DEVELOPMENT OF THE AIR CUSHION EQUIPMENT TRANSPORTER

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INTRODUCTION

The United States Air Force, in its on-going programs to counter the threat of runway denial to fighter aircraft due to intervening battle damaged terrain between runway and aircraft dispersal points, identified a potential solution in the application of an Air Cushion Equipment Transporter (ACET) capable of transporting a fully operational aircraft over rough terrain. Bell Aerospace Textron, having previously undertaken extensive study in the application of air cushion technology to Alternate Aircraft Takeoff System (AATS), has gained valuable experience in both vehicle design concepts and cushion research which was directly applicable to the design of an ACET vehicle. To capitalize on this work, Bell Aerospace Canada Textron under contract to the Canadian Commercial Corporation in a jointly funded program between the Department of Industry, Trade and Commerce, and the Flight Dynamics Laboratory of the USAF Wright Aeronautical Laboratories undertook to design and test under realistic conditions, a vehicle capable of transporting a fully operational fighter aircraft.

Based upon the design concept evolved for the AATS program, the ACET is essentially a low cost derivative of the vehicle proposed for that program. Its construction follows closely the methods used producing the LACV-30 and its cushion lift air system employs almost exlusively the hardware previously used on the XC-8A Aircraft Cushion Landing System (ACLS) program.

Using a fully operational F101 aircraft the ACET undertook a test and development program at Bell's facility located at Grand Bend Airport in South-Western Ontario. This paper describes briefly the development of the vehicle.

DESIGN DESCRIPTION

Based upon AATS studies, the ACET vehicle is essentially the same design as that proposed for that program. Both vehicles are shallow depth rafts supported by three plenum cell cushions. The raft is composed of three modules assembled in a "T" configuration held together with lateral and vertical splice plates. The forward section of the vehicle comprises the power module housing, the cushion air supply fans, engines and associated systems. Two rear modules mount the main cushions. The Structure of the vehicle is identical in build to that employed on the LACV-30. Extensive use is made of hollowcore panelling and edge extrusions made from 6061-T6 alumium alloy. A nose wheel track used to mount the aircraft forms a structural beam spanning the three modules at the vehicle center line. Two similar beams span the aft modules at the center lines of the cushion cells and provide a track to mount the aircraft main wheels. A winch is mounted at the forward end of the nose wheel track to facilitate loading the aircraft. At the aft end of the track is a detachable ramp. Two articulated ramps attach to the main wheel tracks. These ramps carry twin wheel assemblies which function as drift counters when the transporter is in motion. The entire vehicle is supported by six shallow depth landing pads when off cushion.

Skirt System

The air cushion system consists of three simple skirts surrounding large circular pads located beneath the aircraft wheel gear, as seen in Figure 1. The raft structure joining these pads forms a duct through which air is supplied to the air cushion cells enclosed by the skirts, two larger ones at the rear beneath the main gear and a smaller one at the front, beneath the nose gear.

The concept of three skirted plenum cells is based on a considerable air cushion background with this type of vehicle, including for example, the Bell Sk-3 "Carabao" tri-cell plenum ACV. The advantage of having independent air cushion cells is that a very stable (stiff) raft, firm in pitch, roll and heave is provided.

Two skirt systems were employed during the development of the craft. The first configuration was a simple jupe arrangement of which two examples were produced. The second configuration is a full fingered design.

The jupe skirt arrangement employed a unique pleat system designed to permit obstacles to pass through the cushion without damage to the skirt whilst at the same time independently providing cushion venting to assist in increasing the dynamic stability of the craft.

Lift System

The lift system employed on the ACET comprises two ASP-10 air supply packages each composed of a two stage axial fan driven by a PWACL PT6-70 turbine engine. The units are mounted from the side of the central structure box similar to the way they were mounted on the fuselage at the XC-8A. The fan shroud is retained down to the original CX-8A cuff (which is not used). The seal butts the hollow-core panel forming the front of the air duct. Each fan shroud fits into a large hole in this panel, effectively into a plenum box either side. From this location fan air feeds the front filter bank for the engine air.

