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Hampton, Virginia

National Aeronautics
and Space Administration

**Scientific and Technical
Information Office**

Contents

Summary

The Langley Research Center has recently upgraded the Landing Loads Track (LLT) to improve the capability of low-cost testing of conventional and advanced landing gear systems. The unique feature of the Langley Aircraft Landing Dynamics Facility (ALDF) is the ability to test aircraft landing gear systems on actual runway surfaces at operational ground speeds and loading conditions. A historical overview of the original LLT is given, followed by a detailed description of the new ALDF systems and operational capabilities.

Introduction

The Langley Aircraft Landing Dynamics Facility (ALDF) became operational in 1985. It has the capability of testing full-size aircraft landing gear systems under closely controlled simulated takeoff and landing conditions on actual runway surfaces. Testing landing gear systems on the ALDF is advantageous over flight testing for reasons such as safety, economy, parameter control, and versatility. Virtually any aircraft landing gear system or subsystem can be accommodated on the ALDF test carriage. New and novel landing gear concepts can also be investigated, and the versatility of the facility permits testing on a variety of runway surfaces under many different simulated weather conditions.

The purpose of this paper is to give a brief historical overview of the Langley Landing Loads Track (LLT), the facility preceding the ALDF, and to discuss how the older facility was upgraded to the present ALDF configuration. The paper describes the main features of the ALDF, including the high-pressure propulsion system, the test carriage, the track, the arresting gear system, and the data acquisition system.

Historical Overview—Langley Landing Loads Track Facility, 1955–1981

The need for a facility to conduct landing gear tests on actual runway surfaces was identified by researchers at the NACA Langley Aeronautical Laboratory in the late 1940's. Reference 1 presents the results of an early study to define the most cost-effective catapult system to accelerate a 100 000-lb test carriage to a speed of 130 knots (1 knot equals 0.5 m/sec). The study considered many catapult options including a dropping weight, flywheel, blowgun, high-pressure piston, and rocket power. Yet, the most promising and cost-effective concept appeared to be a high-pressure water jet catapult system. As a result of this study, the Langley Landing Loads Track was constructed and became operational in 1955 (ref. 2). Many of the design features of the LLT described in the following paragraphs were later incorporated into the ALDF. Table 1 lists the key characteristics of the LLT.

The LLT is shown in figures 1, 2, and 3. The major components of the water jet catapult, identified in figures 1 and 2, included the L-shaped water vessel (identified as L-vessel), compressed air storage tanks, a quick-opening valve, and the reaction bucket at the rear of the test carriage. Figure 3 is a photograph of a typical run of the test carriage being catapulted at the LLT. The L-vessel was sized with a volume that would allow only the water contained in the horizontal leg, about 3000 gal, to be expelled during a maximum-speed catapult. This design feature minimized turbulence within the jet and thereby enhanced jet integrity over the 400-ft catapult stroke.

The LLT test carriage shown in figures 1, 2, and 3 was a space truss structure constructed of tubular steel. The carriage was about 60 ft long, 30 ft wide, and 30 ft high and for most test applications weighed about 106 000 lb. The main features of the carriage were the reaction bucket, the drop carriage, and the nose block. The carriage reaction bucket, which turned the water jet through about 177°, was based upon the efficient water wheel design of Pelton (refs. 3 and 4). The bucket design maximized the impingement thrust on the carriage and produced a water exit which did not interfere with the water jet. The air storage tanks, L-vessel, and valve area were all sized to provide about 350 000 lb of thrust on the carriage and to catapult it up to test speed in about 3 sec over a maximum distance of 400 ft. The drop carriage rode on a set of vertical guide rails located in the middle of the test carriage. The landing gear test article, attached to the drop carriage, could be lowered at a predetermined location and rate to simulate a landing impact.

The nose block on the front end of the carriage was shaped to capture five arresting gear cables which spanned the track at the end of the test section. For the LLT, the 5 cables were attached to 20 energy absorbers which dissipated the carriage kinetic energy over the last 600 ft of track. The energy absorbers were hydraulic rams which dissipated the carriage energy by forcing hydraulic fluid through orifices. The arresting gear hardware, procured from Navy surplus, had previously been used onboard World War II vintage aircraft carriers.

The test carriage rode on steel rails that were 30 ft apart. The carriage was supported at each corner by a two-steel-wheel bogie which also had two wheels for lateral constraint against the track rail system. The operating sequence of the LLT was simple and resembled what is used today. The catapult system propelled the test carriage to the desired speed over the first 400 ft. The carriage then coasted through the 1200-ft test section where the landing gear test article was tested on the runway surface. Finally, the test carriage engaged the arresting gear system and was brought to a stop within the last 600 ft of track. The versatility of the LLT has been demonstrated over the years by a variety of test programs (refs. 5 through 17) ranging from taxi tests over runway lights to the tests of the Space Shuttle Orbiter nose gear tires.

Most design features of the LLT catapult, carriage, and track rail system have been incorporated into the design of the new Langley Aircraft Landing Dynamics Facility. In fact, the LLT test carriage has been retained as a second test carriage for the ALDF. The main drawback of the LLT was its limited speed capability. When the LLT facility became operational in 1955, the maximum speed capability of 110 knots was adequate to cover the landing speeds of most commercial, propeller-driven aircraft. With the advent of the commercial jet aircraft in the 1960's, landing speeds climbed above the speed limitation of the facility. This progressive increase in touchdown speeds is shown in figure 4 for several commercial aircraft. Some military aircraft have touchdown speeds higher than those shown, especially when there are failures in the flap or swing wing mechanisms. In addition, the Space Shuttle Orbiter lands at speeds between 190 and 220 knots. Thus, a facility update was required to enable testing at landing speeds up to 220 knots which would cover all current and proposed aircraft.

Langley Aircraft Landing Dynamics Facility

The major components built or refurbished for the Langley Aircraft Landing Dynamics Facility are shown schematically in figure 5 and pictorially in figure 6. The new propulsion system utilizes a water jet concept similar to the original system. A new, larger L-vessel with an 18-in-diameter nozzle and a high-speed shutter valve are mounted on a more massive foundation. A new test carriage, with a larger open bay, was constructed to withstand the water jet maximum thrust of 2 200 000 lb. The existing test track was extended 600 ft, resulting in a test section of 1800 ft, to provide additional test time at the higher speeds. A new arresting gear system was installed to bring the carriage to a safe stop within 500 ft. The calibration building was rebuilt at the end of the extended track and a transfer system was modified to transfer either of the two carriages from a second set-up building to the test track. Table 2 provides quantitative specifications concerning the major component capabilities of the ALDF which are described in the following sections.

Propulsion System

The propulsion system uses the stored energy of compressed air acting on water as a carrier medium to impart energy to the test carriage. The major components of the propulsion system shown in figures 5 through 12 are the air storage tanks, the L-vessel, the internal nozzle, and the high-speed shutter valve.

The air storage system consists of three tanks, a manifold, and piping to the top of the L-vessel. Compressed air is stored at a maximum system pressure of 3150 psi in the three tanks which have a total of 4800 ft^3 of air storage volume. Each tank feeds into a manifold and then into a gooseneck-shaped pipe which carries the air to the top of the L-vessel. (See fig. 8.)

The steel L-vessel has an 8-ft inside diameter, with a wall thickness of 7.25 to 9.5 in. It weighs approximately 720 000 lb and is mounted to a massive pile-supported concrete foundation. The L-vessel contains 26 000 gal of potable water and can be pressurized to 3150 psi. To accommodate an effective propulsion distance of 400 ft, the horizontal leg of the L-vessel is oriented upward 0.75° so that a slight upward water jet stream trajectory is produced. The water expelled during the catapulting process is contained initially in the horizontal leg of the L-vessel. As high-pressure water moves out of the horizontal leg during the catapult process, it is replaced by the water initially contained in the vertical leg. This is done so that no water turned by the elbow section of the L-vessel flows out the nozzle and no air escapes through the nozzle. The maximum water system flow rate during catapulting is 72 100 ft^3/min at 3150 psi.

The stainless-steel internal nozzle, 18 in. in diameter, is mounted to the end of the L-vessel as shown in the photograph in figure 8. The nozzle provides a smooth contour from the end of the L-vessel and forms the 18-in-diameter water jet. The valve opening is centered over the nozzle to give unobstructed flow. The valve shown in figures 7 through 11 is a high-pressure, quick-acting valve with a hydraulic-nitrogen actuation system. In figure 8, the high-speed shutter valve is shown beside the L-vessel before installation and the internal nozzle can be seen protruding from the end of the L-vessel. The valve shown schematically in figure 9 consists of a spherical valve body, inner shutter, outer high-speed shutter, dual hydraulic actuator, linkage system, and associated control systems. The inner shutter and valve body provide the primary pressure boundary and watertight seal for the valve. This seal allows operational checkout of the high-speed shutter without losing water from the valve. During a typical catapult operation, the high-speed shutter seal is actuated and the pressure equalizer valve is opened to allow water to flow into the cavity between the shutters (equalizing pressure across the inner shutter). The inner shutter translates axially away from its sealing surface and rotates into the top of the valve body. The high-speed shutter seal is then retracted, and the high-speed shutter is opened by the hydraulic actuator and linkage system. The high-speed shutter opens in approximately 0.4 sec, is held open for the dwell time necessary to obtain the desired carriage speed, typically less than 1 sec, and then returned to the closed position in approximately 0.3 sec. The high-speed shutter opening and closing times are adjustable and are set to control the water jet acceleration rate on the carriage. By controlling the propulsion system pressure and the dwell time of the fully open jet valve, the operator can modify both the peak acceleration and the velocity of the carriage. At a maximum pressure of 3150 psi, the water jet will produce a thrust on the carriage of approximately 2 200 000 lb. With the new carriage weight of approximately 108 000 lb, this thrust creates a peak acceleration of approximately $20g$.

Figure 10 is a photograph of the high-speed shutter valve fully assembled and ready for mounting prior to attachment on the L-vessel. The shutter valve linkage mechanism used for opening and closing the high-speed shutter is shown. Near the top of the valve are the hydraulic and nitrogen supply system controls which regulate the pressure and flow of oil and nitrogen in the dual actuator which opens and closes the high-speed shutter. These systems also control the flow of oil to the inner shutter actuators and several mechanical safety pins around the valve.

A water flow straightener mounted at the exit of the high-speed shutter valve is shown in figure 11. As the high-speed shutter is in the process of being opened, the developing water jet is deflected downward and the flow straightener redirects the water into the carriage reaction bucket. A photograph of the carriage during a low-pressure catapult is shown in figure 12. The valve is fully open and a coherent jet can be seen shooting through the flow straightener.

High-Speed Test Carriage

The high-speed test carriage shown in figure 13 is a welded space truss structure made of seamless quenched and tempered low alloy steel tubes. The carriage is 30 ft wide, 70 ft long, and 26 ft high. It has a centrally located open bay, 20 ft wide and 40 ft long, to facilitate testing of large test articles. At the rear of the carriage, a reaction bucket with a 10-ft opening captures the high-velocity jet of water from the propulsion system. The reaction bucket turns the water jet approximately 177° before releasing it rearward and downward away from the test carriage.

At the front of the carriage is a nose block assembly which engages the five pendant cables that are part of the arresting gear system. The nose block is a segment of a cylinder, approximately 30 in. in radius and 5.5 ft high, with internal ring-stiffened bulkheads. Five V-shaped grooves on the face of the cylinder catch the arresting cables. The entire nose block structure is made of 0.25-in. steel and is welded into a single unit.

The test article drop carriage is shown at the top of the test carriage in figure 14. It is also made of tubular quenched and tempered low alloy steel and is located in the open test bay of the carriage. The test article, such as a landing gear strut or a test tire mounted to a dynamometer, is attached directly to a mounting flange on the drop carriage. The drop carriage with a dynamometer weighs 14 000 lb. It travels vertically on four vertical rails with two hydraulic lift cylinders being used to control the vertical motion. The drop carriage can reach vertical velocities up to 20 ft/sec for tests of landing gear systems, and simulated wing lift can be applied to the drop carriage just prior to tire touchdown. Four hydraulic load cylinders can be used to obtain additional vertical loading up to approximately 65 000 lb on the test article. The hydraulic system is powered by onboard hydraulic accumulators. Solenoid valves are used to actuate the hydraulic system, to lower or raise the drop carriage, and to apply vertical loading during a test run.

The carriage wheel truck assemblies which provide vertical support and lateral restraint are located at each corner of the carriage along with hold-down outriggers to prevent the carriage from lifting off the track rails during catapulting. Additional hold-down rails are located below the reaction bucket because of the significant uplift that occurs during initial development of flow in the bucket while the valve is opening. Once the carriage is arrested at the end of the test run, an antirollback brake system located at the rear of the carriage prevents the carriage from rolling backwards.

Electrical power on the carriage is provided by a pair of aircraft-type batteries. They are used to power the onboard cameras, data systems, and electrical controls (e.g., solenoid valves). All carriage test data from onboard instrumentation are routed through a signal conditioner in the instrumentation box, identified in figure 13, and telemetered to a recording station in the command center building. (See section "Data Acquisition System" for more information.)

