Drop Testing Naval Aircraft and the VSD Landing Gear Dynamic Test Facility

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This paper describes a laboratory facility developed by Vought Systems Division (VSD) of LTV Aerospace Corp. and techniques used to realistically simulate landings of full scale aircraft under precisely controlled conditions. Capabilities are included to evaluate effects of running over deck obstructions during carrier landings or other types of bumps that might be encountered in rough field operations of aircraft. The project provided VSD with the most accurate method known for dynamic simulation of aircraft landings and safe evaluation of the structural adequacy of airframes and landing gear systems for landing loads. Operational characteristics of the facility are predictable and repeatable. A deck obstruction or bump can be repeatedly passed under the landing gear wheel within 1/2 in. of any preselected point in the stroke of a landing gear strut at any sink speed or landing velocity to 120 knots. Tests performed in the facility have shown that running over a bump can increase both main gear and nose gear loads significantly and can also result in tires being cut and rims bent at lower sink speeds than previously anticipated. Comparison of data shows the laboratory data to be characteristic of flight test data.

Introduction

ACCURATE analytical prediction of design loads and accurate verification by test simulation is necessary to insure the efficiency and reliability of structural systems. In the design of carrier-based aircraft, the loads incurred by running over carrier deck obstructions are difficult to predict. These loads are particularly important in that they can be superimposed over already high landing loads. Past efforts by airframe manufacturers to simulate this effect during drop tests have been unsatisfactory. Realistic simulation of the spin-up of nonrotating tires and of tire cornering for yawed landings and lateral stroking gears has also been unsatisfactory.

Recognizing these deficiencies in past test methods, Vought Systems Division constructed a special drop test facility which permitted actual spin-up of the airplane tire and wheel during positive stroking of the gear struts. It also simulated running over a deck obstruction at the critical point in the stroke. Contract N00019-72-C-0220 was negotiated for demonstration of the facility by VSD and evaluation of operational characteristics by the Naval Air Systems Command (NASC). The demonstration was conducted in anticipation of utilizing the facility in the Navy's S-3A airplane drop test program.

This report describes the facility and techniques used in drop testing, and presents the results of some tower drops made with an S-3A main gear. Also, since drop tests and carrier suitability tests of the S-3A have been completed, data from these tests are presented for comparison.

Basic Drop Test Techniques

To accomplish a drop test, a full size structural shell of the airplane to be tested is ballasted to the proper weight, center of gravity, and moments of inertia. It is then rigged to be lifted above a selected drop point and to be dropped on that point. More rigging is added to obtain a constant downward velocity, or sink speed as it is called, just prior to touch down, and to keep the airframe from bouncing and rolling out of the area. Energy absorbers in the form of stainless steel straps are also added to keep the airframe from falling to the floor in the event of a gear failure.

Generally, one of the main gear assemblies is designated the test assembly along with the nose gear assembly. These assemblies are then strain gaged and calibrated to permit determination of vertical and drag loads at the wheel axle and axial loads in each of the struts. A transducer is also installed on the shock strut to correlate stroke with load. Other strain gages and accelerometers are located in critical structural areas for determination of loads and stresses.

Drop testing of carrier based aircraft has long been a fairly common test in the industry and most manufacturers have the facilities and capabilities to do these tests in a satisfactory manner. In recent years, however, it has become more and more desirable with the advent of each new carrier based airplane to have the capability to not only make the test aircraft land in any prescribed attitude and at any prescribed forward and downward velocity, but to also make it run over a deck obstruction or bump at any preselected point in the stroke of the landing gear shock strut.

It is important in the tests to be able to run over a bump at the right time because the additional loads placed on the landing gear on encountering a bump such as an arresting cable or a deck centerline light cover can be especially critical if encountered while the gear is already under maximum landing loads.

Until recently, there has been no satisfactory way to measure or test to these bump loads. Laboratory facilities have been nonexistent and the number of parameters that have to be closely controlled to obtain a precise data point exceed flight test capabilities; not to mention the risk involved for the pilot. Vought, however, now has a facility in which such testing can be readily accomplished.

Description of Facility

General

The more realistic loading conditions for landing gear are achieved by propelling a piece of simulated carrier

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deck down a tract and under the airplane wheel at velocities representative of carrier aircraft landing velocities and by dropping the airplane onto it from a height sufficient to obtain the required sink speed. The method for accomplishing this is explained in the following paragraphs which describe the major components of the system. The general arrangement of the facility is shown in the photograph, Fig. 1.

Shuttle Plate Assembly

The shuttle plate is the piece of simulated carrier deck. It is an aluminum plate 5-ft wide and 48-ft long. An aluminum tube and several slipper fittings are attached on each side. The aluminum tubes form the outer cylinders of the propulsion system and the slipper fittings retain the plate on the guide rail and guide it along the rail. Any deck obstruction for which roll-over effects are to be determined can be attached to the plate.

