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ADVANCED STRUCTURES TECHNOLOGY AND AIRCRAFT SAFETY

Harvey G. McComb, Jr.

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Langley Research Center
Hampton, Virginia 23665

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INTRODUCTION

Advanced aeronautical structures technology at NASA encompasses research in the technology base and projects sponsored by the Aircraft Energy Efficiency (ACEE) Project Office. Base technology research includes mechanics of composite structures, crash dynamics, and landing dynamics. ACEE projects involve development and fabrication of selected composite structural components for existing commercial transport aircraft. The technology emanating from this research is intended to result in airframe structures with improved efficiency and safety.

BASE TECHNOLOGY

Mechanics of Composite Structures.- Aircraft structures fabricated from composite materials which incorporate graphite or Kevlar filaments embedded in an epoxy resin matrix can have substantially lower mass than equivalent metal structures. Saving of structural mass can lead to reduced fuel consumption or increased performance. NASA base technology programs in mechanics of composite structures are primarily focussed on advancing technology to introduce these structures into commercial transport aircraft. This work is illustrated in figure 1 and includes research on design technology, damage tolerance, behavior of structures with buckled skin (post buckling), and analytical methods (nonlinear analysis). It also includes research on fundamental processes of structural failure, fail-safe design, structural joints, improved matrix properties, fatigue and fracture, non-destructive evaluation, and effects of service environment. Because of the detailed configurations of laminated, filamentary composite structures, they exhibit failure modes which are unknown in metal structures. These failure modes must be identified and understood so that strength prediction analyses can be developed and validated. Examples of such failure modes are illustrated in figures 2 and 3. Recent results from this research are contained in reference 1.

Certain types of damage can severely reduce the load-carrying ability of these structures. For example, impact damage from runway debris can cause delamination or other internal damage, sometimes not detectable by visual examination, which can be very deleterious. Design concepts are needed which tolerate damage in the sense that the damage is contained within a local zone and damage propagation is limited. Research is in progress on fail-safe structures,

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that is, structural arrangements which incorporate sufficient redundancy to carry safe loads in the event of failure of selected structural elements. The objective of this effort is to provide technology to design structures which can function in damaged or partially failed conditions until a safe landing and possible repair can be accomplished.

Joints are critical features in composite structures because the materials can be seriously weakened by fastener holes and by localized load eccentricities that cause through-the-thickness tensile and shear stresses. Research is underway to understand factors that govern joint failures and to develop procedures to predict strengths and fatigue lives of bolted and bonded joints.

Research is also underway to find resins with improved toughness, moisture resistance, and processability. Research on fatigue of thick-section composite structures is underway along with in-depth studies of fracture and crack growth processes. Ultrasonic methods of non-destructive evaluation are studied theoretically and experimentally to gain understanding of their use for quantitative analysis of properties and integrity of composites. Research is underway to determine long-time durability of composites under expected service environment. Finally, analyses to describe nonlinear behavior of these structures are being developed to include buckled skin behavior and ultimate strength behavior.

Crash Dynamics.- Research on crash dynamics of general aviation aircraft has been underway at Langley Research Center since 1973. A total of 32 full-scale crash tests have been performed on various types of general aviation aircraft and military helicopters. In this program a data base of crash pulses and appropriate analysis has been developed to provide representative crash dynamic loadings for use in design of airframe structure as well as floor, seat, and occupant restraint system structure. In addition, load-limiting subfloor structural concepts and seat concepts have been developed which can reduce dynamic loads to occupants in crash situations by as much as 50 percent. This work is illustrated in figure 4, and results on crash pulses are contained in reference 2.

The general aviation crash dynamics program is phasing out, and attention is now being focussed on crash dynamics of transport aircraft. In cooperation with the Federal Aviation Administration (FAA) a full-scale remotely-piloted air-to-ground crash test is planned using a Boeing 720 transport aircraft. The purposes of this test are to evaluate a fuel antimisting agent to prevent fuel fires in crashes and to acquire fundamental crash response data from airframe, seat and restraint systems, and occupant dummies. The airframe data is expected to provide a metallic baseline for future research on crash dynamics of composite structures. A research program on crash dynamics of composite structures is being implemented. The approach is very fundamental and includes systematic tests and analyses of structural elements and components. Initial tests of abrasion of aluminum and composite elements are in progress.

Landing Dynamics.- The purpose of landing dynamics research is to provide technology for safe, economical all-weather aircraft ground operations. The scope of the effort is illustrated in figure 5 and includes investigation of tire mechanics and tire properties, operational problems such as runway traction and steering response, data and software for ground handling simulation, and new landing systems including actively-controlled landing gear and air-cushion landing gear. In addition, research is conducted on dynamics of brakes and anti-skid systems and definition of landing hazards such as low altitude turbulence, runway slipperiness, and tire blowouts.

New emphasis is being placed on tire mechanics. Fundamental experiments are planned to measure tire mechanical properties and to develop tire mathematical modeling and analysis technology. An actively-controlled landing gear can reduce fatigue damage and improve ride quality in ground operations. The concept may be applicable to large, flexible aircraft or to fighter aircraft which must negotiate bomb-damaged and repaired runways. Development of such a gear has reached the point where a flight or taxi test is needed to validate the concept. The Aircraft Landing Dynamics Facility at Langley (fig. 6) is being upgraded to increase speed capability from 110 knots to 220 knots and to increase the size of landing gear which can be tested.

