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# JOHN F. KENNEDY SPACE CENTER

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## SPACE SHUTTLE HORIZONTAL FLIGHT TEST PLAN





SPACE SHUTTLE TASK GROUP
CENTER PLANNING AND FUTURE PROGRAMS

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# SPACE SHUTTLE HORIZONTAL FLIGHT TEST PLAN

Prepared by:

Robert L. Mosley
Space Shuttle Task Group
Kennedy Space Center, Florida 32899

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## REFERENCE DOCUMENTS


A. A Concept For Flight Testing Space Shuttle Vehicles, NASA/KSC TR-1116, June 30, 1971, Rev 1

B. F-15 Category II Test Plan, AF Flight Test Center Report, Aug 1971

C. C-133 B Flight Test Plan, AF Flight Test Center Report, Oct 1959

D. MIL SPEC 8785B (ASG), 7 Aug 1969, with Interim Amendment-1 (USAF), 31 March 1971

E. 747 Flight Test Certification, Document ND 70028, Flight Test Operations, Boeing Aircraft Company (Undated)

F. Pilots Handbook For Stability And Control Flight Testing, USAF Experimental Flight Test Pilot School, Edwards AFB, Calif.

G. Pilots Handbook For Performance Flight Testing, USAF Experimental Flight Test Pilot School, Edwards AFB, Calif.

# SECTION I

# INTRODUCTION

The horizontal takeoff flight test concept presented is a generic type test plan, that is, for an orbiter or a booster. This concept has been prepared to provide broad guidelines in planning and support requirements for such testing of a space shuttle vehicle. The test program shown is based on the concept that all testing will be conducted at the final fabrication site and involves no planned ferry operations (see reference A). Details of the test program are provided in Appendices A through C. Details of the instrumentation requirements are provided in Appendix D. A factor of prime consideration in the structuring of the test program is the predicted limited flight endurance and maneuvering capability of the shuttle booster/orbiter in the horizontal test flight mode. This limitation is unique in large aircraft testing and will greatly influence the manner in which the program is conducted. Maximum utilization of all flight test time will be essential.

A second factor of significance is the limited number of vehicles dedicated to the test program. The availability dates of the vehicles for horizontal test flight are not firm at this time. It is known that not more than two orbiters or boosters will be available for the respective test program prior to the first manned orbital flight. There is a possibility, however, that the second vehicle may not be available for as many as 12 to 18 months after test commencement on the first vehicle. In view of this it was deemed necessary to structure the testing as a single vehicle program. It is to be noted that this is not considered to be the most desirable approach as a single vehicle program induces a high risk factor to timely program completion, if in fact only one vehicle is available and it should become out of commission for an extended period. An additional consideration is the fact that the second orbiter is scheduled to have an ablative Thermal Protection System (TPS), whereas the first vehicle, for reasons of expediency, will likely have none or at best a substitute nonablative material simulating a TPS. This difference in configuration may preclude or at least complicate using the second orbiter as part of a two-vehicle test program should the second vehicle be available for testing earlier than the period stated above. These considerations are discussed further in Appendix B.

A basic consideration used in determining the type, number, and detail of flight tests to be accomplished was that the shuttle vehicle will not require the in-depth flight testing usually associated with a new aircraft. This is because the operational mission profile in the phase of flight investigable in the horizontal takeoff mode is very rigid, that is, the return-to-earth portion of the mission (from entry into the atmosphere to landing) will be a prescribed flight path in the sky much the same on each flight. Consequently, flight characteristic investigations can be generally directed to those maneuvers associated with this relatively rigid and limited operational profile, as opposed to the type investigation required on a vehicle that has a requirement to perform over a broad operational spectrum, such as a military aircraft or a commercial airliner. Thus, the number of data points required will be reduced in some areas, that is, stall/buffet, CG determinations, maximum performance takeoff and landing considerations, etc., and consequently a reduction in test time is possible. This concept was applied in the structuring of the horizontal takeoff test flight program presented herein and as a result, the estimated total flight hours and time involved for the test program has been reduced to 125 flying hours, 78 weeks and approximately 100 horizontal launches.

# SECTION II

# BACKGROUND INFORMATION

## A. GENERAL

The NASA will have overall responsibility for the shace shuttle horizontal test flight program and, although the contractor will develop the test program, NASA will be the final approving authority of the plan and any changes that are introduced as the test progresses.

A test organization will be established by NASA to coordinate the effects of all participating agencies toward the completion of the test objectives.

Simulators for flight crew familiarization will be procured as early as practical to ensure maximum proficiency prior to first flight. This will also assure maximum proficiency with minimum transition flight training for additional crews to be used in follow-on testing and operational missions.

The limited flight envelope attainable from a horizontal launch of the shuttle booster or orbiter provides for only the invesitgation of the final phase of the vehicle's mission. This phase is critical and it is imperative that the reliability, performance and stability, and control investigations made during the horizontal test flight program verify a safe operational capability. However, from an aerodynamic standpoint, a very sensitive portion of the operational mission profile, that is, the transonic region through approximately Mach 5.0 remains unexplored with the conclusion of the horizontal flight test program presented herein. In this regard several concepts that could possibly provide the needed data are being studied by the various contractors. It is imperative that serious deliberation be given to these concepts as Mach effect in this region bears careful consideration. Also, the time lines shown for test program progress do not include test time for such investigations. The possibility of this additional testing is another consideration to be added to the tests discussed in Appendix B with regard to possible difficulties in meeting the first manned orbital flight date. See figure 1 for flight test schedule.

The horizontal test program will provide an opportunity for a near duplication of the 10,000 feet altitude to completion of the landing rollout portion of the actual mission profile at the termination of each test flight. This fits well with the concept of maximum utilization of all flight time, but in general the very limited flight duration attainable on each flight will be very restrictive to test operations. Consideration should be given to providing an inflight refueling capability for the booster and orbiter to increase individual flight duration in the horizontal test program as well as to provide for increased ferry flight capability. Additionally, it would provide for an expansion of the flyback capabilities of the booster in the operational mission profile (See figure 2).

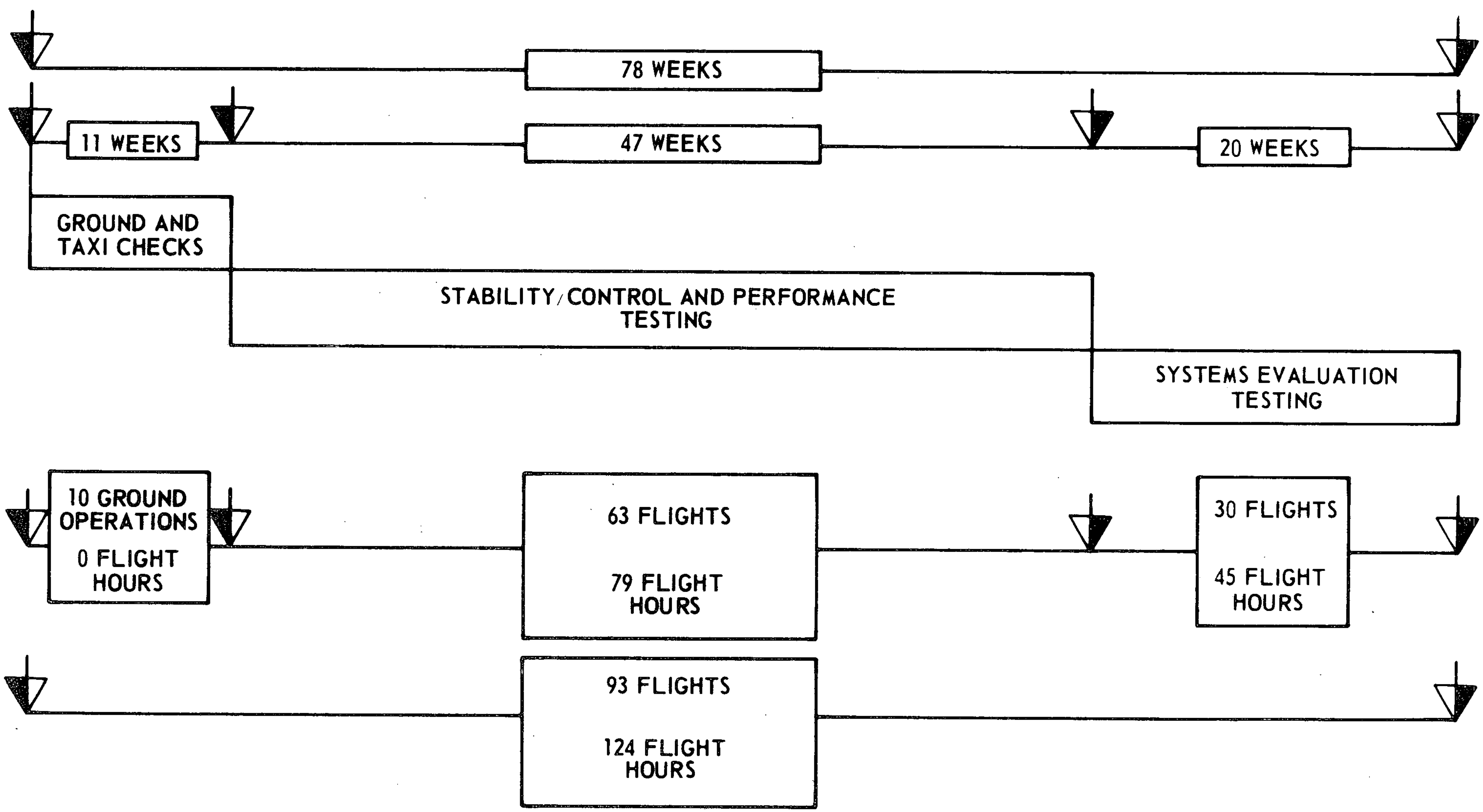


Figure 1. Horizontal Flight Test Schedule (Shown for a one vehicle test program)

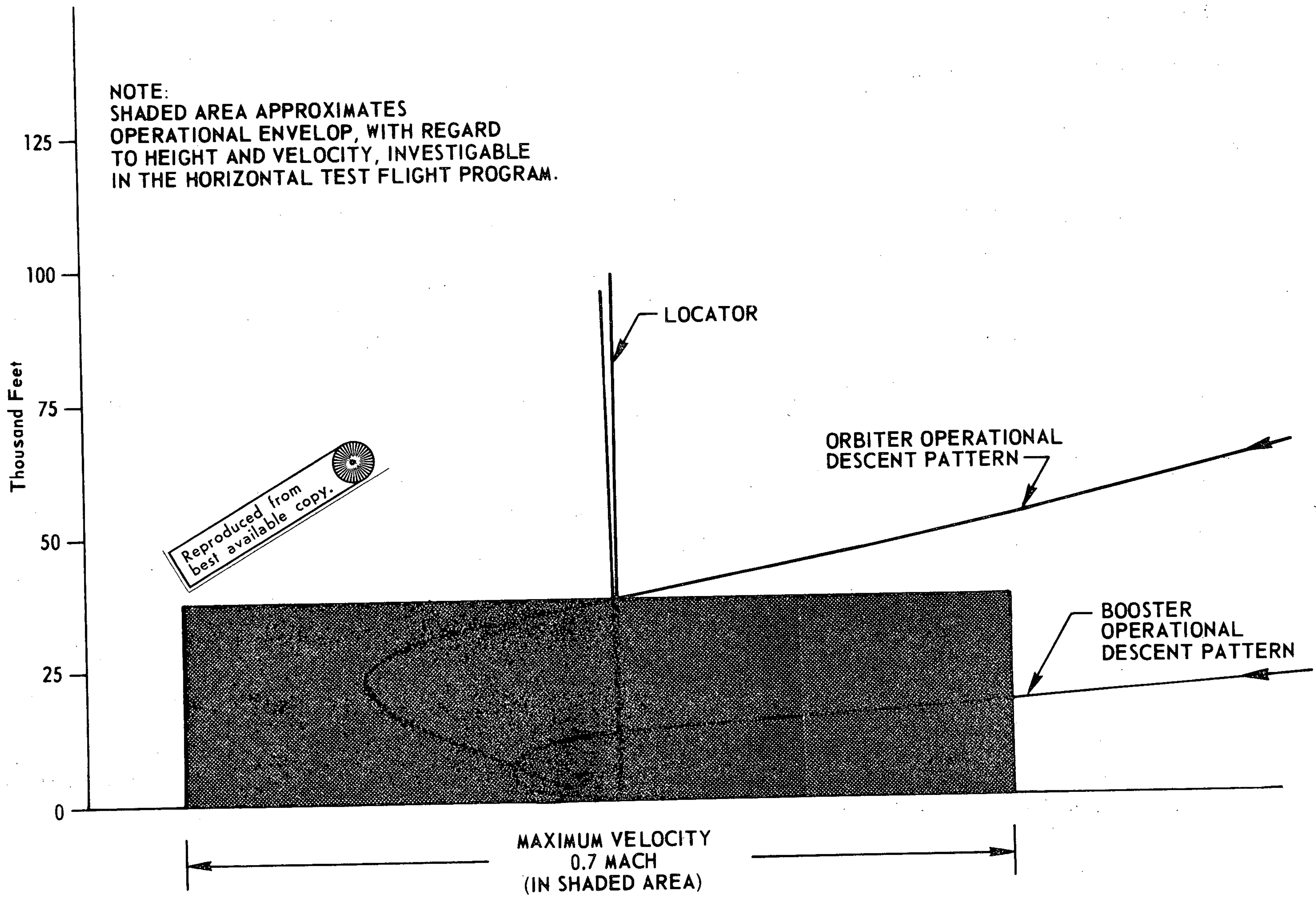




Figure 2. Possible Return Flight Paths for Orbiter/Booster

## B. ASSUMPTIONS

In the development of a horizontal test flight plan at this point in time, consideration must be given to the uncertainties involved because of the fact that to date, the performance of the shuttle vehicles has only been qualitative. However, from preliminary estimates of size, shape, and thrust limitations, it is logical to assume that vehicle flight characteristics in the near-earth environment (in which this phase of the test will be conducted) will be far from impressive in comparision with any previous testing of large aircraft. This fact, in conjunction with the high cost of the vehicle and the very limited number of vehicles available for testing, make this a unique flight test program in many respects.

In view of the above unknowns and limitations, certain assumptions have been made in the structuring of this horizontal flight test concept. They are as follows:

1. Testing will be done at one facility (no ferry flights necessarily involved)

2. Sea level takeoff

3. 15,000' Runway

4. Airbreathing engines (integral to vehicle or strap-on)

5. Flight envelope to be investigated is limited by following constraints:

   a. No thrust augmentation for takeoff other than ABES

   b. Mach regime out to approximately 0.7 (If better ABES performance is attained it will not significantly effect the structure of the plan presented herein).

   c. No in-flight refueling or disposable tanks (flights 1 to 1.5 hours in duration)

   d. Will have an arresting device other than brakes, that is, drag chute, thrust reverser, tail hook

6. Average 6 flights per month ( $<6$ in beginning, $>6$ as program matures)

7. Avionics equipment to be evaluated is installed in test vehicle at time ground checks commence.

8. Simulators available one year prior to first flight

9. Test aircraft fully instrumented at beginning of ground checks

10. Test facilities and equipment requirements:

    a. Dedicated test real-time data readout and analysis

    b. Tracking and photo coverage available

    c. Chase aircraft available (one instrumented for pacer operations)

    d. Auto recovery and auto land capability and related ground support (although all flights will be manned)

    e. Weight and balance facilities available

    f. Thrust measurement and test stand facilities

11. Limited flutter/strength testing required because of rigid structural requirements for vertical flight and limited flight regime in horizontal mode.

12. Ejection seats available

13. Anti-spin device available

14. Stall warning stick shaker installed

15. CG position change capability in flight

16. CG onboard computer

## C. INSTRUMENTATION

The limited number of airframes and flight test hours demand an effective and efficient test flight data acquisition and processing system. Techniques and data systems similar to those used in the Grumman F-14 and McDonnell Douglas DC-10 test aircraft should be considered for the space shuttle test program as they can quickly provide the processing of great amounts of test data and display it, real time, in many usable formats. These real time displays of processed data, in addition to discovery or prediction of unsafe vehicle conditions while in flight, are particularly suitable because of the test constraints frequently mentioned. The system will allow on-the-spot analysis of vehicle performance which will permit eliminating investigations of unneeded data points, with an attendant savings in flight test time. Details of instrumentation requirements and procedures are presented in Appendix D.

## SECTION III

## MISSION OF TEST ORGANIZATION

The mission of the test organization is to direct the testing of the shuttle booster/orbiter in the most effective and efficient manner to prove that the vehicle is flight ready for the return-to-earth portion of the operational mission. The specific objective is to demonstrate, within the confines of a limited horizontal test flight envelope as described herein, that the pre-agreed specifications for performance, stability and control, subsystem operations, maintainability, and reliability have been met. Additional objectives are:

1. Data Analysis. The scope of the total space shuttle program encompasses 445 orbital flights over a ten-year period. To meet the launch rate requirements of the mission model planned to execute the total program, logistic considerations will be of prime importance. Consequently, it will be imperative to develop and employ trend analysis techniques on the reliability and maintainability of vehicle subsystems and supporting equipment throughout the horizontal test flight program. These techniques will assure that: (1) unpredicted failure rates and/or delays in supply line support do not prevent timely completion of the horizontal test flight program, and (2) extensive data will be obtained and recorded on vehicle subsystem suitability, reliability, maintainability and compatibility with supporting ground equipment during the test program which can be applied to the total logistic support function throughout the ten-year space shuttle program.

2. Training. Necessary training activities and equipments will be developed and employed in a timely and effective manner to assure that trained personnel are available to support all phases of the horizontal test flight program. Training techniques developed during the test phase may be applied to the total operational program as applicable.

3. Engineering Change Proposals. Determination will be made of needed engineering changes during the test program and proposals will be developed to bring about such changes.

# SECTION IV

## TEST PHASE CONCEPT

A test phase concept consisting of three phases has been used in the structuring of this test plan. These phases are defined as follows:

1. Phase I - Ground Test Phase. Verification that the ground handling qualities are as desired and that the vehicle is ready for first flights.