Guide Rail Assembly

The guide rail assembly is a pair of light crane rails 199-ft long. Only in the area of the load platform do they perform any function other than to support and guide the shuttle plate. At either end of the load platform they are cut; in between they are attached to the platform for the purpose of reacting landing gear side loads into the platform foundation.

Hold-Back and Release System

The hold-back and release hook is a mechanical quick-release hook used to restrain the shuttle plate when in the firing position with the propulsion system charged. Action of the hook and release of the plate are initiated electrically and in sequence with release of the airplane. A solenoid valve is used to release nitrogen to a small pneumatic cylinder which drives an over-center mechanism to open the hook.

Load Platform Assembly

A set of steel-topped stationary platforms is used to react the landing gear vertical and lateral loads into the foundation to which they are bolted. One is located between the rails and directly under the point where the landing gear being tested will impact the shuttle plate.

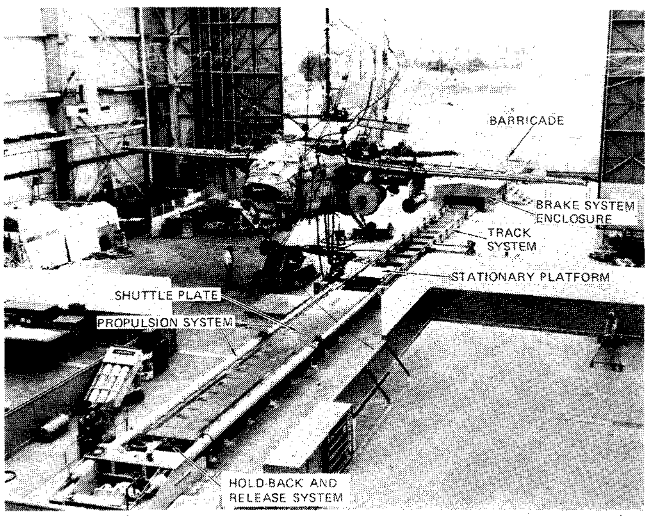

Fig. 1 VSD landing gear dynamic test facility with S-3A rigged for drop tests.

Others are suitably located to react the impact of the other gear assemblies.

The shuttle plate slides over the top plate of the center platform and is "sandwiched" between it and the landing gear wheel and tire. A lubricant is used to minimize friction between the plates during their brief contact.

All of the platforms are easily convertible to a roller rack assembly for testing landing gear of the side stroking type without using the shuttle plate.

Propulsion System

The complete propulsion system consists of two piston and accumulator assemblies, the two aluminum tubes attached to the shuttle plate, and a reaction structure and foundation. The piston and accumulator assemblies are large diameter steel pipes bolted together in series and located on each side of the shuttle plate in line with the aluminum outer cylinders. The accumulators are bolted to the reaction structure and the pistons fit inside the aluminum outher cylinders when in the firing position. When ready to be fired, the outer cylinders, pistons, and accumulators are charged with high pressure nitrogen. As the shuttle plate is released, the outer cylinders are propelled down the track, carrying the shuttle plate with them. During the powered portion of the catapult stroke, the plate travels 21.5 ft before the outer cylinders and pistons separate. A portion of the powered stroke (13.33 ft normally) is used to accelerate the plate; the remainder of the stroke is used to spin up the airplane wheel. Objectionable blast effects at separation are prevented by quick-acting valves located in the end of each of the tubes which close just prior to separation. The valves located in the outer cylinders are called "flap" valves and those in the end of the pistons, "plug" valves. The flap valves are closed by cams and the plug valves by differential pressure.

Brake Assembly

The brake assembly consists of a primary brake and an energy absorbing barrier. The primary brake is a squeeze type friction brake which is designed to absorb 150% of the energy generated by the propulsion system. A heavy steel barrier is located at the end of the track as a backup for the brake system. A collapsible balsa wood-in-tube energy absorber is incorporated in the barrier and can absorb 50% of the energy generated.

Data Acquisition Equipment

Equipment is installed as required for sensing and recording such parameters as noise, pressure, strain, deflection, motion, and acceleration. A Sigma 3 computer system located in the laboratory is used for data reduction, tabulation, and plotting. Standard and high speed motion pictures are taken of events of special interest.