Track

The ALDF track, as shown in figure 15, has a total length of 2800 ft. The maximum effective jet propulsion distance is approximately 400 ft, and the test section is 1800 ft, which allows for 5 sec of test time during a maximum speed test. The carriage arrestment section is 600 ft. A cross-sectional view of the track is given in figure 16.

The track rails are 6 in. square and are welded together forming one continuous rail. Each track rail is supported by chair units which restrain the rail along its length by friction clamping only allowing thermal expansion of the rail at each end. The chairs are spaced 3 to 4 ft apart at random intervals on a pattern that repeats every 81 ft or after 22 chair units. The purpose of this random support spacing is to prevent buildup of harmonic frequencies that could excite the natural frequencies of the carriage.

The transfer dolly, shown in figure 17, is located at the end of the track just ahead of the calibration building. It is 72.5 ft long and is used to transport the carriages from the calibration building to the main support building. The same tug which tows the test carriage back to the L-vessel after a run is used to move the transfer dolly holding a test carriage.

Arrestment System

A photograph of the carriage arrestment system is shown in figure 18 and a schematic of the system is shown in figure 19. The system is located approximately 600 ft from the calibration building at the end of the track. The major components of the system include five independent sets of energy absorbers. Each set of energy absorbers is connected by a cable/tape assembly. The system can routinely absorb 167 000 000 ft-lb of energy which is sufficient energy-absorbing capability to successfully arrest the carriage in the event of a failure of any two sets of energy absorbers.

The gantry tower, shown in figures 18 and 19, supports the five cables and is used to position the cable assemblies at the proper elevation for carriage nose block engagement. The gantry is also used to raise the cables above the maximum height of the carriage so that the test carriage can be towed the entire length of the track without interfering with the arrestment system.

Each cable assembly spanning the track consists of a steel wire pendant, as shown in figure 20. Each pendant is 1.25 in. in diameter and 100 ft long. Special connectors, shown in figure 20, are used to attach the pendant to the nylon tapes. The tapes which are 8 in. wide, 0.344 in. thick, and 483 ft long are shown after an arrestment in figure 21. The top and bottom edges of each tape are reinforced with extra nylon to accommodate wear and abrasion during the arrestment operation. Each tape is coated with a black resin polymer to resist the degrading effects of ultraviolet radiation and moisture. The cable system has a minimum breaking strength of 150 000 lb.

Figure 22 is a photograph of one energy absorber before installation. Each absorber assembly consists of a tub, rotating shaft, and spool. The tub is filled with a mixture of water and glycol as a work medium. Rotor vanes are located between top and bottom stator vanes inside the tub and are connected to a rotating shaft which protrudes through the top of the tub. The spool is connected to the rotating shaft and the nylon tapes are wound about the spool. The energy absorbed in the carriage arrestment process is converted into heat and dissipated into the water/glycol mixture.

The arrestment system is equipped with subsystems that pretension the cable assemblies before arrestment such that the catenary deflection does not exceed 6 in. at the center of the track. A safety interlock system prevents the opening of the jet valve unless arresting gear system parameters, such as cable tension and position, and water levels and temperature in each turbine are within allowable limits.

Buildings

The control room for the ALDF is located on the second floor of the command center building at the propulsion end of the track. (See fig. 6.) The control console graphically displays all facility operational safety interlocks and houses all the controls needed for regulating the operating sequence of the high-speed shutter valve. A process controller checks all safety interlocks just prior to valve actuation to confirm that all systems are ready before a launch. A communications system consisting of a public address system, intercom system, and portable handheld radios is used to secure the area of all but essential personnel prior to and during a test run. The instrumentation room, which is located on the first floor of the command center building, contains the telemetry receiving equipment and all the computer and recording equipment necessary to reduce the data received from the test carriage and test article. (See section "Data Acquisition System" for more information.)

The calibration and setup building, identified in figures 5 and 6, is also a storage building for either carriage. A rail system to support the carriage, a test model assembly pit, a massive concrete structure for calibration and drop tests, and an overhead crane are contained in the building. General maintenance service for the carriages and installation of test articles can be performed in this building as well as carriage instrumentation calibration.

Data Acquisition System

The carriage onboard battery-powered instrumentation system uses signal conditioners with a telemetry system for data transmission. The data system is versatile enough to accommodate a wide range of sensors which are located on the carriage and send analog signals to the signal conditioners. The signals are amplified or attenuated and sent to an analog to digital (A-D) converter and then multiplexed (i.e., each channel is sampled and then sent to one data channel). The multiplexed data are sent to the microwave transmitter and telemetered to the ground station in the instrumentation room. The signal is demultiplexed and sent to a 26-megabyte, 12-bit hard disc computer and to a digital to analog (D-A) converter. The computer processes 28 channels of data directly and can provide output to a printer or multipen plotter. The digital data that goes to the D-A converter is recorded on an FM magnetic tape recorder. Magnetic tape data can be played into a multichannel galvanometer oscillograph system for quick-look purposes of the raw data. The system has a 1600/sec sample rate capability and approximately a 1-percent error on vertical, drag, and lateral load measurements. Speed measurements are accurate within ±1 knot.

Forces developed by the test tire are measured by strain gauge load beams that make up the force dynamometer as shown in figure 3 and schematically in figure 23. The dynamometer has five beams measuring the axle loads with two in the vertical, two in the fore-and-aft, and one in the lateral direction. The load transfer between the drag-load beams gives a measure of aligning torque, and the load transfer between the vertical-load beams gives a measure of the overturning torque. Torque links are used to measure the brake torque. Strain gauge type accelerometers are used to measure the axle acceleration along the three axes so that inertial loads can be isolated. Typically 10 channels of data are recorded from the dynamometer. Additional measurements include test wheel vertical displacement, angular speed, and angular acceleration together with carriage position and velocity.

Photographic Coverage

High-speed motion picture cameras can be placed at various positions around the track, near the propulsion and arresting gear systems, and onboard the carriage to photograph the test articles. The cameras on the carriage are contained in watertight boxes with plexiglass windows.

Concluding Remarks

The Langley Aircraft Landing Dynamics Facility has been described. This unique facility, which became operational during the summer of 1985, is capable of testing various types of landing gear systems at velocities up to 220 knots on a variety of runway surfaces under all types of weather conditions. The facility has a track 2800 ft long with a test section 1800 ft long, which allows 5 sec of test time at maximum speed. Test articles can be subjected to vertical loads of up to 65 000 lb or sink rates of 20 ft/sec.

This facility significantly increases the capability to conduct low-cost testing of conventional and advanced aircraft landing gear systems. The capabilities facilitate testing at speeds and sizes pertinent to large transport aircraft, fighter aircraft, and the Space Shuttle Orbiter.

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August 24, 1987

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Table 1. Comparison of Capabilities of LLT and ALDF

Parameter	LLT	ALDF
Maximum test speed, knots	110	220
Length of—		
Overall track, ft	2200	2800
Test section, ft	1200	1800
Arrestment section, ft	600	600
Test duration at—		
100 knots, sec	7	11
220 knots, sec		5
Propulsion system:		
Maximum catapult stroke, ft	400	400
Maximum pressure, psi	2950	3150
Exit nozzle diameter, in.	7.16	18
Water consumption, gal	3000	9600
Carriage:		
Maximum carriage acceleration, *g* units on carriage	3.3	20
Maximum carriage deceleration, *g* units on carriage	1.1	6
Maximum catapult force on carriage, lb	350 000	2 200 000
Open bay size, ft	10 × 15	20 × 40
Maximum vertical velocity of test article, ft/sec	0–20	0–20
Maximum vertical load on test article, lb	0–45 000	65 000 at 200 knots >65 000 at lower speeds

Table 2. ALDF Component Specifications

Propulsion system:	
L-vessel:	
Inside diameter, ft	8
Wall thickness, in.	7.25–9.5
Exit nozzle diameter, in.	18
Weight, lb	720 000
Concrete foundation thickness, ft	12
Maximum operating pressure, psi	3150
Maximum flow rate, ft^3/min	72 100
Maximum force on carriage, lb	2 200 000
Water reservoir, gal	26 000
Maximum water jet velocity, ft/sec	680
Gooseneck pipe inside diameter, ft	4
Shutter valve:	
Opening, in.	20
Opening time, sec	0.38–0.4
Closing time, sec	0.3
Dwell time, sec	0.40–0.86
Carriage:	
Weight, lb	108 000
Dimensions, ft	30 × 70 × 26
Open bay, ft	20 × 40
Drop carriage weight, lb	14 000
Maximum vertical load on test article, lb	65 000
Maximum vertical velocity of test article, ft/sec	20
Maximum test speed, knots	220
Maximum acceleration, g units on carriage	20
Maximum deceleration, g units on carriage	6
Track:	
Catapult section, ft	400
Test section, ft	1800
Arrestment section, ft	600
Total length, ft	2800
Test track runway foundation:	
Thickness, ft	1.5
Width, ft	10
Arrestment system:	
Maximum energy absorption, ft-lb	167 000 000
Maximum stopping distance, ft	545
Cable:	
Diameter, in.	1.25
Length, ft	100
Minimum breaking strength, lb	150 000
Tape belt:	
Width, in.	8
Thickness, in.	0.344
Length, ft	483
Minimum breaking strength, lb	150 000

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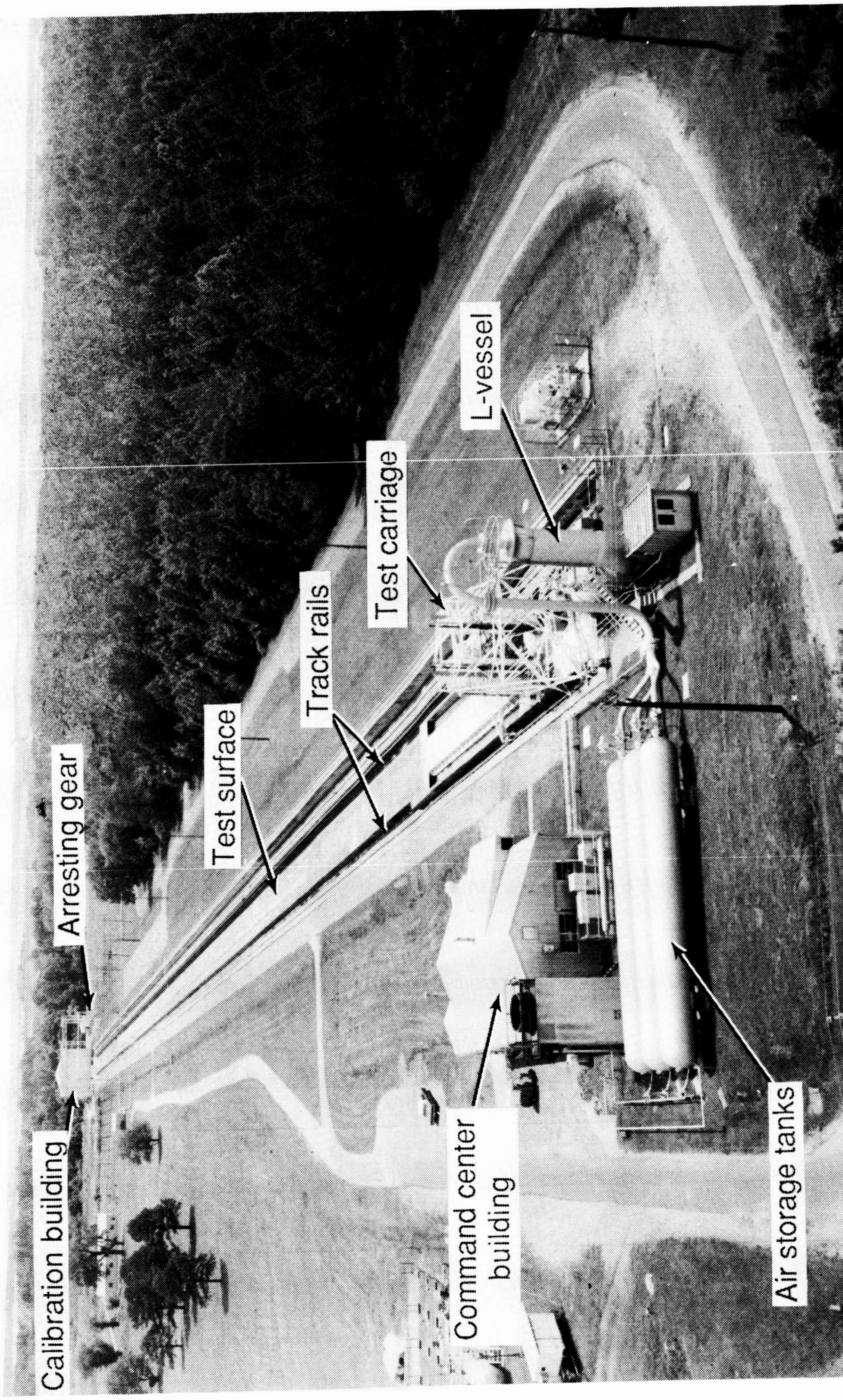

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Figure 1. Langley Landing Loads Track.

