on such flights (ref. 24).

The use of flight simulation for investigating handling qualities has a long history. Figure 9 indicates some of the work that has been, and is being, done in this area. References 25 to 28 are representative of the work being done in this area. The only example of this type of simulation that will be discussed is the latest, the general-purpose airborne simulator (GPAS), which is as yet only in development. The usual airborne simulator is a variable-stability airplane which has been mechanized by use of a response feedback system to provide any desired stability characteristics by driving the airplane control surfaces in the same manner as is done by conventional stability augmentation systems. Recently, a more advanced concept has come into use consisting of the use of an electronic model to control the aircraft. The GPAS is of this type. The GPAS project is described in some detail in reference 28, and the aircraft is illustrated in figure 10. The aircraft is a small subsonic jet transport which will incorporate the model-controlled simulation system, a variable-feel system, and a display driven to represent the simulated aircraft. The ailerons, rudders, elevators, and engine throttles are controlled by the simulation system. A hybrid computer with a capability of providing a model ranging in complexity from two degrees of freedom to six degrees of freedom will be incorporated.

This simulator should enable the pilot to evaluate handling qualities, control feel, display, and to some extent performance of the simulated aircraft. It is planned to use this simulator in support of the supersonic-transport program for the development and validation of handling-qualities criteria, evaluation of piloting problems, and investigation of pilot training requirements.

A PROCEDURE FOR UTILIZING SPECIAL AIRCRAFT

Flight research has long had the reputation of being the most expensive form of aerodynamic research, in terms of money and time, and also one of the most difficult from which to obtain precise data. In recent years, the expense has become so large, particularly for performance expansion, that only a few special aircraft are initiated. Where in the 1940's and 1950's it was possible to have several special aircraft in work simultaneously, high costs now force long paper studies to "optimize" and "justify" the research mission and the particular design. This results in long periods of time in the initial stages where much paper is being generated but little new information is being obtained on which to base decisions. Considerable study of this problem as it relates to development and production of service aircraft has been performed, primarily by Rand (refs. 29, 30, and 31, for example), and it appears that some of the general conclusions may apply just as well to the special aircraft being considered here. Some of these conclusions may be paraphrased to state:

> Do not try to make detailed plans and analyses far into the future at the expense of actual tests now. This can result in the program being "committeed or studied to death."
>
> Avoid placing remote mission requirements on special aircraft, but instead have general research objectives and stick to them without continuous redirection of goals.
>
> Investigate several promising approaches in the early inexpensive stages by getting hardware into test as soon as possible.

Everyone can think of projects in the recent past which have been excessively delayed, some to the point of cancellation, and whose costs have soared exorbitantly through failure to observe some of these guidelines.

In this portion of the paper, an attempt will be made to apply these general guidelines, and the experiences alluded to previously in the paper, to develop a procedure of flight research that promises to be more productive at less cost than current techniques.

One of the first major steps of such a program is the identification of sufficiently broad research goals to allow the establishment of the program and the identification of the time to initiate flight work. This is the period when the general research program is perhaps in most danger of being studied to death as a result of insufficient data and perhaps attempts to place vague mission requirements on the research program. For example, a broad, general research objective would be the investigation of the aerodynamic and flight characteristics of that class of vehicles known as "lifting bodies" which are generally characterized as being semi-blunt, wingless configurations having a hypersonic $(L/D)_{max}$ near 1 1/4 and capable of horizontal landing. Many such configurations have been investigated by various groups, and it has been established that they might be suitable for reentry application. No mission requirements, however, have been established. When then should the flight program be initiated, and what kind of a flight program should it be?

It is obvious that to attempt to initiate a program involving an entry vehicle at this early date would be difficult, there being insufficient knowledge, money, and justification for such a step. A flight program limited to research investigation of the low-speed range, however, would not suffer from these shortcomings. Once the requirement for large sums of money is removed, it is possible to make decisions earlier when less detailed information is available and, similarly, to carry several approaches into test to give a broader base to the research. Thus, the decision to initiate a special aircraft program could be made as soon as sufficient wind-tunnel tests had indicated that the aircraft had a reasonable chance of successful flight. It would not be necessary, or desirable, for the aircraft to be of optimum configuration. In fact, if two potential configurations were available, it would be advantageous to utilize both in order to avoid the impression that the selected configuration was thought to be optimum.

The decision to go into a special aircraft program has an immediate salutary effect on the wind-tunnel and analytical programs by giving them a focus and forcing some attention to the problems involved in operational use of a configuration. The investigators have a greatly heightened interest and enthusiasm because the results of their labors are going to be put in use at an early date.

The flight research program decision sequence is illustrated in figure 11, and a possible time phasing is shown in figure 12. In figure 11, the squares denote decision points and the circles flight test activities. The solid lines indicate the portion of the program that is currently firm, and the dashed lines indicate hypothetical extensions. Only one chain of decisions is illustrated; the alternative choices are not traced out.