Tests and Demonstrations

Facility Tests

To determine the operational characteristics and to calibrate the facility, a series of tests were conducted on completion of construction. The facility tests included component fit and function tests, structural verification tests, system functional tests, and a series of tower drops of the S-3A main landing gear. The tower drops permitted complete checkout of the facility including the system for synchronizing release of the test article and the shuttle plate prior to beginning airplane tests. Figure 2 is a photograph of this setup. Data from these tests were com-

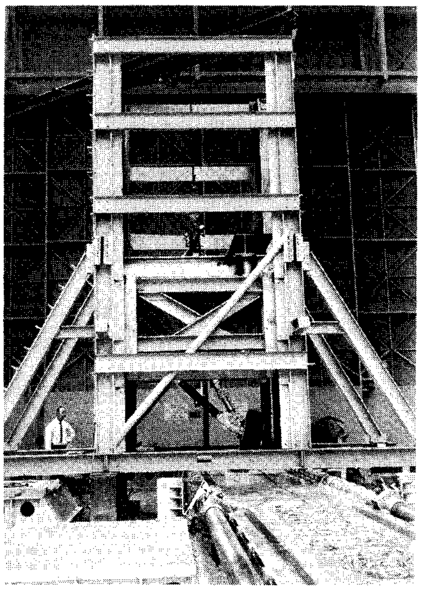

Fig. 2 Landing gear dynamic test facility looking in direction of shuttle plate travel at drop tower.

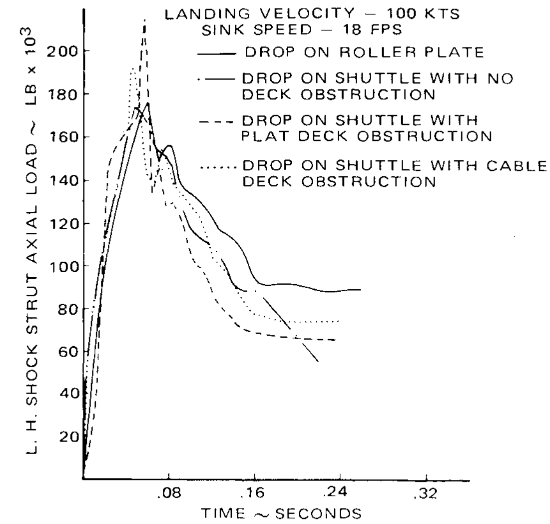

Fig. 4 Comparison of tower drops on roller plate vs shuttle plate—shock strut axial load vs time.

pared with data obtained from the S-3A main landing gear tower drop tests conducted earlier using the previous method of dropping the gear on a fixed platform incorporating a lightweight rack containing many small rollers sandwiched between a fixed plate underneath and a lightweight sliding plate on top. The method included spinning the tire and wheel backward at landing velocity prior to touchdown for simulation of wheel spin-up. Figure 3 is a photograph of that setup. Figures 4–6 are plots of data taken in drops at a sink speed of 18 fps from each of the two series of tests. These plots are typical and show principally that strut loads build up sooner when the gear is allowed to spin-up and corner properly as is accomplished on the shuttle plate. The plots also show that for the specific test condition examined, running over a piece of 1.375-in-diam arresting cable increased the shock strut load about 15% and running over a 1.25-in. high PLAT (Pilot Landing Aid Television) camera cover increased the shock strut load about 25%.

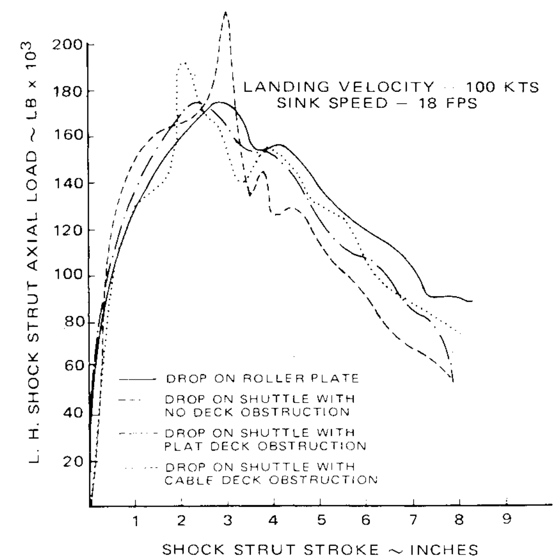

Fig. 5 Comparison of tower drops on roller plate vs shuttle plate—shock strut load vs stroke.

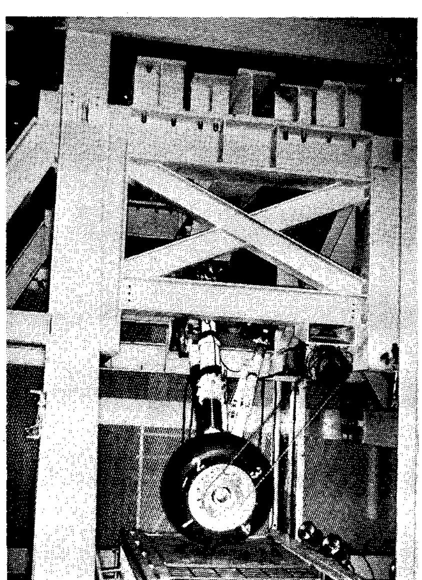

Fig. 3 Model S-3A main landing gear tower drop test setup with roller plate.