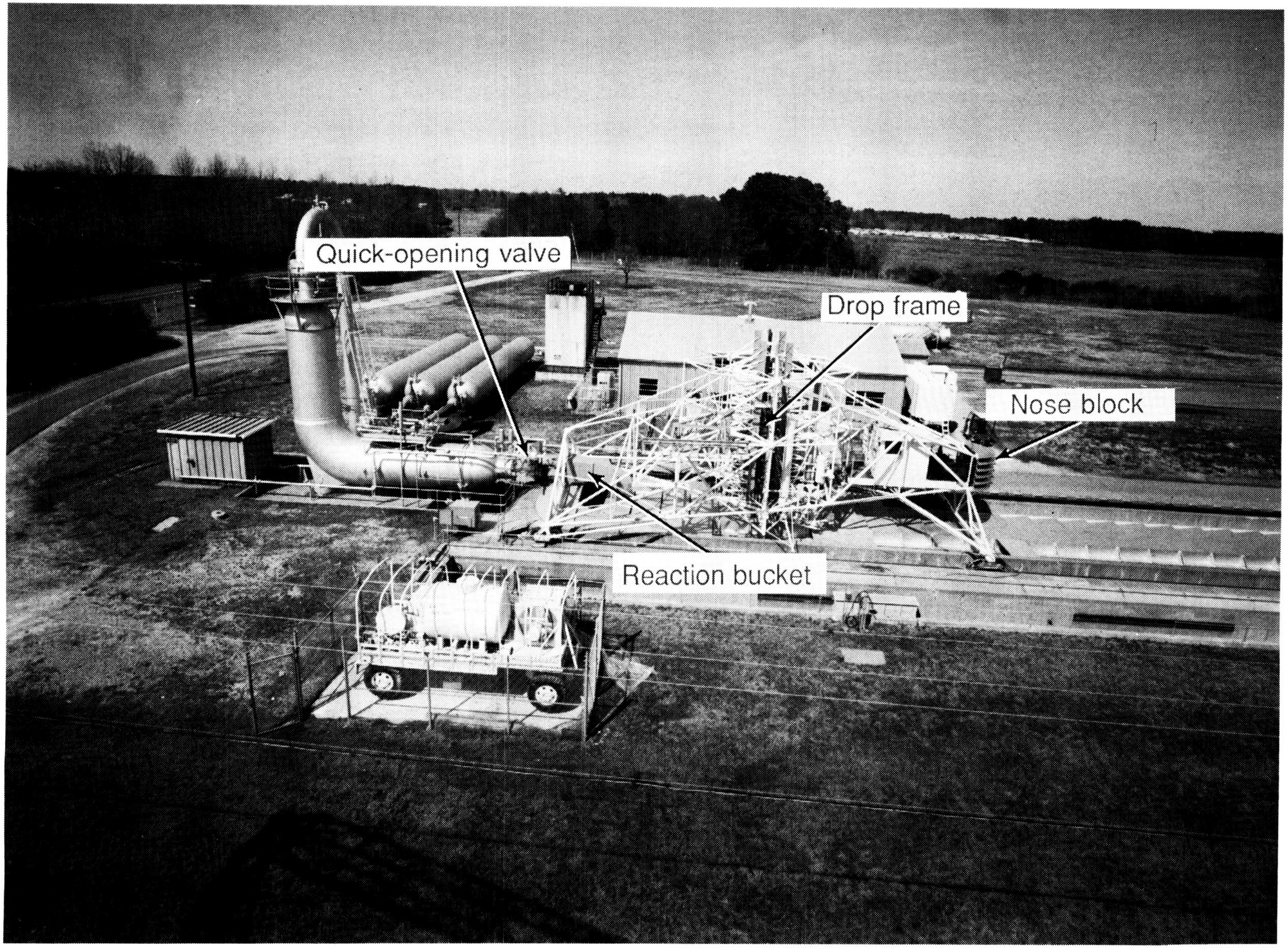

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Figure 2. Low-speed test carriage in launch position.

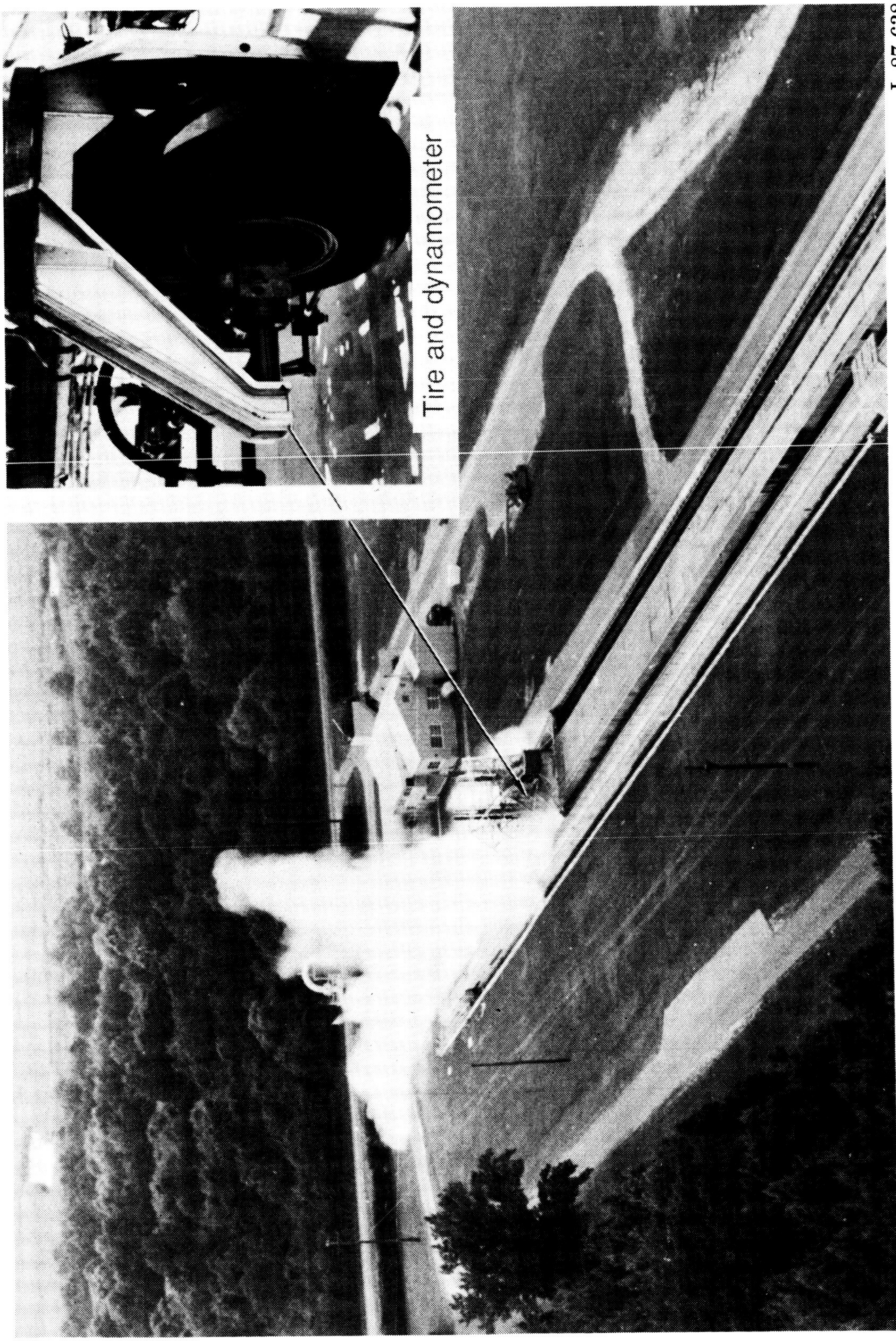

Figure 3. Typical run at Langley Landing Loads Track.

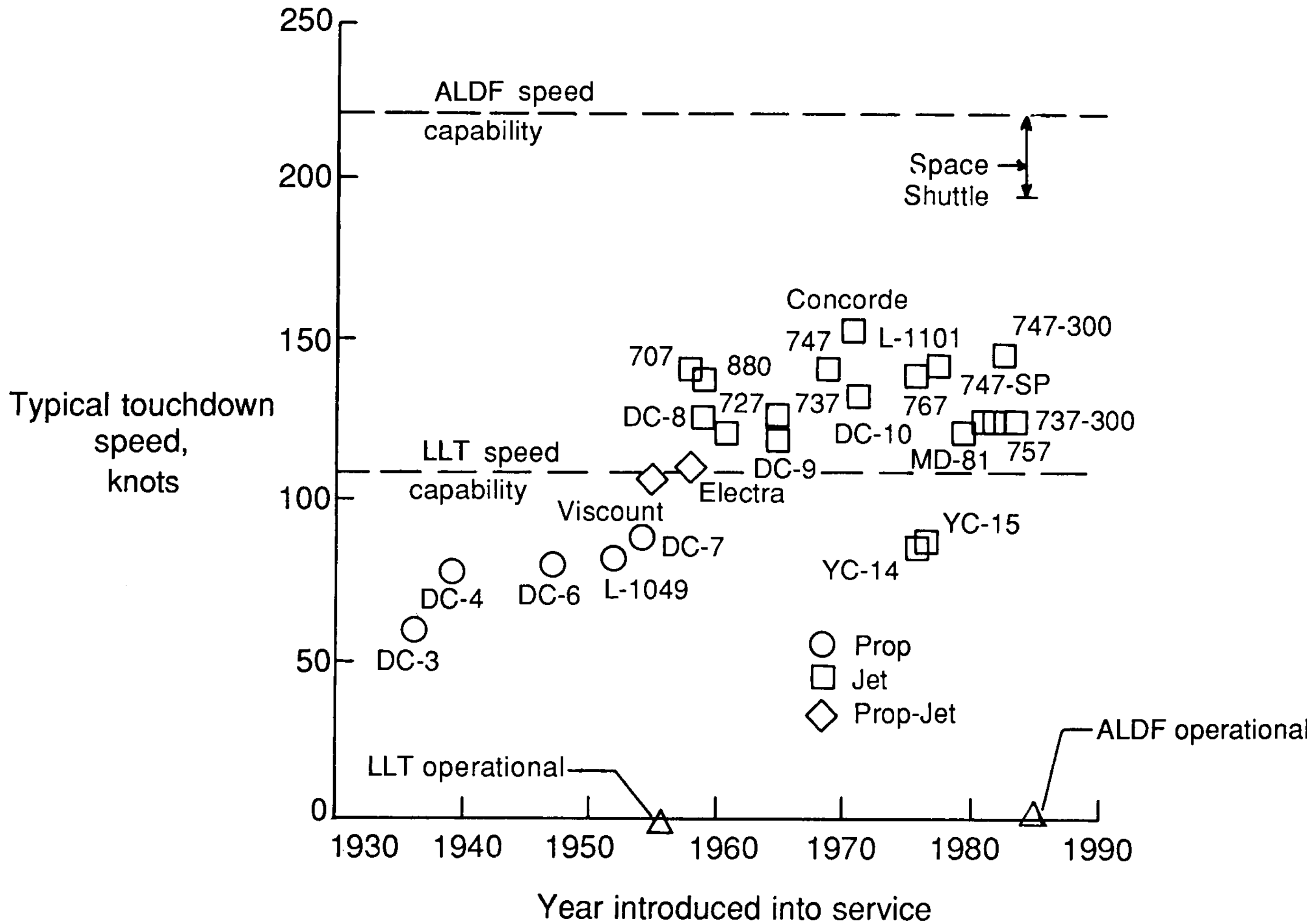

Figure 4. Touchdown speed chronology for commercial transports.

