NASA TECH BRIEF
Marshall Space Flight Center

Ascent Control Analysis for S-II Derivative Launch Vehicles, Digital Computer Program

The problem:

Accurate analysis of the flight dynamics of a spacecraft during ascent control.

The solution:

The development of a computer program that has the capability to analyze the six degrees-of-freedom flight dynamics.

How it's done:

A model is used for the analysis of the six degrees-of-freedom dynamics of a general launch vehicle during atmospheric boost. The equations of motion are developed for a rigid body and flat earth. A case may be started at any time beginning with the ignition of the stage and may be ended upon, or prior to, stage burnout. The end of a case may be either at a specified time or based on propellant expended.

The individual stages of the booster may be either in a piggyback or tandem configuration. The centers of gravity and inertias are entered as a function of weight so that they will be valid for engine-out cases. Three moments and three cross products of inertia are used.

Atmospheric parameters are based on the 1963 Patrick Reference Atmosphere. Here, either actual or synthetic wind conditions can be used. For an actual wind, the wind speed and direction are functions of altitude. For a synthetic wind, the wind speed is a function of wind percentile and gust altitude for Cape Kennedy and the wind direction is constant. All of the aerodynamic coefficients are functions of Mach Number except for the base axial force which is a function of altitude, and can be entered in the program body or stability frame.

From 1 to 12 main engines of the same type, but arbitrarily located, can be handled. Each may be gimballed or non-gimballed, and each gimballed engine can be commanded individually in pitch and yaw. Engine angular misalignments and pitch pre-cant angle are included. Furthermore, the engines can be throttled at a specified time and to maintain a specified acceleration limit.

The roll, pitch, and yaw attitude commands for guidance are generated open-loop as functions of time. The sign convention for engine gimbal and aerodynamic control surface deflections is such that a positive deflection causes a positive moment. Vehicle attitude control is by thrust vector control of the main engines with aerodynamic control augmentation.

For thrust vector control, attitude error, rate, integral, accelerometer (normal and lateral), angle of attack, and sideslip feedback can be used. The gains are functions of time. Attitude error and command limiters are available in roll, pitch, and yaw. In pitch, the limiters are functions of time with different upper and lower limits. The Honeywell Shuttle control concept can also be used. For this technique, $q\alpha$ and $q\beta$ are used for feedback and to adjust the pitch and yaw attitude gains. Also, there is no aerodynamic control surface augmentation in the Honeywell Shuttle technique. A general engine actuator selection logic is used in which each pitch and yaw actuator can be commanded separately. Vehicle roll control is obtained by differential control of the engines in pitch and yaw. Engine and actuator failures can occur at any arbitrary time and in any combination, and actuator failures can occur at any angle.

Elevators, ailerons, and a rudder can be used for aerodynamic control. Canards with a fixed incidence angle are also available. The gains are functions of time. Automatic or manual (pilot represented as a first order lag) control can be used. Aerodynamic control surface failures can occur at any time, in any combination, and at any angle from null to hardover.

For engine gimbals and aerodynamic control surfaces, the actuator dynamics are represented as (1) a first order lag with attitude and rate limits or (2) attitude limit only.

(continued overleaf)

An angular position term is included for accelerometers which are not located at the center of gravity. Bias and scale factor errors can be included for all instruments. Angle of attack sensors can be represented as either a first or second order lag. Pressure transducers can be represented as a first order lag.

The performance measures which can be used include:

1. Time histories of critical parameters
2. Terminal conditions
3. Mean-squared attitude error
4. Bending moments
5. Maximum q α and q β
6. Maximum engine deflections.

Multiple stages cannot be run consecutively as part of one case. Slosh, bending, staging, and separation dynamics are not included. The program was developed for the analysis of first or second stage flight within the atmosphere. It will not accurately determine conditions for an upper stage injection into orbit because it uses flat earth instead of round earth equations of motion and open loop instead of closed loop guidance.

For launches from other than Cape Kennedy, consideration should be given to the use of an alternate atmosphere and modification of the synthetic wind data. Synthetic wind data for other launch sites can be precomputed and entered as actual wind data with a constant wind direction.

There is no provision for attitude control using a reaction control system. Therefore, there would be no attitude control capability during coast periods or roll control with only one engine remaining when aerodynamic controls are either not available or not effective. Guidance and control computation cycle times are not included. The commands are updated at each integration point. There are no filter equations.

Notes:

1. This program was written in FORTRAN IV for an IBM-360 system.
2. Inquiries concerning this program should be directed to:

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   112 Barrow Hall
   University of Georgia
   Athens, Georgia 30601
   Reference: MFS-24324

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