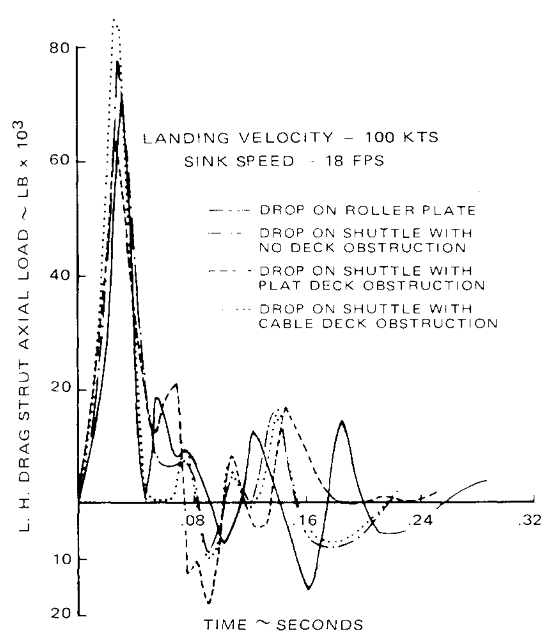

Fig. 6 Comparison of tower drops on roller plate vs shuttle plate—drag strut axial load vs time.

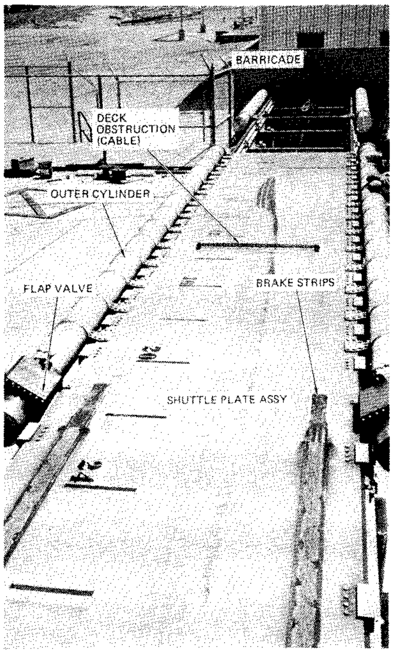

Fig. 7 Landing gear dynamic test facility—arresting cable installation and other components.

A view of the arresting cable installation is shown along with some other components of the facility in Fig. 7. Figure 8 is a photograph of the PLAT installation.

Repeatability of the system is shown graphically in the plots of Figs. 9 and 10. These runs were made in series with three similar runs made at a landing velocity of 120 knots to investigate the effect of higher landing velocities on strut loads. In this very limited investigation the 20% increase in landing velocity resulted in a 10% increase in the peak loads of both the shock and drag struts. The apparent reversal of direction in the shock strut stroke during run number 3 at about 3 in. of stoke is unexplained. The phenomenon was not observed in any of the other runs although the strut apparently ceased to stroke momentarily or nearly so, at about this same point relative to rolling over the obstruction in some of the other runs. Additional testing is needed to determine whether the apparent reversal is a characteristic of the instrumentation or truly a dynamic response of the gear as it leaves the obstruction.

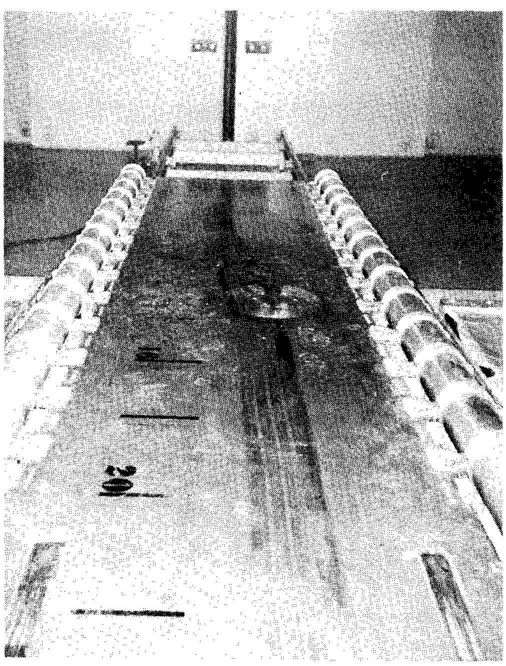

Fig. 8 Landing gear dynamic test facility—PLAT camera cover installation.