AIRCRAFT ENERGY EFFICIENCY PROJECT OFFICE

Projects sponsored by the ACEE Project Office involve development of selected structural components for existing commercial transport aircraft. The transport manufacturers redesign the components with composite material, fabricate several articles and perform comprehensive ground qualification tests, and in some cases place composite structural components into airline service. The objective of this program is indicated on figure 7 along with aspects of technology and confidence being addressed.

The approach is to start with secondary structural components, that is, components not critical to safety of flight. Subsequently, so-called medium primary structure is addressed, that is, components such as empennage fins and stabilizers. Finally, large primary fuselage and wing components are to be addressed. The secondary component programs are complete, and selected articles are in flight service on commercial airliners (see fig. 8). The articles include rudders on Douglas DC-10 aircraft, ailerons on Lockheed L-1011 aircraft, and elevators on Boeing 727 aircraft. The medium primary component programs have passed through development, design, and fabrication phases and have completed all ground qualification tests. The large primary component programs are just getting underway in study contracts with the transport manufacturers.

The medium primary structural component programs sponsored by the ACEE Project Office are illustrated in figure 9 and encompass the vertical stabilizer for the Douglas DC-10, the vertical fin for the Lockheed L-1011, and the horizontal stabilizer for the Boeing 737. A principal element in the program for each component is an extensive ground test series on full size structure. The programs for two components, the 737 horizontal stabilizer and the DC-10 vertical fin, include ground tests and flight checkout for FAA certification. Following certification the manufacturers are expected to place the components in airline flight service. The ground test series for these components, therefore, are essential steps in verifying compliance with FAA certification requirements. The composite components ranged from 22 to 28 percent lower in mass than the comparable aluminum components. A 25 percent reduction in structural mass for the total airplane is expected to correspond to reduction in fuel consumption of 12 to 15 percent. The ground test experience from these medium primary components was very illuminating. In all three cases initial ground testing resulted in structural failure at less than ultimate design load. Subsequent investigation and analysis of each failure revealed significant lessons for effective use of composites in large transport structures. First, composite structures do not yield like metal structures. As a result, diffusion of local loads is difficult to accomplish. Second, eccentricities, irregular shapes, stiffness changes, and discontinutities in structural configuration can cause through-the-thickness tension and shear. Composite structures are particularly susceptible to failure under these interlaminar stress conditions. Sources, magnitudes, and effects of such secondary stresses need to be thoroughly understood and accounted for to arrive at safe designs. Design modifications have been made on all three structural components, and all ground tests have now been successfully completed. Additional detail on these programs is contained in reference 3.

CONCLUDING REMARKS

Research in composite structures, crash dynamics, and landing dynamics is producing technology for improved aeronautical structures. Safety-related research in progress on filamentary composite structures includes understanding failure modes, bonded and bolted joints, non-destructive evaluation, and environmental effects. Crash dynamics research has produced crash pulse data, structural concepts, and seat concepts which can increase occupant survivability in general aviation aircraft crashes. Landing dynamics research on tire mechanics, runway traction, tire blowouts, low altitude turbulence, and actively-controlled gear can lead to improved safety.

Transport manufacturers are challenged to develop composite components and certify selected articles for flight with comprehensive ground test programs. Through this process the manufacturers are validating the reduced mass and cost benefits possible with these new structures and gaining valuable experience in design, fabrication, and certification of safe, efficient advanced structure for commercial transports. It is expected that the high standards of safety transport structures have exhibited in the past will be maintained by application of sound structural engineering in terms of thorough developmental and qualification testing coupled with application of advanced analysis technology.