2. Phase II - Initial Flight Tests. Verification of user prerequisits to assure operational capability in the performance, stability/control, and flying qualities of the vehicle.

3. Phase III - Systems Evaluation. Verification that all systems of the vehicle are suitable and reliable and to determine the maintainability of such systems.

Details of Phase I, II, and III are presented in Appendixes A, B, and C respectively.

## SECTION V

## SUPPORTING TASKS

The following are supporting tasks to be accomplished:

1. Development of the test organization structure with delineation of functions, authority and responsibilities.

2. Determination of personnel requirements to support the test organization and support functions associated with the test program (to include numbers and degree of qualification for flight crews, number of contractor technical representatives needed, etc.)

3. Development of a total logistics concept (to satisfy all aspects of maintenance, supply, transportation, modifications and refurbishments associated with the test program for later application to the total program)

4. Development of a support functions plan (to include flight test data acquisition and reduction, radar flight following and recovery, runway photo measurements, chase aircraft, technical report writing, rescue and fire-fighting, meteorological and administrative support)

5. Determine and provide facilities for support requirements (to include runway, taxi ways, parking/safing area requirements, hangars, instrument measurement lab, thrust calibration facilities, and an industrial area to include such items as storage, fire fighting facilities, operations buildings, maintenance areas, shop support, and non-movable maintenance and test support facilities)

6. Determination of ground support equipment requirements

7. Determination of additional test sites and associated support requirements, (alternate landing sites for weather or emergency circumstances, development of host tenant agreements, etc.)

# APPENDIX A

# GROUND TESTS

# APPENDIX A

# GROUND TESTS

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# APPENDIX A

## SECTION I

## INTRODUCTION

The purpose of delineating this ground test phase is to specifically designate types of tests and time involved in such tests in order to arrive at an overall estimate of time and aircraft operational hours involved. It has been assumed that all flight test instrumentation has been installed by the time the first flight crew commences aircraft start and taxi tests, and additionally, that all avionics applicable to the flight regime encompassed by the test flight envelope for the version of the particular test vehicle involved are installed and ready for test and operational evaluation. Additional checks to have been completed prior to this test phase are stated in paragraphs A through D in the following section. The time indicated for an operation, flight, or series of flights is the estimated number of weeks from the completion of one test to the completion of the next test operation, flight or series of flights. The time is shown following the test description. This includes all ground times in preparation for and during that particular test, that is, configuration changes, weight and balance, instrumentation, system repair or replacement, modification, unscheduled delays, etc.

Figure 3 shows a schedule for the ground test phase.

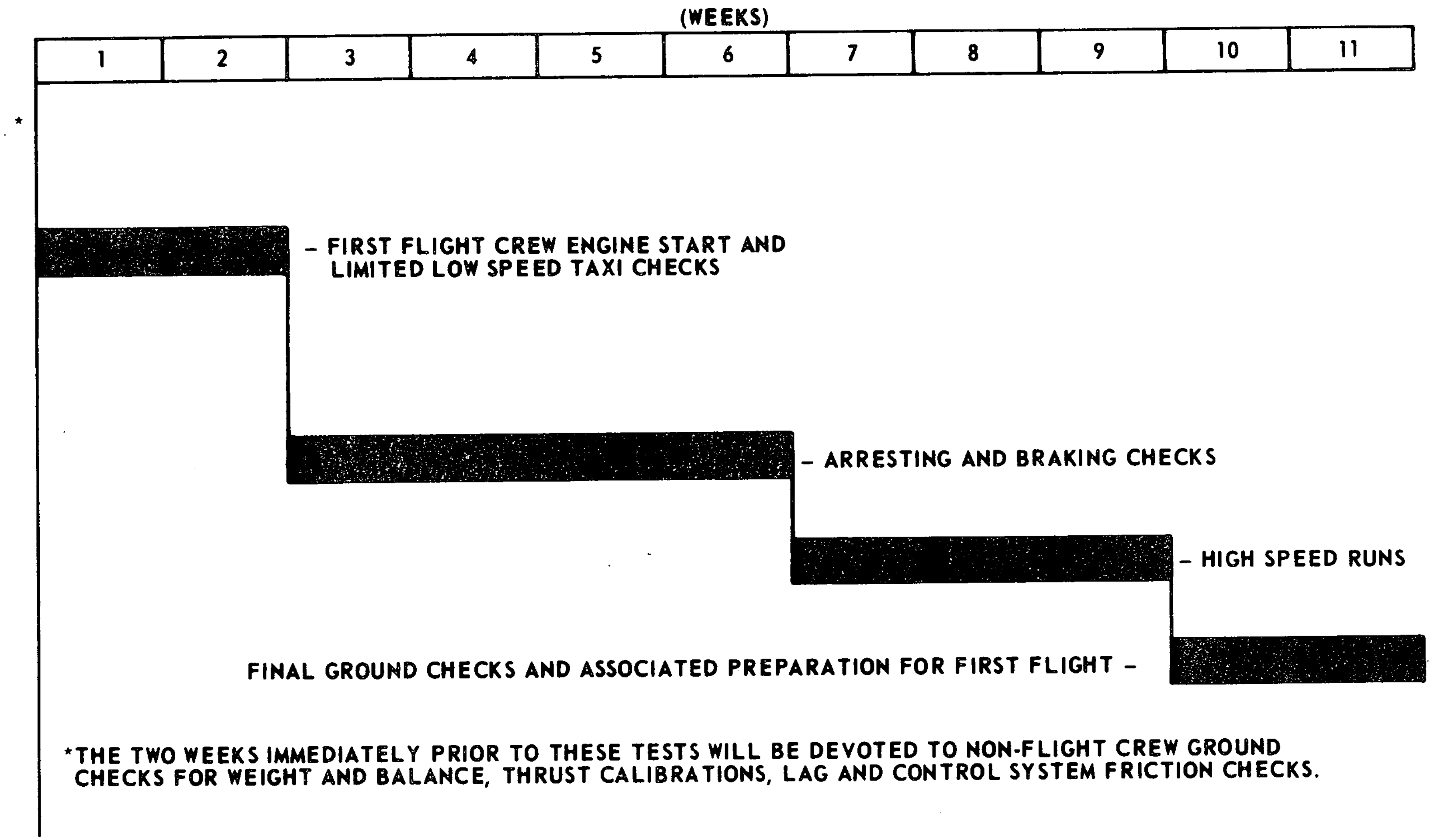


Figure 3. Phase I Ground Test Schedule

# APPENDIX A

## SECTION II

## TESTS TO BE CONDUCTED

### A. WEIGHT AND BALANCE

The vehicle will be weighed with full oil tanks and empty fuel tanks prior to the first taxi operations. The vehicle will be weighed before and after each operation or flight until fuel tank calibration is considered satisfactory and as required thereafter for configuration changes, etc. Dummy loads of equal weight, effective location and aerodynamic effect (if applicable) will be added for motors, tanks, equipment etc. unavailable at the time of horizontal test flight commencement. Fuel samples will be taken before and after each flight.

### B. CONTROL SYSTEM FRICTION TESTS

(As applicable for the configuration designed). The control system friction or artificial feel will be measured with the aircraft in a closed hangar or during zero wind conditions if outside. Tests will be conducted by making intermittent steady movements of all controls throughout the entire range of control deflection to obtain well-defined curves of breakout forces and sliding friction forces versus control deflections. All data will be recorded. These breakout and friction forces will be checked again during flight tests. Also, deflections of associated aerodynamic surfaces with control movement will be made.

### C. THRUST CALIBRATIONS

Detailed installed static thrust measurements of the engines will be made prior to the first taxi test operations. Engine characteristic measurements will be made from idle through maximum power (with afterburner on if so designed). Values will be obtained for the thrust decrease effect of bleed air usage for auxiliary power, anti-icing, acceleration bleed value operation, etc. Additional calibrations will be required when engine changes are made and/or modifications to the propulsion system are made.

### D. PITOT-STATIC SYSTEM CHECK

The pitot-static system will be measured for static and total pressure lag before the first taxi operations are begun. Additional calibrations may be required later in the program.

Time (tests A through D) 2 Weeks

## E. TAXI CHECK

Towing tests will be made during the accomplishment of the four operations listed above. The first flight crew operation will be an engine start and a limited taxi test to make qualitative observations on such characteristics as those listed below (not necessarily limited to those shown). The aircraft will be fully instrumented for this test and all follow-on tests; thus, many of the qualitative observations listed below may be quantitatively evaluated during the same operation, that is, air conditioning, noise level, breakout forces, etc.

1. Ingress/egress

2. Seats (comfort, room, ejection considerations, adjustments)

3. Air conditioning (comfort, effectiveness)

4. Crew proximity and effectiveness to each other

5. Cockpit lighting (natural, artificial)

6. Checklists (presentation method, adequacy, complicity)

7. Operational flight instrumentation (complicity, adequacy, readability)

8. Starting (ease of start, effect of wind, reliability, proneness for hot start complicity)

9. Avionics (complicity, location, display, controls, adequacy, lighting)

10. Interphone (effectiveness, annoyance, methods of keying)

11. Actuator locations and operations (trim, gear, flaps, brakes, etc.)

12. Controls (yoke, rudder, aileron, location and ease of movement, position, mechanical advantage)

13. Throttle response

14. Noise level (cockpit and ground crew areas)

15. Crew visibility

16. A/C response at idle throttle when brake released

17. A/C response to throttle movement

18. Brake response (amount of movement, force required, sensitivity, deflection, effectiveness, symmetry, effect in turn)

19. Taxi speed impressions (noise/vibrations/oscillation/roll/yaw)

20. Nose wheel steering

a. Effectiveness (amount of movement vs amount of turn, symmetry, range, response)

b. Dynamics

c. Pressure (breakout forces)

d. Turning radius (control rate)

21. Degree of effort to taxi and assurance of safety

22. Visibility forward and in turns

23. Stopping (smoothness, effectiveness, dynamics, pedal force, pilot sensations)

24. Setting brake (effort)

25. Effect of brake in holding aircraft (engine at runup power)

26. Shut down (complicity of procedures, anomalies, time involved, safing, etc.)

## F. LOW SPEED TAXI TEST

The second operation will be a low speed taxi test. Instrumentation channels as required will be activated for this test. Additionally, the following qualitative (and quantitative where applicable) evaluations will be made.

1. On start and engine runup the following observations will be made:

a. Any complications during actual start

b. Characteristics of brakes (ease of setting, ease of release)

c. Vibrations, noise

d. Dynamics (oscillations, roll, wind effect)

e. Flight crew to ground crew communications

f. Engine parameters monitored and recorded thru telemetry

g. Comm/Nav/Flight instruments/Other instrumentation checked as applicable

2. Aircraft will be given a low speed taxi run and be evaluated with regard to the following:

a. Vibrations, noise, oscillation, roll, yaw, nose wheel steering effectiveness, visibility, operation of flight and systems instrumentation, brake response (minimal braking), brake pedal movement required, angle of foot, brake chatter, symmetry of brake application and effect, brake heating, walking of gear, readability of flight and systems instrumentation (location, natural lighting), effect of flight controls, crew coordination (communication and visually, ability to assist each other), need for help from each other in nose wheel steering, turning radius, brakes.

b. The aircraft will be towed back and given post taxi check of all systems with repair and modification as required.

## G. LOW SPEED TAXI CHECK

If previous taxi check proved satisfactory, the aircraft will be taxied to the runway and given a low speed taxi run similar to the previous taxi check.

The aircraft will be stopped for ground checks at the end of the runway. If systems are satisfactory, it will be turned around and a medium speed (50% of predicted take-off speed) run will be made making similar checks as before with additional actions such as increased control actions, actuation of drag devices, and increased braking.

Tow back with post taxi check of all systems, repair and modifications as required.

Time (tests E through G) 2 Weeks

## H. ARRESTING AND BRAKING CHECKS (Methods to be determined by design characteristics)

With the satisfactory accomplishment of the foregoing checks a series of refused takeoffs with incremental increases in speed will be made checking all aspects of arresting and braking equipment. Investigations will be made for both wet and dry runway conditions. Tests will be made at maximum takeoff and landing gross weights. The test procedure will be to accelerate, using takeoff thrust for the time needed to reach a pre-selected speed (consider use of onboard Inertial Navigation System (INS) for precise target speeds) and then retard all engines. Wheel brakes and other arresting devices will be applied and energy absorption rates determined. The results of each test or series of tests will dictate the degree of testing and the manner in which the follow on tests will be conducted.

Time 4 Weeks

## I. HIGH SPEED RUNS

Dependent on level of confidence attained from arresting and braking tests, three high speed runs will be made, increasing velocity to 90% of predicted takeoff speed for a maximum operational gross weight condition. These tests will provide the flight crews with the opportunity to become more adjusted to aircraft environment and will allow for more extensive investigations of control system feel and effectiveness, pilot's visibility, rotational attitude and accelerations, horizontal accelerations, trim characteristics, crosswind effect, verification of calculated nose wheel liftoff speed, and elevator effect-iveness, etc.

Successful accomplishment of these tests and assuming successful checkout of all other instrumentation, Accessory Power Units (APUs), communications, electrical, hydraulics, flight controls, etc., during the ground check phase the aircraft should be considered for first flight.

Time 3 Weeks

## J. FINAL GROUND CHECKS AND ASSOCIATED PREPARATIONS FOR FIRST FLIGHT

This block of time is provided for final ground checks and associated preparations for the first horizontal takeoff test flight. It may also be used for any additional testing required as a result of previous testing accomplished, hardware modifications, delays, etc.

Time 2 Weeks

APPENDIX A

SECTION III

SUMMARY

It is estimated that the ground check phase as outlined herein will take a minimum of eleven weeks and will involve at least ten operations; an operation in this phase being a function wherein a large percentage of the total support force required for the launch of a horizontal test flight will be needed, that is, flight crew, ground crew, and ground support equipment.

# APPENDIX B

# INITIAL FLIGHT TESTS

# APPENDIX B

# INITIAL FLIGHT TESTS

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## APPENDIX B

## SECTION I

## INTRODUCTION

The primary objective of this testing is to demonstrate that the vehicle meets the design specifications proclaimed by the contractor in predevelopment contractual negotiations. The tests to be accomplished in this phase, as listed in the following pages, are an estimate of the actual test plan to be developed as design concepts at this time are too undefined to be more specific. The tests listed, however, are those usually associated with this phase of testing and for planning purposes will provide a satisfactory measurement of the capability of the vehicle. In the same concept, the standards to which these test results are to be compared will be subject to negotiation; however, for the purpose of this document, and at this point in time, testing specifications of MIL F 8785B are considered adequate.

As stated in the introduction, it may develop that the second vehicle will not be available for as many as 18 months after test commencement on the number 1 vehicle, thus constituting, for all practical purposes, single vehicle availability. For this reason the test program has been structured as a single vehicle test program; however, it is necessary that consideration be given to the effects this could have on the test program. While an 18 month test program, with all emphasis concentrated on one vehicle, is considered (as shown in the following sections of this report) adequate to demonstrate the airworthiness of the space shuttle vehicle in its relatively limited near earth operational flight envelope, there are inherent detrimental factors in a one-vehicle program that introduce a high risk factor in meeting a preselected manned orbital flight date. One undesirable feature is that the one test vehicle will of necessity be unusually heavily instrumented as it will have to perform all phases of the testing. The thousand or more channels of telemetry data needed would be more functional in many respects if they were divided among three or four vehicles. More significantly, there is no scheduling flexibility.

If the one vehicle encounters any lengthy unplanned delay for a failing system or accidental damage, all knowledge gain is terminated until the failure is corrected or the damage is repaired. The arrival of the second vehicle would not likely alleviate the problem unless it arrived only a few months after test commencement. The second vehicle is scheduled for the first manned orbital flight and a great amount of time is planned for pre-vertical launch and checkout activities. Thus, time would likely not be available to fully instrument the second vehicle and conduct a meaningful test program if the first vehicle is indefinitely grounded. Earliest availability of the second vehicle is imperative to meet the scheduled first manned orbital flight date.

An additional factor to consider is that present planning calls for the second orbiter to have a Thermal Protection System (TPS) installed whereas the first orbiter does not. The TPS (yet to be determined) could introduce dimensions of two additional inches on many sections of the airframe. The possible ramifications of such a change in weight, configuration, and parasite drag are significant. This fact, along with the likely probability of needing to install more advanced avionics systems in the second vehicle, presents the possibility that the testing on the second vehicle be more in the realm of determining the characteristics of a new unknown quantity, rather than the more desirable case of having an identical second vehicle to add additional data increments to the investigations being conducted on the number 1 vehicle. In view of these considerations, if in fact the second orbiter does have a TPS and the first does not, there is even more reason for early availability of the second vehicle, as it is imperative that allowances be made for the additional testing that could be required.

A significant difference in configurations between the number 1 and number 2 vehicles is a high risk consideration that should be thoroughly evaluated with regard to the imperativeness of meeting the planned first manned orbital flight date.

The time indicated for an operation, flight or series of flights is the estimated number of weeks from the completion of one test to the completion of the next operation, flight or series of flights. The time is shown following the test description. This includes all ground times in preparation for and during that particular test, that is, configuration changes, weight and balance, instrumentation, systems repair or replacement, modification, scheduled maintenance, unscheduled delays, etc.

Figure 4 shows the stability/control performance test schedule for this phase.