The engine exhausts are retained in the same location as they were on the XC-8A. The lower exaust gases because of their ejection close to the ground are directed through shallow ducts to be dumped outboard clear of both the ground and front skirt.

The engines are controlled in the same manner as they were on the XC-8A. A single control panel houses engine performance monitoring instruments, switches and necessary system circuit breakers. The panel is portable, being attached to the ACET by an umbilical cord carrying electric/electronic signals from the control panel to individual engine control boxes (ECB) which are mounted in the forward electrical distribution bay. Not all the control and engine management functions that were necessary on the XC-8A installations are required on the ACET since there is no parallel requirement for thrust/cushion selection and certain other interlock mechanisms.

The port engine is equipped with a generator for use on the ACET to provide 28VDC electrical power for battery charging, for the instrumentation package and for the winch.

Turbine Combustion Air Filtration

On ACET, as with any turbine powered ACV, considerable attention must be given to providing clean dry air to the turbine combustion air intake face. The avoidance of foreign object damage (FOD) is of paramount importance. The LACV-30 is designed to operate in the extremes of poor turbine environments and in consequence is equipped with a total air management system. Proven in service, component parts of the system have been incorporated into the ACET. Derived from cushion lift air turbine combustion air is drawn through an inertial partical separator and a barrier filter into a centrally located open plenum and from there to the engines.

Cushion Dynamic Stability

Analysis of the ACET cushion platform was extensive and concluded that the platform would be quite stable in both pitch and heave for aircraft weights up to 60,000 lb. without having to resort to the use of centrifugal fans with shallow pressure to flow slopes.

For the power available to the ASP-10 fans, the maximum flow is generally fixed at about 1830 cfs for pressures of interest; the combined fan and duct loss slopes are so steep that the fans contribute little to heave stability. Significant improvement could be obtained by going to centrifugal fans, but within the context of the ACET program this would not have been cost effective.

The cushion area of the ACET is made as large as practical for providing good heave stability, considering overall configuration size, weight and constraints. The cushion areas are 98 sq ft for the forward cell and 235 sq ft for each aft cell. The cushion depth is optimized at 24" to provide both satisfactory ground clearance and good heave stability characteristics.

To provide further heave stability, air is introduced into each cushion cell at its periphery. With this air feed mechanism, the ACET configuration is very stable by itself and can theoretically support aircraft weights up to 35,000 lb before instability is reached. To improve stability beyond this point, pressure sensitive cushion venting is employed.

Two methods of cushion venting were employed. The first a system of cushion air release pleats incorporated into the walls of the jupe skirts, the second mechanical vents accessing the cushion compartments.

Early tests of the transporter indicated a tendency towards cushion instability at the higher gross weights when heave oscillations in the range of 2 to 2½ hz were experienced. Initially the cushion vents incorporated into the skirt release pleats worked satisfactorally serving to damp these oscillations. As testing continued, performance of the release pleats deteriorated due to skirt material stretch significantly changing the skirt geometry. This change modified the performance of the release pleats to the extent that they no longer exhibited the venting characteristics to provide the cushion with desired levels of heave attenuation. Using the EASY air cushion computor models and programs developed by the Boeing Airplane Company to study AATS cushion-dynamics, modifications were incorporated to represent the ACET/F101 aircraft configuration to determine parameters for the design of a mechanical cushion vent system.

The vent system proposed was a hinged door arrangement spring loaded to correspond to a cracking pressure equivalent to a transporter/aircraft weight of 35,000 lb. Provisioned with adjustable spring loading and variable damping, the venting arrangement was designed as a passive heave attenuation system. With this system the EASY program predicated stable dynamic cushion performance up to gross weights of 78,000 lb.

Crosswind and Side Slope Drift Compensation

The ACET is designed to be towed by a standard vehicle of inventory type. The type of tow is a simple pivot at the front of the vehicle with the hitch at the apex of a triangular tow bar. In the towing configuration, because the air cushion does not itself provide side force, there is a tendency for the ACET to jack-knife, particularily in crosswind or on a side slope. To compensate for this a trailing wheel pair is mounted on the auto ramps and loaded against the ground by pneumatic jacks which load the wheels to a nominal operating load of 1750 lb. which provides sufficient side force to counter a crosswind of over 30 kt, and is sufficient to hold on a 3% side slope at maximum combined gross weight of 68,880 lb.