The next decision to be taken is the type of special aircraft to be constructed as characterized by its performance range. This is determined by the speed range in which problems are expected and the cost of attaining the particular speed range. In the case of the lifting-body class, it was felt that landing and transonic speeds were the immediate problem areas. In particular, landing was felt to be worthy of initial attention because it, of course, was one of the primary reasons for considering this class of aircraft. Consequently, the decision was made to initiate flight test with the minimum, lightweight M-2 aircraft described previously. This was done despite the knowledge that the results would be of limited value because of the low wing loading. It was felt that the configuration was sufficiently radical that the tests would be a persuasive indication of potential. In addition, as indicated, the cost was low enough that failure would not cause undue censure.

With the satisfactory accomplishment of the initial flight tests of this minimum vehicle, the next phase of the general research program could be initiated. This, as indicated in figure 11, is the procurement of full-scale heavyweight special aircraft which will enable the investigation of the actual subsonic flight and landing characteristics. It is planned to utilize two configurations in this phase, since the feasibility of flight has been established by the minimum vehicle and a broader research base will be beneficial. These aircraft will be of variable wing loading to permit an incremental approach to full wing loading and will be air-launched from the B-52, as is the X-15.

Tests of these special aircraft will still leave unanswered questions regarding the transonic speed range; consequently, a third generation of special aircraft might be required. However, in actuality, it is expected that the heavyweight aircraft used in the subsonic tests will be suitable for this purpose when retro-fitted with a rocket powerplant. This retro-fitting will again be rather inexpensive by virtue of using available production parts and systems.

During or upon completion of the transonic phase of the program, a decision will have to be made. The program can be terminated, a more promising configuration may have evolved which could be tested, or mission requirements might have been established and actual development of a mission vehicle have been initiated. It is quite probable, in this latter case, that the same approach (fig. 12) utilizing some special aircraft, will be economic and productive, leading to a more satisfactory prototype at an earlier date.

The approach, as illustrated, applies to special aircraft for configuration study, but modified programs could be evolved for other research objectives. Of course, it is not always feasible to keep the cost to the low level of the example configuration program (probably a total cost less than 5 million dollars), particularly in performance exploration or propulsion research; however, ingenuous observance of the guidelines mentioned earlier will minimize cost and time.

FUTURE SPECIAL AIRCRAFT

It is apparent from the foregoing survey that there will be many special aircraft obtained for various purposes in the future. There will undoubtedly be continued use of aircraft having unique characteristics such as the X-15 and the B-70 for a range of investigations in their particular areas of capability. The X-21 is probably the first evidence of renewed interest in laminar-flow research in flight and may well be followed by other special aircraft in this field. It is probable that the extreme performance requirements being considered, such as entry, low-level penetration, VSTOL, and supersonic cruise, will stimulate a variety of special aircraft for all types of research.

One other potential development in future special aircraft should be discussed. Aircraft, as their size and performance outgrew ground facilities, have come to be developed, and qualified, essentially in flight test. The same is true of space vehicles, both boosters and reentry vehicles. Engines, however, continue to be developed and qualified in ground facilities, although flight tests in other aircraft (ref. 6) are made during the final development phase. However, the time may very well have arrived when it is impractical to provide ground facilities to adequately develop the engines required for high-performance future aircraft. The development of a large ramjet to operate at Mach numbers from 8 to 10 requires a ground facility of staggering complexity and cost. Consequently, serious consideration should be given toward the development of a special aircraft for in-flight development and qualification of engines.

This aircraft, in keeping with the previous discussion, should be kept as simple as possible consonant with its mission. Its size would be such as to accommodate one of the engines to be developed and, since it will be utilized in a geographical area abounding in landing sites, it need have only that single engine. If sufficiently small, it may be air-launched; otherwise, it should take off and land normally. It should be capable of the performance range in which it is designed to develop the engine, but need not have high aerodynamic or structural efficiency. Above all, it should not be compromised in a misguided attempt to incorporate an ultimate mission capability. Properly designed, such an aircraft would provide a facility that would serve to develop and qualify engines and conduct flight research on structures, aerodynamics, and operations as well. It would serve well as a predecessor to the hypersonic transports and recoverable boosters of the future and provide a facility for the investigation of their problems for years to come.