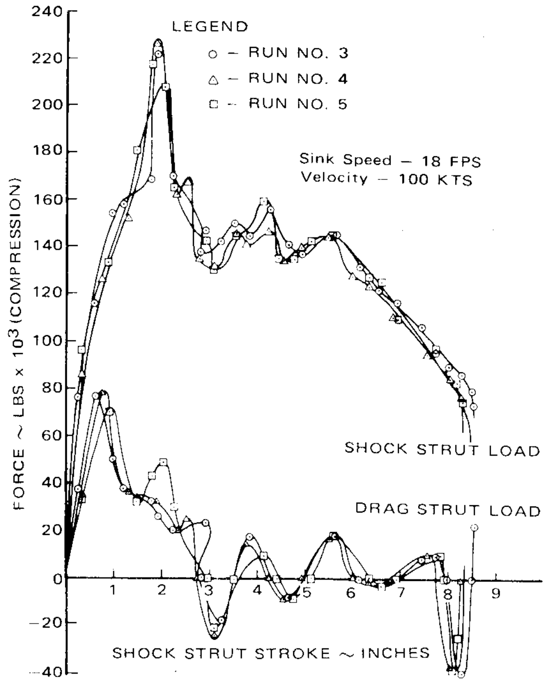

Fig. 9 Model S-3A main landing gear tower drop test using the landing gear dynamic test facility—force vs stroke with PLAT camera cover.

Airplane Tests

Subsequent to the facility testing using the drop tower, S-3A airplane drop tests were conducted utilizing the facility. The drop tests were then followed by carrier suitability testing at the Patuxent River Naval Air Test Center. This testing provided data for comparative purposes to aid in evaluation of the facility.

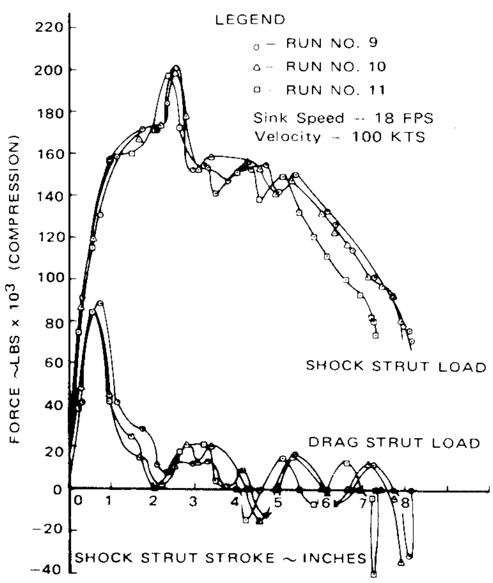

Fig.10 Model S-3A main landing gear tower drop test using the landing gear dynamic test facility—force vs stroke with arresting cable.

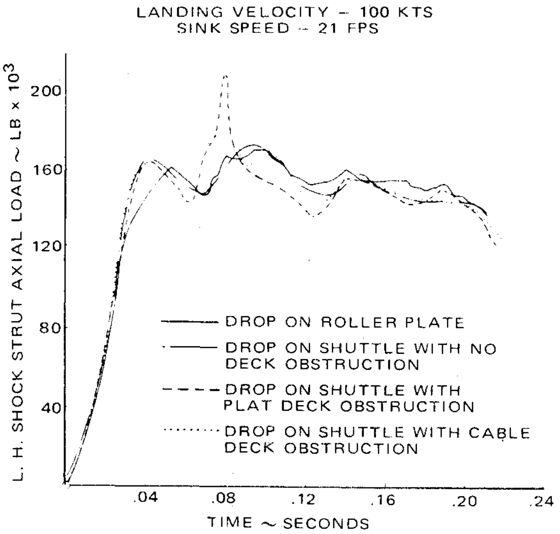

Fig. 11 Comparison of airplane drops on roller plate vs shuttle plate—shock strut axial load.

Drop Tests

Drop tests of the S-3A airplane were conducted using the static test airplane properly ballasted to the critical weight distributions for the various landing attitudes and conditions. The tests included dropping the test gear on the roller plate platform and on the shuttle plate.

In the tests using the shuttle plate, runs were made with and without deck obstructions attached to the plate. The deck obstructions used were the same piece of cable and the same PLAT cover used in the tower drops. In all the tests of the main gear the left hand gear was the test gear. The right-hand gear was dropped on a roller plate platform and the nose gear on a flat, rigid platform. All wheels, except the left-hand wheel when impacting on the shuttle plate, were prespun backward to simulate tire/ground relative motion.