Towing the Vehicle

The loaded ACET was towed by two different types of vehicles, a half ton pick-up and a four wheel drive Mercedes Unimog. Tow loads were smaller than predicted and in most instances the pick-up truck proved to be an adequate tow vehicle. It was capable of towing the ACET over the simulated battle damaged terrain and rough ground in all but wet conditions. The Unimog was used for extended running over grassy surfaces, ploughed fields and snow and ice. The transporter remote control unit, instrumentation package and operator were carried in the back of the tow vehicles. An intercom provided communications between tow vehicle driver and ACET operator. The ACET was satisfactorally towed over a variety of terrain in a full range of environmental conditions. Deep snow over ploughed surfaces proved the most difficult to negotiate. Snow deflected by the nose cushion tended to build in banks against the leading edge of the main cushion when a ploughing action would take place resulting in high tow forces. These forces coupled with the loss of traction of the tow vehicle often necessitated the use of a second tow vehicle. Traversing dry ploughed fields created visibility problems for the operating crew especially in downwind situations when dust made airborne by the escaping cushion air created dust storms of great intensity. Traversing battle damage terrain in the form of a simulated bomb crater of 40 ft dia some 12 inches deep with 12 inch overburden presented no difficulty. The ACET was satisfactorally towed across this type of surface using only the pick-up truck. Towing the craft over grass covered undulating surfaces with slopes of 5% was achieved without difficulty. The drift counter wheels proved effective in providing directional stability in cross winds of greater than 30 mph on smooth surfaces assuring positive tracking of the craft behind the tow vehicle.

In general, drag loads tended to be appreciably lower than predicted. The ACET does not have to rely on heavy duty equipment to tow it around. The type of vehicle most suited for towing is the one most able to negotiate the terrain the craft is required to cross.

Operating the ACET

Operation of the ACET requires no special skills or prolonged periods of training. Essentially, operating the vehicle requires only control of lift fan engine rpm. The ASP-10 air supply units are controlled by electronic sequencing of the engine fuel and ignition systems. R.P.M. and consequently cushion air supply are controlled by a simple potentiometer housed on the control console. At operating speeds above idle, the two engines are coupled electronically with adjustment of the potentiometer proportionally increasing or decreasing r.p.m. as required. Because of physical limitations with the engine trim mechanism it was not possible to attain balanced engine output speeds throughout the full r.p.m. range. Matched r.p.m.'s were available at only one setting which were at 95% of maximum.

Because each ASP-10 fed cushion air directly into what was essentially a single plenum area feeding all three cushions it was necessary to start both engines simultaneously. Starting one engine and stabilizing it at idle r.p.m. before starting the second engine imposed heavy loading on the second engine starter. Because escaping cushion air through the second fan caused a high speed reverse rotation of the fan, the starter motor first had to act as a brake to arrest and then reverse the fan rotation before the start cycle could be automatically initiated. This induced a high current drain on the batteries and the use of an external power source is therefore used to prolong the life of both battery and engine starter.

Fuel for the engines is contained in two 100 gallon fuel tanks located on either side of the forward module. The tanks are interconnected both feeding to a single low pressure delivery pump which supplies fuel to the engine driven pumps via firewall shut off valves. A five suppression system is incorporated in the engine nacelles which is manually activated by the operator in the event that it is needed.

Test Operations

As discussed earlier, two skirt systems were produced for the ACET. The original design identified a plain jupe for each of the three cushion cells. This skirt was produced from a 90oz. nylon coated neoplene of the same type used in the LACV-30 skirts. The method of tailoring the skirt at first did not fully compensate for the effects high tensile loadings would have on material stretch. The stretch was of proportions sufficent to change the cushion geometry making the relief pleats ineffective as both cushion vent machanisms and load release devices. A redesign of the skirt to counter the effects of material stretch, minus the relief pleats, was successful in maintaining the desired cushion geometry but was lacking in providing an adequate surface seal when operating over rough or fractured surfaces. Operations over snow were impeded by the skirts ploughing rather than riding over the snow covered surfaces. Cushion collapse would result in many instances which at the lighter gross weights could be overcome by an increase in cushion airflow. At the higher gross weights increased airflow was not available and the transporter could become hung if the situation was not recognized early in its onset.