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SIMPLIFIED SPECIAL AIRCRAFT FOR CONFIGURATION RESEARCH

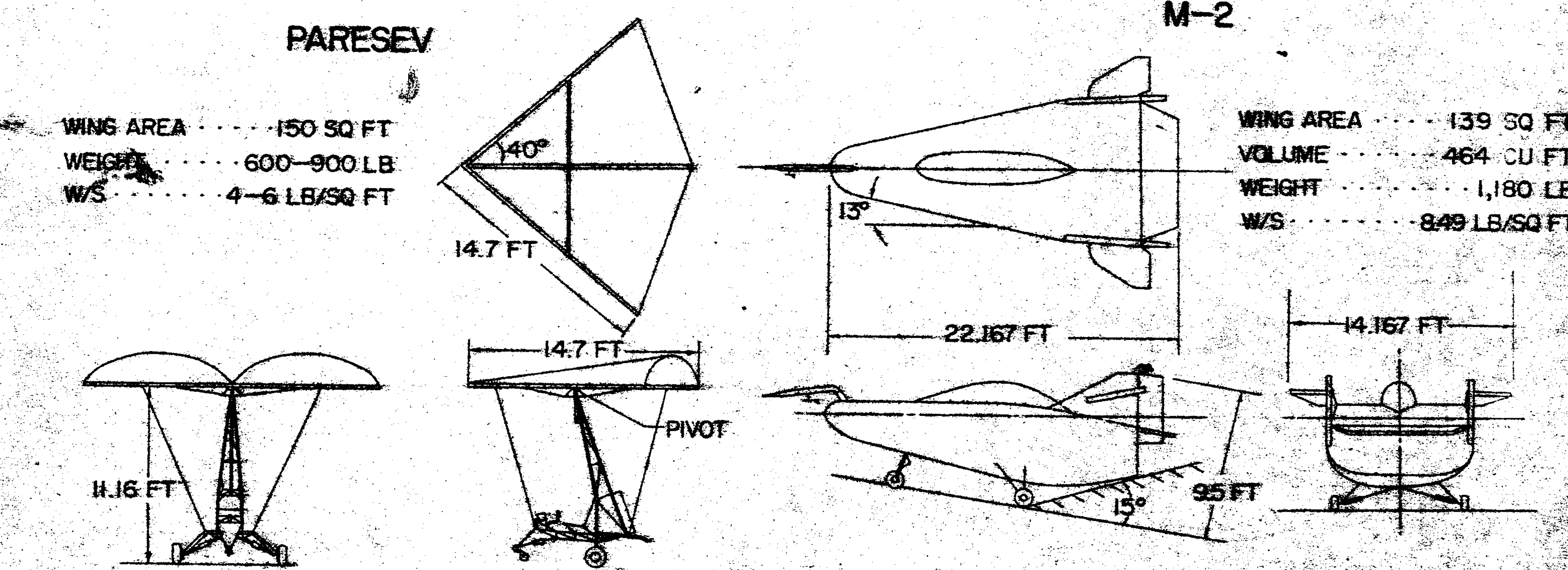