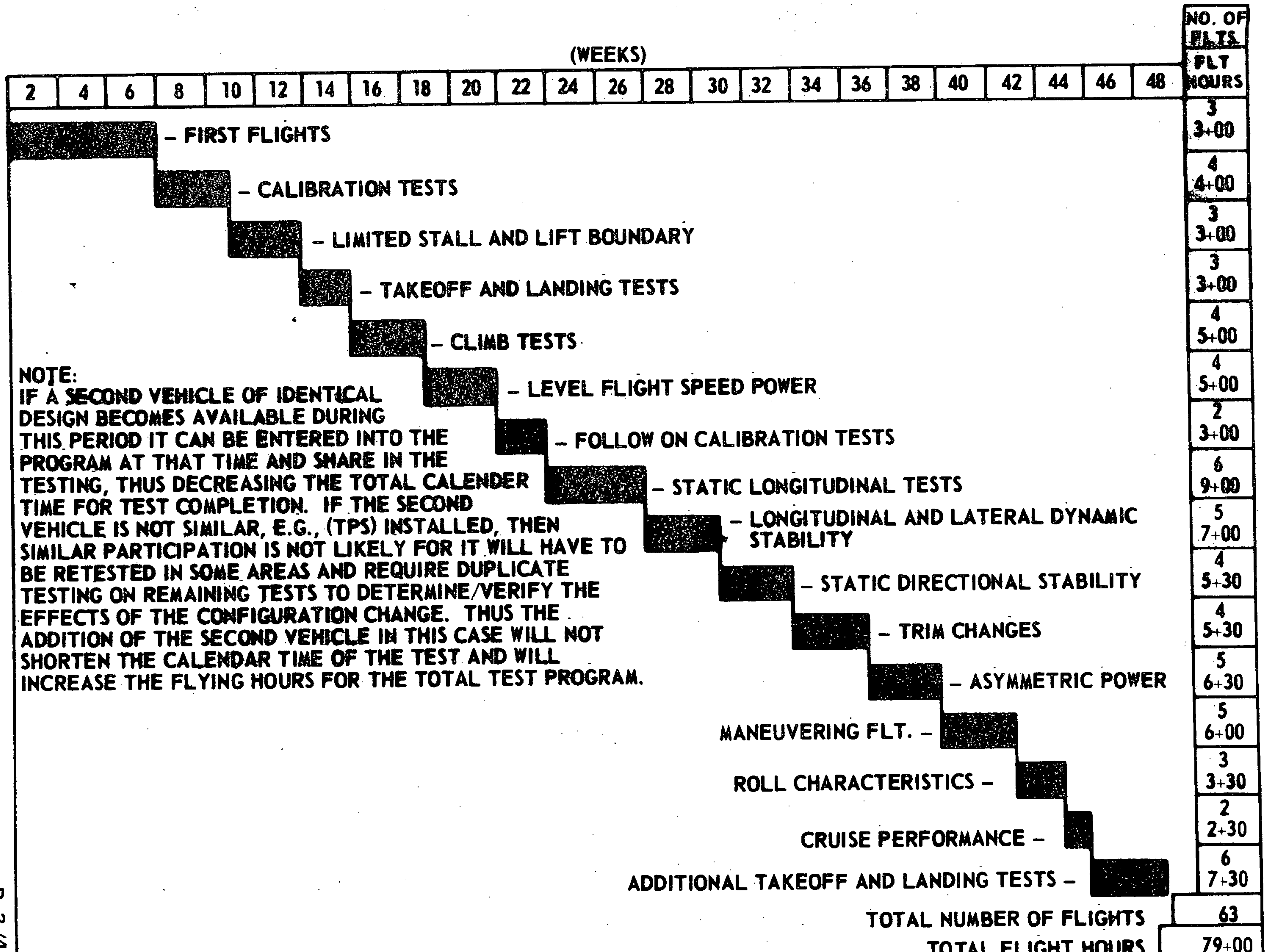



Figure 4. Phase II Stability/Control and Performance Test Schedule

APPENDIX B

SECTION II

# FLIGHT TESTS TO BE ACCOMPLISHED

## A. FIRST FLIGHTS

Low performance capabilities are predicted for the space shuttle vehicle in the horizontal flight mode due to design requirements of size, shape, and relatively limited thrust available from the airbreathing engines. Consideration of these factors suggest that very limited test objectives be planned for the first flights. As confidence is attained, more test objectives will be investigated. It is estimated that three confidence building flights will be accomplished prior to the more specific tests associated with a new vehicle test program.

Specific channels of instrumentation will be activated as required. General test objectives on the three first flights are as follows:

1. First Flight. (to determine basic airworthiness)

    a. Takeoff (leaving gear down)

    b. Verify predicted rotation speed, nose wheel lift off distance, takeoff distance

    c. Climb out - Determine takeoff climb gradients

    d. Gentle turns

    e. General systems operations (electrical, hydraulic, fuel, etc.)

    f. General and qualitative checks of maneuverability, control force and response, trim characteristics, etc.

    g. Approach and landing

    h. Ground checks, clear discrepancies, repair/modify as necessary

2. Second Flight. (to verify correction of first flight discrepancies and extension of flight envelope)

    a. Takeoff (gear retract) - Verify predicted rotation speed, nose wheel lift off distance, takeoff distance - compare with first flight data

    b. Climb Out - Determine and compare takeoff climb gradients with gear down climb out

c. Climbing turns (control response)

d. Qualitative stability checks (trim changes/control forces associated with varying air speeds and attitudes)

e. Avionics checks as necessary

f. Chase aircraft (instrumented for pacer operations )take airspeed and altitude readings

g. Gear extension

h. Further investigations of handling qualities in landing configuration

i. Approach and landing

j. Ground checks, clear up anomalies, modifications

k. Weight and balance

3. Third Flight. (to further verify basic airworthiness with adjustments for knowledge gained on first two flights)

a. Check items same as second flight, compare results in real time read out data presentation system

b. Primary interest in stability and control at higher speeds and accelerations

c. Emphasis on landing configuration handling qualities

d. Approach and landing

e. Ground checks, clear up anomalies, update/modify procedures as necessary, weight and balance, etc.

Three flights/Test Time Six Weeks/
3+00 Hours Flight Time

## B. CALIBRATION TESTS

The purpose of the test is to determine the position error in the pitot static system so that appropriate corrections may be made to data obtained from the system. Test objectives are as follows:

1. The airspeed system will be calibrated over the available speed range of the aircraft at varying weights, altitudes, and configurations.

2. Several methods available to perform tests, recommend instrumented pacer aircraft. Can verify data later with tower flyby, trailing bomb, etc.

3. Test may take as many as four flights.

4. Initial checks on autopilot, avionics, auto recovery, auto landing, engine performance, fuel systems calibrations and other systems may be made in conjunction with these tests as time will allow and as equipment is available, that is, autopilot, avionics, auto land.

5. Applicable instrumentation channels will be activated for this test. As a minimum, test aircraft indicated altitude, indicated airspeed, indicated termperature, weight, time, center of gravity, engine parameters, flight control position/deflections/ flutter, fuselage vibrations, gear/flap/drag device positions and relevant chase aircraft parameters should be recorded.

Four Flights/Test Time 3 Weeks/
4+00 Hours Flight Time

## C. STALL AND LIFT BOUNDARY TEST

For flight safety considerations it is desirable to evaluate the stall characteristics of the aircraft early in the test program. Investigations should be made in unaccelerated and accelerated flight and to accurately determine the minimum safe flying speed in several configurations, also to determine limiting normal acceleration that can be achieved at various speeds and mach numbers as identified by buffet or pitch up. These investigations will be made in increments building on previous test results. A stall warning stick shaker device will be installed and evaluated. A spin recovery parachute will be available to assist in recovery in the event of an inadvertant spin. Consideration should be given to providing a backup hydraulic/electrical supply package in event of high angle of attack/stall engine flame outs. Test objectives are as follows:

1. Stall characteristics to be investigated at various altitudes, CG positions, and accelerations.

2. Stability characteristics demonstrated will determine scope of lift boundary test.

3. High speed flight in dive could be run in conjunction with end of test and return to base (this would start investigation of flutter characteristics and descent performance).

4. Applicable instrumentation channels will be activated for this test. As a minimum all flight control positions, flight control forces, angle of bank, angle of attack,

roll rates, load factor, trim tab positions, gear/flap/drag device positions, pitch, pitch rate, yaw rate, angle of side slip, fuselage variations/vibrations, airspeed, altitude, temperature,weight, CG, mach number, engine parameters, control surface flutter, cockpit temperatures, and pressurization should be recorded. Real time data readout provides on the spot evaluation of test progress and any flight safety considerations involved. Rapid calculations of test data are possible with such automatic data gathering techniques thus allowing in-flight data evaluation and consequently possible reductions in data points and flight test time.

5. No spin program will be conducted.

6. The following paragraphs of MIL-F-8785B describe applicable stall characteristic specifications:

"3.4 Miscellaneous flying qualities

3.4.1 Approach to dangerous flight conditions. Dangerous conditions may exist where the airplane should not be flown. When approaching these flight conditions, it shall be possible by clearly discernible means for the pilot to recognize the impending dangers and take preventive action. Final determination of the adequacy of all warning of impending dangerous flight conditions will be made by the procuring activity, considering functional effectiveness and reliability. Devices may be used to prevent entry to dangerous conditions only if the criteria for their design, and the specific devices, are approved by the procuring activity.

3.4.1.1 Warning and indication. Warning or indication of approach to a dangerous condition shall be clear and unambiguous. For example, a pilot must be able to distinguish readily among stall warning (which requires pitching down or increasing speed), Mach buffet (which may indicate a need to decrease speed), and normal airplane vibration (which indicates no need for pilot action). If a warning or indication device is required, functional failure of the device shall be indicated to the pilot.

3.4.1.2 Prevention. As a minimum, dangerous-condition-prevention devices shall perform their function whenever needed, but shall not limit flight within the Operational Flight Envelope. Neither normal nor inadvertent operations of such devices shall create a hazard to the aircraft. For Levels 1 and 2, nuisance operation shall not be possible. Functional failure of the device shall be indicated to the pilot.

3.4.2 Flight at high angle of attack. The requirements of 3.4.2 through 3.4.2.2.2 concern stalls, loss of control, post-stall gyrations, spins and related characteristics. They apply at speeds and angles of attack which in general are outside the Service Flight Envelope (although in some instances warning is allowed to commence slightly inside that envelope). They are intended to assure safety and the absence of mission limitations due to stall and post-stall situations. These requirements may be met with the aid of certain special devices only if it can be shown that appropriate aerodynamic design and mass distribution are not feasible.

3.4.2.1 Stalls. The stall is defined in terms of airspeed and angle of attack in 6.2.2 and 6.2.5 respectively. It usually is a phenomenon caused by airflow separation induced by high angle of attack, but it may instead (3.1.9.2.1) be determined by some limit on usable angle of attack. The stall requirements apply for all Airplane Normal States in straight unaccelerated flight and in turns and pullups with normal acceleration up to $n_{o_{max}}$. Specifically, the Airplane Normal States, in straight unaccelerated flight and in throttle settings, and trim settings of 6.2.2 shall be investigated; also, the requirements apply to Airplane Failure States that affect stall characteristics.

3.4.2.1.1 Stall approach. The stall approach shall be accompanied by an easily perceptible warning. Acceptable stall warning for all types of stalls consists of shaking of the cockpit controls, buffeting or shaking of the airplane, or a combination of both. The onset of this warning shall occur within the ranges specified in 3.4.2.1.1 and 3.4.2.1.1.2 but not within the Operational Flight Envelope. The increase in buffeting intensity with further increase in angle of attack shall be sufficiently marked to be noted by the pilot. The warning shall continue until angle of attack is reduced to a value less than that for warning onset. This warning may be provided artifically only if it can be shown that natural stall warning is not feasible. At all angles of attack up to the stall, the cockpit controls shall remain effective in their normal sense, and small control inputs shall not result in complete loss of control. Prior to the stall, uncommanded oscillations shall not exceed ±10 degrees bank, ±2 degrees sideslip, ±2 degrees pitch attitude. These requirements apply whether $V_S$ is as defined in 6.2.2 or as allowed in 3.1.9.2.1.

3.4.2.1.1.1 Warning speed for stalls at 1g normal to the flight path. Warning onset for stalls at 1g normal to the flight path shall occur between the following limits:

| Flight Phase | Minimum Speed for Onset | Maximum Speed for Onset |
|---|---|---|
| Approach | Higher of $1.05V_S$ or $V_S + 5$ knots | Higher of $1.10V_S$ or $V_S + 10$ knots |
| All Other | Higher of $1.05V_S$ or $V_S + 5$ knots | Higher of $1.15V_S$ or $V_S + 15$ knots |

3.4.2.1.1.2 Warning range for accelerated stalls. Onset of stall warning shall occur outside the Operational Flight Envelope associated with the Airplane Normal State and within the following angle-of-attack ranges:

| Flight Phase | Minimum Angle of Attack for Onset | Maximum Angle of Attack for Onset |
|---|---|---|
| Approach | $\alpha_0 + 0.82\,(\alpha_S - \alpha_0)$ | $\alpha_0 + 0.90\,(\alpha_S - \alpha_0)$ |
| All Other | $\alpha_0 + 0.75\,(\alpha_S - \alpha_0)$ | $\alpha_0 + 0.90\,(\alpha_S - \alpha_0)$ |

where $\alpha_S$ is the stall angle of attack and $\alpha_0$ is the angle of attack for zero lift ($\alpha_S$ is defined in 6.2.5; $\alpha_0$ may be estimated from wind-tunnel tests).

3.4.2.1.2 Stall characteristics. In the unaccelerated stalls of 3.4.2.1, the airplane shall not exhibit uncontrollable rolling, yawing, or downward pitching at the stall in excess of 20 degrees for Classes I, II and III, or 30 degrees for Class IV airplanes. It is desired that no pitch-up tendencies occur in unaccelerated or accelerated stalls. In unaccelerated stalls, mild nose-up pitch may be acceptable if no elevator control force reversal occurs and if no dangerous, unrecoverable, or objectionable flight conditions result. A mild nose-up tendency may be acceptable in accelerated stalls if the operational effectiveness of the airplane is not compromised and:

a. The airplane has adequate stall warning

b. Elevator effectiveness is such that it is possible to stop the pitch-up promptly and reduce the angle of attack, and

c. At no point during the stall, stall approach, or recovery does any portion of the airplane exceed structural limit loads.

The requirements apply for all stalls resulting from near zero to 4 knots per second speed reduction rate for Class I, II and III airplanes, 2 degrees per second angle-of-attack rate for Class IV.

3.4.2.2.1 Resistance to loss of control. Neither post-stall gyrations nor spins shall be readily attainable from the entry conditions specified in 3.4.2.2 except by prolonged gross misapplication of controls. With the control misapplications of 3.4.2.2 held for at least 3 seconds, or longer if there is no clear indication, the airplane shall exhibit no uncommanded motion which cannot be arrested promptly by application of elevator control to reduce the magnitude of the angle of attack (neutralizing the aileron and rudder controls is allowed). In addition, Class I training airplanes shall be capable of a developed spin, such that the pilot can identify the spin mode.

3.4.2.2.2 Recovery from post-stall gyrations and spins. For Class I and IV airplanes, the following requirements apply. For any loss of control that can occur with the control misapplications of 3.4.2.2 held for as long as 15 seconds, the start of recovery shall be apparent to the pilot within 3 seconds, or one spin turn, of the instant he initiates recovery. The proper recovery technique must be readily ascertainable by the pilot, and all techniques must be simple and easy to apply under the motions encountered. Whatever the motions, safe, consistent recovery and pullout shall be possible without exceeding the control forces of 3.4.5.1, and without danger of violating airplane limits or of excessive altitude loss. A single technique shall provide recovery from all post-stall gyrations and incipient spins, without tendency to develop a spin; prompt recovery is required using only the elevator control.

3.4.2.1.3 Stall prevention and recovery. It shall be possible to prevent the stall by moderate use of the elevator control alone at the onset of the stall warning. It shall be possible to recover from a stall by simple use of the elevator, aileron, and rudder controls after a brief delay, with reasonable forces, and to regain level flight without excessive loss of altitude or build-up of speed. Throttles shall remain fixed until speed has begun to increase when an angle of attack below the stall has been regained. In the straight-flight stalls of 3.4.2.1, with the airplane trimmed at a speed not greater than $1.4V_S$ and with a speed reduction rate of at least 4.0 knots per second for

Class I, II and III airplanes, and an angle-of-attack rate of 2 degrees per second for Class IV airplanes, elevator control power shall be sufficient to recover from any attainable angle of attack; that is, to preclude inability to recover from a deep stall.

3.4.2.1.3.1 One-engine-out stalls. On multiengine airplanes, it shall be possible to recover safely from stalls with the critical engine inoperative. This requirement applies with the remaining engines at up to thrust setting for level flight but these engines may be throttled back during recovery.

3.4.2.2 Post-stall gyrations and spins. The post-stall gyration and spin requirements apply to all modes of motion that can be entered from upsets, decelerations and extreme maneuvers appropriate to the Class and Flight Phase Category. For Class IV airplanes this includes air combat, ground attack and other tactical and training maneuvers. For Class I and IV airplanes, entries from inverted flight shall be included. Less extreme entry conditions are also included for all classes. Entry angles of attack and sideslip up to maximum control capability and those obtained under dynamic flight conditions are to be included, except as limited by structural considerations. For all Classes, thrust settings up to and including MAT shall be included, with and without one critical engine inoperative at entry. At the critical time the elevator, aileron and rudder controls are to be misapplied abruptly: for Class I and IV airplanes, full deflection; for Classes II and III, gross deflection changes. MIL-S-83691 contains more detailed guidance for entry conditions and techniques. The requirements hold for all Airplane Normal States and for all States of stability and control augmentation systems except approval Special Failure States. Store release shall not be allowed during entry, spin or gyration, recovery, or subsequent dive pullout. Automatic disengagement of augmentation systems, however, is permissible if it is necessary and does not prevent meeting any other requirements; reengagement shall be possible in flight. A spin/post-stall-gyration recovery system initiated by pilot action or an automatic prevention device may be accepted only if it can be shown (3.4.1) that the requirements of 3.4.2.2 through 3.4.2.2.2 cannot be met by normal means and the device meets the requirements of 3.4.1.2."

Three Flights/Test Time 3 Weeks/
3+00 Hours Flight Time

## D. TAKEOFF AND LANDING TESTS

More comprehensive horizontal takeoff and landing performance tests will be conducted later in the test program, but it is desirable to determine the general characteristics early in the program. This is particularly applicable for the shuttle system since design constraints point up the fact that such takeoff and landing may well be one of the more critical operations in this test program. The following design constraints are considered:

1. Landings and takeoffs will be conducted at various weights and associated CG positions.

2. Various high lift and drag device configurations normally associated with the takeoff and landing mode will be investigated.

