SYNOPTIC: Full-Scale Apollo Docking Simulation Tests, J. F. Siller, McDonnell Aircraft Company, St. Louis, Mo.; *Journal of Spacecraft and Rockets,* Vol. 7, No. 8, pp. 957–962.

Spacecraft and Component Ground Testing and Simulation: Crew Training

Theme

Test methods and results related to the full-scale simulation of transposition and lunar orbit docking of Apollo 9 and subsequent Apollo missions are discussed.

Content

Full-scale Apollo docking tests were conducted using vehicles which simulated the mass, mass moments of inertia, and critical geometry of the Command and Service Module (CSM), Lunar Module (LM), and Lunar Module/Saturn IVB (LM/SIVB) vehicles. Test vehicle weights ranged from 5670 lb for the LM up to 65,600 lb for the case 1 LM/SIVB. Three cases were simulated: the case 1—Normal Transposition Docking (CSM and LM/SIVB), case 2—Lunar Orbit Docking (LM and CSM), and case 3—Transposition Docking

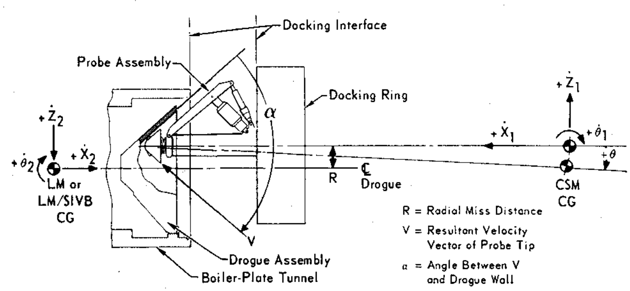

Fig. 1 Test parameter legend (conditions of initial impact).

of the Earth-orbital Apollo 9 Mission (CSM and heavy LM/SIVB). Test objectives included a) determination of latch capture boundaries, b) ascertaining the structural and functional integrity of the docking hardware, c) comparing experimental and math model data, and d) providing the astronauts with visual training aids via film coverage through the Crewman Optical Alignment Sight (COAS).

Except for the case 3 LM/SIVB, which, because of its 222,384-lb weight, was simulated with a rigidly mounted

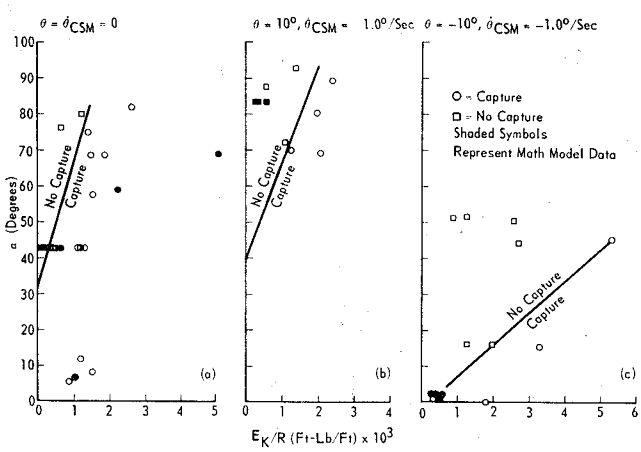

Fig. 2 Latch capture boundaries for case 1 (no thrust).

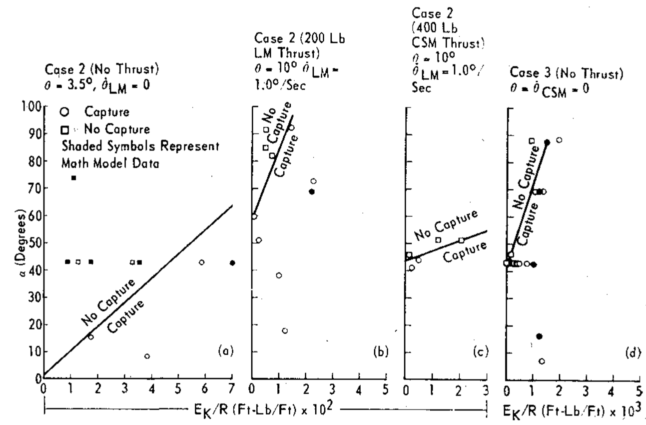

Fig. 3 Latch capture boundaries for cases 2 and 3.

frame, each test vehicle was provided with 5 degrees of freedom through a gimbal system and an air bearing assembly from which it was suspended as a simple pendulum. CSM mass properties were scaled down for case 3 to accommodate the fixed LM/SIVB and to avoid inducing artificially high loads in the docking hardware. Flight-type docking hardware consisted of a probe assembly and docking ring on the CSM and a drogue assembly with attach fittings mounted on the LM or LM/SIVB. Angular rates and longitudinal

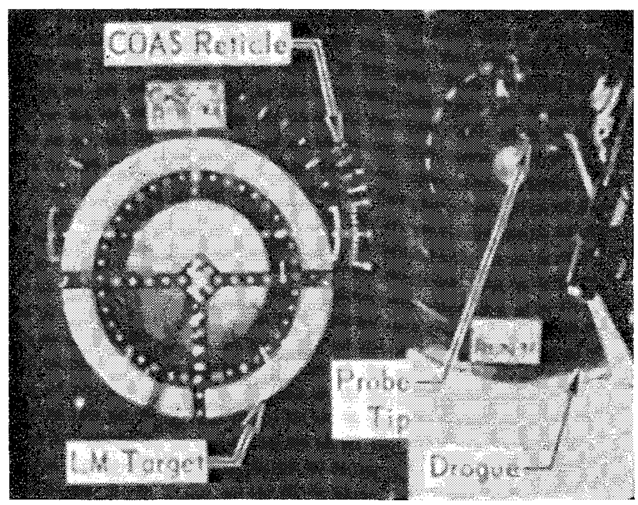

Fig. 4 Split-frame training aid view.