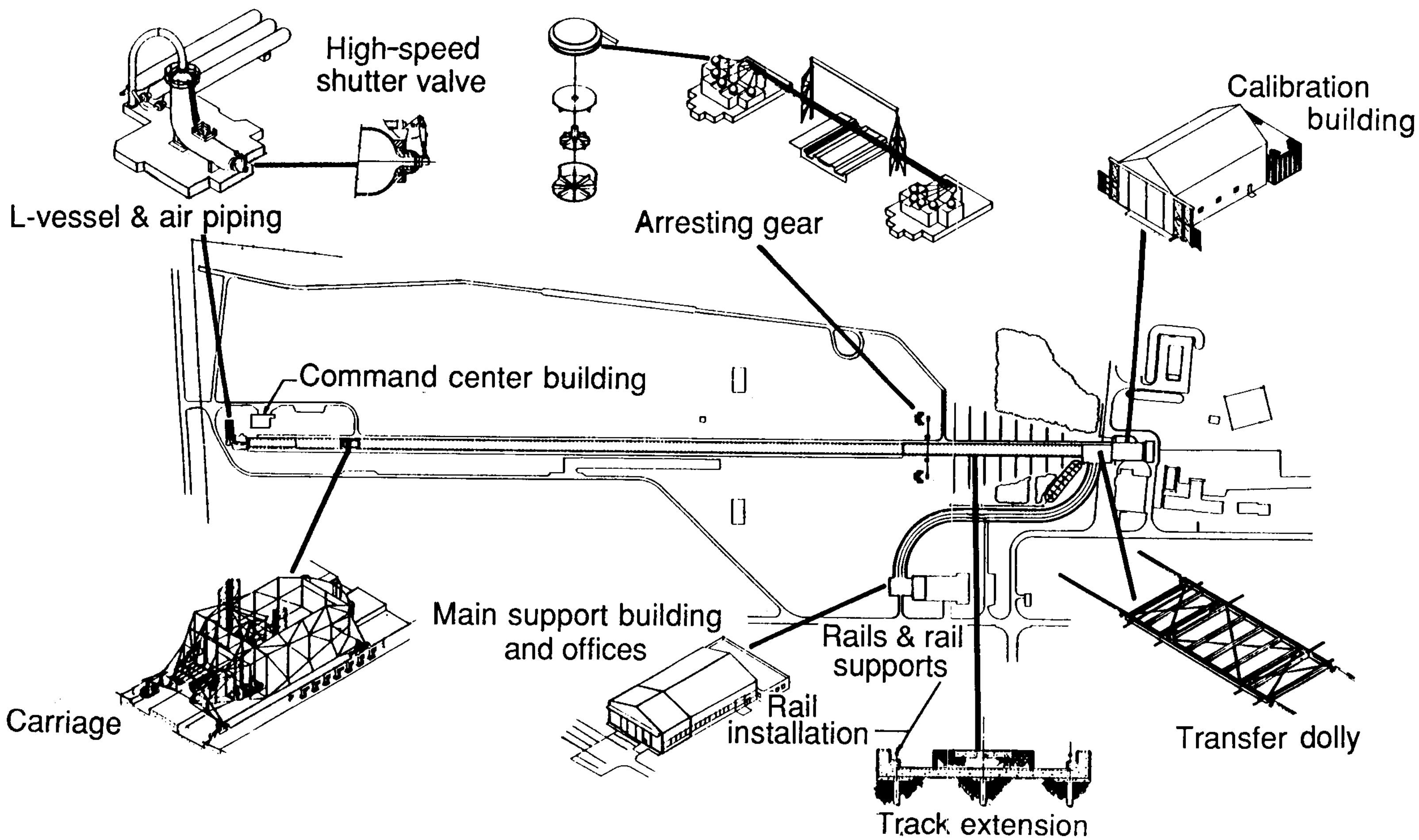

Figure 5. Extent of Langley Aircraft Landing Dynamics Facility upgrade.

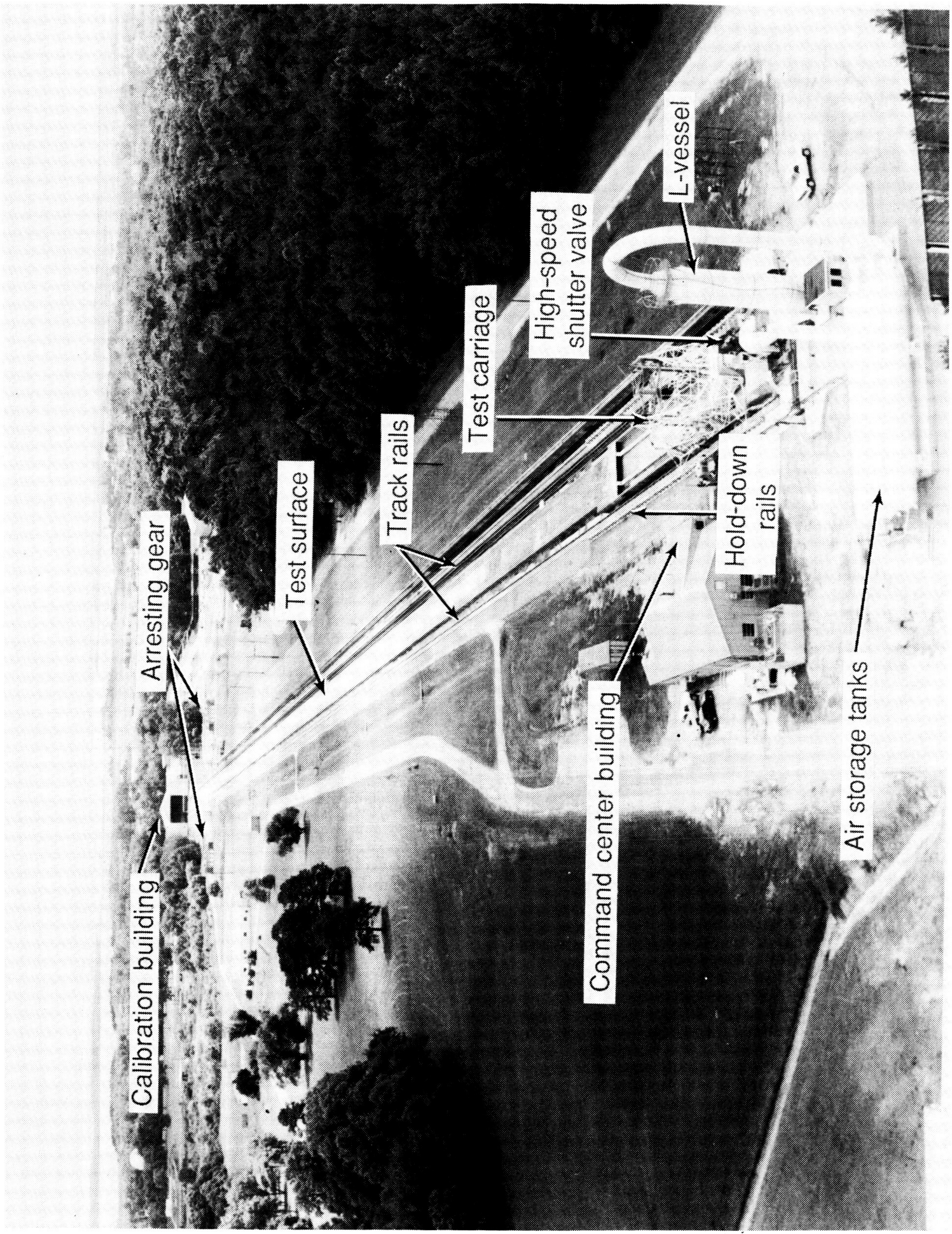

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Figure 6. Langley Aircraft Landing Dynamics Facility.

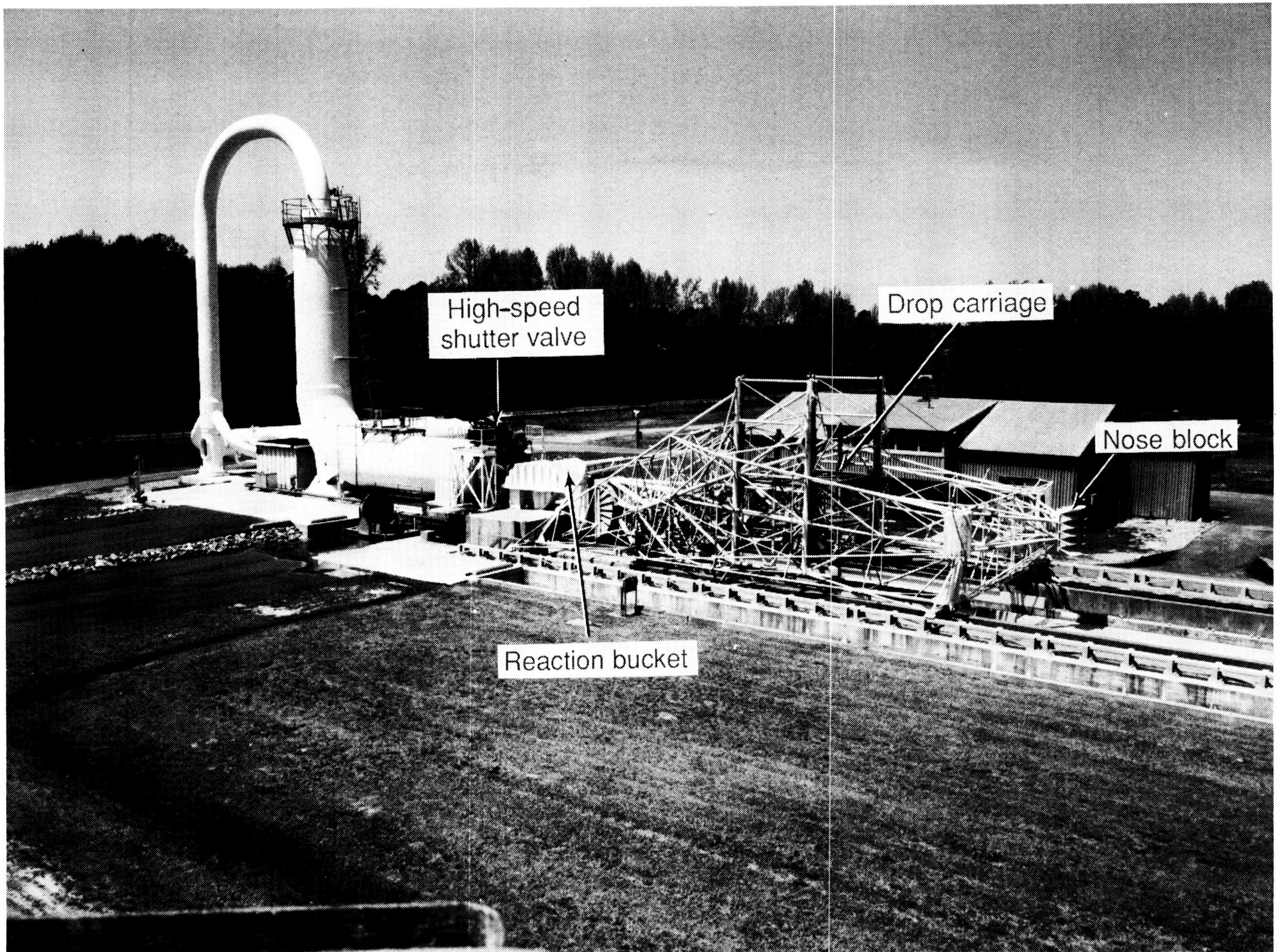

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Figure 7. High-speed test carriage in launch position.

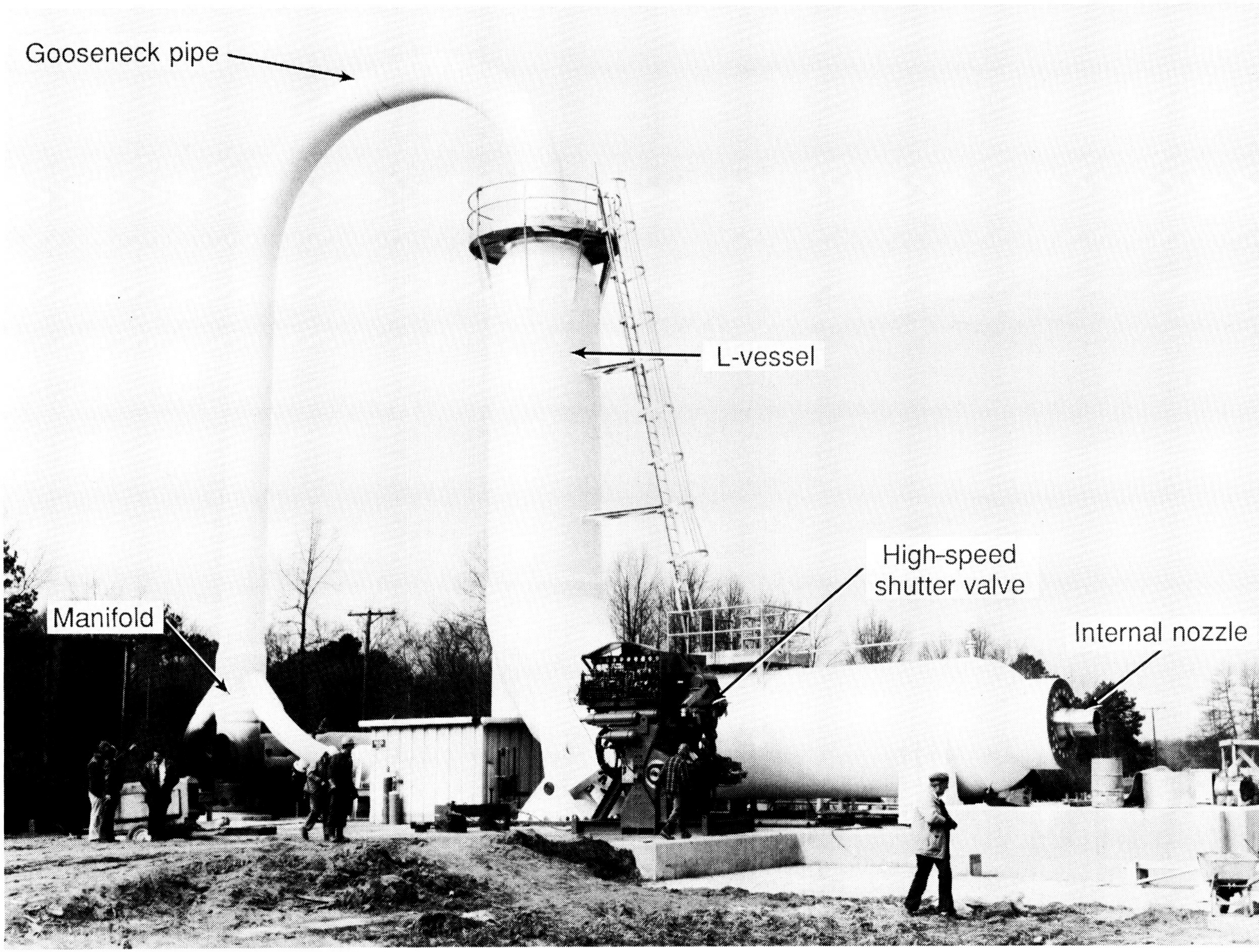

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Figure 8. Propulsion system components during construction.