3. Vehicle flight instrumentation position/lag errors in ground effect will be investigated in conjunction with these tests.

4. Telemetry, oscillograph, camera, photo-grind, photo theodolite equipment as necessary will be activated for these tests.

5. Atmospheric conditions will be closely monitored and recorded.

6. Specific performance and characteristics to be determined as a result of these tests are acceleration rates, rotation speed, liftoff speed, takeoff distance and air speed to 50' altitude, critical engine failure speed and balanced field length data, rotation attitude, visibility, climb rate after takeoff, directional control on runway with loss of engine, lateral and directional control with loss of engine immediately after becoming airborne, engine parameters, longitudinal control, structural vibrations, control surface effectiveness, wet runway impact on performance, approach attitude, sink rates (a vertical doppler radar system should be considered), approach speeds, lateral control, touchdown speeds, visibility, stopping distances, brake effectiveness, drag devices effectiveness, crosswind effects, rotate and go around characteristics, and control response throughout approach and landing. (Loss of engine will be simulated by retarding throttle to idle).

7. Inertial navigation systems capabilities should be used to facilitate the conduct of these tests where applicable.

8. The following paragraphs of MIL-F-8785B describe applicable takeoff and landing specifications:

> "3.3.7.1 Final approach in cross winds. For all airplanes except land-based airplanes equipped with cross-wind landing gear, or otherwise constructed to land in a large crabbed attitude, rudder and aileron-control power shall be adequate to develop at least 10 degrees of sideslip (3.3.6)

in the power approach with rudder pedal forces not exceeding the values specified in 3.3.7. For Level 1, aileron control shall not exceed either 10 pounds of force or 75 percent of control power available to the pilot. For Levels 2 and 3, aileron-control force shall not exceed 20 pounds.

3.3.7.2 Takeoff run and landing rollout in cross winds. Rudder and aileron-control power, in conjunction with other normal means of control, shall be adequate to maintain a straight path on the ground or other landing surface. This requirement applies in calm air and in cross winds up to the values specified in Table XI with cockpit control forces not exceeding the values specified in 3.3.7.

3.3.9.1 Thrust loss during takeoff run. It shall be possible for the pilot to maintain control of an airplane on the takeoff surface following sudden loss of thrust from the most critical factor. Thereafter, it shall be possible to achieve and maintain a straight path on the takeoff surface without a deviation of more than 30 feet from the path originally intended, with rudder pedal forces not exceeding 180 pounds. For the continued takeoff, the requirement shall be met when thrust is lost at speeds from the refusal speed (based on the shortest runway from which the airplane is designed to operate) to the maximum takeoff speed, with takeoff thrust maintained on the operative engine(s), using only elevator, aileron, and rudder controls. For the aborted takeoff, the requirement shall be met at all speeds below the maximum takeoff speed; however, additional controls such as nosewheel steering and differential braking may be used. Automatic devices which normally operate in the event of a thrust failure may be used in either case.

3.3.9.2 Thrust loss after takeoff. During takeoff, it shall be possible without a change in selected configuration to achieve straight flight following sudden asymmetric loss of thrust from the most critical factor at speeds from $V_{min}$ (TO) to $V_{max}$ (TO), and thereafter to maintain straight flight throughout the climb-out. The rudder pedal force required to maintain straight flight with asymmetric thrust shall not exceed 180 pounds. Aileron control shall not exceed either the force limits specified in 3.3.4.2 or 75 percent of available control power, with takeoff thrust maintained on the operative engine(s) and trim at normal settings for takeoff with symmetric thrust. Automatic devices which normally operate in the event of a thrust failure may be used, and the airplane may be banked up to 5 degrees away from the inoperative engine.

3.2.3.3 Longitudinal control in takeoff. The effectiveness of the elevator control shall not restrict the takeoff performance of the airplane and shall be sufficient to prevent over-rotation to undesirable attitudes during takeoffs. Satisfactory takeoffs shall not be dependent upon use of the trimmer control during takeoff or on complicated control manipulation by the pilot. For nose-wheel airplanes it shall be possible to obtain, at $0.9V_{min}$, the pitch attitude which will result in takeoff at $V_{min}$. For tail-wheel airplanes, it shall be possible to maintain any pitch attitude up to that for a level thrust-line at $0.5\ V_S$ for Class I airplanes and at $V_S$ for Class II, III, and IV airplanes. These requirements shall be met on hard-surfaced runways. In the event that an airplane has a mission requirement for operation from unprepared fields, these requirements shall be met on such fields.

3.2.3.3.1 Longitudinal control in catapult takeoff. On airplanes designed for catapult takeoff, the effectiveness of the elevator control shall be sufficient to prevent the airplane from pitching up or down to undesirable attitudes in catapult takeoffs at speeds ranging from the minimum safe launching speed to a launching speed 30 knots higher than the minimum. Satisfactory catapult takeoffs shall not depend upon complicated control manipulation by the pilot.

3.2.3.3.2 Longitudinal control force and travel in takeoff. With the trim setting optional but fixed, the elevator-control forces required during all types of takeoffs for which the airplane is designed, including short-field takeoffs and assisted take-offs such as catapult or rocket-augmented, shall be within the following limits:

Nose-wheel and bicycle-gear airplanes

Classes I, IV-C -------------- 20 pounds pull to 10 pounds push

Classes II-C, IV-L ----------- 30 pounds pull to 10 pounds push

Class II-L, III --------------- 50 pounds pull to 20 pounds push

Tail-wheel airplanes

Classes I, II-C, IV------------20 pounds push to 10 pounds pull

Classes II-L, III--------------35 pounds push to 15 pounds pull

The elevator-control travel during these takeoffs shall not exceed 75 percent of the total travel, stop-to-stop. For purposes of this requirement, the term takeoff includes the ground run, rotation and lift-off, the ensuing acceleration to $V_{max}$ (TO), and the transient caused by assist cessation. Takeoff power shall be maintained until $V_{max}$ (TO) is reached, with the landing gear and high-lift devices retracted in the normal manner at speeds from $V_{o_{min}}$ (TO) to $V_{max}$ (TO).

3.2.3.4 Longitudinal control in landing. The elevator control shall be sufficiently effective in the landing Flight Phase in close proximity to the ground, that:

a. The geometry-limited touchdown attitude can be maintained in the level flight, or
b. The lower of $V_S$ (L) or the guaranteed landing speed can be obtained.

This requirement shall be met with the airplane trimmed for the approach Flight Phase at the recommended approach speed. The requirements of 3.2.3.4 and 3.2.3.4.1 define Levels 1 and 2. For Level 3, it shall be possible to execute safe approaches and landings in the presence of atmospheric disturbances.

3.2.3.4.1 Longitudinal control forces in landing. The elevator-control forces required to meet the requirements of 3.2.3.4 shall be pull forces and shall not exceed:

Classes I, II-C, IV ----------- 35 pounds

Classes II-L, III------------- 50 pounds"

Three Flights/Test Time 2 Weeks
3+00 Hours Flight Time

## E. CLIMB PERFORMANCE

The objective of the test is to determine best climb speed and optimum energy climb schedule. This data is necessary to develop climb schedules and procedures that will enable maximizing the very limited flight time available during a horizontally launched shuttle flight. This information will be applicable to the remaining horizontal test flights and possible ferry flights in the future where flight endurance and range will be critical. Test requirements will include the following:

1. Level flight acceleration method recommended. (If speed range is small and acceleration poor it may be necessary to resort to saw tooth climbs.)

2. Gear down effects on climb capability should be determined.

3. Four altitudes should be checked.

4. Temperature probe check done in conjunction with this check.

5. Avionics, engine performance, fuel systems calibration, auto recovery, auto landing checks also may be done in conjunction with these checks.

6. Descent performance continued as test will allow.

7. Applicable instrumentation channels will be activated for these tests.

8. Specific parameters to be recorded are airspeed, altitude, time, fuel consumption, aircraft weight, engine performance indicators. From these parameters the objectives as stated above will be determined as well as furnishing data on excess thrust, fuel flow, drag data, distance and fuel used to accelerate.

Four Flights/Test Time 3 Weeks/
5+00 Hours Flight Time

## F. LEVEL FLIGHT SPEED POWER

The unusually short duration predicted for horizontally launched shuttle flights makes it desirous that engine performance, that is, relationship of true airspeed, engine speed and altitude at a standard weight and altitude - (standard day level flight performance) be determined earlier in the test program than normal to have the needed data available to determine the maximum utilization of flight time.

1. W/S method should be used.

2. Climb performance can be verified in climbing to altitude.

3. Four altitudes should be investigated.

4. Descent performance continued, limited flutter investigation possible during descent.

5. Avionics, engine performance, auto recovery, auto landing tests may be accomplished in conjunction with these tests as applicable.

6. Applicable instrumentation channels as determined by finalized test flight plan will be activated for these tests.

7. Specific parameters to be recorded are airspeed, altitude, time, fuel consumption, aircraft weight and engine performance indicators.

8. Specific engine performance characteristics to be determined are:

a. Fuel flow characteristics for all weights, speeds and altitude conditions.

b. Drag characteristics for all weights, speeds, and altitude conditions.

c. The specific range characteristics for all weights, speeds and altitude conditions.

Four Flights/Test Time 3 Weeks/
5+00 Hours Flight Time

## G. FOLLOW ON CALIBRATION TEST

To verify the performance data accumulated in the tests completed, the pitot static system should be rechecked to assure that the original calibration determinations were correct and/or to assure that no vehicle configuration changes, modifications, etc., have occurred invalidating the data obtained or which would invalidate future data.

1. Calibration method found most suitable during first calibration flights should be used.

2. Instrumentation channels and test data parameters as outlined in para 2 above should be activated and recorded.

3. Additional checks may be accomplished in conjunction with or at the termination of these flights as the test will allow.

4. Major data recording instrumentation update if necessary, modification, or recalibrations should be accomplished during this period.

Two Flights/Test Time 2 Weeks/
3+00 Hours Flight Time

## H. STATIC LONGITUDINAL STABILITY STICK FIXED AND FREE

To evaluate the static longitudinal stability characteristics of the vehicle the stabilizer or acceleration flight test methods, with adjustment as required, will be used.

1. The static longitudinal stability of the aircraft will be investigated in various configurations at different speeds, altitudes and CG positions.

2. Additional testing may be accomplished on these flights as time will allow, i.e., avionics, engine performance, auto approach and landing, etc. Particularly suitable to this series of tests would be determination of longitudinal control forces in dives. In conjunction with these determinations flutter investigations (natural and induced) could be made.

3. Applicable instrumentation channels as determined by the finalized test flight plan will be activated for these tests.

4. Specific parameters to be recorded are altitude, airspeed, time, attitude, fuel flow, weight, CG position, temperature, elevator position, elevator control force, engine parameters, and load factors.

5. Advanced flight control systems on the space shuttle could require reevaluation of flight test techniques to be used in determining the longitudinal stability of the vehicle and could require adjustments in applying the specifications of MIL-F-8785B.

6. The following paragraphs of MIL-F-8785B describe applicable static longitudinal specifications:

> "3.2 Longitudinal flying qualities
>
> 3.2.1 Longitudinal stability with respect to speed
>
> 3.2.1.1 Longitudinal static stability. There shall be no tendency for the airspeed to diverge aperiodically when the airplane is disturbed from trim with the cockpit controls fixed and with them free. This requirement will be considered satisfied if the variations of elevator control force and elevator control position with airspeed are smooth and the local gradients stable, with:
>
> Trimmer and throttle controls not moved from the trim settings by the crew, and
>
> 1g acceleration normal to the flight path, and
>
> Constant altitude
>
> over a range about the trim speed of ±15 percent or ±50 knots equivalent airspeed, whichever is less (except where limited by the boundaries of the Service Flight Envelope). Stable gradients mean increasing pull forces and aft motion of the elevator control to maintain slower airspeeds and the opposite to maintain faster airspeeds. The term gradient does not include that portion of the control force or control position versus airspeed curve within the preloaded breakout force or friction range.

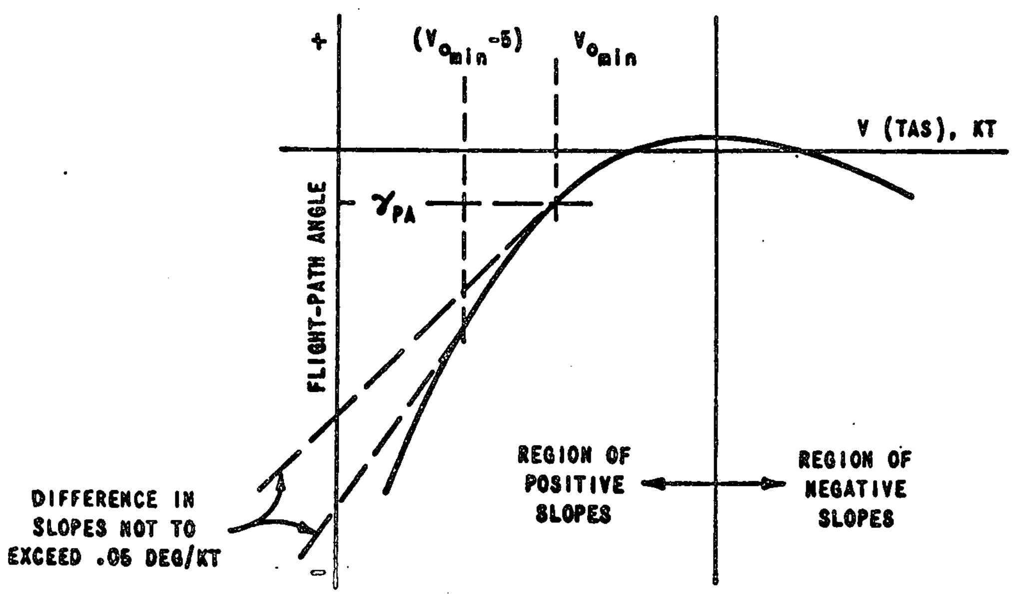
3.2.1.3 Flight-path stability. Flight-path stability is defined in terms of flight-path-angle change where the airspeed is changed by the use of the elevator control only (throttle setting not changed by the crew). For the landing approach Flight Phase, the flight-path-angle versus true-airspeed curve shall have a local slope at $V_{o_{min}}$ which is negative or less positive than:

a. Level 1------0.06 degrees/knot

b. Level 2------0.15 degrees/knot

c. Level 3------0.24 degrees/knot

The thrust setting shall be that required for the normal approach glide path at $V_{o_{min}}$. The slope of the flight-path angle versus airspeed curve at 5 knots slower than $V_{o_{min}}$ shall not be more than 0.05 degrees per knot more positive than the slope at $V_{o_{min}}$, as illustrated by:



3.2.3 Longitudinal control

3.2.3.1 Longitudinal control in unaccelerated flight. In erect unaccelerated flight at all service altitudes, the attainment of all speeds between $V_S$ and $V_{max}$ shall not be limited by the effectiveness of the longitudinal control, or controls.

3.2.3.5 Longitudinal control forces in dives - Service Flight Envelope. With the airplane trimmed for level flight at speeds throughout the Service Flight Envelope, the elevator control forces in dives to all attainable speeds within the Service Flight Envelope shall not exceed 50 pounds push or 10 pounds pull for airplanes with center-stick controllers, nor 75 pounds push or 15 pounds pull for airplanes with wheel controllers. In similar dives, but with trim optional following the dive entry, it shall be possible with normal piloting techniques to maintain the forces within the limits of 10 pounds push or pull for airplanes with center-stick controllers, and 20 pounds push or pull for airplanes with wheel controllers. The forces required for recovery from these dives shall be in accordance with the gradients specified in 3.2.2.2.1 although speed may vary during the pullout.

3.2.3.6 Longitudinal control forces in dives - Permissible Flight Envelope. With the airplane trimmed for level flight at $V_{MAT}$ but with trim optional in the dive, it shall be possible to maintain the elevator control force within the limits of 50 pounds push or 35 pounds pull in dives to all attainable speeds within the Permissible Flight Envelope. The force required for recovery from these dives shall not exceed 120 pounds. Trim and deceleration devices, etc., may be used to assist in recovery if no unusual pilot technique is required."

## I. LONGITUDINAL AND LATERAL DIRECTIONAL DYNAMIC STABILITY

An investigation of the primary longitudinal, lateral, and directional modes of motion (phugoid, short period, spiral, dutch roll) will be made.

1. Dynamic longitudinal stability tests will be conducted at any convenient, but consistent, gross weight at the forward and aft center of gravity positions for various trim speeds, altitudes and configurations.

2. Spiral mode and dutch roll mode will be checked in conjunction with the longitudinal tests and may be accomplished during changing CG conditions since CG location in general does not affect lateral dynamic characteristics.

3. Additional checks may be made in conjunction with these flights as time and procedures will allow.

4. Real time read out of data is particularly suitable for these tests from the standpoint of flight safety as well as reducing flight time to a minimum thru immediate determination that sufficient data points have been obtained.

5. Applicable instrumentation channels as determined by the finalized flight test plan will be activated for this series of flights. Specific parameters of interest are flight control surface positions and forces, timing of events, atmospheric values, airspeeds, altitudes, pitch rates, roll rates, pitch angles, angles of attack, flight path angles, accelerations, yaw rates, sideslip angles, control wheel/stick and rudder positions, natural frequencies, induced frequencies, roll yaw coupling, damping characteristics, aircraft structural bending/vibrations/stresses, flutter values (natural and induced if testing will permit) and engine performance measurements. The effect yaw dampers and powered control surfaces off (if so designed) have on the dynamic characteristics being investigated is a significant consideration. The following paragraphs MIL-F-8785B describe applicable dynamic specifications.