thrust were provided by onboard, cold-gas thrusters. Variable test parameters included closing velocity, radial velocity, angular velocity, angular misalignment, radial miss distance, and longitudinal thrust/no thrust conditions. Automatic and manually initiated probe retractions were demonstrated. Velocities were induced in the system by temporarily restraining the air bearing of one vehicle and then swinging the vehicle through an arc. Probe load-stroke and vehicle motions versus time were monitored during the program.

Figure 1 shows parameters used to define the latch capture curves of Figs. 2 and 3, where E_k is the total kinetic energy induced in the system of vehicles. Capture probability is greater at low values of α or for docking maneuvers wherein the radial velocity of the probe tip is directed away from the drogue wall that is initially contacted. The docking hardware sustained the imposed dynamic loads without failure or malfunction, although several latching anomalies occurred during case 1 and 3 testing. These events were attributed to repeated use of the probe assembly at high energy levels which were not indicative of actual flight conditions. Math model data with inputs for flight vehicle mass properties and 6 degrees of freedom compared favorably with experimental data for all test cases. In general, correlation improved as the energy of the various systems of docking vehicles increased. The astronaut training film consisted of a split-frame view showing the COAS reticle pattern superimposed over the opposing vehicle target, combined with a view of the probe/drogue behavior (Fig. 4). This combination of views provided the astronauts with their first opportunity to simultaneously observe a time-correlated accounting of the two events. A composite film depicting the various test conditions is reviewed by primary crew members prior to each Apollo mission.

Full-Scale Apollo Docking Simulation Tests

JAMES F. SILLER*
McDonnell Aircraft Company, St. Louis, Mo.

Transposition and lunar docking associated with Apollo 9 and subsequent manned Apollo missions were simulated using test vehicles equipped with flight-type docking hardware. Flight vehicle mass properties were simulated and each test vehicle was provided with 5 degrees of freedom, except for the heavy Apollo 9 LM/SIVB vehicle which was simulated by a fixed structural frame. The test vehicles were suspended as simple pendulums with each suspending cable terminating at the vehicle CG in a three-axis gimbal system. The overhead pendulum pivots were supported on air bearings. Program objectives included latch capture boundary studies, demonstration of docking hardware capabilities, experimental and math model data comparisons, and the procurement of astronaut training aids via film documentation of the docking targets as viewed through the Crewman Optical Alignment Sights. Variable test parameters included velocity, attitude, angular rate, radial miss distance, and longitudinal thrust applications.

Nomenclature

COAS = crewman optical alignment sight
CSM = command and service module
Ek = kinetic energy
I = mass moment of inertia
LM = Lunar Module
LM/SIVB = Lunar Module/Saturn IVB
M = mass
R = radial miss distance
r = distance from initial impact point to vehicle CG
V = resultant velocity of CSM probe tip
$\dot{X}$ = vehicle longitudinal velocity
$\ddot{X}$ = vehicle longitudinal acceleration
$\dot{Z}$ = vehicle radial velocity
α = angle between CSM probe tip resultant velocity vector and drogue wall
θ = relative angular misalignment of vehicles' longitudinal axes
$\dot{\theta}$ = vehicle angular velocity

Subscripts

1 = CSM
2 = LM or LM/SIVB

Introduction

FULL-SCALE Apollo docking tests were conducted using vehicles which simulated the CSM, LM, and LM/SIVB. The program was divided into three phases simulating the following missions and related docking vehicles: 1) transposition docking of the Earth-orbital Apollo 9 mission (case 3—CSM docking with heavy LM/SIVB), 2) lunar orbit docking (case 2—docking between the LM and CSM following lunar rendezvous), and 3) normal transposition docking associated with Apollo 10 and successive missions (case 1—CSM docking with LM/SIVB during translunar coast).

Each test vehicle incorporated flight-type docking subsystem components that were mounted on a steel framework and, except for the case 3 LM/SIVB, each vehicle was provided with three angular and two translational degrees of freedom through a gimbal system and air bearing assembly, respectively. The case 3 LM/SIVB vehicle was simulated by a fixed structural frame.

The program included the following test objectives: a) to determine the latch capture boundary conditions, b) to ascertain the structural and functional integrity of the docking hardware in a dynamic environment, c) to compare experimental and math model data, and d) to provide the astronauts with visual training aids via film coverage of the tests through the COAS depicting the docking vehicle behavior at and following initial contact.

Vehicle initial contact test parameters included longitudinal closing velocity, radial velocity, angular velocity, angular misalignment, radial miss distance, and longitudinal thrust/no-thrust conditions. Automatic and manually-initiated CSM probe retractions were demonstrated following latch capture during three test runs. The test vehicles were instrumented to record translational and angular accelerations, planar excursions, angular rates and attitudes, and longitudinal thrust magnitude. The probe assembly was instru-

Presented as Paper 70-170 at the AIAA 8th Aerospace Sciences Meeting, New York, January 19–21, 1970; submitted February 19, 1970; revision received April 27, 1970. This work was supported by NASA under contract NAS9-9004.

* Group Engineer, Structures and Dynamics Laboratories.