Articulated Off-the-Road Vehicles

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Continued development of articulated off-the-road vehicles has resulted in new wheeled and tracked models which are examined in the following article together with a number of other and hitherto little-known vehicles.

TWO earlier articles[1,2] described in some detail the basic features of articulated off-the-road vehicles and the history of their development. Since they were written several new vehicles of this type have appeared and additional information has come to light about others. It is opportune, therefore, to return to the subject and survey again the whole field. This implies an examination of civilian as well as military applications and both tracked and wheeled vehicles in various stages of development, from the purely experimental to regular commercial utilisation.

Wheeled Vehicles

One of the articulated wheeled vehicles which can now be considered fairly well established is the Wagner tractor referred to in one of the earlier articles.[2] This tractor is being made in four different sizes by FWD Wagner Inc.—formerly Wagner Tractor Inc. but now a subsidiary of the FWD Corporation—of Portland, Oregon, for a wide variety of industrial and agricultural applications. The four models range from the WA-9, which has a gross weight of 18 100 lb, through the WA-14 and WA-17 of 23 000 lb and 24 000 lb respectively, to the 52 000 lb WA-24, a variant of which is shown in Fig. 1. However, all four are basically similar having four-wheel drive and a joint which allows considerable movement in roll between the front and rear halves of the tractor and, also, in the steering plane—thereby providing for steering by articulation. The degree of permissible movement in roll is well brought out in Fig. 1. which also illustrates the kind of terrain this type of tractor is able to negotiate. Fig. 2 shows details of the "centre-pin" steering joint with the hydraulic ram controlling the attitude of the two halves of the tractor in the steering plane.

A basic advantage of the articulated wheeled tractor is that it permits four-wheel drive with less mechanical complication than a conventional tractor with a rigid frame. Therefore, whenever maximum traction—and hence four wheel drive—are essential the articulated tractor becomes very attractive from the cost point of view, in addition to offering greater freedom with regard to the use of large diameter tyres and the ability to extricate itself from patches of difficult muddy ground by a series of steering manoeuvres.

Maximum traction may not be essential for the average small or medium size agricultural tractor but it is imperative in many industrial applications and it is highly desirable for large agricultural tractors. Thus, the John Deere Company decided from the start on four wheel drive for its large 8010 tractor and having done this very sensibly adopted an articulated construction. As a result, it has obtained a four wheel drive tractor with a simple transmission drive line which is well illustrated in Fig. 3. The sectional drawing of the John Deere 8010 tractor also illustrates the design of the joint between the front and rear sections which allows 16° of relative angular movement in roll and 40° in the steering plane, in each direction. Steering movements are accomplished by means of a single double-acting hydraulic cylinder having a diameter of 5in and a stroke of 16in, and it is relevant to add that without liquid ballast the tractor weighs 19 700 lb.

The advantages of articulated construction have been exploited in a different form in the design of the XM561 1¼-ton six-wheeled articulated truck which is being developed for the U.S. Army by Chance Vought Corporation—a division of the Ling-Temco-Vought, Inc. The XM561 is an outgrowth of the "Gama Goat" developed since 1959 by Chance Vought Corporation as a private venture and already described on these pages.[2] In mid-1961 the "Gama Goat" prototype was submitted by the U.S. Army to competitive trials with seven other experimental and operational vehicles and it proved superior to all the others. In fact, it was the only one of the eight vehicles to negotiate the whole of a gruelling test course in the Auburn Hills north-west of Detroit. As a result, the U.S. Army selected it as the basis of a new 1¼-ton truck which has been designated the XM561.

The XM561 retains the basic layout of the "Gama Goat" but differs considerably in detail, as well as being larger and heavier. Thus, it consists of a four-wheeled prime mover section and a two-wheeled detachable rear section. But, instead of the air-cooled spark-ignition engine of the original model, it has a General Motors GM 3-53 engine—a 159in^3 three-cylinder compression-ignition two-stroke. The drive from the engine is taken through a four-speed and reverse gear-box to a two-speed transfer box and then to the front and centre differential assemblies, and from the centre differential assembly, through a double universal joint at the intersection articulation joint, to the rear differential assembly. The final drive from the differentials to the wheels is through splined half-shafts with a universal joint at each end. The drive to the front and rear axles may, however, be disengaged for road operation when the vehicle can be driven by the centre wheels alone.

The articulation joint allows ±30° of movement in roll and ±40° in pitch between the front and rear sections. In addition, the whole centre axle assembly can roll ±15° in relation to the front section. As a result of all this freedom of relative movement between the two sections all six wheels can remain in contact with the ground, even under adverse terrain conditions, and thereby maintain the highest possible traction. At the same time, body torsional loads are greatly reduced and lighter vehicle construction is possible.