> "3.2.1.1.2 Elevator control force variations during rapid speed changes. When the airplane is accelerated and decelerated rapidly through the operational speed range and through the transonic speed range by the most critical combination of changes in power, actuation of deceleration devices, steep turns and pullups, the magnitude and rate of the associated trim change shall not be so great as to cause difficulty in maintaining the desired load factor by normal pilot techniques.
>
> 3.2.2 Longitudinal maneuvering characteristics.
>
> 3.2.2.1 Short-period response. The short-period response of angle of attack which occurs at approximately constant speed, and which may be produced by abrupt elevator control inputs, shall meet the requirements of 3.2.2.1.1 and 3.2.2.1.2. These requirements apply, with the cockpit control free and with it fixed, for responses of any magnitude that might be experienced in service use. If oscillations are nonlinear with amplitude, the requirements shall apply to each cycle of the oscillation. In addition to meeting the numerical requirements of 3.2.2.1.1 and 3.2.2.1.2, the contractor shall show that the airplane has acceptable response characteristics in atmospheric disturbances.
>
> 3.2.2.1.1 Short-period frequency and acceleration sensitivity. The short-period undamped natural frequency, $\omega_{n_{sp}}$, shall be within the limits shown in figures B-1, B-2, and B-3. If suitable means of directly controlling normal forces are provided, the lower bounds on $\omega_{n_{sp}}$ and $n/\alpha$ of figure 3 may be relaxed if approved by the procuring activity.

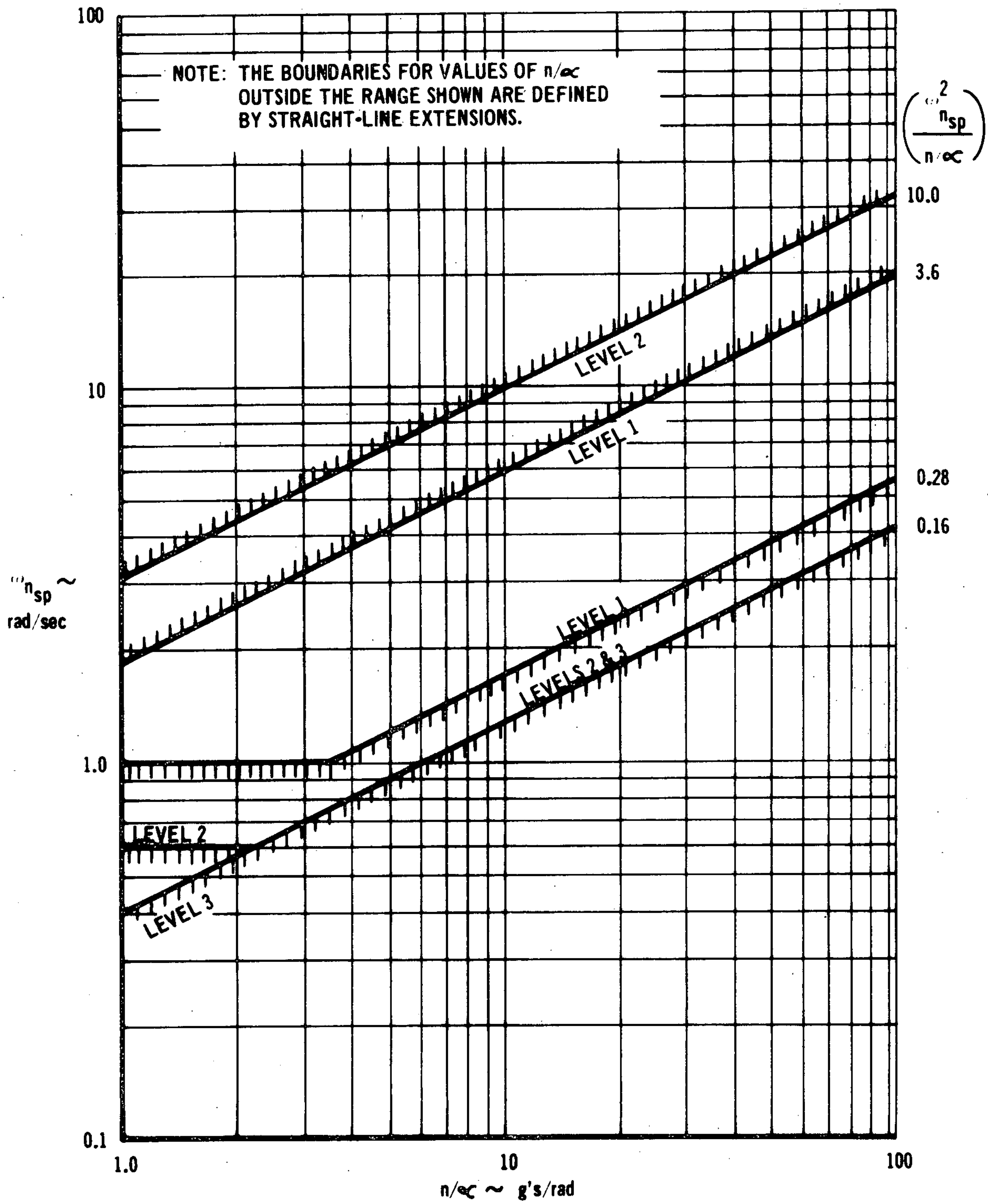



Figure B-1. Short-Period Frequency Requirements – Category A Flight Phases

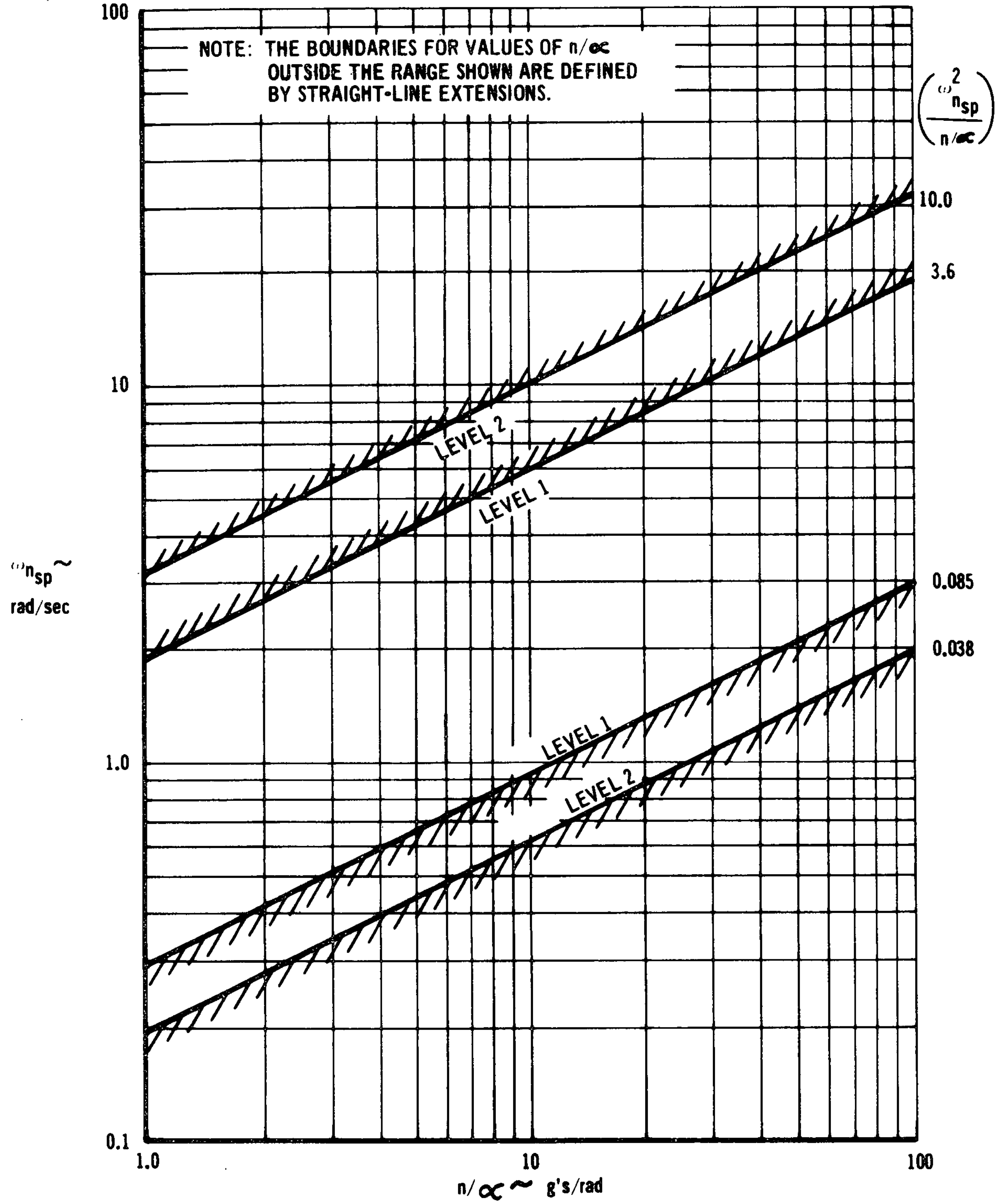



**Figure B-2. Short-Period Frequency Requirements – Category B Flight Phases**

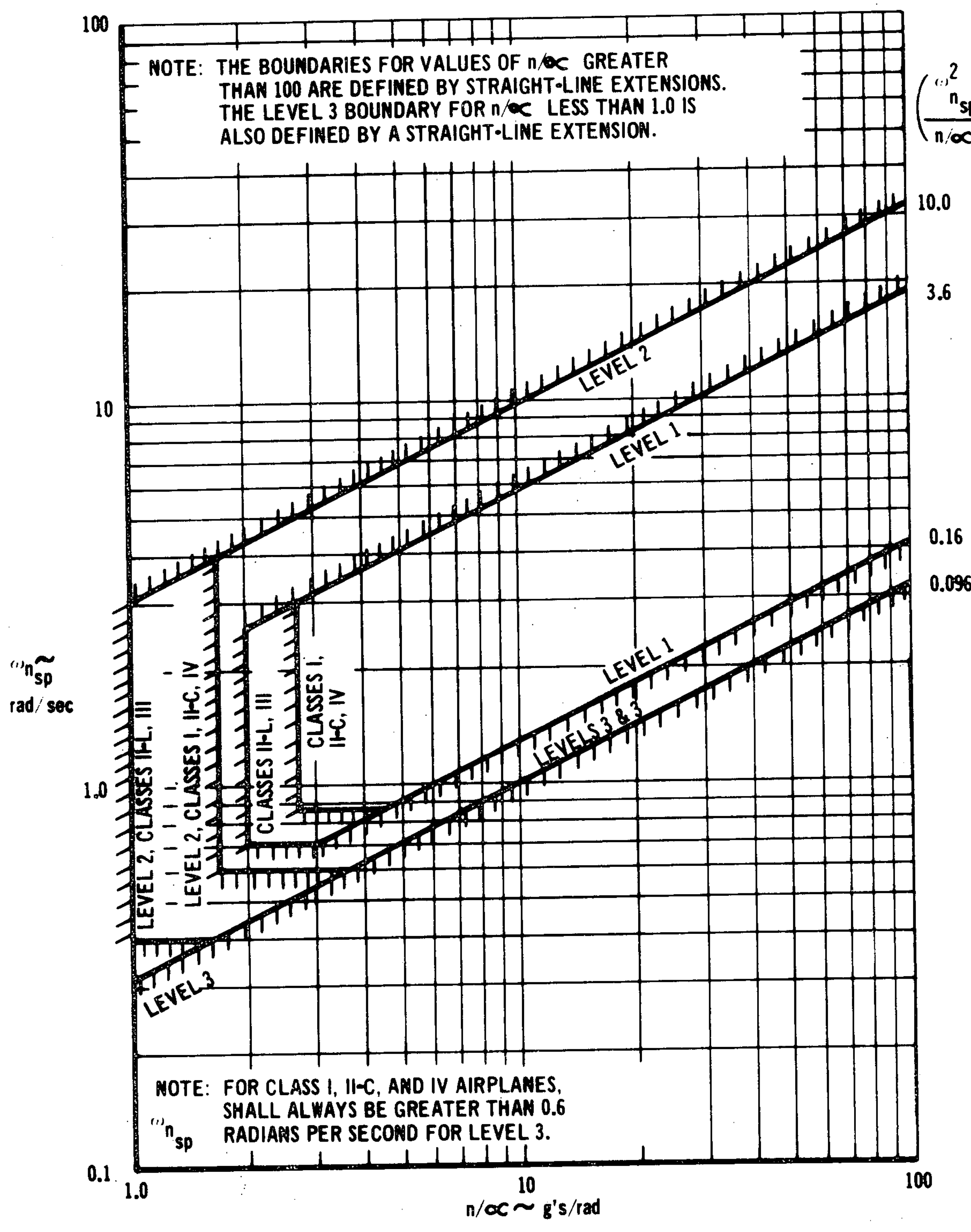



Figure B-3. Short-Period Frequency Requirements – Category C Flight Phases

3.2.2.1.2 Short-period damping. The short-period damping ratio, $\zeta_{sp}$, shall be within the limits of table IV.

TABLE IV. Short-period Damping Ratio Limits

| Level | Category A and C Flight Phases Minimum | Category A and C Flight Phases Maximum | Category B Flight Phases Minimum | Category B Flight Phases Maximum |
|---|---|---|---|---|
| 1 | 0.35 | 1.30 | 0.30 | 2.00 |
| 2 | 0.25 | 2.00 | 0.20 | 2.00 |
| 3 | 0.15* | - | 0.15* | - |

*May be reduced at altitudes above 20,000 feet if approved by the procuring activity.

3.2.2.1.3 Residual oscillations. Any sustained residual oscillations shall not interfere with the pilot's ability to perform the tasks required in service use of the airplane. For Levels 1 and 2, oscillations in normal acceleration at the pilot's station greater than ±0.05g will be considered excessive for any Flight Phase, as will pitch attitude oscillations greater than ±3 mils for Category A Flight Phases requiring precision control of attitude. These requirements shall apply with the elevator control fixed and with it free.

## 3.3 Lateral-directional flying qualities

### 3.3.1 Lateral-directional mode characteristics

3.3.1.1 Lateral-directional oscillations (Dutch roll). The frequency, $\omega_{n_d}$ , and damping ratio, $\zeta_d$ , of the lateral-directional oscillations following a rudder disturbance input shall exceed the minimums in table VI. The requirements shall be met with cockpit controls fixed and with them free, in oscillations of any magnitude that might be experienced in operational use. If the oscillation is nonlinear with amplitude, the requirement shall apply to each cycle of the oscillation. Residual oscillations may be tolerated only if the amplitude is sufficiently small that the motions are not objectionable and do not impair mission performance. For Category A Flight Phases, angular deviations shall be less than ±3 mils. With the control surfaces fixed, $\omega_{n_d}$ shall always be greater than zero.

TABLE VI. Minimum Dutch Roll Frequency and Damping

| Level | Flight Phase Category | Class | Min $\zeta_d$ * | Min $\zeta_d \omega_{n_d}$ *, rad/sec. | Min $\omega_{n_d}$, rad/sec. |
|---|---|---|---|---|---|
| 1 | A | I, IV | 0.19 | 0.35 | 1.0 |
| | | II, III | 0.19 | 0.35 | 0.4** |
| | B | All | 0.08 | 0.15 | 0.4** |
| | C | I, II-C, IV | 0.08 | 0.15 | 1.0 |
| | | II-L, III | 0.08 | 0.15 | 0.4** |
| 2 | All | All | 0.02 | 0.05 | 0.4** |
| 3 | All | All | 0.02 | - | 0.4** |

*The governing damping requirement is that yielding the larger value of $\zeta_d$.

**Class III airplanes may be excepted from the minimum $\omega_{n_d}$ requirement, subject to approval by the procuring activity, if the requirements of 3.3.2 through 3.3.2.4.1, 3.3.5 and 3.3.9.4 are met.

When $\omega_{n_d}^2 |\phi/\beta|_d$ is greater than 20 (rad/sec)$^2$, the minimum $\zeta_d \omega_{n_d}$ shall be increased above the $\zeta_d \omega_{n_d}$ minimums listed above by:

Level 1 - $\Delta\zeta_d \omega_{n_d} = .014\ (\omega_{n_d}^2 |\phi/\beta|_d - 20)$

Level 2 - $\Delta\zeta_d \omega_{n_d} = .009\ (\omega_{n_d}^2 |\phi/\beta|_d - 20)$

Level 3 - $\Delta\zeta_d \omega_{n_d} = .005\ (\omega_{n_d}^2 |\phi/\beta|_d - 20)$

with $\omega_{n_d}$ in rad/sec.

3.3.1.2 Roll mode. The roll-mode time constant, $\tau_R$, shall be no greater than the appropriate value in table VII.

TABLE VII. Maximum Roll-Mode Time Constant

| Flight Phase Category | Class | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| A | I, IV | 1.0 | 1.4 | 10 |
| | II, III | 1.4 | 3.0 | 10 |
| B | ALL | 1.4 | 3.0 | 10 |
| C | I, II-C, IV | 1.0 | 1.4 | 10 |
| | II-L, III | 1.4 | 3.0 | 10 |

3.3.1.3 Spiral stability. The combined effects of spiral stability, flight-control-system characteristics, and trim change with speed shall be such that following a disturbance in bank of up to 20 degrees, the time for the bank angle to double will be greater than the values in table VIII. This requirement shall be met with the airplane trimmed for wings-level, zero-yaw- rate flight with the cockpit controls free.

TABLE VIII. Spiral Stabilitv - Minimum Time to Double Amplitude

| Class | Flight Phase Category | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| I & IV | A | 12 sec | 12 sec | 4 sec |
| | B & C | 20 sec | 12 sec | 4 sec |
| II & III | All | 20 sec | 12 sec | 4 sec |

3.3.1.4 Coupled roll-spiral oscillation. A coupled roll-spiral mode will not be permitted.

3.3.2 Lateral-directional dynamic response characteristics. Lateral-directional dynamic response characteristics are stated in terms of response to atmospheric disturbances and in terms of allowable roll rate and bank oscillations, sideslip excursions, aileron stick or wheel forces, and rudder pedal forces that occur during specified rolling and turning maneuvers. The requirements of 3.3.2.2, 3.3.2.3, and 3.3.2.4 apply for both right and left aileron commands of all magnitudes up to the magnitude required to meet the roll performance requirements of 3.3.4 and 3.3.4.1.