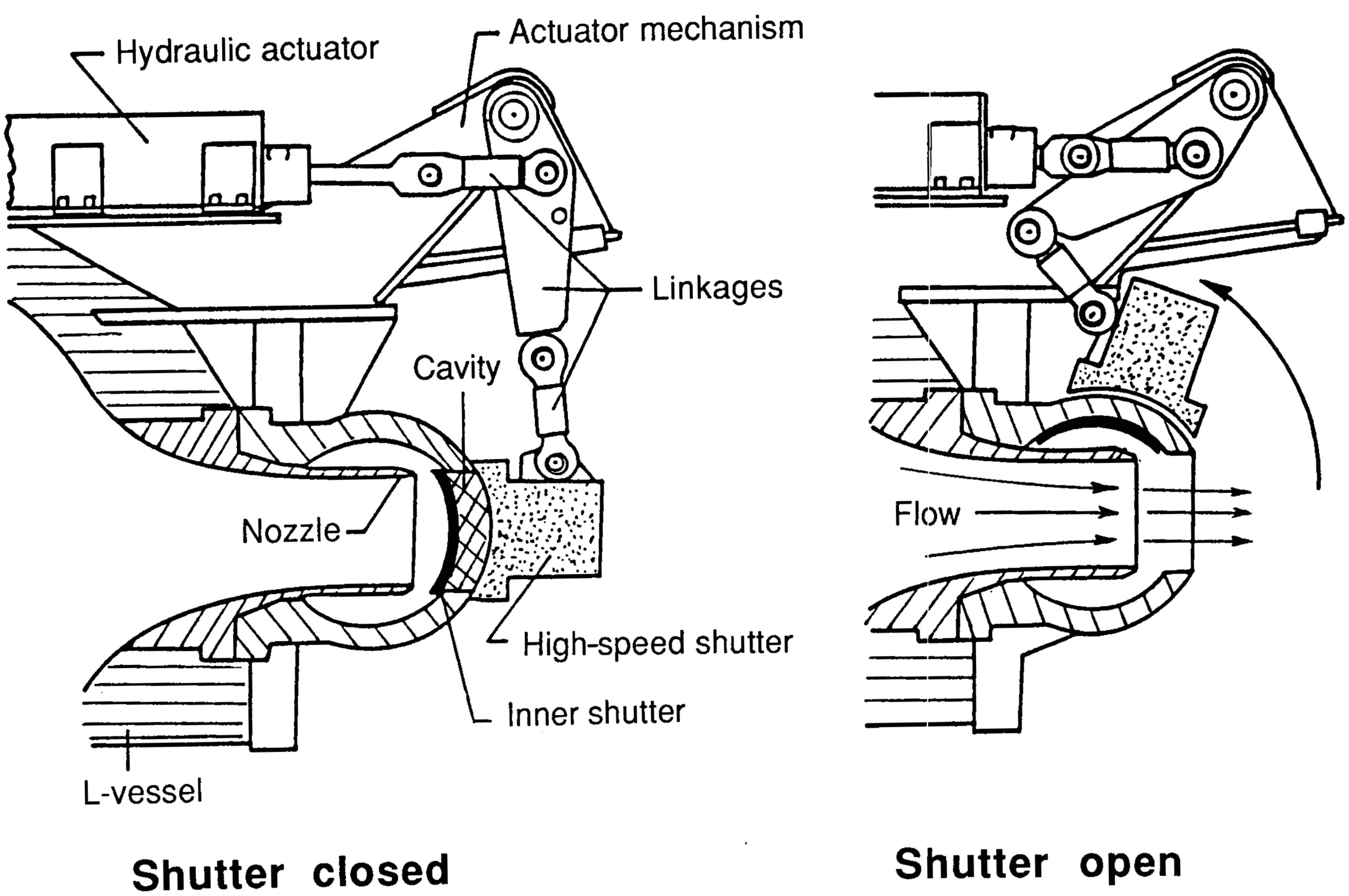

Figure 9. High-speed shutter valve schematic.

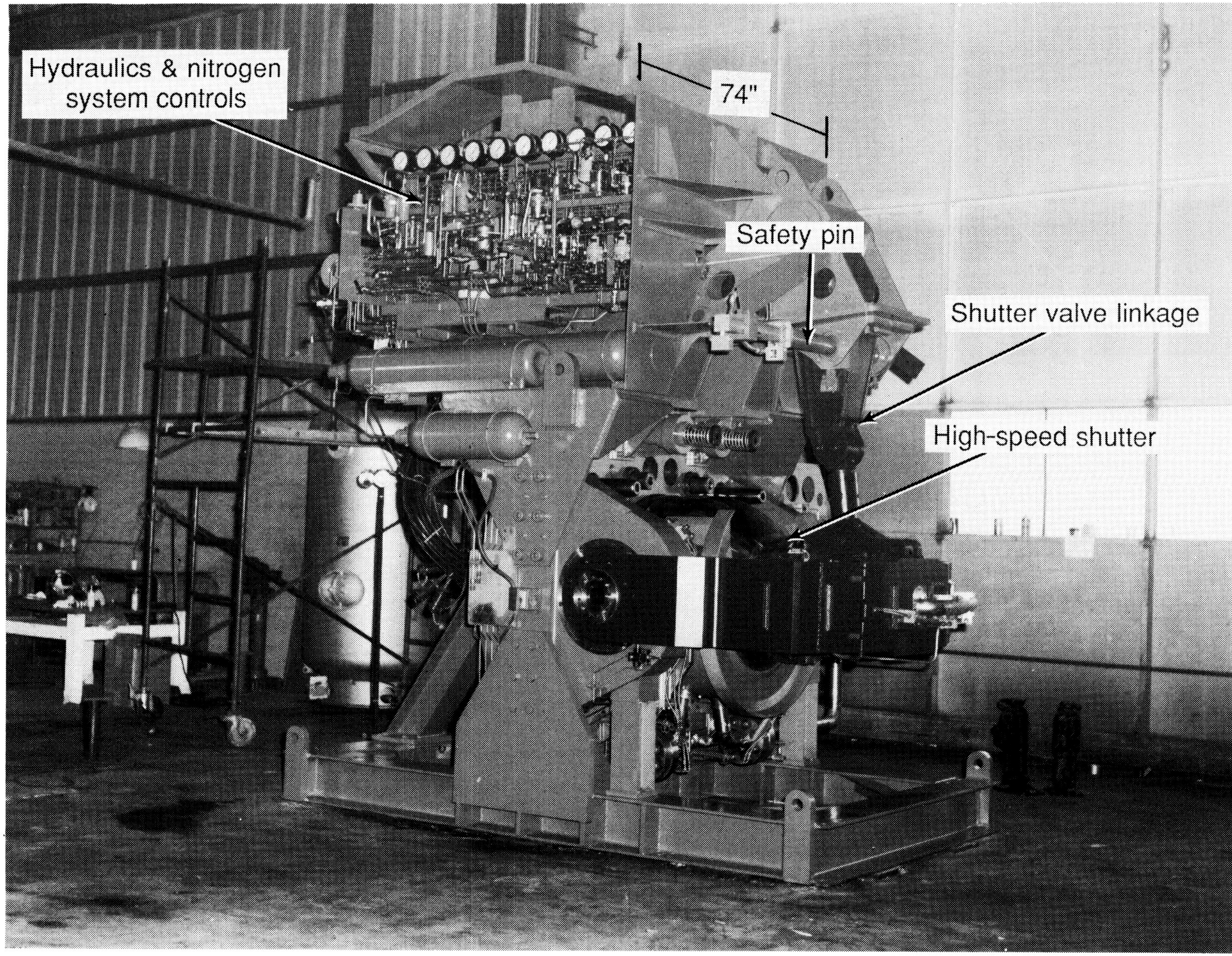

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Figure 10. High-speed shutter valve prior to mounting.

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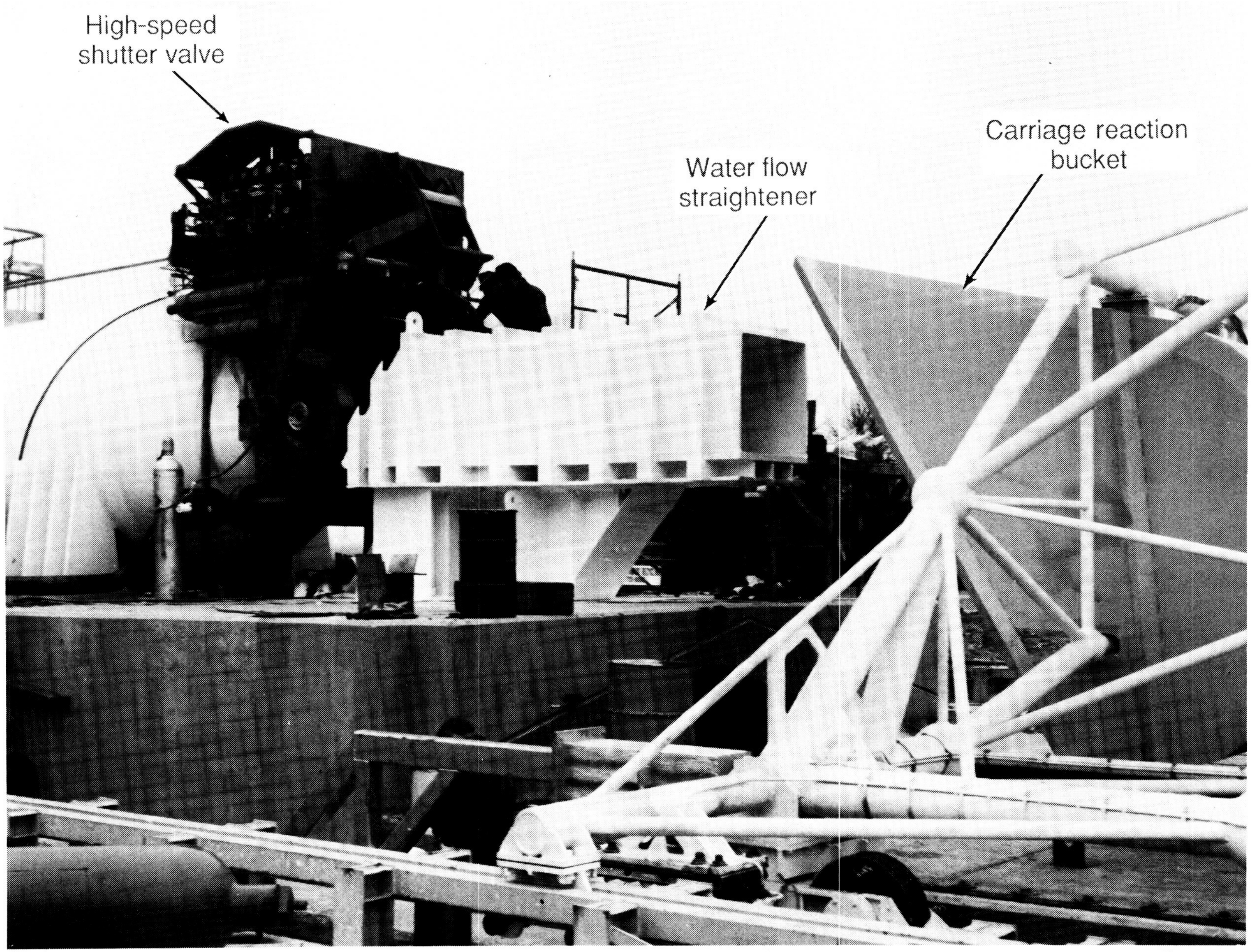

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Figure 11. Water flow straightener.