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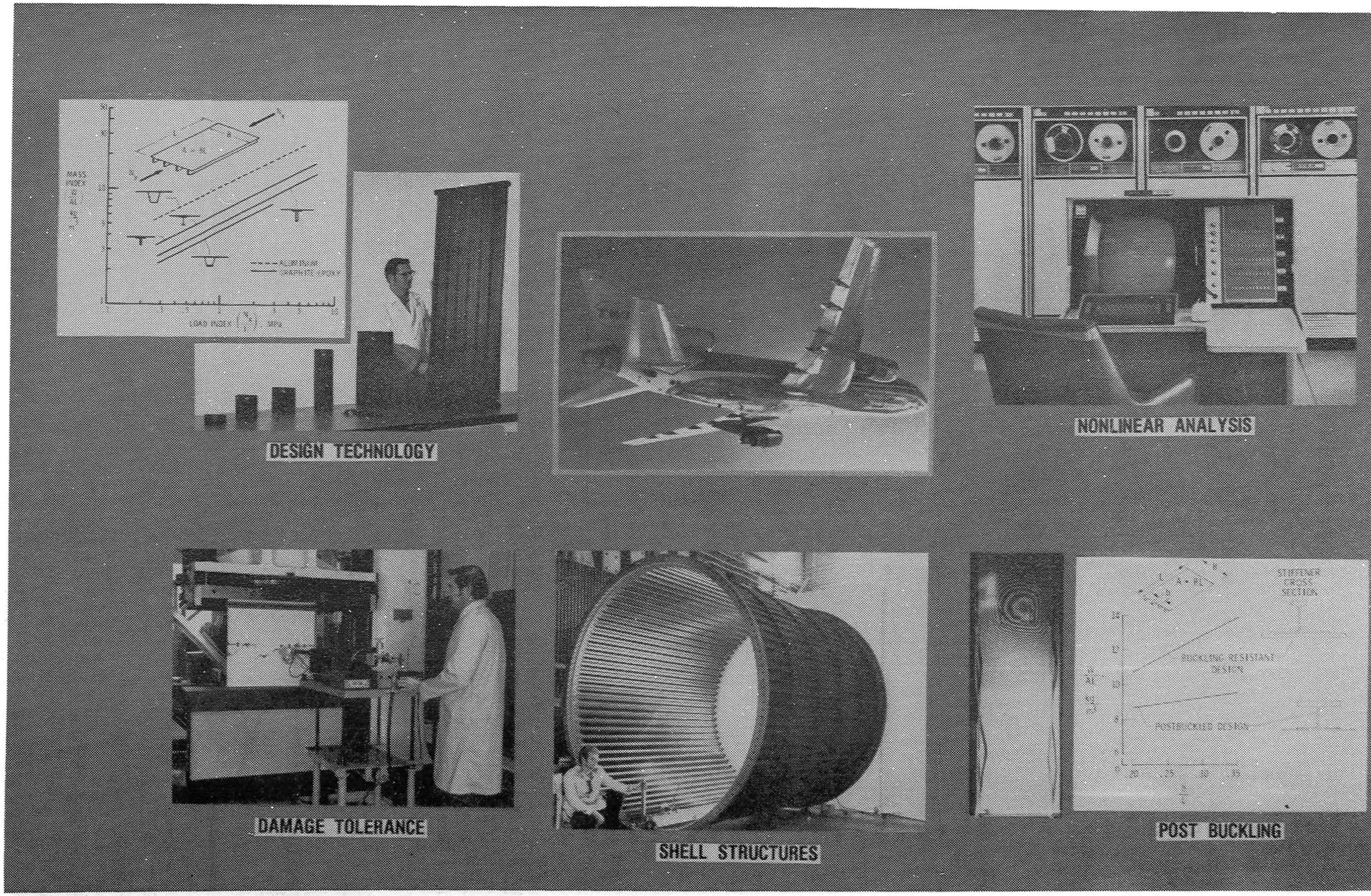

Figure 1. Research on mechanics of composite structures.