Figure 4

PERFORMANCE COMPARISON

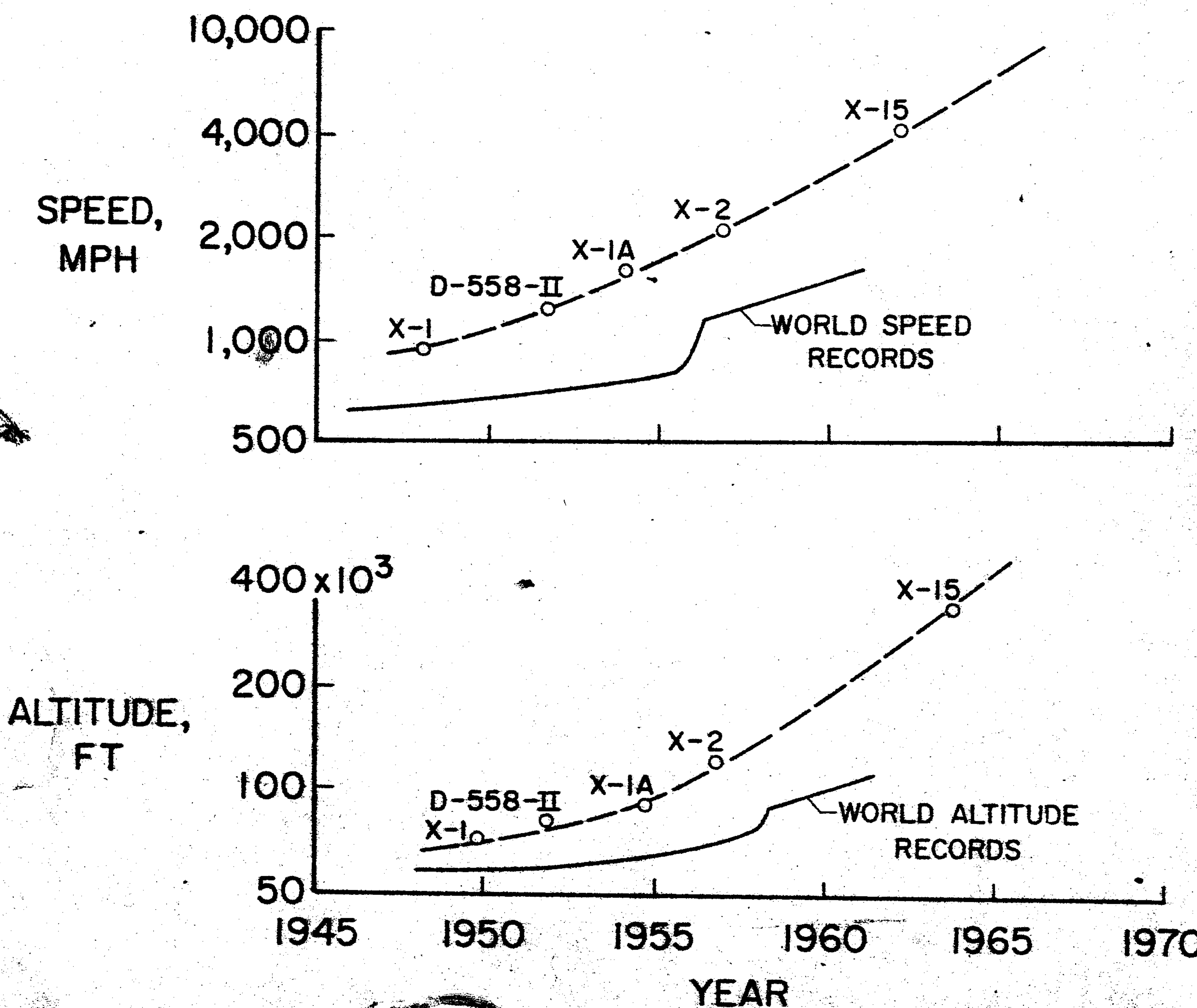
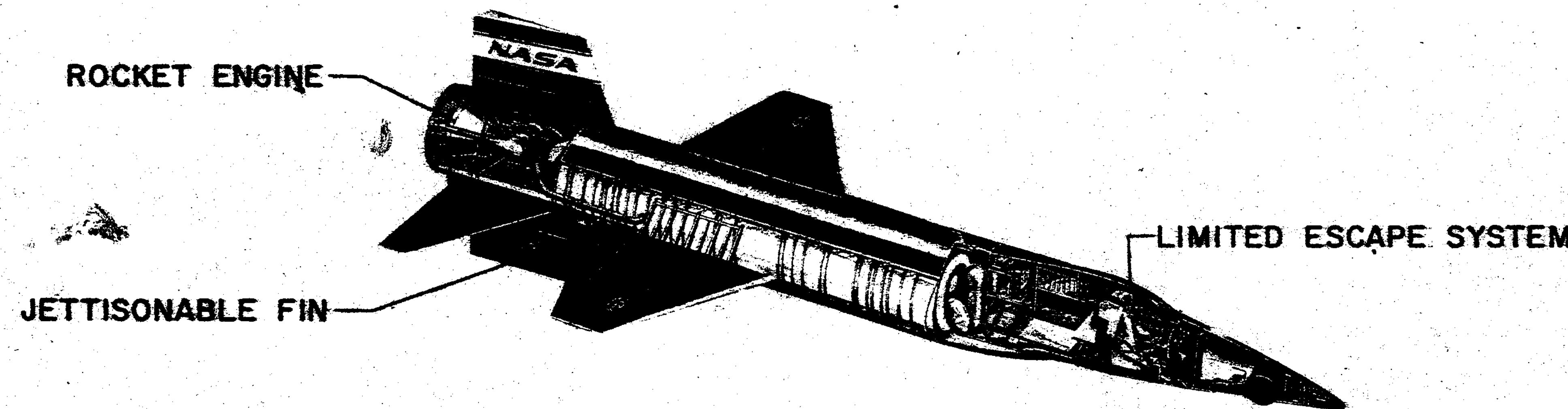