3.3.2.1 Lateral-directional response to atmospheric disturbances. Although no numerical requirements are specified, the combined effect of
gust sensititivity, and flight-control-system nonlinearities shall be such that the airplane will have acceptable response and controllability characteristics in atmospheric disturbances. In particular, the roll acceleration, rate, and displacement responses to side gusts shall be investigated for airplanes with large rolling moment due to sideslip.

3.3.3 Pilot-induced oscillations. There shall be no tendency for sustained or uncontrollable lateral-directional oscillations resulting from efforts of the pilot to control the airplane."

Five Flights/Test Time 3 Weeks/
7+00 Hours Flight Time

## J. STATIC DIRECTIONAL STABILITY

An investigation will be made of the static lateral and directional stability characteristics of the aircraft in each of several configurations.

1. The static directional stability and control characteristics will be investigated at any convenient center of gravity location and light gross weight at various trim speeds and altitudes.

2. The aircraft will be placed in a series of sideslips of gradual increasing magnitude (not to exceed recommended sideslip angle) both right and left while maintaining a straight flight path.

3. Time permitting limited investigation of sideslip and roll interactions will be made. These investigations will be completed in the roll characteristics tests later in the program.

4. Additional checks may be performed in conjunction with these tests as time and procedures will allow.

5. Applicable instrumentation channels as determined by the finalized flight test plan will be activated for this series of flights. Specific parameters of interest are flight control surface positions and forces, timing of events, atmospheric values, airspeeds, altitudes, roll rates, yaw rates, angles of attack, angles of sideslip, control wheel and rudder pedal position, roll yaw coupling, accelerations, oscillations, natural and induced frequencies of airframe and control surfaces, damping characteristics, pitch angles and rates, airframe loads imposed by sideslip conditions, asymmetric considerations, and engine performance measurements.

6. The following paragraphs of MIL-F-8785B describe applicable directional stability specifications.

> "3.2.3.7 Longitudinal control in sideslips. With the airplane trimmed for straight, level flight with zero sideslip, the elevator-control force required to maintain constant speed in steady sideslips with up to 50 pounds of rudder pedal force in either direction shall not exceed the elevator-control force that would result in a 1g change in normal acceleration. In no case, however, shall the elevator-control force exceed:
>
> Center-stick controllers -------- 10 pounds pull to 3 pounds push
>
> Wheel controllers ------------- 15 pounds pull to 10 pounds push

If a variation of elevator-control force with sideslip does exist, it is preferred that increasing pull force accompany increasing sideslip, and that the magnitude and direction of the force change be similar for right and left sideslips. These requirements define Levels 1 and 2. For Level 3, there shall be no uncontrollable pitching motions associated with the sideslips discussed above.

3.3.5 Directional control characteristics. Directional stability and control characteristics shall enable the pilot to balance yawing moments and control yaw and sideslip. Sensitivity to rudder pedal forces shall be sufficiently high that directional control and force requirements can be met and satisfactory coordination can be achieved without unduly high rudder pedal forces, yet sufficiently low that occasional improperly coordinated control inputs will not seriously degrade the flying qualities.

3.3.5.1 Directional control with speed change. When initially trimmed directionally with symmetric power, the trim change of propeller-driven airplanes with speed shall be such that straight flight can be maintained over a speed range of ±30 percent of the trim speed or ±100 knots equivalent airspeed, whichever is less (except where limited by boundaries of the Service Flight Envelope) with rudder pedal forces not greater than 100 pounds for Levels 1 and 2 and not greater than 180 pounds for Level 3 without retrimming. For other airplanes, rudder pedal forces shall not exceed 40 pounds at the specified conditions for Levels 1 and 2 nor 180 pounds for Level 3.

3.3.5.1.1 Directional control with asymmetric loading. When initially trimmed directionally with each asymmetric loading specified in the contract at any speed in the Operational Flight Envelope, it shall be possible to maintain a straight flight path throughout the Operational Flight Envelope with rudder pedal forces not greater than 100 pounds for Levels 1 and 2 and not greater than 180 pounds for Level 3, without retrimming.

3.3.5.2 Directional control in wave-off (go-around). For propeller-driven Class IV, and all propeller-driven carrier-based airplanes, the response to thrust, configuration, and airspeed change shall be such that the pilot can maintain straight flight during wave-off (go-around) initiated at speeds down to $V_S$ (PA) with rudder pedal forces not exceeding 100 pounds when trimmed at $V_{o_{min}}$ (PA). For other airplanes, rudder pedal forces shall not exceed 40 pounds for the specified conditions. The preceding requirements apply for Levels 1 and 2. For all airplanes the Level 3 requirement is to maintain straight flight in these conditions with rudder pedal forces not exceeding 180 pounds. For all Levels, bank angles up to 5 degrees are permitted.

3.3.6 Lateral-directional characteristics in steady sideslips. The requirements of 3.3.6.1 through 3.3.6.3.1 and 3.3.7.1 are expressed in terms of characteristics in rudder-pedal-induced steady, zero-yaw-rate sideslips with the airplane trimmed for wings-level straight flight. Paragraphs 3.3.6.1 through 3.3.6.3 apply at sideslip angles up to those produced or limited by:

a. Full rudder pedal deflection, or

b. 250 pounds of rudder pedal force, or

c. Maximum aileron control or surface deflection,

except that for single-propeller-driven airplanes during wave-off (go-around), rudder pedal deflection in the direction opposite to that required for wings-level straight flight need not be considered beyond the deflection for a 10-degree change in sideslip from the wings-level straight flight condition.

3.3.6.1 Yawing moments in steady sideslips. For the sideslips specified in 3.3.6, right rudder pedal deflection and force shall produce left sideslips and left rudder pedal deflection and force shall produce right sideslips. For Levels 1 and 2 the following requirements shall apply. The variation of sideslip angle with rudder pedal deflection shall be essentially linear for sideslip angles between +15 degrees and -15 degrees. For larger sideslip angles, an increase in rudder pedal deflection shall always be required for an increase in sideslip. The variation of sideslip angle with rudder pedal force shall be essentially linear for sideslip angles between +10 degrees and -10 degrees. Although a lightening of rudder pedal force is acceptable for sideslip angles outside this range, the rudder pedal force shall never reduce to zero.

3.3.6.2 Side forces in steady sideslips. For the sideslips of 3.3.6, an increase in right bank angle shall accompany an increase in right sideslip, and an increase in left bank angle shall accompany an increase in left sideslip.

3.3.6.3 Rolling moments in steady sideslips. For the sideslips of 3.3.6, left aileron-control deflection and force shall accompany left sideslips, and right aileron-control deflection and force shall accompany right sideslips. For Levels 1 and 2, the variation of aileron-control deflection and force with sideslip angle shall be essentially linear.

3.3.6.3.1 Exception for wave-off (go-around). The requirement of 3.3.6.3 may, if necessary, be excepted for wave-off (go-around) if task performance is not impaired and no more than 50 percent of roll control power available to the pilot, and no more than 10 pounds of aileron-control force, are required in a direction opposite to that specified in 3.3.6.3.

3.3.6.3.2 Positive effective dihedral limit. For Levels 1 and 2, positive effective dihedral (right aileron control for right sideslip and left aileron control for left sideslip) shall never be so great that more than 75 percent of roll control power available to the pilot, and no more than 10 pounds of aileron-stick force or 20 pounds of aileron-wheel force, are required for sideslip angles which might be experienced in service employment.

3.3.2.4 Sideslip excursions. Following a rudder-pedals-free step aileron control command, the ratio of the sideslip increment, $\Delta\beta$, to the parameter k (6.2.6) shall be less than the values specified herein. The aileron command shall be held fixed until the bank angle has changed at least 90 degrees.

| Level | Flight Phase Category | Adverse Sideslip (Right roll command causes right sideslip) | Proverse Sideslip (Right roll command causes left sideslip) |
|---|---|---|---|
| 1 | A | 6 degrees | 2 degrees |
| | B & C | 10 degrees | 3 degrees |
| 2 | All | 15 degrees | 4 degrees |

3.3.2.4.1 Additional sideslip requirement for small inputs. The amount of sideslip following a rudder-pedals-free step aileron control command shall be within the limits shown on figure 6 for Levels 1 and 2. This requirement shall apply for step aileron control commands up to the magnitude which causes a 60-degree bank angle change within $T_d$ or 2 seconds, whichever is longer.

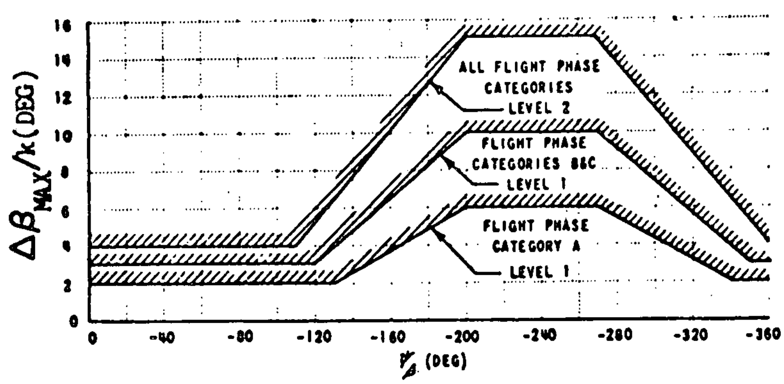



FIGURE 6. Sideslip Excursion Limitations

3.3.2.5. Control of sideslip in rolls. In the rolling maneuvers described in 3.3.4, but with the rudder pedals used for coordination for all Classes, directional-control effectiveness shall be adequate to maintain zero sideslip with a rudder pedal force not greater than 50 pounds for Class IV airplanes in Flight Phase Category A, Level 1, and 100 pounds for all other combinations of Class, Flight Phase Category and Level."

As previously stated advanced flight control systems will require adjustments in the above noted specifications to provide a meaningful criteria for a shuttle type vehicle.

Four Flights/Test Time 3 Weeks/
5+30 Hours Flight Time

## K. TRIM CHANGES

The magnitude of control force changes associated with normal configuration changes, trim system failure or transfer to alternate control systems in relation to desirable limits will be ascertained. It must also be determined that no undesirable flight characteristics accompany these configuration changes.

1. The control forces and deflections required to maintain specified parameters constant with specified configuration changes will be determined.

2. Trim changes will be checked at conditions for the most adverse conditions, i.e., generally highest airspeed and lowest altitude.

3. Simulated trim and control system failure effects will be evaluated with stability augmentation control systems on and off.

4. Mid - CG investigation results will determine further testing requirements at fore and aft CG locations.

5. Some testing will likely be required for logical simultaneous configuration changes.

6. Previous flights will have provided an opportunity to obtain much of the required information and will determine what configuration change measurements remain to be investigated.

7. Applicable instrumentation channels as determined by the finalized flight test plan will be activated for these tests. Specific parameters to be recorded are atmospheric values, airspeeds, altitudes, roll rates, yaw rates, control surface deflections, control wheel and rudder pedal position and forces, airframe oscillations, vibrations, and flutter, noise, pitch angles, pitch rates, angle of attack, air loads on wing, body, fin, horizontal stabilizer, nacelles, flaps, slats, spoilers, etc., sideslip angles, roll yaw couplings, natural and induced frequencies of control surfaces/ fuselage and engine performance measurements.

8. The following paragraphs of MIL-F-8785B describe trim change specifications.

"3.6 Characteristics of secondary control systems

3.6.1 Trim system. In straight flight, throughout the Operational Flight Envelope the trimming devices shall be capable of reducing the elevator, rudder, and aileron control forces to zero for Levels 1 and 2. For Level 3, the untrimmed cockpit control forces shall not exceed 10 pounds elevator, 5 pounds aileron, and 20 pounds rudder. The failures to be considered in applying the Level 2 and 3 requirements shall include trim sticking and runaway in either direction. It is permissible to meet the Level 2 and 3 requirements by providing the pilot with alternate trim mechanisms or override capability. Additional requirements on trim rate and authority are contained in MIL-F-9490 and MIL-F-18372.

3.6.1.1 Trim for asymmetric thrust. For all multiengine airplanes, it shall be possible to trim the elevator, rudder, and aileron control forces to zero in straight flight with up to two engines inoperative following asymmetric loss of thrust from the most critical factors (3.3.9). This requirement defines Level 1 in level-flight cruise at speeds from the maximum-range speed for the engine(s) -out configuration to the speed obtainable with normal rated thrust on the functioning engine(s). Systems completely dependent on the failed engines shall also be considered failed.

3.6.1.2 Rate of trim operation. Trim devices shall operate rapidly enough to enable the pilot to maintain low control forces under changing conditions normally encountered in service, yet not so rapidly as to cause over-sensitivity or trim precision difficulties under any conditions. Specifically, it shall be possible to trim the elevator control forces to less than ±10 pounds for center-stick airplanes and ±20 pounds for wheel-control airplanes throughout (a) dives and ground attack maneuvers required in normal service operation and (b) level-flight accelerations at maximum augmented thrust from 250 knots or $V_{R/C}$, whichever is less, to $V_{max}$ at any altitude when the airplane is trimmed for level flight prior to initiation of the maneuver.

3.6.1.3 Stalling of trim systems. Stalling of a trim system due to aerodynamic loads during maneuvers shall not result in an unsafe condition. Specifically, the longitudinal trim system shall be capable of operating during the dive recoveries of 3.2.3.6 at any attainable permissible n, at any possible position of the trimming device.

3.6.1.4 Trim system irreversibility. All trimming devices shall maintain a given setting indefinitely, unless changed by the pilot, by a special automatic interconnect such as to the landing flaps, or by the operation of an augmentation device. If an automatic interconnect or augmentation device is used in conjunction with a trim device, provision shall be made to ensure the accurate return of the device to its initial trim position on completion of each interconnect or augmentation operation.

3.6.2 Speed and flight-path control devices. The effectiveness and response times of the fore-and-aft force controls, in combination with the other longitudinal controls, shall be sufficient to provide adequate control of flight path and airspeed at any flight condition within the Operational Flight Envelope. This requirement may be met by use of devices such as throttles, thrust reversers, auxiliary drag devices, and flaps.

3.6.3 Transients and trim changes. The transients and steady-state trim changes for normal operation of secondary control devices (such as throttle, flaps, slats, speed brakes, deceleration devices, dive recovery devices, wing sweep, and landing gear) shall not impose excessive control forces to maintain the desired heading, altitude, attitude, rate of climb, speed or load factor without use of the trimmer control. This requirement applies to all in-flight configuration changes and combinations of changes made under service conditions, including the effects of asymmetric operations such as unequal operation of landing gear, speed brakes, slats, or flaps. In no case shall there be any objectionable buffeting or oscillation of such devices. More specific requirements on secondary control devices are contained in 3.6.3.1, 3.6.4, and 3.6.5 and in MIL-F-9490 and MIL-F-18372.

3.6.3.1 Pitch trim changes. The pitch trim changes caused by operation of secondary control devices shall not be so large that a peak elevator control force in excess of 10 pounds for center-stick controllers or 20 pounds for wheel controllers is required when such configuration changes are made in flight under conditions representative of operational procedure. Generally, the conditions listed in table XIV will suffice for determination of compliance with this requirement. (For airplanes with variable-sweep wings, additional requirements will be imposed consistent with operational employment of the vehicle.) With the airplane trimmed for each specified initial condition, the peak force required to maintain the specified parameter constant following the specified configuration change shall not exceed the stated value for a time interval of at least 5 seconds following the completion of the pilot action initiating the configuration change. The magnitude and rate of trim change subsequent to this time period shall be such that the forces are easily trimmable by use of the normal trimming devices. These requirements define Level 1. For Levels 2 and 3, the allowable forces are increased by 50 percent.

3.6.4 Auxiliary dive recovery devices. Operation of any auxiliary device intended solely for dive recovery shall always produce a positive increment of normal acceleration, but the total normal load factor shall never exceed 0.8 $n_L$, controls free.

3.6.5 Direct normal-force control. Use of devices for direct normal-force control shall not produce objectionable changes in attitude for any amount of control up to the maximum available. This requirement shall be met for Levels 1 and 2."

Four Flights/Test Time 3 Weeks/
5+30 Hours Flight Time

## TABLE XIV. Pitch Trim Change Conditions

| | Flight Phase | Initial Trim Condition | | | | | Configuration Change | Parameter to be held constant |
|---|---|---|---|---|---|---|---|---|
| | | Altitude | Speed | Landing Gear | High-lift Devices & Wing Flaps | Thrust | | |
| 1 | Approach | $h_{o_{min}}$ | Normal pattern entry speed | Up | Up | TLF | Gear down | Altitude and airspeed* |
| 2 | | | | Up | Up | TLF | Gear down | Altitude |
| 3 | | | | Down | Up | TLF | Extend high-lift devices and wing flaps | Altitude and airspeed* |
| 4 | | | | Down | Up | TLF | Extend high-lift devices and wing flaps | Altitude |
| 5 | | | | Down | Down | TLF | Idle thrust | Airspeed |
| 6 | | | $V_{o_{min}}$ | Down | Down | TLF | Extend approach drag device | Airspeed |
| 7 | | | | Down | Down | TLF | Takeoff thrust | Airspeed |
| 8 | Approach | | $V_{o_{min}}$ | Down | Down | TLF | Takeoff thrust plus normal clean-up for wave-off (go-around) | Airspeed |
| 9 | Takeoff | | | Down | Take-off | Take-off thrust | Gear up | Pitch attitude |
| 10 | | | Minimum flap-retract speed | Up | Take-off | Take-off thrust | Retract high-lift devices and wing flaps | Airspeed |
| 11 | Cruise and air-to-air combat | $h_{o_{min}}$ and $h_{o_{max}}$ | Speed for level flight | Up | Up | MRT | Idle thrust | Pitch attitude |
| 12 | | | | Up | Up | MRT | Actuate deceleration device | |
| 13 | | | | Up | Up | MRT | Maximum augmented thrust | |
| 14 | | | Speed for best range | Up | Up | TLF | Actuate deceleration device | |

*Throttle setting may be changed during the maneuver

Notes: - Auxiliary drag devices are initially retracted, and all details of configuration not specifically mentioned are normal for the Flight Phase.