The articulation joint does not, however, allow any motion between the two sections in the steering plane. No steering by articulation is, therefore, possible. Instead, the front and rear wheels are steered in the usual way by interconnected Ackermann-type linkages. The wheels are independently suspended by means of double transverse wishbones with ball-jointed outer ends and coil springs with telescopic dampers. In this respect the XM561 differs considerably from the original

Fig. 1—FWD Wagner TR-24 tractor demonstrating the degree of roll possible between its front and rear halves

Fig. 2—The centre steering joint of a FWD Wagner articulated tractor showing the rod of the hydraulic steering ram

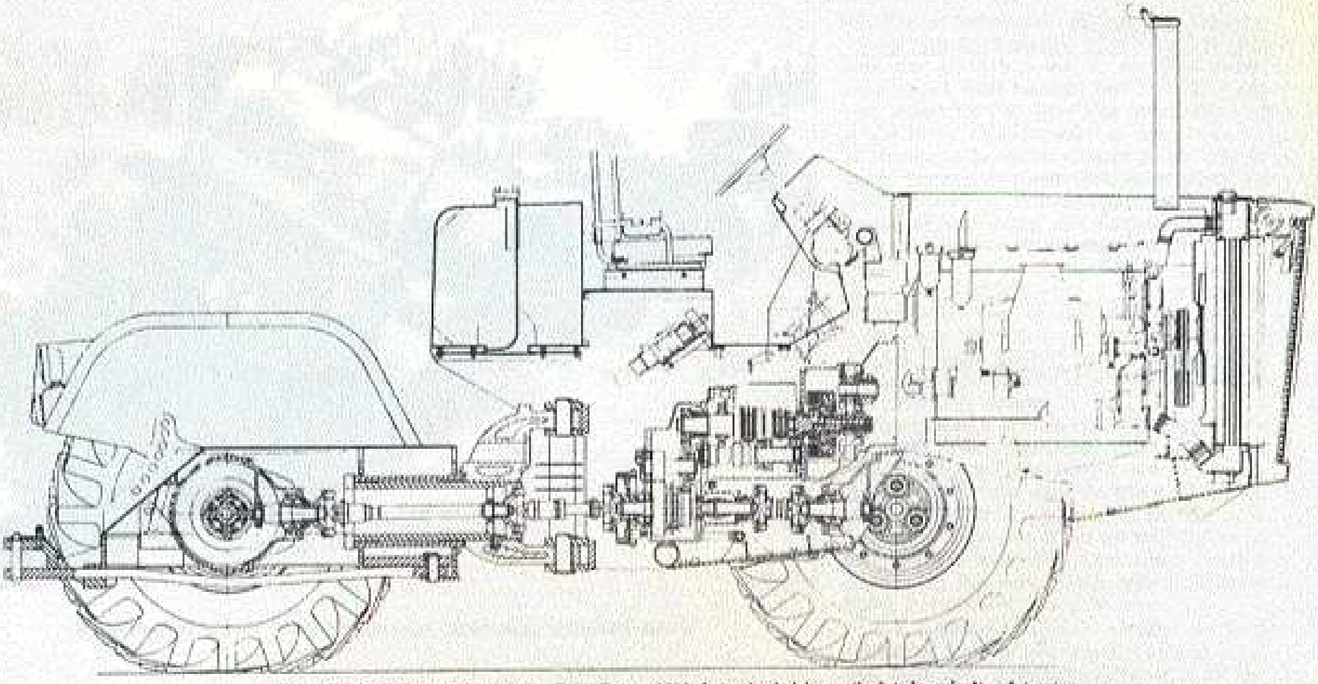

Fig. 3—Sectional drawing of the John Deere 8010 four-wheel drive articulated agricultural tractor

model, which had a torsion-bar suspension, and it also has different size tyres, now 11·00 × 18.

According to the preliminary design information, the XM561 weighs 8 800 lb with a 2 900 lb payload, and is 18ft 4in long and 7ft wide overall. Its wheel track is 5ft 9in and the distances from the centre to the front and rear axles are 6ft 7in and 7ft respectively. The relatively long wheelbase, made possible by articulated construction and coupled with its other features, enables the XM561 to negotiate vertical obstacles better than conventional, rigid-chassis vehicles. At the same time, its relatively large-diameter low-section tyres ensure good performance over soft ground. It also has sufficient buoyancy to float across water obstacles. Unlike the "Gama Goat", it does not have a propeller, but it can paddle itself across calm waters by means of its wheels at up to about 2 m.p.h. On hard paved surfaces, however, the XM561 is expected to be able to reach 58 m.p.h.