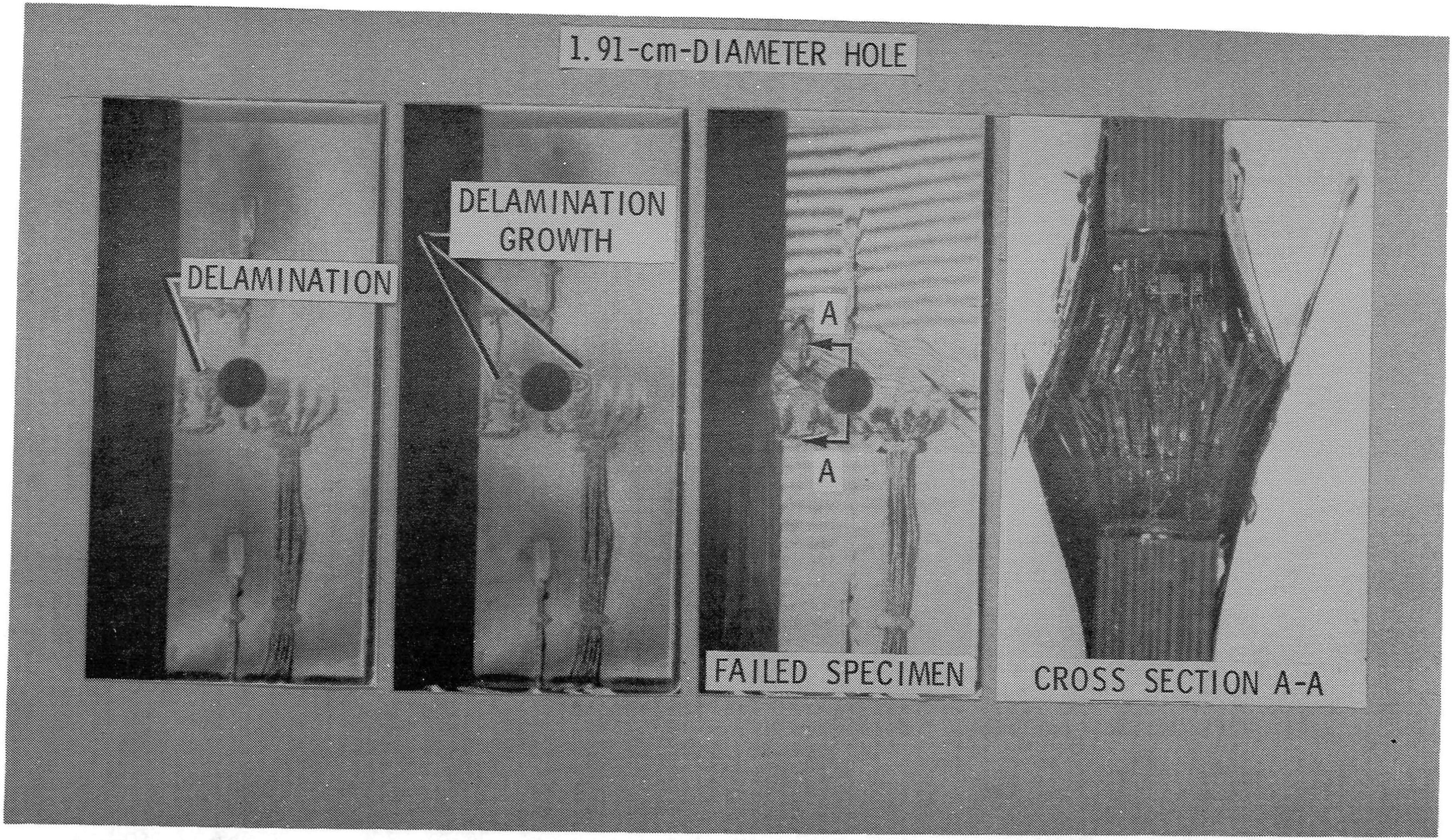

Figure 2. Local delamination failure mode in a 48-ply composite plate under in-plane compression load.

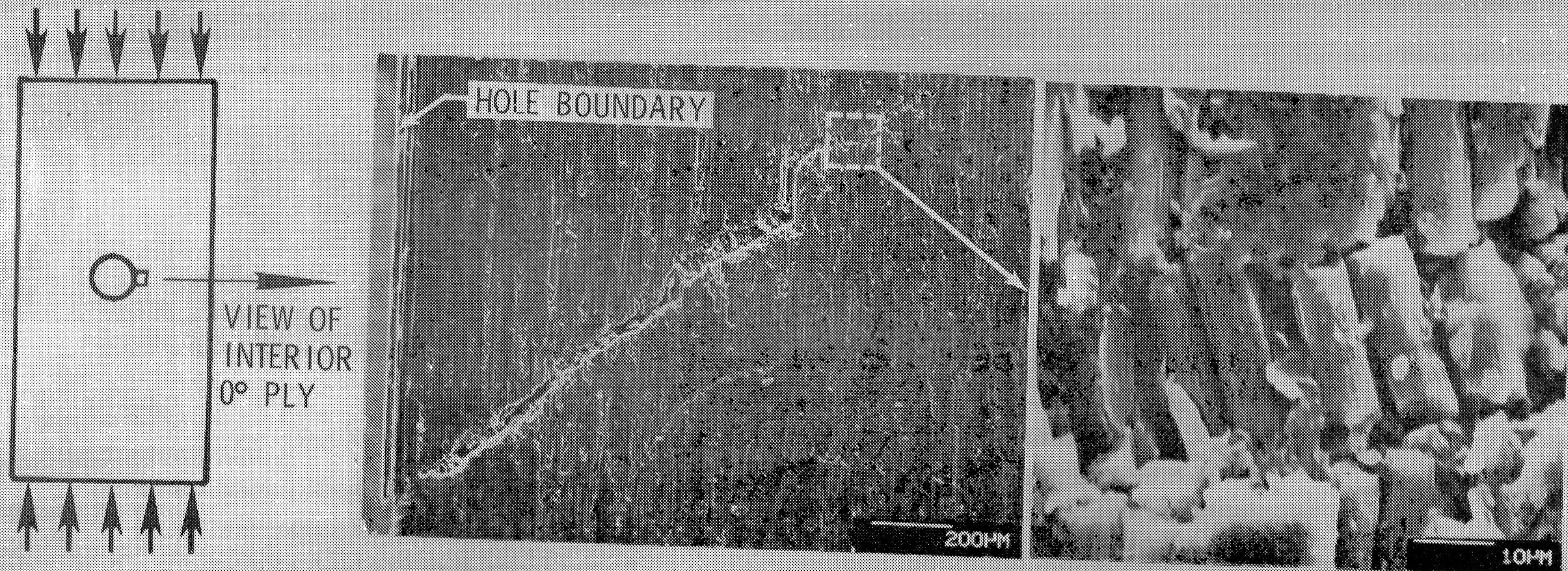

Figure 3. Shear crippling failure mode in a composite plate under in-plane compression load.