Figures 11–14 are some typical plots of landing gear strut loads obtained during this airplane drop test program. These plots are shown to permit a comparison of data obtained from drops on the moving shuttle plate versus the roller plate platform and to show the effects of running over the two kinds of deck obstructions. These plots cannot be compared directly with the tower drop

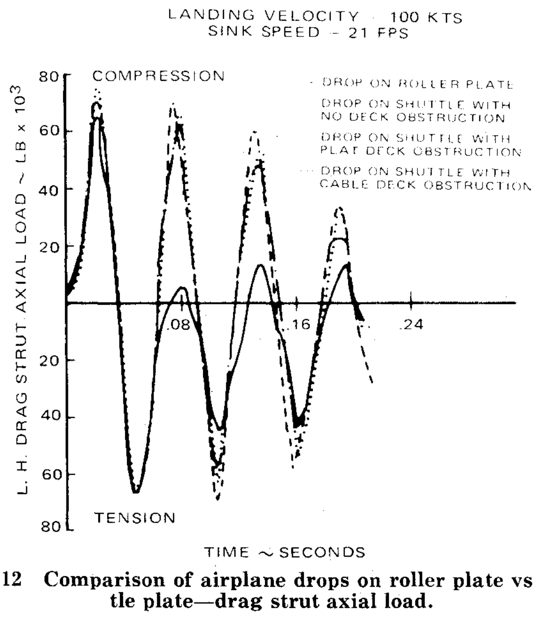

Fig. 12 Comparison of airplane drops on roller plate vs shuttle plate—drag strut axial load.

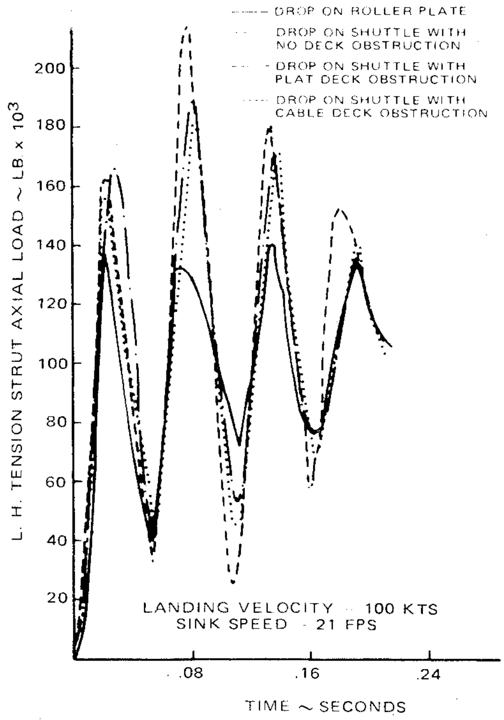

Fig. 13 Comparison of airplane drops on roller plate vs shuttle plate—tension strut axial load.

tests because of the different weight distributions, wing lift to weight ratios, and metering pin configurations in use at the time of the particular series of drops. Figures 15–17 compare the peak strut loads produced on the roller plate vs those produced on the shuttle plate as a function of sink speed.

Flight Tests

In the carrier suitability tests of the S-3A airplane, a number of landings were made to verify predicted landing gear loads and to further demonstrate the structural integrity of the aircraft. In these tests the same weight aircraft was used as in the drop tests, but two deck obstructions were located on the runway. The first to be encountered in a landing was a simulated deck light 1.25-in. high. Twenty feet further down the runway was an arresting cable actually used to arrest the aircraft. About 30 ft beyond the cable was a nondescript discontinuity in the runway which also appeared as an impact load in the data.

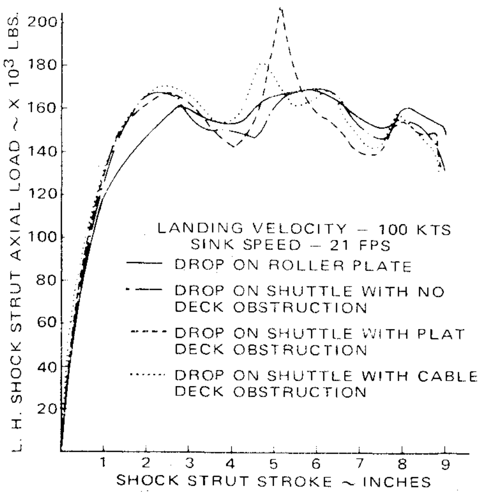

Fig. 14 Comparison of airplane drops on roller plate vs shuttle plate—shock strut.

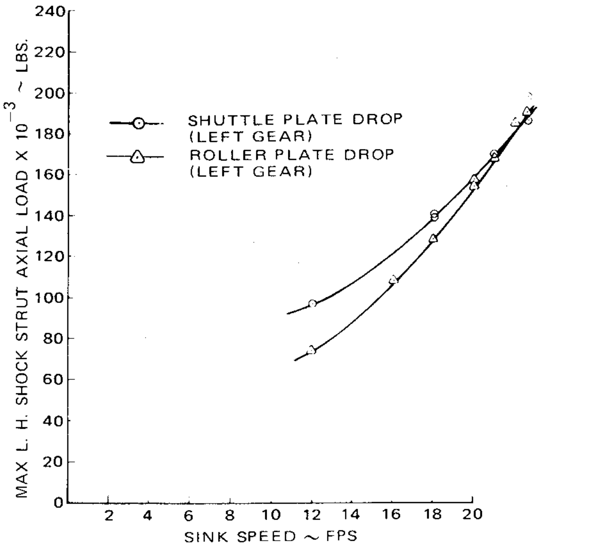

Fig. 15 Model S-3A airplane drop test—peak main gear shock strut load vs sink speed.