To correct the surface sealing problem it was decided to equip the craft with a full fingered skirt. The design of the fingers followed conventional practice and with minimual changes to the craft structure to provide a means of attachment, the craft was outfitted in such a manner that either a fingered or plain jupe skirt could be installed. Initial tests with the fingered skirt were highly satisfactory, but a problem that had persisted with cushion heave oscillations remained not attenuated by the heave stability vent. At certain combinations of cushion airflow and gross weight these oscillations became divergent.

The problem with heave oscillations proved to be rather troublesome. The mechanical heave attenuation system appeared to be working satisfactorally but at the higher gross weights and higher cushion airflows, a divergent oscillation could take place with spectacular results. Searching for the source of the problem revealed the frequency of vibration to be of the order of 6Hz, significantly different from the 2.5 Hz for which the heave attenuation system had been designed. Further compounding the problem was the fact that the spring loaded doors relieving cushion airflow had a natural frequency that coincided with the 6Hz. The source of the problem was found to eminate from the two lift fans running at slightly different r.p.m.'s and hence flow and pressures feeding air into a common plenum. The originial cushion borne stability analysis did not consider this condition and in consequence no compensatorary actions were undertaken in the design of the cushion vents. The problem was overcome by providing additional cushion air bleed in the form of hole perforations placed in every fourth finger. The holes were positioned in a triangular pattern becoming progressively exposed as cushion heave height increased with increased airflow. This simple mechanism provided the necessary cushion airflow relief and worked well in eliminating the undersireable heave oscillations.

CONCLUSION

The development of ACET like all pieces of equipment of a dynamic nature posed its share of problems and difficulties. These were accepted for the challenge they presented and were overcome. New ideas for improved performance and future development were identified and in due course will be acted upon.

ACET completed its initial test programs at Grand Bend and is currently undertaking trials program with the United States Air Force.