An even more unorthodox six-wheeled vehicle is being developed by the General Motors Defense Research Laboratories. This is the "MARV"[2], which consists of three similar units, each with its own engine and two independently-sprung wheels. As can be seen in Fig. 5, the three units are capable of considerable relative movement in roll and the vehicle is steered by turning the units relative to one another in the steering plane while constraints, which need to be imposed between the units in the pitch plane, are provided by springs. In view of the promising performance of the "MARV" over rough terrain, there are obvious military applications for similar train-like vehicles, but the latter have also been considered as a possible basis for a complete transportation system for the underdeveloped areas of the world.

Yet another and entirely different application for which articulated-wheeled vehicles are being considered is lunar exploration. A three-unit model of an articulated lunar rover, developed at the General Motors Defense Research Laboratories[4] is shown in Fig. 6. Recently this particular model was chosen by N.A.S.A. for further development in preference to several other competing designs. One of its outstanding features is the elasticity of the links connecting the three axle units which allows the vehicle to adjust itself to the contour of the ground and enables it to cope much better with vertical obstacles, as demonstrated by Bekker.[3]

The best known, probably, of the wheeled articulated vehicles demonstrated in recent years are the "Goers" of the U.S. Army.[2] Three new vehicles of this type have appeared since the original models were described on these pages.[2] They are the XM437E1 16-ton cargo truck, the XM438E2 5 000-(U.S.) gallon tank truck and the XM520E1 8-ton cargo truck, shown respectively, in Figs. 7, 8 and 9. The first two have been built by the LeTourneau Westinghouse Company and are closely related to its original XM437 and XM438 "Goers", although the payload of the cargo version has been increased from 15 U.S. tons to 16 U.S. tons. As before, they have mechanical drive to the front wheels only; the rear wheels are powered only when heavy going is encountered by means of an electric motor; and steering, by articulation about a pin-joint behind the cab, is also accomplished by means of an electric motor. Power for both the rear drive and steering motors is obtained from a three-phase, 425V generator directly coupled to the vehicle's GM 8V-71 two-stroke diesel.

The third of the new "Goers", the 8-ton XM520E1, is very different in several respects and, in spite of the similarity in the designation, has little to do with the earlier 5-ton XM520. It has been built by the Caterpillar Tractor Company and has a mechanical drive to all four wheels. Its steering is hydraulically actuated and, because of the mechanical drive to all wheels the amount of possible movement in the steering plane between the front and rear sections is considerably less than in the larger LeTourneau Westinghouse "Goers". This means that the turning circle is greater.

The gross weight of the XM520E1 is approximately 20 U.S. tons and it has a maximum speed of 30 m.p.h., but whether it can, in fact, travel at anything like this speed for any length of time is doubtful as it has no springing other than that provided by the resilience of its tyres, which have little inherent damping. However, in common with the larger "Goers", it has one additional virtue in its ability to float without any

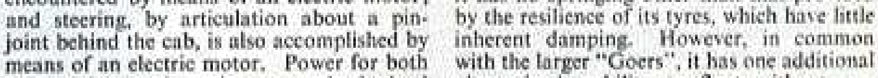

Fig. 4—"Gama Goat" prototype of XM561 six-wheeled articulated truck now being developed for the U.S. Army

Fig. 5—General Motors "MARY" three-unit experimental articulated vehicle

assistance and it can propel itself in calm inland waters at up to about 4 m.p.h. by the paddling action of its wheels.

Now that the "Goers" have been under development for about six years their weaknesses as well as their virtues have become more evident. In consequence, enthusiasm for them has waned, while criticism has grown and the U.S. Army already appears to have lost interest in the larger models of LeTourneau Westinghouse type, although it purchased fifty "Goers" during the 1962 fiscal year.[3] Some of the shortcomings were obvious from the early stages of their development[3] but the criticisms are apt to ignore the fact that the design of the "Goers" was circumscribed for it was as much an exercise in the adaptation of earth-moving equipment to military purposes as an attempt to develop a new type of military vehicle. As a result, their performance has suffered and does not represent the optimum that might be achieved with wheeled articulated vehicles designed under other conditions.