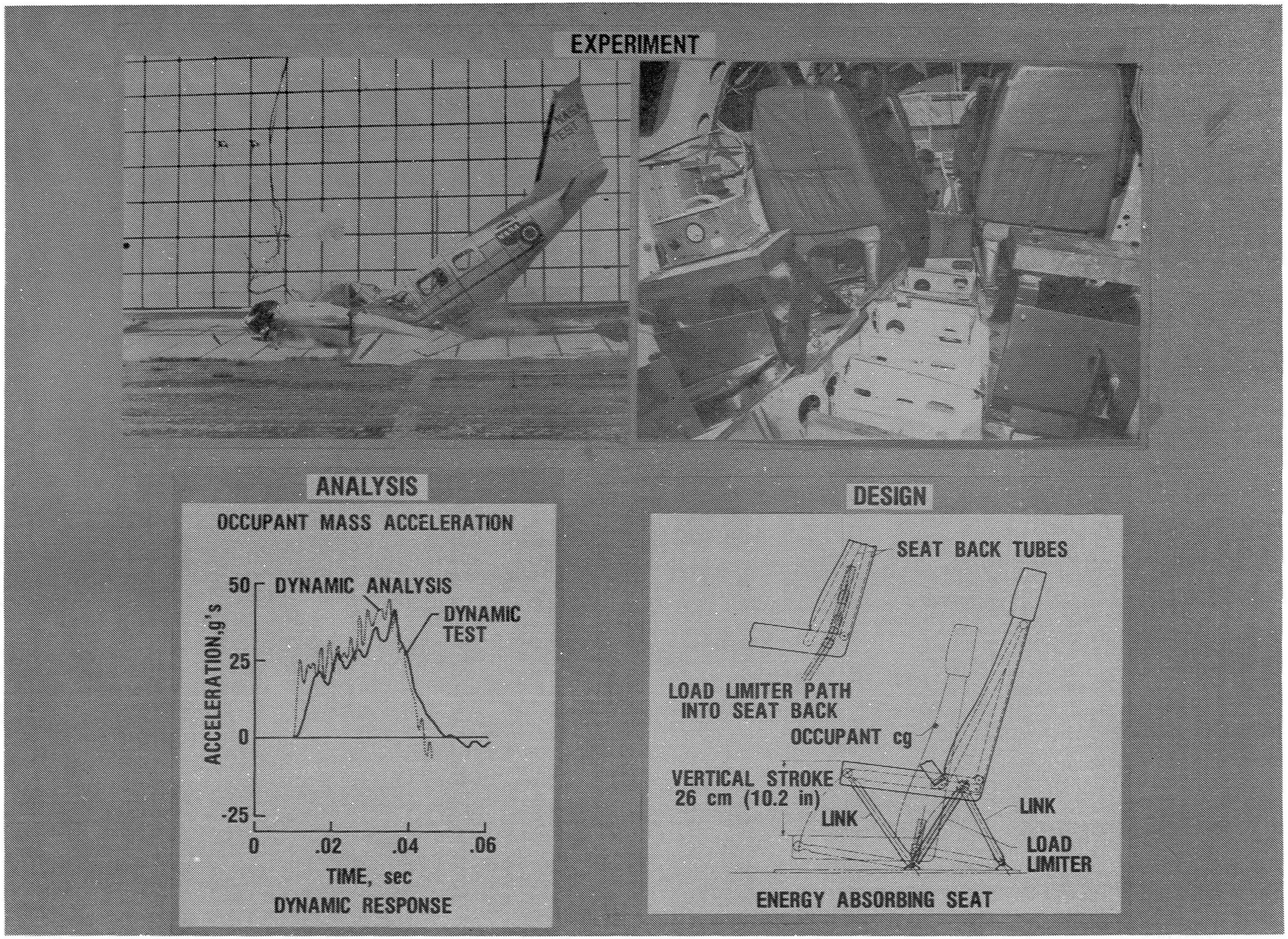

Figure 4. Research on crash dynamics of general aviation aircraft.