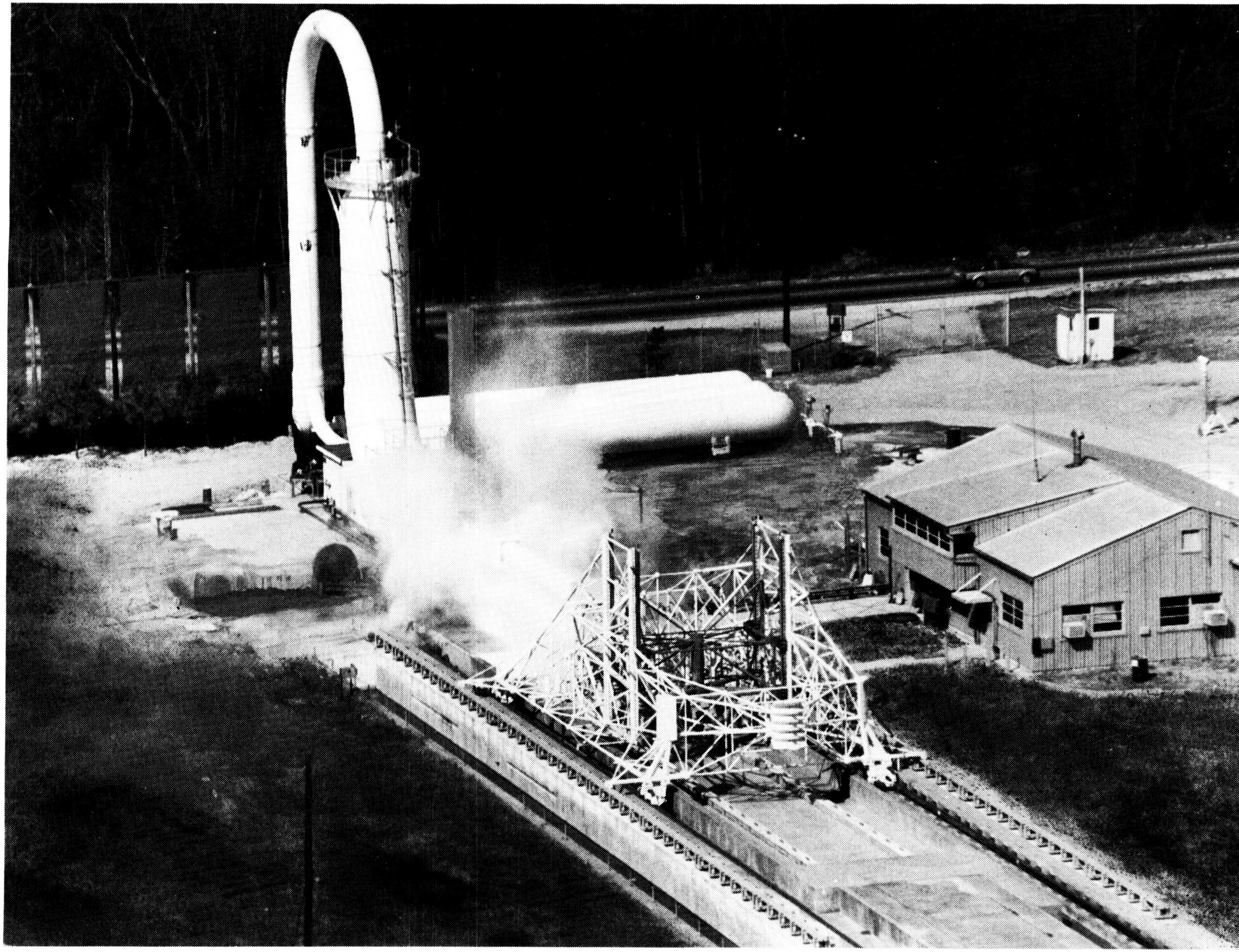

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Figure 12. Low-pressure catapult of carriage.

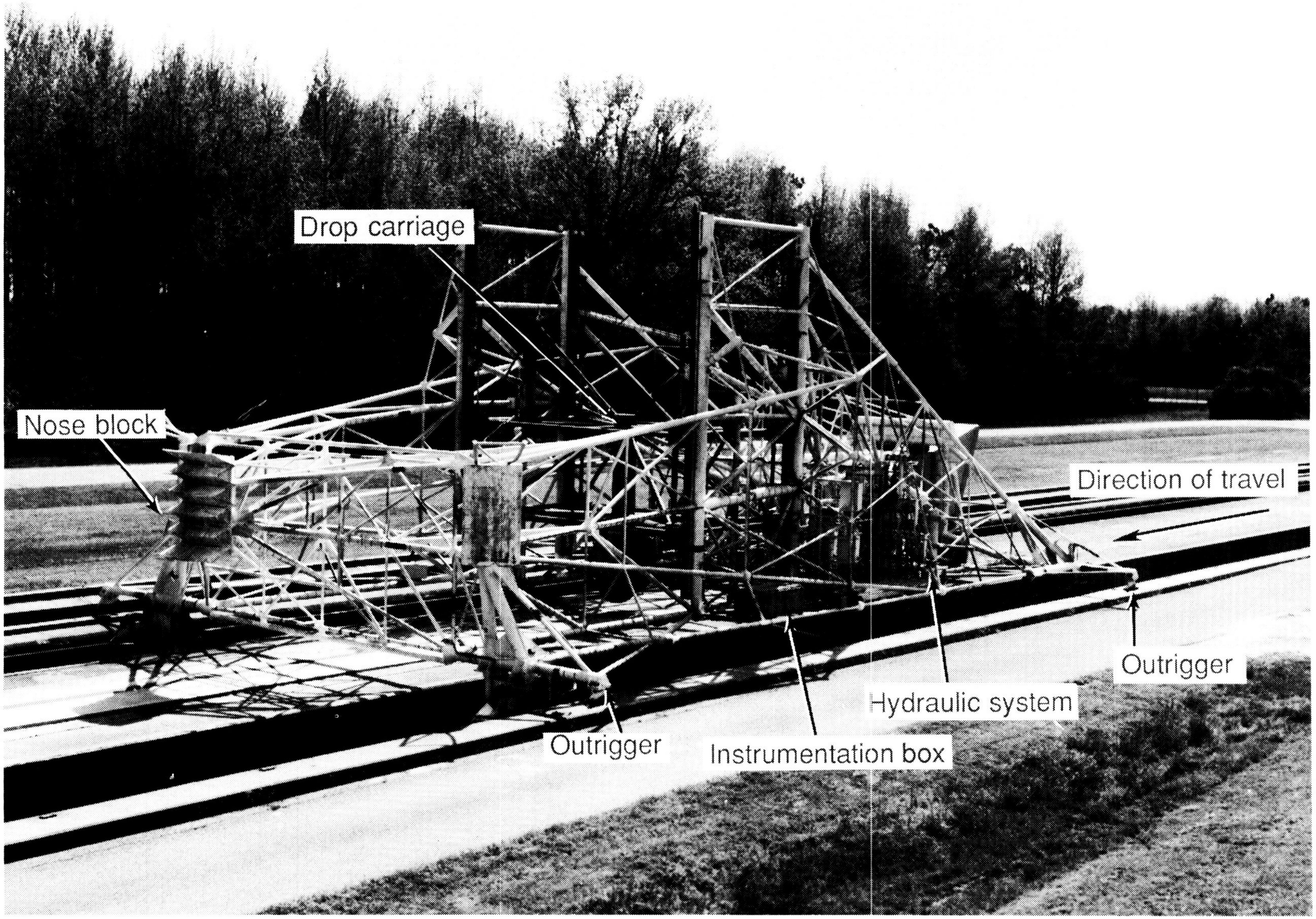

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Figure 13. High-speed test carriage.

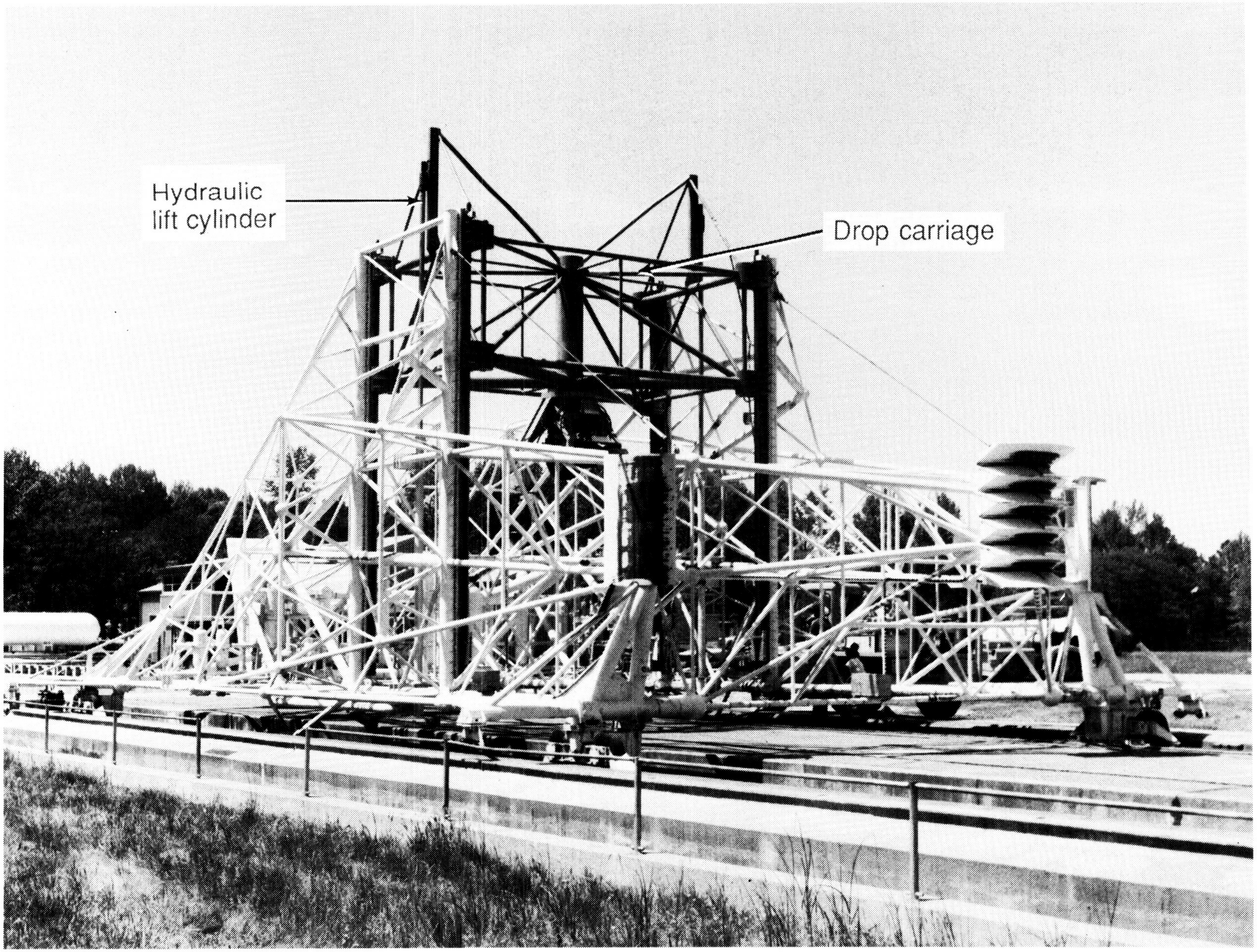

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Figure 14. High-speed test carriage with raised drop carriage.

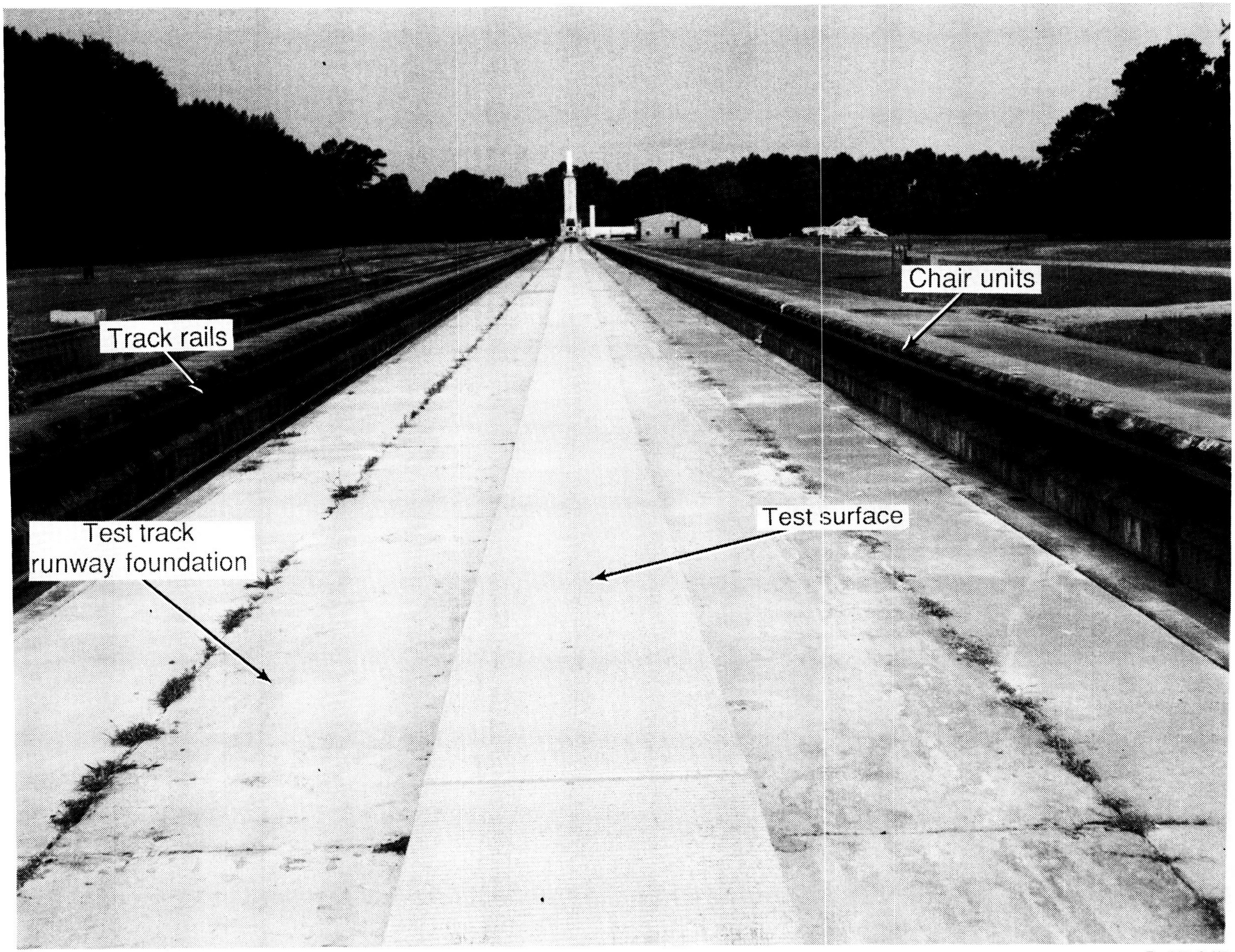

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Figure 15. Langley Aircraft Landing Dynamics Facility test section.