One weakness of the existing four-wheeled "Goers" is their relatively low ratio of net drawbar pull to weight, in spite of their relatively large-diameter tyres whose advantages are partly nullified by the high load per tyre. Another major criticism levelled at "Goers", particularly of the LeTourneau Westinghouse type, is their proneness to belly when attempting to cross transverse ridge type obstacles. This arises out of their large ratio of wheelbase to ground clearance. There is, however, at least one way out of this difficulty by increasing the number of wheels to eight and thereby reducing the ratio of the longitudinal wheel spacing to ground clearance. A model for this exists in the experimental Armstrong Siddeley Pavesi-type 8 × 8 tractor of the early thirties and the XM549 5-ton 8 × 8 "quad-track" cargo truck built recently for the U.S. Army and shown in Fig. 10. The main object of the XM549 "quad-track" is not, however, to develop articulated vehicles better able to cross transverse ridges but to explore the possible use of demountable tracks as a means of increasing still further the cross-country mobility of wheeled vehicles.[6] The vehicle itself is an eight-wheeled version of the earlier XM520 5-ton 4 × 4 experimental cargo truck, one of the original "Goers" which was derived from the Michigan 75 Timber Tractor built by the Clark Equipment Company, as already described in one of the preceding articles.[2]

The idea of a vehicle capable of operating on tracks or on wheels, using the same set of running gear, is by no means new. It originated around 1920 with J. Walter Christie, who embodied it in several of his tank designs.[7] It did not prove entirely successful and has not been used since some Russian designs of the late thirties but it deserves being reconsidered, none the less.

It is doubtful, however, whether an 8 × 8 vehicle of the XM549 type is likely to bring out fully the potential advantages of the convertible wheel-or-track design. After all, the greatest attraction of the scheme is that it gives the mechanical simplicity of a tracked vehicle together with its off-the-road performance and, at the same time, a vehicle which is capable of operating efficiently on its wheels whenever roads are available and the tracks can be removed. Off-the-road performance of the lighter tracked vehicles can be approximated to, of course, by multi-wheel drive vehicles but at the cost of mechanical complication of the drive train with its numerous gears and universal joints, which is evident in the case of such highly developed vehicles as the 8 × 8 Panhard E.B.R. and the 6 × 6 Alvis "Saladin".[8] On the other hand, if a vehicle already has multi-wheel drive, as the XM549 does, then the addition of tracks is only going to produce a modest gain in performance and will not bring about any simplification.

The use of tracks with non-articulated wheeled vehicles implies some form of skid steering mechanism, but this need not be a deterrent. In fact, the skid steering mechanism could be used to steer the vehicle when running on wheels, as well as tracks, as has been done in the case of the T.V.1000 experimental six-wheeler developed by the F.V.R.D.E.[9] T.V.1000 was developed with pneumatic tyres, but for fighting vehicles, of

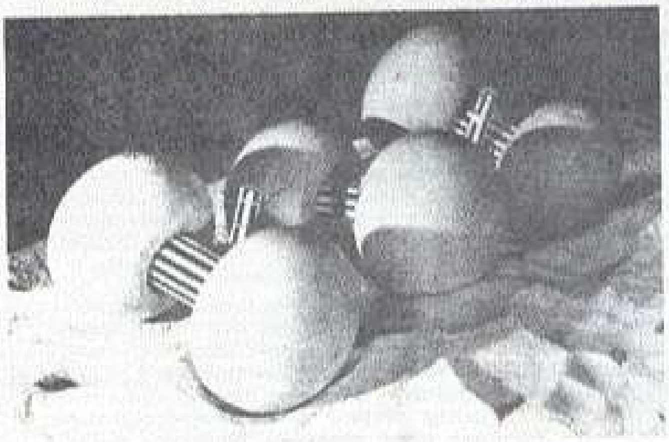

Fig. 6—Articulated wheeled lunar vehicle model built at the General Motors Defense Research Laboratories

Fig. 7—XM437E1 16-ton cargo truck developed from the earlier "Goers" of the U.S. Army

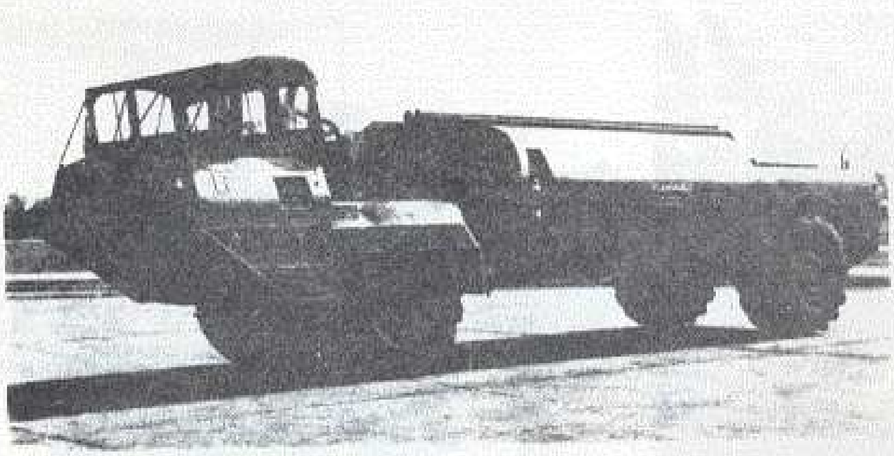

Fig. 8—XM438E2, a new version of the 5 000 U.S. gallon "Goer" tanker built by the LeTourneau-Westinghouse Company