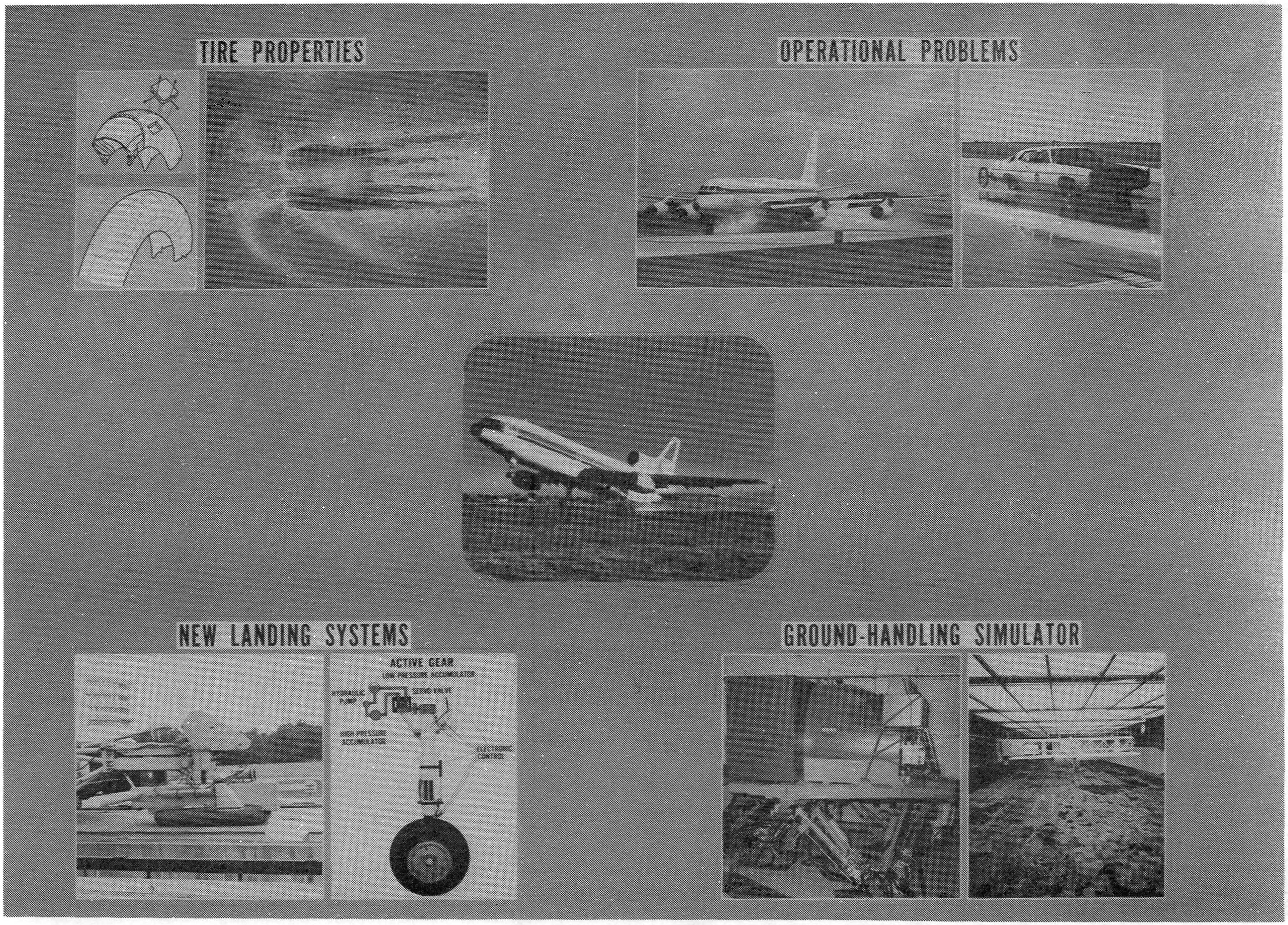

Figure 5. Aircraft landing dynamics research.