Figure 1

X-15 SPECIAL FEATURES



NONOPTIMIZED CONFIGURATION

AIR LAUNCH

"SIMPLE" SYSTEMS

HEAT-SINK CONSTRUCTION

Figure 2

AIRCRAFT FOR CONFIGURATION STUDY

AIRCRAFT	MANUFACTURER	CONFIGURATION
XP-55	CURTISS	CANARD
XP-56	NORTHROP	TAILLESS
XP-79	AVION	TAILLESS
V-173	VOUGHT	DISC
XF5U-1	VOUGHT	DISC
B-35/B-49	NORTHROP	TAILLESS
L-39	BELL	SWEPTWING
D-558-II	DOUGLAS	SWEPTWING
X-4	NORTHROP	TAILLESS
X-5	BELL	VARIABLE SWEEP
XF-92A	CONVAIR	DELTA

Figure 3

FLARE SPEED AND ALTITUDE AS AFFECTED BY W/S AND L/D

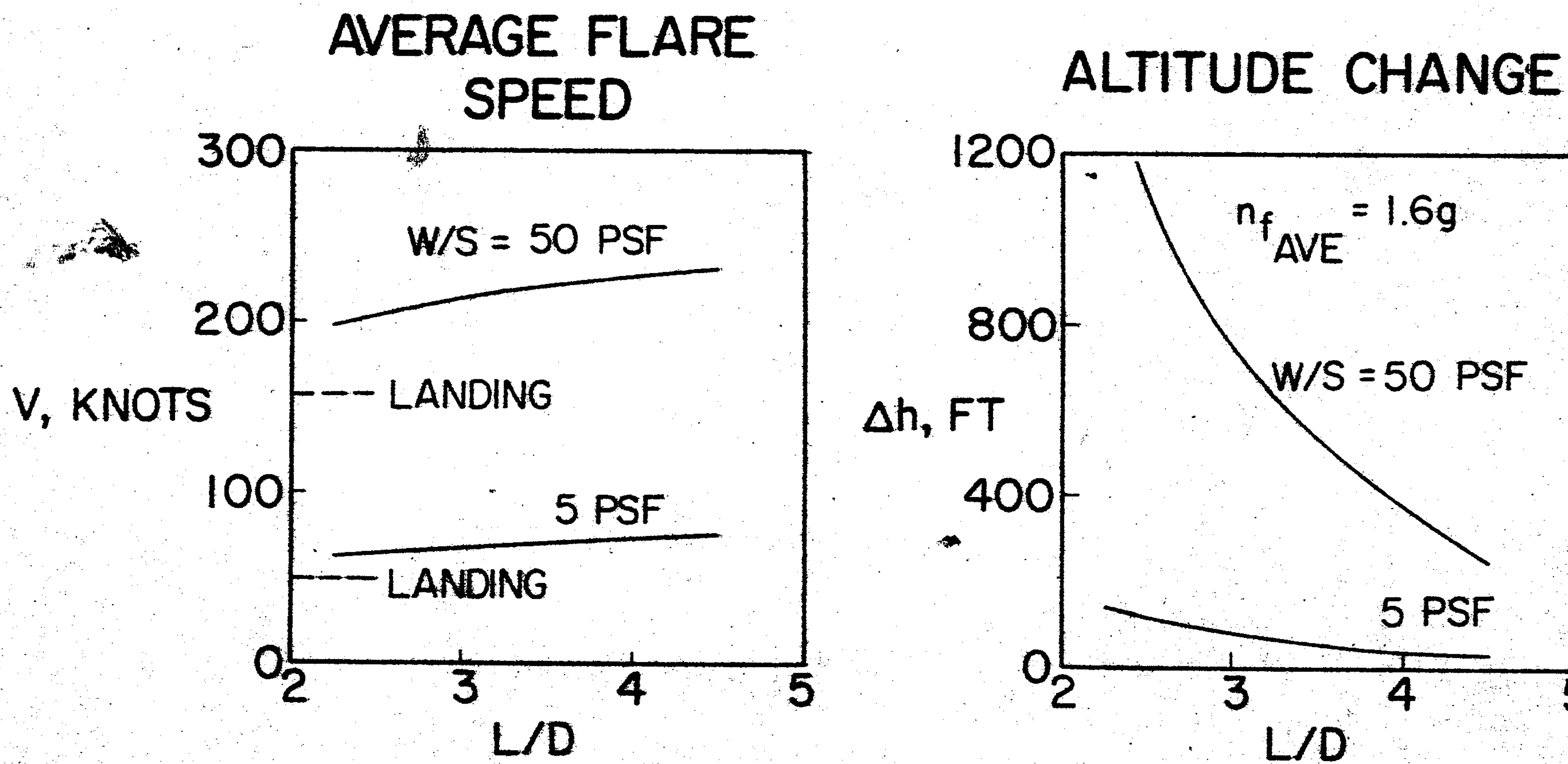


Figure 5

LANDING MANEUVER TIME AS AFFECTED BY W/S AND L/D

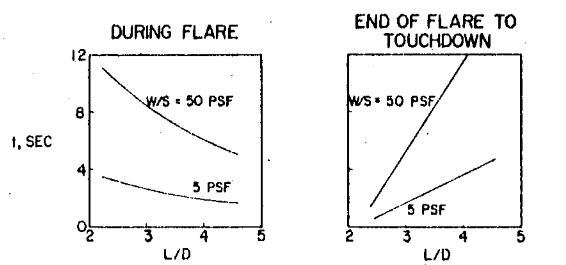


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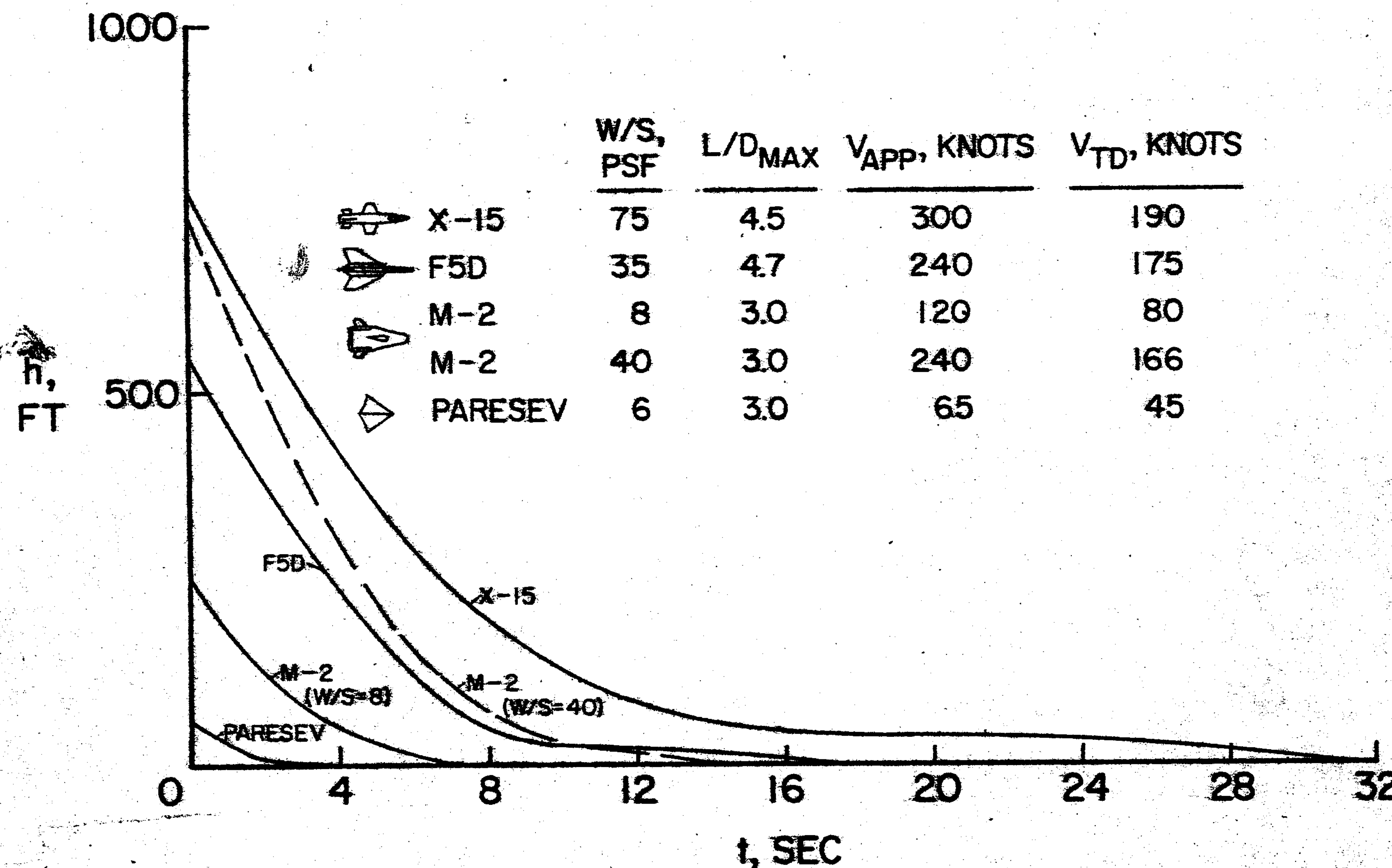
Figure 6

COMPARISON OF LANDING FLARES



	W/S, PSF	L/D_{MAX}	V_{APP}, KNOTS	V_{TD}, KNOTS
X-15	75	4.5	300	190
F5D	35	4.7	240	175
M-2	8	3.0	120	80
M-2	40	3.0	240	166
PARESEV	6	3.0	65	45

Figure 7

FLIGHT SIMULATION
PERFORMANCE AND OPERATIONS

	SIMULATOR	SIMULATED
LANDING	F-104	X-15
	F-102	X-20
	F5D	SST
OFF-THE-PAD ABORT	F5D	X-20
AIR-TRAFFIC CONTROL	A5A	SST
BOOST TRAJECTORY	X-15	RECOVERABLE BOOSTER

Figure 8

FLIGHT SIMULATION
FLYING QUALITIES

REACTION CONTROL

- FRC - X-1B, F-104A ZOOM, X-15

VARIABLE STABILITY

- CONVENTIONAL AIRCRAFT
  - CORNELL AERONAUTICAL LABORATORY
  - NASA ARC, LRC, AND FRC
- HELICOPTERS
  - NASA LRC
- V/STOL
  - NASA ARC - X-14A