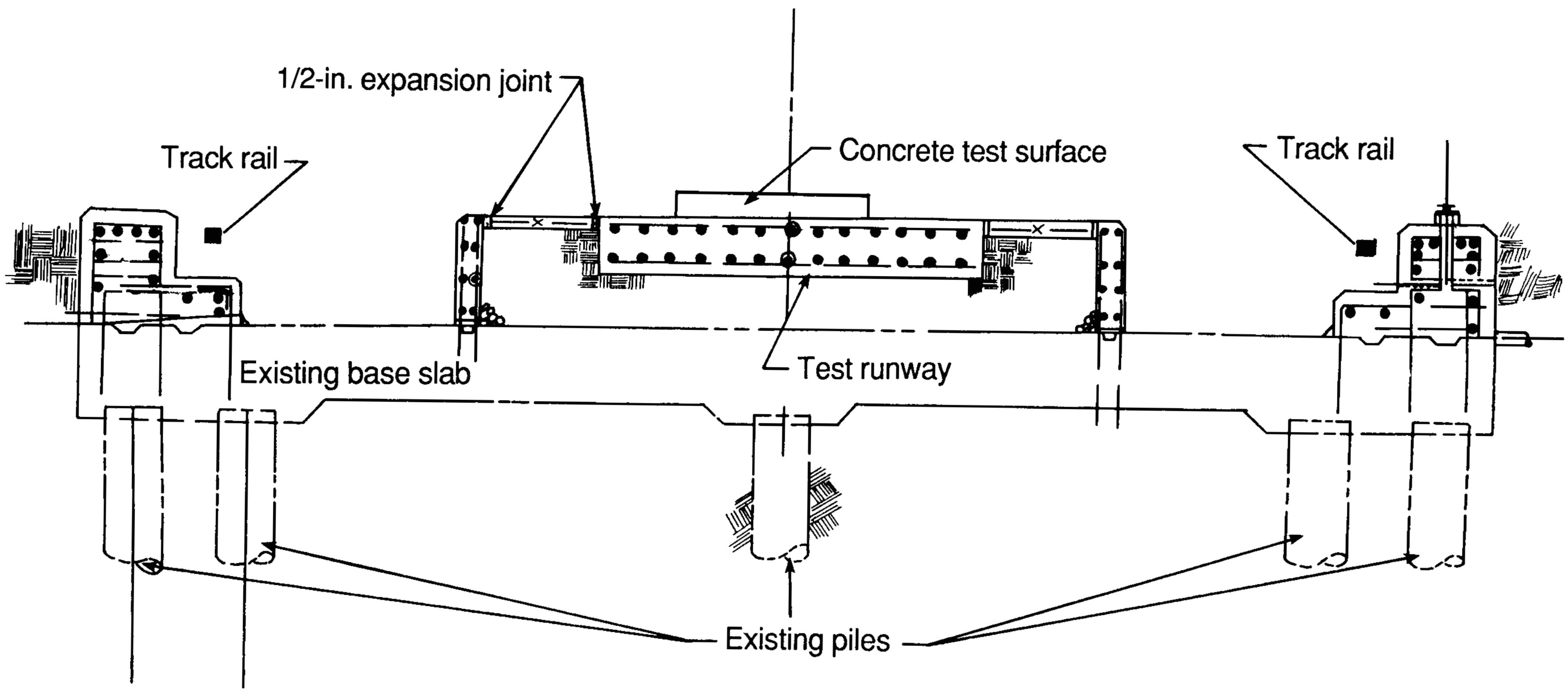

Figure 16. Cross-sectional schematic of track.

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Figure 17. Transfer dolly.

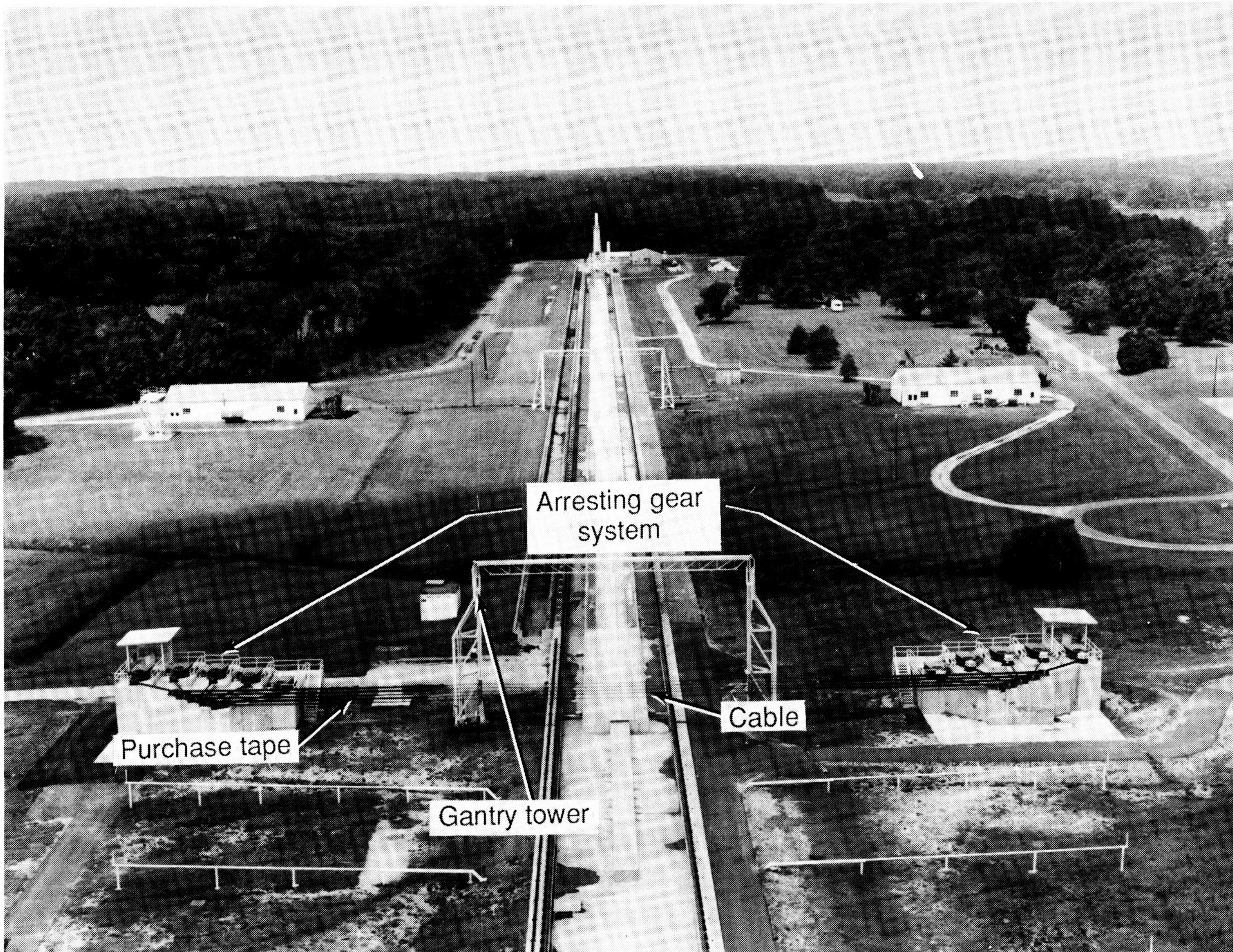

Figure 18. Carriage arrestment system.

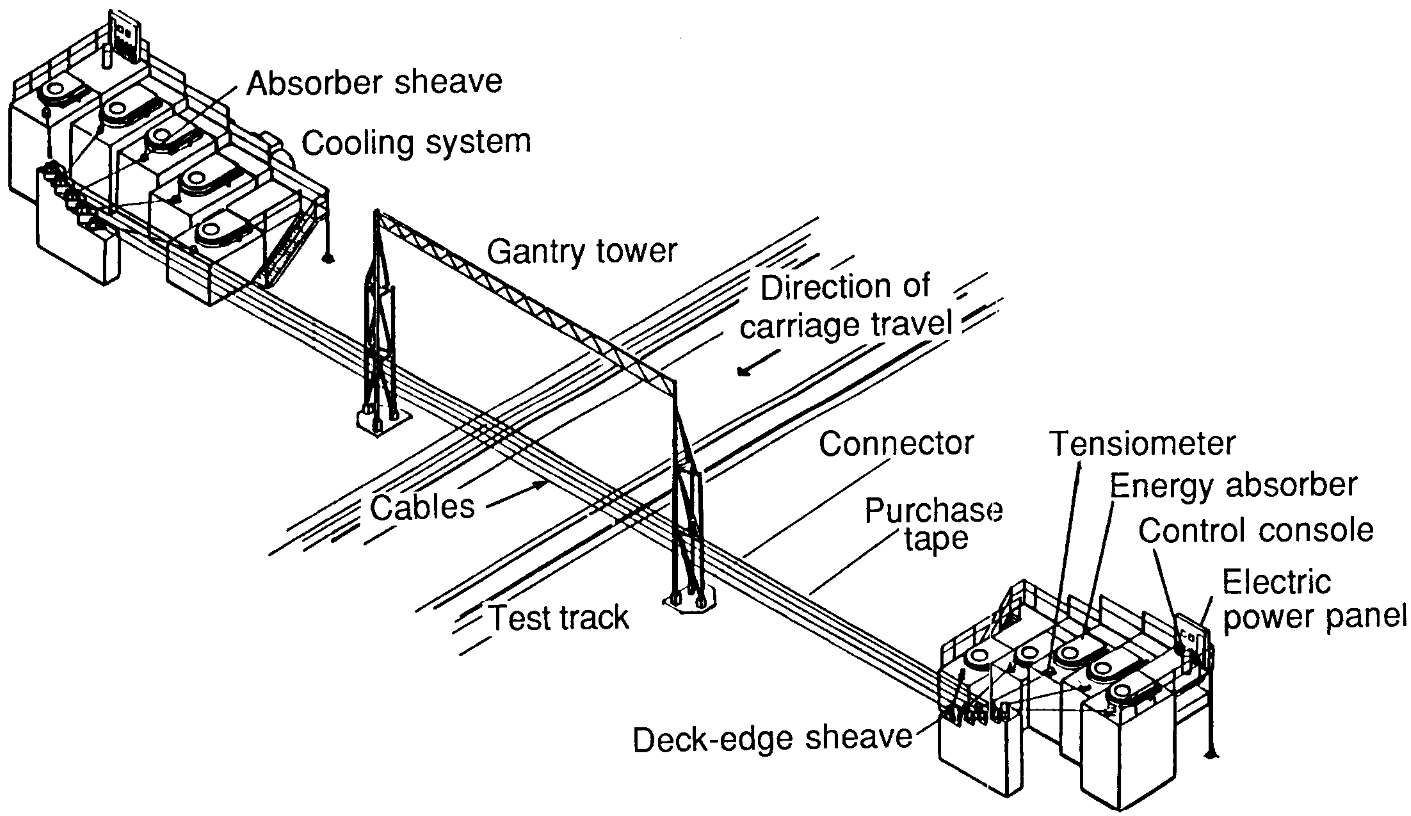

Figure 19. Schematic of carriage arrestment system.

