DYNA-SOAR STEP I FLIGHT TEST PROGRAM

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INTRODUCTION

The objectives of the Dyna-Soar project have been stated to be the development of a piloted, maneuverable, hypersonic glider capable of a controlled landing following reentry from orbital flight. The Step I flight-test objectives of Dyna-Soar, as shown in figure 1, are twofold: exploration of the flight regime of the glider and development of satisfactory subsystems and vehicle.

Development and verification of the operational concepts and requirements for a Dyna-Soar type vehicle are significantly important from military, astronautical, and possibly commercial standpoints. Verification of the vehicle and subsystems design and modification and development of the hardware as problems arise is the historic role of flight testing and constitutes a primary objective of the Dyna-Soar flight-test program.

The cost, effort, and complexity of conducting ground-launched flights of the Dyna-Soar will be nearly an order of magnitude higher than those on previous airplanes, including the North American X-15. As a consequence, the number of flights that can be expended in developing a satisfactory vehicle and in exploring the flight regimes must be held to the absolute minimum.

FLIGHT REGIME

The general configuration contemplated for Dyna-Soar was described in a previous paper by R. L. Rotelli as being a winged glider with a hypersonic lift-drag ratio on the order of 2. The flight envelope of the Dyna-Soar glider is shown in figure 2 in terms of altitude and velocity. The equilibrium glide corridor is the primary regime to be explored during the flight tests, although some semiballistic flights above the corridor will be performed. The booster currently planned for Step I of the Dyna-Soar program is a modified Titan ICBM which will limit the maximum Step I velocity to about 19,000 feet per second. For comparison, the design flight envelope of the X-15 is shown at the left in figure 2, and the nominal reentry trajectory of the Project Mercury capsule is indicated by the heavy line.

Within its relatively limited envelope, the X-15 will provide very valuable information on aerodynamic heating, flight control at high altitude, atmospheric reentry, piloting techniques, and terminal guidance. Project Mercury experience in utilizing an ICBM for boosting a manned vehicle, developing man's capabilities in a space environment, operating a global range, and developing recovery techniques will, likewise, be of much value. As may be seen, however, the flight regime of the Dyna-Soar is a tremendous extension of the X-15 envelope and there is a basic conceptual difference between the lifting-vehicle Dyna-Soar glider and the ballistic-vehicle Project Mercury capsule. Additionally, as the flight regime extends to higher velocities, the capabilities of wind tunnels and rocket models to support the design and development of the vehicle become substantially reduced. To reiterate, exploration of the hypersonic-glide corridor is the primary objective of the Dyna-Soar flight test.

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DATA OBJECTIVES

The general flight-test areas of interest and the data objectives are shown in figure 3. In each area, onboard instrumentation will provide data by which the conduct of the flight and operation of the systems may be monitored to either confirm the design or provide information to correct deficiencies.

The aerodynamics area is perhaps the most important in that it encompasses aerodynamic heating, flow characteristics, performance, and stability and control. Adequate aerodynamic-heating information for progressive conduct of the flight test can be obtained from a knowledge of the temperatures that exist throughout the skin and airframe during the flight, the flight conditions, and the structural properties (fig. 4). A large number of temperature sensors will be located to provide for determination of experimental heat-transfer characteristics and verification of the structural design.

Detailed analysis of experimental heat-transfer data requires a knowledge of free-stream and local-flow conditions and local gas properties. Use of the nondimensional heat-transfer coefficient, Stanton number S_T, is convenient in comparing experimental results and theory and is given in the following expression:

$$S_T = \frac{h}{\rho C_p V} = f\left(R_e, P_r, T_s, T_w, M_\infty, \alpha \ . \ . \ .\right)$$

where

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h heat-transfer coefficient

ρ density

C_p specific heat of fluid

V free-stream velocity

R_e Reynolds number

P_r Prandtl number

T_s stagnation temperature

T_w wall temperature

M_∞ Mach number

α angle of attack

Some measurements of both free-stream local-flow characteristics pertinent to heat-transfer analysis are planned for a few specific locations. As shown in figure 5, the required free-stream data consist of total pressure P_T, total temperature T_T, angle of attack α, and angle of sideslip β.

Local-flow conditions will be determined primarily from surface-pressure measurements, together with such measurements of surface and boundary-layer temperatures, boundary-layer pressures, dissociation, and gas composition as are possible. The extent of the flow-characteristics measurements obtained during Dyna-Soar flight tests and the quality of information that can be attained depend to a large extent on successful development of both transducers and flight-measuring techniques.