Figure 9

GENERAL—PURPOSE AIRBORNE SIMULATOR

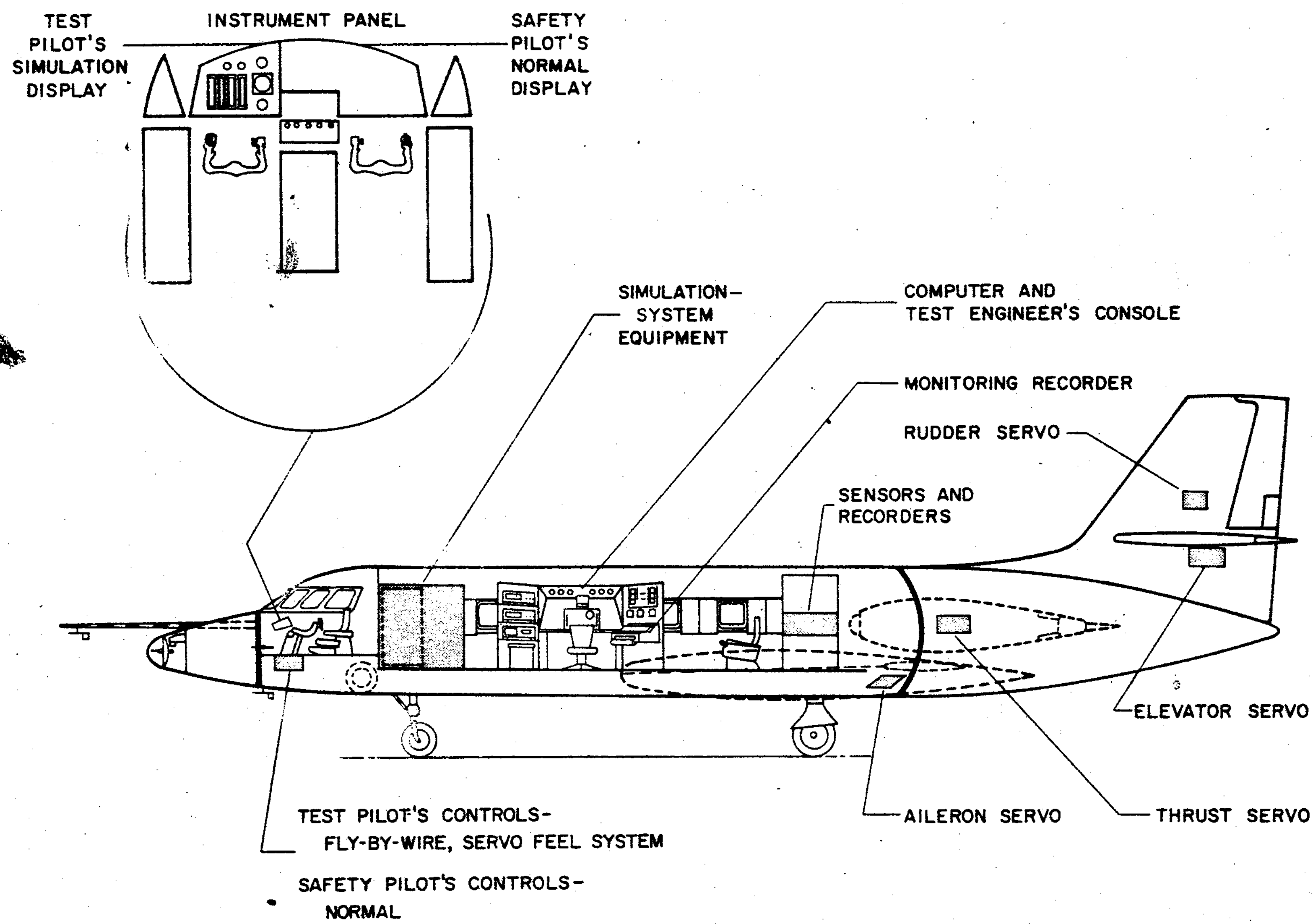


Figure 10

SCHEDULE EXAMPLE