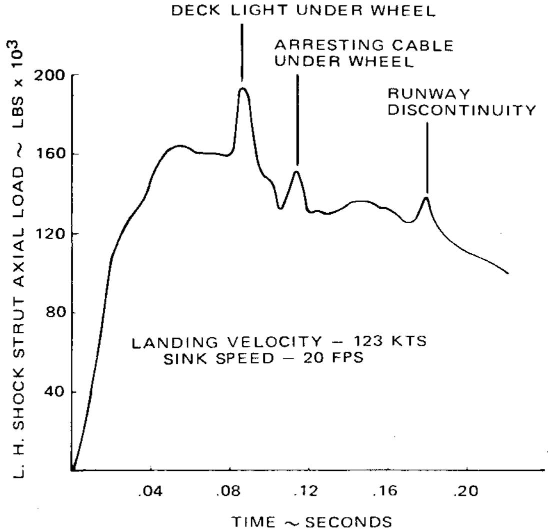

Fig. 18 Flight test data—shock strut axial load.

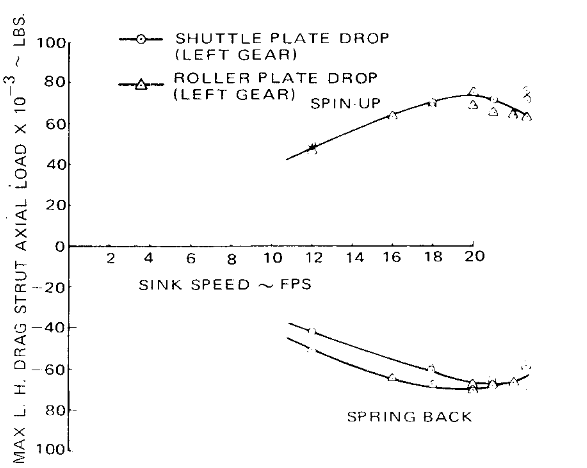

Fig. 16 Model S-3A airplane drop test—peak main gear drag strut load vs sink speed.

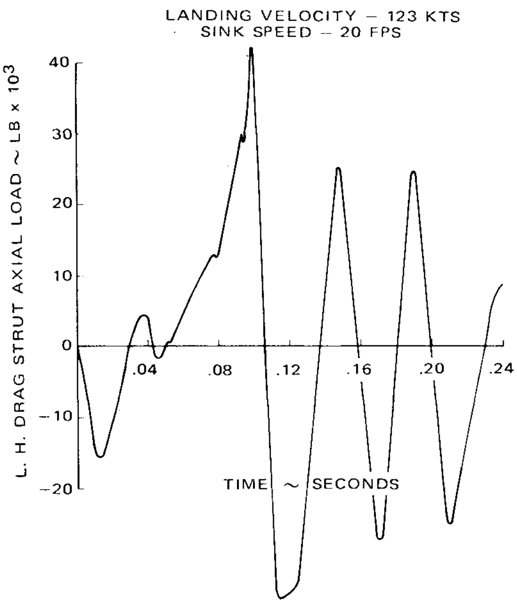

Fig. 19 Flight test data—drag strut axial load.

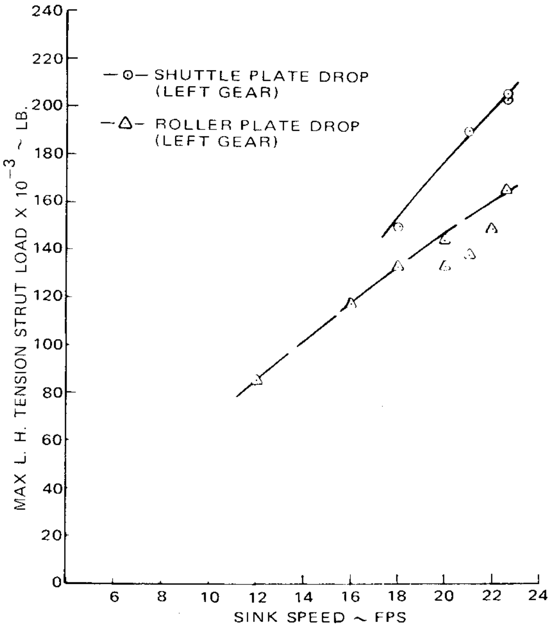

Fig. 17 Model S-3A airplane drop test—peak main gear tension strut load vs sink speed.