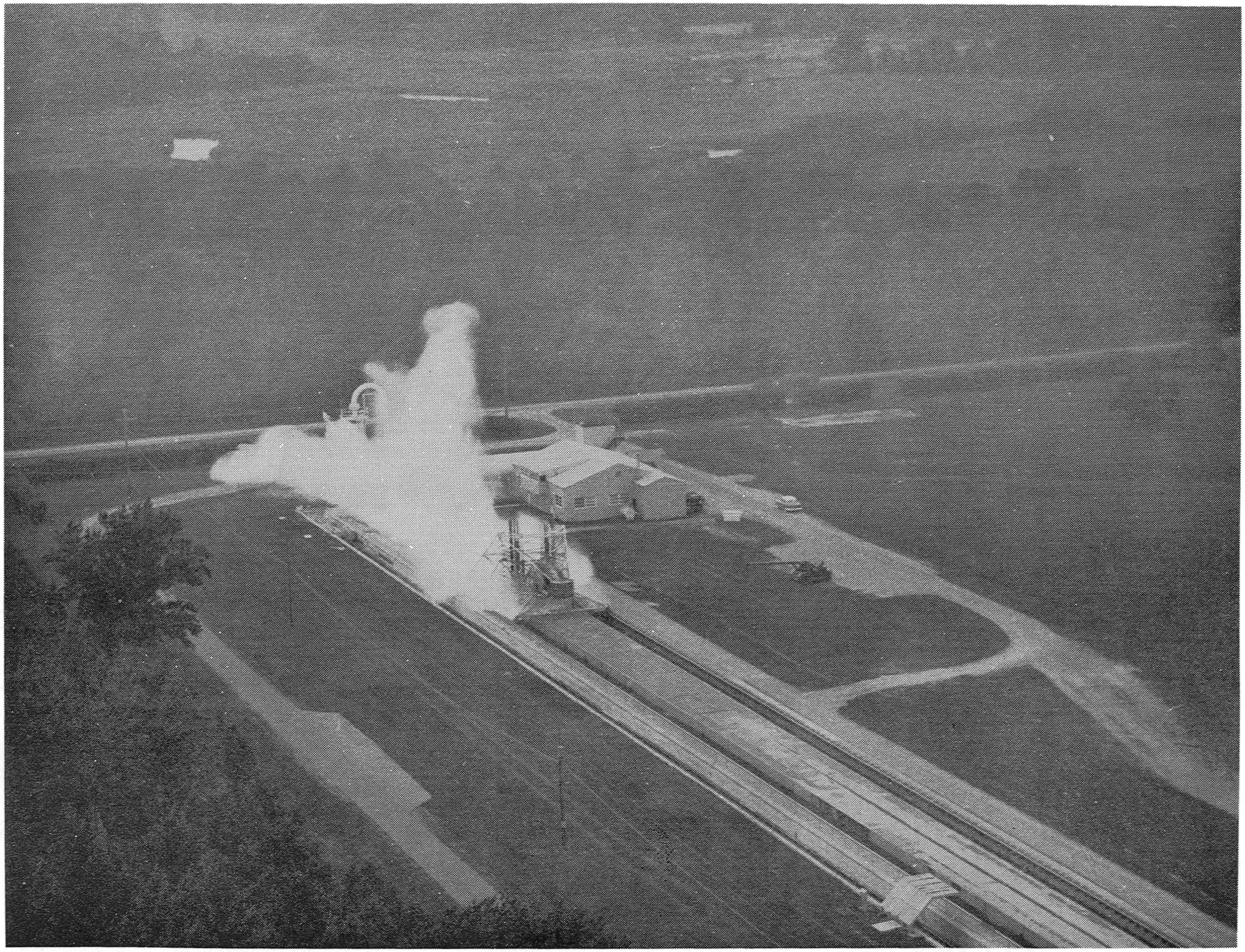

Figure 6. Aircraft landing dynamics facility at Langley Research Center.

A C E E COMPOSITE PROGRAM

OBJECTIVE

PROVIDE THE **TECHNOLOGY** AND **CONFIDENCE** SO THAT COMMERCIAL TRANSPORT MANUFACTURERS CAN COMMIT TO PRODUCTION OF COMPOSITES IN THEIR FUTURE AIRCRAFT:

SECONDARY STRUCTURE - 1980 TO 1985

PRIMARY STRUCTURE - 1985 - 1990

TECHNOLOGY

- DESIGN CRITERIA, METHODS AND DATA
- QUALIFIED DESIGN CONCEPTS
- COST COMPETITIVE MANUFACTURING PROCESSES

CONFIDENCE

- DURABILITY/WARRANTY
- QUANTITY COST VERIFICATION
- FAA CERTIFICATION
- AIRLINE ACCEPTANCE

Figure 7. Aircraft Energy Efficiency (ACEE) Project Office composite structures program.

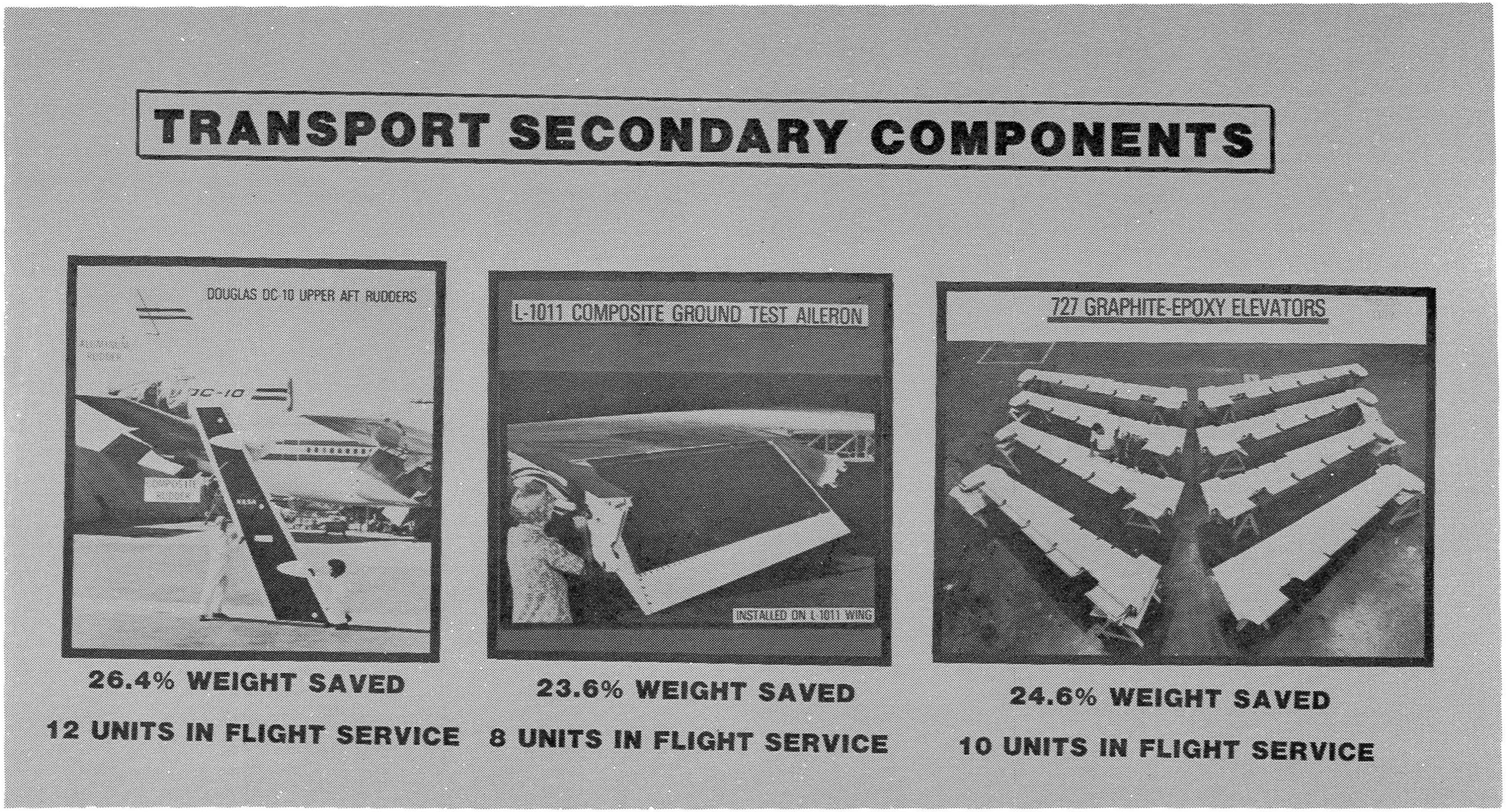

Figure 8. Aircraft Energy Efficiency (ACEE) Project Office transport secondary components.