Acquisition of accurate performance data is essential to the conduct of the Dyna-Soar flight program and can only be obtained during flight of the full-scale glider. Performance measurements during gliding flight require vehicle velocities, accelerations and attitudes, and a measure of the atmospheric environment. Ground-tracking trajectory information will be utilized as backup for onboard data.

Aerodynamic stability and control considerations are virtually inseparable from the vehicle's flight-control and guidance systems. These areas are considered under the general heading "Flight Controls" in figure 6. The flight-controls test objectives are determination of stability derivatives and control effectiveness parameters throughout the flight corridor. Such information is essential for the flight-program buildup discussed subsequently and also is of general research interest. Also, development of an adequate flight-control system is mandatory, and full-scale flight testing is required for final development and evaluation. A description of the flight-control system envisioned for the Dyna-Soar was presented in a previous paper by Alan H. Lee and Leroy J. Mason. The automatic and redundant features of the primary flight-control system, the guidance and navigation system, and cockpit-display equipment will require development in the course of the flight-test program.

One of the basic concepts of the Dyna-Soar flight-control system is to provide for maximum pilot utilization. Also of considerable interest is the determination of desirable handling qualities of hypersonic vehicles. The information gained from the Dyna-Soar flight-test program will be directly applicable to the verification of man's role and capabilities in piloting space and reentry vehicles and in the establishment of design guidelines for hypersonic handling qualities.

The data requirements in the area of flight controls for the Dyna-Soar flight-test program will be much like those of the X-15. Basically, it is necessary to establish the flight conditions, determine the control motions, and measure the vehicle response. The analysis procedure to be used for data evaluation will take various forms. Where possible, as with the trim evaluation, analysis will be made directly from the flight records. For maneuvering or dynamic analyses, where changes in flight conditions are appreciable or glider response is altered by spurious control inputs, a data-matching procedure utilizing analog computer synthesis methods will be used. It is anticipated that the X-15 flight-research program will develop new techniques and methods in this area of stability analysis which can be utilized in the Dyna-Soar program.

In the areas of dynamics, loads, structures, and materials, the objective, and subsequent contribution, of the Dyna-Soar flight-test program is primarily one of demonstration. The usual accelerations, noise measurements, and strains required to verify the integrity of the vehicle will be obtained. Additionally, some measure of the distortion of the external shape of the glider will be made. The structural and aerodynamic measurements, when analyzed together, will provide useful design information on aerodynamic and heating loads.

The human-factor aspects of reentry from orbital and near-orbital speeds and altitudes will continue to be of importance. Reentry flight times during Step I testing will require up to 30 minutes, wherein longitudinal decelerations of from 0.3g to 2.0g will be experienced. Physiological effects of decelerations, time, and cockpit environment on pilot operation of the glider during reentry will be studied.

Development of reliable and efficient subsystems, such as environmental control and secondary power, and demonstration of their operation in the Dyna-Soar flight environment is no less an objective than exploration of the flight corridor. Adequate monitoring sensors will be included in the instrumentation package to assure acquisition of significant subsystem operating data.

The areas of military applications and geophysical research are additional flight-test objectives. The suitability of the Dyna-Soar type vehicle for military applications will be determined during the course of exploring its flight corridor, as will its suitability as a platform for conducting geophysical experiments.

FLIGHT-TEST PROCEDURE

The flight-test procedure to be utilized in developing the Dyna-Soar I and in exploring the hypersonic flight regime has been developed to stay within cost limitations but, at the same time, maintain a high degree of confidence in extending the flight envelope. The resulting flight-test program (fig. 7) consists of manned air-launch flights covering the subsonic and supersonic flight regimes, unmanned ground-launch flights for investigation of conditions from launch to hypersonic speeds, and the main test-program objective - manned exploration of the hypersonic flight corridor.

The air-launch phase of the test program, utilizing the Boeing B-52 for air drop, will provide the first opportunity to evaluate the test article under actual flight conditions. There are several important objectives (fig. 8) which must be accomplished during this phase before the test program can proceed to the manned ground-launch tests.