- If power reduction is permitted in meeting the deceleration requirements established for the mission, actuation of the deceleration device in #12 and #14 shall be accompanied by the allowable power reduction.

C2

## L. ASYMMETRIC POWER

A thorough evaluation will be made of the aircraft under asymmetric powered conditions.

1. The aircraft response to abrupt throttle reductions in a series of configurations, CG conditions, and altitude combinations will be investigated and recorded.

2. Roll yaw coupling will be investigated.

3. Engine out handling qualities will be evaluated. Engine out conditions will be simulated by retarding throttle to idle. As confidence is gained consideration of engine shutdown to detemmine these qualities will be made if it is determined to be necessary to provide more valid data.

4. Engine response and performance.

5. Flight control and trim system failure simulations will be integrated into this test as level of confidence will practically allow. Effectiveness of stability augmentation system will be evaluated in conjunction with this portion of the test.

6. Minimum inflight control speed will be determined in relation to the specific criteria to be used, i.e., (out of control, out of force, high sink rate, stall, etc). This criteria will be determined as a result of these tests.

7. This test will provide confidence level for follow on propulsion tests, i.e., engine shut down, retraction, extension, air start, etc.

8. Additional testing may be accomplished on return to base portion of flight as time will allow. Exchange of altitude for speed in order to simulate, as nearly as possible, the final portion of the return of an operational mission is a prime candidate for test time at the completion of a flight test. Associated with this phase would be determination of best high key entry pattern, glide slope/path capture, flight path angle, angle of attack, approach speed, drag devices, conditions and method for flare and auto land capabilities.

9. Applicable instrumentation as determined by the finalized flight test plan will be activated. Specific parameters to be recorded are atmospheric values, engine performance measurements, control surface deflections, control wheel and rudder pedal deflections and forces required, pitching moments yaw rates, roll rates, accelerations, sideslip angles, roll/yaw/pitch couplings, rudder free aileron effectiveness, airloads on airframe, sink rates, stability augmentation system effect on and off, and human factor considerations where measurable.

10. The following paragraphs of MIL-F-8785B describe asymmetric power specifications:

"3.3.9 Lateral-directional control with asymmetric thrust. Asymmetric loss of thrust may be caused by many factors including engine failure, inlet unstart, propeller failure, or propeller-drive failure. Following sudden asymmetric loss of thrust from any factor, the airplane shall be safety controllable. The requirements of 3.3.9.1 through 3.3.9.4 apply for the appropriate Flight Phases when any single failure or malperformance of the propulsive system, including inlet or exhaust, causes loss of thrust on one or more engines or propellers, considering also the effect of the failure or malperformance on all subsystems powered or driven by the failed propulsive system.

3.3.9.3 Transient effects. The airplane motions following sudden asymmetric loss of thrust shall be such that dangerous conditions can be avoided by pilot corrective action. A realistic time delay (3.4.9) of at least 1 second shall be considered.

3.3.9.4 Asymmetric thrust - rudder pedals free. The static directional stability shall be such that at all speeds above 1.4 $V_{min}$, with asymmetric loss of thrust from the most critical factor while the other engine(s) develop normal rated thrust, the airplane with rudder pedals free may be balanced directionally in steady straight flight. The trim settings shall be those required for wings-level straight flight prior to the failure. Aileron-control forces shall not exceed the Level 2 upper limits specified in 3.3.4.2 for Levels 1 and 2 and shall not exceed the Level 3 upper limits for Level 3.

3.3.9.5 Two engines inoperative. With any engine initially failed, it shall be possible upon failure of the most critical remaining engine to stop the transient motion at the one-engine-out speed for maximum range, and thereafter to maintain straight flight from that speed to the speed for maximum range with both engines failed. In addition, it shall be possible to effect a safe recovery at any service speed above $V_{o_{min}}$ (CL) following sudden simultaneous failure of the two critical failing engines."

Five Flights/Test Time 3 Weeks/
6+30 Hours Flight Time

## M. MANEUVERING FLIGHT/TURNING PERFORMANCE

The objective of the test is to determine stick force versus load factor gradients and the forward and aft center of gravity limits for the vehicle in accelerated flight conditions. Also to determine elevator power and turning performance characteristics. The test will be flown at high, medium and low altitudes at different velocities throughout the flight envelope. Testing to be performed by constant velocity within specified altitude band, pull up or wind up turn method.

1. Control forces and flight control surface deflections required to produce stabilized values of normal acceleration will be determined at a forward and aft CG condition for a variation of configurations, altitudes and trim speeds.

2. Elevator power characteristics will be investigated.

3. V-n envelope investigation (this data used in conjunction with data from previous lift/boundary test).

4. As a part of this series of flights the turning performance of the vehicle will be evaluated.

5. Additional testing suitable during return to base may be accomplished in conjunction with these flights, i.e., aeroelasticity, vibration, flutter (natural and/or induced as previous test results dictate).

6. Applicable instrumentation channels will be activated as dictated by the finalized test plan. Specific parameters to be recorded are control surface positions, control wheel/stick and rudder positions and forces involved, trim positions, accelerations, airspeed, altitude, atmospheric values, yaw rates, airframe airload measurements, CG positions, angle of attack and engine performance indicators.

7. The following paragraphs of MIL-F-8785B describe maneuvering flight specifications:

> "3.2.2.2 Control feel and stability in maneuvering flight. In steady turning flight and in pullups at constant speed, increasing pull forces and aft motion of the elevator control and airplane-nose-up deflection of the elevator surface are required to maintain increases in normal acceleration throughout the range of service load factors defined in 3.1.8.4. Increases in push force, forward control motion, and airplane-nose-down deflection of the elevator surface are required to maintain reductions of normal accelerations in pushovers.

3.2.2.2.1 Control forces in maneuvering flight. At constant speed in steady turning flight, pullups, and pushovers, the variations in elevator-control force with steady-state normal acceleration shall be approximately linear. In general, a departure from linearity resulting in a local gradient which differs from the average gradient for the maneuver by more than 50 percent is considered excessive. All local force gradients shall be within the limits of table V. In addition, whenever the short-period frequency is near the upper boundaries of figure 1, $F_s/n$ should be near the Level 1 upper boundaries of table V. This may be necessary to avoid abrupt response, sensitivity, or tendencies toward pilot-induced oscillations. The term gradient does not include that portion of the force versus n curve within the preloaded breakout force or friction band.

3.2.2.2.2 Control motions in maneuvering flight. The elevator-control motions in maneuvering flight shall not be so large or so small as to be objectionable. For Category A Flight Phases, the average gradient of elevator-control force per inch of elevator-control deflection at constant speed shall be not less than 5 pounds per inch for Levels 1 and 2.

3.2.2.3 Longitudinal pilot-induced oscillations. There shall beno tendency for pilot-induced oscillations, that is, sustained or uncontrollable oscillations resulting from the efforts of the pilot to control the airplane.

3.2.2.3.1 Transient control forces. The peak elevator-control forces developed during abrupt maneuvers shall not be objectionably light, and the buildup of control force during the maneuver entry shall lead the buildup of normal acceleration. Specifically, the following requirement shall be met when the elevator control is pumped sinusodially. For all input frequencies, the ratio of the peak force amplitude to the peak normal load factor amplitudes at the c.g. measured from the steady oscillation, shall be greater than:

Center-Stick Controllers -------- 3.0 pounds per g

Wheel Controllers---------------6.0 pounds per g"

TABLE V. Elevator Maneuvering Force Gradient Limits

| Center Stick Controllers | | |
|---|---|---|
| **Level** | **Maximum Gradient, $(F_s/n)_{max}$, pounds per g** | **Minimum Gradient, $(F_s/n)_{min}$, pounds per g** |
| 1 | $\frac{240}{n/\alpha}$ but not more than 28.0 nor less than $\frac{56}{n_L-1}$ * | The higher of $\frac{21}{n_L-1}$ and 3.0 |
| 2 | $\frac{360}{n/\alpha}$ but not more than 42.5 nor less than $\frac{85}{n_L-1}$ * | The higher of $\frac{18}{n_L-1}$ and 3.0 |
| 3 | 56.0 | 3.0 |

*For $n_L < 3$, $(F_s/n)_{max}$ is 28.0 for Level 1, 42.5 for Level 2.

| Wheel Controllers | | |
|---|---|---|
| **Level** | **Maximum Gradient, $(F_s/n)_{max}$, pounds per g** | **Minimum Gradient, $(F_s/n)_{min}$, pounds per g** |
| 1 | $\frac{500}{n/\alpha}$ but not more than 120.0 nor less than $\frac{120}{n_L-1}$ | The higher of $\frac{45}{n_L-1}$ and 6.0 |
| 2 | $\frac{775}{n/\alpha}$ but not more than 182.0 nor less than $\frac{182}{n_L-1}$ | The higher of $\frac{38}{n_L-1}$ and 6.0 |
| 3 | 240.0 | 6.0 |

As previously stated, advanced flight control systems may require adjustments in these evaluation criteria.

Five Flights/Test Time 3 Weeks/
6+00 Hours Flight Time

## N. ROLL CHARACTERISTICS

A determination will be made of the rolling characteristics of an airplane throughout its flight envelope in various specified configurations. (These include roll rate rolling effectiveness parameter pb/2V, cockpit lateral control forces, adverse yaw and inertial coupling).

1. Test techniques and exact envelope of characteristics to be evaluated will be determined from data obtained on preceding stability and control tests.

2. A significant objective of this investigation will be to determine the lateral response handling qualities of the vehicle as they relate to runway alignment and flare when making a high energy approach under low ceiling conditions.

3. Applicable instrumentation channels will be activated as dictated by the finalized test plan. Specific parameters to be recorded are control surface positions, control wheel/stick and rudder positions and forces involved, trim positions, stability augmentation system on and off effects, accelerations, airspeed, altitude, atmospheric valves, yaw rates, pitch rates, sideslip, angle of attack, pitch angles, yaw angles, roll rates, bank angles, human factor considerations where measureable, airframe air-load measurements, CG positions, oscillations, vibrations, damping effects, and engine performance indicators.

4. The following paragraphs of MIL-F-8785B describe roll characteristic specification:

> "3.3.2.1 Lateral-directional response to atmospheric disturbances. Although no numerical requirements are specified, the combined effect of $\omega_{n_d}$, $\zeta_d$, $\tau_R$, $\measuredangle p/\beta$, $|\phi/\beta|_d$, gust sensitivity, and flight-control-system nonlinearities shall be such that the airplane will have acceptable response and controllability characteristics in atmospheric disturbances. In particular the roll acceleration, rate, and displacement responses to side gusts shall be investigated for airplanes with large rolling moment due to sideslip.
>
> 3.3.2.2.1 Additional roll rate requirement for small inputs. The value of the parameter $p_{OSC}/p_{AV}$ following a rudder-pedals-free step aileron command shall be within the limits shown in figure 4 for Levels 1 and 2. This requirement applies for step aileron control commands up to the magnitude which causes a 60 degree bank angle change in $1.7T_d$ seconds.

3.3.2.3 Bank angle oscillations. The value of the parameter $\phi_{OSC} / \phi_{AV}$ following a rudder-pedals-free impulse aileron control command shall be within the limits in figure 5 for Levels 1 and 2. The impulse shall be as abrupt as practical within the strength limits of the pilot and the rate limits of the aileron control systems.

3.3.2.4 Sideslip excursions. Following a rudder-pedals-free step aileron control command, the ratio of the sideslip increment, $\Delta\beta$, to the parameter k (6.2.6) shall be less than the values specified herein. The aileron command shall be held fixed until the bank angle has changed at least 90 degrees.

| Level | Flight Phase Category | Adverse Sideslip (Right roll command causes right sideslip) | Proverse Sideslip (Right roll command causes left sideslip) |
|---|---|---|---|
| 1 | A | 6 degrees | 2 degrees |
| | B & C | 10 degrees | 3 degrees |
| 2 | All | 15 degrees | 4 degrees |

3.3.2.4.1 Additional sideslip requirement for small inputs. The amount of sideslip following a rudder-pedals-free step aileron control command shall be within the limits shown in figure 6 for Levels 1 and 2. This requirement shall apply for step aileron control commands up to the magnitude which causes a 60-degree bank angle change within $T_d$ or 2 seconds, whichever is longer.

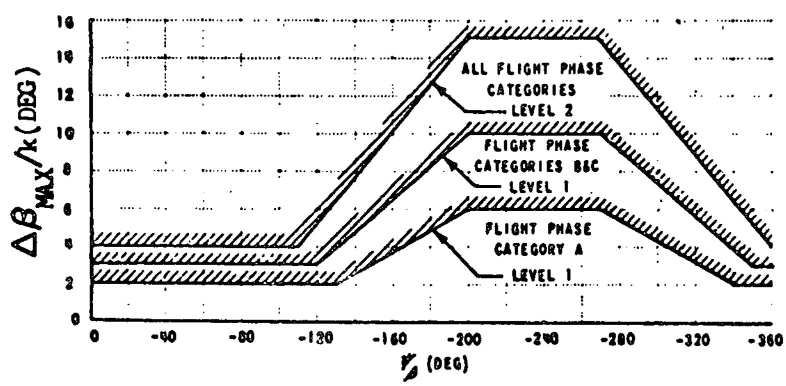



FIGURE 6. Sideslip Excursion Limitations

3.3.2.5 Control of sideslip in rolls. In the rolling maneuvers described in 3.3.4, but with the rudder pedals used for coordination for all Classes, directional-control effectiveness shall be adequate to maintain zero sideslip with a rudder pedal force not greater than 50 pounds for Class IV airplanes in Flight Phase Category A, Level 1, and 100 pounds for all other combinations of Class, Flight Phase Category and Level.

3.3.2.6 Turn coordination. It shall be possible to maintain steady coordinated turns in either direction, using 60 degrees of bank for Class IV airplanes, 45 degrees of bank for Class I and II airplanes, and 30 degrees of bank for Class III airplanes, with a rudder pedal force not exceeding 40 pounds. It shall be possible to perform steady turns at the same bank angles with rudder pedals free, with an aileron stick force not exceeding 5 pounds or an aileron wheel force not exceeding 10 pounds. These requirements constitute Levels 1 and 2 with the airplane trimmed for wings-level straight flight.

3.3.4 Roll control effectiveness. Roll performance in terms of bank angle change in a given time, $\phi_t$ is specified in table IX and in 3.3.4.1. Aileron control commands shall be initiated from zero roll rate in the form of abrupt inputs, with time measured from the initiation of control-force application. Rudder pedals shall remain free for Class IV airplanes for Level 1, and for all carrier-based airplanes in Category C Flight Phases for Levels 1 and 2; but otherwise, rudder pedals may be used to reduce sideslip that retards roll rate (not to produce sideslip that augments roll rate) if rudder pedal inputs are simple, easily coordinated with aileron-control inputs, and consistent with piloting techniques for the airplane Class and mission. Roll control shall be sufficiently effective to balance the airplane in roll throughout the Service Flight Envelope in the atmospheric disturbances of 3.7.3 and 3.7.4.

3.3.4.3 Linearity of roll response. There shall be no objectionable nonlinearities in the variation of rolling response with aileron control deflection or force. Sensitivity or sluggishness in response to small aileron control deflections or forces shall be avoided.

3.3.4.4 Wheel control throw. For airplanes with wheel controllers, the wheel throw necessary to meet the roll performance requirements specified in 3.3.4 shall not exceed 60 degrees in either direction. For completely mechanical systems, the requirement may be relaxed to 80 degrees.

3.3.4.5 Rudder-pedal-induced rolls. For Levels 1 and 2, it shall be possible to raise a wing by use of rudder pedal alone, with right rudder pedal force required for right rolls and left rudder pedal force required for left rolls. For Level 1, with the aileron control free, it shall be possible to produce a roll rate of 3 degrees per second with an incremental rudder pedal force of 50 pounds or less. The specified roll rate shall be attainable from coordinated turns at up to ±30 degrees bank angle with the airplane trimmed for wings-level, zero-yaw-rate flight."

Three Flights/Test Time 2 Weeks/
3+30 Hours Flight Time

## O. CRUISE PERFORMANCE

The standard day level flight performance of the aircraft, specifically to determine fuel flow, CG shifts, drag and specific range characteristics at various weights, speeds and altitudes, will be determined.

1. Much of the data needed will have been obtained on previous tests.

2. Two verification flights should be scheduled.

3. Additional follow up testing on avionics including auto approach and landing would be suitably accomplished in conjunction with these flights.

4. Applicable instrumentation channels as determined by the finalized test flight plan will be activated. Testing procedures and objectives are an extension of the level flight speed power investigation made earlier in the program.

Two Flights/Test Time 1 Week/
2+30 Hours Flight Time

## P. ADDITIONAL TAKEOFF AND LANDING TESTS

Dependent upon the landing and takeoff data obtained in the preceding test flights, a determination will be made as to the remaining test flights needed in this area.

1. Test procedures and instrumentation will be basically the same as those in the earlier takeoff and landing tests (para 4 above), the investigation envelope being extended as required.

2. This series of tests are both Phase II (initial flight tests) and Phase III (systems evaluation) and are combined as a result of the one vehicle test program

previously discussed. A significant portion of these tests should be directed to the investigation of high key entry pattern, glideslope/path capture, flight path angle, angle of attack, approach speed, drag device use, conditions and method for flare and auto land capabilities. These tests are a logical phase in to the systems evaluating testing described in Appendix C. Additionally, these tests will provide an opportunity to familarize and train additional flight crews needed with the input of the second vehicle.

3. Additional systems evaluation testing should be initiated in conjunction with these tests as the flight plan will allow.

Six Flights/Test Time 3 Weeks/
7+30 Hours Flight Time

APPENDIX B

SECTION III

SUMMARY

It is estimated that the Phase II testing as described in this Appendix will take a minimum of 47 weeks, and will require 63 horizontal launch operations. Flying time is estimated to be 79 hours.