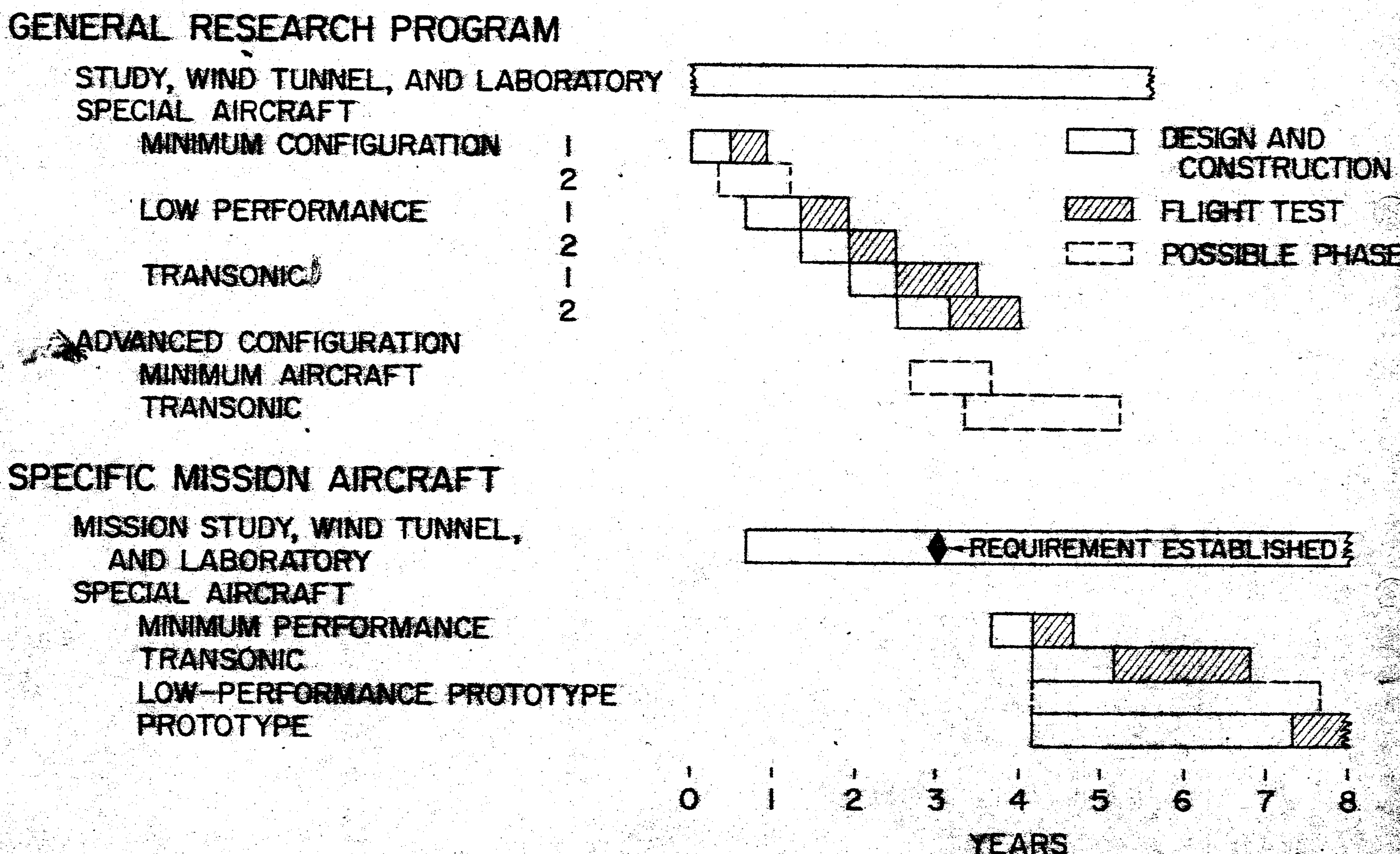


Figure 12

EXAMPLE FLIGHT RESEARCH PROGRAM

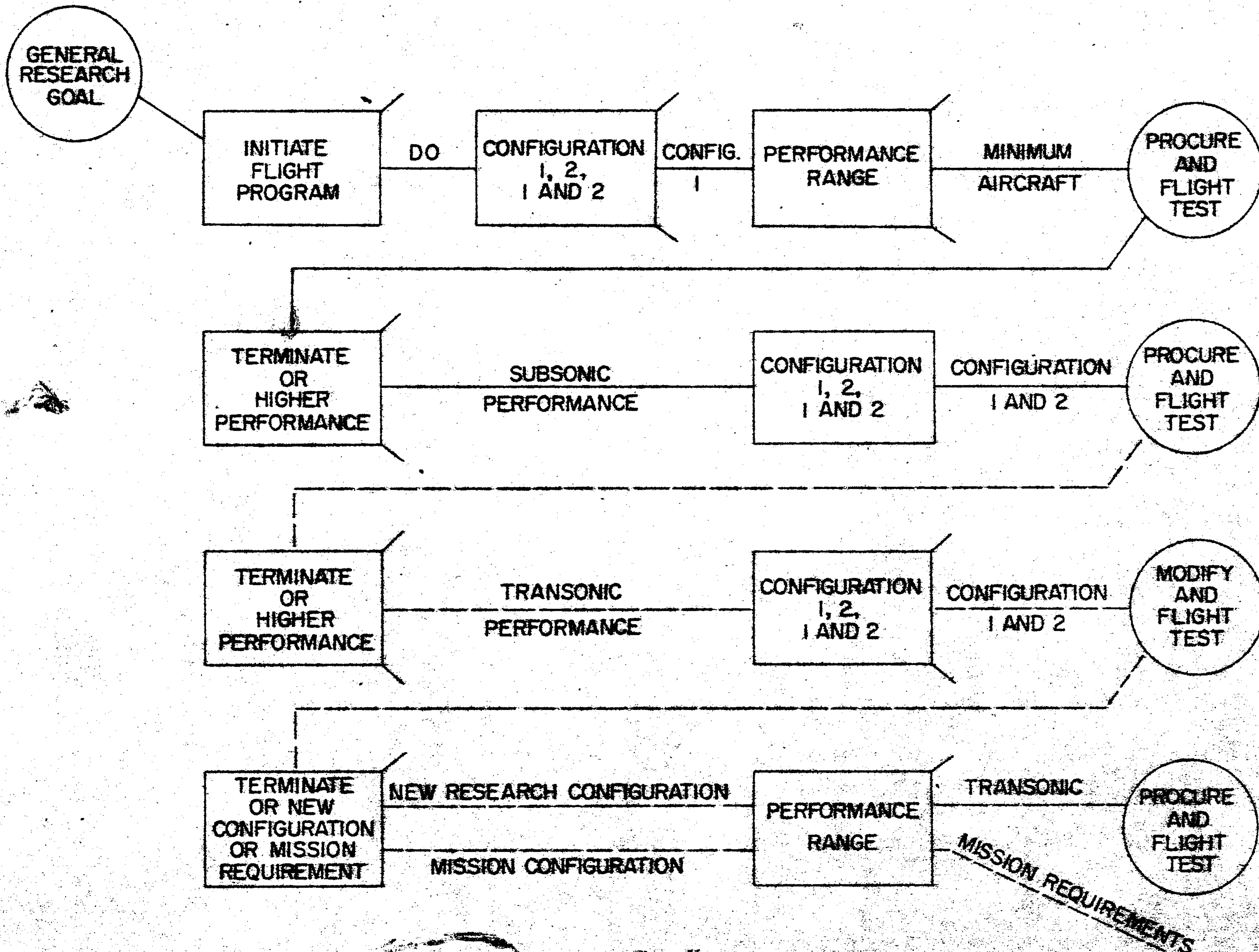


Figure II