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The first of these objectives is systems checkout and demonstration. Some systems development, including data-acquisition systems, will be most easily accomplished during the air-launch flights. Aerodynamic and structural verification, including investigation of stability and control characteristics, will be accomplished throughout the attainable speed and lift-coefficient range. Another objective is pilot familiarization with the low-speed flight and landing characteristics of the Dyna-Soar, together with the development of optimum approach and landing techniques. The maximum velocity that can be achieved during the air-launch phase utilizing a rocket-boosted glider is uncertain. Attainment of a supersonic Mach number of about 7 is highly desirable, but, because of technical and economic factors, the maximum feasible velocity for the air-launch phase may be a Mach number of about 2.

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The unmanned ground-launch test phase will be conducted on the Atlantic Missile Range, with launch from Cape Canaveral. Although there will have been approximately 40 Titan firings prior to this time, modifications for Dyna-Soar - such as the addition of first-stage stabilizing fins, structural beef-up, and any booster-subsystems changes - will require flight testing. The prime requirements of unmanned tests are demonstration of the booster-glider combination and glider separation from the booster. Some assessment of the reliability of both the first and second stages of the booster is necessary before the manned portion of the test program can be initiated, and each of the unmanned test flights will be carried through ignition and separation of the second stage. Escape system tests will also be accomplished during this phase.

The third and major phase of the flight-test program consists of a manned systematic expansion of the Dyna-Soar flight envelope, with launch at Cape Canaveral down the Atlantic Missile Range utilizing downrange islands as intermediate landing sites. Improved landing strips, 8 to 10,000 feet in length, have been specified as landing-site runway requirements. The locations of the landing sites must be compatible with the glider range and maneuverability, desired burnout velocities, and test objectives. A summary of the results of the landing-site study is shown in figure 9. The limits of injection velocity for each landing site are determined from the lift coefficient (or lift-drag ratio), angle of bank, and the permissible launch azimuths of Cape Canaveral.

The first manned ground-launch flight has been planned for an injection velocity of approximately 9,000 feet per second. Selection of this speed was dictated by economic and geographical considerations as well as the knowledge that flight environment up to speeds of approximately 7,000 feet per second will have already been investigated during the X-15 program. The landing sites which would permit the most comprehensive coverage of injection velocities from 9,000 feet per second

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to approximately 19,000 feet per second are Mayaguana, Santa Lucia, and Fortaleza, Brazil.

The test-flight tracks down the Atlantic Missile Range for maximum and minimum burnout velocities with landings at Mayaguana, Santa Lucia, and Fortaleza are indicated in figure 10. It should be noted that all the possible landing sites lie at approximately 130° azimuth from Cape Canaveral, but, since a maximum launch azimuth of 110° must be observed during boost, turning flight must be performed to arrive at the high key point over each of the landing sites.

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The step-by-step expansion of the hypersonic flight regime during the manned test phase will provide a reasonable degree of confidence in exploring the unknown flight regime and attainment of test results. This test phase will commence with a glider injection at an optimum lift coefficient and a velocity of approximately 9,000 feet per second. Each successive flight in the speed range above 9,000 feet per second is a moderate extension in both speed and lift coefficient over the previous flights. Data obtained from each flight will be analyzed sufficiently to reveal possible danger areas so that they may be cautiously approached or avoided during follow-on test missions.

A typical flight for the systematic exapnsion of the Dyna-Soar flight envelope is presented in figure 11. The clear area denotes that portion of the flight envelope which has previously been explored, and the grey area denotes the unexplored regions of flight. The cross-hatched areas indicate the portion of the flight envelope which will be expanded by this particular test mission. It should be noted that the vehicle injection takes place at a mid lift coefficient and that the lift coefficient is increased as velocity decreases. A similar technique will be utilized for investigation of the lower lift coefficients. Testing at any particular lift coefficient and velocity combination will be a moderate extension in speed or lift coefficient, or both, over a previous test mission. Once the flight envelope has been extended, the remainder of the flight will be devoted to both data fill-in and energy-management requirements for arrival over the landing site.

The test flight outlined in figure 11 was simulated on an analog computer, and a time history of pertinent trajectory parameters is presented in figure 12. Although the simulation was limited, in that it was only a three-degree-of-freedom point mass simulation, it does provide an insight into the times which will be available for flight testing. As can be noted, something less than 5 minutes is available for testing during the flight-envelope expansion, while the remainder of the flight will provide for data fill-in and energy management.

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Extensive use of six-degree-of-freedom flight simulation is a prerequisite to all Dyna-Soar flight planning. It is also necessary that the pilot fly each proposed mission on the simulator, including the higher probability boost-abort situations. All flights will be planned to allow maximum assurance of a successful landing of the glider in case of a boost abort.