which it was intended to be a prototype, various solid wheels have been considered. The resulting wheels proved inevitably complicated and one wonders whether some of the ingenuity and effort devoted to them might not have been more profitably spent on the development of convertible vehicles.

The different characteristics of tracks and wheels and the desire to possess their advantages in one vehicle have also prompted another attempt to develop a light vehicle with two separate sets of running gear. The new version has been developed in France by J. Garnier and takes the form of a lightly-armoured 2·2-ton tracked weapon carrier with four wheels which can be lowered for driving on roads. Only the two rear wheels are driven, which is sufficient for operation and helps to keep the vehicle simple. The vehicle, called the JMG 20, has been developed as a private venture, but apparently it is being considered by the French Army. It should be emphasised that it is not articulated, but is worth mentioning here as a different attempt at obtaining some of the things which the U.S. XM549 is intended to explore.

Tracked Vehicles

So far as tracked articulated vehicles are concerned, no new models have been produced by Wilson, Nuttall, Raimond Engineers Inc., the Maryland company which has developed several original designs.[1] W.N.R.E. vehicles have, however, gained further operational experience. The first "Musk-Ox", the large 90 000 lb gross weight model, has now completed four years of operation, during which it has logged about 55 000 miles over the difficult terrain of the Canadian North. Most of the time it has been used in oil field work, but in February, 1962, it took part in the U.S. Army "Great Bear" exercise in Alaska where it performed creditably as a supply carrier.[10]

Two other articulated tracked vehicles were also tested in the "Great Bear" exercise. One was the Wagner "Quad-Track", a single product of private enterprise unrelated either to the Wagner wheeled tractors or the XM549, described earlier in this article. The Wagner "Quad-Track" had already been tried once in Alaska; in the 1961 "Willow Freeze" exercise of the U.S. Army, when it drew particular attention to the advantages of using articulated tracked vehicles in that country during the winter.[11]

Another of the articulated tracked vehicles tested in Alaska was the Nodwell RN 200, which was described in one of the previous articles.[1] Further vehicles of this type might be built in the future by the Ordnance Division of the Food Machinery and Chemical Corporation, of San Jose, California, which has recently come to an agreement with Robin-Nodwell Manufacturing Ltd., of Calgary, Alberta, to manufacture Nodwell vehicles, including, if there is a demand for it, the RN 200.

Military interest in the use of articulated tracked cargo carriers for operation over snow has manifested itself even more clearly in the vehicle built by Canadair Ltd., the Canadian subsidiary of the General Dynamics Corporation, under a joint U.S.-Canadian development programme. This vehicle is the Canadair CL-91 "Dynatrac", also known under its U.S. Army designation as the XM571. A trials batch of ten has now been built and their testing was started in August, 1962. The results, so far, appear very favourable and the "Dynatracs" have attained their design speed of 30 m.p.h. and demonstrated their ability to swim in inland waters.

A high level of performance is only to be expected, however, since the "Dynatrac" is a development of the earlier series of "Bat" articulated carriers.[1] Thirty-six of these were built by Canadair Ltd. since the mid-fifties and they were extensively tested by the Canadian Army and other users. The result of all this was to establish the concept of a light articulated cargo carrier, which paved the way for the "Dynatrac". But the "Dynatrac" differs considerably from its forerunner. It is larger, more solidly built and also, unfortunately, more expensive.

As shown in Fig. 11, the "Dynatrac" consists of two units connected by an articulation joint which permits relative displacement of the two units of up to 30° from the centre line in any plane. The front unit houses a General Motors "Corvair" six-cylinder, horizontally-opposed, 164in³ air-cooled engine developing 65 b.h.p. at 3 600 r.p.m., which drives through a four-speed and reverse gear-box in series with a two-speed auxiliary box. From the drop box the drive is taken to a "drive-through" hypoid gear-box at the rear of the front unit where it is split between the half-shafts driving the track sprockets of the front unit and the drive to the rear unit. The drive from the front unit hypoid gear-box to the rear passes through the articulation joint, with a Rzeppa constant-velocity universal joint, and then, through a long shaft, to an identical hypoid box at the rear of the rear unit and thence to the rear unit track sprockets. There is also a secondary drive shaft from the drop box which powers a 5 000 lb winch.