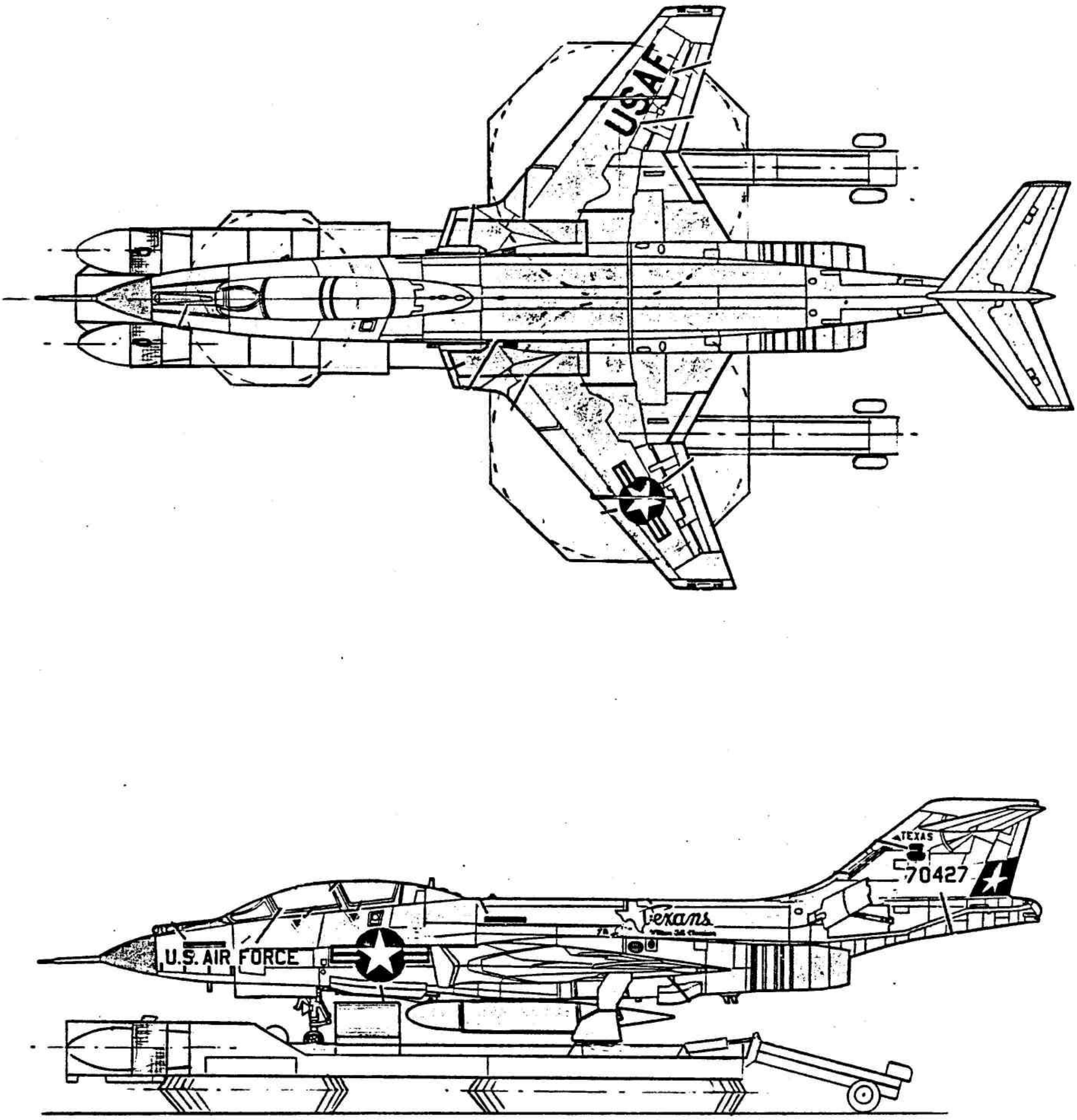

Figure 1
General Arrangement ACET

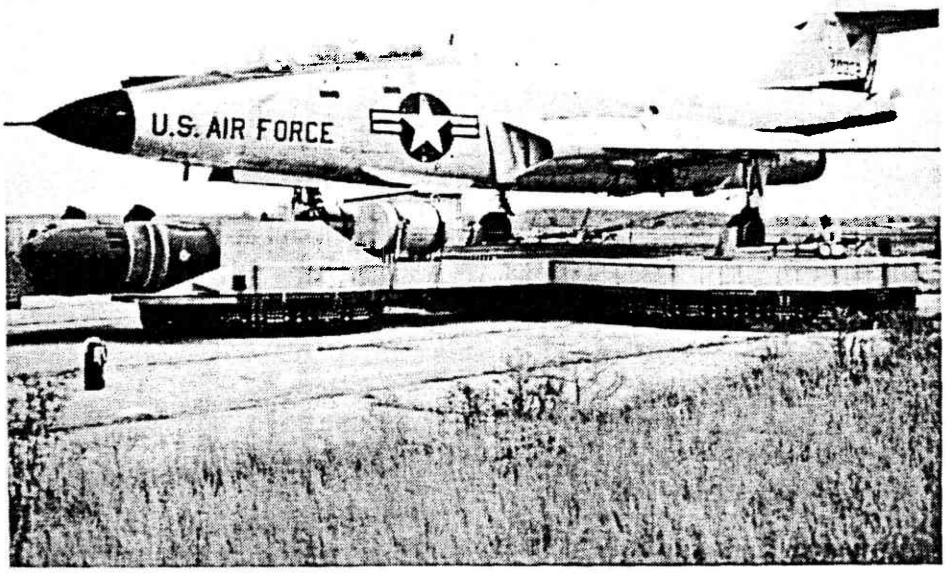

Figure 2

ACET on cushion with F101 aircraft aboard.