CONCLUDING REMARKS

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In summary, the Dyna-Soar flight-test program will consist of three phases: (1) air-launched tests using a powered glider to checkout and demonstrate the operating characteristics of the vehicle; (2) unmanned ground-launched tests to demonstrate the integrity of the booster-glider combination; and (3) the major phase, ground-launched manned exploration of the hypersonic flight regime.

Development and verification of the Dyna-Soar design and its operational concepts and requirements will be accomplished during the flight-test program which will be conducted as a joint operation by an Air Force - NASA - contractor team. This program will provide aerodynamic data from the reentry flight corridor, will verify the design requirements of reentry vehicles, and define their operational capabilities in this flight regime. These results, which must be timely for proper military exploitation of the aerospace medium, will provide valuable contributions to other astronautical ventures.

It is readily admitted that there are many unknowns to be discovered in this program. One thing is certain, however, this will be one of the greatest testing efforts that the free world has ever known.

DYNA-SOAR I STEP I

FLIGHT TEST OBJECTIVES

EXPLORE FLIGHT REGIME TO M ≈ 20

DEVELOP VEHICLE AND SUB-SYSTEMS

- ♦ definition and solution of problems
- ♦ development of operational concepts
- ♦ verification of design

Figure 1

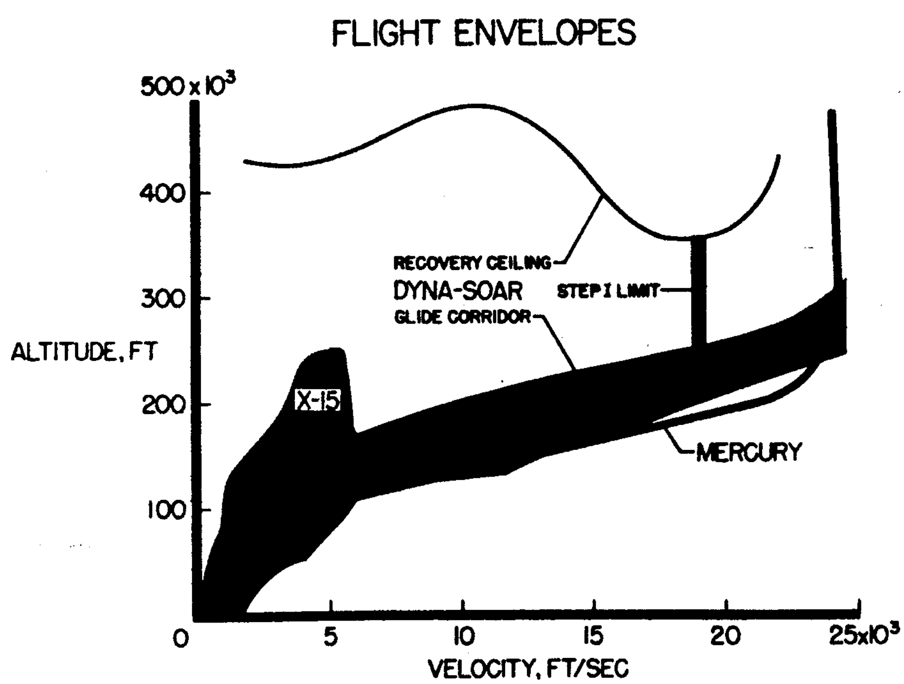

Figure 2

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FLIGHT TEST DATA OBJECTIVES

- aerodynamics
- control and guidance
- dynamics and loads
- structures and materials
- human factors
- vehicle subsystems

- military applications
- geophysics

→ MONITOR, CONFIRM, DEVELOP, RESEARCH

Figure 3

AERODYNAMIC HEATING

FLIGHT TEST:

$h \Leftarrow$ {skin temperatures; flight conditions; structural properties}

ANALYSIS:

$$S_T = \frac{h}{\rho C_P V} = f\left(R_e, P_r, T_s, T_w, M_\infty, \alpha \cdots\right)$$

$\doteq f$ {free-stream conditions; local flow conditions; local gas properties}

Figure 4

[redacted]

FLOW CHARACTERISTICS

- FREE-STREAM CONDITIONS, P_T, T_T, α, β.
- LOCAL FLOW CONDITIONS,
  - surface pressures
  - surface temperatures
  - boundary layer profile
  - disassociation detection
  - gas composition
  - skin friction