Steering is normally accomplished by means of two double-acting hydraulic cylinders, controlled by a valve connected to the steering wheel, which move the front and rear units with respect to each other. This gives the 19ft 6in long vehicle a turning radius of 20ft. The two units may also be disconnected and the front one driven on its own, steering then being accomplished by means of clutch-and-brake units interposed in it in the drive from the hypoid gear-box to the track sprockets. Alternatively, a third unit may be coupled on to the back of the second: the third unit is identical with the second and its tracks are powered through the same type of articulation joint but without steering actuators.

Each unit has four double bogie wheels per side, mounted on trailing arms and sprung by transversely located torsion bars. The four tracks are of the continuous band type, 18in wide, which gives a mean ground pressure, at no sinkage, of 1·9 lb/in² when fully laden to 7 271 lb. This figure includes the driver and co-driver, and a payload of 2 500 lb. When the third unit is attached the payload goes up to 3 500 lb.

To keep the weight of the "Dynatrac" to a minimum considerable use has been made in its construction of aluminium alloy components, including aluminium honeycomb sandwich panels for the bodywork.

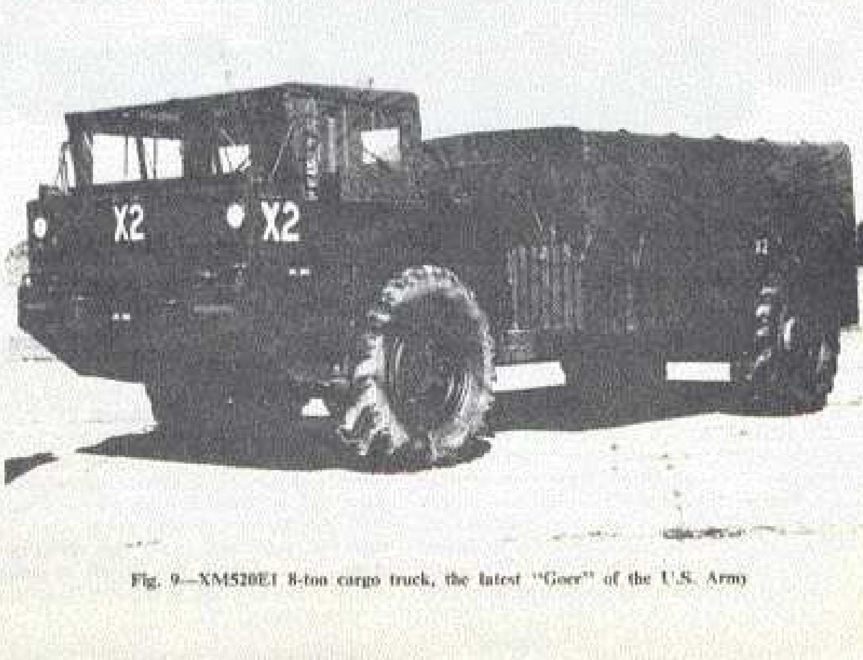

Fig. 9—XM520E1 8-ton cargo truck, the latest "Goer" of the U.S. Army

Fig. 10—XM549 5-ton experimental "quad-track" cargo truck

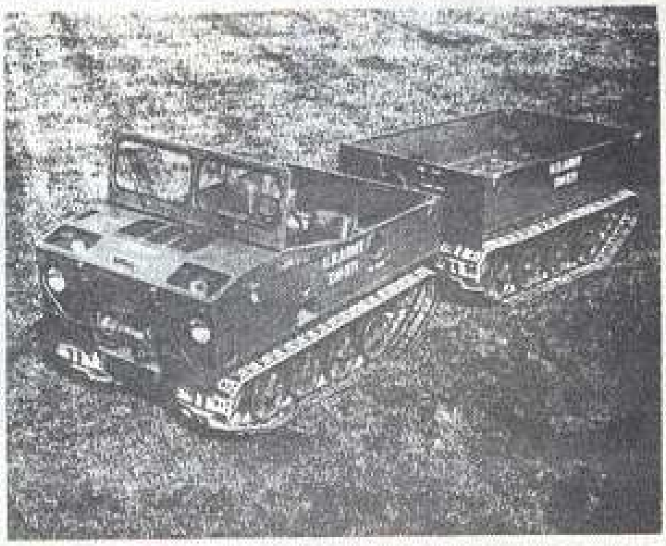

Fig. 11—Canadair CL-91 "Dynatrac" articulated tracked vehicle

Due to its relatively light weight the "Dynatrac" has a freeboard of 8in when fully laden and to improve its ability to operate in water both front and rear units are fitted with electrically operated bilge pumps.