# APPENDIX C

# SYSTEMS EVALUATION TESTING

# APPENDIX C

## SYSTEMS EVALUATION TESTING

## TABLE OF CONTENTS

# APPENDIX C

## SECTION I

## INTRODUCTION

The objective of the systems evaluation testing is to determine the suitability and reliability of the vehicles' subsystems. The actual conduct of this phase will be largely dependent upon the results of the testing previously completed. For this reason the tests outlined in the following sections have not been delineated in as much detail as those in Appendixes A and B. Subsystems that will require extensive testing in this phase, however, will be the propulsion (ABES) system, the automatic landing system and the various navigation systems. The total number of flights and flight hours shown for this testing is at best a rough estimate; a troublesome subsystem could cause lengthy delays and many additional flight hours. In this regard, one significant consideration is the possibility of the first orbital flight of the vehicle being unmanned. In this event, the flight path capture and auto-land capabilities of the vehicle would require more time and flight hours for investigation than shown, as it has been assumed in the structuring of the testing requirements that all flights will be manned.

APPENDIX C

SECTION II

# TESTS TO BE CONDUCTED

## A. PROPULSION

The main objective of these tests (see figure 5) is to determine the functionality of airstarting the ABES in various vehicle configurations at varying altitudes and airspeeds. The type and amount of testing to be accomplished will depend upon design characteristics and performance capabilities of the ABES and the vehicle itself; the depth of investigations being advanced in increments contingent upon safety and design characteristics.

1. Determination will be made of airstart procedures, characteristics, and reliability within the airstart envelope safety and performance considerations will allow.

2. Hot weather effects on performance will be evaluated.

3. Tests will be made on retraction and extension of engine mechanisms (if so designed); degree of testing will be dependent upon performance capabilities of the vehicle with less than all engines operating.

4. Throttle responses will be evaluated.

5. Inlet duct airflow distortion will be investigated in various flight configurations at high and low speed flight.

6. Engine performance parameters measured, evaluated, verified.

7. Water injection requirements and effects on performance will be evaluated.

8. Testing of Main Rocket Engines, ACPS, and OMS as practical.

9. Flight path capture and auto-land system investigation accomplished at the termination of each flight.

8 Flights/Test Time 5 Weeks/
12+00 Hours Flight Time

## B. OTHER SYSTEMS

The purpose of these tests is to evaluate the various vehicle subsystems under conditions of maximum exercise throughout the flight operating ranges. The results of the testing in the previous two phases will determine the actual amount of testing required.

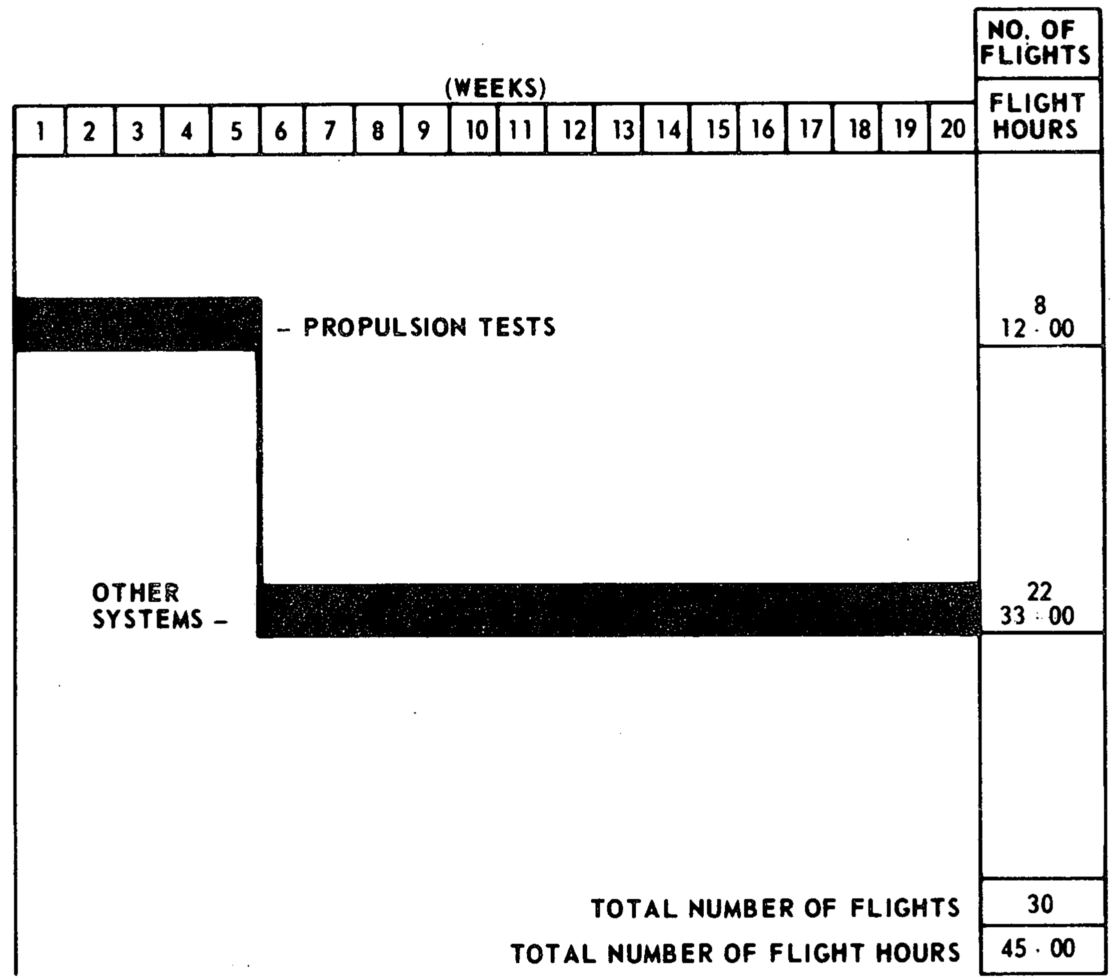



Figure 5. Phase III Systems Evaluation Test Schedule

1. All aircraft subsystems will be operated to their limits (non-destruct) in accordance to the test plan or adjusted plans as a result of Phase I and II testing. All systems will be monitored to insure that safety standards are met and to determine functional suitability, reliability, and maintainability as stated in contractural requirements.

2. The systems will be evaluated individually and simultaneously to assure that they are reliable, operationally effective and compatible with other systems throughout their normal and emergency operating ranges.

3. Proficiency training for additional flight crews will be part of these flights. Systems tested will include auxiliary power units including fuel cells, all hydraulic systems, all electrical systems, flight control systems (normal, emergency, stability augmentation, automatic devices, i.e., CG change compensation, CP changes, etc.) drag devices (flaps, speed brakes, spoilers, reverse thrust, etc. TBD), landing gear operations (all normal and emergency modes), all/any door actuations, extension mechanisms, pneumatic systems, electronic communications systems antenna patterns, cockpit controls, other avionics, instrumentation, and OMS, ACPS, systems as practical.

4. Particular attention and extensive testing will be devoted to Auxiliary Flight Controls (Side Arm Controls) and automatic flight control features, i.e., auto pilot failure simulations, auto recovery/approach and auto landing systems. Command and control processes and communication systems (on board computers, ground control interfaces, telemetry data links, etc.) will require testing to perfection.

5. Inertial navigation system's will require special attention and complete verification.

6. Special considerations in human factors testing, i.e., life support equipment, noise levels, vibrations, accelerations, visibility testing (night landings, rain, cross wind visibility angles, extreme nose high approach angle) will require detailed investigations and procedures.

7. Wet runway and hydroplaning investigations should be made.

8. Any additional testing for determining go around capability not previously accomplished during the takeoff and landing or asymmetric power tests will be conducted.

9. Special testing will be required for flight in actual weather conditions turbulence etc. Ice protection systems and visible moisture effects can be determined by use of a spray tanker. Water injection on takeoff roll should be investigated.

10. Any additionally required ground checks such as further deceleration testing, braking, taxi characteristics, taxi turning radius tests, etc., will be accomplished.

11. Additional testing will be accomplished in investigating special operational procedures found to be applicable to the shuttle vehicle, i.e., possible special drag deployment techniques, etc.

12. Final clean up will be made of any testing previously omitted, partially accomplished, or needed further investigations, i.e., additional structures/flutter testing/slow speed flight investigations, etc.

13. Maximum practical combinations of various test requirements is essential.

22 Flights/Test Time 15 Weeks/
33+00 Hours Flight Time

# APPENDIX C

# SECTION III

## SUMMARY

It is estimated that the Phase III testing as described in this appendix will take a minimum of 20 weeks and will require 30 horizontal launch operations. Flying time is estimated to be 45 flight hours. As previously stated an inadequately designed subsystem or a change in operational concept such as an unmanned orbital mission could require a significant change in the estimated time and flying hours for this test phase.

# APPENDIX D

# BASIC INSTRUMENTATION AND SUPPORT REQUIREMENTS

# APPENDIX D

## BASIC INSTRUMENTATION AND SUPPORT REQUIREMENTS

These requirements were developed on the basis of current instrumentation methods used in the DC-10 and F-14 programs. This involves real time data reduction of pertinent measurements as the test pilot proceeds with the flight. Such a procedure allows:

1. Immediate repeat of a test if a vital measurement is lost instead of having to make a subsequent flight to obtain the values.

2. Timely recognition of safety of flight situations.

3. Acceleration or termination of a test sequence when it becomes apparent that sufficient data has been obtained.

Selected measurements are telemetered to the ground station as the test proceeds, processed by a ground computer, and with (near) real time display or CRT panels. The remainder of the measurements can be stored until the transmission can be made to the ground station if there are not enough telemetry channels available. The ground computer reduces the data and stores it until it is called up for examination by the flight test engineers.

The emphasis is placed on not keeping data on board the flight vehicle any longer than necessary. This is because in the event of an accident on-board data are almost always destroyed. One therefore seeks to use as much real time telemetry as is economically feasible.

Based on aircraft program experience it is estimated that there will be a requirement for about 1,000 to 1,500 measurements. In the F-14 test program the concept for the instrumentation system resulted in 60% of the data being ready for study by the end of each flight along with the flow of real time data outputs. It is therefore projected that a higher percentage of the data can be economically processed within the state of the art in the space shuttle testing.

Data transmission does not have to be limited to telemetry. Other methods could be integrated into the system.

The requirements are listed in Tables 1, 2, and 3. It was not considered feasible to attempt being any more specific at this time since the configurations and performance of the space shuttle vehicles are presently undergoing changes.

Table 1. Airborne Instrumentation Requirements for Horizontal Takeoff Flight Test

| | Purpose | Item |
|---|---|---|
| 1.0 | Correlation | Time from slave to Master Clock in ground station<br>Voice communications<br>Computer (interface to ground computer)<br>Tape Recorder (voice) |
| 2.0 | Performance | |
| | 2.1 Takeoff | Velocity (airspeed)*<br>Attitude*<br>Altitude |
| | 2.2 Landing | Same as 2.1 |
| | 2.3 In-flight | Same as 2.1<br>See paragraph 6.0<br>Chase aircraft (pacer and tracking)<br>Radar Beacon |
| 3.0 | Structures | |
| | 3.1 Fuselage | Vibrations sensors |
| | 3.2 Main spar | Vibrations sensors |
| | 3.3 Cockpit | Vibrations sensors |
| | 3.4 General | Accelerations at c.g. (3 axes)***<br>Attitude*<br>Velocity (airspeed)*<br>Vertical acceleration in cockpit |
| | 3.5 Landing gear | Strut positions<br>Dome pressure<br>Bending moment |
| | 3.6 Engines pads | Vibration sensors<br>Loads and bending moments in engine mounts |
| | 3.7 | Airloads/bending moments on vertical stab/s<br>Airloads/bending moments on flight control surface hinge points. |

*Common requirement
***Common requirement

Table 1. Airborne Instrumentation Requirements for Horizontal Takeoff Flight Test (Continued)

| Purpose | Item |
|---|---|
| 4.0 Stability and Control | |
| 4.1 Controls | All pilot's controls positions** |
| | Aerodynamic controls positions (includes trim tabs, flaps, dampers, etc.) |
| | Aerodynamic controls flutter sensors (includes trim tabs, flaps, dampers, etc.) |
| 4.2 In-flight | Attitude (all three axes)* |
| | Velocity (all three axes)* |
| | Accelerations (all three axes)*** |
| | Velocity (airspeed)* |
| 4.3 Other Items | Center-of-gravity (from c.g. computer) |
| | Continuous weight calibration and read out |
| | Stability augmentation status readout |
| | Angle of attack |
| | Angle of sideslip |
| 5.0 Systems | |
| 5.1 Landing gear | Up and down lock indications (or intermediate) |
| | Main wheels rotation rate |
| 5.2 Hydraulic | Pressure |
| 5.3 Fuel | Quantity |
| | Flow rates |
| | Low and high fuel flow warning |
| 5.4 Electrical | Bus voltages |
| | Output of auxiliary electrical power unit |
| | Output of generators |
| | Telemetering transmitters for all measurements |
| | Telemetering power for all measurements |

*Common requirement
**Based on assumption as irreversible fly by wire control system will be used with artificial feel and stall warning. Brake pedals, etc. will feature power boost.
***Common requirement

Table 1. Airborne Instrumentation Requirements for Horizontal Takeoff Flight Test (Continued)

| | Purpose | Item |
|---|---|---|
| | 5.5 Autopilot | Control(s) positions<br>On, off condition |
| | 5.6 Environmental | Cabin pressure<br>Cabin altitude<br>Cabin relative humidity<br>Cabin temperature<br>Outside air temperature<br>Noise in cabin |
| | 5.7 Data | Pilot's flight instrumentation displays (TV)<br>Inertial navigator outputs |
| | 5.8 Deceleration | Speed brakes position<br>Pilot's wheel brake control position<br>Arresting hook position (if applicable)<br>Arresting hook axial loads<br>Arresting hook bending moments |
| | 5.9 Pilots Controls (all) | Measurement of artificial feel and power boost controls, stall warning, etc. |
| 6.0 | Propulsion (airbreather engines) | RPM ($N_1 N_2$)<br>Engine pressure ratio indications<br>Fuel flow indications<br>Total pressure and temperature<br>Measurements at all stages of the engine.<br>Oil quantity indications/low quantity warning indications<br>Oil pressure indications/low pressure warning indications<br>Oil temperature indications/high temp warning indications<br>Acceleration bleed valve positions<br>Fuel temperatures (before and after heating)<br>Fuel pressures at pump/s outlet/s, filter inlet/outlets<br>Hydraulic pressure<br>Main bleed air valve (to subsystems) position<br>Bleed air pressure main manifold and to subsystems (air conditioning/pressurization/ground turbine compressors/anti-icing/starter, etc.)<br>Bleed air flow rates to subsystems<br>Bleed air temperature pick ups in bleed air manifolds<br>Ignition on/off indications<br>Bleed air valve positions at sub-systems (as above) |

Table 1. Airborne Instrumentation Requirements for Horizontal Takeoff Flight Test (Continued)

| Purpose | Item |
|---|---|
| | Fuel control shutoff valve position indicators<br>Fire detection circuits status and operational capabilities<br>Duct position indicators (if applicable)<br>Vent door position indicators (if applicable)<br>Pressurization and dump valve indications on fuel control<br>Water injection (if so designed) quantities, valve positions, flow rates<br>Fuel/oil/hydraulic shut off valve positions<br>After burner control valve indications (if applicable)<br>Thrust reverser position indicators<br>Individual fuel nozzle flow rate<br>Individual burner can operation<br>Icing condition indications<br>Engine extension/retraction mechanism positions (if so designed)<br>Temp, air flow and pressure measurements in critical areas around engine nacelle and between engine and nacelle (as dictated by engine/cowling design) |

Table 2. Ground Instrumentation Requirements for Horizontal Takeoff Flight Test

| | Purpose | Item |
|---|---|---|
| 1.0 | Correlation | Master clock<br>Time transmission<br>Links to other centers (voice and data)<br>Voice communications (special for testing)<br>Computer (store and process <u>all</u> data)<br>Tape recorder (voice) |
| 2.0 | Performance | |
| | 2.1 Takeoff | Sequential cameras (true slave to Master Clock)<br>Distance markers along runway<br>Movie cameras (time slave to Master Clock) |
| | 2.2 Landing | Same as 2.1<br>Sink speed measurements |
| | 2.3 In-flight | Photo-theodolite(s) |
| 3.0 | Structures | Receive and process<br>Measure tire pressures |
| 4.0 | Stability & control | Calibrate pilot's control positions<br>Calibrate auto pilot control positions<br>Calibrate aerodynamic control positions (includes trim tabs, dampers, etc.) |
| 5.0 | Systems | Receive and process |
| 6.0 | Propulsion | Receive and process |
| 7.0 | Calibrations | Calibration equipment for all airborne displays<br>Calibration equipment for all measurements devices<br>Calibration equipment for all data displays |

Table 3. GSE and Facility Requirements for Horizontal Takeoff Flight Tests (To be retained for operational use)

| | Purpose | Item |
|---|---|---|
| 1.0 | Prepare for Flight | Maintenance Facility and equipment<br>Parking ramp<br>Turbojet engine starters<br>JP type fuel trucks<br>Power supply (for vehicle)<br>Automatic landing system<br>Prime mover<br>Draw bar(s)<br>Towing fixture(s) (if applicable)<br>Jacks (to lift landing gear clear of ground)<br>Weight and balance kit<br>Communications (voice)<br>Access equipment |
| 2.0 | Flight Testing | Taxiway<br>Runway<br>Arresting Gear<br>Arresting Gear test sled<br>Arresting gear instrumentation including cable tensions, runout length, water temperature<br>Weather station<br>Surveillance radar<br>Information link with FAA (voice and flight plan) |
| 3.0 | Support | Industrial shops<br>Center services (housekeeping)<br>Logistics<br>Failure analysis laboratory |
| | | NOTE: Additional support requirements are provided in NASA/KSC TR-1134 "Proposed Concepts and Criteria for Ground Support and Facility Requirements to Support Space Shuttle Final Assembly and Flight Test" dated October 15, 1971 and NASA/KSC TR-1118 "Proposed Preliminary Criteria for Space Shuttle Access Equipment at the Operational Site" dated 15 June 1971. |