Figure 5

FLIGHT CONTROLS

FLIGHT TEST OBJECTIVES:

- determine stability derivatives
- develop flight control and energy management systems
- verify pilot's role and desirable handling qualities

DATA REQUIREMENTS:

- flight conditions
- control motions
- vehicle responses

Figure 6

[redacted]

DYNA-SOAR I FLIGHT TEST

TEST PHASE	FLIGHT REGIME COVERAGE	PRIME TEST INTERESTS
air launch manned	landing → supersonic	glider
ground launch unmanned	launch → hypersonic	booster-glider
ground launch manned	supersonic → hypersonic	pilot-booster-glider

Figure 7

AIR-LAUNCH FLIGHT TEST

- sub systems checkout and demonstration
- aerodynamics and structural verification
- pilot checkout and training
- landing characteristics and requirements

Figure 8

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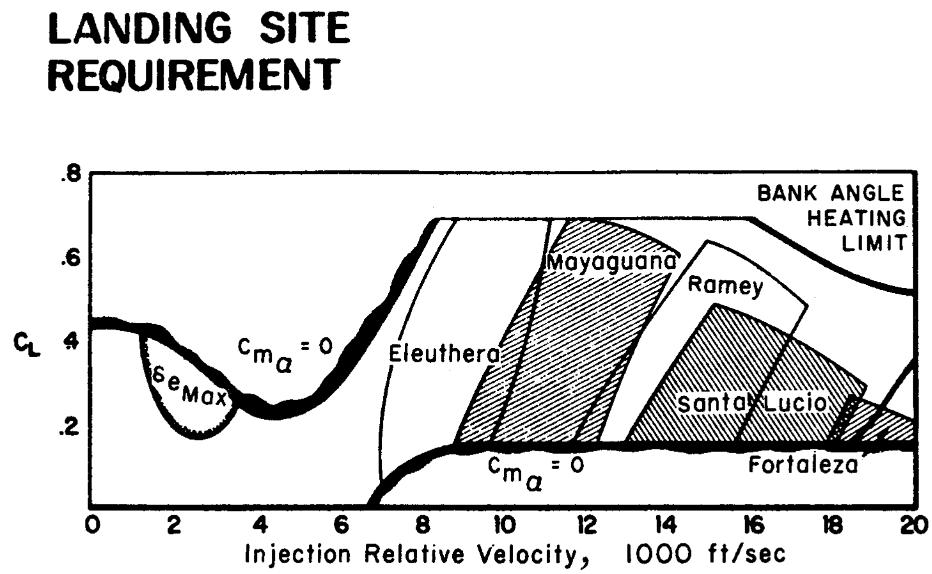