A similar though not quite so elaborate a vehicle has also been developed in Sweden. The decision to develop an articulated tracked carrier was taken by the Swedish military authorities in 1957, that is only about a year or so after work on similar vehicles was started in Canada. Drawings of the Swedish vehicle were prepared in 1958 and the vehicle itself was first demonstrated in the winter of 1959. It proved superior to other vehicles on snow and, as a result, ten were ordered for troop trials which began in 1960. These proved successful and a production order was placed in 1961, the manufacturers being Bolinder-Munktell AB, of Eskilstuna.

The general arrangment of the Swedish vehicle, designated Bandvagn 202A, may be gauged from Figs. 13 and 14. The front unit houses a Volvo B 18 B four-cylinder water cooled engine which develops 80 b.h.p. at 5 500 r.p.m.; the engine drives the front and rear unit tracks through a four-speed and reverse gear-box in series with an auxiliary two-speed gear-box. At the auxiliary gear-box the drive is split, one shaft going forward to a rigid Spicer axle with a differential lock and the other backwards to the articulation joint and through it to another Spicer axle at the front of the rear unit. Sprockets at the ends of semi-floating axle shafts drive continuous rubber band tracks with steel plates. The tracks have a nominal ground pressure of 1·4 lb/in² and the vehicle has a maximum road speed of 28 m.p.h. As on a number of other special-purpose tracked vehicles the road wheels have pneumatic tyres and the wheels are sprung by means of torsion bars.

Steering is accomplished by means of a single hydraulic cylinder and the vehicle has a mean turning radius of 20ft 5in for an overall length of 20ft. In contrast to the "Dynatrac", the Swedish vehicle also has two large dampers to control relative movement of the two units in pitch. Empty it weighs 6 200 lb and fully laden 7 950 lb.

Since the earlier articles on this subject were published another light vehicle has been advertised in the United States under the peculiar name of "Sno-T'rain". The company advertising it, Consolidated Industries, of Dover, Delaware, specialise in selling government surplus "Weasel" tracked tractors and its vehicle, like the original W.N.R.E "Polecat", is built out of two "Weasels".[7] In fact, it represents no advance on the "Polecat" whose mechanical layout it closely follows and none appears to have been sold yet.

Yet another light model has also been announced in the United States by the Twin Industries Corporation, formerly the Twin Coach Company, of Buffalo, New York. This particular model is an outgrowth of an earlier and fairly conventional experimental tracked cargo carrier called the "Pack-Rat" which has been developed into a two unit articulated vehicle with the assistance of Wilson, Nuttall, Raimond Engineers, Inc., whose type of articulation joint it incorporates. According to preliminary design information, the articulated version of the "Pack-Rat" weighs 6 395 lb with 2 000 lb of cargo. It has an overall length of 23ft 10in and is powered by an American Motors AV-108 55 b.h.p. V-4 air-cooled engine which drives all four tracks. The tracks are of the rubber band type with forged aluminium alloy shoes and a mean nominal ground pressure of 1·5 lb/in² at full load. Apart from being intended to operate over soft ground, the "Pack-Rat" has also been designed so that it will float and be able to propel itself in water at up to about 4 m.p.h.

In general, it is comparable with the Canadair "Dynatrac" but it is somewhat simpler and lighter. On the other hand its development is nowhere near as advanced as that of the "Dynatrac".

The possibility of yet another kind of articulated tracked vehicle was brought to light recently by a tank design competition organised by the U.S. Armor Association.[11] In this the winning entry was in the form of a design of an articulated armoured fighting vehicle. The basic idea is not new, however novel an articulated tank might appear. In fact, articulated armoured vehicles were seriously considered in the initial stages of the design investigations which led to the first British tanks of 1915.[3-12] But the idea of an articulated armoured vehicle did not advance at the time beyond layout drawings and a few experiments with coupled tractors. Thereafter it lay dormant until the early 'fifties.