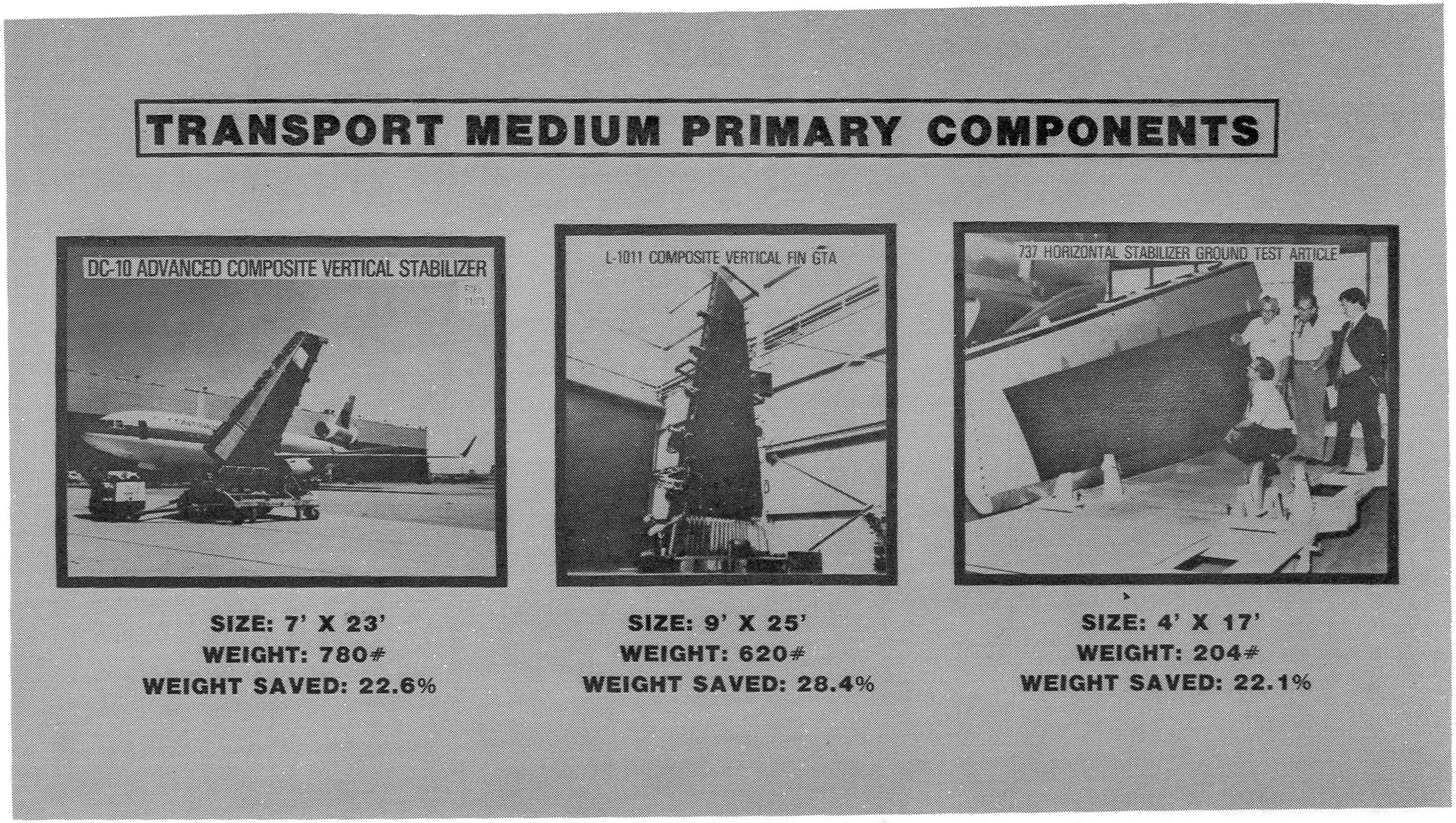

Figure 9. Aircraft Energy Efficiency (ACEE) Project Office transport medium primary components.

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16. Abstract

A concise review is presented of NASA research and development on advanced aeronautical structures technology related to flight safety. The effort is categorized as (1) research in the technology base and (2) projects sponsored by the Aircraft Energy Efficiency (ACEE) Project Office. Base technology research includes mechanics of composite structures, crash dynamics, and landing dynamics. ACEE projects involve development and fabrication of selected composite structural components for existing commercial transport aircraft. The technology emanating from this research is intended to result in airframe structures with improved efficiency and safety.

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