Figure 9

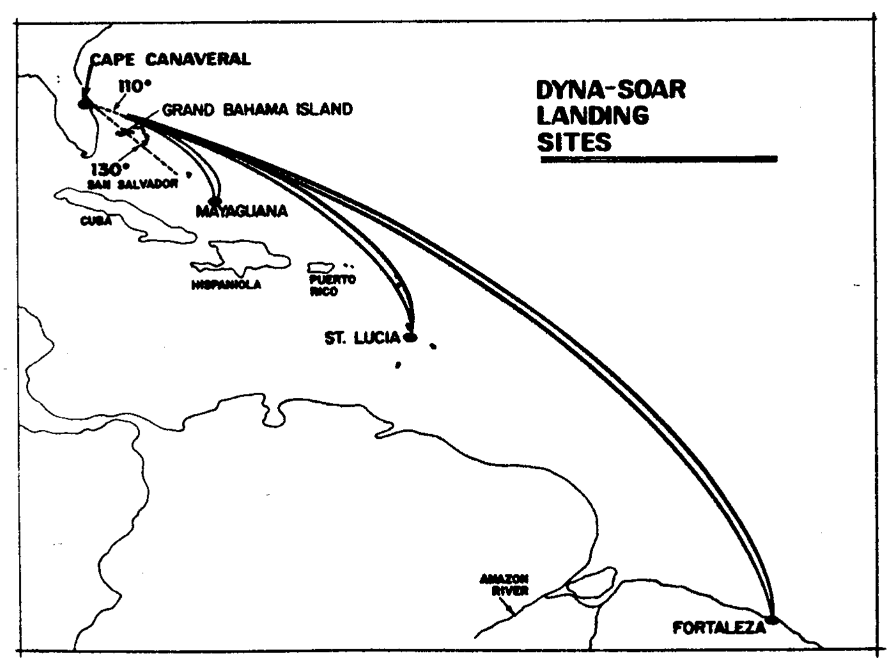

Figure 10

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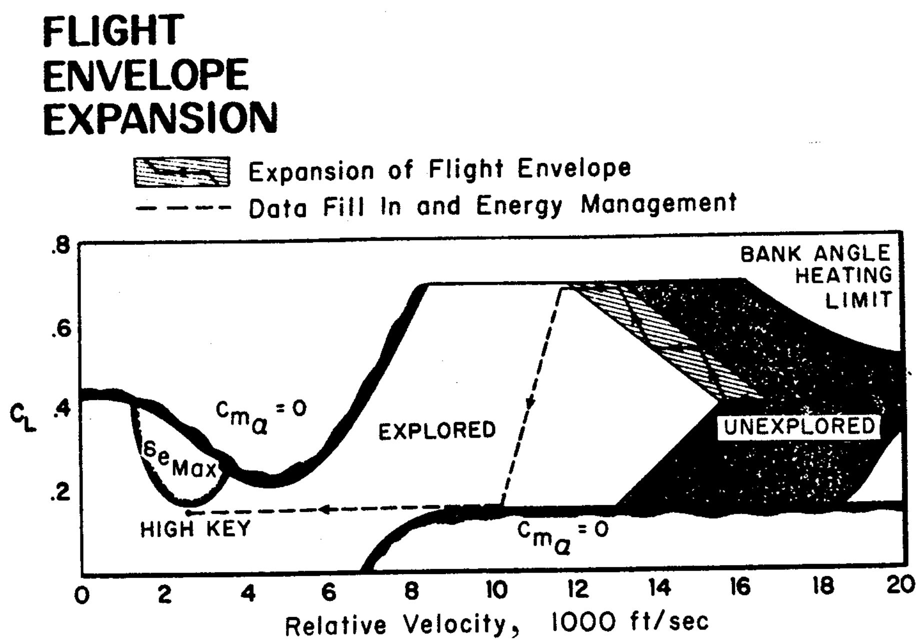

Figure 11

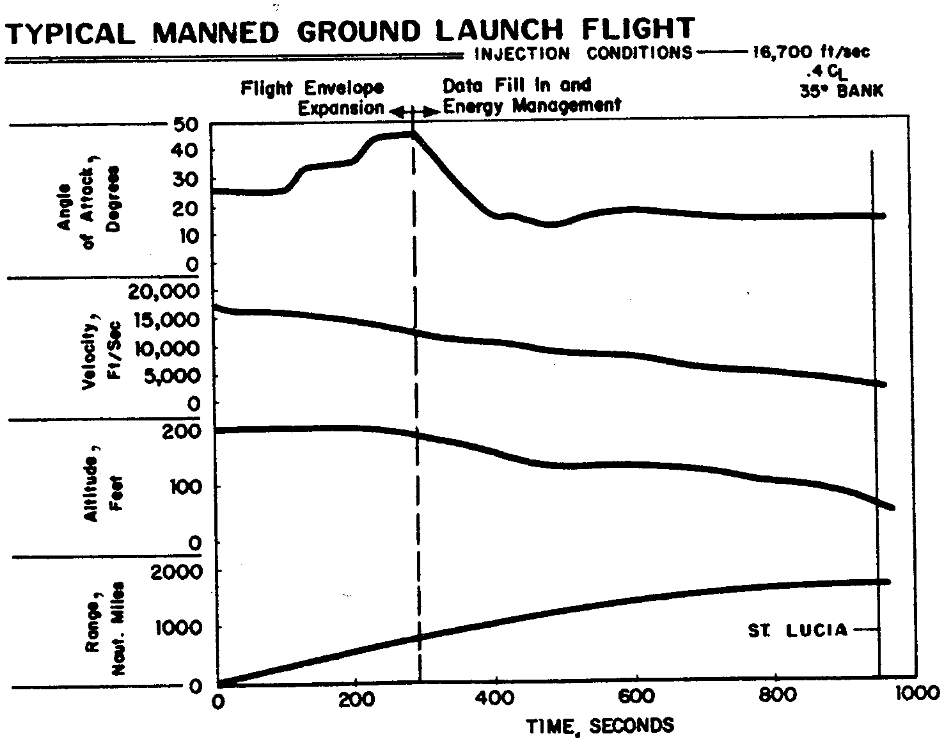

Figure 12

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