The revival of interest in articulated armoured vehicles was due to Bekker, who had become interested in articulated tracked vehicles as a result of his research into soil-vehicle mechanics. This led him first to the construction and experiments with a scale model of an articulated tracked vehicle in Canada.[13] Soon afterwards came a proposal for an articulated armoured vehicle in

Fig. 12—Canadair "Dynatrac" demonstrating the degree of movement in roll and in pitch between the front and rear sections

Fig. 13—Swedish Bandvagn 202A articulated tracked cargo carrier

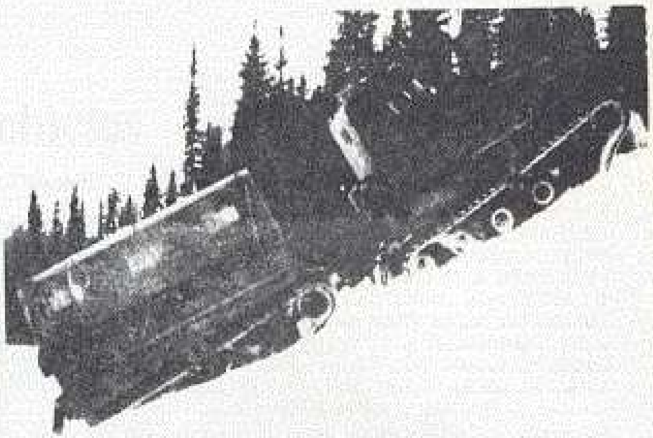

Fig. 14—Side view of the Swedish Bandvagn 202 on snow

response to a U.S. Army requirement for an infantry weapon carrier, especially for the then newly-developed 105mm anti-tank recoilless gun. Bekker put forward some of his ideas as early as 1950 and the proposal for a light articulated tracked armoured vehicle was elaborated in a report prepared in June, 1951, by the Operations Research Office, The John Hopkins University.[14] The report was, however, classified and was not released until recently, in connection with the preparation of this article, so that its contents have not been generally known.

It is of interest to record that the articulated tracked vehicle design proposed in the Operations Research Office report was not adopted. But the idea, once revived, did not pass back into limbo and since 1951 a number of design studies of articulated armoured fighting vehicles has been carried out to assess their possible development. So far, however, none has been able to demonstrate sufficiently clearly its advantages over its disadvantages.

The potential advantages are essentially the same as those of other articulated tracked vehicles, namely higher average cross-country speed because of their greater length and reduced risk of immobilisation in difficult terrain by virtue of their lower ground pressures and articulated steering. The disadvantages of articulated armoured fighting vehicles compared with their conventional counterparts are greater weight, greater shipping length, inferior manoeuvrability in confined spaces and mechanical complication. However, even though the disadvantages of articulated armoured vehicles may have outweighed their advantages so far, an acceptable design might yet be developed.

REFERENCES

[1] Ogorkiewicz, R. M., "Articulated Tracked Vehicles", The Engineer, Vol. 212, November 24, 1961.
[2] Ogorkiewicz, R. M., [illegible] Off-the-Road Vehicles", The Engineer, Vol. 215, Feb. [illegible], 1963.
[3] Bekker, M. G., "Mechanics of Off-the-Road Locomotion", James Clayton Lecture, Institution of Mechanical Engineers, November 13, 1962.
[4] Bekker, M. G., "Mechanics of Locomotion and Lunar Surface Vehicle Concepts", S.A.E. Automotive Engineering Congress, January, 1963.
[5] *Department of Defense Annual Report for the Fiscal Year 1962*, U.S. Government Printing Office, Washington, 1963.
[6] Bechtold, I. J., "Mobility and Tactical Vehicle Design", *Automotive Industries*, Vol. 126, May 1 and 15, 1962.
[7] Ogorkiewicz, R. M., *Armour: the Development of Mechanised Forces and their Equipment*. Stevens, London, 1960.
[8] Ogorkiewicz, R. M., "Sixty Years of Armoured Car Development", The Engineer, Vol. 208, August 28, 1959.
[9] Ogorkiewicz, [illegible] "Military Vehicles", The Engineer, Vol. 214, October [illegible], 1962.
[10] Case, I. B., "The Cross-country Task Force in Northern Operations", *Military Review*, Vol. 42, October, 1962.
[11] Case, I. B., "Logistic Support in Willow Freeze", *Military Review*, Vol. 41, December, 1961.
[12] Legros, L. A., "Tanks and Chain-track Artillery", The Engineer, Vol. 132, December 2, 9 and 16, 1921.
[13] Ogorkiewicz, R. M., "Soil-vehicle Mechanics", No. II, The Engineer, Vol. 214, September 28, 1962.
[14] Johnson, J. W., Bekker, M. G., *et al.*, "Analysis of a Light Cross-country Combat Vehicle—the 'Cobra'", *Technical Memorandum*, Operations Research Office, The John Hopkins University, June 1, 1951.