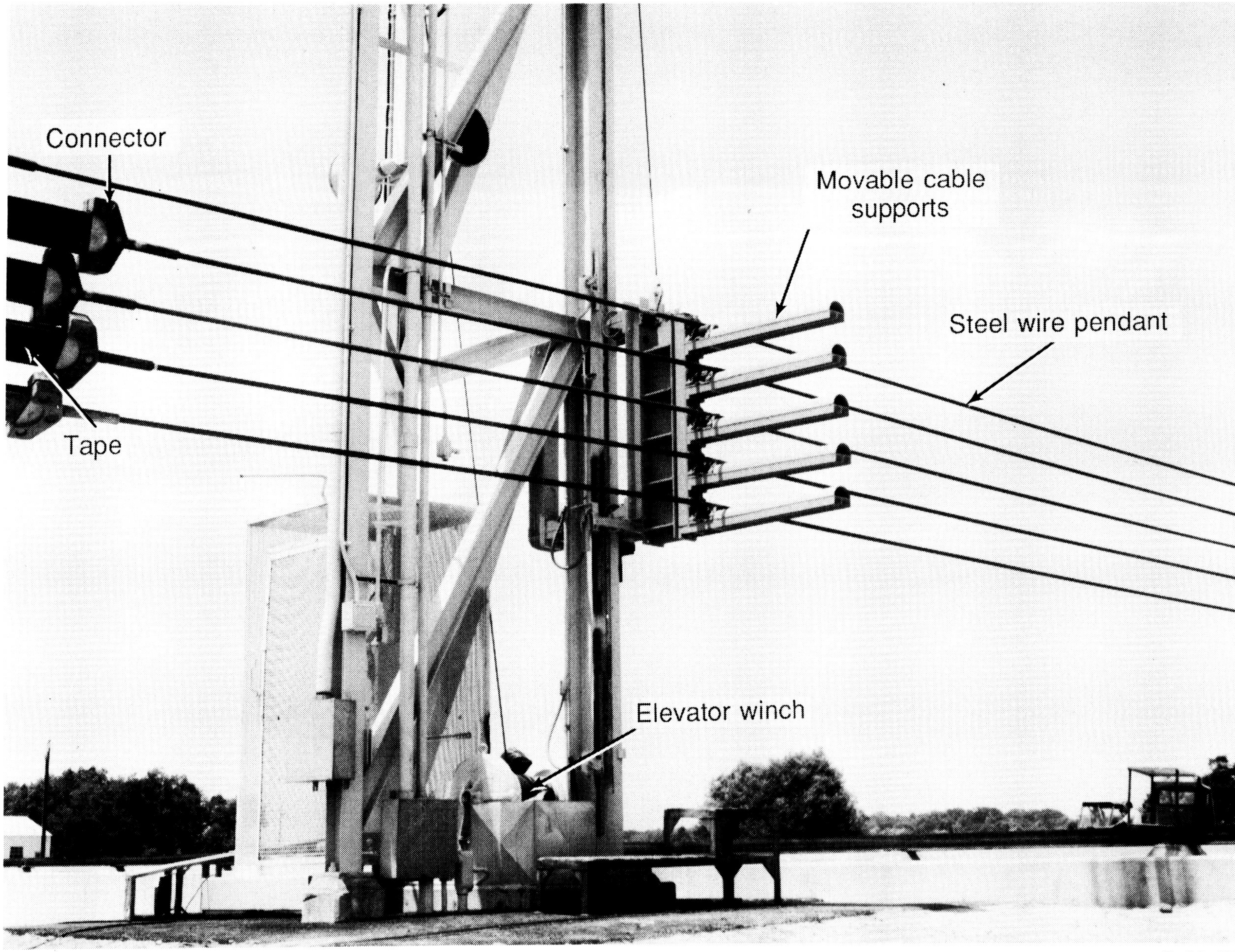

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Figure 20. Arresting gear cables.

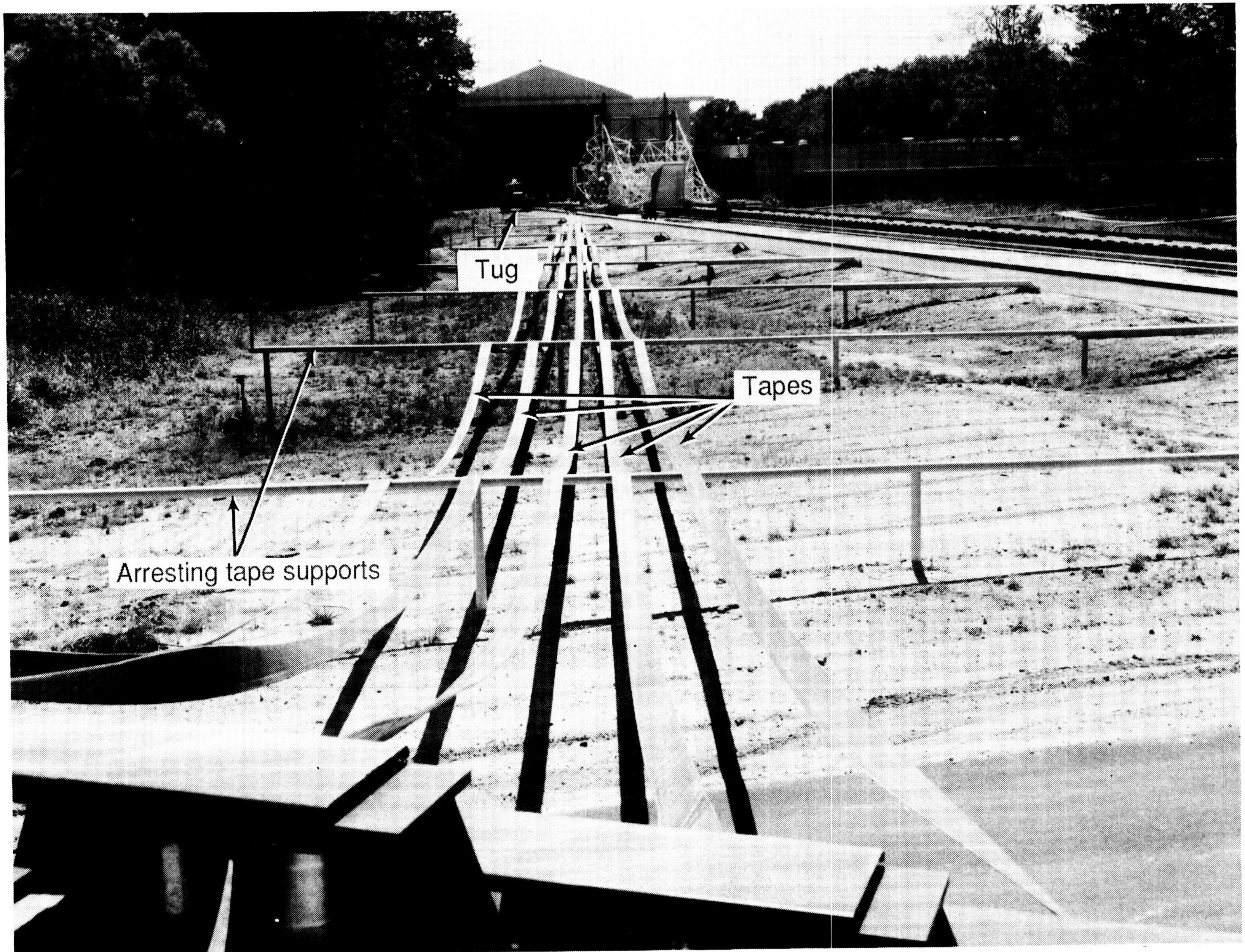

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Figure 21. Arresting gear tapes after deceleration.

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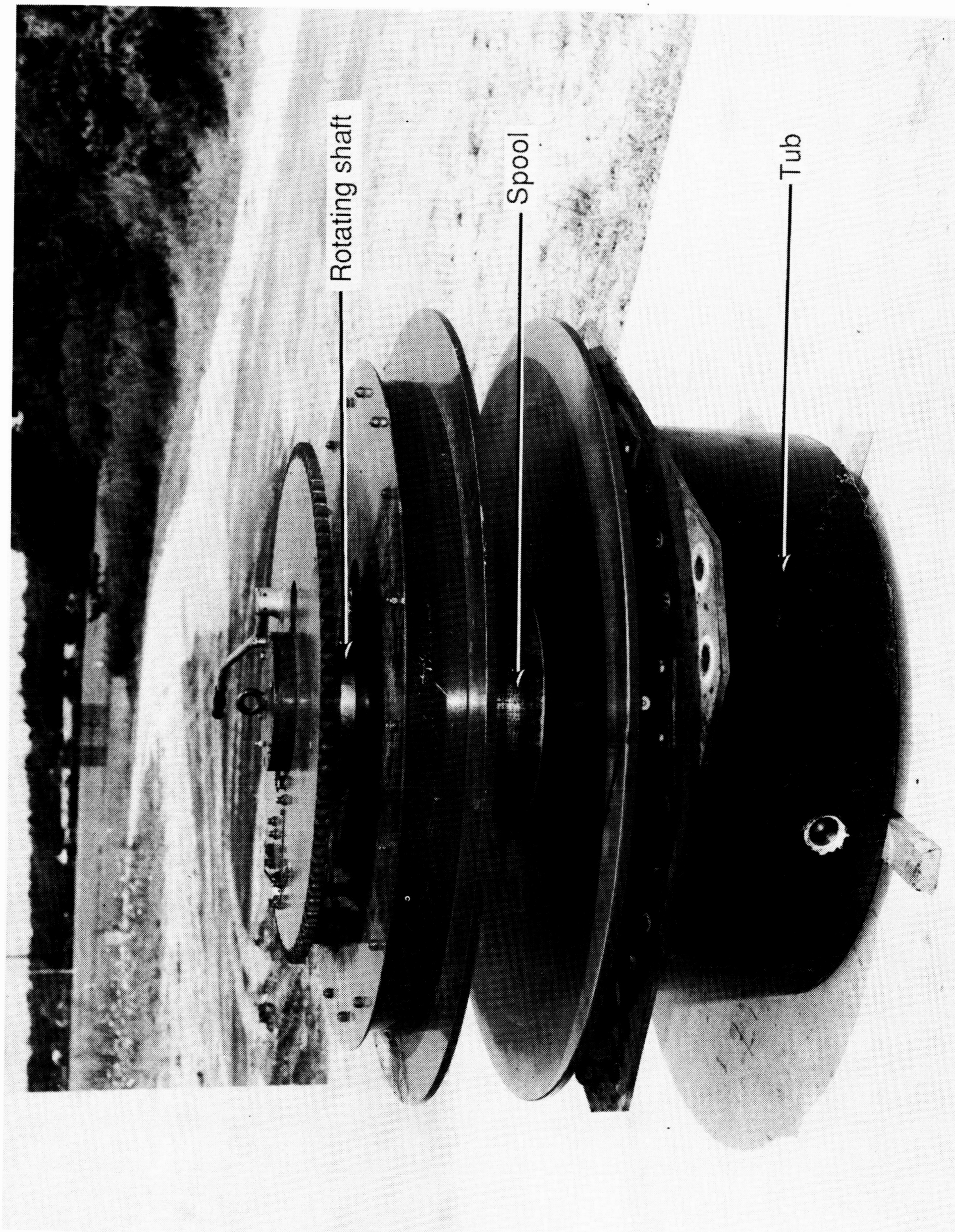

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Figure 22. Energy absorber before installation.

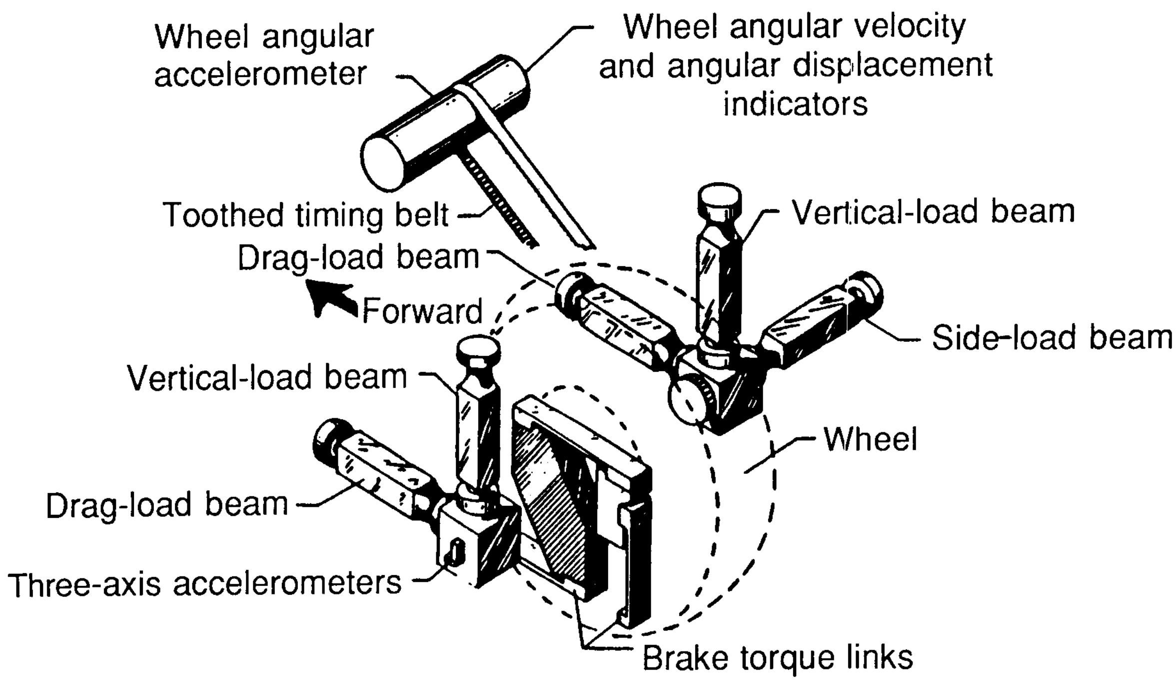

Figure 23. Dynamometer instrumentation schematic.

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15. Supplementary Notes

16. Abstract

The Langley Research Center has recently upgraded the Landing Loads Track (LLT) to improve the capability of low-cost testing of conventional and advanced landing gear systems. The unique feature of the Langley Aircraft Landing Dynamics Facility (ALDF) is the ability to test aircraft landing gear systems on actual runway surfaces at operational ground speeds and loading conditions. A historical overview of the original LLT is given, followed by a detailed description of the new ALDF systems and operational capabilities.

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