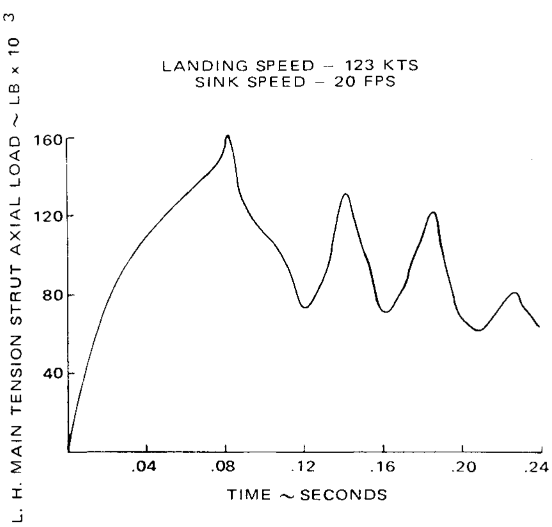

Fig. 20 Flight test data—tension strut axial load.

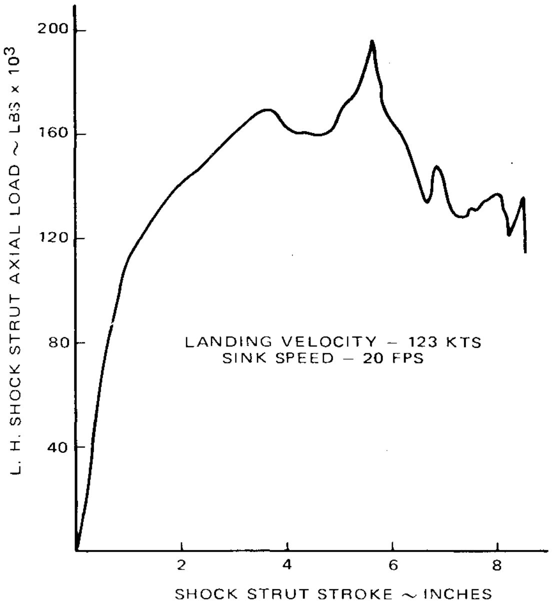

Fig. 21 Flight test data—shock strut.

Figures 18–21 are plots of some data recorded during the flight tests. These data are typical of the flight test data and are included to show the similarity with the laboratory data. These plots cannot be compared directly with any of the other data presented here for the same reasons given in the paragraph on drop tests. They do show, however, that similar data is obtained from the three test methods (roller plate platforms, shuttle plate, and flight test) so long as there is no requirement for running over deck obstructions. When this requirement is present, the shuttle plate provides the better and more economical method.

Conclusions

Construction of the facility provided VSD with the most accurate method known for dynamic simulation of aircraft landings. It provided precise control of the parameters necessary to verify design loads and conditions and, for the first time, the design loads for a navy aircraft resulting from encountering deck obstructions during landing impact have been accurately simulated in the laboratory. Flight testing has not and cannot be expected to serve this purpose because of the inability to accurately control the initial conditions at touchdown such as encountering the obstruction at the critical stroke position. Furthermore, the facility is an improvement on former methods of drop testing disregarding the deck obstruction encounter capabilities. This is because certain critical member loads are not accurately simulated using the roller plates or other past methods, especially in the case of tripod type landing gears.

Utilization of the facility to date, however, has been limited to verification testing of a single landing gear design and, though excellent simulation has been achieved, much more testing needs to be done. Member loads and shock absorption capabilities are affected not only by the geometrical arrangement but also by such variables as landing velocity, lift to weight ratio at touch down, tire size and inflation pressure, and of course the shape and size of obstructions encountered. The facility provides an excellent tool for the study of such variables with or without an airplane. As has been shown in this brief description of tests performed, very valuable data can be obtained by means of relatively simple tower drops of single gear assemblies as well as by means of full scale airplane drops.

It is to be noted also that the facility has other applications. Already it has been used in development tests of a linear induction motor for a ground transportation vehicle and in the study of the effects of velocity on the characteristics of some rather large permanent magnets and electromagnets. Other applications in tests requiring a moving ground plane are being considered.

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Advanced Technology Thrust Vectoring Exhaust Systems

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Systematic studies of a series of candidate thrust vectoring exhaust nozzle systems were performed to identify the best system for an advanced VTOL fighter/interceptor. The investigation used generalized nozzle and installation data in finding that a nozzle arrangement featuring a "trap door" thrust vectoring device was competitive with other types for nonaugmented vertical operation and offered superior installation qualities. A three-bearing rotating elbow nozzle was best when partial afterburning was employed for deflected thrust. Nozzle selections were based on study results as well as subjective appraisals by aircraft companies.

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Index categories: VTOL Aircraft Design; VTOL Mission and Transportation Systems; VTOL Powerplant Design and Installation.

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