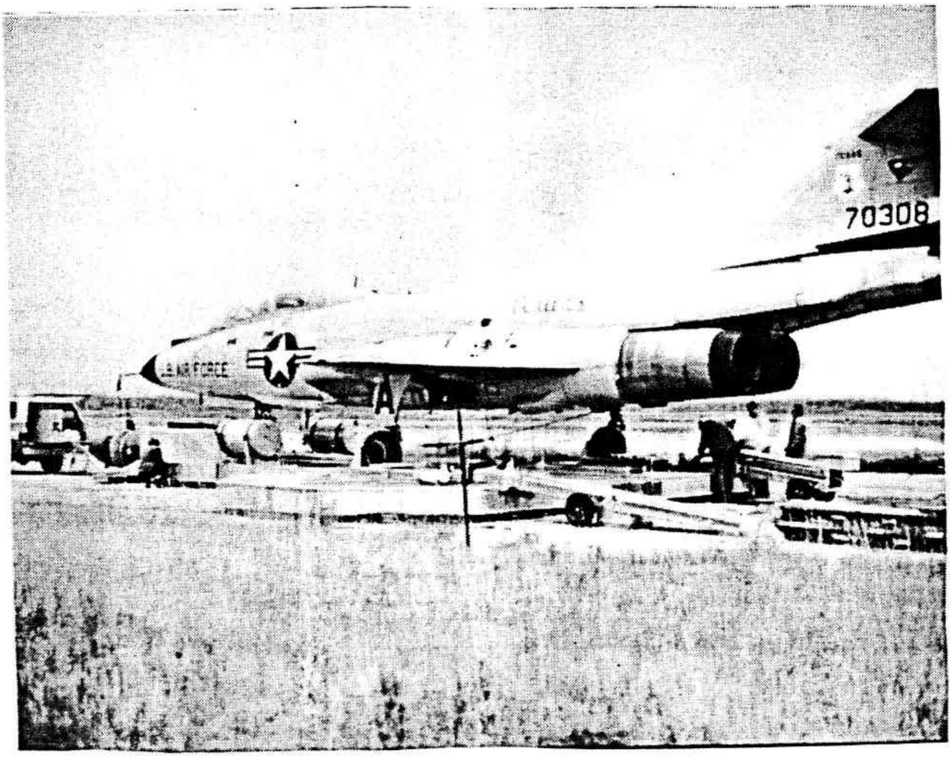

Figure 3

Preparing to dismount the aircraft.

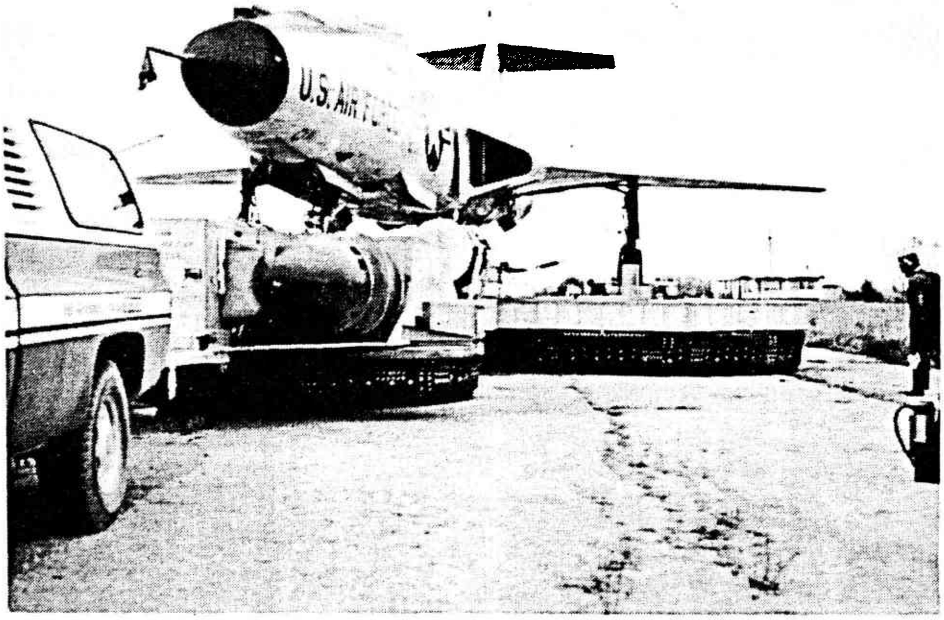

Figure 4

Hard surface tow with pick up truck.

Figure 5

Underway over snow covered surface towed by Unimog.